# DEVELOPMENT OF LOWER EXTREMITIES MOVEMENT ANALYSIS USING ACCELEROMETERS

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**A project report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor (Hons.) of Biomedical Engineering**

**Faculty of Engineering and Science**
**Universiti Tunku Abdul Rahman**

**May 2011**

# DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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# APPROVAL FOR SUBMISSION

I certify that this project report entitled **"DEVELOPMENT OF LOWER EXTREMITIES MOVEMENT ANALYSIS USING ACCELEROMETERS"** was prepared by **CHEW KAH MUN** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Biomedical Engineering at Universiti Tunku Abdul Rahman.

Approved by,

Signature : _________________________

Supervisor : Mr. Chong Yu Zheng

Date : _________________________

Specially dedicated to

my beloved father, mother, sisters and

my supportive friends

## ACKNOWLEDGEMENTS

Firstly, I would like to express my utmost gratitude to the Universiti Tunku Abdul Rahman for providing the opportunity and the modern facilities or equipments for me to pursue the final year project entitled with "Development of lower extremities movement analysis using accelerometers" as a partial fulfillment of the requirement for the degree of Bachelor of Engineering.

I would like to take this opportunity to acknowledge and extends my thanks to everyone who had contributed to the successful completion of this project. Besides that, I would like to express my gratitude to my research supervisor, Mr. Chong Yu Zheng for his invaluable advice, guidance and his enormous patience throughout the development of the research.

In addition, my greatest appreciation and thanks to my behaved family, especially my loving parents, who gave me the best they could and other family members who have been very supportive and give her invaluable advice and guidance.

Last but never the least, I thank all my friends, especially and course mates who are always there for me on good or bad days throughout this project and I am truly grateful to them.

**DEVELOPMENT OF LOWER EXTREMITIES MOVEMENT ANALYSIS**

## ABSTRACT

Human movement have been the subject of investigation since the fifth century when early scientists and researchers attempted to model the human musculoskeletal system. The mechanics of human movement involve synchronization of the skeletal, neurological and muscular systems of the human body. In the recent years, there are many different methods or techniques access in the human movement analysis, such as the accelerometer-based system, force plate system, inertial measurement unit (IMU), optical motion capture system, magnetic system and the others. Therefore, the main purpose of this project is to develop low-cost, reliable and accurate lower extremities movement analysis methods. This can be done by the human movement analysis system which consists of five accelerometers. This progress report consists of 7 main chapters. First section is introduction, which discuss about the history of human lower extremities analysis methods and aim and objective of this research. Second section is presents literature review that mainly focus on the introduction of human movement, the physical components of human motion, skeletal system and biomechanics of human lower extremities. Third section is methodology, which focus on the design and implementation of hardware components and systems, software programming for microcontroller and LabVIEW graphical programming. Fourth section is the result and discussion of the subject testing. Fifth section is the difficulties and problems in this research project that we have encountered with some recommendation for further improvement. Sixth section is the current commercial technologies, future research and development which related to the research project. Last section of this project is conclusions and milestones, which represented the tasks have been completed for two semesters and the Gantt chart for the project.

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| | |
|---|---|
| $a$ | linear Acceleration, m/s$^2$ |
| $u$ | initial velocity, m/s |
| $s$ | linear displacement, m |
| $t$ | time, s |
| $v$ | final velocity, m/s |
| | |
| $\theta$ | angular displacement, deg or rad |
| $\omega$ | angular velocity, deg/s, rad/s, rev/s or rpm |
| $\alpha$ | angular acceleration, deg/s$^2$, rad/s$^2$ or rev/s$^2$ |
| | |
| $f$ | frequency, Hz |
| | |
| g | Gravitation, 9.81 m/s$^2$ |
| | |
| V | Voltage, V |
| | |
| 2D | Two-Dimensional |
| 3D | Three-Dimensional |
| ADC | Analog-to-Digital Converter |
| ADCON0 | A/D Control Register 0 |
| ADCON1 | A/D Control Register 1 |
| ADCON2 | A/D Control Register 2 |
| ADL | Activity Daily Living |
| ADRESH | A/D Result High Register |
| ADRESL | A/D Result Low Register |
| BAUDCON | Baud Rate Control |
| BMI | Body Mass Index |

| | |
|---|---|
| CPU | Computer Processing Unit |
| CU | Control Unit |
| EUSART | Enhanced Universal Synchronous Asynchronous Receiver Transmitter |
| IDE | Integrated Development Environment |
| ISM | Industrial, Scientific and Medical Devices |
| LabVIEW | Laboratory Virtual Instrumentation Engineering Workbench |
| LCD | Liquid Crystal Display |
| LED | Light-Emitting Diode |
| MCU | Microcontroller |
| MRI | Magnetic Resonance Imaging |
| PC | Personal Computer |
| PIC | Processor Integrated Circuits |
| RCSTA | Receive Status and Control |
| RF | Resistor-Capacitor |
| RFID | Radio Frequency Identification |
| STA | Soft Tissue Artefacts |
| TXSTA | Transmit Status and Control |
| UART | Universal Synchronous Asynchronous Receiver Transmitter |
| USB | Universal Serial Port |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Measurement of human posture and movement is an important area of research in the bioengineering and rehabilitation fields. The need for accurate recording of human movement leads to the development of convenient gait analysis techniques. Many of these offer much information regarding the kinematics and kinetics of human gait, but need significant preparation time, are expensive to buy and maintain, and required trained personnel for their function and use.

Previous studies have most often used intrusive techniques for the movement analysis, such as bone pins, external fixators and percutaneous tracking devices to quantify joint motion in vivo. Unfortunately, these devices can restrict the movement of the subject and alter the normal, unimpeded sliding of the soft tissues relative to the underlying bone. (Akbarshani, M. et.al, 2010)

To overcome this problem, the non-invasive methods such as magnetic resonance imaging (MRI) and x-ray fluoroscopy have been used to quantify joint motion in vivo. However, these studies have been associated with several limitations, such as only can investigating a single motor task only. (Akbarshani, M. et.al, 2010)

Then, image-based methods have been developed for measurements of human posture and movements such as photogrammetric, video analysis and optical motion analysis systems are used in the study of human joint motion. However, these systems are complicated to set-up, expensive, only allow measurements in a restricted volume, and the markers are easily obscured from vision resulting in incomplete data. (Mayagoitia, 2002; Wong, Wong and Lo, 2007)

Recent developments in miniature sensor technology have opened many possibilities for motion analysis outside the laboratory. Electronic sensors and systems with advanced technology, namely accelerometer, gyroscopes, flexible angular sensor, electromagnetic tracking system and sensing fabrics have been developed and applied to solve the relevant application problems of the image-based methods.

The use of miniature electronic sensors and systems has become a common practice in ambulatory human movement analysis. Micro-machined gyroscopes and accelerometers are used in several applications which include monitoring of activities of daily living, assessment of internal mechanical working load in ergonomics studies, measurement of neurological disorders and mixed and augmented reality.

For example, wireless tri-axial accelerometer, fixed to a belt at the level of the L3 spinous process, was used to measure trunk acceleration, describe the characteristics of stroke patient gait using the acceleration signals which were obtained during walking. (Mizuike, Ohgi and Morita, 2009)

However, it should be noted that there are important limitations in the current systems. The inherent drift of the orientation and position estimates limits long-term stable application of these sensors. Therefore, there are still having many limitations and drawbacks with using the electronic sensor and system such as the environment influence and signal extraction difficulties. Further development of these electronic sensors and measurement methods could enhance their clinical applications in institutional as well as community levels.

## 1.2 Aims and Objectives

The main aim and objective of this project is to study and develop a 2-Dimensional lower extremities movement analysis by using accelerometers, in order to understand the basic principal and system requirements for this project.

In additional, the general objectives of this project are:

1. To develop a low-cost, reliable and accurate 2-Dimensional lower extremities biomechanical and system.
2. To analysis kinematics parameters of human movement.
3. To collect and analysis the 2-Dimensional kinematic experimental data.

Lastly, the individual objectives are:

1. To understand the principal of 2-Dimensional lower extremities biomechanical and system.
2. To design and develop the hardware / software system and implement into the 2-Dimensional lower extremities biomechanical and system.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction to Movement Analysis

Analysis of human motion originates as far back as the fifty century BC, when Aristotle and his colleagues developed a model of human musculoskeletal system involving levers, forces and a centre of gravity (Godfrey, A. et.al, 2008). Generally, human movement involves a change by the person in place, position or posture relative to some point in the environment. The mechanics of human movement involve synchronization of the skeletal, neurological and muscular systems of the human body.

Many different disciplines use motion analysis systems to capture movement and posture of the human body. Basic scientists seek a better understanding of the mechanisms that are used to translate muscular contractions about articulating joints into functional accomplishment, such as walking. Increasingly, researchers endeavour to better appreciate the relationship between the human motor control system and gait dynamics. (Roetenberg Daniel, 2006)

In the realm of clinical gait analysis, medical professional apply an evolving knowledge for the planning of treatment protocols, such orthotic prescription and surgical intervention and allow the clinician to determine the extent to which an individual’s gait pattern has been affected by an already diagnosed disorder. With respect to sports, athletes and their coaches use motion analysis techniques in a ceaseless quest for improvements in performance while avoiding injury.

## 2.2 Physical components of human motion

The study of the kinesiology and biomechanics components is necessary for the successful physiological understanding and subsequent treatment of disabilitating illness and disorders relating to the human movement.

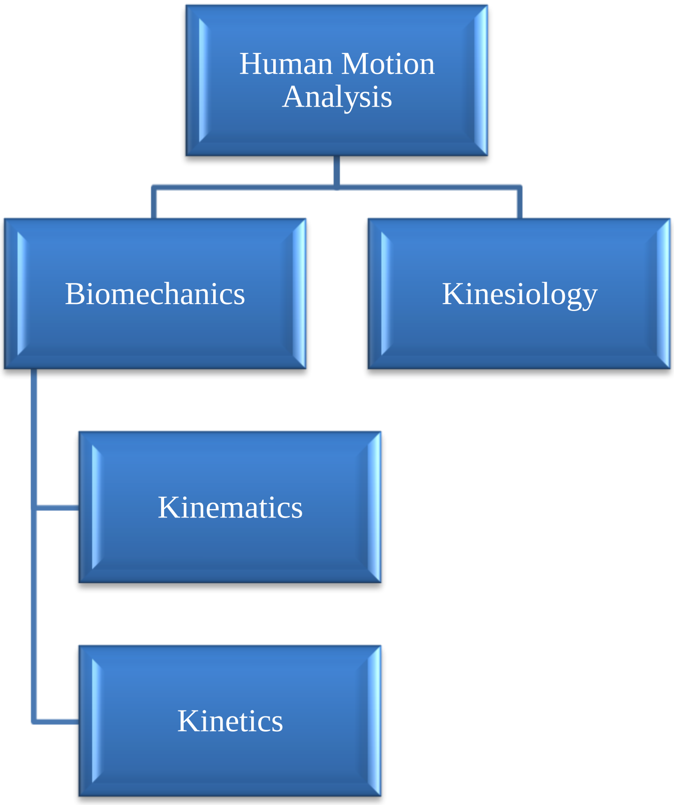



**Figure 2.1 Types of Movement Analysis**

### 2.2.1 Kinesiology and Biomechanics

Kinesiology is the study of the sciences associated with the anatomical, mechanical, physiological basis of human movement, whereas biomechanics is defined as the area of study where the knowledge and methods of mechanics are applied to the structure and function of living system. (Roetenberg Daniel, 2006)

### 2.2.2 Kinematics and Kinetics

Kinematics and kinetics are subdivisions of biomechanics of biomechanical study. Kinematics is mainly concerned with motion characteristics of a subject and examines from a spatial and temporal perspective without reference to the forces causing the motion. Position, velocity and acceleration are of particular interest in kinematics. (Hall, S.J., 2007)

Kinetics examines the forces that act upon a system such as the human body causing it to move. A kinetic analysis can provide information about how the movement is produced or how position is maintained. (Hall, S.J., 2007)

### 2.2.3 Statics and Dynamics

Statics and dynamics are two major sub-branches of mechanics. Statics is the study of systems that are in a state of constant motion, which is either at rest with no motion or moving with a constant velocity. Dynamics is the study of systems in which acceleration is present, either undergoes acceleration and deceleration. (Hall et.al, 2007)

### 2.2.4 Linear and Angular Motion

There are two main types of motion present in human movement. Firstly, there is linear motion that is movement along a straight line (rectilinear) or curved pathways (curvilinear) in which all points on the body move the same distance in the same amount of time. (Hall, S.J., 2007)

For the linear motion subject to the uniform acceleration,

$$v = u + at \quad (2.1)$$

$$s = (u \times t) + 0.5 \times (a \times t^2) \quad (2.2)$$

$$s = (u + v) / 2 \quad (2.3)$$

$$v^2 = u^2 + 2 \times (a \times s) \quad (2.4)$$

Given that,

Linear displacement (s) is measured in a straight linear from initial position to final position. A common unit of displacement is meter, m.

Linear velocity (v) is the change in displacement. A common unit of velocity is in the metric system is m/s.

Linear acceleration (a) is defined as the rate of changes in velocity. A common unit of acceleration in the metric system is $m/s^2$.

The second type of motion is angular motion that involves movement around a point (axis of rotation) so that different regions of the same body do not move through the same distance in a given amount of time. The change in orientation of a rotating body is called its angular displacement.

For the angular motion subject to uniform acceleration, the velocity of the point is obtained as a vector product of the angular velocity and the radius $v = \omega \times r$**.**

$$\omega = (2 \times \pi \times n) / 60 \quad (2.5)$$

$$\omega_2 = \omega_1 + \alpha \times t \quad (2.6)$$

$$\theta = 0.5 [(\omega_2 + \omega_1) \times t] \quad (2.7)$$

$$\omega_2^2 = \omega_1^2 + 2 \times \alpha \times s \quad (2.8)$$

$$\theta = \omega_1^2 + 0.5 (\alpha \times t^2) \quad (2.9)$$

Given that

Theta ($\theta$) represents angular displacement which is the difference in the initial and final positions of the moving body. Common units are in degrees (deg) or radian (rad).

Omega (ω) represents angular velocity which is the change in angular displacement. Common units are in degrees per second (deg/s), radians per second (rad/s), revolutions per second (rev/s) and revolutions per minute (rpm).

Alpha (α) represents angular acceleration which is the rate of change in angular velocity. Common units are in degrees per second squared (deg/$s^2$), radians per second squared (rad/$s^2$) and revolutions per second squared (rev/$s^2$).

## 2.3 The Skeletal System

The human skeleton is made up of 206 bones of different shapes and sizes and associated cartilage, tendons, and ligaments, most of which are paired, with one member of each pair on the right and left sides of the body (Derrickson, J.T.B., 2006). The bones of the adult skeleton are grouped into two principal divisions: the axial skeleton and the appendicular skeleton.

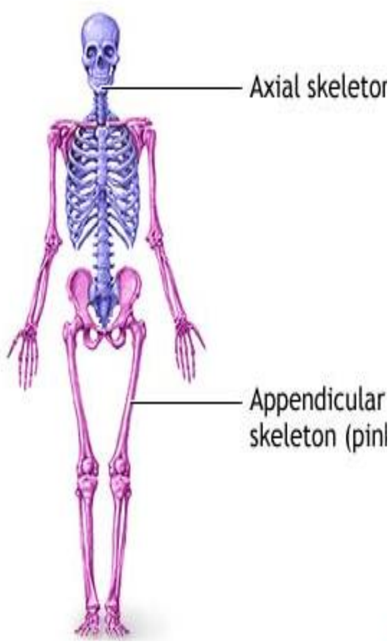



**Figure 2.2 Two Types of Skeleton System** (© Copyright 2001 adam.com, Inc)

The axial skeleton consists of 80 bones that lie around the longitudinal axis of human body, an imaginary vertical line that runs through the body's center of gravity from the head to the space between the feet: skull bones, auditory ossicles (ear bones), hyoid bone, ribs, sternum (breastbone), and bones of the vertebral column.

On the other side, the appendicular skeleton consists of 126 bones that comprises the upper and lower limbs, plus the bones forming the girdles that connect the limbs to the axial skeleton.

The skeleton system make up with bones because bone is rigid, it gives the body a framework, maintains its shape, and protects vital organs. Bones provide a place for muscles and supporting structures to attach, and, with the movable joints, form a system of levers upon which muscles can act to produce body movements. A joint is a place of union between two or more bones that may be movable or immovable. Bone also functions as a site for mineral storage and blood cell formation. Tendons and ligaments are strong bands of fibrous connective tissue that attach muscles to bones, and bones to bones, respectively. (National Geographic Society, 2007)

## 2.4 Anatomy and Biomechanics of the Human Lower Extremities

The human lower extremity consists of 31 bones with two sets. The lower extremities included the pelvis, hip, knee, ankle and foot. The bones which consist of all the lower extremities are 2 hip bones, 2 femur, 2 tibia, 2 fibula, 2 patella, 14 tarsals, 10 metatarsals and 28 phalanges. (Derrickson, 2006)

Although there are some similarities between the joints of the upper and the lower extremities, the upper extremity is more specialized for activities requiring large ranges of motion. In contrast, the lower extremities are well equipped for its function of weight bearing and locomotion.

The main functions of the lower limbs are to support the body when standing and to enable locomotion. To be able to stand and move is a key part of normal, active life, and it is important for therapists to have a detailed understanding of the structure and function of the lower limbs in order to plan purposeful rehabilitation programmes. (Trew, M. and Everett, T., 2001)

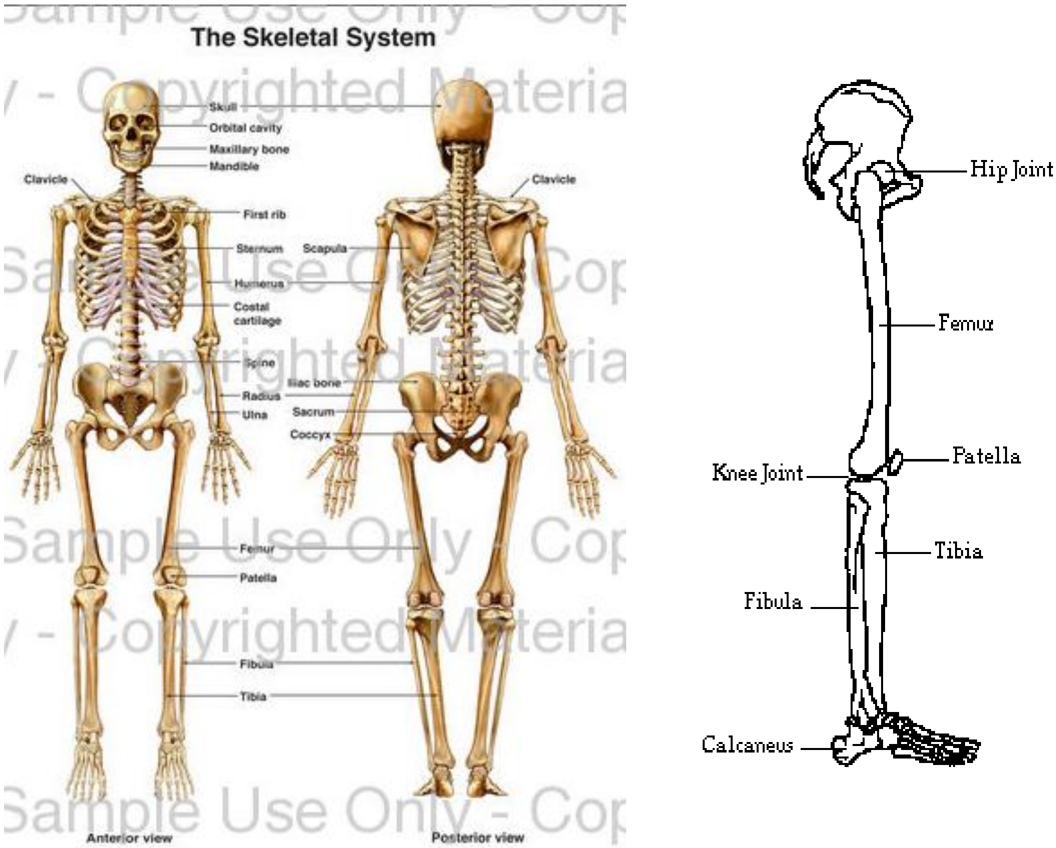



**Figure 2.3 Anatomy of Skeletal System and Lower Extremities bones**

(© Copyright 2001 adam.com, Inc)

### 2.4.1 Hip Joint

The hip joint is the articulation between the head of the femur and the acetabulum of the innominate bone (Derrickson, J.T.B., 2006). It is a synovial ball and socket joint and such permits a wide range of movements compatible with a wide range of locomotors activities.

The hip joint connects the lower limb to the trunk, and therefore is involved in the transmission of weight. Indeed, the mechanical requirements of the joint are severe. It must be capable not merely of supporting the entire weight of body. The joint must therefore possess great strength and stability, even at the expense of limitation of range of movement (Palastanga, N., Field, D. and Soames, R., 2006). Several large, strong ligaments are contributed to the extremity stability of the hip.

The movements possible are those of a typical ball and socket joint, being flexion and extension around the transverse axis, adduction and abduction around an anteroposterior axis, and medial and lateral rotation around a vertical axis. Circumduction is also allowed. (Palastanga, N., Field, D. and Soames, R., 2006)

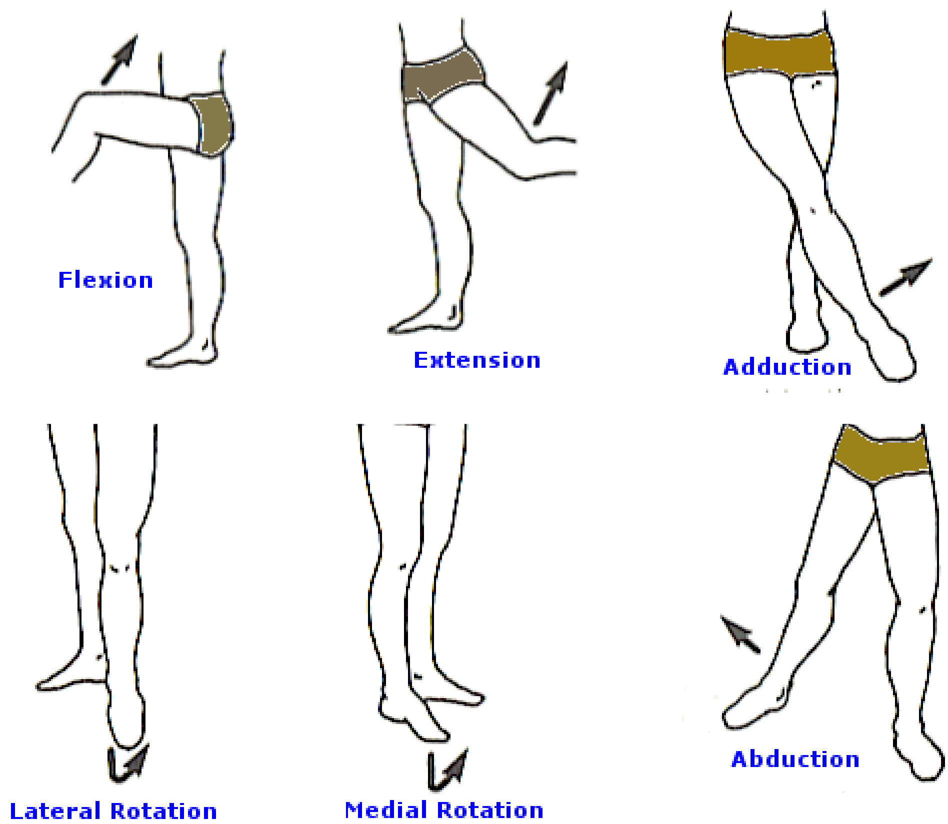



**Figure 2.4 Movement of Hip Joint** (© Copyright 1997 Sports Coach)

### 2.4.2 Knee Joint

The knee is the largest and most complex joint of the body. It is a synovial bicondylar hinge joint between the condyles of the femur and those of the tibia (Derrickson, J.T.B., 2006).

The knee joint satisfies the requirements of a weight-bearing joint by allowing free movement in one plane only combined with considerable stability, particularly in extension. Although functionally the knee joint is a hinge joint, allowing flexion and extension in the sagittal plane, it also permits a small amount of rotation of the leg, such as slight medial rotation and lateral rotation of leg in the fixed position. (Palastanga, N., Field, D. and Soames, R., 2006)

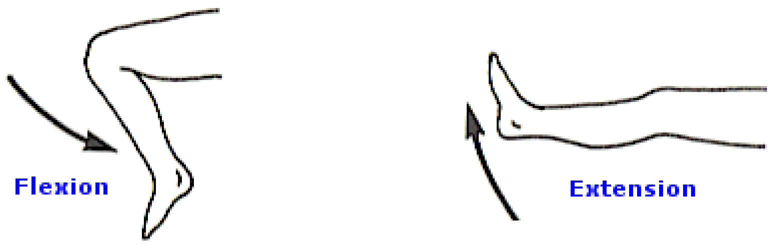



**Figure 2.5 Movement of Knee Joint** (© Copyright 1997 Sports Coach)

The knee joint also plays an important role in locomotion, being the shortener and lengthener of the lower limb. It can also be considered to work by axial compression under the action of gravity.

### 2.4.3 Ankle Joint

The ankle functioning as a hinge joint connects the distal ends of the tibia and fibula in the lower limb with the proximal end of the talus bone in the foot. (Derrickson, J.T.B., 2006)

Basically, ankle joint is formed by the connection of three bones. The ankle bone is called the talus. The top of the talus fits inside a socket that is formed by the lower end of the tibia and the fibula. The bottom of the talus sits on the heel bone, called the calcaneus. The talus works like inside the socket, which is allows for the movement of dorsiflexion and plantar flexion. (Derrickson, J.T.B., 2006)

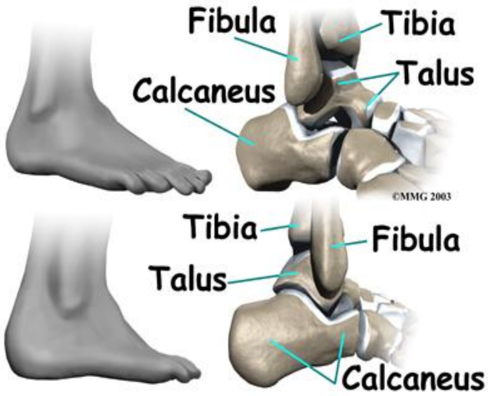



**Figure 2.6 Ankle Anatomy** (© Copyright 2009 eOrthopod)

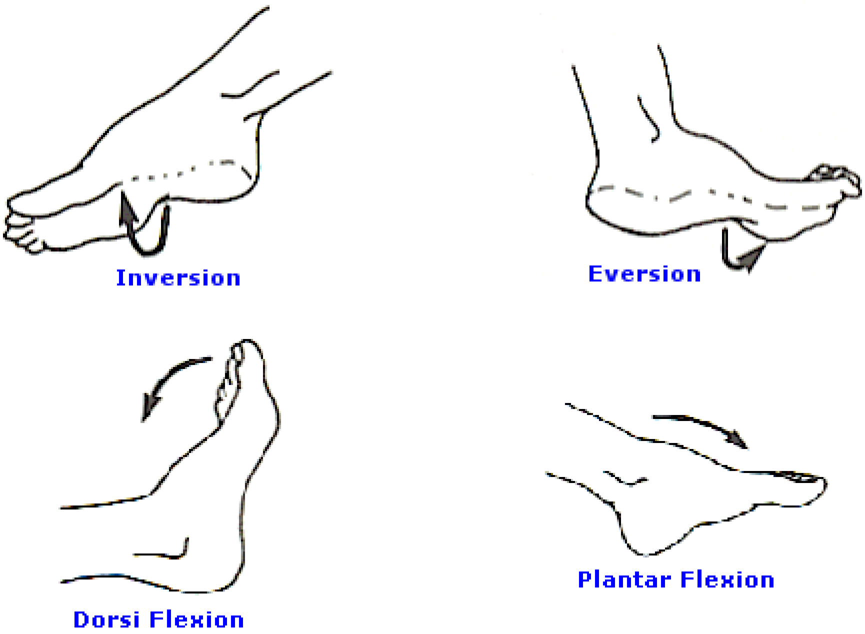



**Figure 2.7 Movement of Ankle Joint** (© Copyright 1997 Sports Coach)

### 2.4.4 Foot

Foot is a multibone structure. It is consists a total of 26 bones with numerous articulations. It can provide a foundation of support for the upright body and help it adapt to uneven terrain and absorb shock. (Derrickson, J.T.B., 2006). Basically, The foot can be subdivided into the hindfoot, the midfoot, and the forefoot.

The hindfoot also known as rearfoot is composed of the talus and the calcaneus. The two long bones of the lower leg, the tibia and fibula, are connected to the top of the talus to form the ankle. The calcaneus, the largest bone of the foot, is cushioned inferiorly by a layer of fat. The five irregular bones of the midfoot, the cuboids, navicular, and three cuneiform bones, form the arches of the foot which serves as a shock absorber.

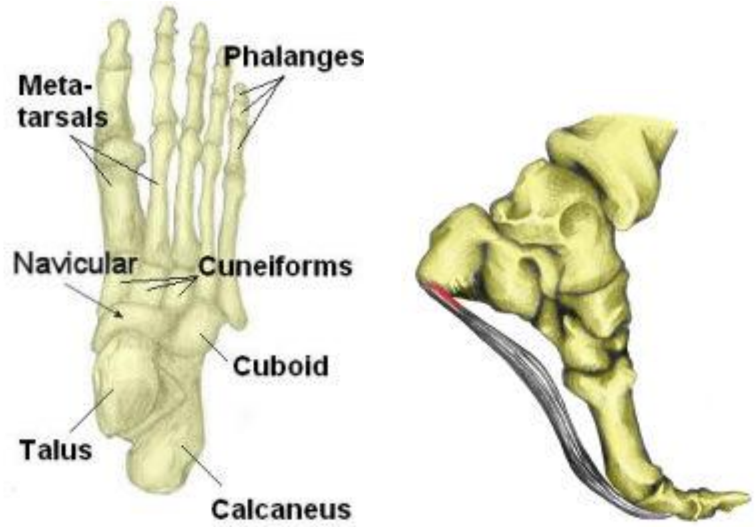



**Figure 2.8 Foot Anatomy** (© Copyright 2007 eOrthopod)

The midfoot is connected to the hindfoot and forefoot by muscles and the plantar fascia. The forefoot is composed of five toes and the corresponding five proximal long bones forming the metatarsus. Similar to the fingers of the hand, the bones of the toes are called phalanges and the big toe has two phalanges while the other four toes have three phalanges. (Derrickson, J.T.B., 2006)

## 2.5 Human Movement Analysis Application

In the areas of medicine, sports, and animation, human motion analysis has become an investigative and diagnostic tool.

### 2.5.1 Medical Diagnosis

Motion analysis of body parts is critical in the medical field. In postural and gait analysis, joint angles are used to track the location and orientation of body parts. Pathological gait may reflect compensations for underlying pathologies, or be responsible for causation of symptoms in itself. The study of gait allows these diagnoses to be made, as well as permitting future developments in rehabilitation engineering. (National Geographic Society, 2007).

For example, gait analysis techniques allow for the assessment of gait disorders and the effects of corrective orthopedic surgery. Options for treatment of cerebral palsy include the paralysis of spastic muscles using Botox or the lengthening, re-attachment or detachment of particular tendons. Corrections of distorted bony anatomy are also undertaken. (National Geographic Society, 2007).

### 2.5.2 Sports Analysis

Gait analysis is also used in sports to optimize athletic performance or to identify motions that may cause injury or strain. Physical training in team sports is extremely important for top performance during the matches, and training should be based on the knowledge of the specific requirements of a particular sport. Player motion data can reveal many aspects of team play that are not directly visible: for example, it can highlight the reasons why some athletes perform better than others, and it can suggest the methods of training to make good athletes perform even better. (Pers, J., Bon, M., Kovacic, S., Sibila, M, and D, B., 2002)

### 2.5.3 Animation

In the animation making, special motion capture systems are used to capture facial animation data or body movement animation data. The captured data and reuse it with 3D and cartoon heads, consisting of a fixed skeleton and animated with spring simulations (muscle). (Hsieh, J.W. et.al, 2008)

Motion capture data can be used for directly animating and directing in real-time characters similar to the tennis game and virtual dancing, even enhanced with additional motion recognition routines.

# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction to Methodology

A human movement analysis system can vary in many ways depending on its application and user whose using it. Currently, there are many researchers undergoing the testing and trial to improve the accurate and to reduce the complication of the system. For this research project, a low-cost, reliable and accurate lower extremities movement analysis methods would be develop.

This chapter would focus on the selected design components and systems for human lower extremities analysis. Firstly, the reasons and advantages of the selected design are discussed. Following that, the components and procedures of how to assemble them are listed. Lastly, the software part such as PIC programming code of the selected design is discussed with full of explanation.

## 3.2 Accelerometer-based Sensor Systems

Many techniques are used to assess human movement some of these include observation, physical science technology (foot switches, gait mats, force plates, optical motion analysis), diaries and questionnaires. Many of these techniques have clear disadvantages for continuous analysis such as the physical science technologies, which as primarily laboratory based. Thus, accelerometers have become the preferred choice for continuous, unobtrusive and reliable method in human movement detection and monitoring. (Godfrey, A., Conway, R., Meagher, D. & Olaighin, G., 2008)

The motion analysis system used in this study was the accelerometers-based sensor systems due to the main reason of reasonably cost, accurate and effective. Accelerometer are devices that measures applied acceleration acting along a sensitive axis which can be used to measure the rate and intensity of body movement in up to three planes (anterior-posterior, medial-lateral and vertical). As they respond to both the frequency and intensity of movement. Accelerometer can also be used to measure tilt (body posture) making them superior to those devices that have no ability to measure static characteristics.

Advantages of accelerometer devices include their small size, ability to record data continuously for periods of days, weeks and even months. This continuous recording capability is due to the relatively low current draw of modern accelerometer devices in contrast to gyroscope. Models with internal real time clocks also help differentiate activity patterns over this recording period.

Accelerometers also have high resolution at typical sampling frequencies used for ambulatory detection. Their bandwidth may also be set by the simple attachment of coupling filter capacitor to outputs of the accelerometer device. This allows the accelerometer device to be easily matched to the frequency response of the activities performed by human motion, where typically the information for gait patterns corresponds to 0.6Hz – 5.0Hz.

In this research project, total up seven small wearable sensor units use in this selected design for the lower extremities movement analysis. Each of the tri-axial accelerometer which can use to measure the linear acceleration along three orthogonal axes simultaneously. Three sensor units are attached on the hip, knee and ankle for both legs. All these sensors were attached using hypoallergenic double-sided tape to ensure minimum movement of the senor relative to skin. For the pelvis, the sensors unit was attached to the waist with a neoprene belt.

The basic working principles and process system of the lower extremities movement analysis system based on accelerometer in this research project is summarized as follow figure 3.1.

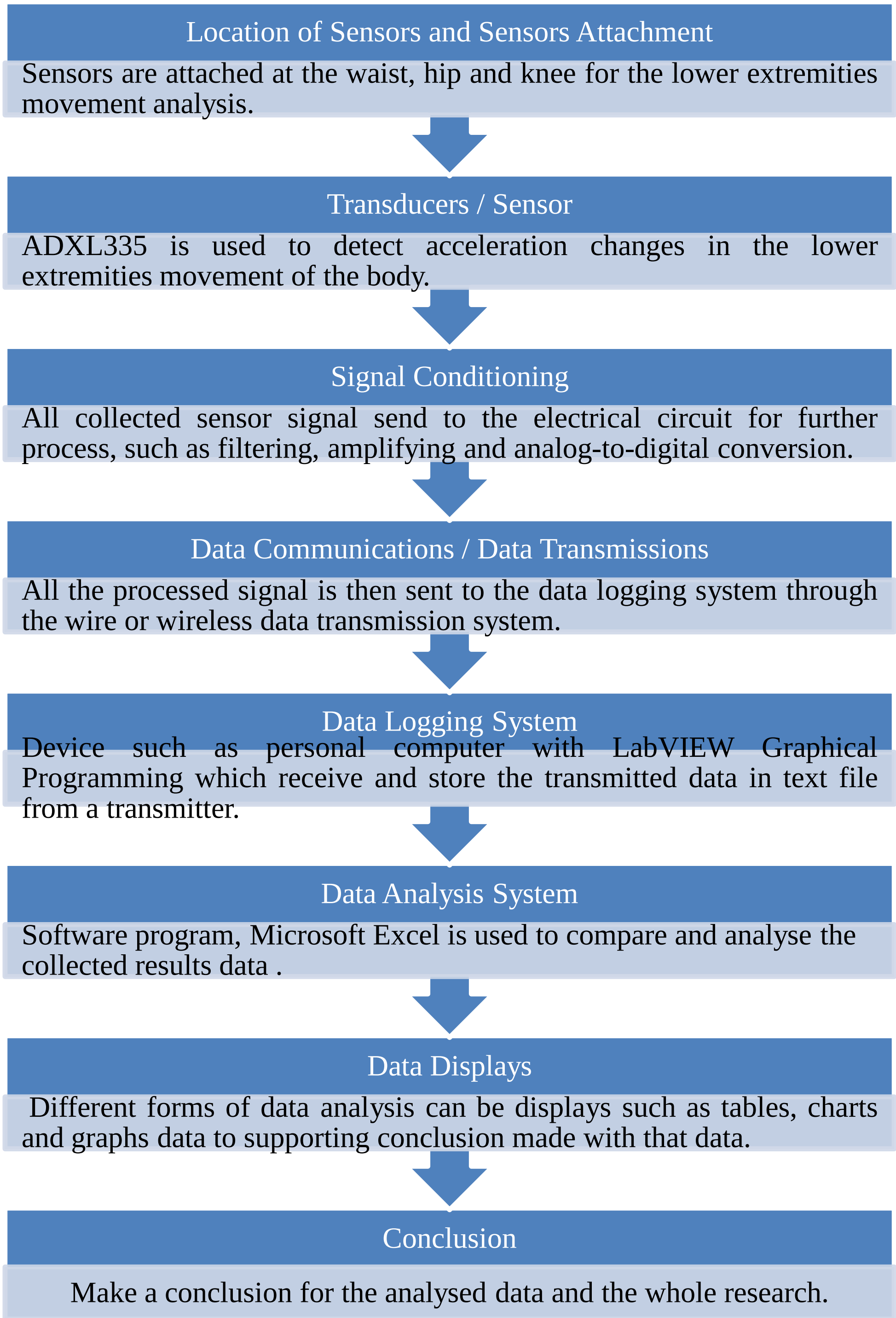



**Figure 3.1 Process Flow of Electronic Sensor based System Analysis**

### 3.2.1 Sensor

A sensor is used to detect a parameter in one form and report it in another form of energy, usually an electrical or digital signal. Sensors such as accelerometer, gyroscopes and magneto sensors are applied for human lower extremities movement analysis.

In this research, the accelerometer selected for this research project is the Analog Devices ADXL330, which has the ability to detect dynamic changes of acceleration in all directions by using independent X, Y and Z axes.

Generally, accelerometer is a type of positional sensor operated by measuring acceleration along the sensitive axis of the sensor based on the principles of Hooke's law (F=kx), and Newton's 2$^{nd}$ law of motion (F=ma). (Kavanagh and Hylton, 2008).

### 3.2.2 Signal Conditioning

In electronics, signal conditioning means manipulating an analog signal in such a way that it meets the requirements of the next stage for further processing. For the sensor signal conditioning can include filtering, amplification and converting processes required to make sensor output suitable for processing after conditioning.

Signal filtering is the most common signal conditioning function, as usually not all the signal frequency spectrum contains valid data. Electronic filters is an electronic circuits which perform signal processing functions, specifically to remove unwanted frequency components from the signal, to enhance wanted ones, or both. Electronic filters which normally use in the human lower extremities movement analysis can be: Low pass second order Butterworth filter, Kalman filter, low pass, high-pass or band-pass filter.

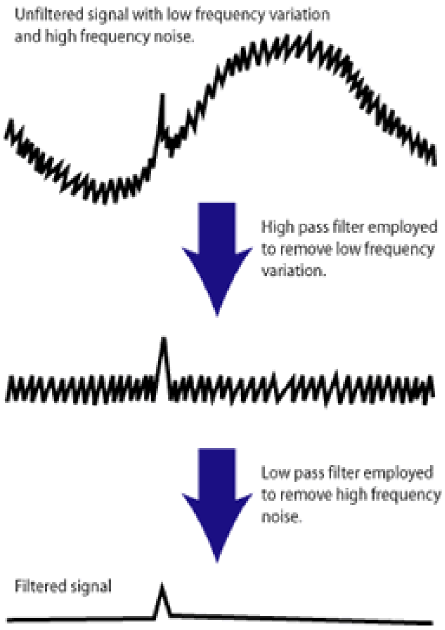



**Figure 0.2 Basic Function of Signal Filtering**

(© Copyright NDT Resource Center)

Signal amplification has two important functions: increases the resolution of the inputted signal and increases its signal-to-noise ratio. Generally, an amplifier is any device that usually used to changes and increases the amplitude of a signal. For example, the output of an electronic sensor is probably in the mV range which is probably too low for an Analog-to-digital converter (ADC) to process directly. In this case it is necessary to bring the voltage level up to that required by the ADC.

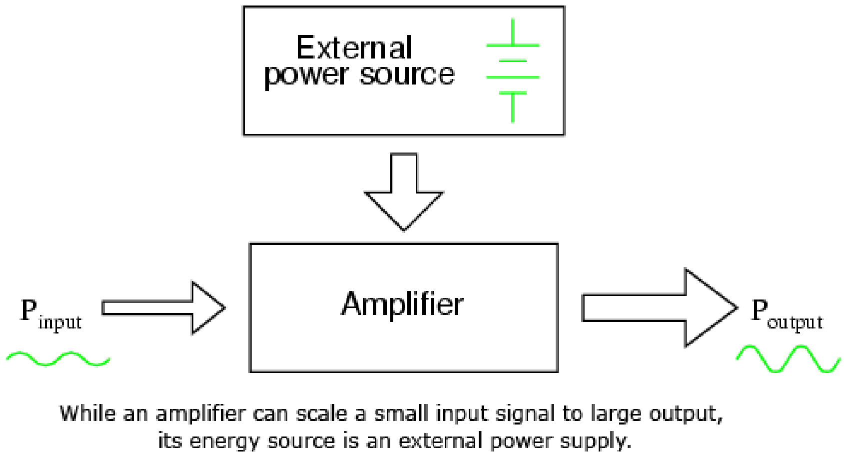



**Figure 3.3 Basic Function of Signal Amplifier** (© Copyright 2008 Keywoniki)

Analog-to-Digital Conversion (ADC) is the process of converting the output of the sample and holds circuit to a series of binary codes that represent the amplitude of the analog input at each of the sample times. The sample and hold process keeps the amplitude of the analog input signal constant between sample pulses. (Floyd, 2009)

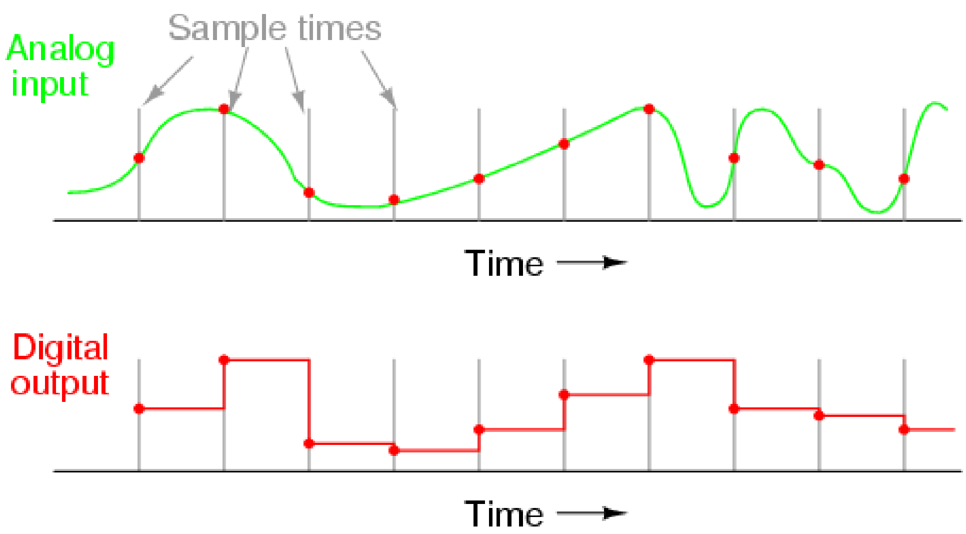



**Figure 3.4 Basic Function of An Analog-to-Digital Converter.**

(© Copyright © All About Circuits)

In this research, noise filtering is done via software instead of using capacitors and resistors for flexibility. For the Analog-to-Digital Conversion (ADC) processing an internal ADC of the microcontroller is used to converts an input analog voltage from the sensor input to a digital number proportional to the magnitude of the voltage. Besides that, Microchip PIC18F4550 microcontroller is used to undergo the data processing.

### 3.2.3 Data Communications / Data transmissions

Data Communications or data transmissions are the transfer of data or information between a source and a receiver. The source transmits the data and the receiver receives it. The actual generation of the information is not part of Data

Communications nor is the resulting action of the information at the receiver. Data Communication is interested in the transfer of data, the method of transfer and the preservation of the data during the transfer process. (Engene Blanchard, 2005)

Several physical data transmission media are available to connect together the various devices on a network. Basically, data transmission media can be classified into two board types, which are wired data transmission and wireless data transmission.

The wired data transmission is to use cables. There are many types of cables, but the most common are coaxial cable, double twisted pair and optical fibre. In contrast, wireless data transmission is transmission the data without the use of cables. Several wireless technologies can be use in the shorter range wireless transmission, such as Radio Frequency Identification (RFID), Bluetooth, ZigBee, Z-wave and wireless sensor networks.

In this research, wire data transmission through the RS232 is used for the data testing and for the emergency case. Whereas wireless data transmission via the Bluetooth is used instead of other wireless data transmission for the research project sample collection due to Bluetooth is inexpensive, does not influenced the human movement, automatic configuration, interoperability, low interference and low energy consumption.

In general, Bluetooth is a wireless network which transmits data via low-power radio waves. It communicates on a frequency of 2.45 GHz (actually between 2.402 GHz and 2.480 GHz). This frequency band has been set aside by international agreement for the use of industrial, scientific and medical devices (ISM). (How Bluetooth Works, 2010).

### 3.2.4 Data Logging System

A data logger or data recorder is an electronic device that records data over time or in relation to location either with a built in instrument or via external instruments. Technically, a data logger is any device that can be used to store data. They are based on a digital processor. They generally are small, battery powered, portable, and equipped with a microprocessor, internal memory for data storage, and sensors. Some data loggers interface with a personal computer and utilize software to activate the data logger and view and analyze the collected data, while others have a local interface device such as keypad or LCD and can be used as a stand-alone device.

In this research, the computer processing unit (CPU) of the personal computer installed with National Instrument LabVIEW 2009 is used as the data logger system which stores all the output data in a text file (.txt file) according to the time. All the signal collected data are storage in respective folder in the CPU during the data transmission and the data collection over a period of time before the real-time analysis is run through.

### 3.2.5 Data Analysis System

Data analysis is a process of inspecting, cleaning, transforming, and modeling data with the goal of highlighting useful information, suggesting conclusions, and supporting decision making with the basic statistical analysis or data analysis software.

The statistical analysis methods that are normally used in the previous work are Student’s t-test, Wilcoxon Rank Sum Test, ANOVA test and the others. In contrast, data analysis software can be used are LabView, MatLab 6.5 (The Mathworks, USA).

In this research, Microsoft Excel is used for the human movement data analysis with the LabVIEW's stored text data. Calculation such as average and standard deviation of acceleration, and plots the graph for the data comparison.

### 3.2.6 Data Display

Different forms of data analysis can be displays such as charts, graphs, and textual write up of data to supporting conclusion made with that data, as is presenting the data in a clear and understandable way.

The forms of analyzed data can be directly display on the LCD of the computer. Besides that, the hardcopy of the analyzed data can be printed out via the external printer. Analyzed data also can be projected to the hall via the projector for the presentation or group discussion.

## 3.3 Instrumentation

A human motion analysis system was developed for capturing gait data. It consists of five main subsystems, which are the sensors and hardware designed for holding these on the lower extremities movement analysis, the microcontroller start-up board, DB9 connector RS232 (wire data transmission), wireless Bluetooth module (wireless data transmission) and personal computer (PC), which is allows the user to set some parameters of interest and display results while capturing and saving data.

This research project implemented sensors and a sensor system that can be used to monitor activity volume and analyzing activity patterns in daily life. For this, ADXL335 (Analog Devices., USA) have been used as an acceleration sensor that is composed of a single chip and can detect tri-axial acceleration information, and measured acceleration information of axis X, Y and Z according to the subject's posture and activity.

Measured acceleration signal was transmitted wire to external circuit board consisted of PIC18F4550 microcontroller and data transmission module. In order to store and analyze the signal, a monitoring program using LabView 2009 (NI Co. Ltd., USA) was implemented in the host computer. The goal of these operations is to generate a single smoothly changing curve that represents the recent activity level of the test subject.

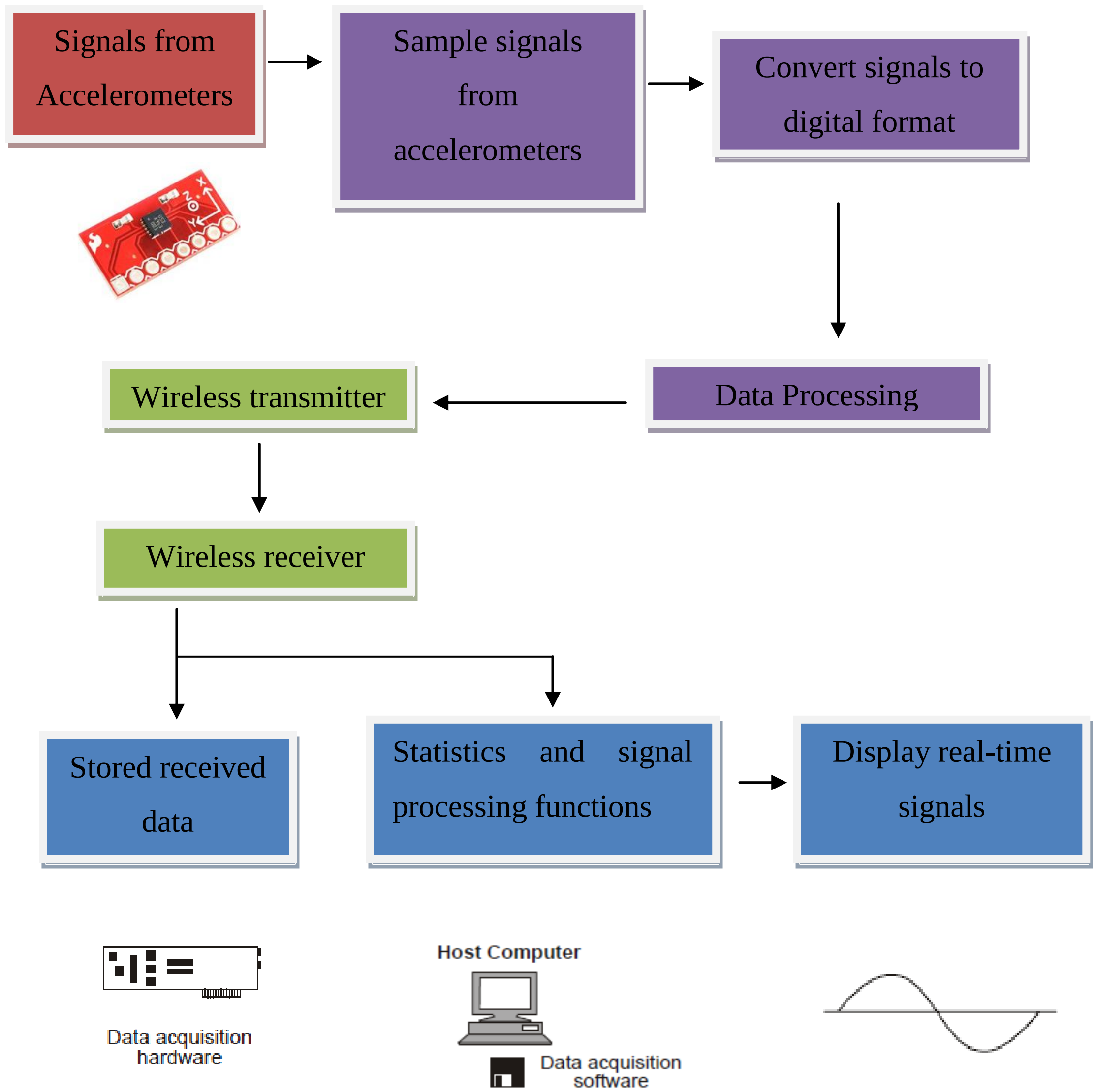



**Figure 3.5 Functional Diagram of a PC-based Data Acquisition System**

In general, data acquisition is the process by which physical phenomena from the real world are transformed into electrical signals that measured and converted into a digital format for processing, analysis and storage by a computer. The basic process and elements of a data acquisition system for the development lower extremities movement analysis using accelerometer research project are shown in the Figure 3.5.

The main hardware and electronic components which used in developing the human movement analysis system includes:

- ADXL335 Analog Devices. Inc Tri-axial Accelerometer
- SK40C Enhanced 40 Pins PIC Start-up Kit
- Microchip PIC18F4550 Microcontroller
- MAX232 and DB9 Connector RS232
- SKKCA-21 KC Wireless Bluetooth Starter Kit

The electronic tools which used in developing the human movement analysis system include:

- Power Supply
    - Rechargeable 9V battery
    - PVC Battery Holders
    - Adapter Teletron TMC-500PM
- Circuit Board
    - Breadboard
- Wire Types
    - Rainbow Cables
    - Single Core Wires
- Soldering
    - Soldering Tools
    - Soldering Irons
- Socket Connection
    - Socket Strip
    - DB-9 Female Connector RS232
    - USB to Serial Port Adapter

- Miscellaneous
  - 20MHz Crystal Oscillator
  - LM1117T 3.3V Voltage Regulator
  - L7805CV 5.0V Voltage Regulator
  - 0.001μF, 0.01μF, 0.1 μF, 0.33μF, 1μF and 10μF Capacitor
  - 1kΩ Resistor
  - LED light 5mm Green
  - LED light 5mm White
- Multi-meter
- USB ICSP PIC Programmer - UIC00B Programmer

### 3.3.1 Accelerometer Module (ADXL335)

Human movement detection is facilitated by an analog accelerometer, which is a sensor that varies an output voltage with a direct correlation to the magnitude of acceleration in a given direction. Since a change in acceleration is inherent to movement, the accelerometer provides information about the movements to which it is subjected.

The accelerometer selected for this research project is the Analog Devices, ADXL335. This accelerometer has the ability to detect dynamic changes of acceleration in all directions (vertical, medial-lateral and anterior-posterior) by using X, Y and Z axes. It runs on low current consumption of 200μA with voltage operation of 2.0V to 3.6V. This tri-axial accelerometer measures acceleration with a minimum full-scale range of ±3g and the dimensions were 4mm length × 4mm width × 1.45mm height.

Each axis reports the current magnitude of acceleration with an analog voltage that is mathematically converted to a "g-value" where "1g" is equal to the force of Earth's gravity. The g-value can be positive or negative with the "0g" location centred at half of the accelerometer supply voltage. In our prototype, the supply voltage is 3.0V that leads to a “0g” location at 1.5V.

The top view, functional block diagram, pin layout and pins layout description of the ADXL335 are shown in Figure 3.6, Figure 3.7, Table 3.1 and Figure 3.8. The pins’ location in the both figure might not appear as the same like the original component but the functions and technical specifications are the same.


**Figure 3.6 ADXL335 Top View**

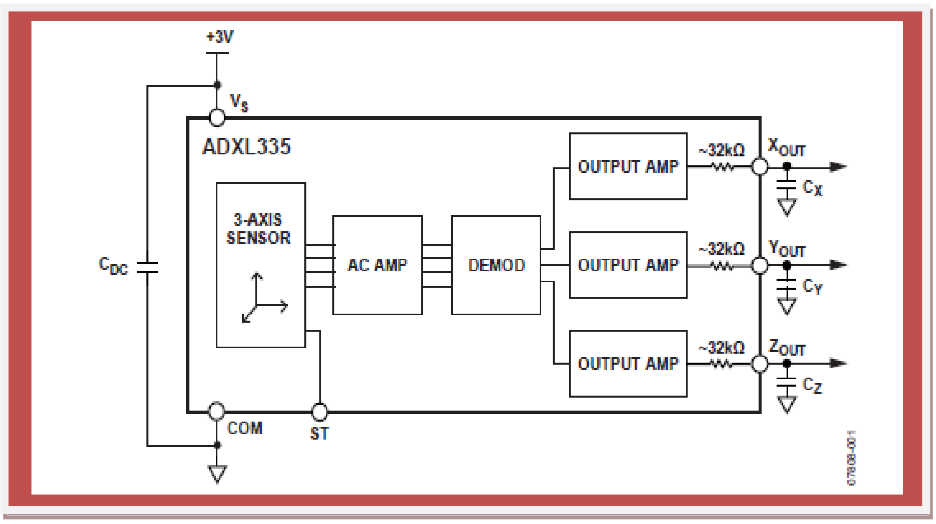



**Figure 3.7 ADXL335 Functional Block Diagram (ADXL335 Technical Datasheet)**

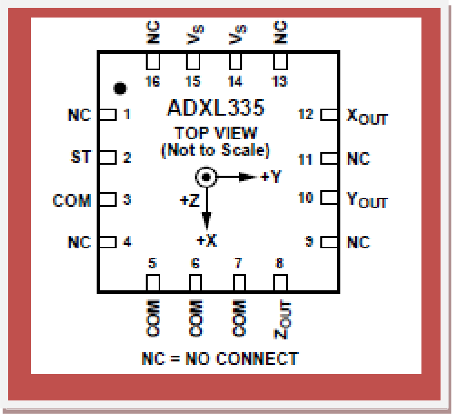



**Figure 3.8 ADXL335 Pin Layout (ADXL335 Technical Datasheet)**

**Table 3.1 Pins Layout Descriptions (ADXL335 Technical Datasheet)**

| Pin No | Mnemonic | Description |
|---|---|---|
| 1 | NC | No Connect |
| 2 | ST | Self-Test |
| 3 | COM | Common |
| 4 | NC | No Connect |
| 5 | COM | Common |
| 6 | COM | Common |
| 7 | COM | Common |
| 8 | $Z_{out}$ | Z Channel Output |
| 9 | NC | No Connect |
| 10 | $Y_{out}$ | Y Channel Output |
| 11 | NC | No Connect |
| 12 | $X_{out}$ | X Channel Output |
| 13 | NC | No Connect |
| 14 | $V_s$ | Supply Voltage (2.0V to 3.6V) |
| 15 | $V_s$ | Supply Voltage (2.0V to 3.6V) |
| 16 | NC | No Connect |

Experiments indicate that a sample rate of 20Hz is ideal for reading accelerometer voltages. Given the average speed, and acceleration of human movements, a rate of 20 samples per second provides finely detailed information about a subject's motion. Higher frequency samples tend to saturate acceleration changes to near-zero change per sample and require more memory for data storage. Lower frequency samples saturate the average change per sample to be very high regardless of the subject's actual movement intensity.

Both of the devised algorithms for abnormal movement detection require a common set of data processing operations that interpret the voltages read from the ADC (generated by the accelerometer) and then convert them into interpretable data. The goal of these operations is to generate a single smoothly changing curve that represents the recent activity level of the test subject.

#### 3.3.1.1 Accelerometer Calibration

An accelerometer calibration is a criteria factor to maintain the accuracy of the accelerometer data result at any different conditions. Simple calibration of accelerometer need to be carrying out by 3 different conditions, such as following:

1. When the accelerometer is placed -90˚ or reverse vertical to the table, the gravitational acceleration is -1g, the voltage for the x-axis is 1.28V and the voltage for y-axis is 1.29V.
2. When the accelerometer is placed on the table, the gravitational acceleration is 0g at offset, the voltage for the x-axis is 1.62V and voltage for y-axis is 1.63V.
3. When the accelerometer is placed 90˚ or vertical to the table, the gravitational acceleration is 1g, the voltage for the x-axis is 1.94V and the voltage for y-axis is 1.95V.

All the voltage of the accelerometer is measured by the digital multimeter and oscilloscopes in the electrical laboratory.

Therefore, the offset voltage is equal to 1.62V for x-axis and 1.63V for y-axis. Due to the offset voltage difference between the x-axis and y-axis is around 0.01V. So, assume the offset voltage for the x-axis and y-axis is equal to 1.62V.

From the datasheet, the gradient of the accelerometer, ADXL335 is equal to 320 mV/g. Therefore,

1. When the accelerometer at maximum +3.6g, the voltage for x-axis is

   320 mV/g × 3.6g + 1.62V = 2.772V

2. When the accelerometer at minimum -3.6g, the voltage for x-axis is

   320 mV/g × (-3.6g) + 1.62V = 0.396V

Voltage supply for the design circuit is 9V. However, 3.3V voltage regulator is used to maintain the voltage supply for the accelerometer between the ranges of 2.0V to 3.6V. Therefore the voltage reference positive, $V_{ref+}$ for the accelerometer is equal to 3.3V. Voltage reference negative, $V_{ref-}$ = for the accelerometer is equal to 0V due to the voltage reference negative is connected to Vss, which grounded.

The useful information which needs to be known is as following:

1. PIC18F4550 consists of 10 bits analog-to-digital converter

   $2^{10}$ steps = 1024 steps

2. Steps per volt

   Steps per volt = 1024 step / 3.3V

   = 310 step / Volt

3. Volt per Steps

   Volt per steps = 3.3V / 1024 Steps

   = 3.23 mV / step

4. g per steps

   g per steps = (3.23 mV / step) / (330 mV/g)

   = 9.79 mg / step

5. Steps per g

   Steps per g = (330 mV/g) / (3.23 mV/step)

   = 102.16 step/g

6. g per volt

   g per volt = 1 / (330 mV/g)

   = 3.03 g/V

Therefore, the calculation of proportional voltage from accelerometer is

$$Voltage = 320\ mV/g \times (g) + 1620\ mV \quad (3.1)$$

Where

g = output data from the accelerometer at the specific time.

The SI unit for voltage is volts (V).

The conversion for gravitational acceleration formula is

$$g\_Conversion = \left\{\left[\left(\frac{\text{Converted ADC}}{1024} \times 3.3\right) - 1.62\right] \times 3.03\right\} \quad (3.2)$$

The SI unit for the equation is g.

### 3.3.2 Microcontroller Start-up Board (SK14C) and Microcontroller (PIC18F4550)

SK14C is an enhanced version of 40 pins PIC microcontroller start up kit. This board contains all of the hardware and comes with basic element for PIC MCU user to begin project development. This board comes with features such as follows:

- Compact, powerful, flexible and robust start-up platform
- Save development and soldering time
- No extra components required for the PIC to function
- UART communication and USB on board
- All 33 input/output pins are nicely labelled to avoid miss-connection by users
- Perfectly fit for 40 pins 16F and 18F PIC
- Maximum current is 1A
- Dimension: 85mm × 55mm

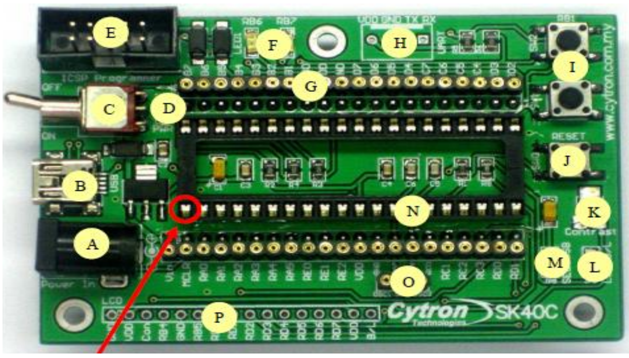



**Figure 3.9 SK14C Board Layout Top View (SK14C Technical Datasheet)**

The board in Figure 3.9 as above contains the remaining facilities necessary to develop accelerometer-based abnormal movement detection algorithms. The significant components on the board are shown in Table 3.2.

**Table 3.2 Components on the SK14C Board**

| Label | Function | Description |
|---|---|---|
| A | DC power adaptor socket | Input voltage ranged from 7 to 15V |
| B | USB Connector | Communication between devices and a host controller (usually PC) |
| C | Toggle Switch for power supply | On/off the power supply from adaptor |
| D | Power indicator LED | Light ON as long as the input power connected |
| E | Connector for UIC00A Programmer | USB ICSP PIC Programmer |
| F | LED Indicator | 2 LEDs as active High output for PIC |
| G | Header pin and turn pin | Consist of several line of header pin and turn pin |
| H | UART Connector | Reserved for UART communication |
| I | Programmable Push Button | Extra input button can be programmed as input switch |
| J | Reset Button | Function of Reset for PIC MCU |
| K | LCD Contrast | 5K of trimmer to set LCD contrast |
| L | JP8 for LCD Backlight | LCD display will have backlight if this pin is shorted |
| M | JP9 for USB | Connect this pins for USB port |
| N | 40 pin IC socket for PIC MCU | Plug in any 40 pins PIC MCU (8 bit) |
| O | Turn pin for crystal | Turn pin is provided for crystal |
| P | LCD Display | Reserved for 2 × 16 LCD Display |

A microcontroller is a single-chip computer. Micro suggests that the device is small, and controller suggests that it is used in control applications. Another term for microcontroller is embedded controller, since most of the microcontrollers are built into or embedded in the devices they control.

A microcontroller, on the other hand, has all the support chips incorporated inside its single chip. All microcontrollers operate on a set of instructions (or the user program) stored in their memory. A microcontroller fetches the instructions from its program memory one by one, decodes these instructions, and then carries out the required operations.

A microcontroller is a very powerful tool that allows a designer to create sophisticated input-output data manipulation under program control. Microcontrollers are classified by the number of bits they process. Microcontrollers with 8 bits are the most popular and are used in most microcontroller-based applications.

The simplest microcontroller architecture consists of a microprocessor, memory, and input-output. The microprocessor consists of a central processing unit (CPU) and a control unit (CU). The CPU is the brain of the microcontroller; this is where all the arithmetic and logic operations are performed. The CU controls the internal operations of the microprocessor and sends signals to other parts of the microcontroller to carry out the required instructions.

Basically, a microcomputer executes a user program which is loaded in its program memory. Under the control of this program, data is received from external devices (inputs), manipulated, and then sent to external devices (outputs). For example, in a microcontroller-based lower extremities movement analysis system using accelerometer, the microcontroller reads the acceleration data using accelerometer sensors and then sends the output for the data analysis.

The human movement analysis algorithms will require specific functionality from the microcontroller. The most important characteristics of this prototype using the Microchip Technology Corporation, 18F4550 microcontroller, are the following:

- 20 MHz clock rate.
- 32k bytes of flash program memory
- Self-programmability
- 10-bit, up to 13-channel analog-to-digital converter (A/D)

- CCP and Enhanced CCP implementation
- Enhanced Addressable USART
- Streaming Parallel Port

All these functions allow such microcontroller to be used in advanced applications in automotive, industrial, appliances and consumer applications.

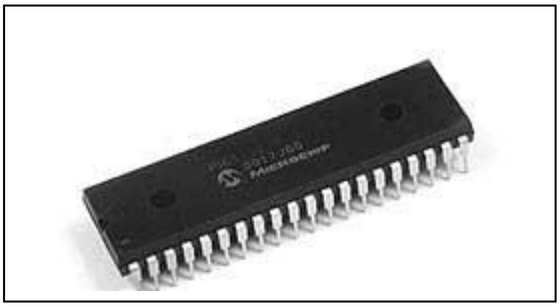


**Figure 3.10 Microchip PIC18F4550 Microcontroller**

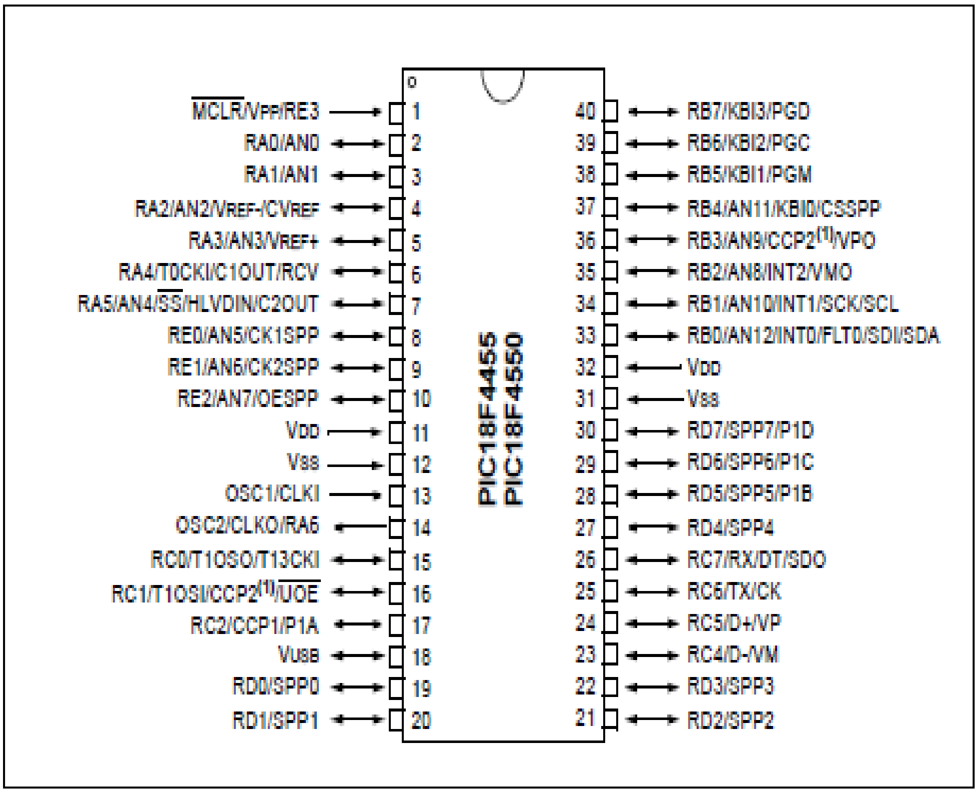



**Figure 3.11 PIC18F4550 Pins Layout (PIC18F4550 Technical Datasheet)**

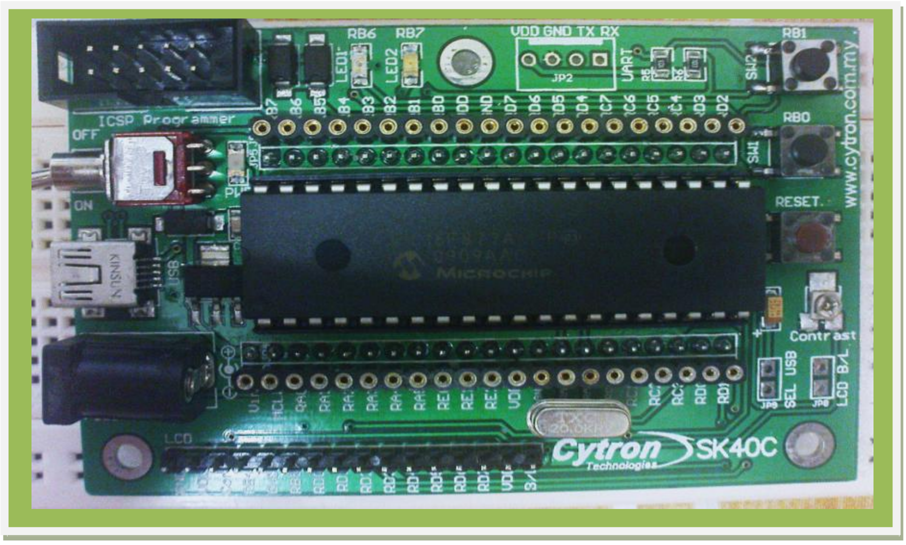



**Figure 3.12 SK14C Start-up Kit and PIC18F4550 Microcontroller**

The purposes for SK40C Enhanced 40 Pins PIC Start-up Kit is used with the PIC18F4550 in this research project are all 33 input/output pins are nicely labelled to avoid miss-connection by users and no extra components or soldering required for the PIC to function. PIC18F4550 provides high computational performance at ana economical price with the addition of high endurance.

### 3.3.3 USB ICSP PIC Programmer - UIC00B Programmer

UIC00B is designed to program popular Flash PIC MCU which includes most of the PIC family. It offers low cost yet reliable, user friendly and allows user to quickly program and debug the source code while the target PIC is on the development board.

Since USB port is commonly available and widely used on personal computer, UIC00B is designed to be used with USB connection. Hence, its power directly from USB connection, thus no external power supply is required, making it a truly portable programmer and ideal for field and general usage.

**Figure 3.13 UIC00B Programmer Set (UIC00B Technical Datasheet)**

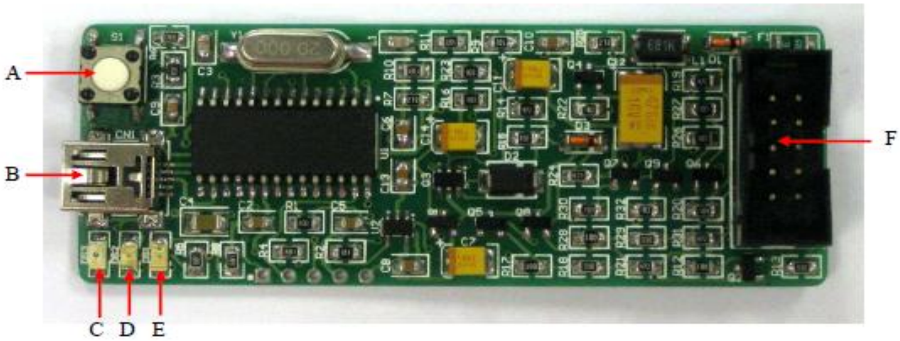



**Figure 3.14 UIC00B Programmer (UIC00B Technical Datasheet)**

**Table 3.3 Components on UIC00B Programmer**

| Label | Function | Description |
|---|---|---|
| A | Switch to initiate write device programming | When programmer write on |
| B | Mini USB port socket | USB connection to laptop |
| C | Main power supply indicator LED (green) | ON once USB connection is ready |
| D | Target indicator LED (orange) | UIC00B is powering the target device |
| E | Busy indicator LED (red) | UIC00B is in program mode |
| F | IDC box header for programming connector | Connection to target board |

### 3.3.4 Data Transmission Module

Two types of the data transmission module are introduced and implemented in this section, which are wireless data transmission module and wire data transmission module.

For the wireless data transmission module, Bluetooth have been used for the data transmission. This is due to Bluetooth technology is inexpensive, low energy consumption, and the devices take care of the entire setup process.

For the wire data transmission module, RS232 via USART have been used for the data transmission. This is a simple and inexpensive way of transferring data from one place to another.

#### 3.3.4.1 Wireless Data Transmission - Bluetooth Module

KC Wirefree Bluetooth Starter Kit module offer simple yet compact Bluetooth platform for embedded application. Since it comes with surface mount layout, starter kits have been developed to ease user to explore the possible development and application.

KC Wirefree Bluetooth Starter Kit, SKKCA has a small dimension of 72mm × 39mm and has been designed for 5V TTL logic interface, no extra voltage divider is necessary. With minimum interface, it is ready to connect to microcontroller for embedded Bluetooth development.

Furthermore, the SKKCA also have been designed with the capabilities and features of:

- USB plug and play UART function
- 5V UART interface, ready for microcontroller interface
- Default baud rate of 115.2Kbps

- Compact yet easy and reliable platform

The SKKCA board have shown in Figure 3.15 which contains the remaining facilities necessary to develop accelerometer-based abnormal movement detection algorithms. The significant components on the board are listed in Table 3.4 and the product specifications are as listed in Table 3.5.

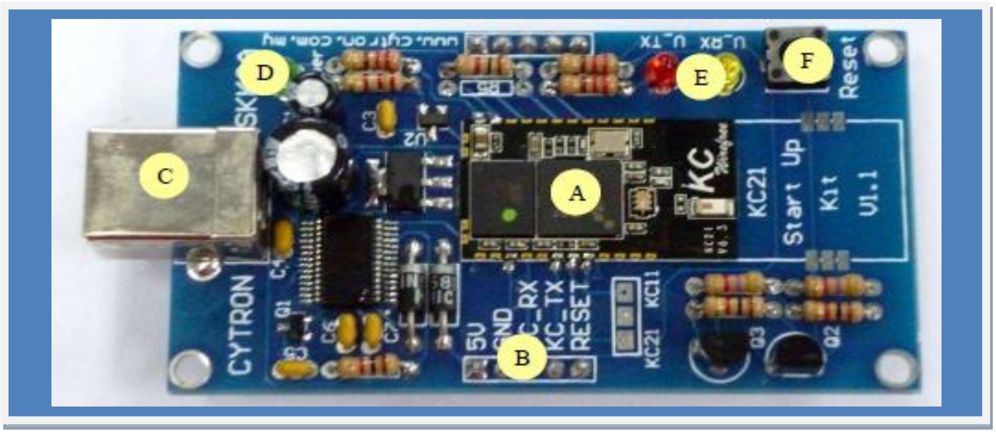



**Figure 3.15 SKKCA Board Layout (SKKCA Technical Datasheet)**

**Table 3.4 Components on the SKKCA Board**

| Label | Function |
|---|---|
| A | KC Wirefree Bluetooth module, either KC21 or KC11. |
| B | 5 ways header pin for external power and interface to microcontroller. If this kit is connected to microcontroller board, it should be powered with 5V. |
| C | USB B type socket. |
| D | On board 3.3V power indicator LED. It is green colour. |
| E | Two LED indicators for USB’s transmitter and receiver status. It will only work if SKKCA is connected to PC or laptop through USB cable. |
| F | On board reset button for KC Wirefree Bluetooth module. |

**Table 3.5 SKKCA Product Specification**

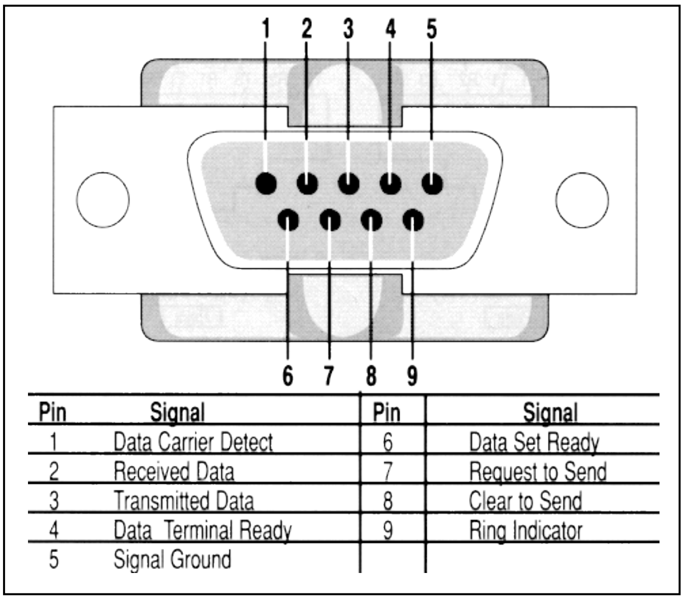
| Label | Definition | Function |
|---|---|---|
| 5V | Power Input | External power source for SKKCA, the typical voltage is 5V. |
| GND | Ground | Ground of power and signal. |
| KC_RX | UART receive signal | This is KC Wirefree Bluetooth module's receiver pin. This is an input pin to SKKCA. It should be connected to microcontroller's transmitter pin. |
| KC_TX | UART transmit signal | This is KC Wirefree Bluetooth module's transmitter pin. This is and output pin from SKKCA. It should be connected to microcontroller's receiver pin. |
| RESET | Reset pin | Reset pin of KC Wirefree Bluetooth module. It should be connected to a push button to ground or NPN transistor. |

The purpose of using SKKCA-21 Bluetooth module in human movement analysis system is due to portability, reliability and cost effectiveness as a wireless transmission module. The small and light weighted board is easy for user to carry around.

#### 3.3.4.2 Wire Data Transmission – RS232 Serial Port

The DB9 version RS232 connector is commonly used on the personal computer via the universal synchronous asynchronous receiver transmitter (USART) of the microcontroller and versa vice. The DB9 Female Connector RS232 and pinout are shown in the Figure 3.16 and Figure 3.17 as below:

**Figure 3.16 DB9 Female Connector RS232** (© Copyright 2011 Basic Micro)




| Pin | Signal | Pin | Signal |
|---|---|---|---|
| 1 | Data Carrier Detect | 6 | Data Set Ready |
| 2 | Received Data | 7 | Request to Send |
| 3 | Transmitted Data | 8 | Clear to Send |
| 4 | Data Terminal Ready | 9 | Ring Indicator |
| 5 | Signal Ground | | |

**Figure 3.17 DB9 Female Connector RS232 Pinout.** (© Copyright 2008 HFLINK)

Furthermore, MAX232 module is needed for the communication between the computer and RS232. MAX232 is the IC which in one package contains the necessary drives and receivers to adapt the RS232 signal voltage levels to TTL logic. MAX232 needs 5V voltage and generates the necessary RS232 voltage levels which approximately -10V and +10V internally. This greatly simplified the design of circuitry.


**Figure 3.18 MAX232**



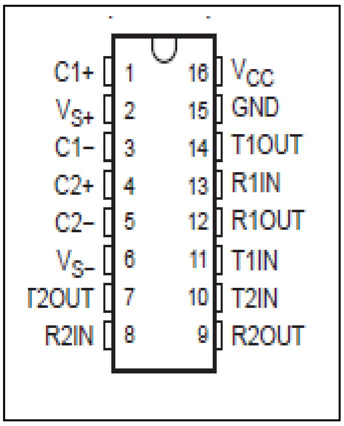



**Figure 3.19 MAX232 Pinout**

(MAX232 Technical Datasheet)

**Table 3.6 MAX232 Product Specification**

| Label | Name | Purpose | Capacitor value MAX232 |
|---|---|---|---|
| 1 | C1+ | + connector for capacitor C1 | 1 µF |
| 2 | V+ | Output of voltage pump | 1 µF to $V_{cc}$ |
| 3 | C1- | - connector for capacitor C1 | 1 µF |
| 4 | C2+ | + connector for capacitor C2 | 1 µF |
| 5 | C2- | - connector for capacitor C2 | 1 µF |
| 6 | V- | Output of voltage pump | 1 µF to GND |
| 15 | Ground | 0V | 1 µF to $V_{cc}$ |
| 16 | Power Supply | +5v | - |

Unfortunately, most modern computers have a USB port and did not have an RS232 serial port, so a USB-to-Serial Adapter which is a commercially available device containing a small circuit built into the enclosure of a DB9 male plug, with a USB connector on the other end is needed. It requires a software driver to be loaded and run on the computer, so the computer can recognize it as a “virtual” RS232 serial port.

**Figure 3.20 USB-to-Serial Adapter and the Software Driver**
(© Copyright 2003 Q.C USA INC)

### 3.3.5 Voltage Regulators

Voltage regulators are components that maintain a consistent voltage output. Electronics components are often made to accept only a low maximum voltage, and can be badly damaged by a power surge. Likewise, a low voltage can fail to provide enough power for the component. Voltage regulators are often responsible for maintaining a voltage within the range that the electronic component can safety accepts. (What are voltage regulators, 2003)

In the human movement analysis system, two types of voltage regulators are used to maintain a consistent voltage output is listed as below:

1. LM1117T 3.3V voltage regulator
2. L7805CV 5.0V voltage regulator

### 3.3.5.1 LM1117T 3.3V Voltage Regulator

LM1117T is used to regulate the voltage output of the batteries which supply to accelerometers. This is due to the voltage supply range can be accepted for accelerometers are between 2.0V to 3.6V. However, 9V battery supply is used in this system. A voltage regulator is used n order to prevent the accelerometers damaged by a power surge.

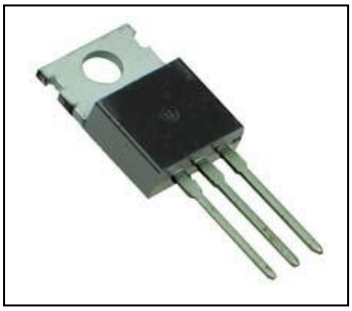


**Figure 3.21 LM1117T 3.3V Voltage Regulator**

The Connection diagram and block diagram of the LM1117T 3.3V voltage regulator are shown in Figure 3.21 and Figure 3.22.

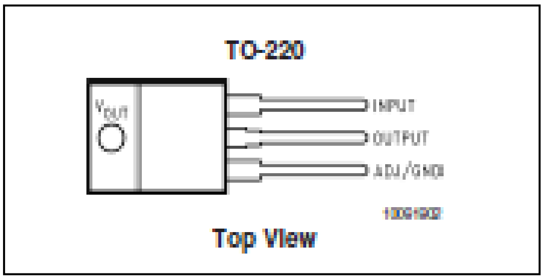



**Figure 3.22 Connection Diagram of LM1117T 3.3V Voltage Regulator (LM1117T Technical Datasheet)**

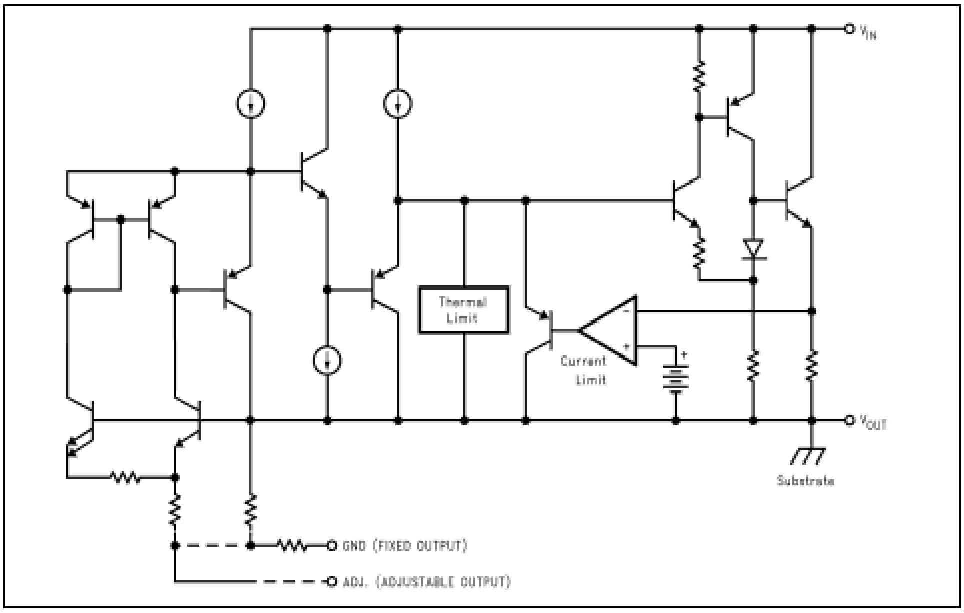



**Figure 3.23 Block Diagram of LM1117T 3.3V Voltage Regulator (LM1117T Technical Datasheet)**

### 3.3.5.2 L7805CV 5.0V Voltage Regulator

L7805CV is used to regulate the voltage output of the batteries which supply to the Wireless Bluetooth module, SKKCA-21. This is due to the voltage supply range can be accepted for SKKCA-21 is between 5.0V to 5.5V. A voltage regulator is used n order to prevent the accelerometers damaged by a power surge.

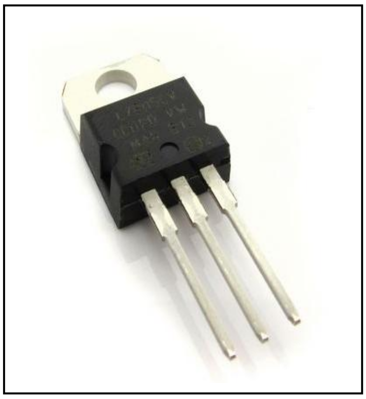


**Figure 3.24 L7805CV 5.0V Voltage Regulator**

The Connection diagram and block diagram of the L7805CV 5.0V voltage regulator are shown in Figure 3.24 and Figure 3.25.

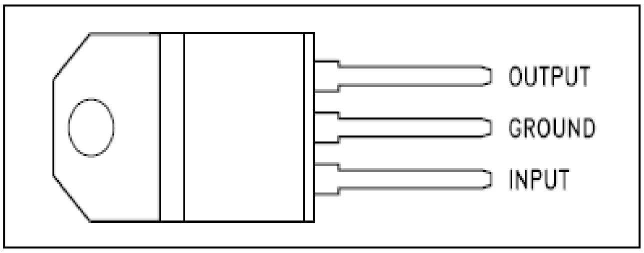



**Figure 3.25 Connection Diagram of L7805CV 5.0V Voltage Regulator (L7805CV Technical Datasheet)**

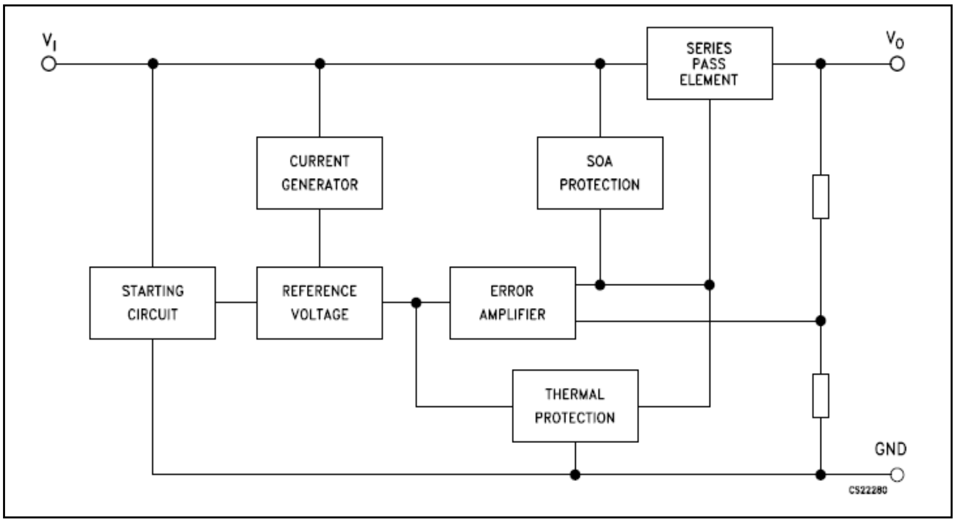



**Figure 3.26 Block Diagram of L7805CV 5.0V Voltage Regulator (L7805CV Technical Datasheet)**

## 3. 4 Hardware Assembly

In this section, the entire part of the circuit diagram assembly procedure would be showed. The following figure is the circuit diagram for the entire human movement analysis system used to assemble the design. A clearer version can be found in Appendix E and F.

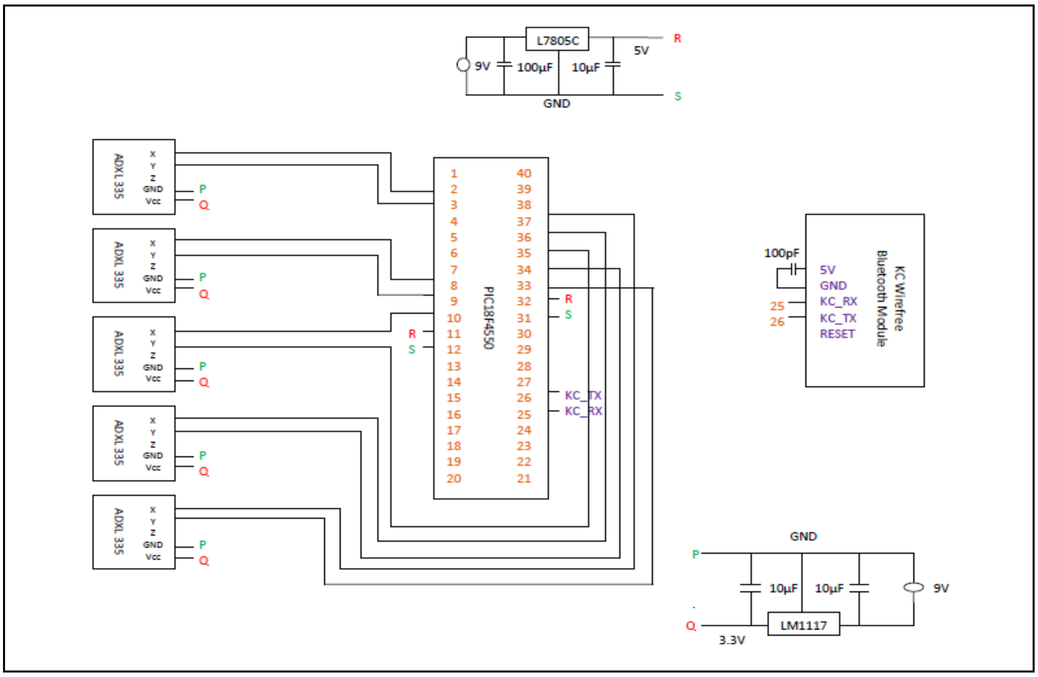



**Figure 3.27 Circuit Diagram of Human Movement Analysis System.**

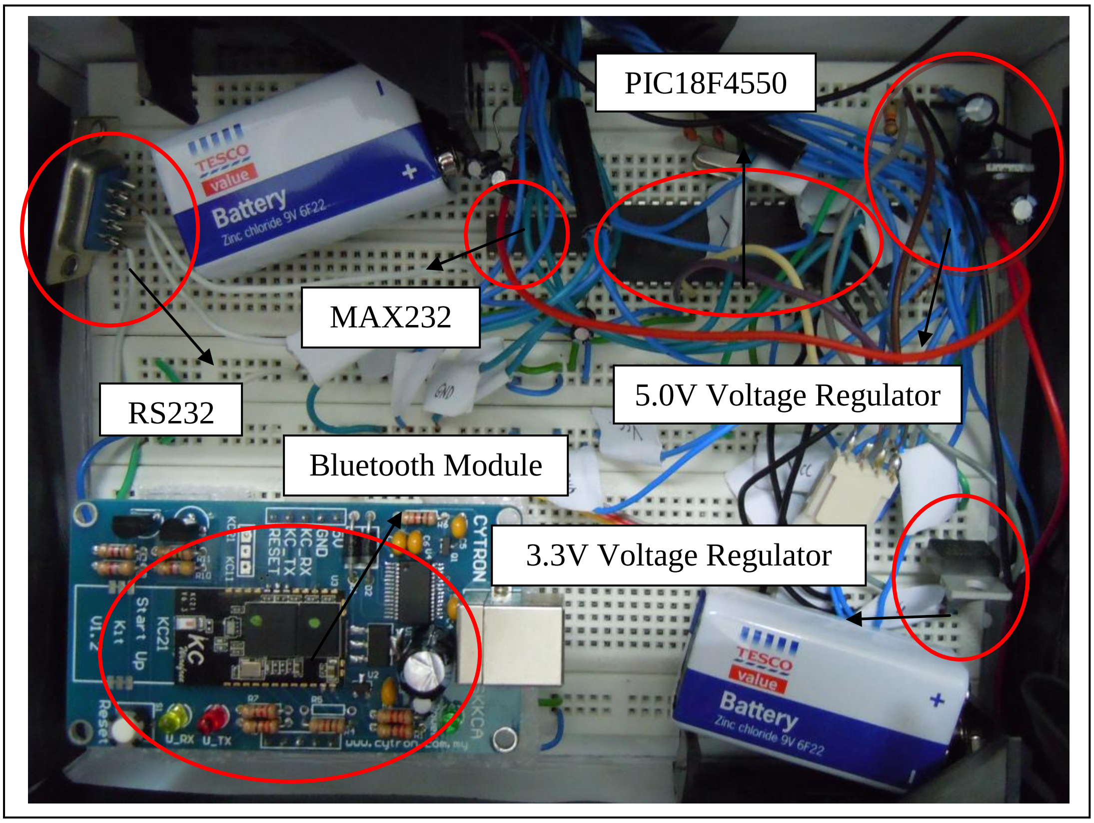



**Figure 3.28 Human Movement Analysis System Circuit Board Photo**

### 3.4.1 Wire Connection and Soldering for Accelerometers

The procedures for single core wire and the accelerometer breakout board connection are shown as below:

Step 1: Cut the lengths of the wire to 2m long with scissor. Total 28 wires are needed. Make sure it does not influence the human movement analysis of the subject.

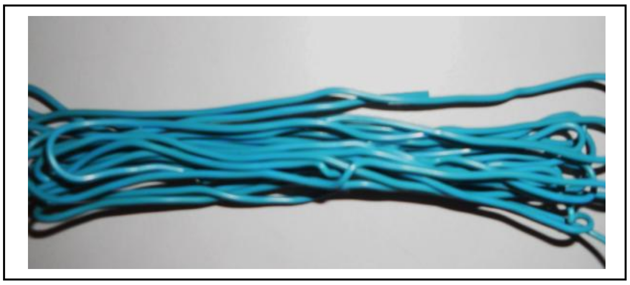


**Figure 3.29 Cut Each Wire with the Length of 2m**

Step 2: Strip the ends of each wire.

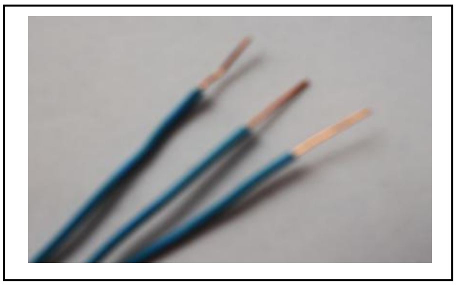


**Figure 3.30 Strip the End of Each Wire**

Step 3: Label the wire with x, y, GND and Vcc.

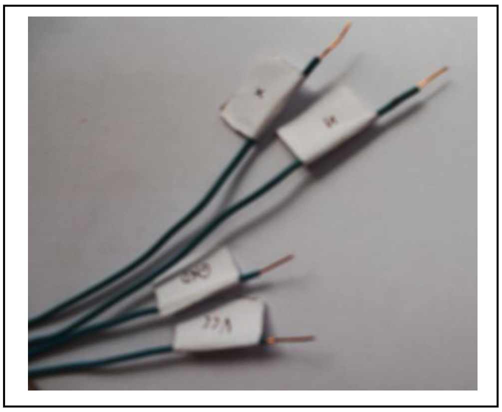


**Figure 3.31 Label Each Wire**

Step 4: Put the wire to their respective hole of the accelerometer, which included x, y, GND and Vcc.

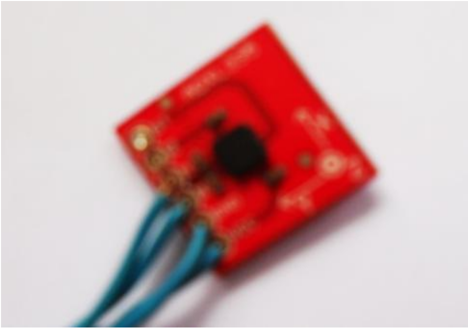


**Figure 3.32 Put Each Wire into their Respective Hole on Accelerometer**

Step 5: Solder the wire with slip the heat shrink over the bare connection and heat with the soldering iron.

**Figure 3.33 Solder Each Wire on the Accelerometer breakout Board**

Step 6: Repeat all the step from 1 to 5 for wire connection of each accelerometer.

**Figure 3.34 Final Products**

### 3.4.2 Preparation of Rainbow Cable Connector for Bluetooth Module

The electronic parts needed for preparation of rainbow cable connector for Bluetooth module are 10 ways rainbow cable, 2510 4 ways connector and 2510 iron pins. The procedures for rainbow cables connector for Bluetooth module are shown as below:

Step 1: Prepare a 2510 4 ways connector and 4 pieces of 2510 iron pins.

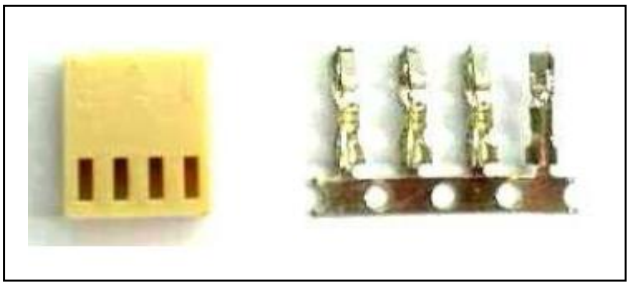


**Figure 3.35 2510 4 Ways Connector and 2510 Iron Pins**

Step 2: Separate the 10 ways rainbow cable to 4 ways rainbow cable.

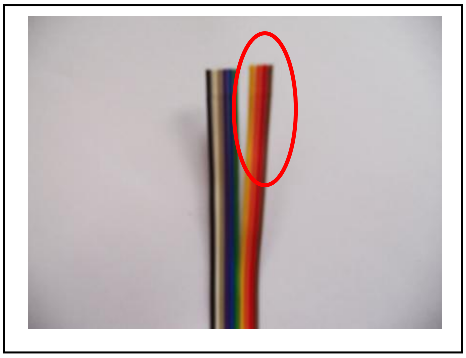


**Figure 3.36 Rainbow Cable**

Step 3: Strip the ends of each rainbow cable.

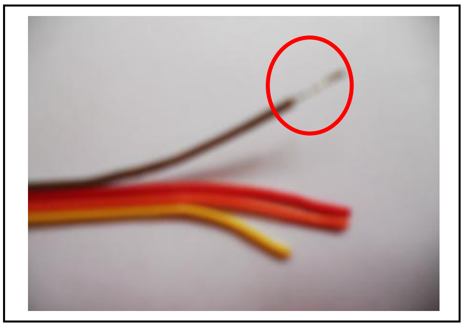


**Figure 3.37 Strip the Ends of Rainbow Cable**

Step 4: Place 1 way rainbow cable to one of the 2510 iron pins and make it tight. Repeat the step 4 for the other 3 way rainbow cable.

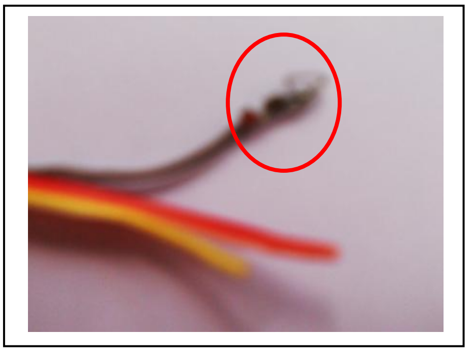


**Figure 3.38 Place Rainbow Cable to 2510 Iron pins**

Step 5: Place 4 ways rainbow cable with 2510 iron pins to the 2510 4 ways connector.

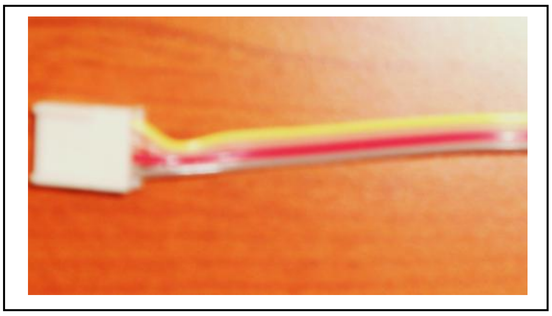


**Figure 3.39 Ribbon Cable Connector**

Step 6: Connect the rainbow cable connector to Bluetooth module.

**Figure 3.40 Completed Connections**

### 3.4.3 3.3V Voltage Regulator Construction

LM1117T 3.3V voltage regulator is used to regulate the voltage output of the batteries which supply to accelerometers. This is due to the voltage supply range can be accepted for accelerometers are between 2.0V to 3.6V. The circuit diagram for the 3.3V voltage regulator is as shown in Figure 3.29.

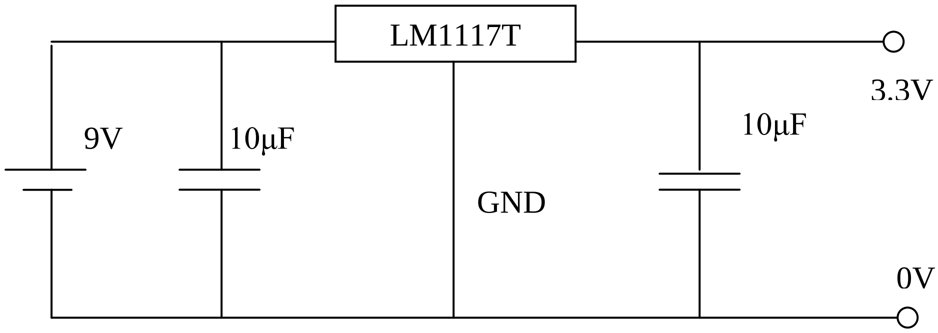



**Figure 3.41 Circuit Diagram of 3.3V Voltage Regulator**

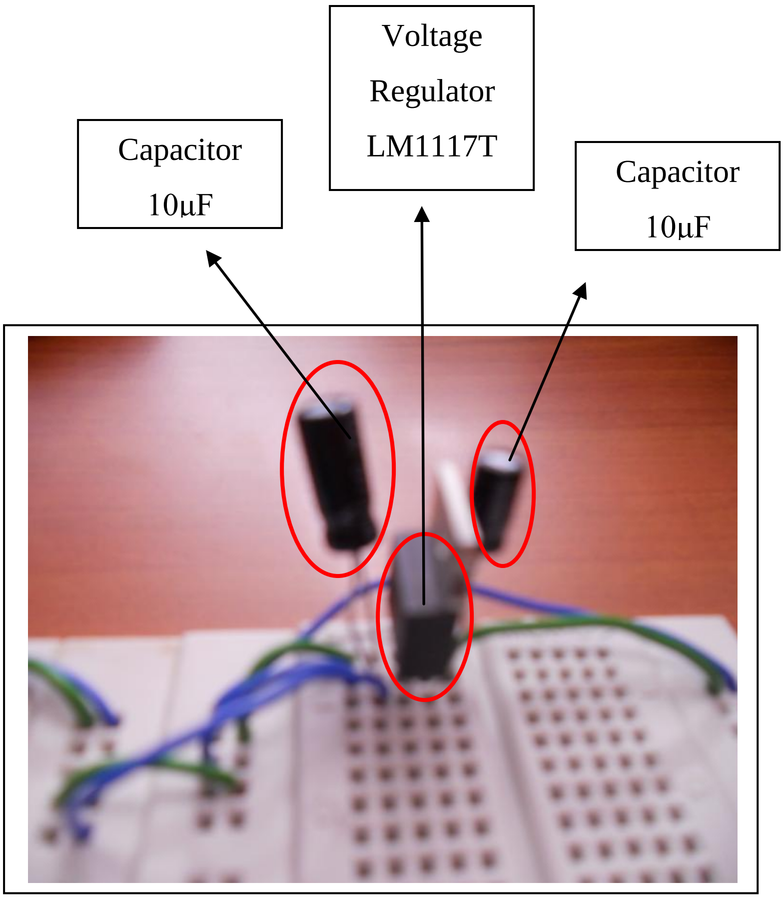



**Figure 3.42 3.3V Voltage Regulator Circuit Connections on Breadboard.**

### 3.4.4 5.0V Voltage Regulator Construction

L7805CV is used to regulate the voltage output of the batteries which supply to the Wireless Bluetooth module, SKKCA-21. This is due to the voltage supply range can be accepted for SKKCA-21 is between 5.0V to 5.5V. The circuit diagram for the 5V voltage regulator is as shown in Figure 3.30.

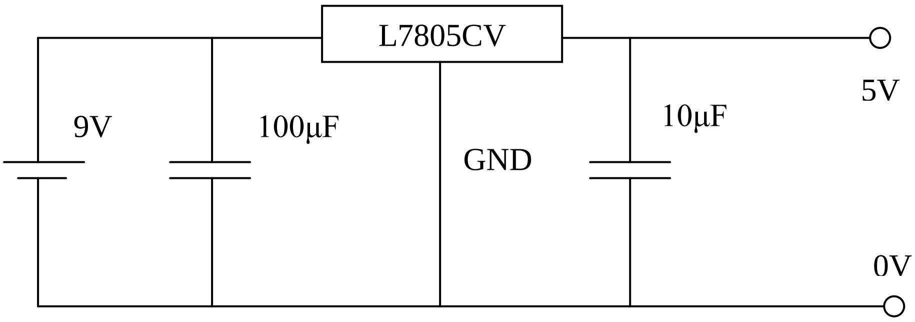



**Figure 3.43 Circuit Diagram of 5V Voltage Regulator**

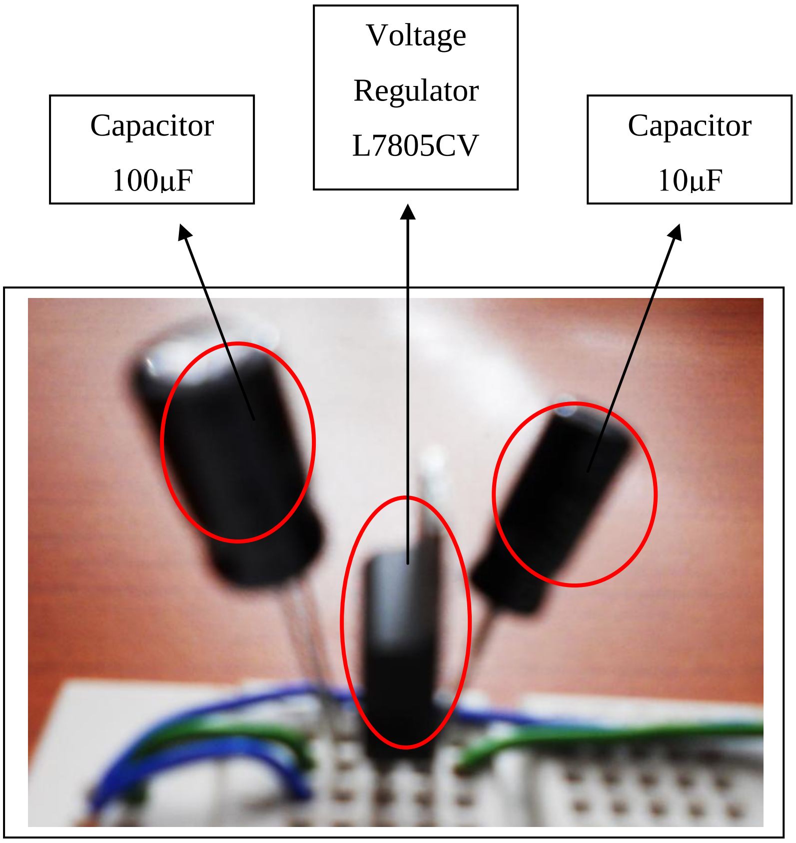



**Figure 3.44 5V Voltage Regulator Circuit Connections on Breadboard.**

### 3.4.5 RS232 and MAX232 Connection for wires data transmission

The circuit connection diagram between the DB9 female connector RS232 and the MAX232 are shown in Figure 3.31.

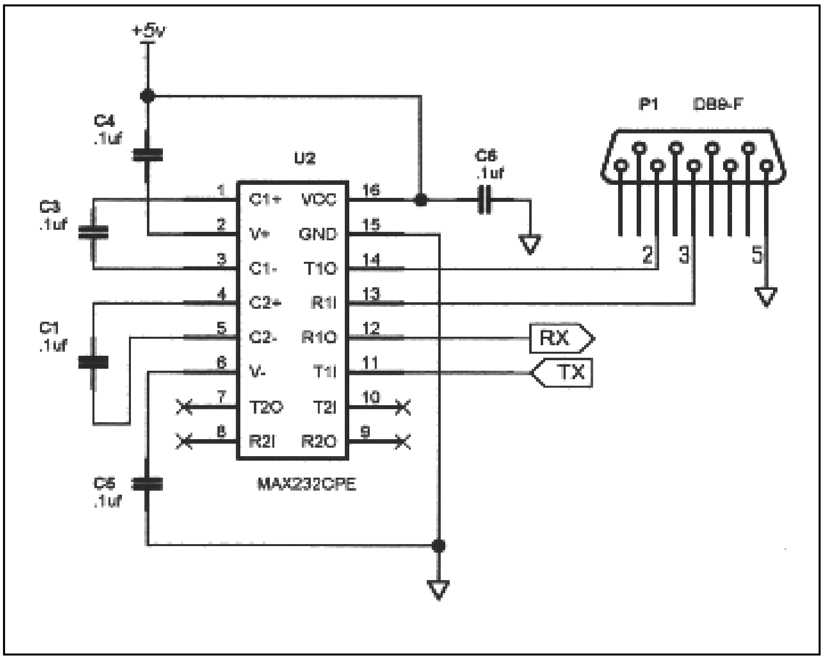



**Figure 3.45 RS232 and MAX232 Circuit Connection Diagram**

(© Copyright Virtual Integrated Design)

### 3.4.6 Portable Box Design

A lightweight portable box is designed by the hard cut board for the placement of lower extremities human movement analysis system circuit and is attached to the backbone of the voluntarily participants by the sport protective cuff, without influenced the human movement analysis.

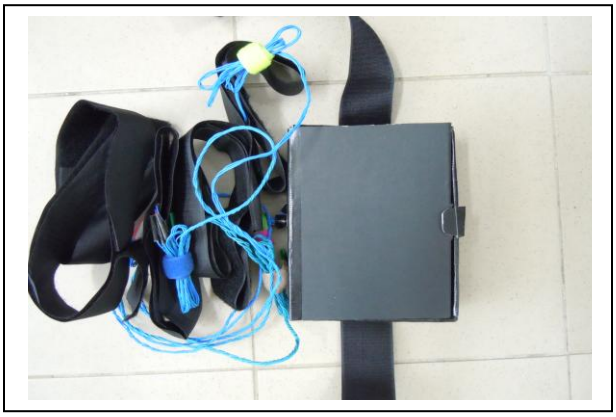


**Figure 3.46 Top View of Portable Box**

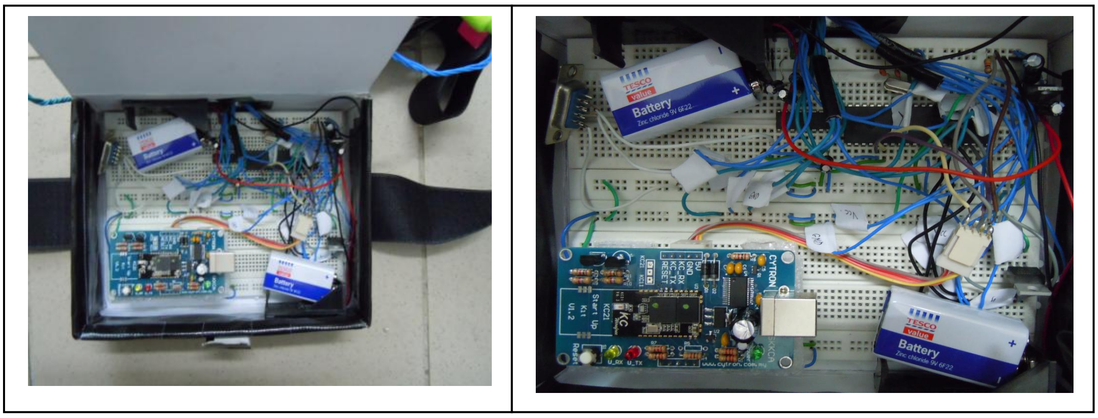



**Figure 3.47 Inside of the Portable Box**

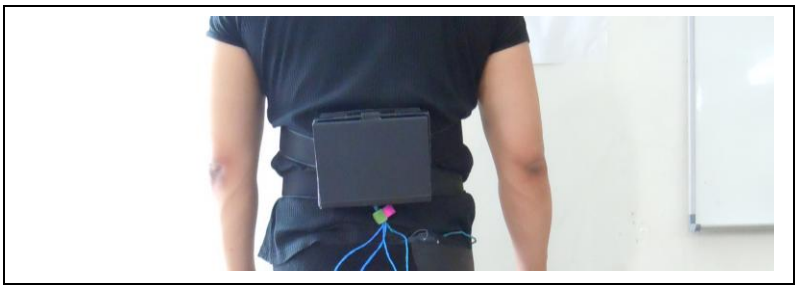


**Figure 3.48 Attached at Backbone of Participants**

## 3.5 Software

The entire procedures regarding software programming and designing are discussed in this section. This section consists of three parts, which included PIC programming, Bluetooth to computer communication and LabVIEW graphical programming.

### 3.5.1 PIC Programming Procedures

The simplest microcontroller architecture consists of a microprocessor, memory, and input-output. The microprocessor consists of a central processing unit (CPU) and a control unit (CU). The CPU is the brain of the microcontroller; this is where all the arithmetic and logic operations are performed. The CU controls the internal operations of the microprocessor and sends signals to other parts of the microcontroller to carry out the required instructions.

A microcomputer executes a user program which is loaded in its program memory. Under the control of this program, data is received from external devices (inputs), manipulated, and then sent to external devices (outputs). For example, in a microcontroller-based lower extremities movement analysis system using accelerometer, the microcontroller reads the acceleration data using accelerometer sensors and then sends the output for the data analysis.

In order to build a microcontroller-based lower extremities movement analysis system, a set of instructions needed to be loaded and burned into the microcontroller to control the whole process of sensor data collection. Two main software programs are needed which are MPLAB IDE and PICkit2. Basically, MPLAB IDE is used to compile and debug the programming language - PIC source code. PICkit2 is used to load and burn the programming language - PIC source code into the microcontroller. The detailed steps and procedures will be discussed in the following sub-chapters.

### 3.5.1.1 PIC Programming Source Code

A PIC source code has been written to program the microcontroller PIC18F4550 to function properly. The complete PIC microcontroller source code is attached in Appendix G.

Before start writing the PIC microcontroller C programming source code, an ease understandable description of the programming will be declared such as the purpose of the program, programmer, program file name, created date and microcontroller types.

```
/******************************************************************
        Lower Extremities Movement Analysis Using Accelerometer
        ****************************************************
This program is designed to obtain the acceleration signal data from accelerometer
which is attached on the human remote body part and transmits to the
microcontroller for further signal processing. After that, the processed signal data
transmit to personal computer for the data analysis.
Programmer: Ms. Chew Kah Mun
File: Human Movement Analysis.C
Date: 15 March 2011
Micro: PIC18F4550
******************************************************************/
```

Next, declaration of type-qualifier and data definition of variables in the source code will take places. There are few standard data definitions such as “short”, “char”, “int”, “long” and “float”. The details of each data definition and type qualifier for C programming are attached in Appendix B and C.

```
unsigned char head[10] = {‘A’, ‘B’, 'C', ‘D’, ‘E’, ‘F’, ‘G’, ‘H’, ‘I’, ‘J’};
```

From above, data qualifier for *unsigned* means the data is always positive if not specified, while data definition for *char* means int8. Therefore, *unsigned char* is an

8-bit data type that takes a value in the range of 0-255 (00-FFH). Prefix variables are defined in the 10 rows array forms with the array name *head*, such as *A, B, C, D* and so on. *A* which refers to the X-axis output of accelerometer sensor 1 and *B* which refers to the Y-axis output of accelerometer sensor 1. *C* and *D* are refers to the respective accelerometer 2 and so on for the others.

```
static unsigned char channelnumber;
```

From above, “static unsigned char cahnnelnumber” means the variable *channelnumber* is always positive if not specified and globally active an initialized to 0. Refer to Appendix D.

```
void main(void)
void delayFunc(unsigned int);
void transmit_data(unsigned char* );
void getAcc(unsigned char *);
void conversion(unsigned char, unsigned char, unsigned char*);
```

The *void main(void)* indicates the starting point of the main function. The coding in this main function is first executed and any other sub-functions, such as

- *void delayFunc(unsigned int)* for time delay function
- *void transmit_data(unsigned char* )* for serial port data transmission function
- *void getAcc(unsigned char *)* for getting accelerometer analogues data
- *void conversion(unsigned char, unsigned char, unsigned char*)* for gravitational acceleration conversion.

are linked directly from this main function.

```
ADCON1 = 0x12;
ADCON0 = 0x00;
ADCON2 = 0xBE;
```

The Analog-to-Digital (ADC) module has 13 inputs for the 40 pin devices. This module allows conversion of an analog input signal to a corresponding 10-bit digital number. The module has five registers:

- A/D Result High Register (ADRESH)
- A/D Result Low Register (ADRESL)
- A/D Control Register 0 (ADCON0) controls the operation of the A/D module.
- A/D Control Register 1 (ADCON1) configures the functions of the port pins.
- A/D Control Register 2 (ADCON2) configures the A/D clock source, programmed acquisition time and justification.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| - | - | VCFG0 | VCFG0 | PCFG3 | PCFG2 | PCFG1 | PCFG0 |

VCFG0: Voltage Reference Configuration bit ($V_{REF-}$ Source)

VCFG0: Voltage Reference Configuration bit ($V_{REF+}$ Source)

PCFG3 – PCFG0: A/D Port Configuration Control Bits

For example, 0x12 (means 00010010 in binary) is assigned to *ADCON1* register. VCFG0 in bit 5 is assigned to 0, which means $V_{REF-}$ source is set to Vss while VCFG0 in bit 4 is assigned to 1, which means $V_{REF+}$ is connecting to voltage supply. The PCFG configuration bits are set as “0010”, which means 13 analogues inputs (AN12 – AN0) are activated.

```
TXSTA = 0x20;
BAUDCONbits.BRG16 = 0;
BAUDCONbits.TXCKP = 0;
BAUDCONbits.ABDEN = 0;
SPBRG = 31;
RCSTAbits.SPEN = 1;
TXSTAbits.TXEN = 1;
```

The next step is to configure the enhanced universal synchronous asynchronous receiver transmitter (EUSART) for data receiver and transmission. The operation of the EUSART module is controlled through three registers:

- Transmit Status and Control (TXSTA)
- Receive Status and Control (RCSTA)
- Baud Rate Control (BAUDCON)

In order to configure RC6/TX/CK and RC7/RX/DT/SD0 as a EUSART, the bit SPEN of RCSTA and bit TXEN of TXSTA must be set to 1.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| CSRC | TX9 | TXEN | SYNC | SENDB | BRGH | TRMT | TX9D |

TX9: 9-Bit Transmit Enable Bit

TXEN: Transmit Enable Bit

SYNC: EUSART Mode Select Bit

BRGB: High Baud Rate Select Bit

For example, 0x20 (means 00100000 in binary) is assigned to *TXSTA* register. TX9 is set to 0, which means 8-bit transmission is selected. While TXEN and BRGB is set to 1 and SYNC is set to 0, which means transmission enabled by asynchronous mode with low speed.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ABDOVF | RCIDL | RXDTP | TXCKP | BRG16 | - | WUE | ABDEN |

TXCKP: Clock and Data Polarity Select Bit

BRG16: 16-Bit Baud Rate Register Enable Bit

ABDEN: Auto-Baud Detect Enable Bit

For *BAUDCON* register, the bit TXCKP, BRG16 and ABREN are set to 0, which means 8-bit baud rate generator with disabled baud rate measurement and TX data is not inverted is used for baud rate control.

```
while(1)
{
  getAcc(acc);
  transmit_data(acc);

  if(channelnumber == 9)
  {
        channelnumber = 0;
        PB7 = ~PB7;
        delayFunc(delayConst);
  } else {
        channelnumber++;
  }
```

*While loop* is consists of a block of code and a condition. The condition is evaluated, and if the condition is true, the code within the block is executed. This repeats until the condition becomes false. Because while loops check the condition before the block is executed, the control structure is often also known as a pre-test loop.

In this *while loop*, there are consists of 3 sub-functions, which are *void getAcc(unsigned char*), void transmit_data(unsigned char*)* and *void delayFunc(unsigned int)*. The microcontroller PIC18F4550 continuously reads the analogues data generated by the accelerometers, ADXL335 and converts them into respective digital signal. The microcontroller starts to read the data from the accelerometer's analogues input, AN0, converts them into digital signal and stores it into the prefix variables defined earlier in the program.

```
void getAcc(unsigned char * pacc)
    {
      unsigned char accH, accL;

      ADCON0 = channel[channelnumber];
      ADCON0bits.ADON = 1;
      ADCON0bits.GO = 1;

      while(ADCON0bits.DONE == 1);
      accH = ADRESH;
      accL = ADRESL;

      conversion(accH, accL, pacc);

      ADCON0bits.ADON = 0;
}
```

The sub-function *void getAcc(unsigned char*)* is used for getting analogues data from accelerometers. The ADC peripheral of the PIC18 is a 10-bit ADC. The converted output binary data is held by two special function registers called ADRESL and ADRESH. Because the ADRESH:ADRESL registers give 16 bits and the ADC data out is only 1o-bit wide, 6 bits of the 16 are unused, either the upper 6 bits or the lower 6 bits.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| - | - | CHS3 | CHS2 | CHS1 | CHS0 | GO/$\overline{\text{DONE}}$ | ADON |

CHS3:CHS0: Analog Channel Select Bits

GO/$\overline{\text{DONE}}$: A/D Conversion Status Bit

ADON: A/D On Bit

The ADON set to 1, which means the A/D feature is powered up. The GO/$\overline{\text{DONE}}$ bit in the *ADCON0* register is a bit used to start conversion and monitor it to see if conversion has ended. The GO/$\overline{\text{DONE}}$ is 1 when the A/D conversion is in progress.

After the A/D conversion is complete, it will go LOW to indicate the end-of-conversion, the sub-function *void conversion(unsigned char, unsigned char, unsigned char*)* takes place, A/D feature is off and consumes no power.

The most important part for whole of the programming source code is the gravitational acceleration conversion, *void conversion(unsigned char, unsigned char, unsigned char*)*. An accelerometer calibration has been tested before getting the conversion formula for the gravitational acceleration as shown as above, which has been explained in the chapter 3.3.1.1.

$$\text{g\_conversion} = \left[\left(\frac{\text{Converted ADC}}{1024} \times 3.3\right) - 1.62\right] \times 3.03$$

```
fSum = sum;
fDeg = (((fSum / 1024)* 3.3) - 1.62);     } First Part

fDeg *= 3.03;
accDeg = fDeg;                            } Second Part
```

The first part of the conversion equation is used to determine the positive or negative gravitational acceleration. This is due to the positive and negative value of the data result is plays an important role in either acceleration or deceleration for the human movement at respective time. After that, the second part of the conversion equation will be carried out and triple digit is determined.

```
if(fDeg == -1.62)
{
  for(i=1; i<4; i++)
  {
        paccVal[i] = 0x30;
  }
  paccVal[0] = '+';
  return;
```

Situation1
When the fsum = 0, then the fDeg = -1.62g.

```
} else if(fDeg < 0){
  accVal[0] = '-';
  fDeg *= -1;
```

Situation 2

When fDeg = negative value

```
} else if(fDeg >=0){
  accVal[0] = '+';
}
```

Situation 3

When fDeg = positive value

Furthermore, the number of the decimal will affect the accurate of the percentage for gravitational acceleration. In this sample code, triple digit of the gravitational acceleration data result is showed at the end of the analysis. For example, if the fDeg is 1.5310 after multiple the 3.03, then fDeg at the end shown in the HyperTerminal is 1.53.

```
fDeg *= 3.03;
accDeg = fDeg;
accDeg2 = accDeg;
accVal[1] = accDeg % 10;
```

Last Digit

For Example, 3

```
fDeg = fDeg - accDeg2;
fDeg *= 10;
accDeg = fDeg;
accVal[2] = accDeg % 10;
```

Second Digit

For Example, 5

```
fDeg *= 10;
accDeg = fDeg;
accVal[3] = accDeg % 10;
```

First Digit

For example, 1

```
void transmit_data(unsigned char *myData)
{
  char i;
  {
        while(PIR1bits.TXIF == 0);
        TXREG = head[channelnumber][i];        For example: A
  }

  for(i=0; i < 4; i++)
  {
        while(PIR1bits.TXIF == 0);
        TXREG = myData[i];        For example: +1.53

        if(i==1)
        {
                while(PIR1bits.TXIF==0);
                TXREG= '.';
        }
  }
  while(PIR1bits.TXIF==0);
  TXREG= '\0';
}
```

After the gravitational conversion, the converted data required sent for storage. Now, sub-function *void transmit_data(unsigned char*)* for data transmission takes place and Peripheral Interrupt Request (Flag) Registers - *PIR1 registers* is involved.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| SPPIF | ADIF | RCIF | TXIF | SSPIF | CCP1IF | TMR2IF | TMR1IF |

TXIF: EUSART Transmit Interrupt Flag Bit

Two of the PIR1 registers bits are used by the UART. They are TXIF (transmit interrupt) and RCIF (receive interrupt). TXIF flag bit is monitored to make sure that all the bits of the last byte are transmitted before write another byte into the TXREG. By the same logic, RCIF flag is monitored if a byte of data has come in yet. TXIF is raised when the last bit of the framed data, the stop bit, is transferred, which indicates that the TXREG register is ready to transfer the next byte.

As known, all the data shown in the HyperTerminal software in the form consists of head and myData. For example, the X-axis data for accelerometer 1 will be shown as A+1.53, which head part is the axis and number of accelerometer and myData part is the gravitational acceleration for the human movement.

```
void delayFunc(unsigned int delayC)
{
  unsigned char a, b;

  for(a=0; a<delayC; a++)
  {
        for(b=0; b<delayC; b++);
  }
}
```

In additional, *void delayFunc(unsigned int)* is a sub-function which is used to control the time delay to ensure that is enough time for the microcontroller to read the entire data from accelerometer and sending the data into the array for storage in the personal computer. If not, an incomplete data result occurred in the research project.

#### 3.5.1.2 SK40C Start-up Kit and UIC00B Programmer Setup

UIC00B ICSP programmer allow quickly program and debug the source code while the target PIC is on the development board. Conveniently, SK40C come with UIC00B ICSP USB programmer connector to offer simple way for downloading program. The setup procedures for the UIC00B programmer during usage are as below:

Step 1: Connect A-type USB connector (one end of USB cable) to USB port at laptop or PC desktop.

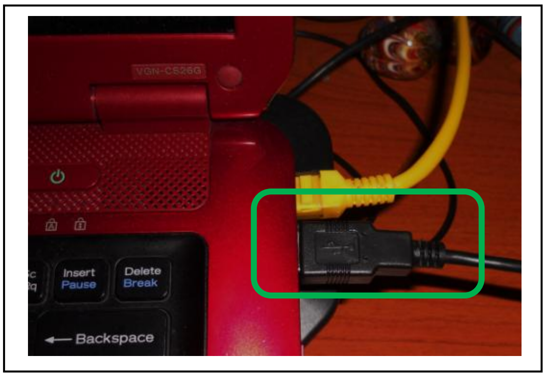



**Figure 4.49 USB Connection to Laptop**

Step 2: Connect another end of USB mini cable to UIC00B USB port. Power supply indication green LED will light on.

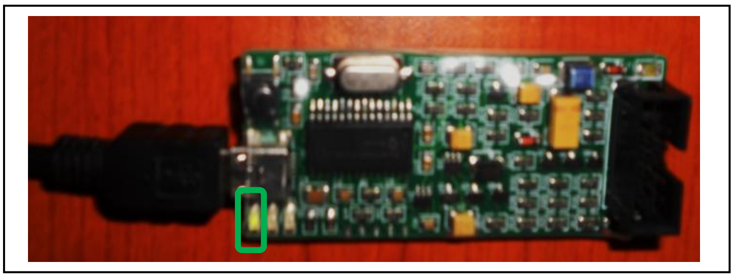


**Figure 3.50 USB Connection to UIC00B Programmer**

Step 3: Continue to software installation as this is first time usage.

Step 4: Connect one side of programming cable to box header of UIC00B and the other side to box header of SK14C with inserted PIC18F4550.

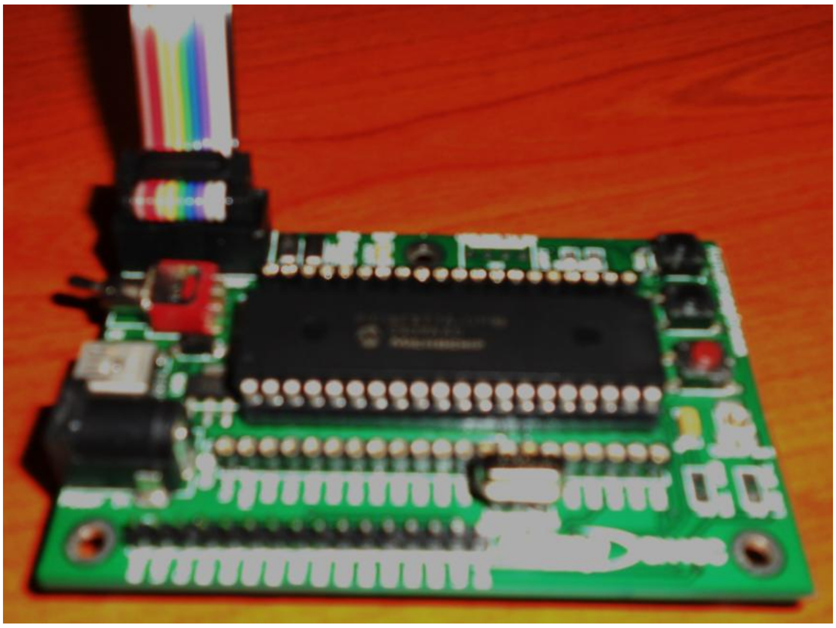


**Figure 3.51 UIC00B Programmer and SK14C Connection**

Step 5: Connection of SK14C and UIC00B programmer connection to Laptop.

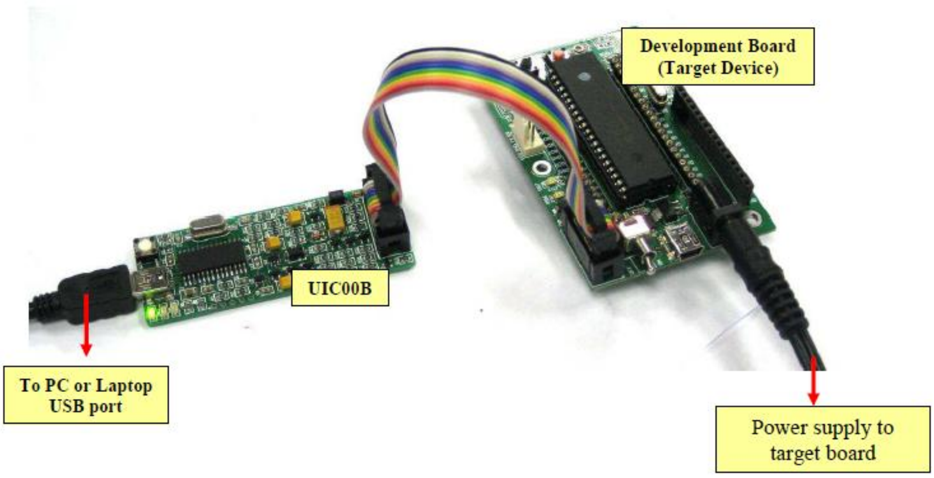



**Figure 3.52 Connection for SK14C and UIC00B Programmer to Laptop**

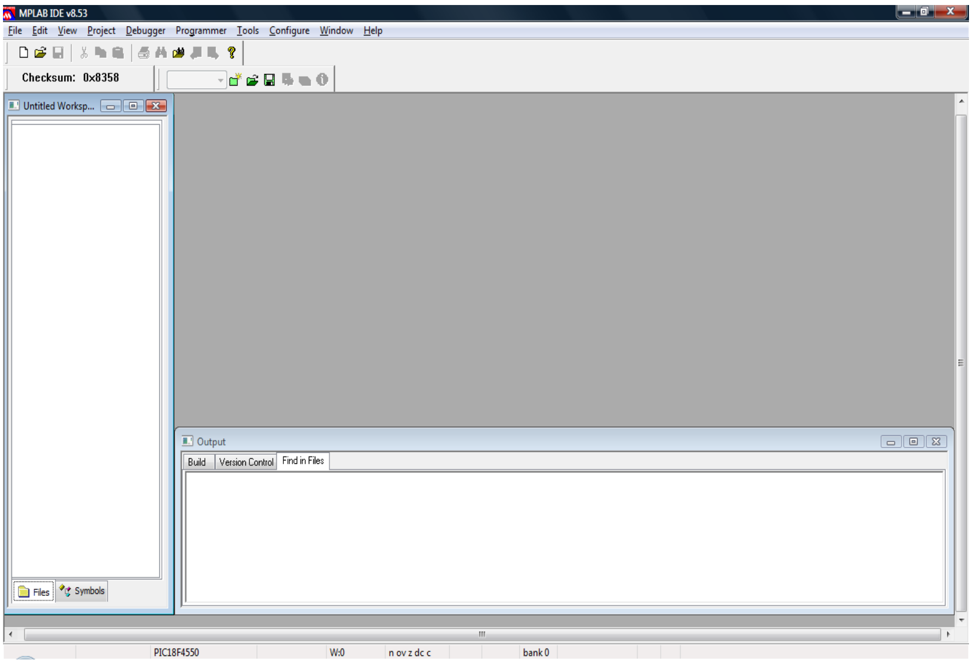
(UIC00B Programmer Technical Datasheet)

### 3.5.1.3 MPLAB IDE Compiler

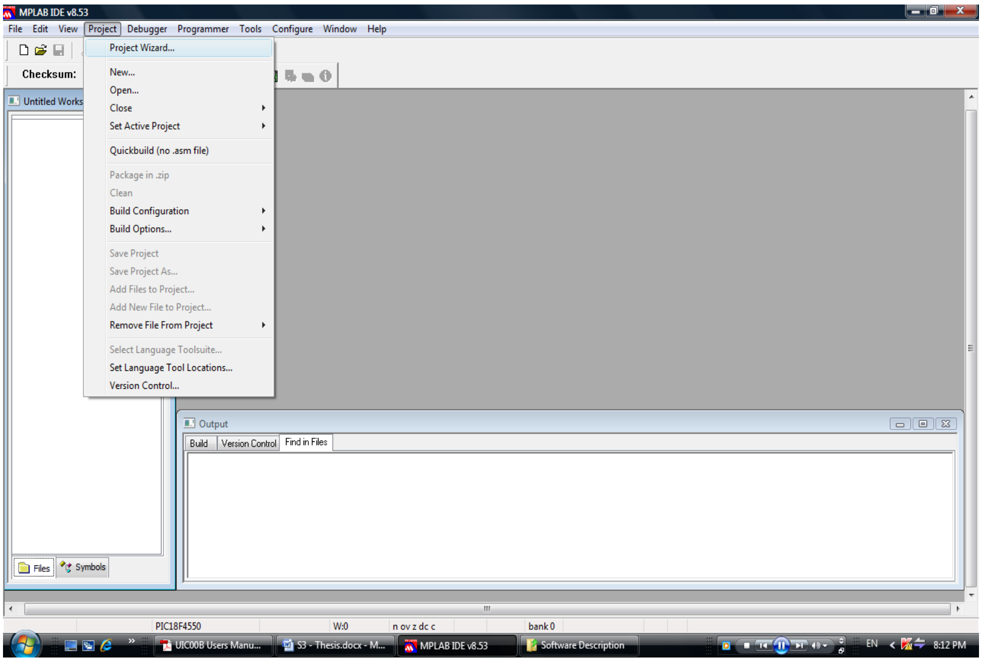
MPLAB Integrated Development Environment (IDE) is a free, integrated toolset for the development of embedded applications employing Microchip's PIC® and dsPIC® microcontrollers. MPLAB IDE is simple, easy to use and includes a host of free software components for fast application development and super-charged debugging. Furthermore, MPLAB IDE also serves as a single, unified graphical user interface for additional Microchip and third party software and hardware development tools. The procedures to compile the program source code into hex file are as below:

Step 1: Install the MPLAB IDE or the other compiler software such as MikroC on the computer for first time.

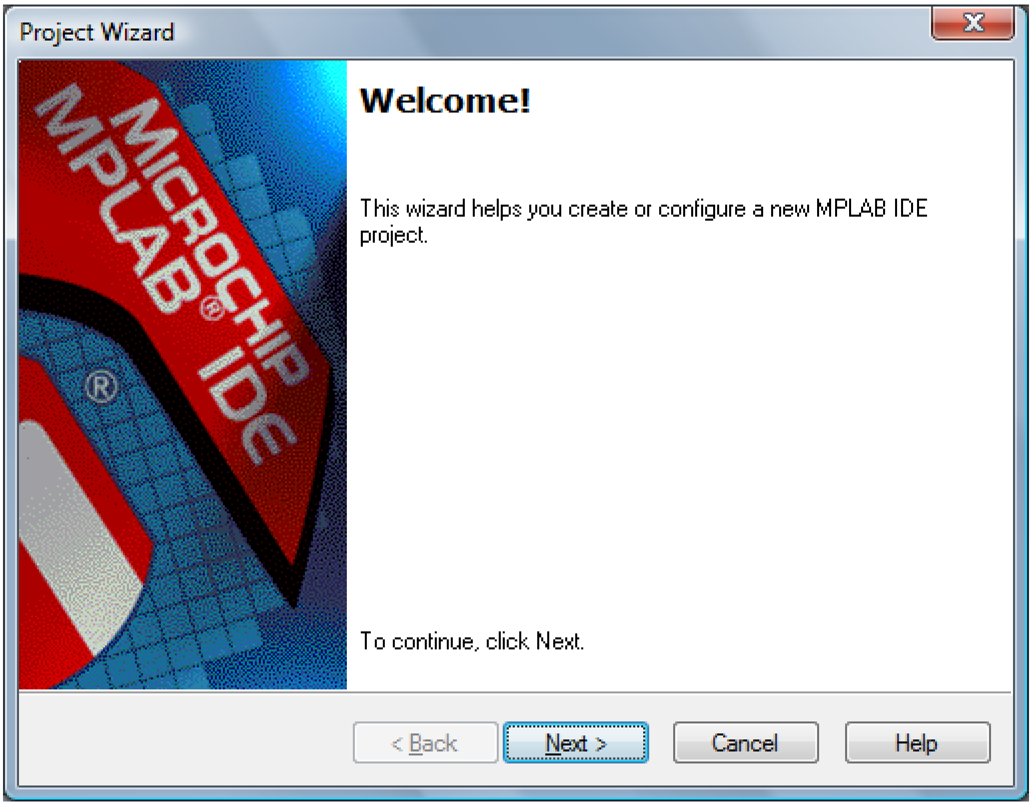
Step 2: Upon complete installation, double-click on the "MPLAB IDE" icon to launch the software.



Step 3: Go to "Project" tab and upon the drop-down menu, select "Project Wizard".



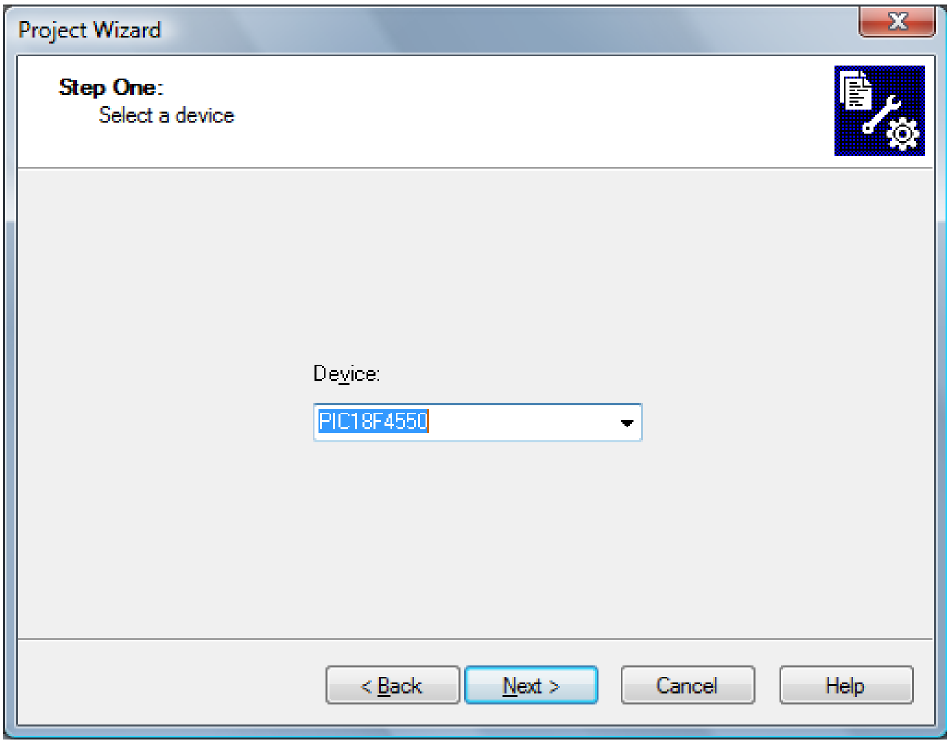

Step 4: A window of "Project Wizard" will be prompted out. Click "Next".



- Select device.

  - Drop-down and select the "PIC18F4550" for the device.

  - Click "Next".

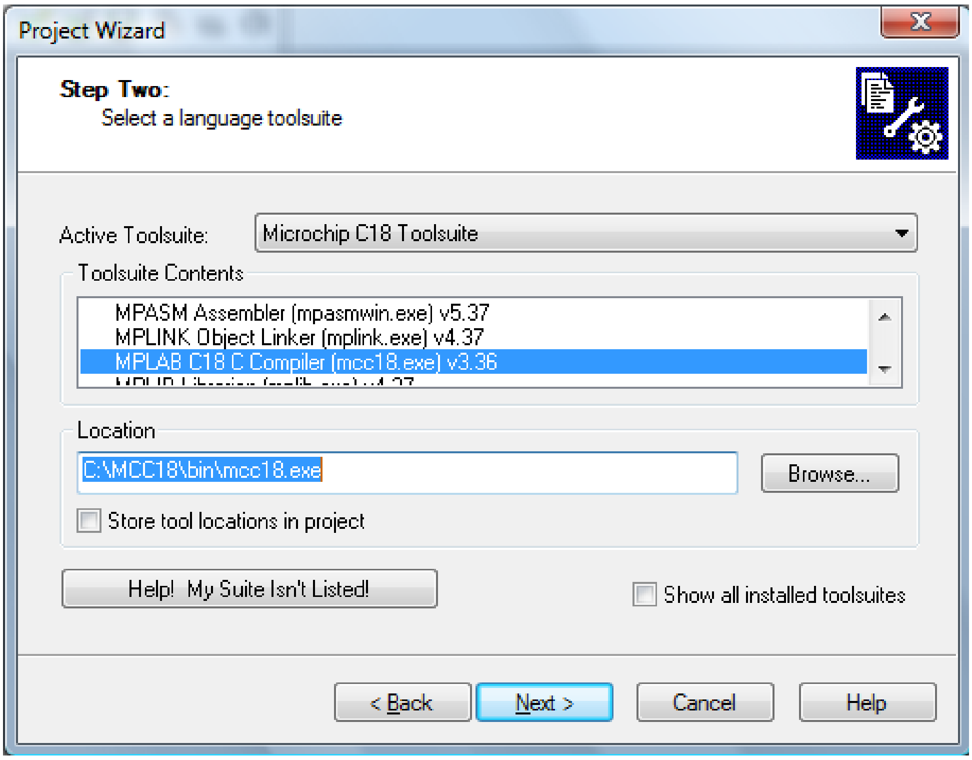



- Select a language toolsuite.

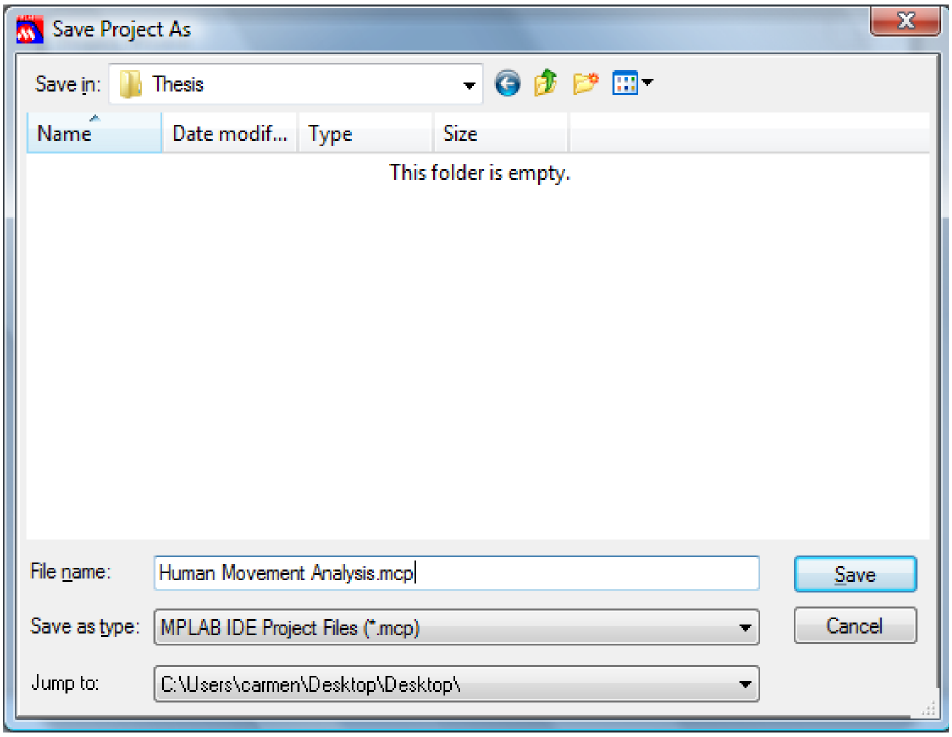
  - Select "Microchip C18 Toolsuite" for active toolsuite.

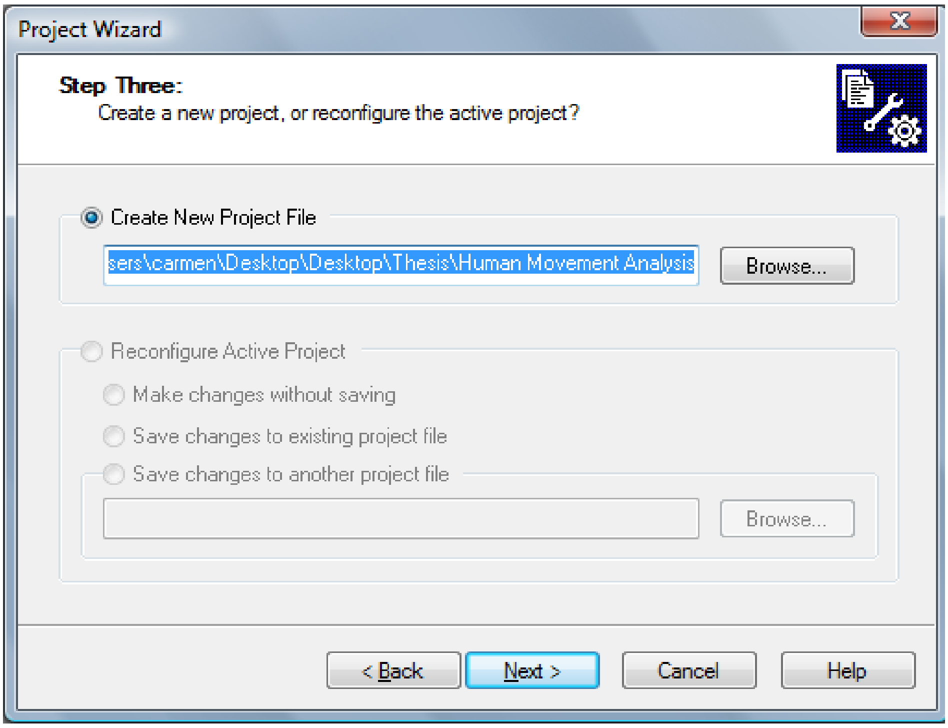
  - Select "MPLAB C18C Compiler" for toolsuite contents.

  - Click "Next".

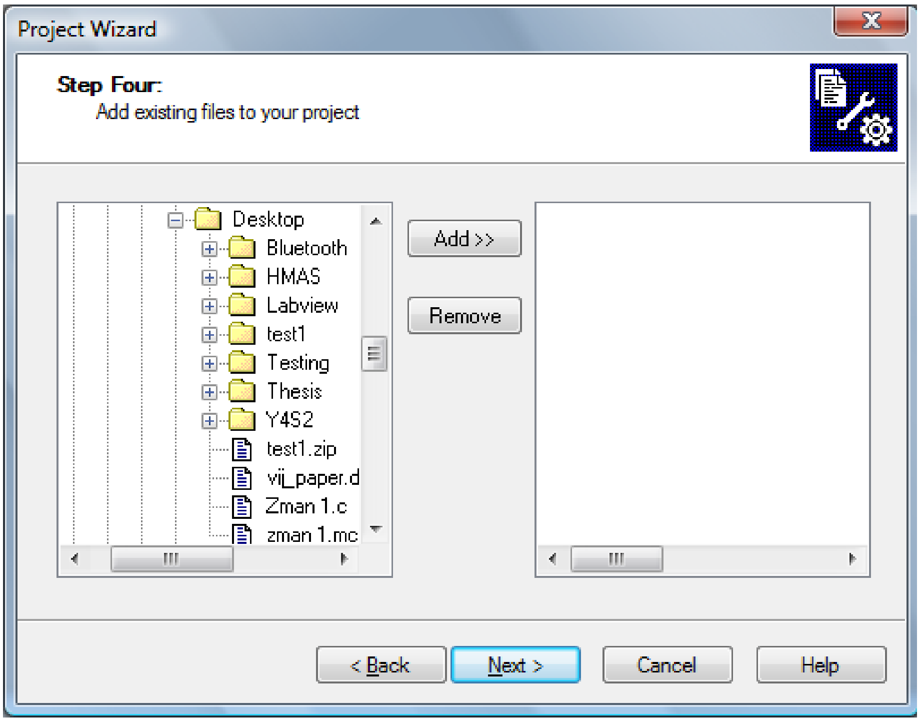


- Create a new project that to build the programme.
  - Click on "Create New Project File", to create a new project file that named "Thesis - MPLAB"
  - Click the "Browse" button and place the project in a folder named "Human Movement Analysis".
  - Click "Next".

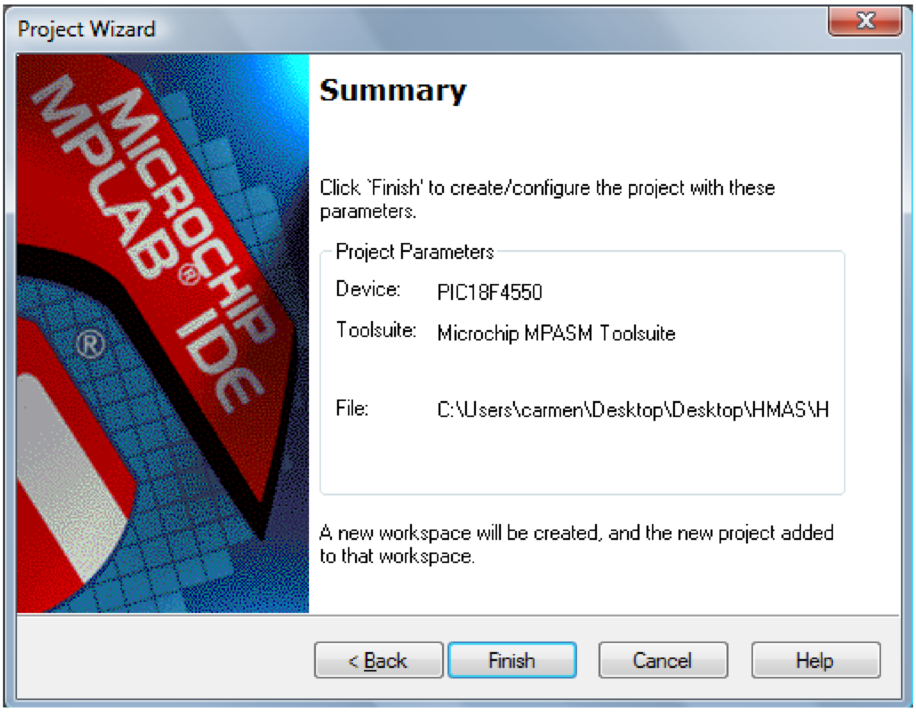


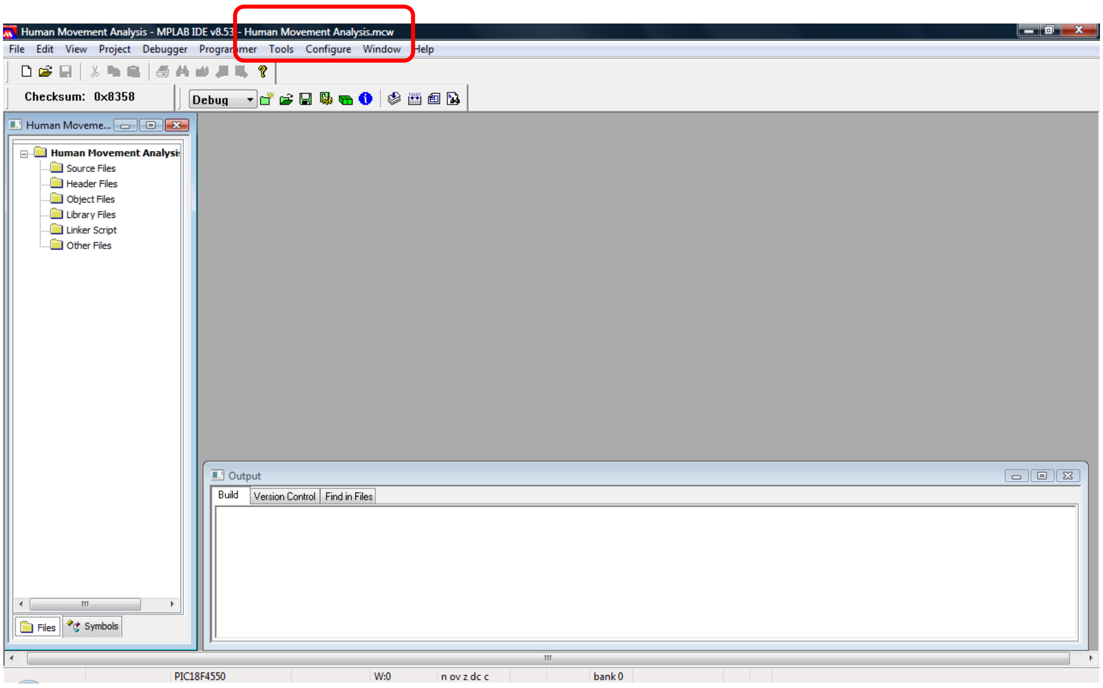
- Add existing files to your project. Click “Next”.



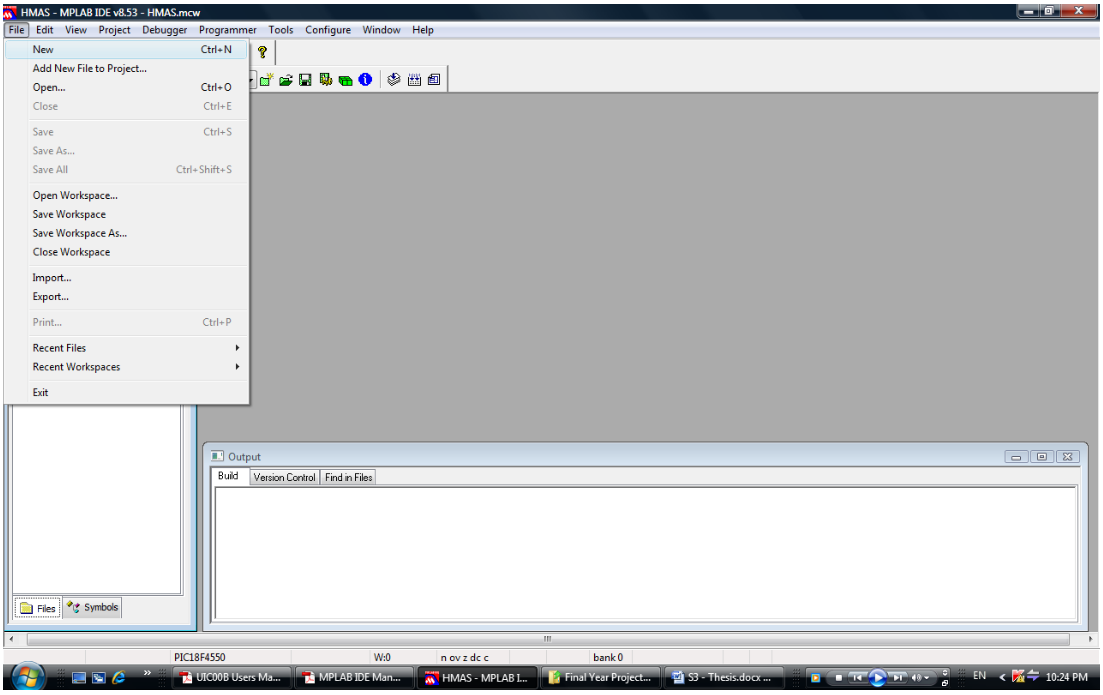

- Summary
  - Click “Finish” to end the process.



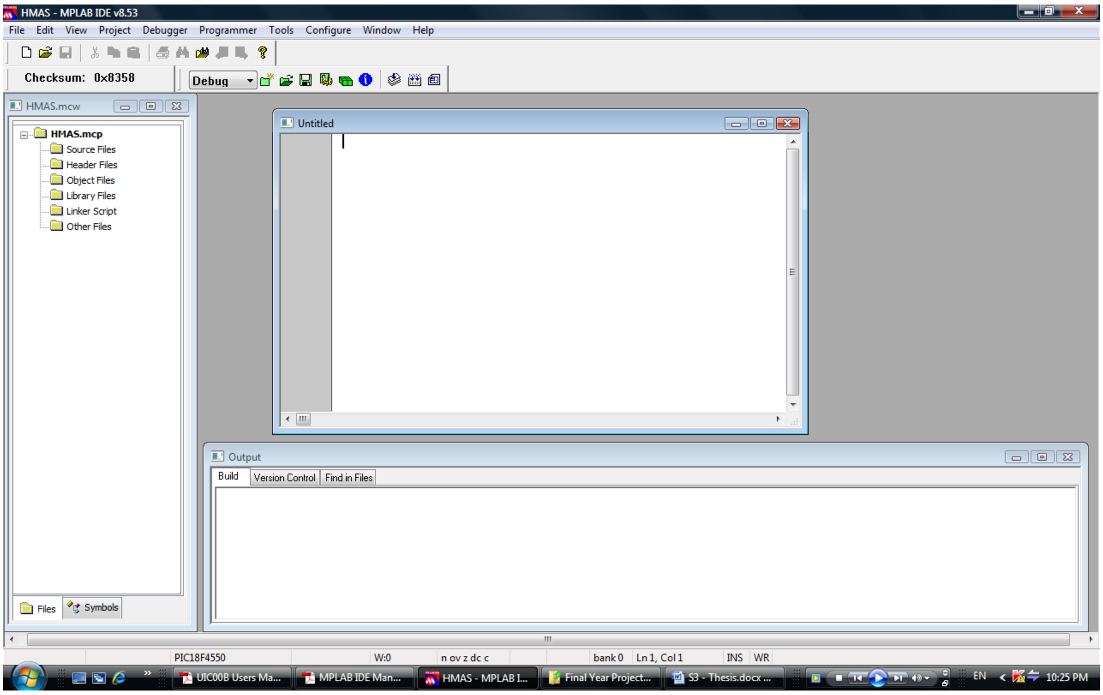
Step 5: After pressing a “Finish” button, a current file with the project name “Human Movement Aanalysis.mcw” will be showed on the screen.



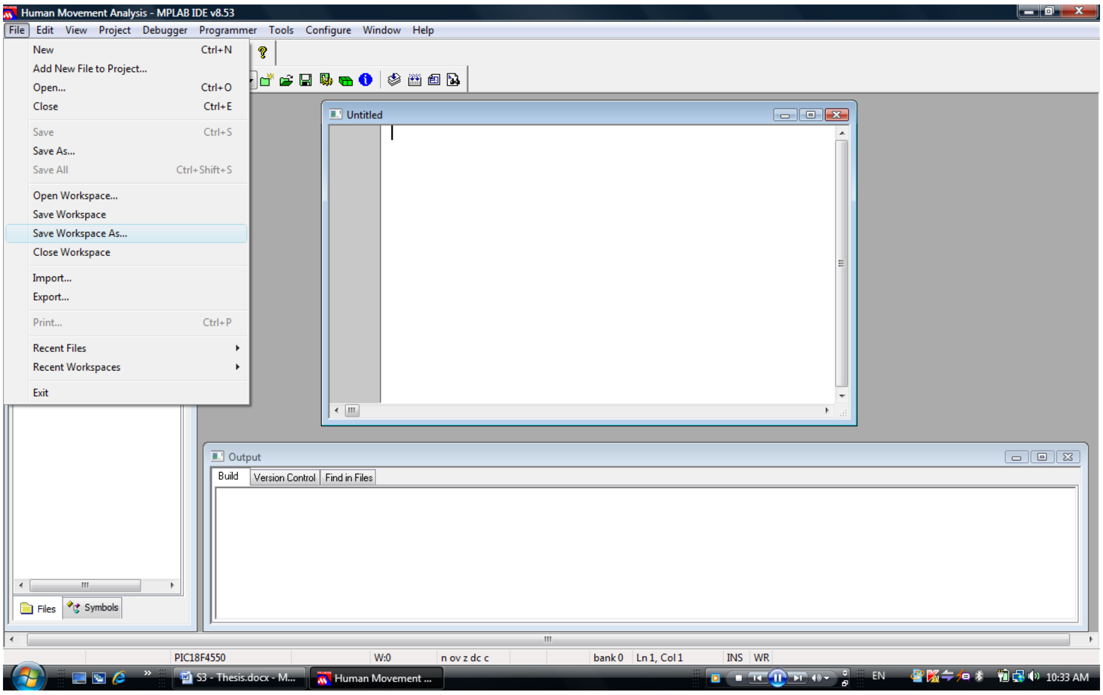

Step 6: Create a new page to write programme. Select “File” tab and click “New”.

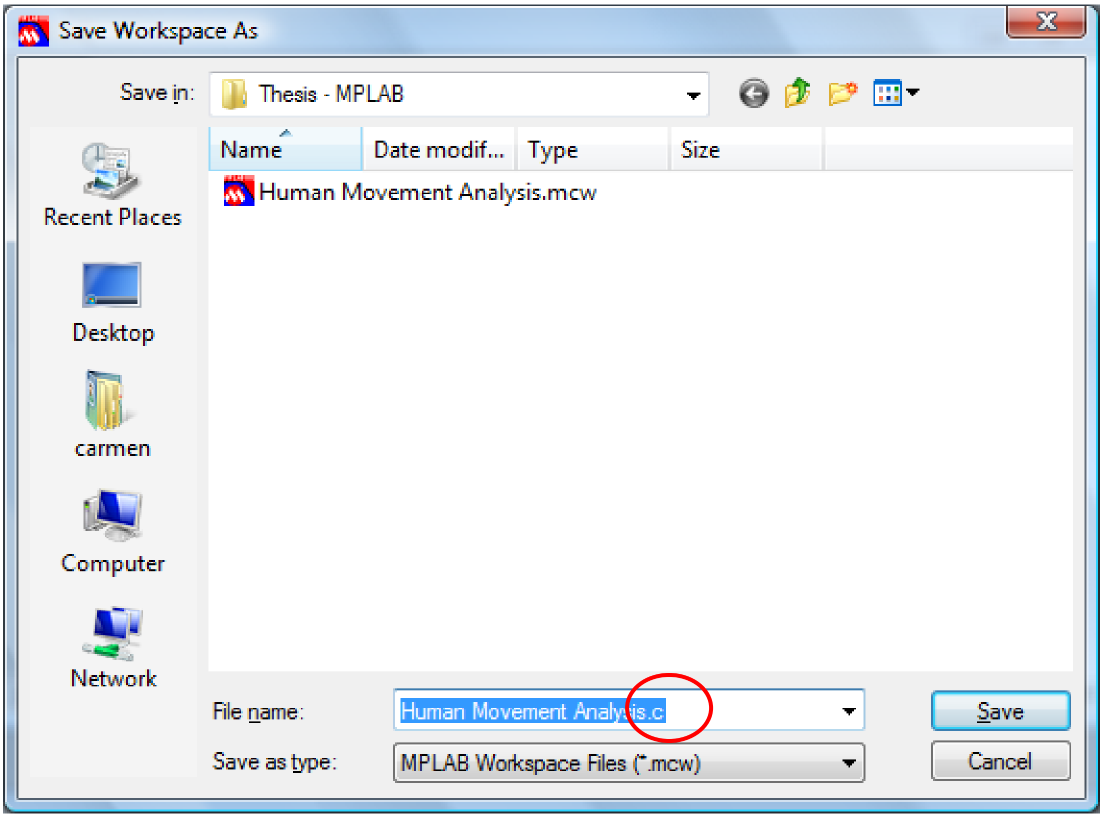


Step 7: An untitled blank sheet will be shown on the screen for creating PIC source code.

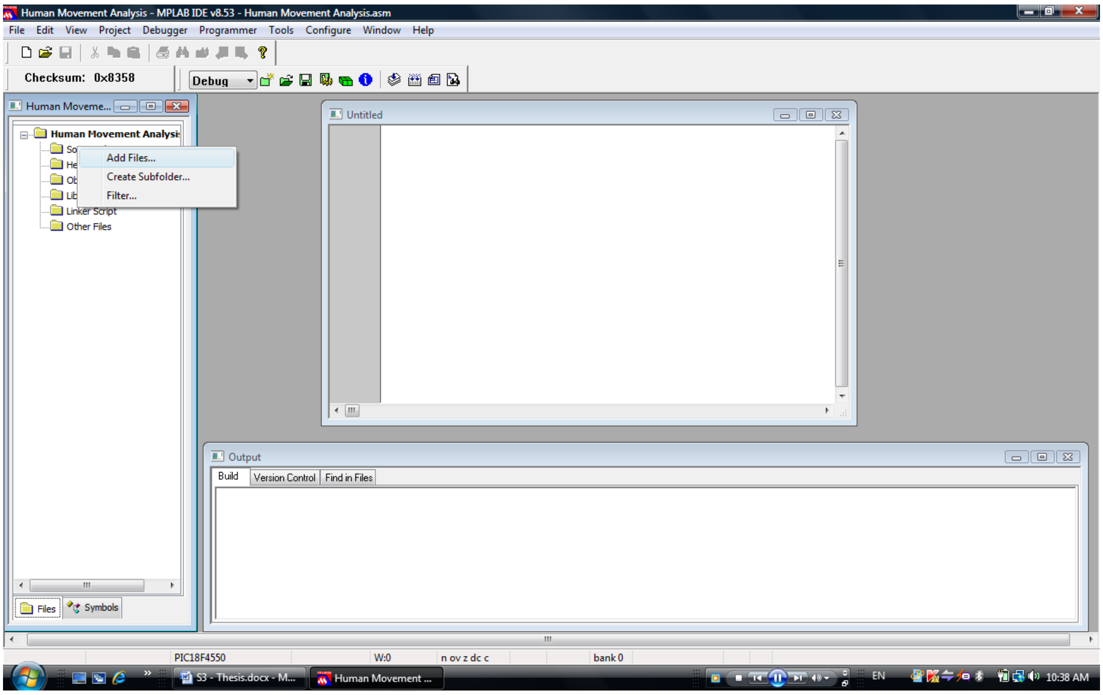


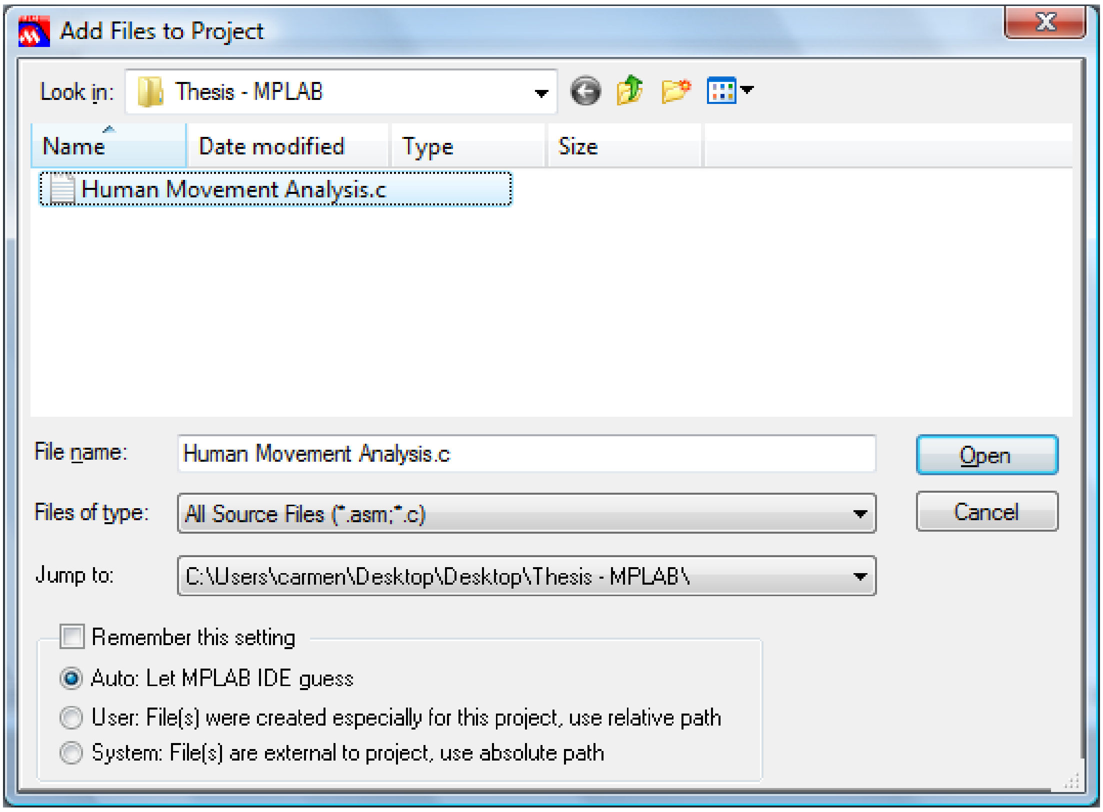

Step 8: Before write down the programme, save the file by clicking "File" and "Save Workspace As" file name.c. Example: Human Movement Analysis.c.



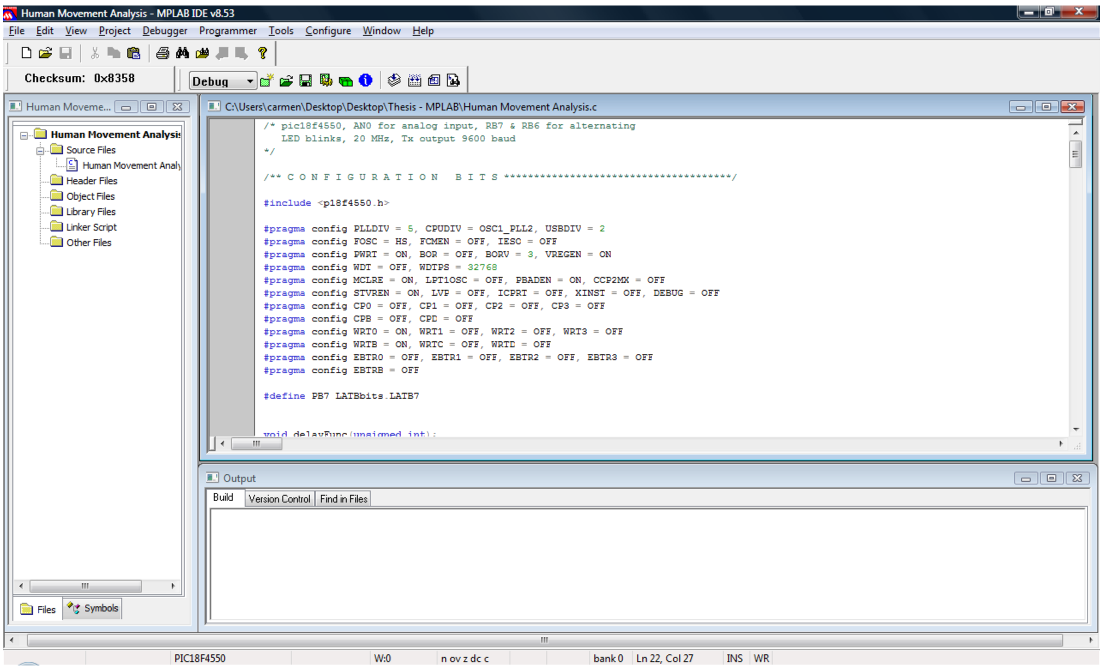


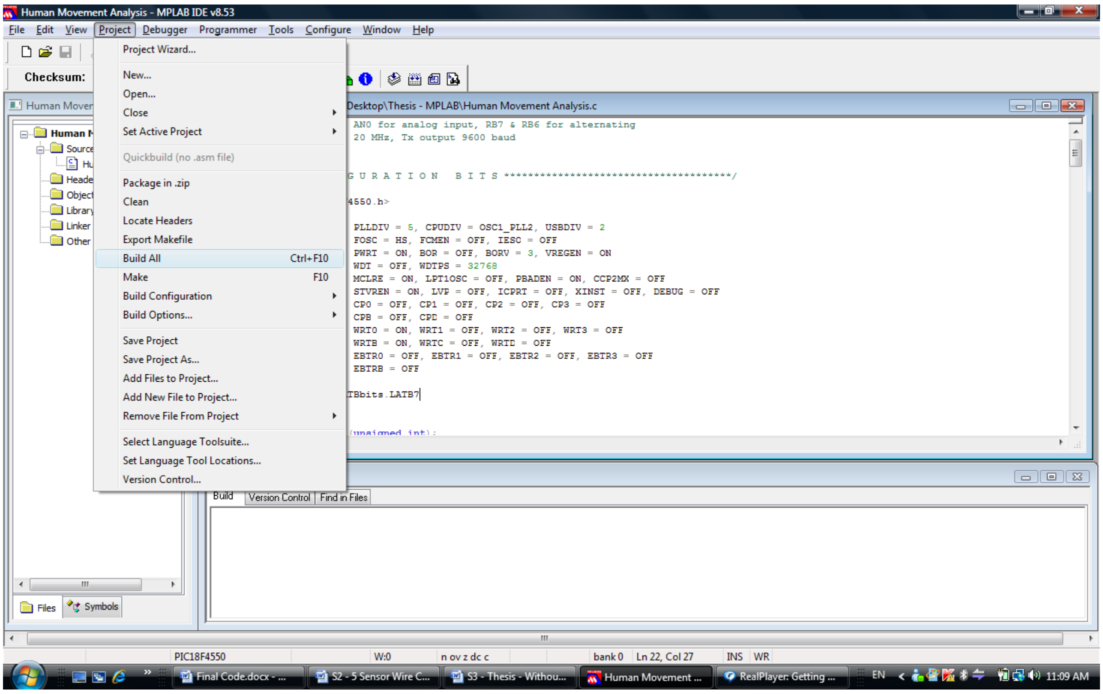

Step 9: On the small window as shown below, right click “Source File” and select “Add Files” to add .c file into the source files folder.



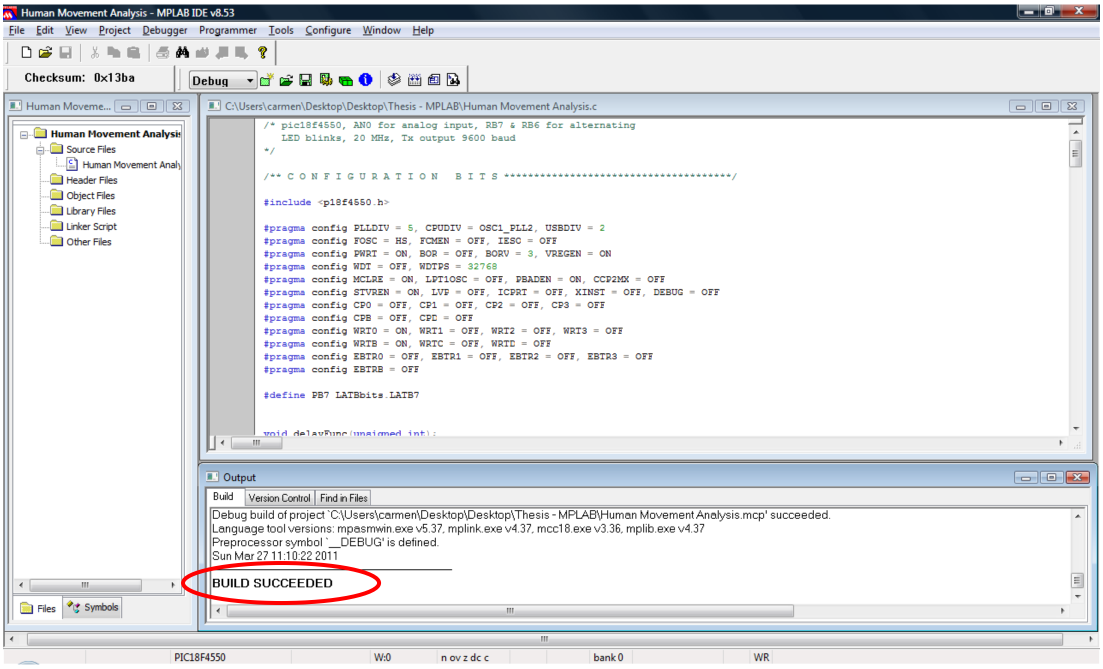



Step 10: Can start to write the programme into the .c file now. After completed the source code, check the source codes by selecting "Project" and click "Build All".





Step 11: If no error is identified, "Build Succeeded" will be shown at the bottom of the output window. Then can use the PICkit2 to burn the program to the microcontroller.



Step 12: If errors are identified, “Build failed” will be shown. Recheck the source codes to identify the errors. Repeat the step10 to build again after making the correction. Burn the programme using PICkit2 if no more errors are identified.

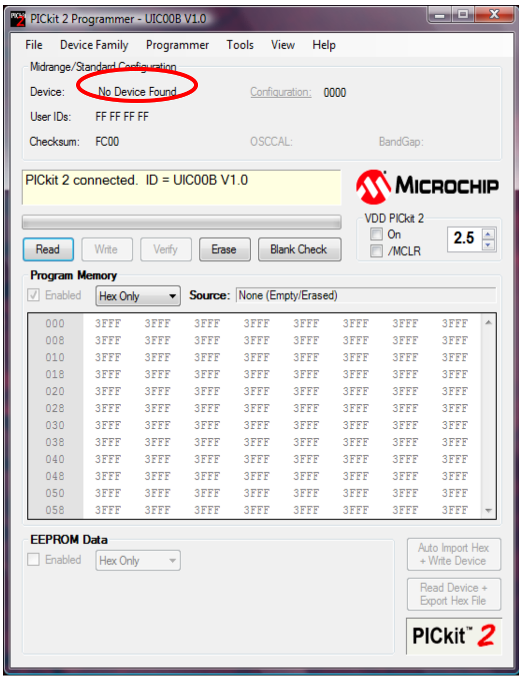
### 3.5.1.4 PICkit2 Development Programmer

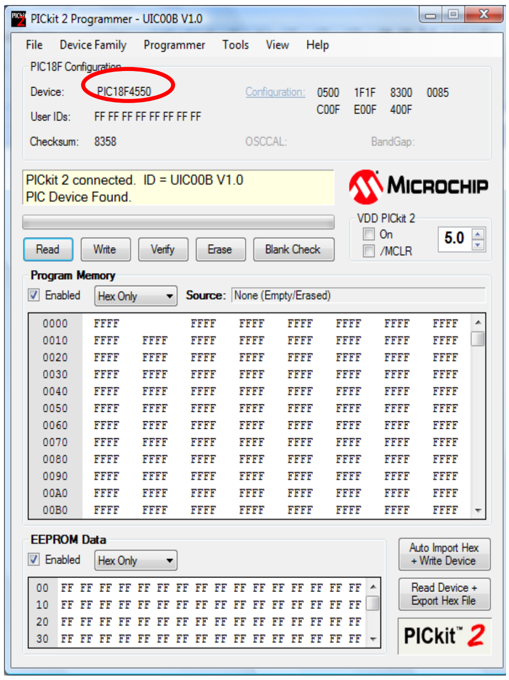
PICkit2 development programmer is a low-cost development tool with an easy to use interface for programming and debugging Microchip’s Flash families of microcontrollers. The procedures to burn the program source codes into microcontroller are as following:

Step 1: Install the PICkit2 programming software on the computer for first time.

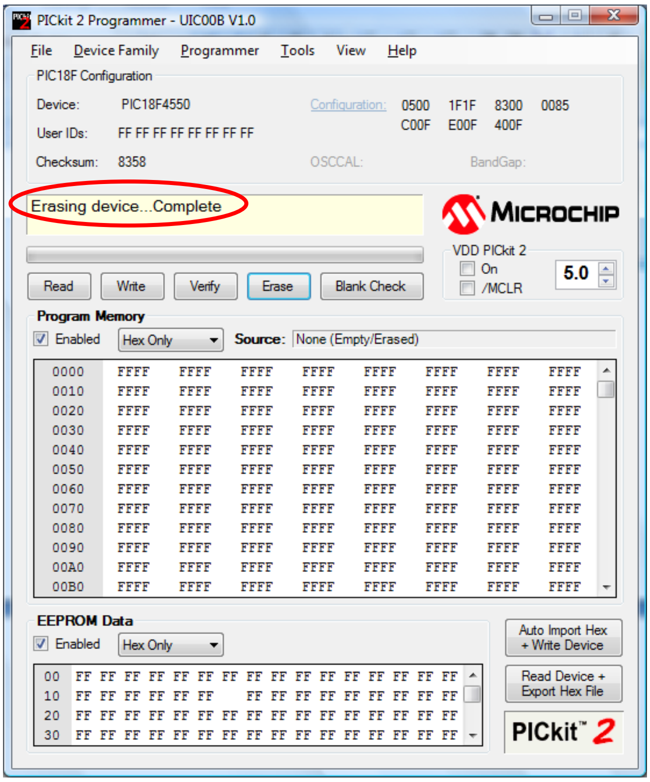
Step 2: Upon complete installation, connect the SK14C and IC00B programmer with laptop and double-click on the “PICkit2” icon to launch the software.

- Before connected to the microcontroller, “No device Found” will be shown in the device list.
- After connected to the microcontroller, the microcontroller device number will be shown in the device list. For example: PIC18F4550.

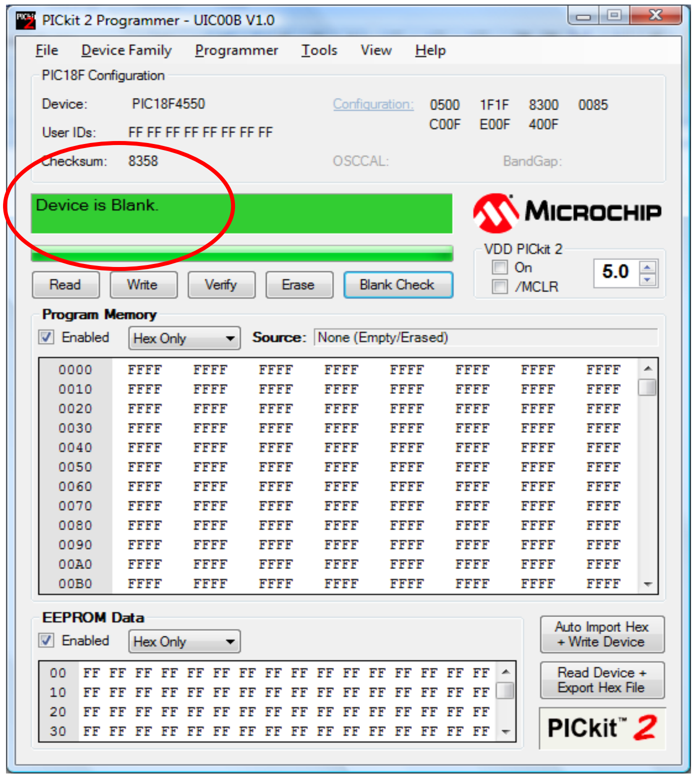


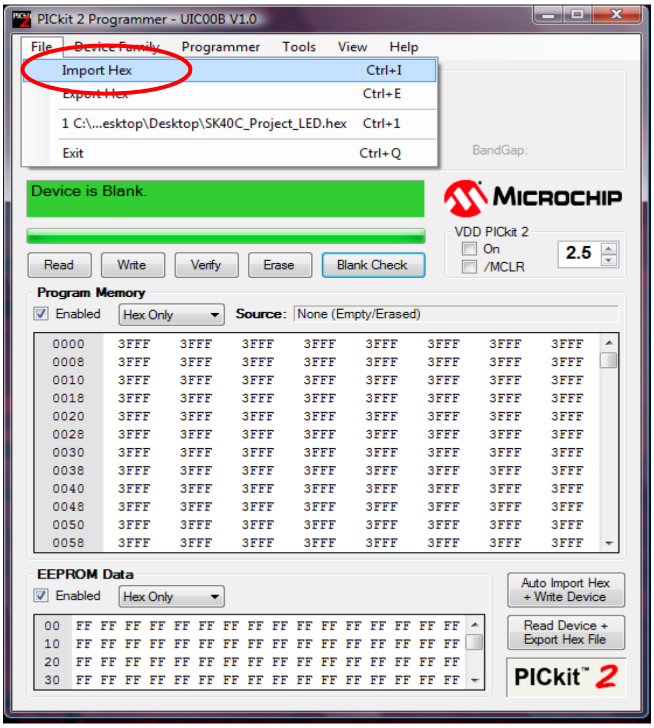
Step 3: Click on "Erase" to make sure the microcontroller is empty and have not contents any programming source code before loading any new programming source code.



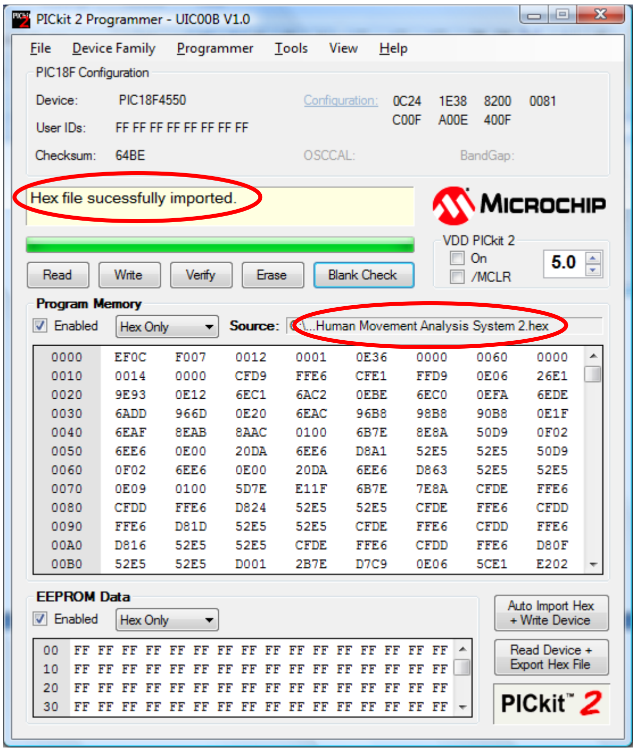
Step 4: After the erase progress, click on "Blank Check" to double confirm the microcontroller is empty.



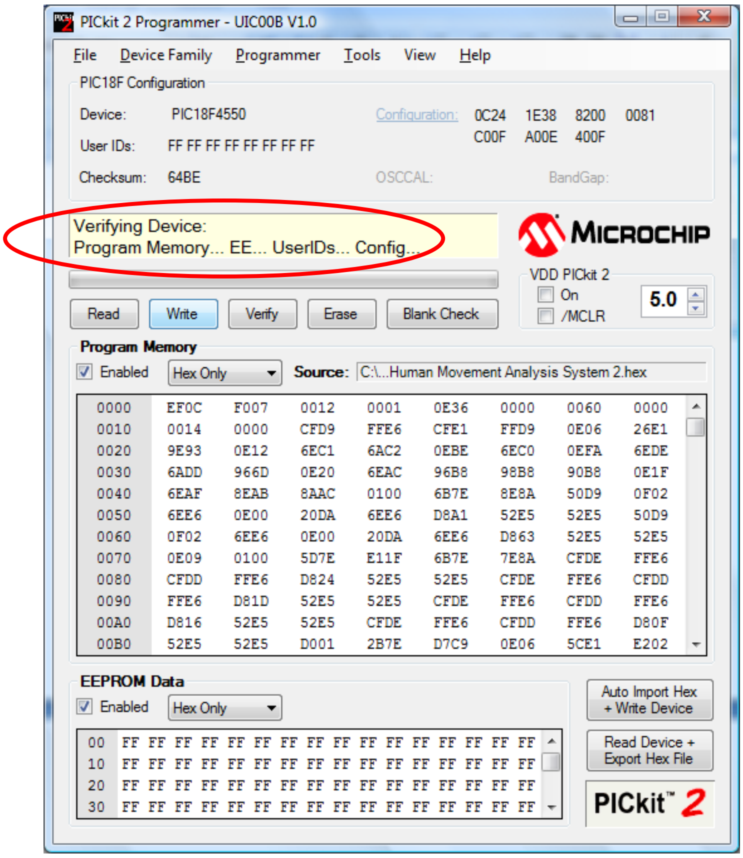
Step 5: Import the hex file by choosing “File” and click “Import Hex”.



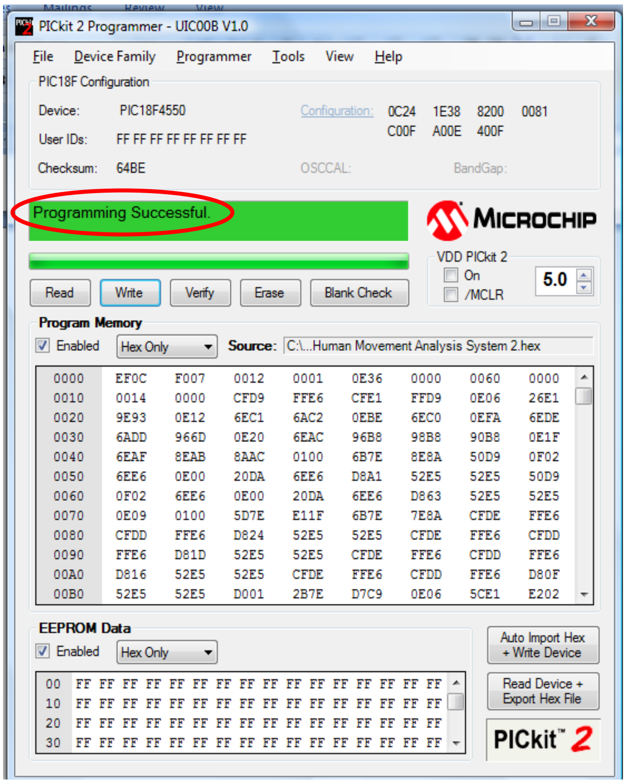

Step 6: Browse the hex file and click open. The code is displayed in the program memory and EEPROM Data windows. The name of hex file is displayed in the Source Block under Program Memory. If the hex file is successfully uploaded, PICkit2 will prompt a message “Hex file successfully imported”.



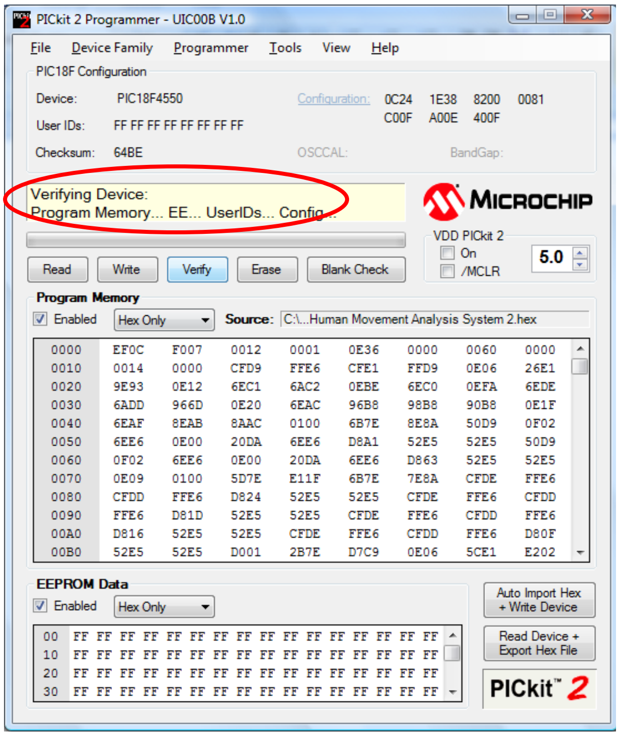
Step 7: After a device family has been selected and a hex file has been imported, the target device can be programmed by clicking "Write".



Step 8: The status of the write operation is displayed in the status bar located under the device configuration window. If the write is successful, the status bar turns green and displays "Programming Successful".




Step 9: Then click on "Verify" to check if the program is properly loaded or burned into the microcontroller.



Step 11: The microcontroller which full of the instruction set is now ready for use. For assure the microcontroller is function purposely, the microcontroller can be test with the HyperTerminal debug software program.

### 3.5.2 HyperTerminal

HyperTerminal is a program can be used to transfer large files from remote terminal onto the portable computer using a serial port than going through the process of setting up the portable computer on a network.

In this research project, HyperTerminal is used to help debug source code from a microcontroller and monitor the data output send to the personal computer before transfer the data onto the LabVIEW for data analysis via the DB9 Connector RS232 or Bluetooth module.

#### 3.5.2.1 HyperTerminal for DB9 Connector RS232 to Computer

The procedures are shown as following:

Step 1: Install the HyperTerminal software and plug the USB-to-Serial Port driven on the computer for first time.

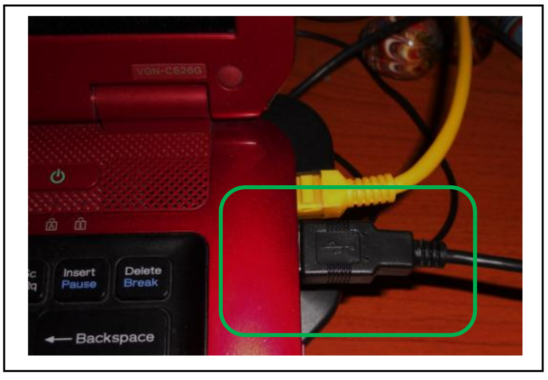
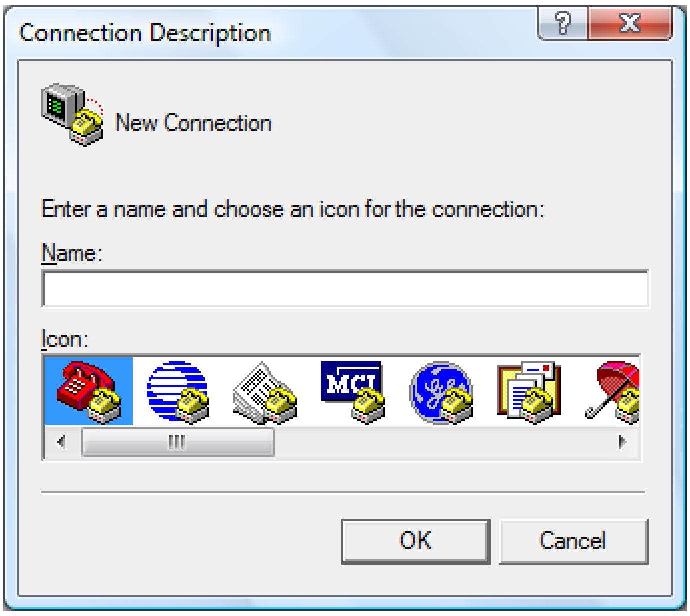
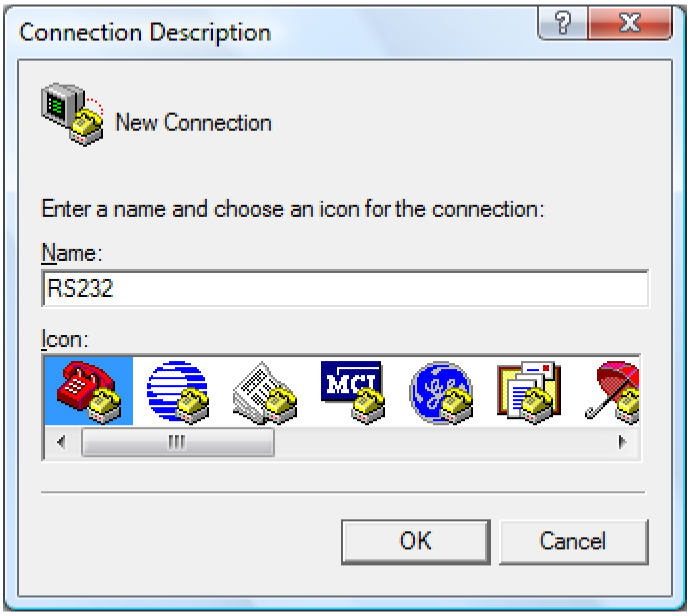



**Figure 3.53 One End of USB Cable (A Type) Connect with PC**

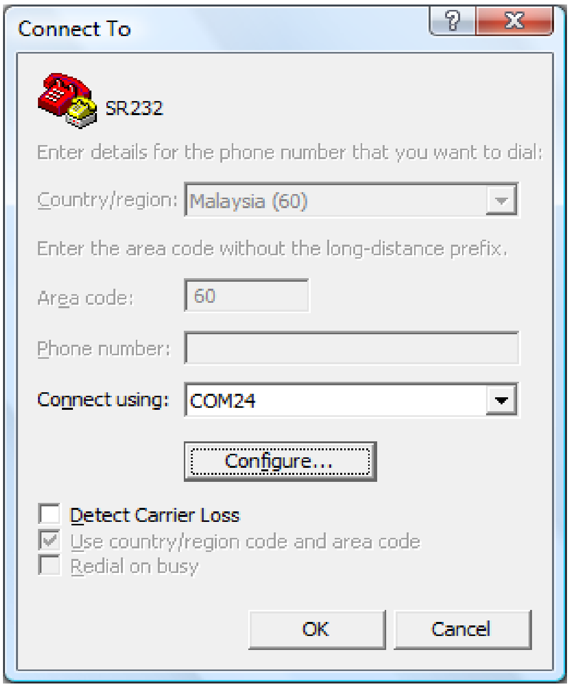
Step 2: Upon complete installation, connect the DB9 connector RS232 and microcontroller circuit with laptop and power it up. Then, double-click on the "HyperTerminal" icon to launch the software. A new window "Connection Description" will pop up.



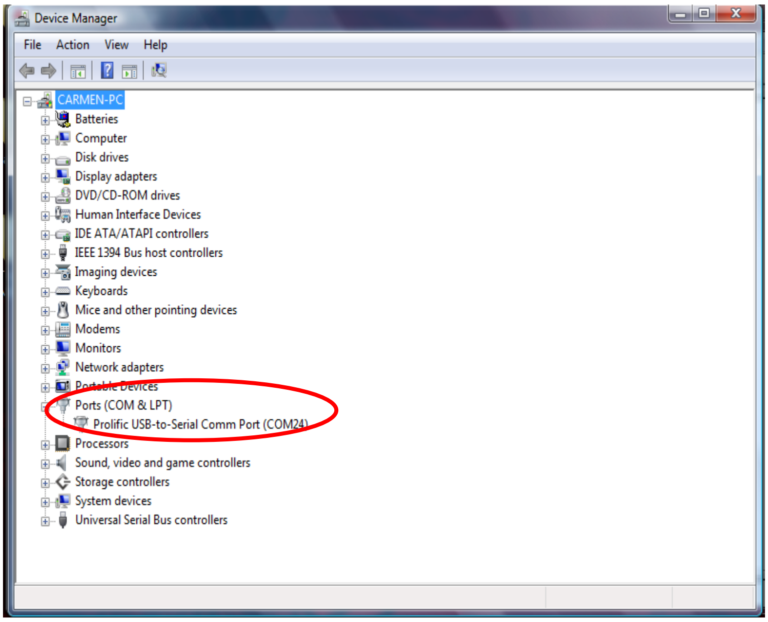

Step 3: Enter a name for the new connection, such as RS232. Then click "OK".



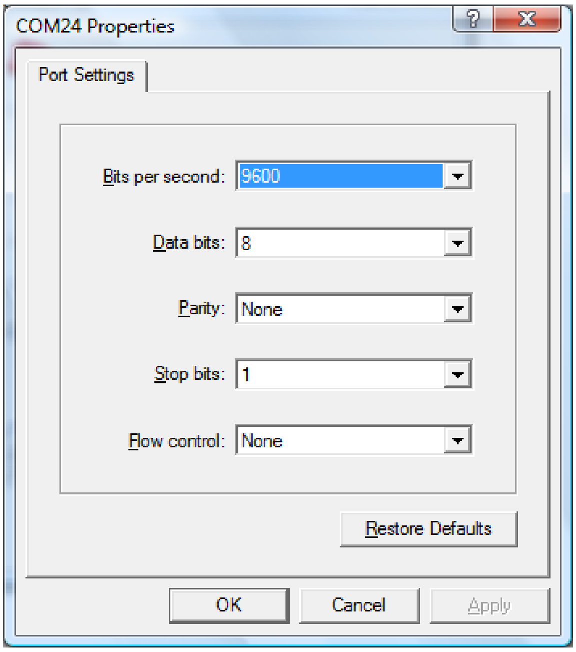
Step 4: Drop-down the "country/region" box and choose for the current country/region and enter the "area code" for the connection. Therefore, drop-down the "Connect Using" box and choose for the respective USB-to-Serial Comm Port. Then click "Configure".



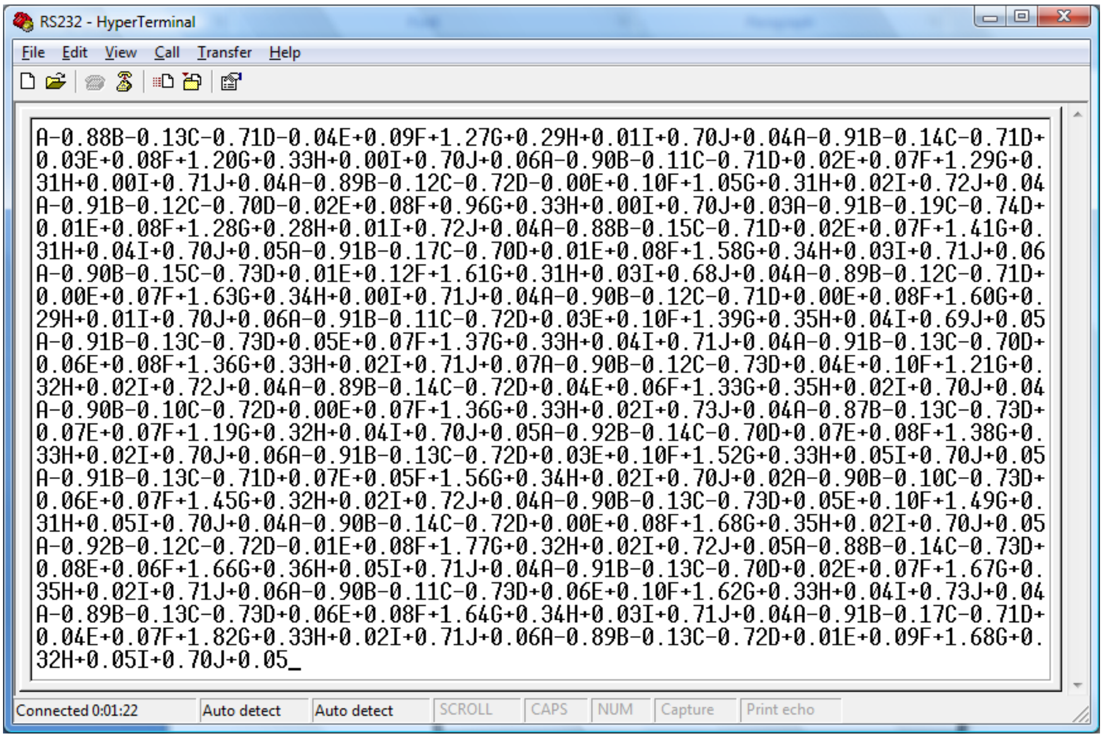

Step 5: If the user unsure the com port number, user can find the com port number by click on "Start" >>"All Program">>"Control Panel">>"Device Manager" >>"Ports (COM&LPT) and check for the USB-to-Serial Comm Port. In this example, COM24 is used for the RS232 connection.



Step 6: A new window "COM24 Properties" will pop out. Then choose 9600 bits per second, 8 data bits, none parity, 1 stop bits, and none flow control. After that, click "Restore Defaults" and "OK".




Step 7: Then a complete result data will be shown on the HyperTerminal as follows:



#### 3.5.2.2 HyperTerminal for Bluetooth to Computer Communication

The basic requirement of wireless data transmission is able to send ASCII code serially (through UART), and also process the data received from Bluetooth module. The ASCII code will actually form the AT Command for microcontroller to communicate with Bluetooth module. Of course, there must be some configurations for microcontroller too. The most important configuration is UART. UART depend on timing or the baud rate, therefore the most important task is to configure the baud rate of microcontroller.

Further configure the whole UART peripherals ready to communicate with Bluetooth module. The settings are:

i. Baud rate = 96500 bps
ii. Data bits = 8
iii. Parity = none
iv. Stop bit = 1

Of course all these settings have to done using programming language of each type of microcontroller.

Figure below shows a flow chart of general concept for microcontroller to communicate and process data from KC Wirefree Bluetooth transceiver. After configuring UART engine of microcontroller, program should wait for data from UART's receiver buffer. Store the received data array and checked whether the "Acceleration Data" is received. If "Acceleration Data" is yet to receive, continue to wait and keep receive data. If "Acceleration Data" is received, process the data array stored and decides which mode to enter or which AT command to be sent.

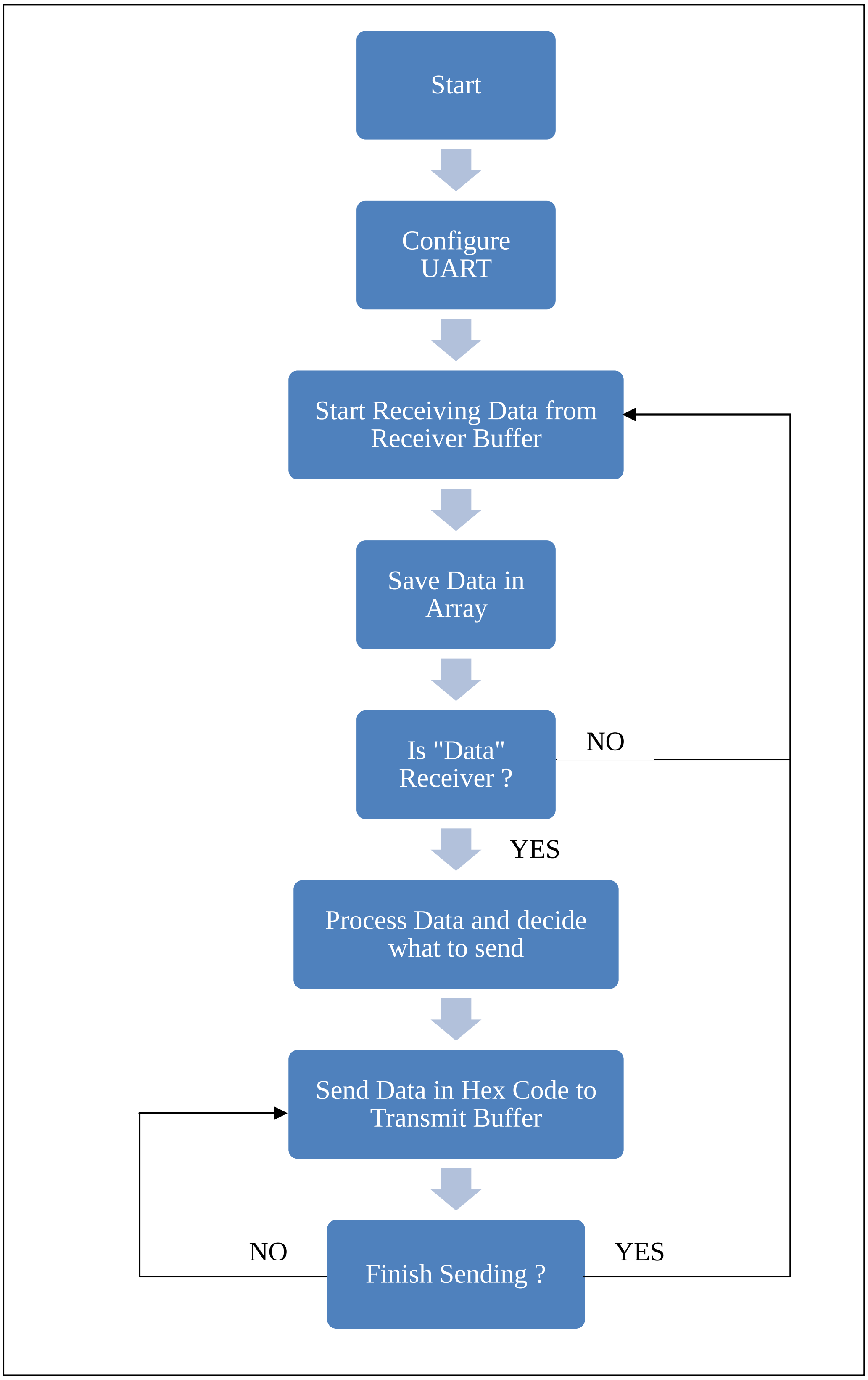



**Figure 3.54 Flow Chart for Microcontroller Communicate with Bluetooth Transceiver**

Therefore, an established connection is needed between SKKCA-21 Bluetooth module and the computer is needed in order to receive the streams of inputs from the accelerometers. To achieve this established connection, certain procedures are required as following:

Step 1: USB driver installation is required for first time.


Step 2: Plug the USB cable on the computer for first time to ensure that the Bluetooth module is function properly with the green light is blinking.

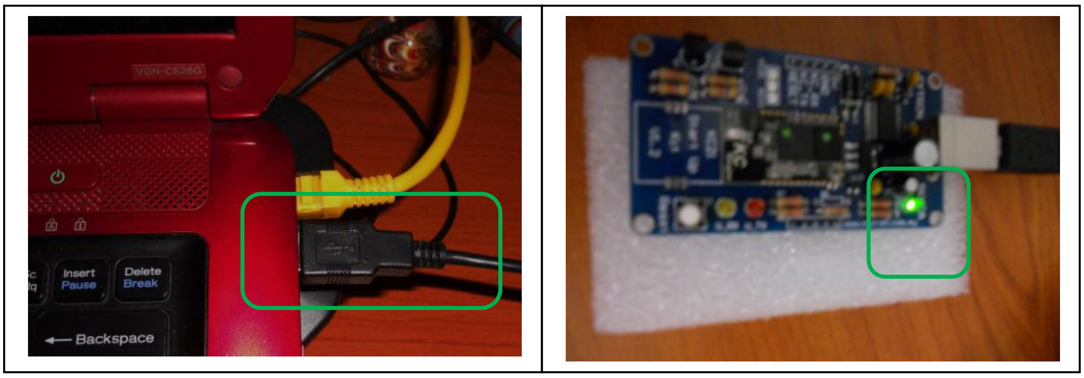
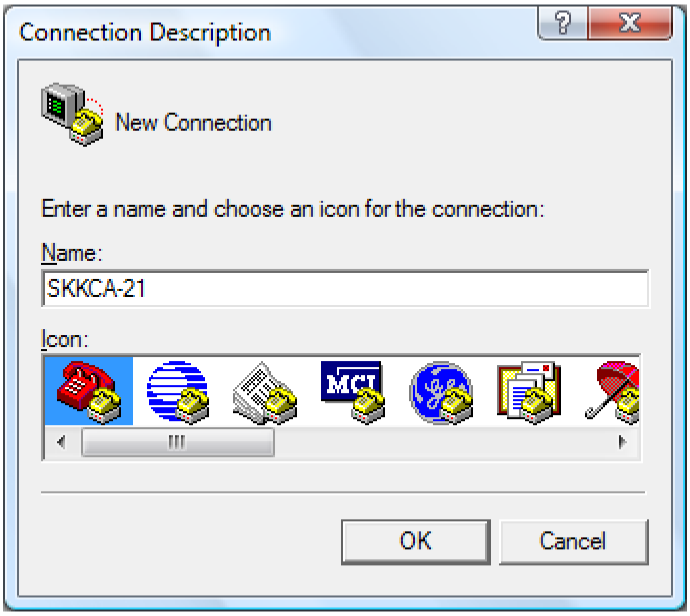
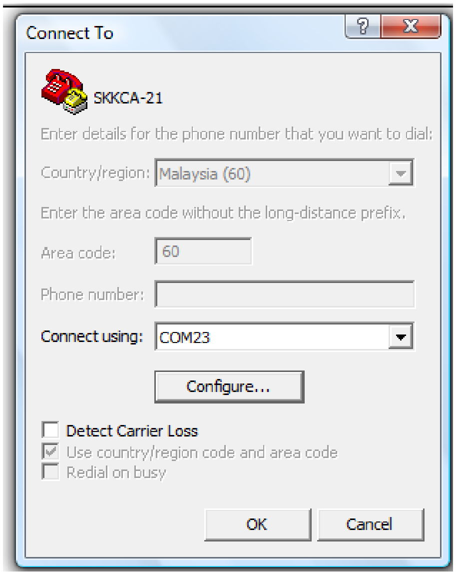



**Figure 3.55 One End of USB Cable (A Type) Connect with PC**

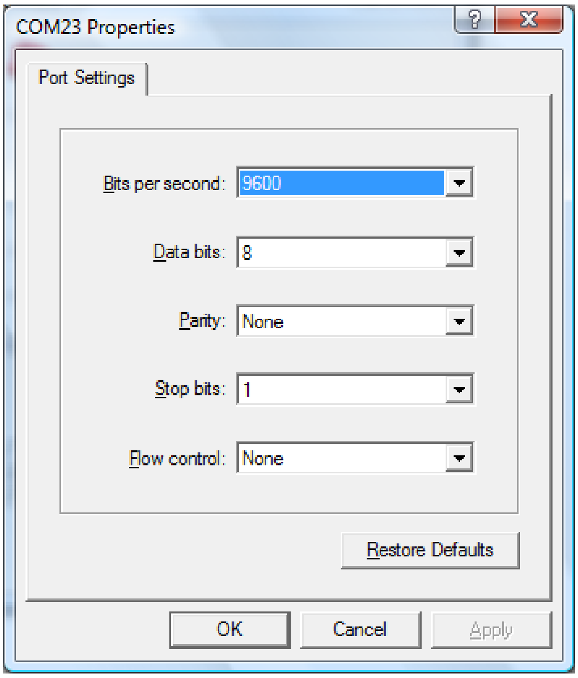
Step 3: After that can remove the USB cable and implement the Bluetooth module to the circuit board. Double click on "HyperTerminal" icon, a HyperTerminal window appears with dialogue box. Enter a name "SKKCA-21" and click "Ok".



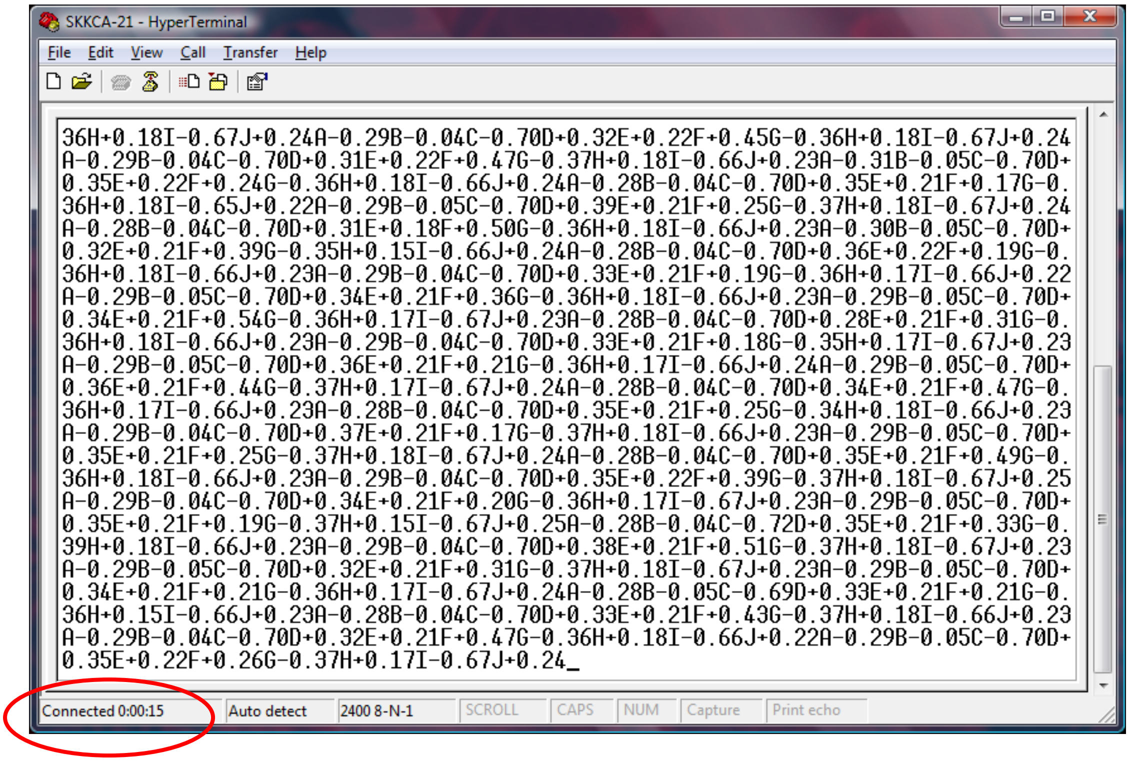

Step 4: Choose the appropriate communication port for each computer and click "Ok". The appropriate communication port is the port to which the Bluetooth transceiver is connected.

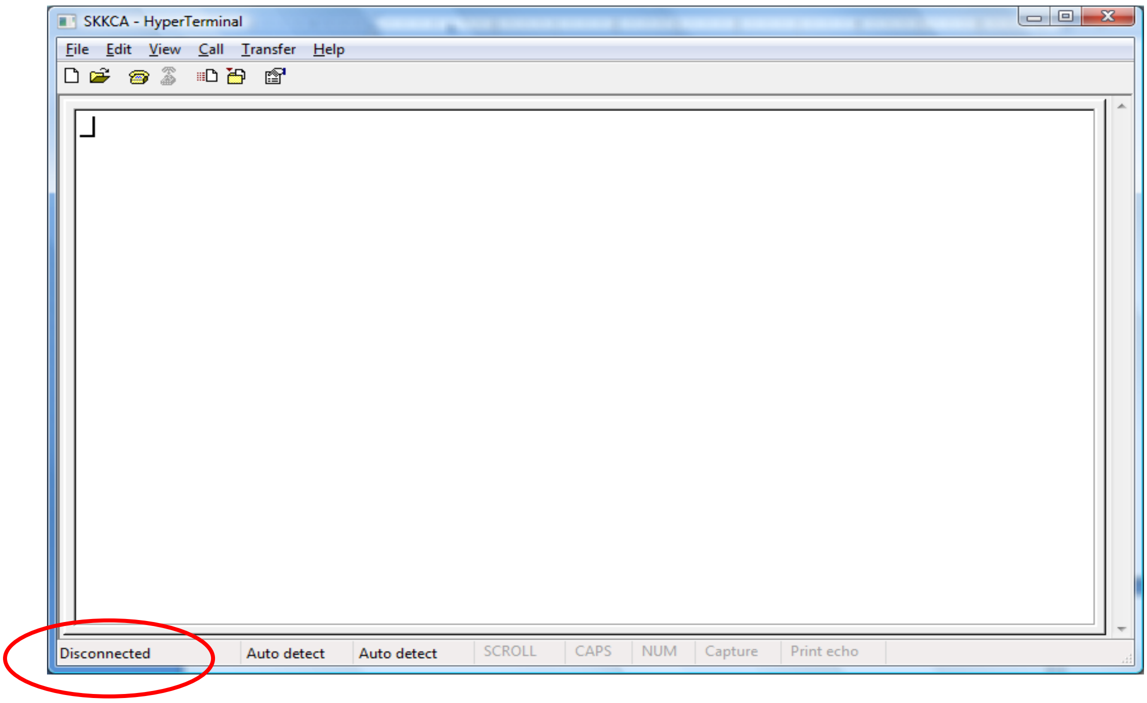


Step 5: The COM Port Properties dialogue box appears. Choose the appropriate settings for each computer and click on "Ok". The default baud rate of KC Wirefree Bluetooth transceiver is 96500 baud. Change flow control to "None" where RTS and CTS are not used.



Step 6: After launching HyperTerminal, a window representing connection appears. Now, reset SKKCA which have been connected earlier. If HyperTerminal is opened before the SKKCA is connected to computer, the HyperTerminal might not work. Click on the “Disconnect” and “Call” icon to disconnect the HyperTerminal and connect back again.



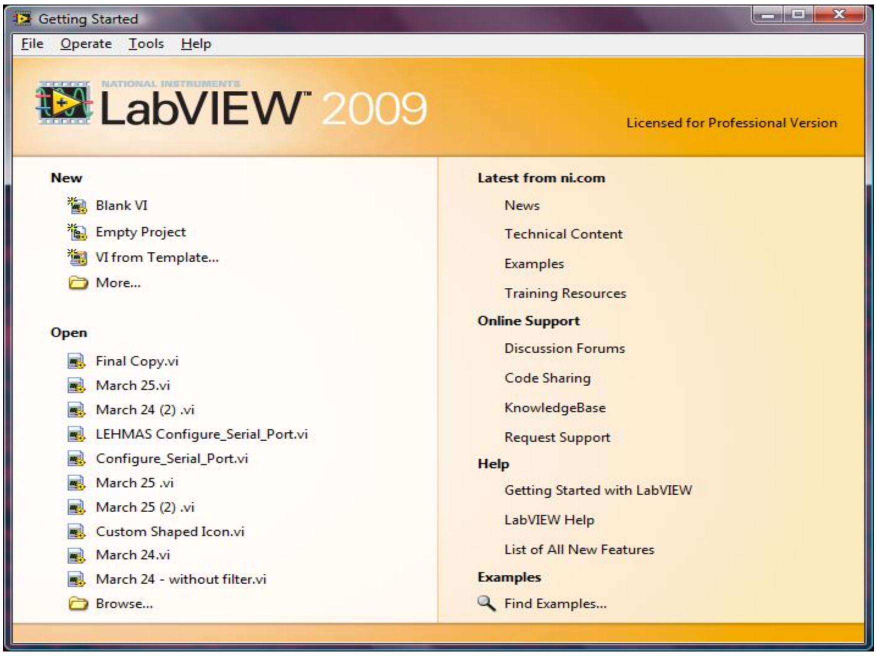
### 3.5.3 LabVIEW Graphical Programming

Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW) is a platform and development environment for a visual programming language from National Instruments. The graphical language is named "G". Originally released for the Apple Macintosh in 1986, LabVIEW is commonly used for engineers and scientists to develop sophisticated measurement, test, and control systems using intuitive graphical icons and wires that resemble a flowchart.

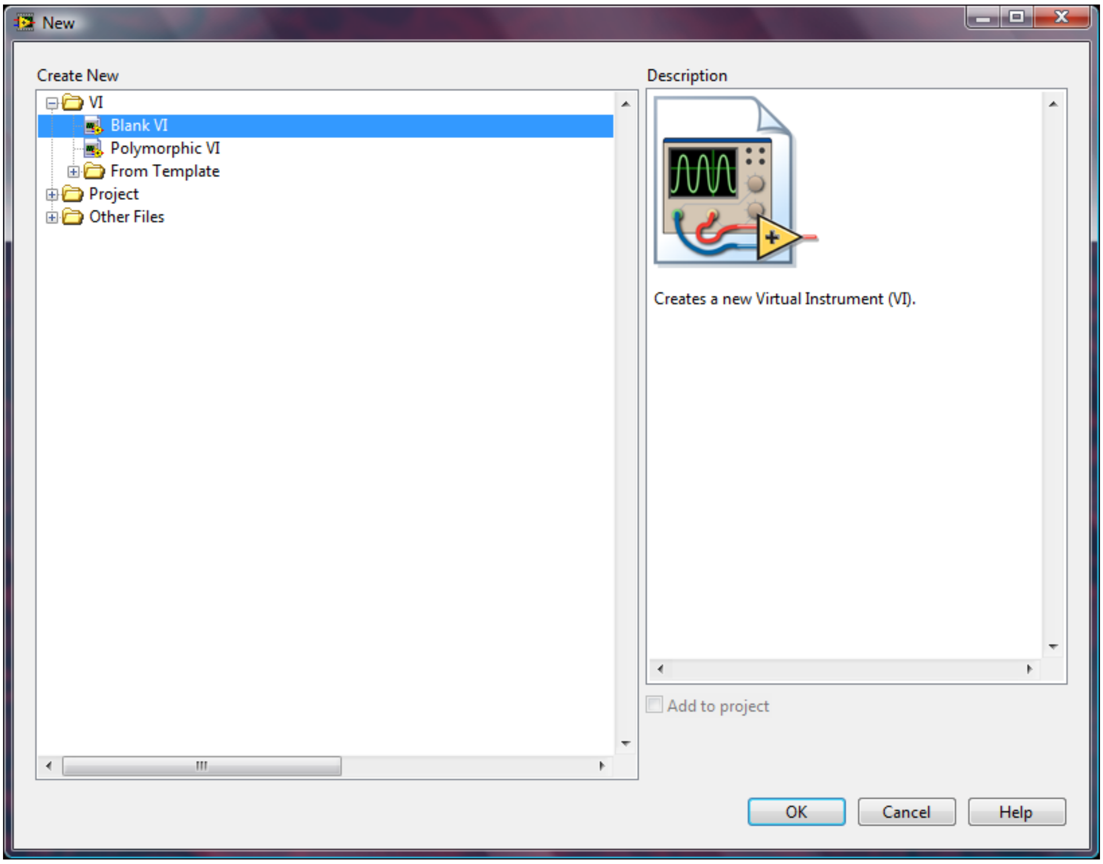
LabVIEW provides built-in template VIs that include the sub Vis, functions, structures, and front panels objects you need to get started building common measurement applications. Complete the following steps to create VI that generates a signal and displays it on the front panel.

Step 1: Install LabVIEW 2009 graphical programming software on the computer for first time.

Step 2: Upon complete installation, double-click on the “LabVIEW” icon to launch the software.

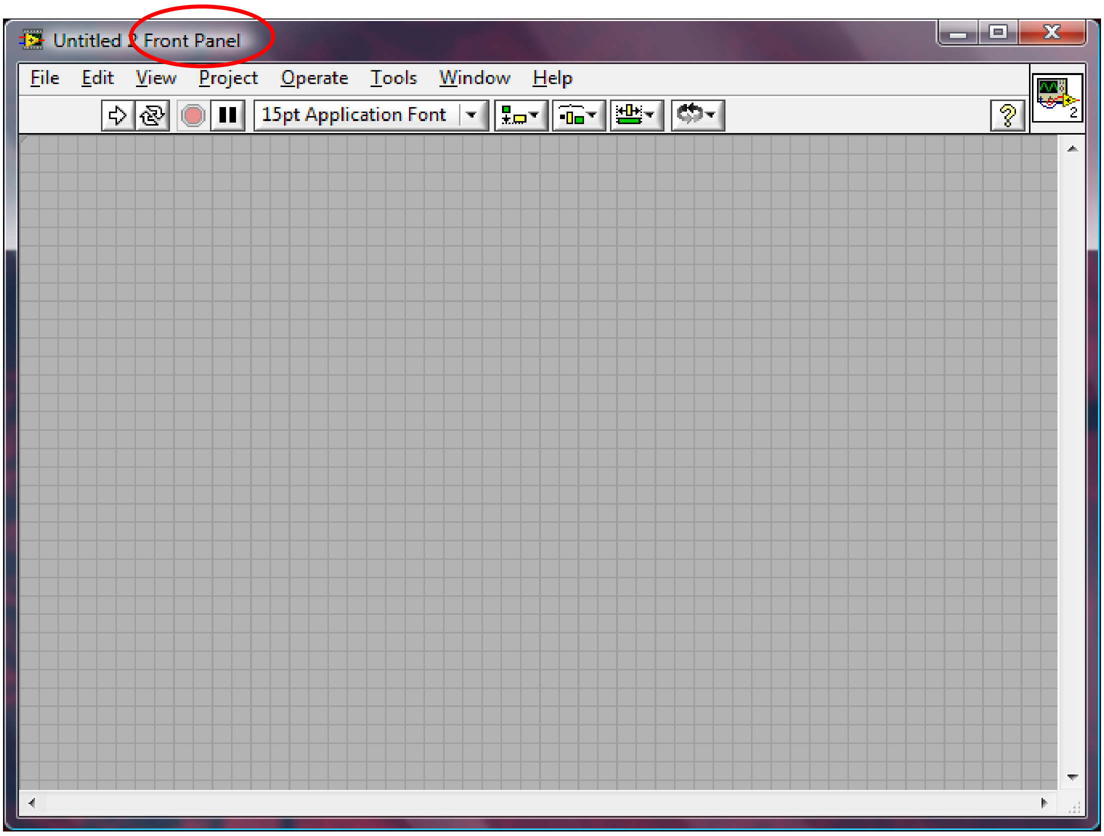


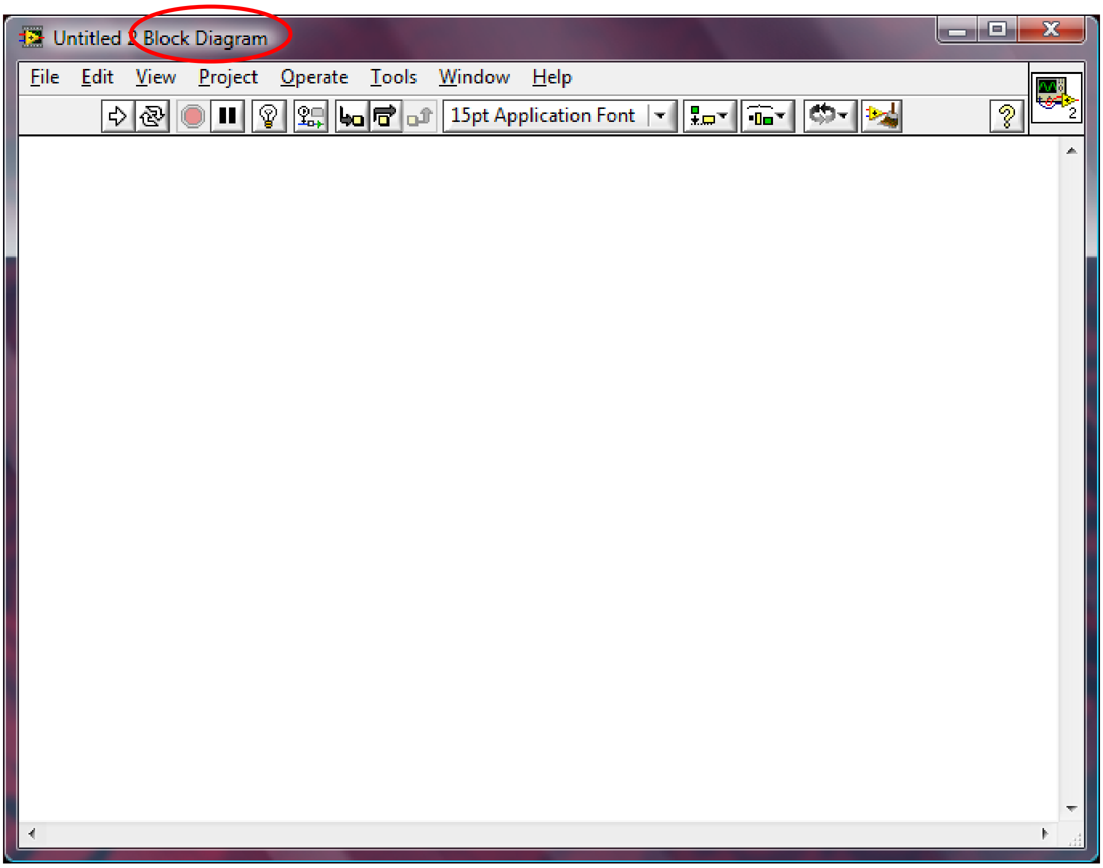
Step 3: In the Getting Started window, click the "New" or "VI from Template" link to display the New dialog box.



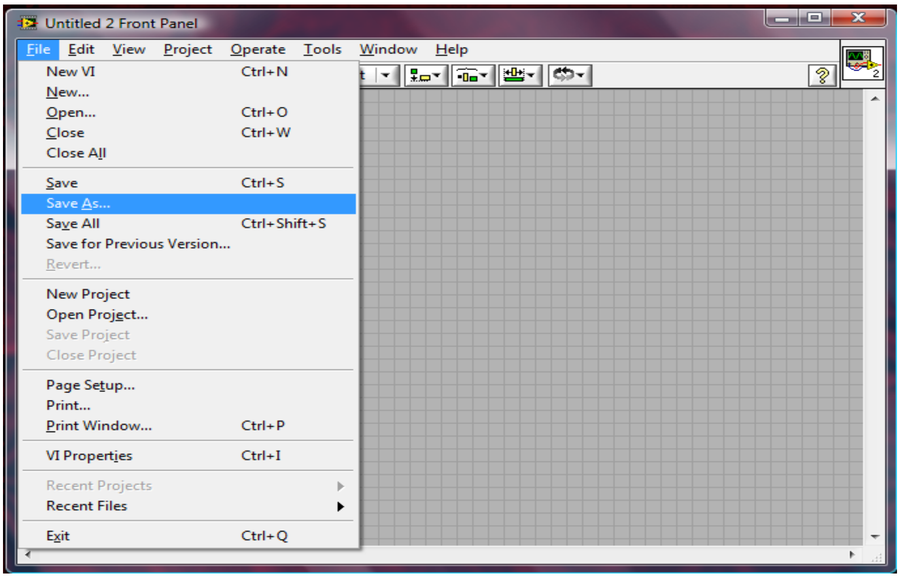

Step 4: From the Create New list, drop-down VI, and select "Blank VI". Then, LabVIEW displays two windows: the front panel window and block diagram window.

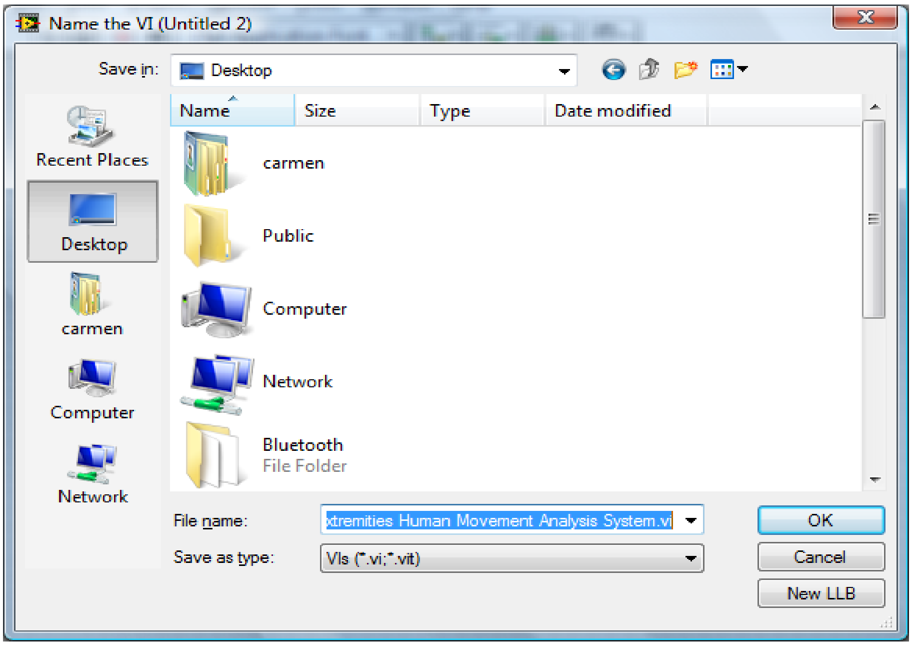
- Examine the front panel window, whether the user interface or front panel, appears with gray background and includes controls and indicators.
- If the front panel is not visible, then can display the front panel by drop-down "Window" and select "Show Front Panel".


Untitled 2 Front Panel
File Edit View Project Operate Tools Window Help
15pt Application Font

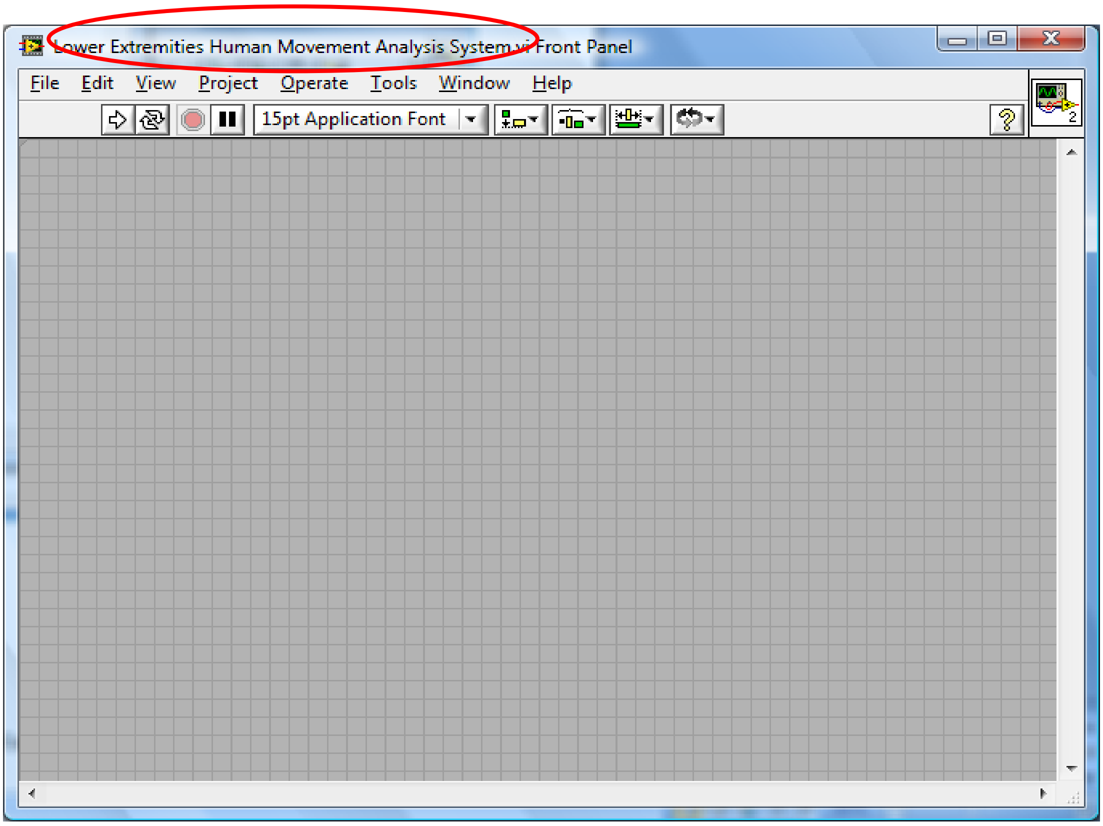

Untitled 2 Block Diagram
File Edit View Project Operate Tools Window Help
15pt Application Font

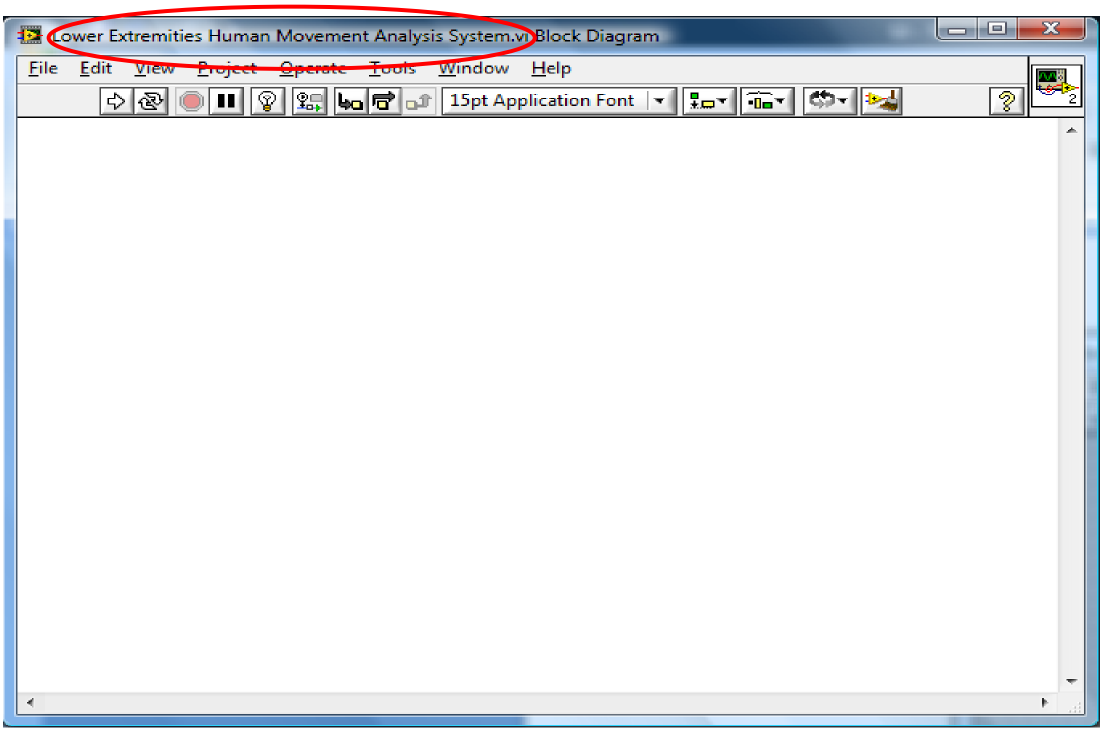
Step 5: Select “File” and “Save As” the file name with “Lower Extremities Human Movement Analysis System.vi” in an easily accessible location.



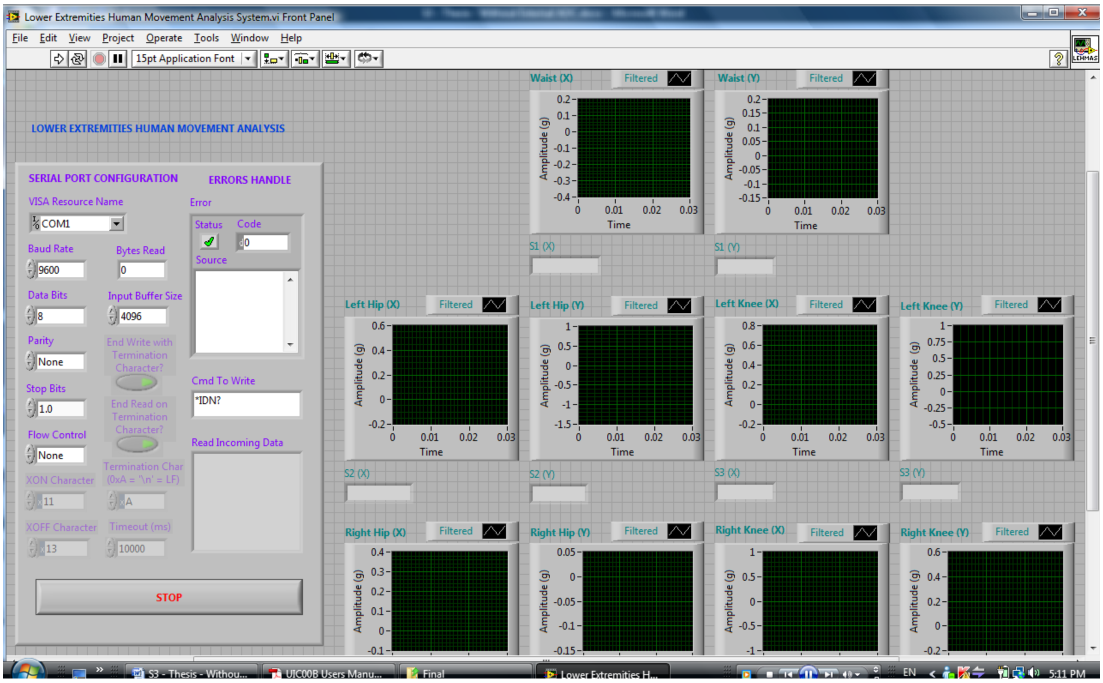



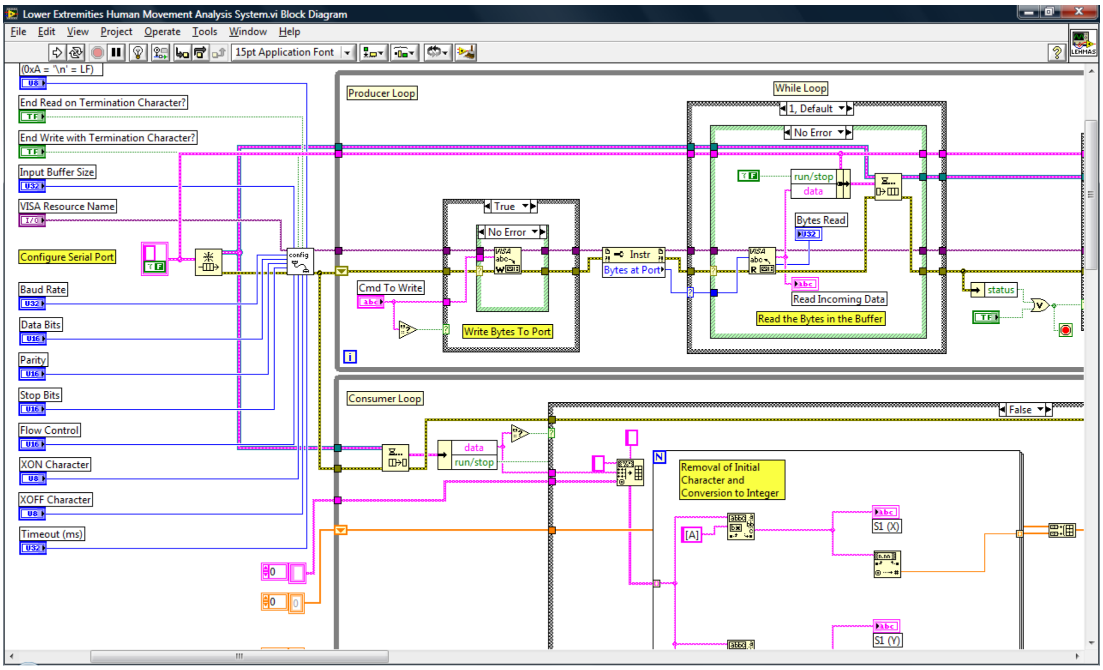
Step 6: A front panel window and block diagram window with the new file name will be shown. Therefore, block diagram for the research project can be started implement on the block diagram window.



Step 7: Final LabVIEW Graphical Programming for "Front Panel Window" and the complete "Block Diagram Window" are shown in Appendix H and I.




In the sub-section, main section of the block diagram interface will be discussed, which included serial COM port configuration, VISA read and write data, String and g-value conversion to integer, signal filtering and storage data in text file.

### 3.5.3.1 Serial Port Configuration

Serial communication is a popular means of transmitting data between a computer and a peripheral device such as programmable instrument or even another computer. Serial communication uses a transmitter to send data, one bit at a time, over a single communication line to a receiver.

The four important parameters required to be specify when drawing the LabVIEW graphical programming, which are the baud rate of the transmission, the number of data bits encoding a character, the sense of the optional parity bit and the number of stop bits.

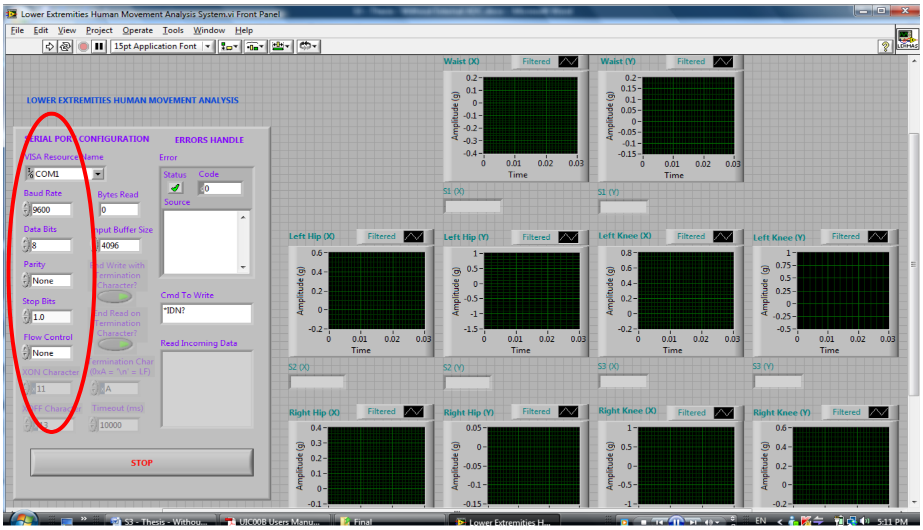



**Figure 3.56 Serial Port Configuration Front Panel Window**

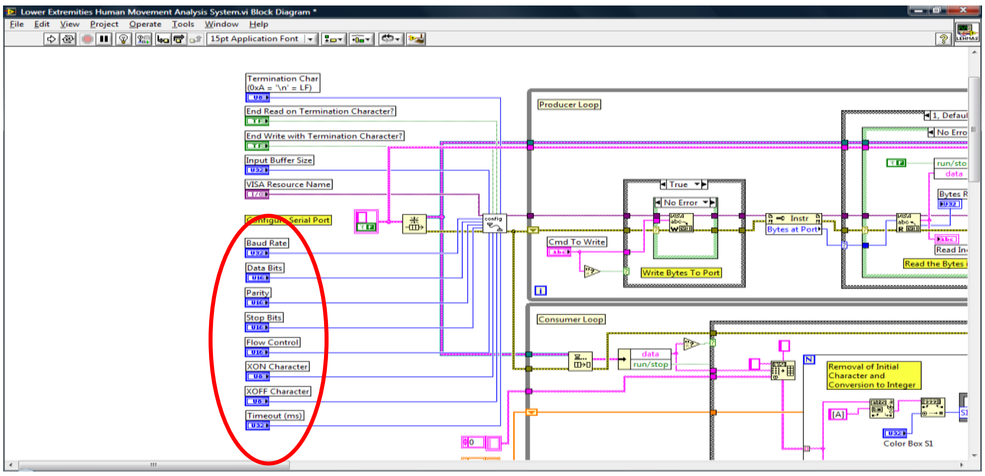



**Figure 3.57 Serial Port Configuration Block Diagram Window**

VISA resource name refers to the virtual COM port created by the Bluetooth module. Basically, the baud rate for the Bluetooth module is set to 9600 and each transmitted character is packaged in a character frame that consists of a single start bit followed by the data bits, the optional parity bit, and the stop bit.

Furthermore, LabVIEW is capable of creating its own "Bluetooth Discovery" function and establishing a connection between the Bluetooth modules of different personal computer by using the third party software BlueSoleil to establish the connection.

### 3.5.3.2 VISA Read and Write Data

VISA read and write data section consists of a while loop which continuously obtain the data from the personal computer serial port. A time delays for 50ms is added for the VISA read and write process to ensure that LabVIEW completely received the data without having any errors or problems before continues of another loops.

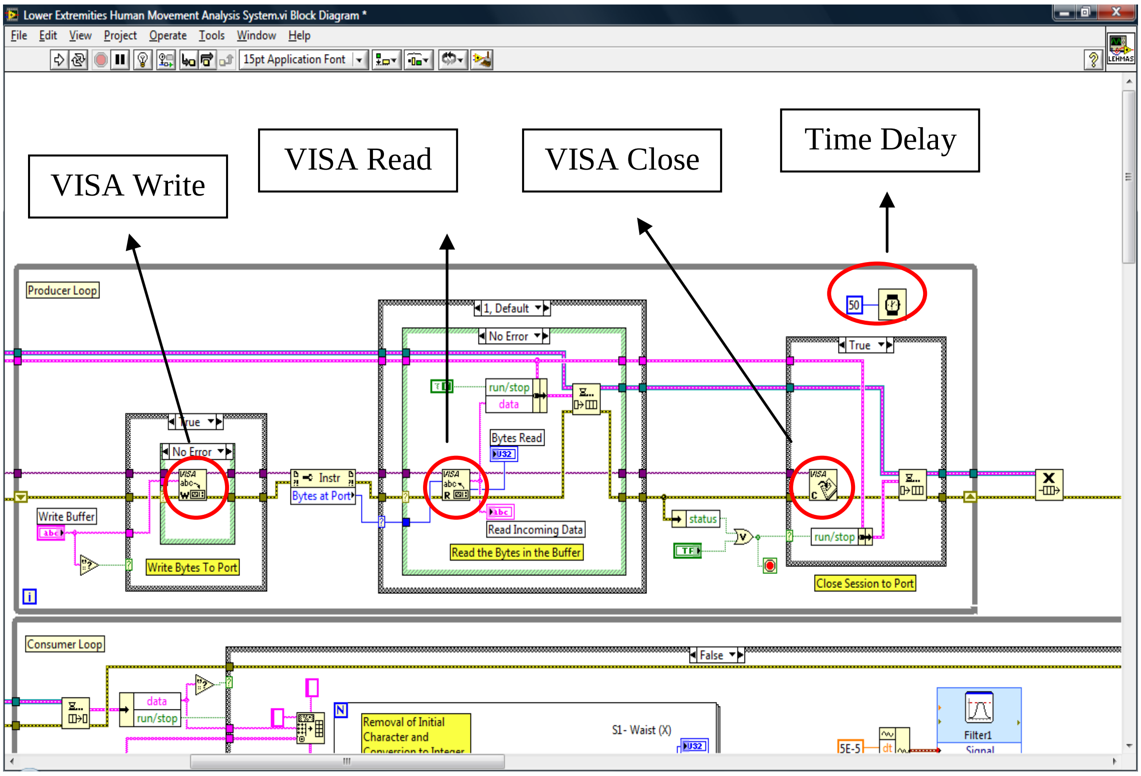



**Figure 3.58 VISA Read and Write Block Diagram Window**

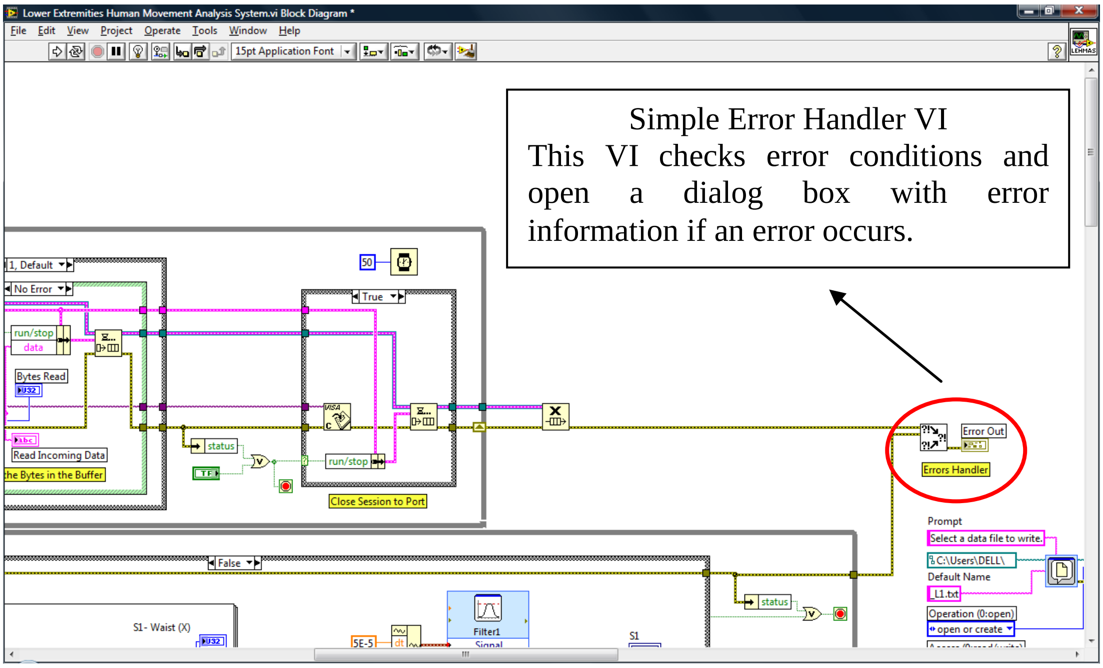



Figure 3.59 VISA Read and Write Block Diagram Window (Continued)

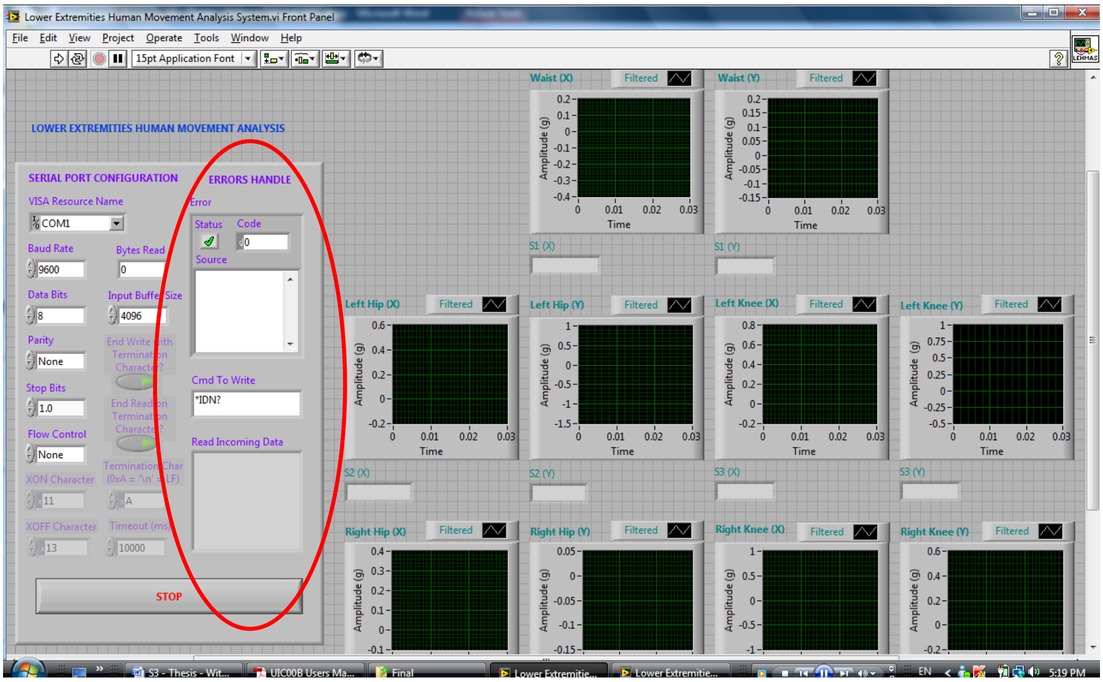



Figure 3.60 VISA Read and Write Front Panel Window

### 3.5.3.3 String Data and Gravitational Acceleration Conversion

The numeric analogues data output in the gravity unit obtained from the accelerometers are represented by the initial characters or alphabet from A to I. To write numeric data to a text or spreadsheet file, the alphabet have to remove and numeric data must convert to a string data, which are in ASCII characters, before being further conditioning process.

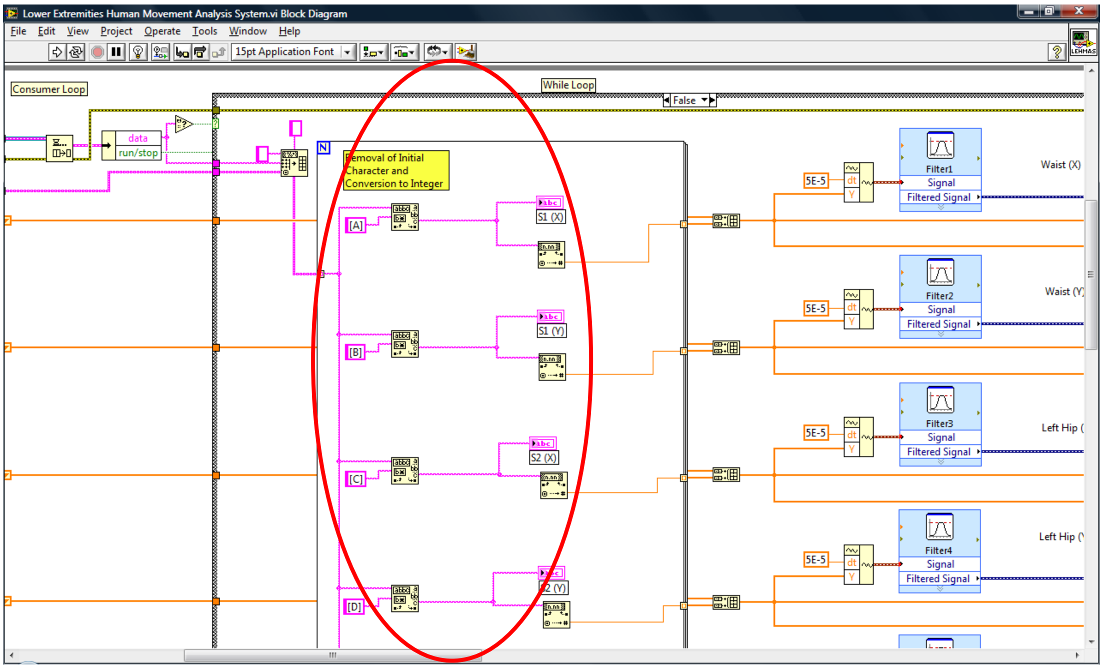



**Figure 3.61 String Data Block Diagram**

In cases the user does not know how to write the programming code in the PIC programming, and then the conversion formula for gravitational acceleration as mention in Chapter 3.3.1.1 can be writing into the LabVIEW as shown in Figure below.

$$g\_\text{Conversion} = \{[(\frac{\text{Converted ADC}}{1024} \times 3.3) - 1.62] \times 3.03\}$$

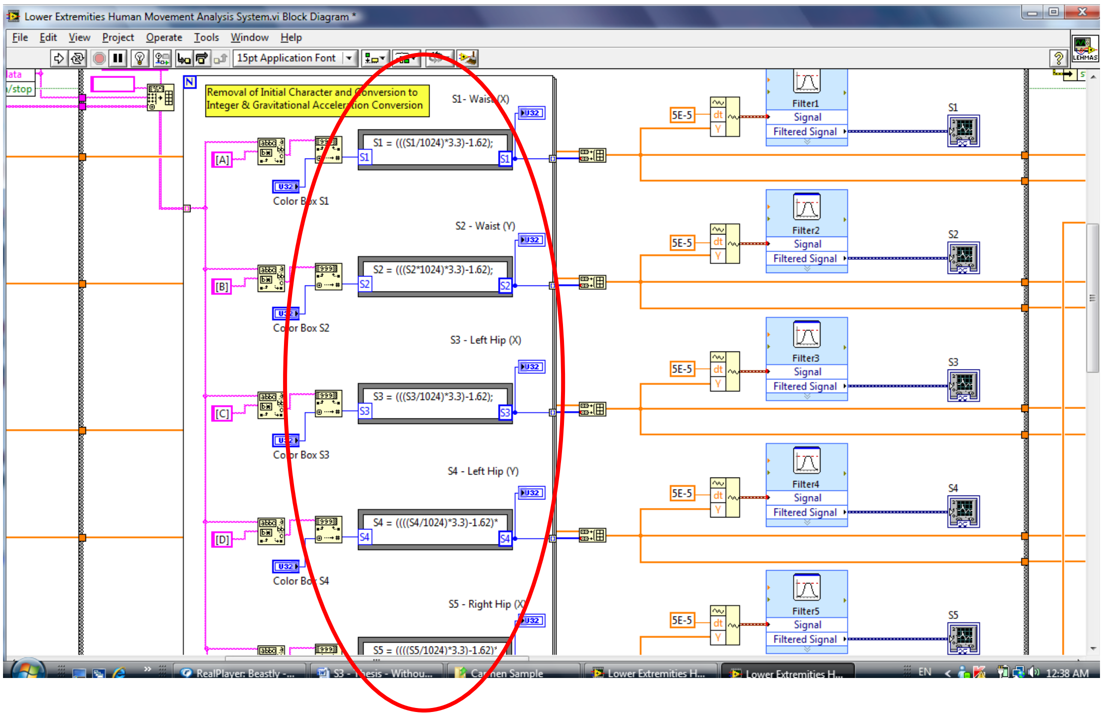



**Figure 3.62 String Data and Gravitational Acceleration Conversion Block Diagram**

### 3.5.3.4 Signal Filtering

The filter function in LabVIEW is powerful, which are capable to carry out different types of filtering, such as low pass filter, high pass filter, band-pass filter, band-stop filter, and smoothening. The filter characteristic such as Butterworth, Chebyshev, Elliptic and Bessel can be chose depending on the application. The order and the cut-off frequency also can be adjusted.

In LabVIEW graphical programming, the filter can be configuring by right click of the filter terminal and select properties. Then configure filter window will be pop-up. For lower extremities human movement analysis research project, low pass filter with 1000Hz cut-off frequency and 6$^{th}$ order of Butterworth filter characteristics is applied. After the signal filtering, then the signal will be displays in the waveform graph shown in the front panel window.

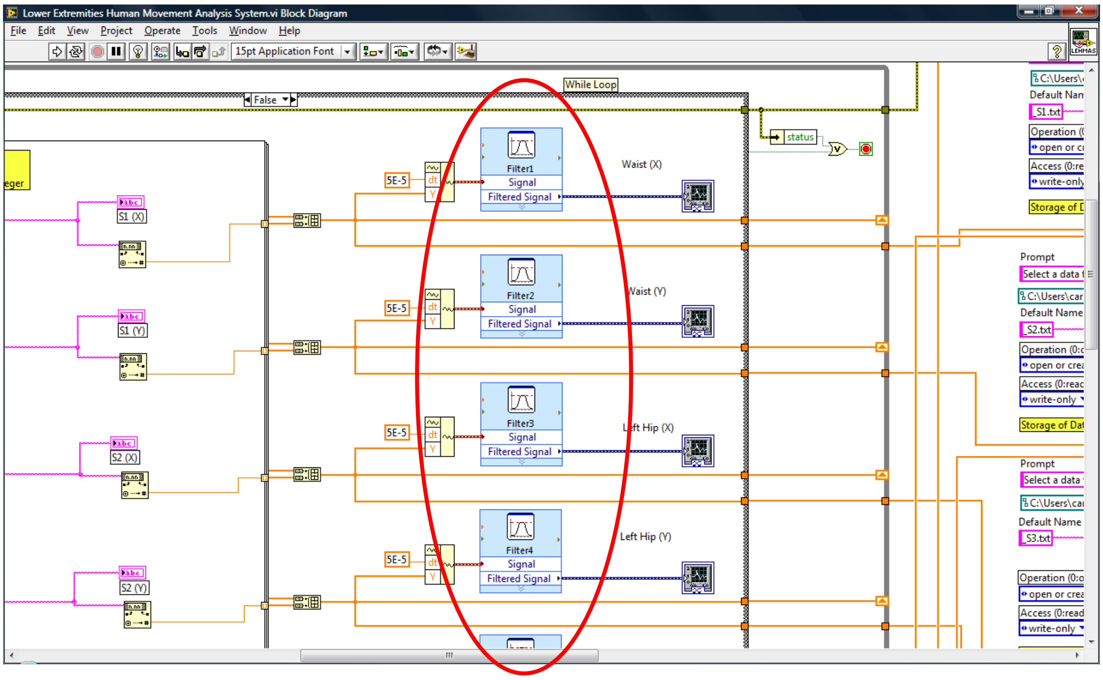



**Figure 3.63 Signal Filtering Block Diagram Window**

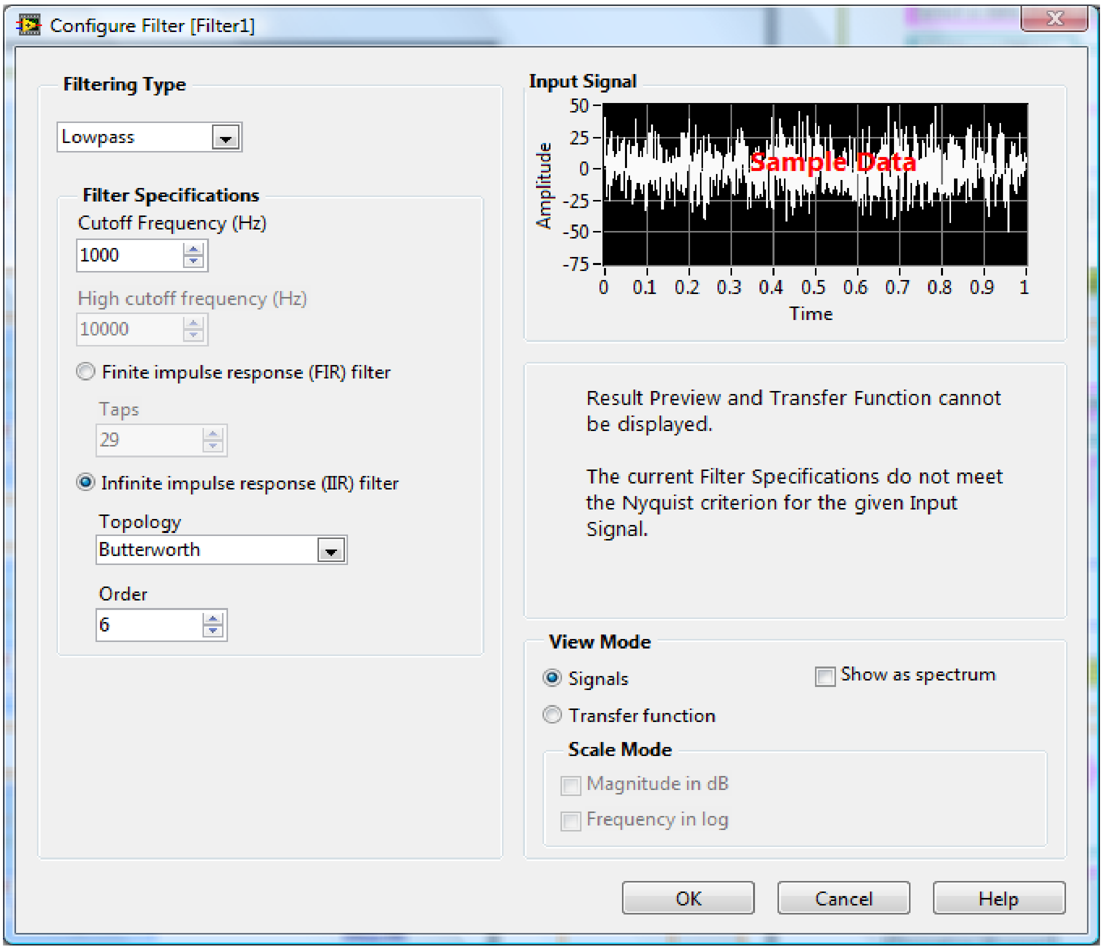



**Figure 3.64 Filter Configuration**

### 3.5.3.5 Storage Data in Text File

The storage data in text file is important for the research because post-processing procedures can be carried out using other analytical software; data can be keeping as electronic record and can share the data with the other research project.

In additional of date and time functions, the current date and time data runs on and data written can be specify and provided. Furthermore, The “Concatenate Strings” combines both strings and allow “Write to Text File” to record the date and the time with the data in the specific pathway that have been browse.

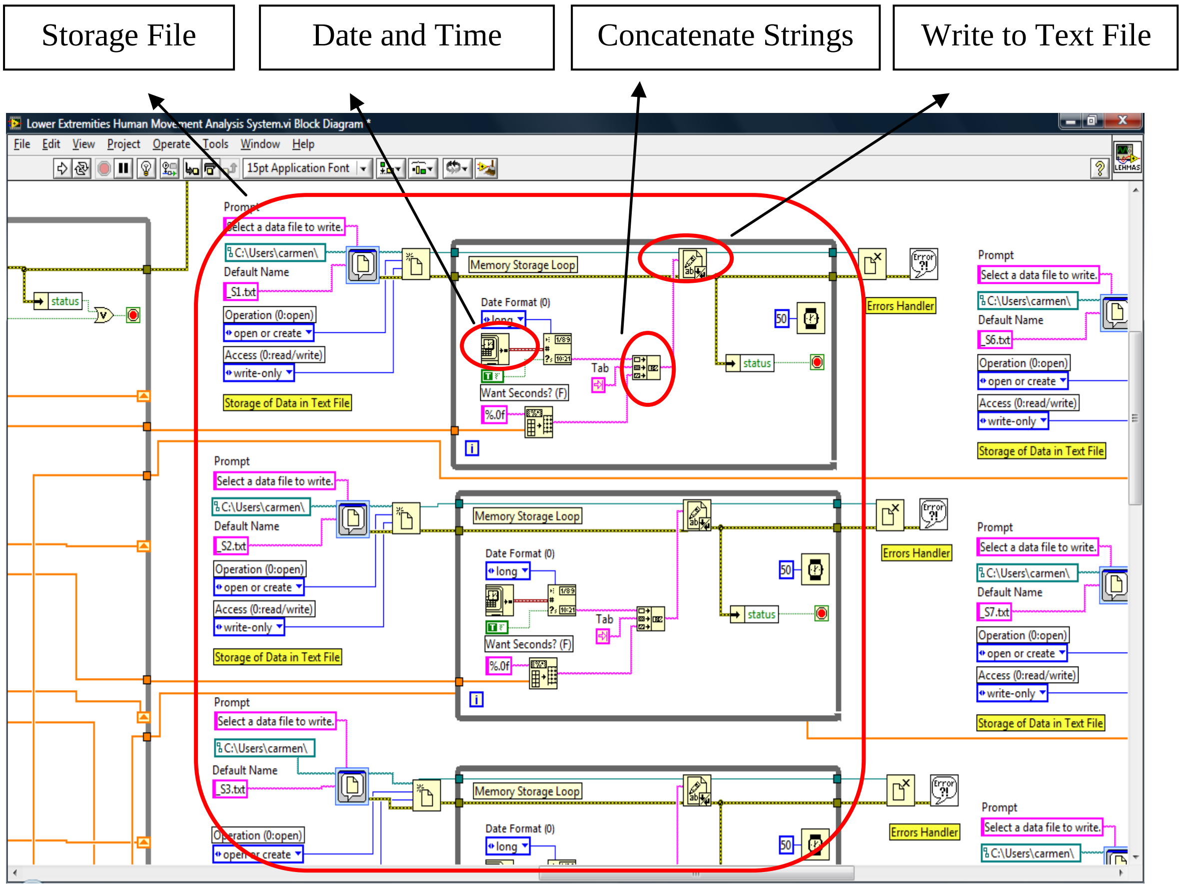


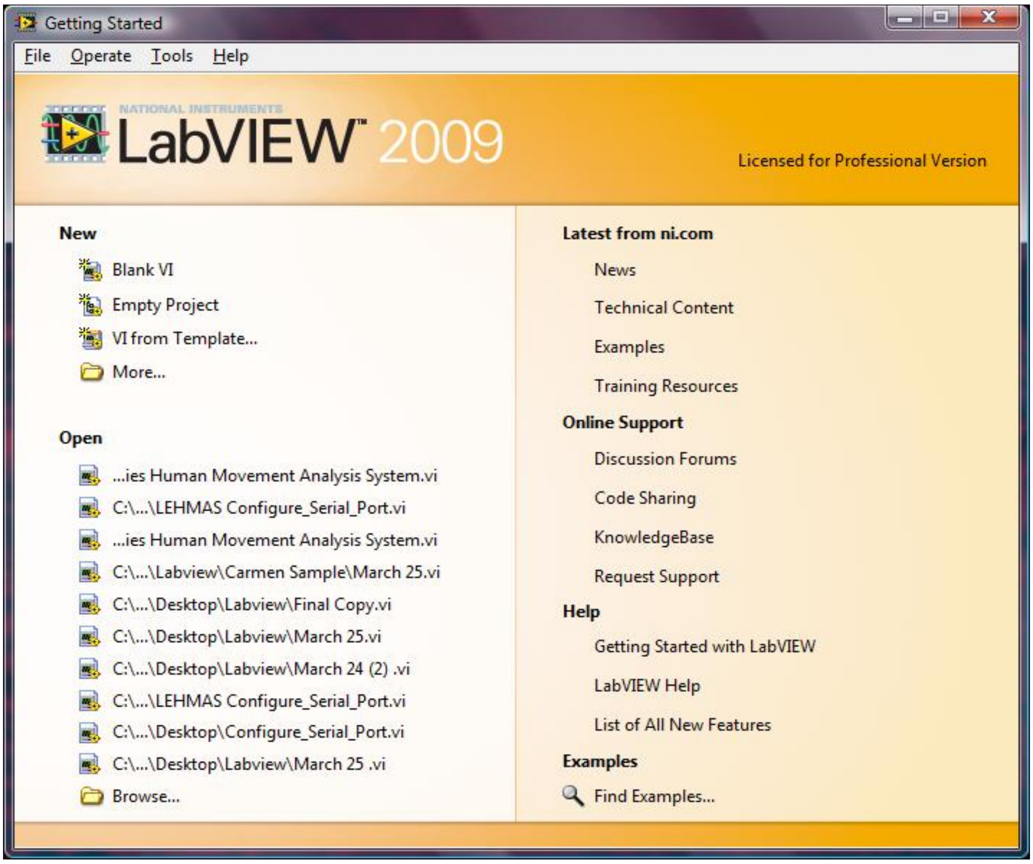

**Figure 3.65 Storage Data in Text File Block Diagram Window**

### 3.5.4 LabVIEW Interactions

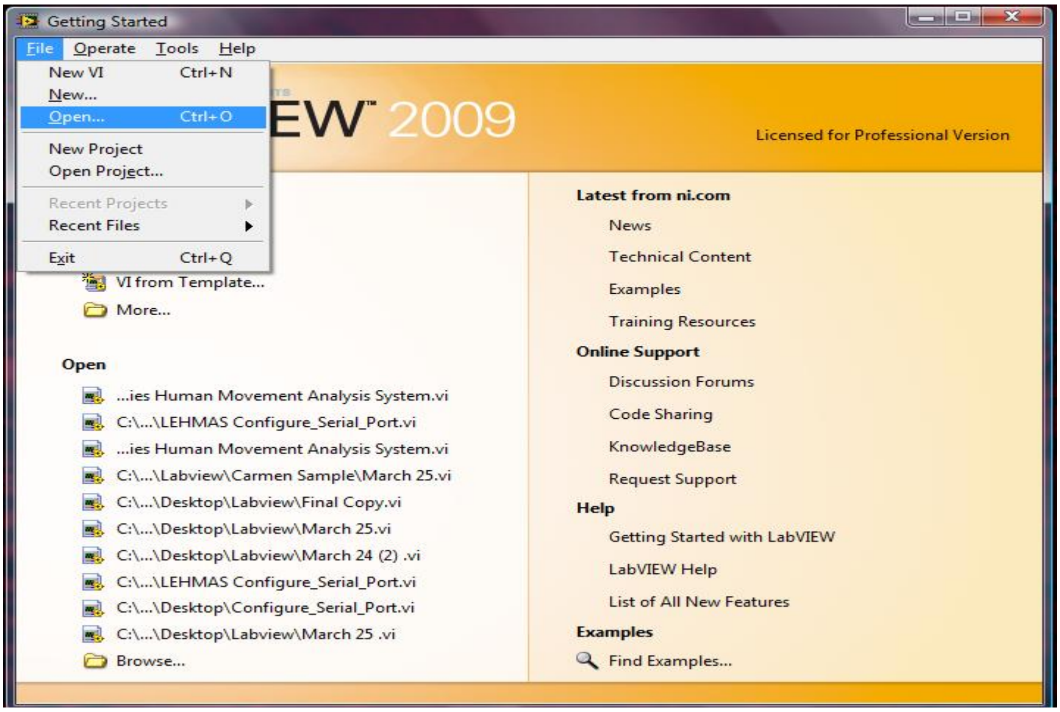
Once the connection between SKKCA-21 and the personal computer is established, the source code of the microcontroller have been compiled and burning and LabVIEW graphical programming have been completed, then the data analysis can be undergo by using National Instrument LabVIEW 2009.

The following are the procedures of running the LabVIEW graphical programming configurations.

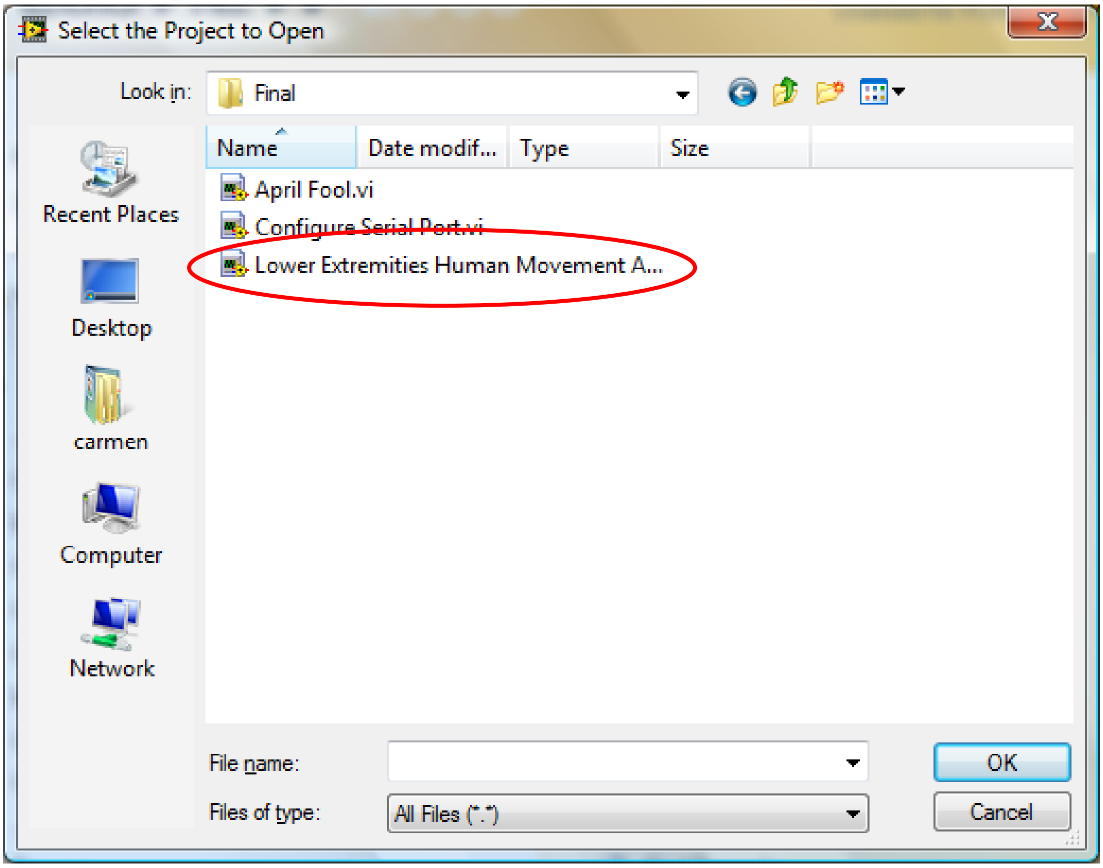
Step 1: Double click on the "LabVIEW" icon on the desktop.



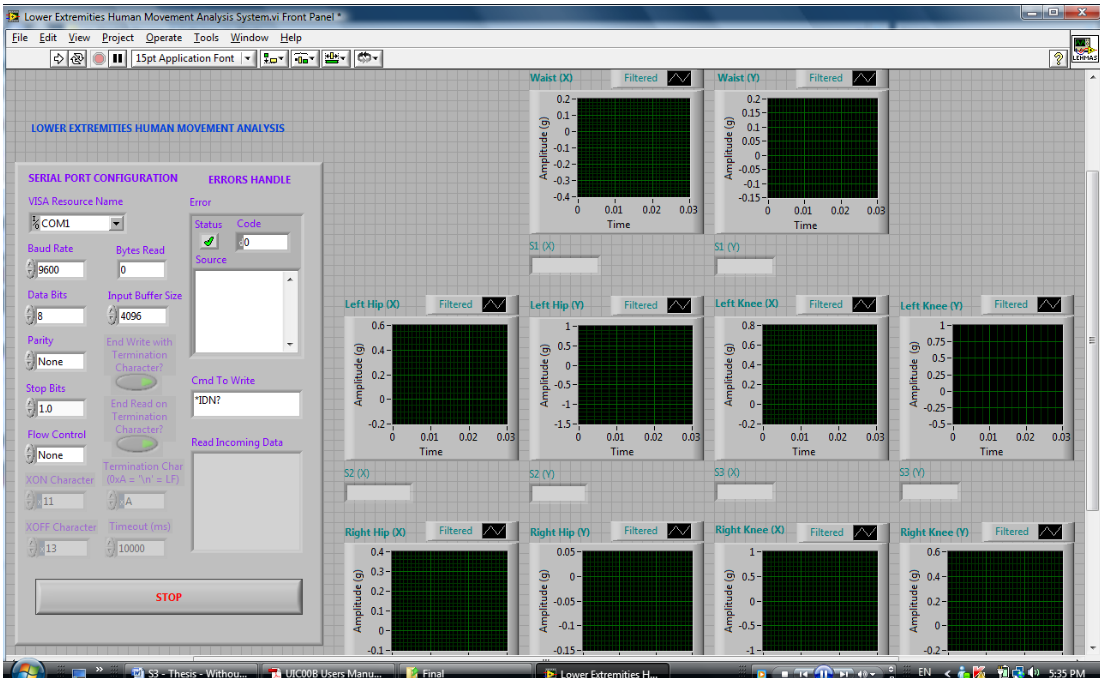
Step 2: To open a saved file, drop-down the "File" tab and select "Open".




Step 3: Select the file "Lower Extremities Human Movement Analysis System.vi" from the appropriate folder.

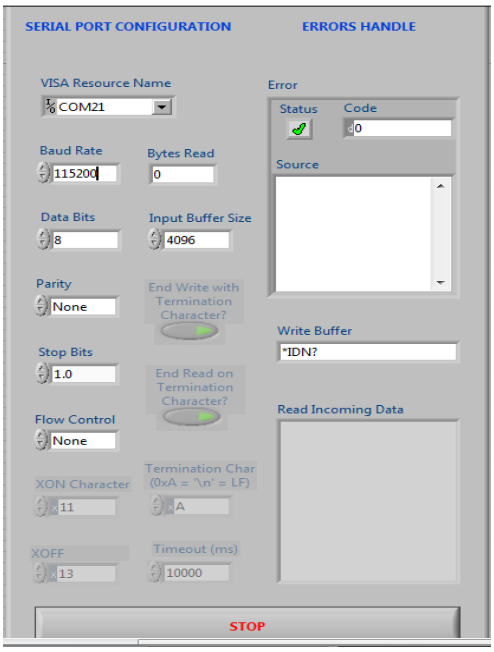


Step 4: The “Lower Extremities Human Movement Analysis Movement.vi” has been shown as follow.

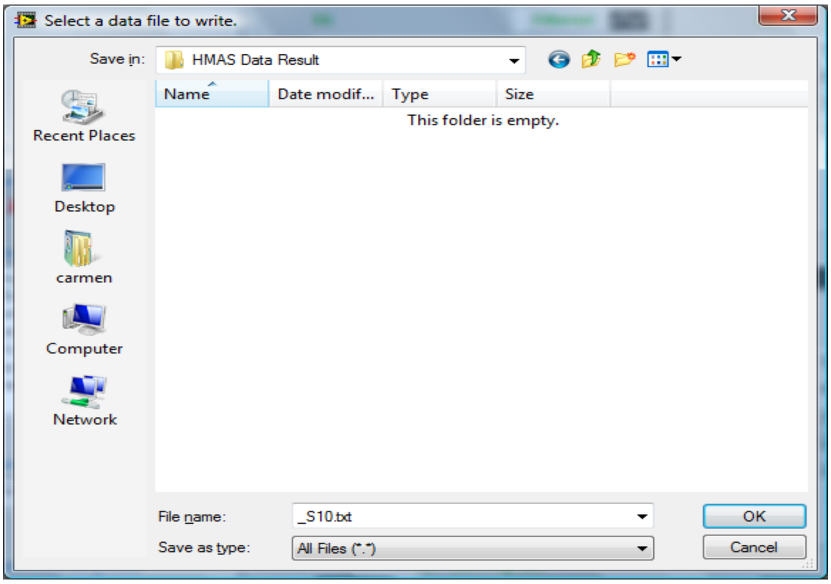



Step 5: Under the “Serial Port Configuration”,

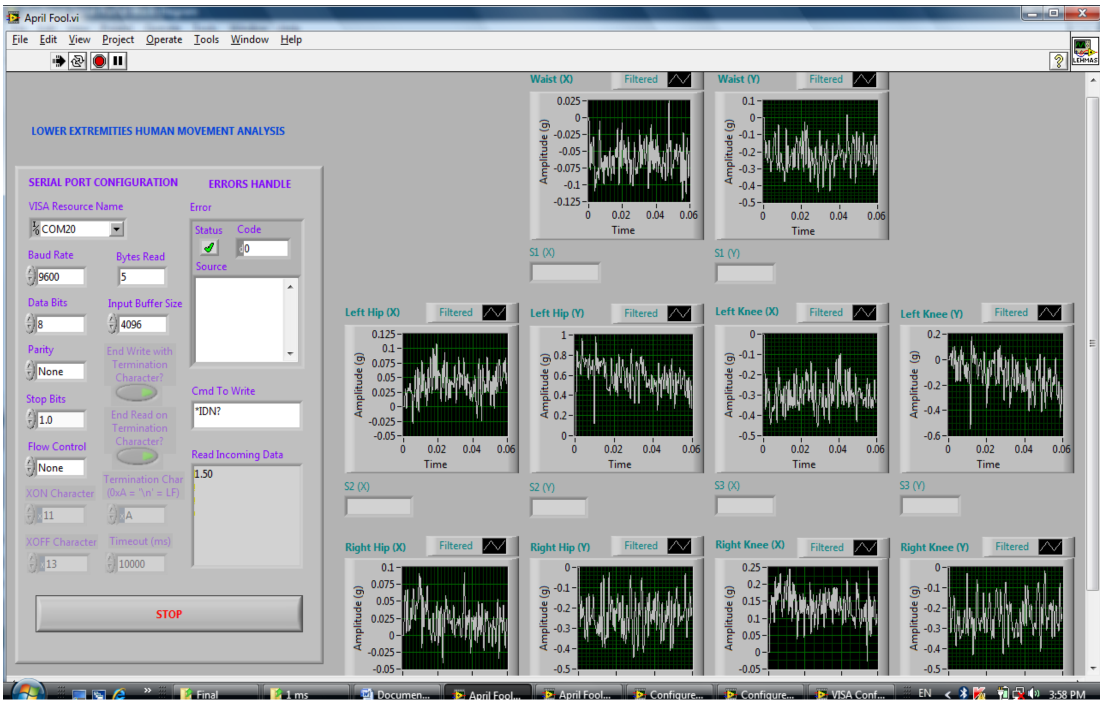
- Select com21 for “VISA Resource Name”.
- Adjusted the “Baud Rate” to 115200.
- Set “Data Bits” to 8.
- Set “Parity” to “None”
- Set “Stop Bits” to “1”.



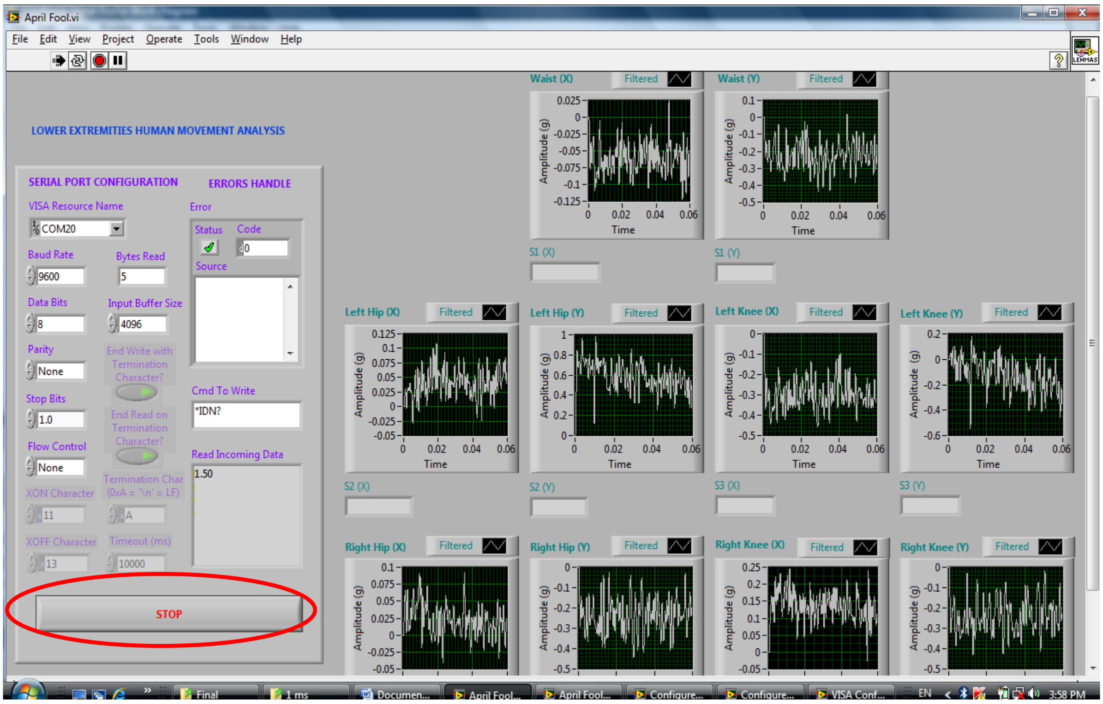
Step 6: To run the LabVIEW, go to the “Operate” tab, select “Run”. A new dialogue box “Select a data file to write” will appear for data storage purpose. Enter a new file name (For example: CKM1.txt) and click “OK”. Repeat this for the next 9 dialogue boxes with different file name.”



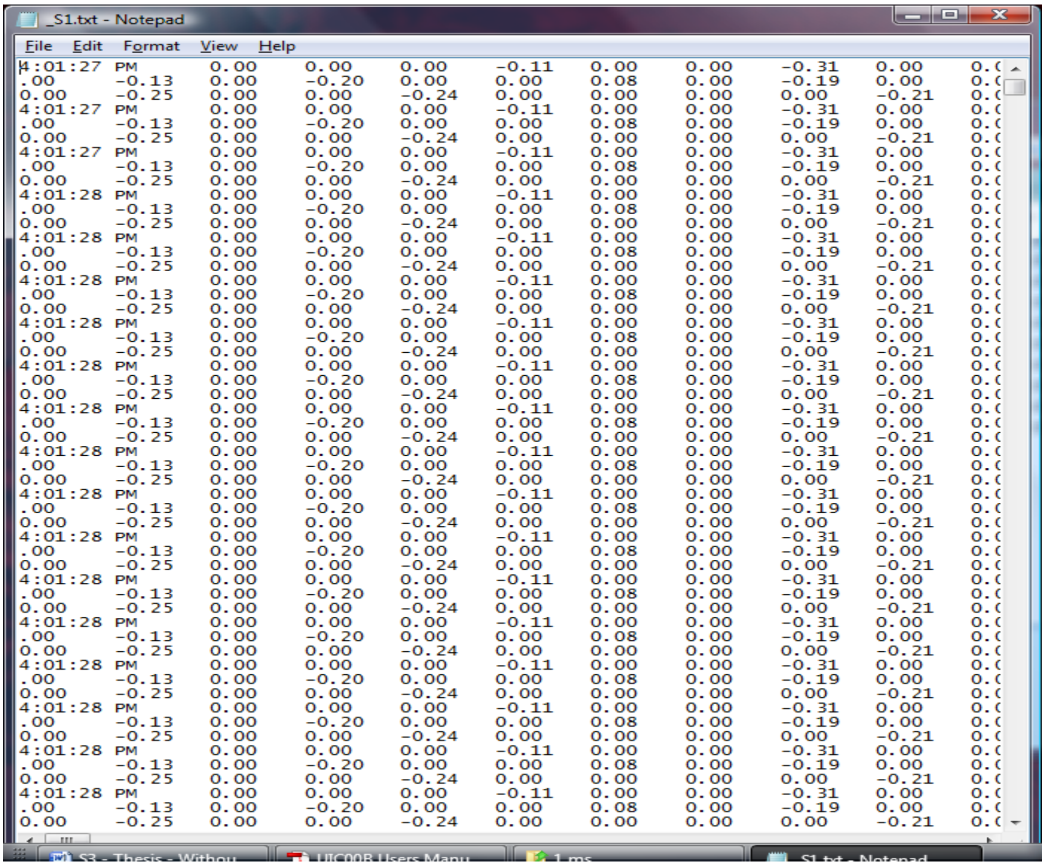

Step 7: The LabVIEW graphical program will start displaying the real-time graphs and collecting the data into the text file. Now the software is ready to monitor the changes of the accelerations with the human movement.



Step 8: To stop the program, click on the “Stop” button in the front panel window.




Step 9: When open the text file, all the incoming data have been recorded according to the time.


_S1.txt - Notepad

File Edit Format View Help

```
4:01:27 PM      0.00   0.00   0.00   -0.11  0.00   0.00   -0.31  0.00   0.(
.00     -0.13   0.00   -0.20  0.00   0.00   0.08   0.00   -0.19  0.00   0.(
0.00    -0.25   0.00   0.00   -0.24  0.00   0.00   0.00   0.00   -0.21  0.(
4:01:27 PM      0.00   0.00   0.00   -0.11  0.00   0.00   -0.31  0.00   0.(
.00     -0.13   0.00   -0.20  0.00   0.00   0.08   0.00   -0.19  0.00   0.(
0.00    -0.25   0.00   0.00   -0.24  0.00   0.00   0.00   0.00   -0.21  0.(
4:01:27 PM      0.00   0.00   0.00   -0.11  0.00   0.00   -0.31  0.00   0.(
.00     -0.13   0.00   -0.20  0.00   0.00   0.08   0.00   -0.19  0.00   0.(
0.00    -0.25   0.00   0.00   -0.24  0.00   0.00   0.00   0.00   -0.21  0.(
4:01:28 PM      0.00   0.00   0.00   -0.11  0.00   0.00   -0.31  0.00   0.(
.00     -0.13   0.00   -0.20  0.00   0.00   0.08   0.00   -0.19  0.00   0.(
0.00    -0.25   0.00   0.00   -0.24  0.00   0.00   0.00   0.00   -0.21  0.(
4:01:28 PM      0.00   0.00   0.00   -0.11  0.00   0.00   -0.31  0.00   0.(
.00     -0.13   0.00   -0.20  0.00   0.00   0.08   0.00   -0.19  0.00   0.(
0.00    -0.25   0.00   0.00   -0.24  0.00   0.00   0.00   0.00   -0.21  0.(
4:01:28 PM      0.00   0.00   0.00   -0.11  0.00   0.00   -0.31  0.00   0.(
.00     -0.13   0.00   -0.20  0.00   0.00   0.08   0.00   -0.19  0.00   0.(
0.00    -0.25   0.00   0.00   -0.24  0.00   0.00   0.00   0.00   -0.21  0.(
4:01:28 PM      0.00   0.00   0.00   -0.11  0.00   0.00   -0.31  0.00   0.(
.00     -0.13   0.00   -0.20  0.00   0.00   0.08   0.00   -0.19  0.00   0.(
0.00    -0.25   0.00   0.00   -0.24  0.00   0.00   0.00   0.00   -0.21  0.(
4:01:28 PM      0.00   0.00   0.00   -0.11  0.00   0.00   -0.31  0.00   0.(
.00     -0.13   0.00   -0.20  0.00   0.00   0.08   0.00   -0.19  0.00   0.(
0.00    -0.25   0.00   0.00   -0.24  0.00   0.00   0.00   0.00   -0.21  0.(
4:01:28 PM      0.00   0.00   0.00   -0.11  0.00   0.00   -0.31  0.00   0.(
.00     -0.13   0.00   -0.20  0.00   0.00   0.08   0.00   -0.19  0.00   0.(
0.00    -0.25   0.00   0.00   -0.24  0.00   0.00   0.00   0.00   -0.21  0.(
4:01:28 PM      0.00   0.00   0.00   -0.11  0.00   0.00   -0.31  0.00   0.(
.00     -0.13   0.00   -0.20  0.00   0.00   0.08   0.00   -0.19  0.00   0.(
0.00    -0.25   0.00   0.00   -0.24  0.00   0.00   0.00   0.00   -0.21  0.(
4:01:28 PM      0.00   0.00   0.00   -0.11  0.00   0.00   -0.31  0.00   0.(
.00     -0.13   0.00   -0.20  0.00   0.00   0.08   0.00   -0.19  0.00   0.(
0.00    -0.25   0.00   0.00   -0.24  0.00   0.00   0.00   0.00   -0.21  0.(
4:01:28 PM      0.00   0.00   0.00   -0.11  0.00   0.00   -0.31  0.00   0.(
.00     -0.13   0.00   -0.20  0.00   0.00   0.08   0.00   -0.19  0.00   0.(
0.00    -0.25   0.00   0.00   -0.24  0.00   0.00   0.00   0.00   -0.21  0.(
4:01:28 PM      0.00   0.00   0.00   -0.11  0.00   0.00   -0.31  0.00   0.(
.00     -0.13   0.00   -0.20  0.00   0.00   0.08   0.00   -0.19  0.00   0.(
0.00    -0.25   0.00   0.00   -0.24  0.00   0.00   0.00   0.00   -0.21  0.(
4:01:28 PM      0.00   0.00   0.00   -0.11  0.00   0.00   -0.31  0.00   0.(
.00     -0.13   0.00   -0.20  0.00   0.00   0.08   0.00   -0.19  0.00   0.(
0.00    -0.25   0.00   0.00   -0.24  0.00   0.00   0.00   0.00   -0.21  0.(
4:01:28 PM      0.00   0.00   0.00   -0.11  0.00   0.00   -0.31  0.00   0.(
.00     -0.13   0.00   -0.20  0.00   0.00   0.08   0.00   -0.19  0.00   0.(
0.00    -0.25   0.00   0.00   -0.24  0.00   0.00   0.00   0.00   -0.21  0.(
4:01:28 PM      0.00   0.00   0.00   -0.11  0.00   0.00   -0.31  0.00   0.(
.00     -0.13   0.00   -0.20  0.00   0.00   0.08   0.00   -0.19  0.00   0.(
0.00    -0.25   0.00   0.00   -0.24  0.00   0.00   0.00   0.00   -0.21  0.(
4:01:28 PM      0.00   0.00   0.00   -0.11  0.00   0.00   -0.31  0.00   0.(
.00     -0.13   0.00   -0.20  0.00   0.00   0.08   0.00   -0.19  0.00   0.(
0.00    -0.25   0.00   0.00   -0.24  0.00   0.00   0.00   0.00   -0.21  0.(
4:01:28 PM      0.00   0.00   0.00   -0.11  0.00   0.00   -0.31  0.00   0.(
.00     -0.13   0.00   -0.20  0.00   0.00   0.08   0.00   -0.19  0.00   0.(
0.00    -0.25   0.00   0.00   -0.24  0.00   0.00   0.00   0.00   -0.21  0.(
```

### 3.6 Subjects

Twenty subjects (10 males and 10 females) were voluntarily took part in the study. Subjects had a mean age of 23.60 ± 0.66 years, height of 167.45 ± 6.32 cm, weight of 62.28 ± 11.53 kg and body mass index (BMI) of 21.95 ± 3.16 kg/m$^2$. The calculation of the participant characteristics - mean and standard deviation are shown in Appendix J and Appendix K.

**Table 3.7 Mean and Standard Deviation of Female Participant Characteristics**

| | **Mean** | **Standard Deviation** |
|---|---|---|
| **Age** | 23.70 | 0.46 |
| **Height** | 161.40 | 6.18 |
| **Weight** | 53.02 | 9.42 |
| **Body Mass Index (BMI)** | 20.28 | 2.96 |

**Table 3.8 Mean and Standard Deviation of Male Participant Characteristics**

| | **Mean** | **Standard Deviation** |
|---|---|---|
| **Age** | 23.50 | 0.92 |
| **Height** | 173.50 | 6.45 |
| **Weight** | 71.53 | 13.64 |
| **Body Mass Index (BMI)** | 23.62 | 3.36 |

Inclusion criteria were had normal or corrected-to-normal vision, the ability to walk unaided, good general health, normal memory function and generally normal cognition. Subjects with lower limb abnormalities, musculoskeletal injuries or disorders that affect walking ability were excluded from the study. Each subjects provided written informed consent prior to participation in the study, which was approved by the Department of Mechatronics and Biomedical Engineering of University.

## 3.7 Experiment Procedures

The experiment was carried out in a Biomechanics facility lab. A continuously walking on a Treadmill with no obstacles nearby was arranged. Subjects wore loose fitting clothing and wore their own sport shoes to ensure their comfort throughout experiments. If they normally used an ankle-foot orthotics or a cane, they used them in the experiments.

A standardised protocol was followed. Informed consent letter, health screening form and anthropometric measurements for each subject were obtained before starting the test. Once accelerometers were attached a static calibration was captured. In total, five accelerometers are attached on the remote body parts of the subjects, such as waist, hips and knees.

Before the test is being carried out, initial test will be conducted. This initial test is important to make sure the human movement analysis system can work properly in a good condition and make sure the accelerometers attached on the different body part accurately and tightly. Furthermore, it also make sure the all the embed system instrumented did not interrupt the human movement analysis of the subject.

The Treadmill walk test is performed twice to record definite data on the time-distance gait parameters and lower extremities acceleration. All subjects were instructed to walk straight at a three different speed, which are slow walking – 1 km/h, comfortable walking – 3 km/h and normal walking – 5 km/h on the Treadmill. Complete test duration is around 30 min. Data from the device are recorded in the real-time.

After finished the test, a survey form was obtained from the subject. It can be used for the purpose of gathering information from subject. From the gathered information, improvement of the research system can be done. A free gift – candy or chocolate has been given to each subject for their participation.

### 3.7.1 Informed Consent

Informed consent is a vital part of the research process, and as such entails more than obtaining a signature on a form. Investigators must educate potential subjects to ensure that they can reach a truly informed decision about whether or not to participate in the research. Their informed consent must be given freely, without coercion, and must be based on a clear understanding of what participation involves.

The process of educating subjects about the study begins during initial contact and continues for the duration of their participation. Thus, information conveyed through written informed consent documents and discussions must be understandable to the subjects and should contribute to their understanding of the research. Technical and medical terminology should be avoided and materials should be written at an 8th grade reading level or lower.

The consent discussion should begin sufficiently in advance of the initiation of study-related procedures to allow potential subjects time to reflect on the potential benefits and risks and possible discomforts of participation. First, potential subjects are given general information about the research. The investigator then meets with the potential subject to review and to discuss the details of the research study using the informed consent document as a guide. This discussion should include all of the required elements of informed consent, such as the purpose of the research, the procedures to be followed, the risks and discomforts as well as potential benefits associated with participation, and alternative procedures or treatments, if any, to the study procedures or treatments.

Preferably, potential subjects are then given a copy of the informed consent document to take home so they can carefully read the document and discuss the research with their family, friends and/or physician and develop questions to ask at their next meeting with the research staff. Subjects must always be given the opportunity to ask questions and have them answered by the investigator and, whenever possible, to consult with friends/family and/or their physicians. Once they have read the consent document and their questions are answered, if they agree to participate in the research, they sign and date the informed consent document.

With few exceptions, the informed consent of subjects, whether patients or healthy volunteers, must be obtained and documented in writing before the start of any study-related procedures, including screening tests and exams done solely to determine their eligibility for the study. Informed consent is to be obtained directly from each subject, with the exception of children and adults who have impaired decision-making capacity. Once the informed consent document has been signed, subjects are considered enrolled in the study.

The informed consent letter have been approved by the Department of Mechatronics and Biomedical Engineering UTAR and signed by the subjects. The sample of the informed consent letter for this research project is shows in Appendix L.

### 3.7.2 Health Information Form

All voluntary subjects have to perform a physical activity in this research. For the reason of safety, an additional health information form has to be completed by all subjects before involved in the research. The sample of the health information form for this research project is show in Appendix M.

### 3.7.3 Anthropometric Measurements

The term anthropometric refers to comparative measurements of the body. Anthropometric measurements are used to assess growth and development in infants, children, and adolescents include length, height, weight, weight-for-length, and head circumference (length is used in infants and toddlers, rather than height, because they are unable to stand). Individual measurements are usually compared to reference standards on a growth chart. (Racic, V., Pavic, A., Brownjohn, J.M.W., 2009)

Anthropometric measurements used for adults usually include height, weight, body mass index (BMI), waist-to-hip ratio, and percentage of body fat. These measures are then compared to reference standards to assess weight status and the risk for various diseases. Anthropometric measurements require precise measuring techniques to be valid. Accurately measuring children with physical abnormalities is often a challenge.

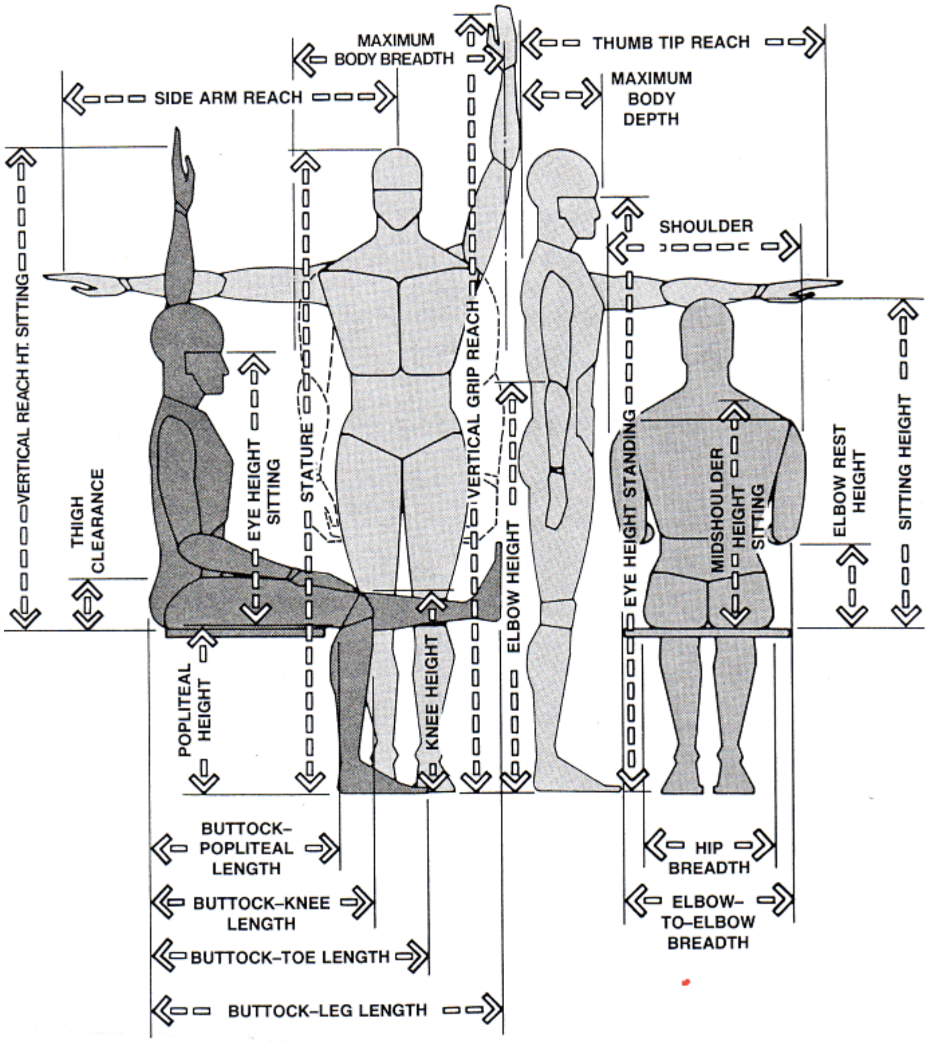



**Figure 3.66 Anthropometric measurements**

(© Copyright 1979 Panero, J. and Zelnik, M., p. 30)

For the lower extremities movement analysis research project, the anthropometric measurement only involved the overall height, weight and the length of lower extremities body parts. The other dimensional of the body parts does not play an important role in this research, such as head circumference and so on.

### 3.7.3.1 Weight Measurement

Weight is measured in all subjects and self-reported weights are not acceptable. The weight of the participants is measured with Treadmill before the walking test is conducted.

1. Calibration is done at the beginning.
2. Subjects are asked to remove their heavy outer garments and shoes.
3. Subject stands in the centre of the Treadmill platform, weight distributed evenly to both feet.
4. Weight is recorded on Treadmill.


**Figure 3.67 Treadmill**


**Figure 3.68 Weight Measurements on Treadmill**

### 3.7.3.2 Height Measurement

Height is measured in all subjects.

1. Subject is asked to remove their shoes and hair ornaments.
2. Subject is asked to stand with his/her back to the height ruler. The back of the head, back, buttocks, calves and heels should be touching the upright, feet together.
3. Subject is asked to look straight.
4. The height is measured with the ruler attached to the height ruler and hair is pressed flat.
5. Height is recorded. If the subject is taller than the measurer, the measurer should stand on a platform so that the measurer can properly read the height value.

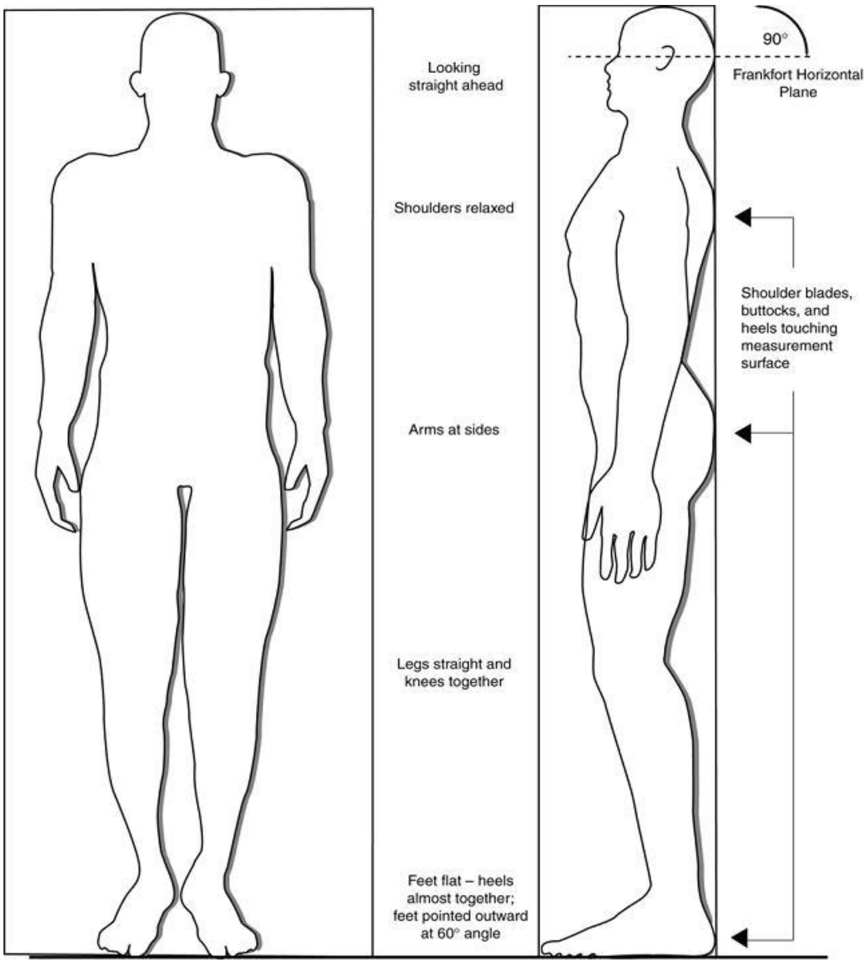


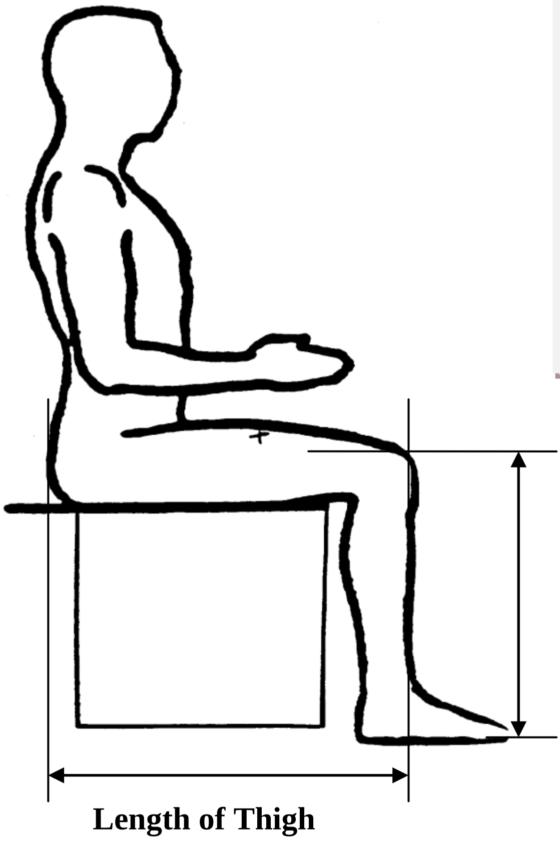

**Figure 3.69 Body Orientation for Standing Height Measurement**

(© Copyright 2010 RTI International)

### 3.7.3.3 Lower Extremities Length

1. Subject is asked sits straight on the chair or measuring box with the right knee bent at a 90 degree angle.
2. The plantar of the foot must put flat on the floor surface.
3. The flexible measuring tape is used to measure the length from the hip to the knee.
4. The length of the right thigh is recorded.
5. The flexible measuring tape is also used to measure the length from the knee to foot.

6. The length of the right shank is recorded.
7. Repeat all the step 1-6 with the left knee bent at a 90 degree angle.
8. The length of the left thigh and shank is recorded.



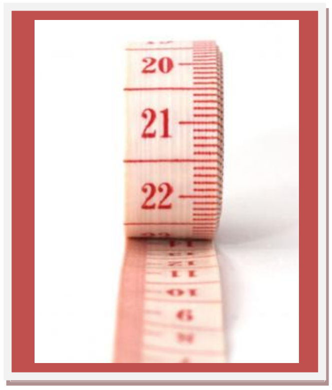




**Figure 3.70 Starting Position for Upper Leg Length Measurement**

(© Copyright 1998 Westat Inc.)

### 3.7.3.4 Anthropometric Measurements Form

All the anthropometric measurement of body, such as of overall height, weight and the length of lower extremities body parts are immediately record in the anthropometric measurement form and signed by the participants and person in charge. The anthropometric measurements form for this research project is shown in Appendix N.

### 3.7.4 Placement of Accelerometers

In addition to monitor reliability, protocol decisions made by researchers may affect the validity of the output. The output of an accelerometer depends on the position at which it is placed, its orientation, posture and activity being performed. Because of this, different acceleration signals are recorded depending on placement.

In this research project, a lightweight and portable box is attached at the backbone for the placement of lower extremities human movement analysis system circuit board, and five accelerometer units in total are attached to the lower extremities of the subject's body, such as attached on pelvis, hips and knees. Three accelerometer units are attached on the remote body parts by using sport protective cuff to ensure minimum movement of the senor relative to skin.


**Figure 3.71 Front View of Accelerometers Placement**

**Figure 3.72 Side View of Accelerometers Placement**


**Figure 3.73 Back View of Accelerometers Placement**

### 3.7.5 Walking Test Performed on Treadmill

In this research project, twenty voluntarily subjects who attached five accelerometer on their waist, hips and knees for both legs performed the same walking test research, which are slow walking (1 km/h), comfortable walking (3 km/h) and normal walking (5 km/h) for 1 minutes in order to measure the lower extremities motion during walking.

All series of walking test research are performed on Treadmill at Biomechanics facility lab. The two-dimensional signals in X and Y directions are transmitted to the computer wirelessly for data acquisition and data analysis. The research project setup is shown in Figure below.

**Figure 3.74 Research Project Setup**

A continuously walking on a Treadmill with no obstacles nearby was arranged. Subjects wore loose fitting clothing and wore their own sport shoes to ensure their comfort throughout experiments. The subjects are asked to remove the jewellery and other accessories such as handphone, key chain or coins, and put inside the box.

Before the walking test is being carried out, initial test will be conducted. This initial test is important to make sure the human movement analysis system can work properly in a good condition and make sure the accelerometers attached on the different body part accurately and tightly. Furthermore, it also make sure the all the embed system instrumented did not interrupt the human movement analysis of the subject.

The Treadmill is then started at a relatively slow “warm-up” speed. The Treadmill speed are increased slowly until becomes constant speed when reached the pre-programmed walking speed, either 1km/h for slow walking, 3 km/h for comfortable walking or 5 km/h for normal walking for 1 minute. The Treadmill walking test is performed twice to record definite data on the time-distance gait parameters and lower extremities acceleration.

### 3.7.6 Questionnaire

A questionnaire is a research instrument consisting of a series of questions and is used for the purpose of gathering information from respondents. Advantages over some other types of surveys in that they are cheap, do not require as much effort from the questioner as verbal or telephone surveys, and often have standardized answers that make it simple to compile data.

However, questionnaires are also sharply limited by the fact that respondents must be able to read the questions and respond to them. Thus, for some demographic groups conducting a survey by questionnaire may not be practical.

After voluntary subjects have performed a physical activity in this research, he / she are asked to complete a questionnaire form. This questionnaire form is included three sections, which are personal details, habitual physical activity and accelerometer.

The personal details section is included basic information about the voluntary subject, such as name, age, gender, course, contact number and email address. All the personal details information that we collect from this research project will be kept confidential.

Habitual physical activity section is the section would cover the physical activity that the subjects normally practised. From this information, we can further research and development the accelerometer-based motion system into another sport science area, not only constraints it application in the walking.

Accelerometer section, which is the section cover the feeling of the subject when the accelerometer attached on the pelvis, hips and knees. After obtained this information data, the improvement of accelerometer-based motion system can be done. Lastly, if the subjects have any suggestion or comment can list down at the specific space at the form.

The complete and clear sample of the health information form for this research project is show An Appendix O.

## 3.8 Summary - Overall Methodology Procedures

The overall methodology procedures included 4 important steps, which are:

Step 1: Informed Consent & Health Information

Step 2: Anthropometric Measurements

Step 3: Sensor Attachment and Treadmill Walking Test

Step 4: Questionnaire

The overall methodology procedures attached with the photo taken when the research is undergoing are show as following:


**Figure 3.75 Overall Methodology Procedures**

# CHAPTER 4

# RESULTS AND DISCUSSIONS

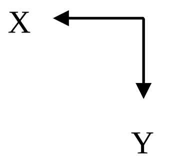
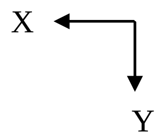
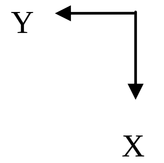
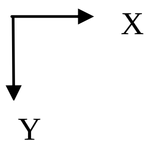
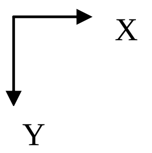
## 4.1 Sample Results and Discussions

In these lower extremities human movement analysis system research project, five tri-axial accelerometers, ADXL335 (Analog Devices, US) are attached on the waist, hips and knees for the lower extremities motion measurement while walking at three different pace, which are slow walking – 1 km/h, comfortable walking – 3 km/h and normal walking – 5 km/h.

Each of tri-axial accelerometer has the ability to detect dynamic changes of acceleration in all directions by using X (anterior-posterior), Y (vertical) and Z (medial-lateral) axes. However, only dual-axis, X in anterior-posterior and Y axes in vertical directions are used for this research project.

The plane detected for the X-axis and Y-axis in this research project are different due to the positioning of the accelerometers. Therefore, the positive and negative directions of the accelerometers have swapped planes. Both the detected direction of X-axis and Y-axis for each accelerometer has been shown in Table 4.1.

**Table 4.1 Direction of Accelerometers**

| Accelerometers | Locations | Directions | Descriptions |
|---|---|---|---|
| 1 | Waist |   | - X-axis is positive when towards left.<br>- Y axis is positive when downward. |
| 2 | Left Hip |   | - X-axis is positive when towards left.<br>- Y-axis is positive when downward. |
| 3 | Left Knee |   | - Y-axis is positive when towards left.<br>- X-axis is positive when downward. |
| 4 | Right Hip |   | - X-axis is positive when towards right.<br>- Y axis is positive when downward. |
| 5 | Right Knee |   | - X-axis is positive when towards right.<br>- Y-axis is positive when downward. |

Since there are five accelerometers with dual-axis, then there are total of ten output displays on LabVIEW front panel.

1. First row of the graph results show Accelerometer 1 which attached at waist.
2. Second row of graphs results show Accelerometer 2 and 3 which attached at left hip and knee.
3. Third row of graphs results show Accelerometer 4 and 5 which attached at right hip and knee.

The graph pattern for acceleration against time of left and right lower extremities is located in adjacent row as comparison can be made easily.

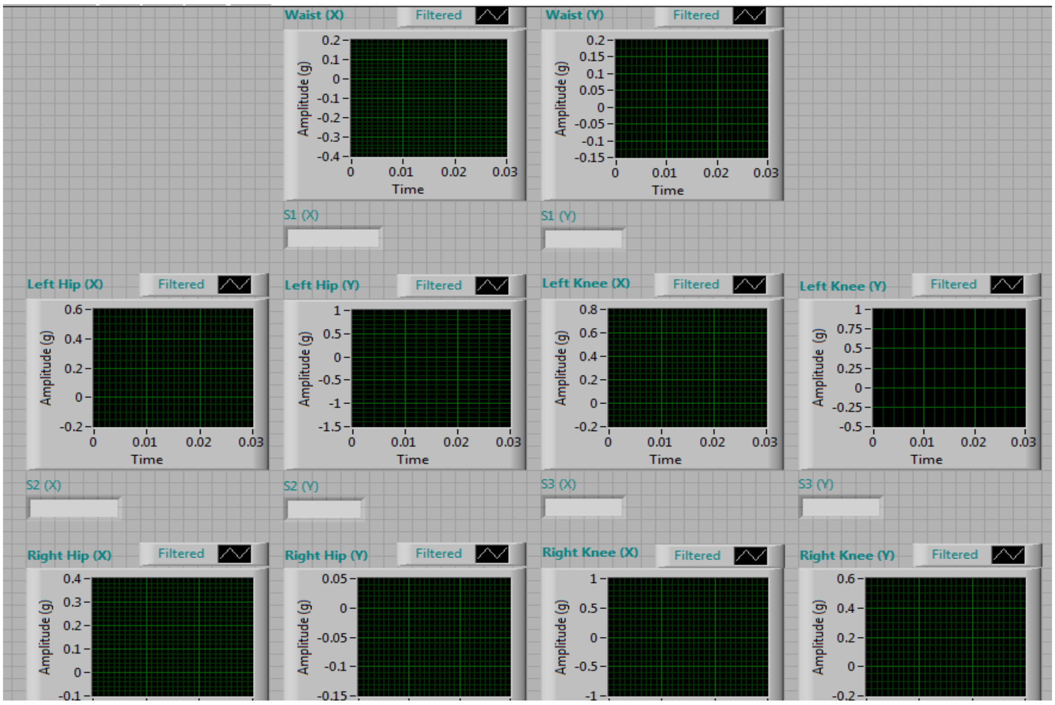



**Figure 4.1 Graph Position for Each Accelerometer in LabVIEW Front Panel**

The graph result for each accelerometer is plot by Amplitude (g) against Time. In this research project, Y-axis represents Amplitude which is the acceleration in unit gravity (g) that converted from the proportional voltage measured from accelerometer. Therefore, the higher the amplitude in the graph means the higher the acceleration of the respective lower extremities motion.

The X-axis represents Time. The scale for the Time unit in the LabVIEW graphical programming is smaller than the original time. The time scale has to multiple by factor of 1000 to get the original time. For example, the graph above shows 0.01 in scale which means 10 seconds in real time. In this research project, 0.06 time scale is taken from each walking test, which means 60s.

All the input result data will be showed in the column located under each graph. From these inputs values, the pattern of acceleration against time graph can be predicted. Furthermore, all the inputs data will store in the text file format for data analysis.

### 4.1.1 Slow Walking – 1 km/h

Slow walking is conducted under treadmill with speed 1 km/h. This is a walking speed which is suitable for the elderly adults or the patients with severe neurological gait impairments, such as stroke or spinal cord injury with little walking ability and patients which undergo lower extremities rehabilitation.

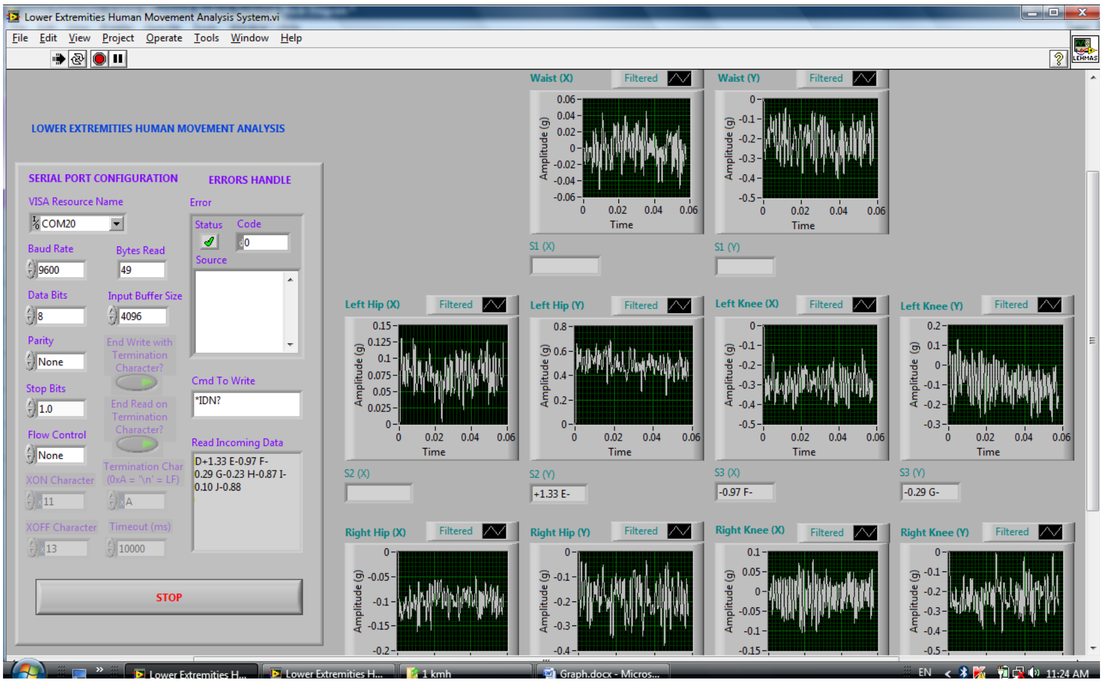



**Figure 4.2 LabVIEW Front Panel for Slow Walking**

The Figure 4.2 as above indicates the real-time graph shown in LabVIEW front panel when the slow walking is conducted for 60s. Observing the graph, the peak-to-peak of left and right lower extremities is slightly different. The average and standard deviation of different body parts acceleration for 20 voluntarily participants have been shown in Table 4.2 as below.

From the Table 4.2, the highest average and standard deviation of different body parts accelerations which are attached at the left hip (1.836642 ± 0.538641 g for female participants and 1.843593 ± 0.795765 g for male participants) and left knee (1.175637 ± 0.339898 g for female participants and 1.573474 ± 0.413872 g for male participants).

However, the average and standard deviation of different body parts acceleration which is attached at the waist (0.848910 ± 0.029266 g for female participants and 0.824876 ± 0.040325 g for male participants), right hip (0.854155 ± 0.031660 g for female participants and 0.860349 ± 0.044571 g for male participants) and right knee (0.845565 ± 0.050001 g for female participants and 0.848406 ± 0.040446 g for male participants) are quite similar.

**Table 4.2 Comparison of Acceleration between Female and Male for Slow Walking at Different Body Parts**

| | **Female** | | **Male** | |
|---|---|---|---|---|
| | **Average (g)** | **Standard Deviation (g)** | **Average (g)** | **Standard Deviation (g)** |
| **Waist** | 0.848910 | 0.029266 | 0.824876 | 0.040325 |
| **Left Hip** | 1.836642 | 0.538641 | 1.843593 | 0.795765 |
| **Right Hip** | 0.854155 | 0.031660 | 0.860349 | 0.044571 |
| **Left Knee** | 1.175637 | 0.339898 | 1.573474 | 0.413872 |
| **Right Knee** | 0.845565 | 0.050001 | 0.848406 | 0.040446 |

### 4.1.2 Comfortable Walking – 3 km/h

Comfortable walking is conducted under treadmill with speed 3 km/h. This is a walking speed which is suitable for the person who intends to get fresh air and to relax, or the person who is thinking something while walking around.

The Figure 4.3 as above indicates the real-time graph shown in LabVIEW front panel when the comfortable walking is conducted for 60s. Observing the graph below, the overall acceleration for waist, hips and knees is slightly higher compared to the slow walking. Furthermore, the pattern of the acceleration is more smoothly, and distributed evenly and constantly, quite different with the slow walking.

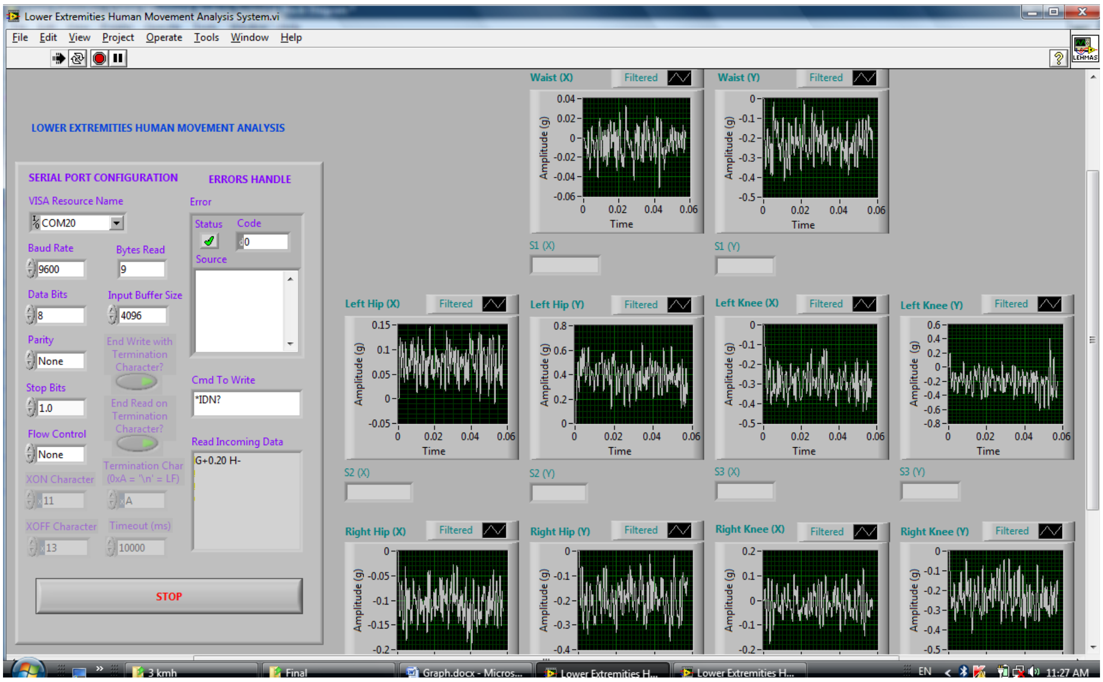



**Figure 4.3 LabVIEW Front Panel for Comfortable Walking**

**Table 4.3 Comparison of Acceleration between Female and Male for Comfortable Walking at Different Remote Body Parts**

| | Female | | Male | |
|---|---|---|---|---|
| | **Average (g)** | **Standard Deviation (g)** | **Average (g)** | **Standard Deviation (g)** |
| **Waist** | 0.846319 | 0.034805 | 0.844579 | 0.044400 |
| **Left Hip** | 1.684790 | 0.716056 | 1.787159 | 0.766727 |
| **Right Hip** | 0.887210 | 0.115523 | 0.906927 | 0.093014 |
| **Left Knee** | 1.264441 | 0.273638 | 1.549103 | 0.390302 |
| **Right Knee** | 0.887210 | 0.059917 | 0.906927 | 0.059731 |

The average and standard deviation of different body parts acceleration for 20 voluntarily participants have been shown in Table 4.3 as above. The table indicates highest average and standard deviation of different body parts accelerations which are attached at the left hip (1.684790 ± 0.716056 g for female participants and 1.8787159 ± 0.766727 g for male participants) and left knee (1.264441 ± 0.273638 g for female participants and 1.549103 ± 0.390302 g for male participants).

However, the average and standard deviation of different body parts acceleration which is attached at the waist (0.846319 ± 0.034805 g for female participants and 0.844579 ± 0.04440 g for male participants), right hip (0.887210 ± 0.115523 g for female participants and 0.906927 ± 0.093014 g for male participants) and right knee (0.887210 ± 0.059917 g for female participants and 0.906927 ± 0.059731 g for male participants) still quite similar.

### 4.1.3 Normal Walking – 5 km/h

Although walking speeds can vary greatly depending on factors such as height, weight and age, the average human walking speed is about 5 km/h (Richard, 1997). Specific studies have found pedestrian walking speeds ranging from 4.51 km/h to 4.75 km/h for older individuals and 5.23 km/h to 5.43 km/h for younger individuals Therefore, 5km/h is selected and conducted on treadmill for normal walking.

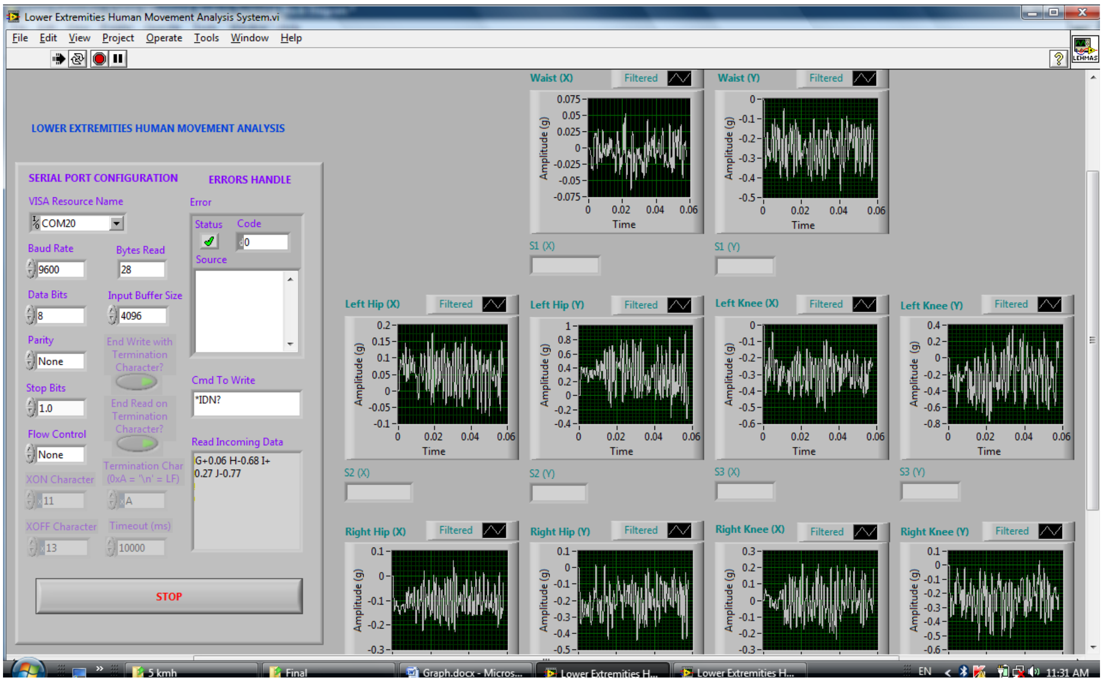


Figure 4.4 LabVIEW Front Panel for Normal Walking

The Figure 4.4 as above indicates the real-time graph shown in LabVIEW front panel when the fast walking is conducted for 60s. Observing the graph above, the peak-to-peak of the acceleration at waist, hips and knees is slightly increased compare to the slow walking or comfortable walking. Besides that, the pattern of the acceleration is smoothly and distributed evenly, quite similar to comfortable walking.

**Table 4.4 Comparison of Acceleration between Female and Male for Comfortable Walking at Different Remote Body Parts**

| | **Female** | | **Male** | |
|---|---|---|---|---|
| | **Average (g)** | **Standard Deviation (g)** | **Average (g)** | **Standard Deviation (g)** |
| **Waist** | 0.873958 | 0.048002 | 0.837516 | 0.041191 |
| **Left Hip** | 1.920104 | 1.400853 | 2.254045 | 1.904780 |
| **Right Hip** | 0.863359 | 0.044140 | 0.863042 | 0.032522 |
| **Left Knee** | 1.788130 | 1.235600 | 2.015694 | 1.845956 |
| **Right Knee** | 0.888318 | 0.048721 | 0.898044 | 0.052616 |

The average and standard deviation of different body parts acceleration for 20 voluntarily participants have been shown in Table 4.4 as below. From that, the highest average and standard deviation of different body parts accelerations which are attached at the left hip (1.920104 ± 1.400853 g for female participants and 2.254045 ± 1.904780 g for male participants) and left knee (1.788130 ± 1.235600 g for female participants and 2.015694 ± 1.845956 g for male participants) is indicated. The deviation of left extremities is higher compare to the slow walking and comfortable walking.

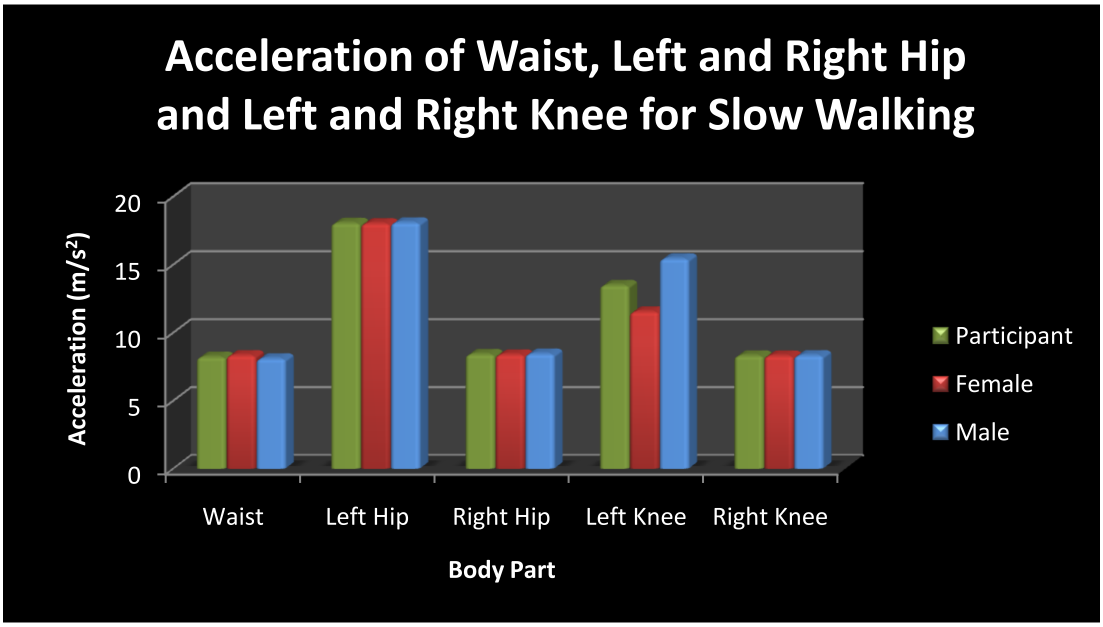
The average and standard deviation of different body parts acceleration which is attached at the waist (0.873958 ± 0.048002 g for female participants and 0.837516 ± 0.041191 g for male participants), right hip (0.863359 ± 0.044140 g for female participants and 0.863042 ± 0.032522 g for male participants) and right knee (0.888318 ± 0.048721 g for female participants and 0.898044 ± 0.052616 g for male participants) still remains similar.

### 4.1.4 Observation of Sample Result and Discussion

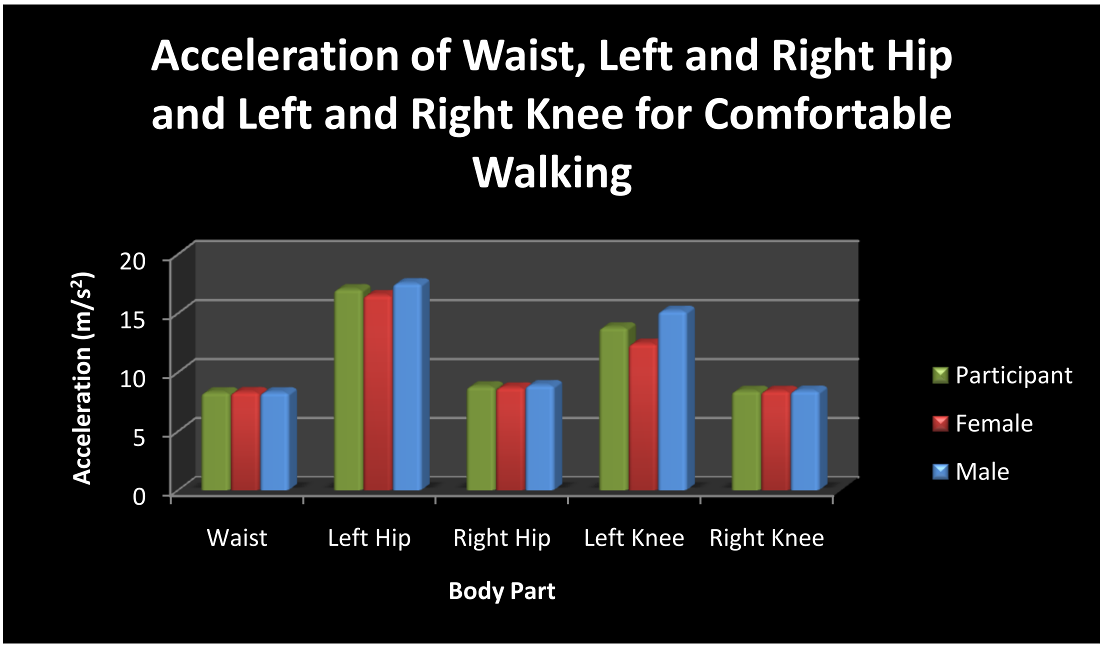
In this section, the observation of result data analysis for three different walking paces is discussed more in detail, such as the average acceleration for different remote body parts (waist, hips and knees) between female and male, and abnormal undershoot and overshoot of the acceleration in the specific time interval. The entire complete and clearer data analysis graph for slow walking, comfortable walking and fast walking are attached from Appendix P to Appendix R.

#### 4.1.4.1 Average Acceleration for Different Remote Body Parts between Female and Male

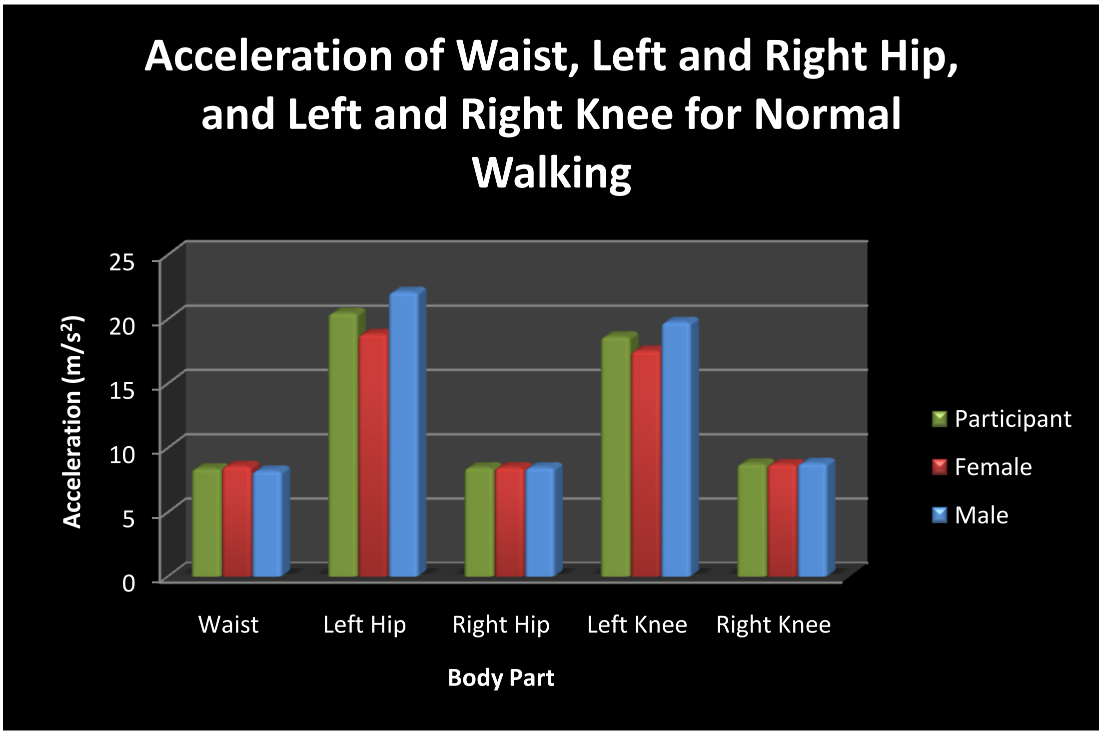
The Graph 4.1, Graph 4.2 and Graph 4.3 as shown in below indicate the difference average acceleration between female and male at waist, hips and knees are small for slow, comfortable and normal walking.




**Graph 4.1 Average Acceleration for Slow Walking (1 km/h)**




**Graph 4.2 Average Acceleration for Comfortable Walking (3 km/h)**



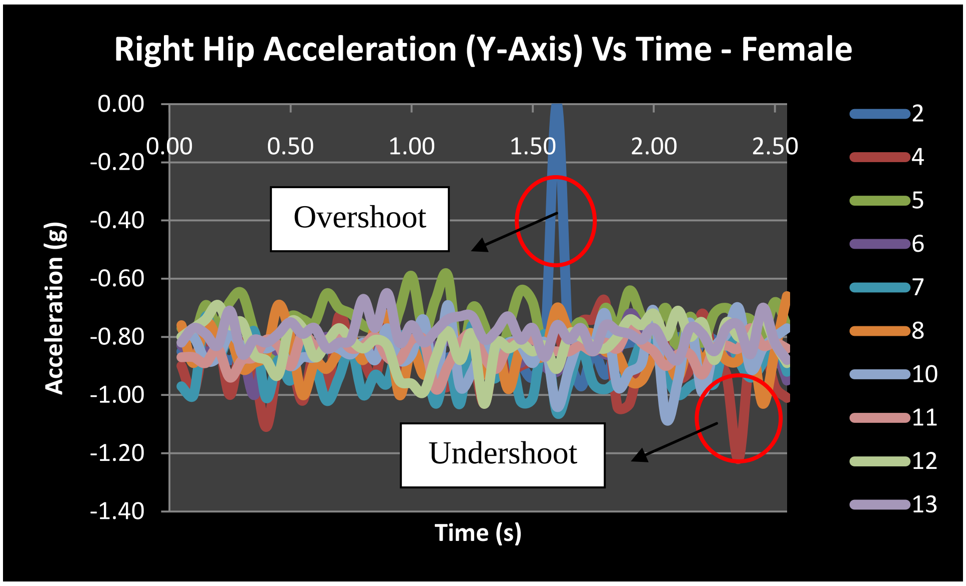

**Graph 4.3 Average Acceleration for Normal Walking (5 km/h)**

Graphs as above showed that the average acceleration at the waist for female is slightly higher than male for slow, comfortable and normal walking. The accelerometer which is attached at the waist is slight affected by the spontaneous exhale and inhale respiratory rate of the participants.

Since the questionnaire data analysis indicates 60% female participants do not have regular exercises even walking nor running, hence female may be experience muscle fatigue and respiratory rate for the female is higher than normal when three different walking tests are undergo continuously. For male participants, 90% of them have exercised regularly, either power lifting, jogging or ball sports. Therefore walking test is not a major problem for male participants.

#### 4.1.4.2 Abnormal Undershoot and Overshoot of Acceleration Data Analysis

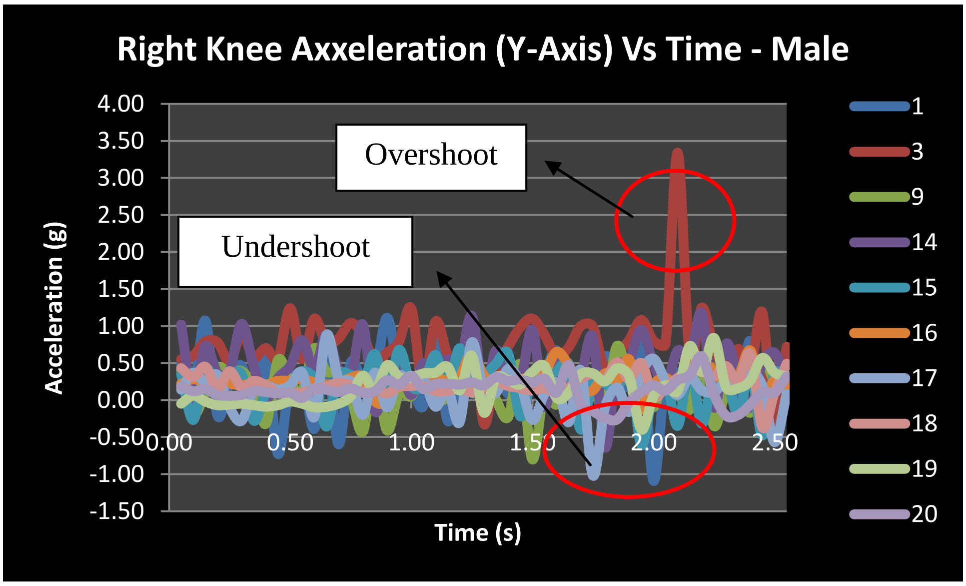
There are some abnormal undershoot and overshoot waveform in the acceleration versus against time data analysis data. These abnormal are occurred in the slow and comfortable walking, especially at hips and knees.




**Graph 4.4 Overshoot and Undershoot Waveform for Slow Walking**

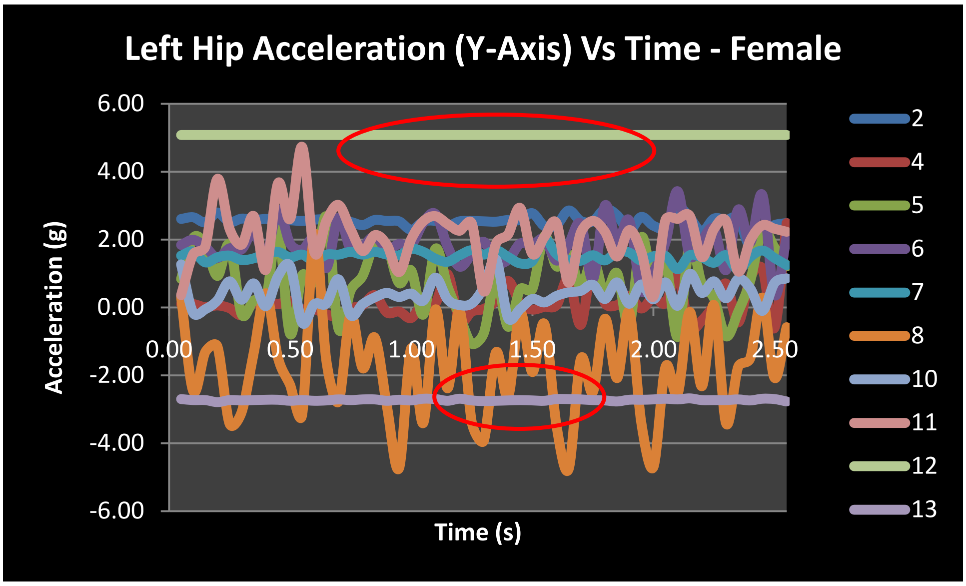
All of the voluntarily participants is between age of 22 to 25, considered as adolescent. Participants are not being accustomed to the slow walking which is normally suitable for the older adult. Therefore, the overshoot and undershoot are ease occurred for the slow walking as participants are frequently try to adjust their walking pace with acceleration or deceleration on the treadmill to avoid their walking steps are over fast or slow. This is also a reason which makes the waveform of slow walking not so natural and smooth.

When slow walking is conducted on treadmill, most of the participants are keep looking downward or keep looking the treadmill conveyer to prevent walking too fast or too slow. When participants walking pace are too fast, immediately deceleration of the lower extremities is undergo to readjust the walking pace which similar with controlled speed and therefore regain the balance and bear the full weight again. When participants walking pace are too slow than controlled speed, immediately acceleration of the lower extremities is undergo to readjust the walking pace and therefore regain the balance and bear the full weight again.




**Graph 4.5 Overshoot and Undershoot Waveform for Comfortable Walking**

For the comfortable walking, participants are walking more natural than slow walking. The waveform of the walking is smoother than slow walking. However, overshoot and undershoot still occurred due to suddenly acceleration and declaration of the lower extremities to regain the suitable walking paces and regain the balance and bear the full weight again.




**Graph 4.6 Linear Waveform for Normal Walking**

Normal walking is the suitable walking speed for the adolescent. More nature and normal walking gait can be collected. Overshoot and undershoot waveform still occurred but not so frequently as slow and comfortable walking. However, a linear or constant waveform is occurred in fast walking. The reason may be due to the constant speed of treadmill is higher, therefore response time for movement of the lower extremities have to regain the balance and bear of full weight in a short time.

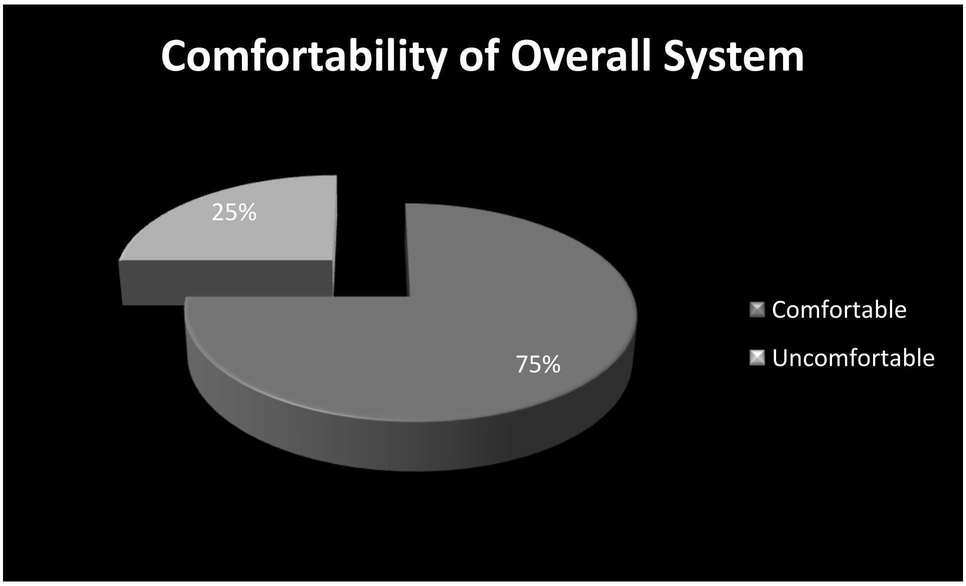
Unfortunately, there is certain time delay for data transmission from accelerometer to microcontroller for further signal processing and transmit wireless to laptop for data analysis. After certain delay, many data sets are sent to LabVIEW for data file storage cannot be done at the short time. Therefore, a linear waveform are shown in Figure 4.6 occurred due to data delay or data lost.

### 4.2 Questionnaire Results and Discussions

After voluntary subjects have performed a physical activity in this research, he / she are asked to complete a questionnaire form. From this information, improvement to the accelerometer-based motion system which suitable for all gender can be made. Besides that, further research and development of the accelerometer-based motion system into another sport science area can be done, not only constraints it application in the walking. Questionnaire is analysed and discussed more in details in following sub-section, which included comfortability and weight of overall system.

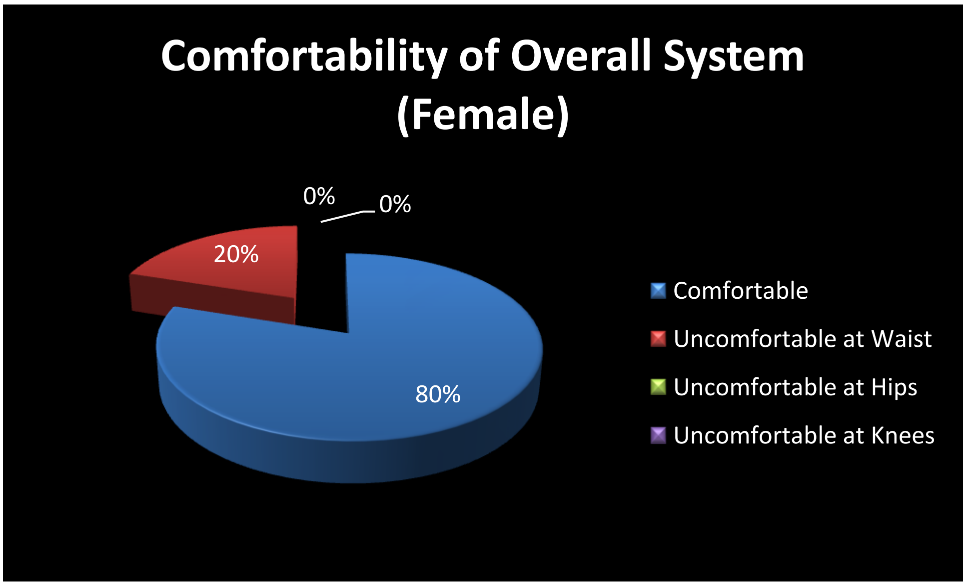
#### 4.2.1 Overall System Comfortability

The data analysis examines comfortability of the design system by indicate which remote body parts of participants will feel uncomfortable when the walking test is conducted.  From this information, further research, development and improvement to the accelerometer-based motion system which suitable for all different gender can be made.




**Graph 4.7 Comfortability of Overall System for All Participants**

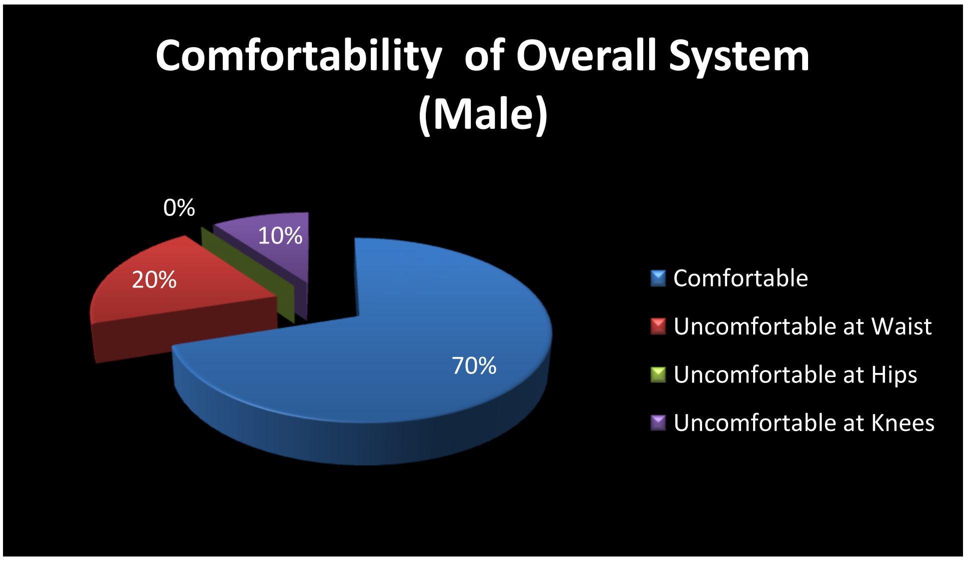
From Graph 4.7 above, data analysis is indicated 75% participants (8 female and 7 male participants) considered the overall system is comfortable, and 25% participants (2 female and 3 male participants) considered that the overall system is uncomfortable when the accelerometer is attached prolonged period on the remote body parts.




**Graph 4.8 Comfortability of Overall System for Female Participants**

From Graph 4.8 above, 80% female participants (8 female participants) considered comfortable when the accelerometer is attached prolonged period on the remote body parts, such as waist, hips and knees for walking test. At the same time, 20% female participants (2 female participants) considered uncomfortable especially the accelerometer attached at waist for prolonged period while walking test is conducted.

From Graph 4.9 below, 70% male participants (7 male participants) considered comfortable when the accelerometer is attached prolonged period on the remote body parts, such as waist, hips and knees for walking test. At the same time, 30% male participants considered uncomfortable when the accelerometer attached for prolonged period, which 20% participants feels uncomfortable at waist and 10% participants feels uncomfortable at knees remote body parts while walking test is conducted.

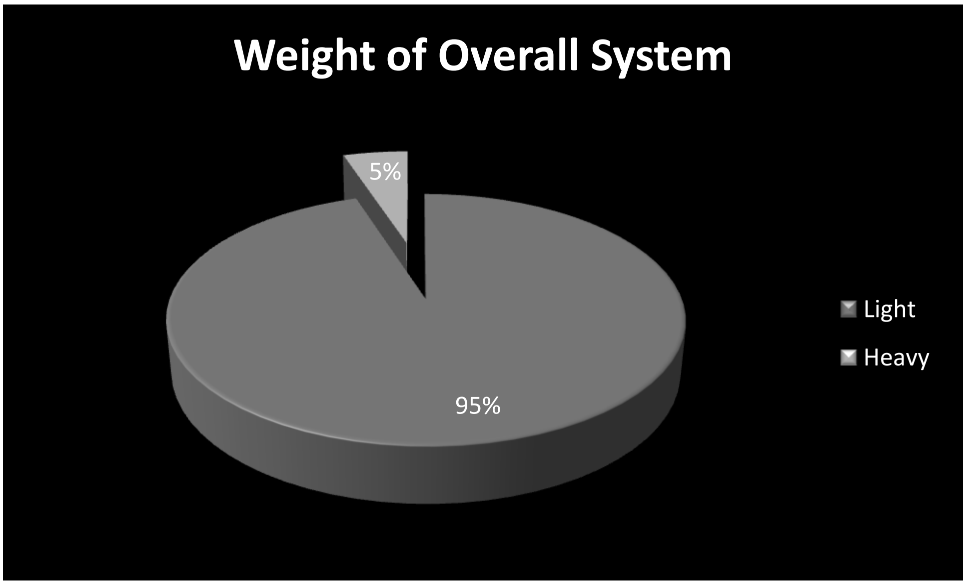



**Graph 4.9 Comfortability of Overall System for Male Participants**

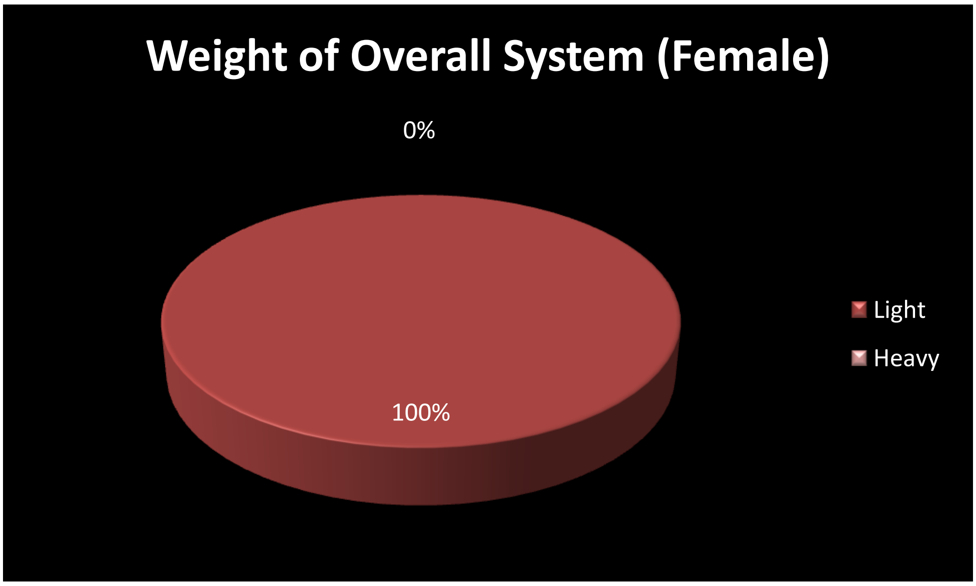
The main reason for the uncomfortable at the different remote body parts, especially waist is due to the sport protective cuff which the accelerometers is attached on are over tighten. A better case is required to ensure the comfortable of participants before the walking test is conducted. As result, the overall system is considered comfortable for all gender participants.

### 4.2.2 Overall System Weight

The data analysis examines overall system weight to ensure further research, development and improvement to the accelerometer-based motion system can be made to minimize or simplify the PIC microcontroller circuit. The accelerometers together with PIC microcontroller are being accountable as lightweight for all participants, which consists of 95% participants. (10 female and 9 male participants) as shown in Graph 4.10 below.

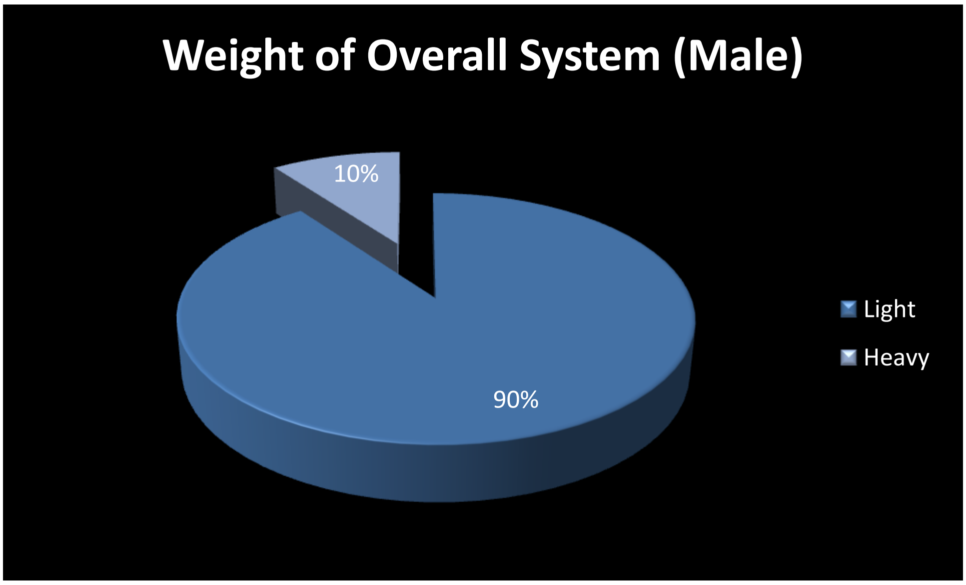



**Graph 4.10 Weight of Overall System for All Participants**




**Graph 4.11 Weight of Overall System for Female Participants**

From Graph 4.11 above, data analysis is indicated the accelerometers together with PIC microcontroller are being accountable as lightweight for all female participants (10 female participants). From Graph 4.12 below, data analysis is indicated the accelerometers together with PIC microcontroller are being accountable as lightweight for 90% male participants (9 male participants) and being accountable as a bit heavy for 10% male participants (1 male participants).




**Graph 4.12 Weight of Overall System for Male Participants**

### 4.2.3 Summary of Questionnaire Results and Discussions

The overall performance for the lower extremities human movement analysis overall system is accountable good, as it considered lightweight (95% participants) and comfortable (75% participants) for all participants. However, further research, development and improvement can be done to either minimize or simplify the PIC microcontroller circuit or new techniques for the attachment of accelerometers can be discovery to reduce the uncomfortable level of the participants with higher accuracy of data results.

# CHAPTER 5

# DIFFICULTIES, PROBLEMS AND RECOMMENDATIONS

## 5.1 Difficulties and Problems

Everything that happens in life plays an important role in shaping the future and present. Difficulties and problems are not forced but natural. Life is a continuous process, a journey. Things that seem to be difficulties or problems in life are actually milestones of the life, everyone should have to cross them one after the other.

As an example, there are a lot of difficulties and problems have encountered along the whole process of developing the human movement analysis system. The main reasons for problems raised are due to the lack of the experience in the circuit system design and lack of the basic knowledge in the software programming.

However, trial and error has to be carried out from time to time to gain more understanding on how the system works without despair or dismay. As a result, all the difficulties and problems encountered in this research project have been over came by stamina and strength. In this section, all the difficulties and problems encountered have been categorized into three sections, which are hardware design, software programming and analysis and sample collection. All of the difficulties and problems will discussed with full of explanations.

### 5.1.1 Hardware Design

All the difficulties and problems encountered in the hardware design will be discussed in this section, which included imperfect design of accelerometer, Bluetooth drains power, attachment and numerous cables of accelerometer and Accelerometer soldering.

#### 5.1.1.1 Imperfect Design of Accelerometer

The ADXL335 is an accelerometer which is high in sensitivity. The purpose of the measurement does influence sensor location, thus affected the accuracy of the accelerometer. Noises and small deviation would encountered by the accelerometer which would affect the outcome of the result data.

Attachment and location of accelerometer are a critical factor since the movement of loosely attached sensors creates spurious oscillations after an abrupt movement that can generate false events. The skin and soft tissues artefacts (STA) also have to consider in the sensor attachment. This is due to the skin and soft-tissue artefacts will significantly affects the collected data results.

Furthermore, accelerometer generated heat when it is powered up along the sample collections. Sample collections of the human movement analysis have to be conducted to make sure all the hardware and software of human movement analysis system is in order. The faster the heat generation of the accelerometer when the accelerometer has attached to the remote part of the body. This is due to accelerometer is affected by subject's core body temperature and self-generating heat while walking task is conducted.

The heat generation does increased temperature of accelerometer thus influenced the performance of accelerometer. Thus, performance of the accelerometer is decreased when the temperature is slightly increased as accelerometer is a temperature dependent device and high in sensitivity. Consequently, there have a small deviation in the outcome of result data and data become inaccurate at all.

#### 5.1.1.2 Bluetooth Drains Power

Although the Bluetooth module is low energy and power consumption compared to the other wireless data transmission module, such as ZigBee and Infrared module. However, it is still considered as high energy and power consumption data transmission device as power consumption of Bluetooth module for data transmission at 9600 kbps baud rate using UART at max throughput is required around 98 mA.

When the sample collections section is being conducted, the Bluetooth module which is supplied by 9V battery and regulated by L7805CV 5.0V voltage regulator only can withstands for 2 hours. That means around 4 set of sample collections can be conducted before battery exchange or battery recharge.

Besides that, the data transmission performance of Bluetooth module does affected when the battery gets weak and drains out. Thus, does influence the accurate of the result data. The main reason is Bluetooth module will not able to transmit the data properly as the Bluetooth module will keep start sending looping results which signifies the power is low.

#### 5.1.1.3 Attachment and Numerous Cables of Accelerometer

In human movement analysis system, a numerous accelerometers have applied to subject’s remote body part for motion detection. The attachment of the accelerometers on the body part is an important criterion. A secure and firmly attachment of accelerometers on the remote body part are needed to avoid the noise-vibration problems. However, there are still have numerous cables running across the joints and along the body.

In this research project, accelerometers are attached on the sport protective pad by double sided-tapes because the size of sport protective pad can be adjusted according to the subject’s circumference size at waist, hips, knees and ankles. However, attachments of the accelerometers are not secure by double-sided tapes. The accelerometers would slightly change in position if the subject’s movement is in heavily walking. Therefore, noise-vibration problems have occurred.

Furthermore, the anthropometric measurements, which include height, weight and lower extremities length, will be different for every subject. However, the length of the wires from the microcontroller to accelerometer is in 2m standards. That is suitable for a subject in 180m height. That is not suitable for the short subject. The resistance increased proportional to length of wire and the excess wire will influenced or affected the movement of the subject.

#### 5.1.1.4 Accelerometer Soldering

Soldering is accomplished by quickly heating the metal parts to be joined, and then applying a flux and a solder to the mating surfaces. The finished solder joint metallurgically bonds the parts - forming an excellent electrical connection between wires and a strong mechanical joint between the metal parts. Heat is supplied with a soldering iron.

The most common soldering problems encountered in this research project is the adjacent electronic cables being joined together which would cause short circuit or system failure, if not properly cleaned off the joint. Besides that, failure to properly heat and fill a joint has occurred, which an area inside a soldered joint where solder is unable to completely fill the fittings' cup, because flux has become sealed inside the joint, preventing solder from occupying that space.

Furthermore, bad looking soldered joint or unreliable cracked joint which caused weak mechanically and poor conductor electrically also encountered. As a soldering beginner, it is hard to solder a joint in a concave fillet outlook which is good wetting and minimal use of solder. Therefore, some of the electronic cables soldering is unsmooth, dull and grainy appearance instead of being smooth, bright and shiny. As result, have to spend some time in desoldering and resoldering.

### 5.1.2 Software Design

All the difficulties and problems encountered in the software design will be discussed in this section, which included PIC source code programming, LabVIEW programming and interactions and delay in data display.

#### 5.1.2.1 PIC Source Code Programming

For the PIC source code programming, many problems have encountered. The first problem is the lack of experience in programming the source code for external analog-to-digital converter (ADC), ADC0809CCN, especially when use with the 555-timer to control the clock. Therefore, PIC16F877A have been replaced by PIC18F4550. With that, no additional ADC and 555-timer is required in the circuit connection.

#### 5.1.2.2 LabVIEW Graphical Programming and Interactions

In the LabVIEW graphical programming and interactions, a main problem has encountered is each accelerometer's axis output have to saved to an individual text file for data storage. In this research project, there are five accelerometers with ten accelerometer's axis outputs, then ten individual text files is required for one subject testing. If the number of the accelerometer is increased, there will be an increased in text file created.

#### 5.1.2.3 Delay in Data Display

One of the things discovered during the testing and trial of the LabVIEW graphical programming is delay in data display. The graphs and values of accelerometers only displays after a few seconds delay. This is may be due to the time delay caused by the wireless data transmission by the Bluetooth module to LabVIEW for data processing. The accumulation of a few milliseconds of delay for each result eventually will stack up to a few seconds of delay after a long run of the sample collection.

## 5.2 Recommendation

Recommendation for this research project included noise reduction, increase number of tri-axial accelerometers, combinations of accelerometer with gyroscopes and magnetometer, full body movement analysis and wireless limb attachment sensors.

### 5.2.1 Noise Reduction

To solve the noise-vibration problem which affected by the imperfections of accelerometer and the loose of the accelerometer attachment, a resistor-capacitor (RF) filter can be placed before the analog input from accelerometer transmitted to the microcontroller. The resistor will be connected in series with the input and the capacitor will be connected to the ground as shown as Figure 5.1.

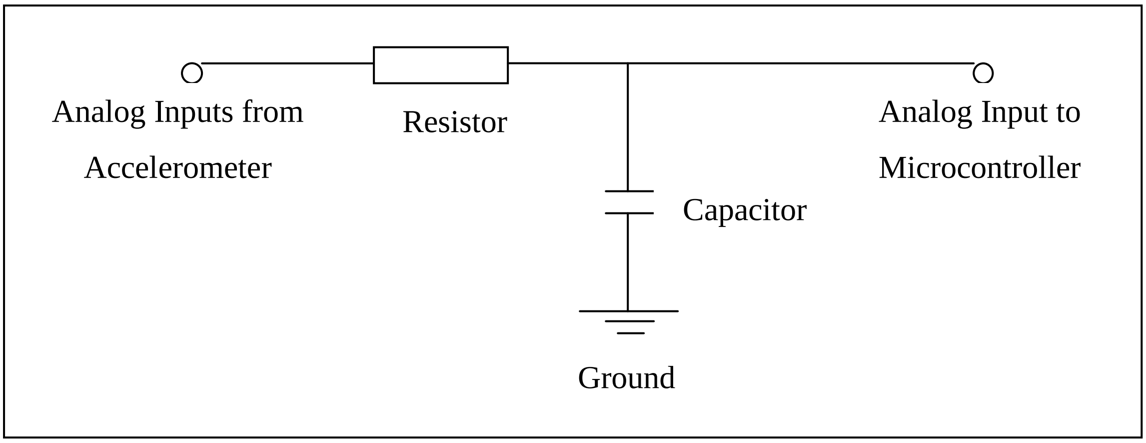



**Figure 5.1 Resistor-Capacitor (RF) Filter Connection**

### 5.2.2 Increase Number of Tri-axial Accelerometers

Increasing the number of tri-axial accelerometers is a good way in improving the accuracy of the human movement analysis system. The lower extremities human movement analysis can be improved by attaching seven tri-axial accelerometers on the human remote part, such as waist, hips, knees, and ankles.

For the hardware part, there are slightly different with the project with 5 accelerometers. This is due to seven tri-axial accelerometers have 21 analog output need to be converter before connect to the microcontroller for further processing. Therefore, additional external analog-to-digital converter, ADC0809CCN is required.

The wire and wireless circuit diagram connection of seven tri-axial accelerometers with the external analog-to-digital converter (ADC) have been shown in the appendix S and Appendix T at the back of the thesis report.

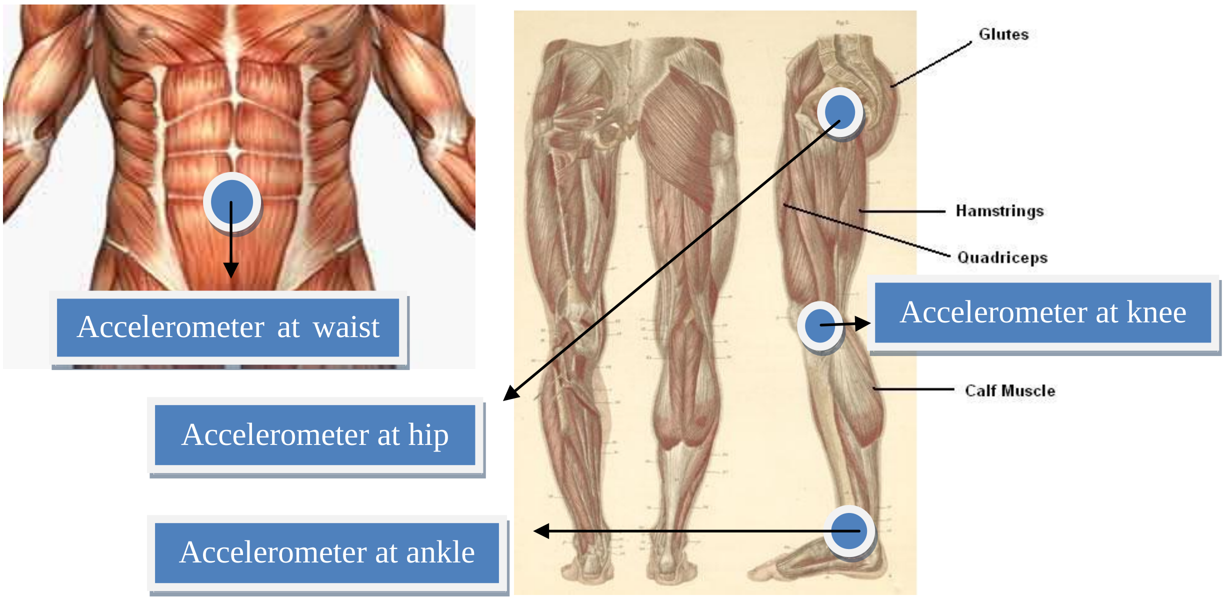



**Figure 5.2 Location of Tri-axial Accelerometers**

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### 5.2.3 Combination Accelerometer with Gyroscopes and Magnetometer

The precision and reliability of the tri-axial accelerometers was demonstrated to be good enough for detecting posture changes in physical activity. With further investigations and modifications of tri-axial accelerometers-based sensing systems, for instance, in combination with gyroscope and magnetometer, it might give more reliable information in tracking dynamic postural changes in daily activities. (Wong, W.Y. & Wong, M.S., 2008)

The reason is tri-axial accelerometer and rate gyroscopes can use to measure the linear acceleration and angular rate in three-dimensional. Measurement of the earth magnetic field vector by a magnetometer provides besides the earth gravity field a reference measure for body orientation.

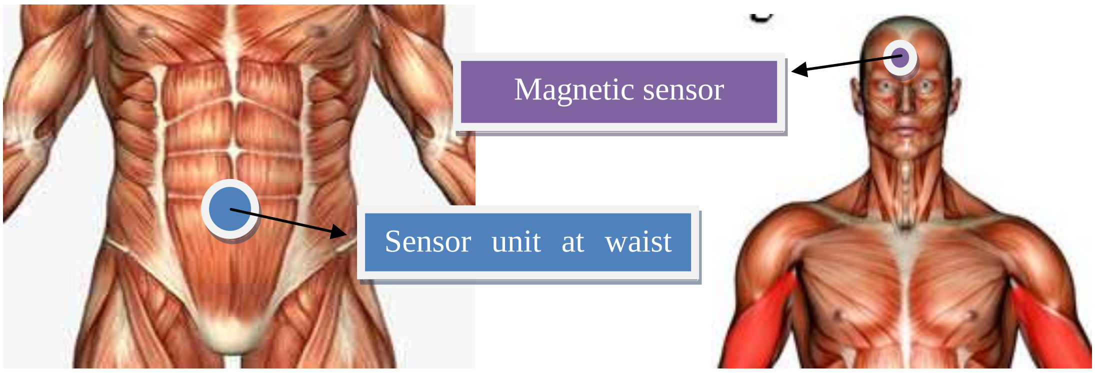



**Figure 5.3 Location of Sensors at Upper Part of the Body**

(© Copyright 2009-10 Boddunan)

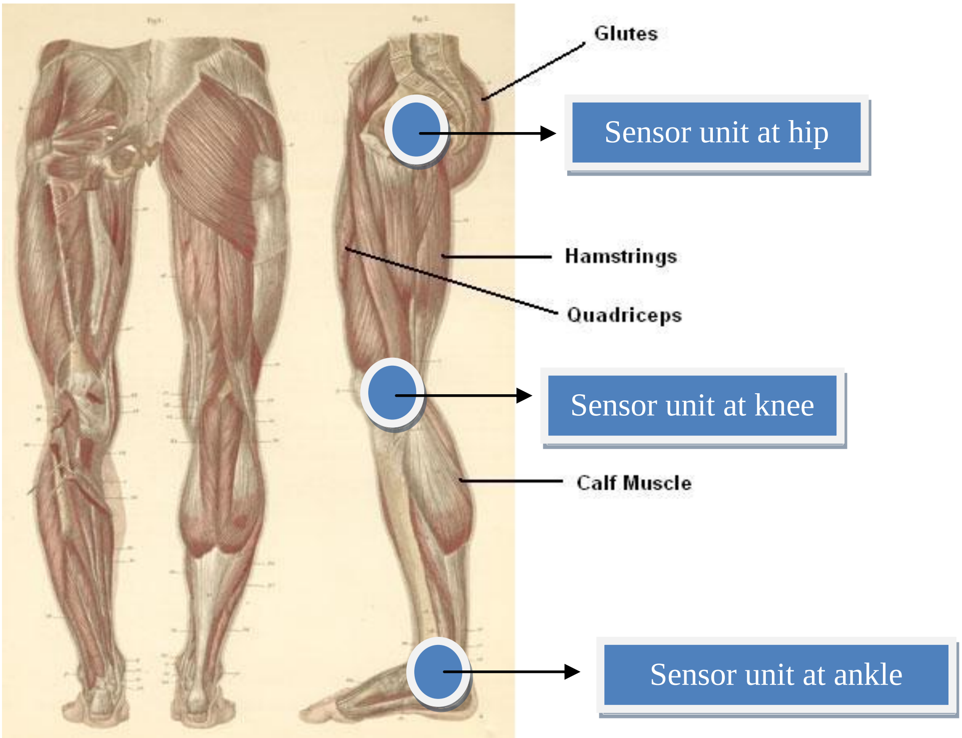



**Figure 5.4 Location of Sensor Units with Tri-axial Accelerometers and Rate Gyroscopes** (© Copyright 1995 Anatomy Atlases)

For the lower extremities movement analysis as shown as figure above, six accelerometer and gyroscopes sensor units were attached on the hips, knees and ankles for both legs. The magnetometer attached on the forehead and additional sensor unit is attached at the pelvis with a neoprene belt. The others sensors were attached using hypoallergenic double-sided tape to ensure minimum movement of the senor relative to skin.

### 5.2.4 Full Body Human Movement Analysis

This research project entitled "Development of Lower Extremities Movement Analysis by Accelerometers". As known, the purpose of this research project only focus on the lower extremities of human movement analysis such as hips, knees, and ankles, the other remote body parts of human movement analysis is excluded.

This research project can be focused on full body movement analysis, which included the head, neck, upper extremities and lower extremities. The multiple accelerometer arrangements on the full body enable the researcher to define more daily activities and more accurate human movement analysis data can be collected.

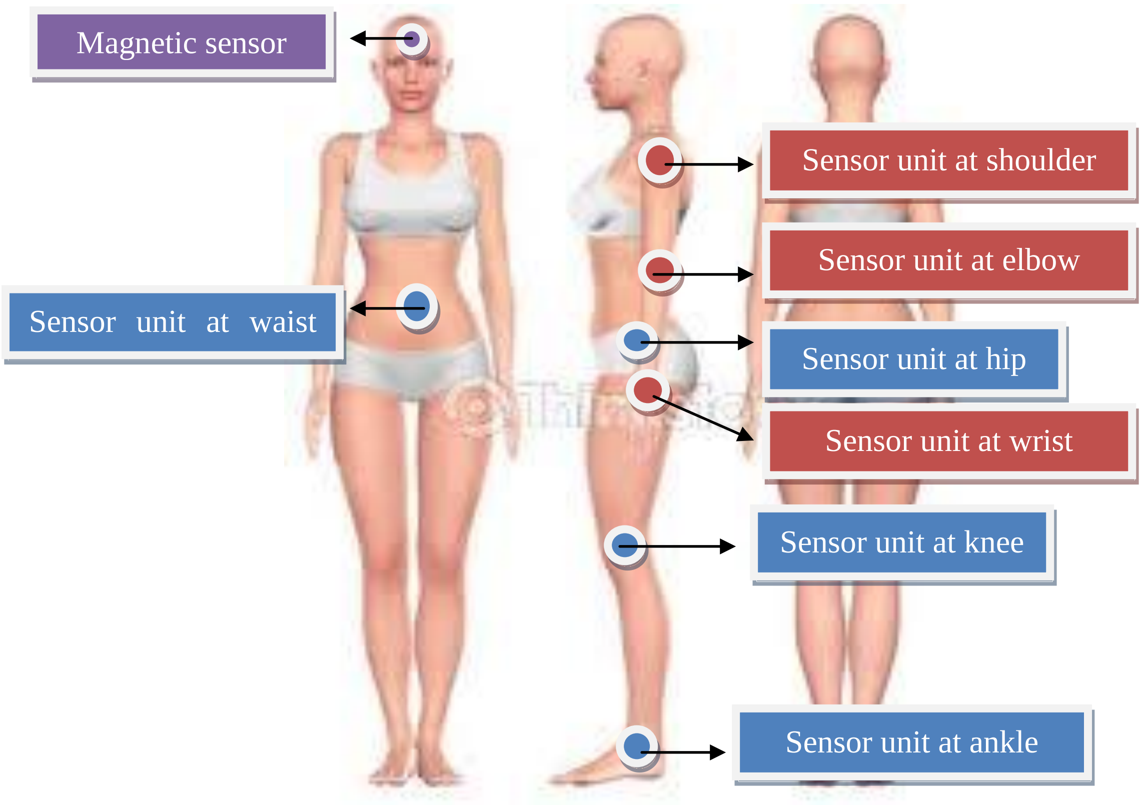



**Figure 5.5 Location of Sensor Units for Full Body Human Movement Analysis**

(© Copyright 2011 Thinkstock)

However, the other challenge for the full body human movement analysis is these sensor arrangements are impractical for long-term monitoring and commercial use as it involves numerous cables running across the joints and along the body. Unless, incorporation of wireless limb attachment sensors would make this multiple arrangement possible. (Simcox, S., 2004)

### 5.2.5 Wireless Limb Attachment Sensors

Multiple accelerometer arrangements enable the researcher to define more daily activities. However, these sensor arrangements are impractical for long-term monitoring and commercial use as it involves numerous cables running across the joints and along the body. Incorporation of wireless limb attachments sensors would make this multiple arrangement possible.

# CHAPTER 6

# CURRENT COMMERCIAL TECHNOLOGIES & FUTURE RESEARCH AND DEVELOPMENT

## 6.1 Current Commercial Technologies

There are many commercially available physical activity monitors on the market for academic research and individual health care monitoring that incorporate accelerometers. The following is a summary of some of the commercially available monitors that are attached to variety lower extremities body parts for various applications.

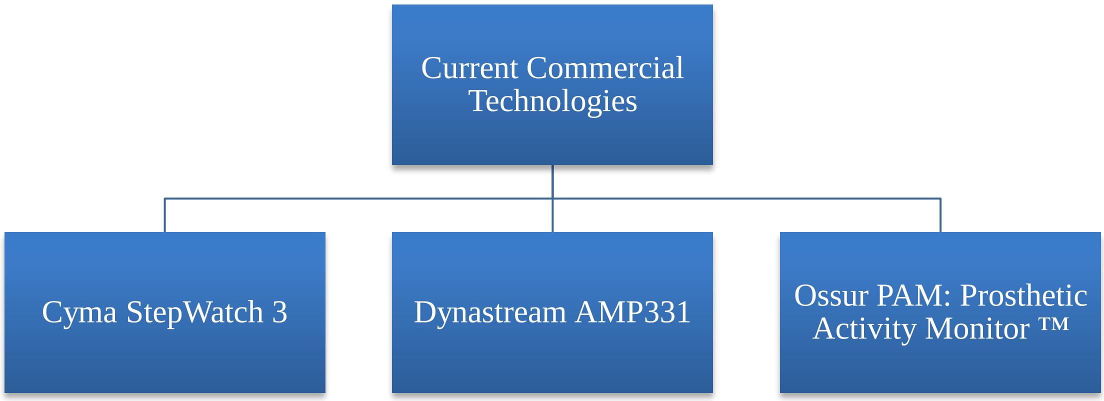



**Figure 6.1 Current Commercial Technologies on the Market**

### 6.1.1 Cyma StepWatch 3

The StepWatch3 was previously known as the step Activity Monitor, SAM. The device is programmed through a PC, which has the capability of adjusting the sensitivity of the StepWatch by adjusting its characteristic to suit that of its user. The standard mode permits users to program the StepWatch3 by entering the subject's height and answering simple question that describe the subject's gait for more accurate recordings. (Godfrey, A., Conway, R., Meagher, D. & Olaighin, G., 2008)

The StepWatch is a microprocessor controlled step counter that has the capability of recording the number of steps performed by its wearer for up to 2 months. The StepWatch is also a validated activity monitor for use on the health, obese, amputees, stroke, spinal injury, and the young old. The Step Watch has also been validated against a number of devices on nursing home residents with dementia. (Godfrey, A., Conway, R., Meagher, D. & Olaighin, G., 2008)


**Figure 6.2 StepWatch3 Worn at the Ankle**

(© Copyright 2010 The Board of Regents of the University of Oklahoma)

The features of StepWatch3 are as following:

1. Unobtrusive and well-tolerated.
2. Durable, maintenance-free
3. Waterproof
4. Battery lasts for 7 years of continuous use
5. 98% regardless of gait style

### 6.1.2 Dynastream AMP331

The AMP311 from Dynastream6 is an ankle mounted activity monitor. The AMP331 pod houses two accelerometers (one uni-axial and one bi-axial). Data analysis is based on Dynastreams patented ‘SpeedMax’ technology which was customised for the recreational running market. Its multi-dimensional motion tracking ability gives a continuous method of measuring distance and velocity travelled for both runners and walkers. Data is downloaded to a PC via Dynastream’s proprietary RF protocol and exported to Excel where further data analysis can be performed. (Godfrey, A., Conway, R., Meagher, D. & Olaighin, G., 2008)

The AMP331 device is a relatively new and unused device for clinical studies. It has been shown to be accurate for counting steps to within 3% at walking speeds of 67 m/min and faster but underestimates at slower walking speeds. The device also underestimated distance by a mean estimate of 11% for various speeds above 40 m/min. However, the device does not seem prone to spurious movement that may occur during daily activity. (Godfrey, A., Conway, R., Meagher, D. & Olaighin, G., 2008)


**Figure 6.3 The AMP331 Pod and Attachment Sleeve from Dynastream**

### 6.1.3 Ossur PAM: Prosthetic Activity Monitor™

The PAM is a lower leg mounted device that is designed especially for the orthotic and prosthetic industry. It monitors the level of daily activity and walking patterns of lower amputee patients that incorporates one bi-axial and one uni-axial accelerometer. This device has been validated in comparison with visual observation, video and 3D motion analysis during treadmill testing but limitations exist for normal activity of daily living (ADL) and distance measured. Also, calculation of step length by the PAM is calculated by dividing stride length by a factor of 2. This assumes the patient is walking symmetrically, for amputees this may not always be the case. (Godfrey, A., Conway, R., Meagher, D. & Olaighin, G., 2008)


**Figure 6.4 The Ossur PAM: Prosthetics Activity Monitor™**

(© Copyrights 2008 Godfrey, A., Conway, R., Meagher, D. & Olaighin, G)

## 6.2 Future Research and Development

Future research and development of human movement analysis system plays an important role in quality life improvement. By the ways, an abnormal motion can be detected early by the new technologies or non-invasive methods. The future research and development can be mainly focus on different walking conditions, focus on children and older adults, and gait recognition algorithms development.

### 6.2.1 Research Focus on Different Walking Conditions

Accelerometers can be used to approximate energy expenditure, however, they do not capture the full energy cost of certain activities, such as walking while carrying load or walking uphill, because acceleration patterns do not change under these conditions (Murphy, S.L., 2009).

Future research will need to examine the generational comparability under different conditions and evaluate the sensor system in other walking conditions, such as walking or running round a corner, not in the straight line. (Lau, H.Y. & Tong, K.Y., 2008; Cooper, G. Et.al., 2009)

### 6.2.2 Research Focus on Children and Older Adults

Current accelerometer-based techniques have been reasonably well defined for physical activity monitoring of adolescents but there are still reliability and accuracy issues concerning children and older adults (Godfrey, A., Conway, R., Meagher, D. & Olaighin, G., 2008). This is due to children's physical activity pattern have a short and sporadic nature (James, J.M.C & Catrine, T.L., 2009) and older adults have the different type and intensity of physical activities due to age-related changes, such as loss of flexibility, decreased bone and muscle mass (Murphy, S.L., 2009).

Basically, accelerometer patterns for older adults are more susceptible to noise as the fluidity of movement becomes impaired with increasing age. More advanced signal processing, perhaps incorporating multi-resolution analysis techniques, or the development of more suitable biomechanical models of human motion would help improve the accuracy. Algorithms should also be validated in the elderly to account for slow and erratic movement (Godfrey, A., Conway, R., Meagher, D. & Olaighin, G., 2008). As consequences, further development and research in physical activity measurement is needed to the children and older adult population.

### 6.2.3 Gait Recognition Algorithms Development

Gait recognition algorithms can be implemented to for monitoring of activity volume and recognition of emergent situations such as falling during daily life. For the aged with disease such as hypertension, myocardial infarction and cerebral apoplexy, the possibility of falling is very high because their body functions may become suddenly uncontrollable. (Jeong, D.U., Kim, S.J. & Chung, W.Y., 2007)

The gait recognition can be used to identify and describe different subjects' gait patterns due to different gait cycles tend to have unequal lengths, and the gait cycle of each user may be different (Liu, R., Zhou, J.Z., Liu, M., Hou, X.F., 2007; Anna, A.S. & Wickstrom, N., 2009). The algorithm also can be further develop and used to detect abnormal human movements or extensible to other non-medical applications (Burchfield, T.R. & Venkatesan, S., 2008).

# CHAPTER 7

# CONCLUSION AND MILESTONES

## 7.1 Conclusion

Real-time lower extremities human movement analysis with different walking pace by using accelerometer is proven to be successful to determine the physical activity or movement of adolescents groups. A low-cost, reliable and accurate 2-Dimensional lower extremities biomechanical and system with PIC18F4550 microcontroller and simple Bluetooth module has been developed.

However, further improve for the lower extremities human movement analysis system still can be done, especially noise reduction by adding the filter circuit, increase the number of accelerometers, combination accelerometer with gyroscopes and magnetometer, and change to full body human movement analysis.

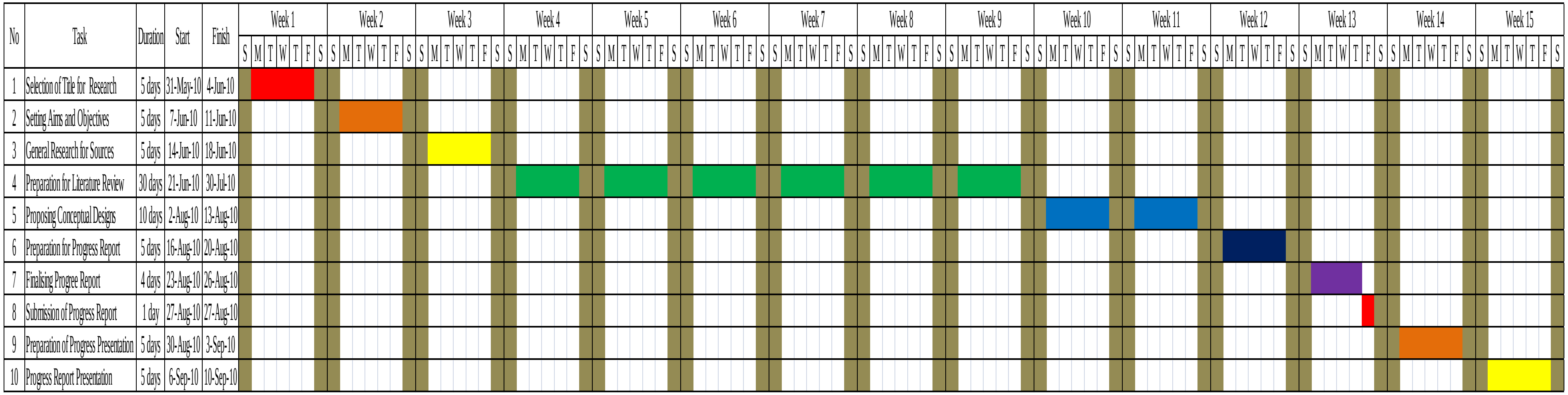
Future research focus on different walking conditions and research focus on children and older adult can be carrying out as their accelerometer patterns more susceptible to noise. Furthermore, gait recognition algorithms can be further develops and implemented to for monitoring of activity volume and recognition of emergent situations such as falling during daily life.

## 7.2 Gantt Chart

A Gantt chart is a type of bar chart that illustrates a project schedule. Gantt charts illustrate the start and finish dates of the terminal elements and summary elements of a project. Terminal elements and summary elements comprise the work breakdown structure of the project.

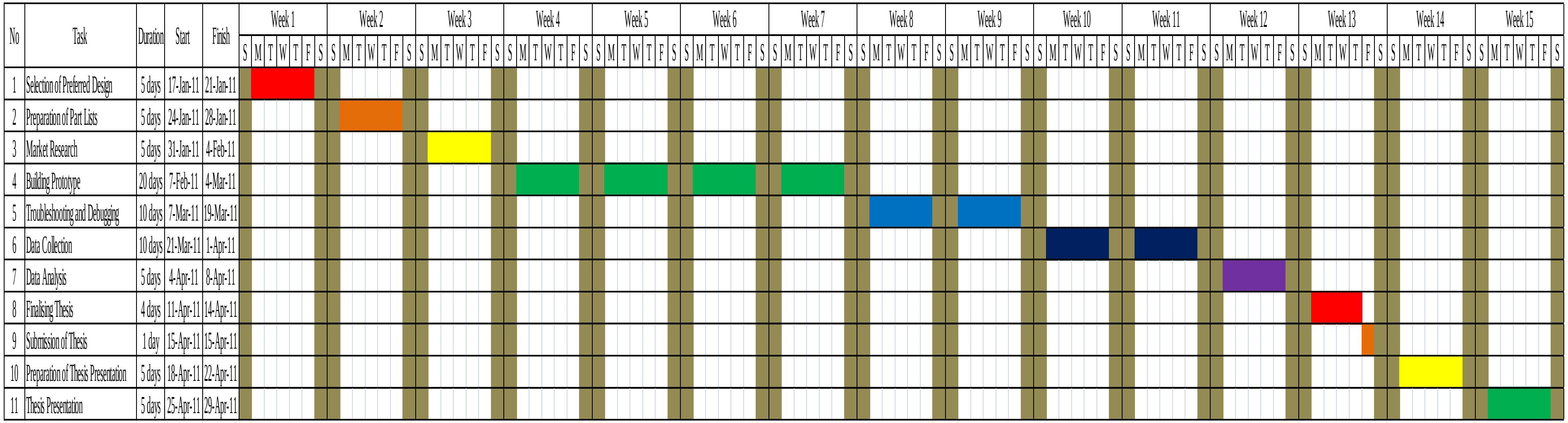
The Gantt chart for Final Year Project during the first semester and second semester has been proposed as below.

### 7.2.1 Gantt Chart for First Semester




| No | Task | Duration | Start | Finish |
|---|---|---|---|---|
| 1 | Selection of Title for Research | 5 days | 31-May-10 | 4-Jun-10 |
| 2 | Setting Aims and Objectives | 5 days | 7-Jun-10 | 11-Jun-10 |
| 3 | General Research for Sources | 5 days | 14-Jun-10 | 18-Jun-10 |
| 4 | Preparation for Literature Review | 30 days | 21-Jun-10 | 30-Jul-10 |
| 5 | Proposing Conceptual Designs | 10 days | 2-Aug-10 | 13-Aug-10 |
| 6 | Preparation for Progress Report | 5 days | 16-Aug-10 | 20-Aug-10 |
| 7 | Finalising Progree Report | 4 days | 23-Aug-10 | 26-Aug-10 |
| 8 | Submission of Progress Report | 1 day | 27-Aug-10 | 27-Aug-10 |
| 9 | Preparation of Progress Presentation | 5 days | 30-Aug-10 | 3-Sep-10 |
| 10 | Progress Report Presentation | 5 days | 6-Sep-10 | 10-Sep-10 |

### 7.2.2 Gantt Chart for Second Semester




| No | Task | Duration | Start | Finish |
|---|---|---|---|---|
| 1 | Selection of Preferred Design | 5 days | 17-Jan-11 | 21-Jan-11 |
| 2 | Preparation of Part Lists | 5 days | 24-Jan-11 | 28-Jan-11 |
| 3 | Market Research | 5 days | 31-Jan-11 | 4-Feb-11 |
| 4 | Building Prototype | 20 days | 7-Feb-11 | 4-Mar-11 |
| 5 | Troubleshooting and Debugging | 10 days | 7-Mar-11 | 19-Mar-11 |
| 6 | Data Collection | 10 days | 21-Mar-11 | 1-Apr-11 |
| 7 | Data Analysis | 5 days | 4-Apr-11 | 8-Apr-11 |
| 8 | Finalising Thesis | 4 days | 11-Apr-11 | 14-Apr-11 |
| 9 | Submission of Thesis | 1 day | 15-Apr-11 | 15-Apr-11 |
| 10 | Preparation of Thesis Presentation | 5 days | 18-Apr-11 | 22-Apr-11 |
| 11 | Thesis Presentation | 5 days | 25-Apr-11 | 29-Apr-11 |

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# APPENDICES

## APPENDIX A: Summary of the Journal and Technical Papers

Table 1: Journals and Technical Papers Review

| No | Title & Authors | Specifications / Equipments | Key Points |
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| 1 | **Title:** Wireless patient monitoring on shoe for the assessment of foot dysfunction: An overview<br><br>**Authors:** Abraham, J.K., Witchurch, A.K., Varadan, V.K. & Sarukesi, K. | Continuous wireless ankle motion monitoring system<br>- accelerometers<br>- gyroscopes fixed inside the shoe | Overview of the wireless monitoring and quantitative assessment of joint dynamics of ankle which has suffered from soft tissue injury, immobilization or any dysfunction with special focus on the treatment and rehabilitation applications.<br><br>Acceleration sensors which is related to the intensity of body-segment movement.<br><br>Gyroscopes attached to the shoe which is related to turning and angular movements.<br><br>Joint monitoring system uses a data logging unit to record the signal produced by the sensors and later the data is analyzed off-line.<br><br>**Wireless ankle motion monitoring system**<br>- Provide a way to monitor the foot motion in real-time making it suitable for various applications.<br>- Able to monitor any required parameters without placing any restrictions on the subject's movement.<br>- Uses a Bluetooth network to wirelessly connect the sensing unit on the shoe to a notebook computer or a handheld PC.<br>- Wireless MEMS-based accelerometers |

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| | | | and gyroscopes are used to determine the acceleration along the three axes and the angular velocity of the foot.<br>- Ankle and foot movement could be evaluated by analyzing the two parameters – the pitch angle and horizontal velocity of the foot.<br>- Pitch angle is the only angle which changes during the walking phase of the foot.<br><br>**Methods**<br>a. Development of sensing unit<br>- Contains a MEMS based accelerometer and a MEMS based gyroscopes.<br>- PIC16C773 8 bit CMOS microcontroller with a built in 12 bit A/D converter with 6 analog channels to digitize the analog signal produces by the sensors.<br>- Ericsson ROK101008 Bluetooth wireless communications module to wirelessly transmit the digital signals to a computer.<br>- Microcontroller controls the Bluetooth module by issuing Host Controller Interface (HCI) commands and accepting responses from the module.<br>b. Development of monitoring system<br>- Window application developed using Microsoft Visual C.net.<br>- Xirom Credit Card Bluetooth adapter was used to receive the signals from the sensing unit Bluetooth interface.<br>- Software interfaces to the Bluetooth hardware at the Host Controller Interface (HCI) protocol level in order to ensures that the data in received from the sensors without any knib of loss resulting in improper data recording. |
| 2 | **Title:**<br>Non-invasive assessment of soft-tissue artifact and its effect on knee joint | | Soft-tissue interface between skin-mounted markers and the underlying bones poses a major limitation to accurate, non-invasive measurement of joint kinematics.<br><br>Combine subject-specific, MRI-based, 3D |

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| | kinematics during functional activity<br><br>**Authors:** Akbarshani, M. Schache, A.G., Fernandez, J.W., Baker, R., Banks, S. & Pandy, M.G. | | bone models and x-ray fluoroscopy to quantify lower limb soft-tissue artifact in young healthy subjects during functional activity and to determine the effect of soft-tissue artifact (STA) on the calculation of knee joint kinematics.<br><br>**Previous methods**<br>- Often used intrusive techniques for their analyses, such as bone pins, external fixators and percutaneous tracking devices to quantify joint motion in vivo.<br>- Can restrict the movement of the subject<br>- Alter the normal, unimpeded sliding of the soft tissues relative to the underlying bone.<br><br>**Current methods**<br>- Non-invasive methods such as magnetic resonance imaging (MRI) and x-ray fluoroscopy have been used to quantify joint motion in vivo.<br>- Capturing several static poses throughout an arc of motion rather than measuring a continuous dynamic motion.<br>- Investigating a single motor task only.<br>- Using elderly subjects fitted with knee implants.<br><br>**MRI bone models**<br>- 4 able-bodied adult males with no history of lower limb musculoskeletal injury.<br>- Images of each subject's left lower limb, from the pelvis to the ankle joint, were acquired from a 3T Siemens MRI device using a T2 fat-suppressed sequence.<br><br>**Human motion experiments**<br>- Ten reflective markers were placed on each subject's left leg.<br>- Kinematic data were collected simultaneously from an x-ray fluoroscopy unit operating in pulsed mode at 30Hz and a video motion capture system with 9 high-resolution M1 cameras sampling at 120Hz. |

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| | | | - X-ray images were corrected for image distortion.<br><br>Soft-tissue artifact for the thigh was found to be higher than that for shank.<br><br>**Limitation of the study**<br>- The procedure used to validate the fluoroscopy measurements did not replicate the exact experimental conditions.<br>- The quality of the fluoroscopic images and hence the accuracy of the pose estimation process may have been influenced by dynamic motion and the presence of soft tissue.<br>- Reduced speed of movement used to enhance X-ray image quality may be resulted in an underestimation of the effect of inertia on the magnitude of STA.<br>- Time and computational cost of deriving subject-specific models limited the sample used in this study to 4 subjects. |
| 3 | **Title:**<br>A low-cost rate-grade nickel micro-gyroscope<br><br>**Authors:**<br>Alpher, S.E., Silay, K.M. & Akin, T.F. | Nickel micro-gyroscope | A low-cost microgyroscope with a resolution in the rate-grade at atmospheric pressure, which is fabricated using a CMOS-compatible nickel electroforming process.<br><br>**Advanced silicon micromachining technologies**<br>- Polysilicon trench refill<br>- Dissolved wafer process<br>- SOI micromachining<br>- Silicon-on-glass micromachining<br>- Polysilicon surface micromachining<br>- Silicon bulk micromachining<br>- SOI wafer bonding to glass substrates |
| 4 | **Title:**<br>Do kinematic models reduce the effects of soft tissue artefacts in skin marker-based motion | | Investigated the effects of including kinematic constraints in the analysis of knee kinematics from skin markers and compared the result to simultaneously recorded trajectories of bone pin markers.<br><br>**Soft tissue artefacts (STA)**<br>- Skin-mounted markers tend to slide |

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| | analysis? An in vivo study of knee kinematics<br><br>**Authors:** Andersen, M.S., Benoit, D.L., Damsgaard, M., Ramsey, D.K. & Rasmussen, J. | | relative to the underlying bone, a phenomena known as soft tissue artefacts (STA).<br>- Have a frequency component in the same region as the bone motion, rendering standard filtering ineffective.<br>- Both subject- and task-dependent.<br>- Local motion of a cluster of skin markers is composed of a deformation and relative motion with respect to the underlying bone.<br><br>The goal of motion analysis is typically to determine the motion of the underlying bones. Using idealized knee joint constraints have the potential of limiting or eliminating actual bone motions. Besides that, it did not eliminate or reduce the effects of STA and did not improve the validity of the knee joint kinematics derived from skin markers on the thigh and shank.<br><br>Skin markers and idealized joint constraints for the knee is not an ideal approach to reduce STA and improve measurement validity. |
| 5 | **Title:** Developing a motion language: Gait analysis from accelerometer sensor systems<br><br>**Authors:** Anna, A.S. & Wickstrom, N. | Accelerometer sensor systems | **Applications of gait analysis**<br>- Predicting the risk of developing dementia and Alzheimer's disease.<br>- Indicate of an increased risk of developing permanent cognitive impairment.<br>- Help identify and quantify the risk of an elder falling.<br>- Essential tool in the treatment and evaluation of cerebral palsy patients<br>- Evaluating the success of an orthopaedic surgery.<br><br>**Methods**<br>**Motion capture (mocap) systems**, in combination with force-plates.<br>a. Advantages<br>- Provide very accurate descriptions and models of gait.<br>b. Limitations<br>- Expensive<br>- Only can be installed in appropriate |

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| | | | rooms<br>**Pressure sensitive mats**<br>a. Advantages<br>- More mobile<br>b. Limitations<br>- Less informative<br>**Time up and go test (TUG)**<br>a. Limitations<br>- Subjective<br>- Inconsistent<br>**Wearable sensor systems**<br>a. Advantages<br>- Inexpensive<br>- Unobtrusive<br>- Easy-to-use system<br>- Allow quantitative analysis of gait patterns outside the lab<br>b. Accelerometers are suitable for wearable systems since current enhancements in micro-electro-mechanical systems (MEMS) technology.<br>Advantages: miniaturized, low power & low cost accelerometers.<br><br>**Gait analysis studies from accelerometer sensor systems may be divided into 3 main categories**<br>- Reconstruction of movements in space<br>- Detection of gait phases and evaluation of temporal parameters<br>- Classification of walking patterns<br><br>**Motion language methodology**<br>- Movement classification techniques which aims at generalizing movements and providing easy interpretation of motion signals.<br>- Aims at both tasks: identifying the phases of gait and describing the dynamics of the walking pattern.<br><br>**Development of motion language**<br>- **Segmentation**: determine how to segment the signal into suitable building blocks.<br>- **Feature extraction**: various features extracted from each segment of the signal are used to classify them into different symbols. |

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| | | | - **Symbol assignmen**t: segments with similar characteristics may be assigned one symbol.<br>- **Grammar inference**: express how symbols may be put together to form words and sentences which represent different movements.<br><br>**Experimental setup**<br>- 2 SHIMMER sensor nodes composed of tri-axial accelerometers were attached to both shins of the subjects, close to the ankle.<br>- Data was continuously streamed via Bluetooth to nearby computer.<br>- Subjects walked a straight line one a 6m Gold Gait Rite pressure mat<br>- Data obtained from the pressure mat was used as reference for heel-strike and toe-off.<br>- 7 subjects asked to walk at comfortable self-paced speed, at a very slow speed taking shorter steps and at a comfortable self-paced speed while having their right knee immobilised with a brace in order to stimulate limp walk.<br><br>**Goal:**<br>- Apply the proposed motion language methodology to acceleration data in order to extract gait parameters and symmetry for measures for the 3 different types of walk.<br><br>**Future development**<br>- Find symbols robust enough to describe different subjects' gait patterns, and comprehensive enough to span different walking patterns.<br>- Algorithms will be assigned to automatically extract rules describing gait parameters, based on previous knowledge of the system.<br>- Investigating new segmentation method, investigating new features and rules, and investigating new clustering and symbolization techniques. |

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| 6 | **Title:**<br>Compact time-independent pattern representation of entire human gait cycle for tracking of gait irregularities<br><br>**Authors:**<br>Balista, J.A.F., Soriano, M.N. & Saloma, C.A. | | **Three-dimensional image pattern representation**<br>- Entire front-view gait.<br>- Generated by applying a Freeman vector-based silhouette feature extractor algorithm called curve spreads (CS) on a front-view video recording of a human subject obtained using a single stationary CCD camera.<br><br>**Method**<br>- Subjects: 3 males and 2 females<br>- To achieve optimal video recording contrast, human subjects were made to wear white body suits against a black background.<br>- Observed in locomotion with a video camera.<br>- Camera's height from the ground is half of the subject's height and it is placed at a distance that is twice the entire walkway length.<br>- To record pathological gaits, the same subjects were asked to walk towards the camera while carrying a load or with one or both of their arms being restrained.<br><br>**Preprocessing of video frame**<br>- Modified the CS algorithm to permit a frame-by-frame processing of the recorded video.<br>- Each color frame is converted to grayscale.<br>- Image of the subject is separated from its environment by background subtraction.<br>- Background-free image is converted into binary image by imposing a suitable intensity threshold.<br>- Edge detection is applied to generate an outline of the binary image.<br>- Starting pixel and direction are arbitrarily chosen.<br>- Pixels are assigned values using the Freeman Code, effectively converting them to vectors.<br>- Outline curvatures are computed from the difference or gradient of two adjacent vectors. |

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| | | | - Positive, negative and zero values represent convexities, concavities and flat segments, respectively.<br>- Color intensities are assigned to the convex and concave values.<br>- Divide the image into 2 regions about the waistline and each region is processed independently.<br>- Color bands are then reassembled by image addition and the recombination is stacked chronologically with recombined bands from other frames of the video to yields the two-dimensional gait image.<br>- Gait image is easily to process unlike direct video images of human movement that requires time for pause, playback / play forward or slow / fast motion.<br>- The shift of the body weight from one leg to another is revealed clearly in the gait image.<br>- The static image representation could reveal subtle differences in human locomotion under physical stress and is a promising tool to physical therapists, fashion school instructions and security personnel. |
| 7 | **Title:** Kinematics estimation of straddled movements on high bar from a limited number of skin markers using a chain model<br><br>**Authors:** Begon, M., Wieber, P.B. & Yeadon, M.R. | Reflective markers | To reduce the effects of skin movement artefacts and apparent joint dislocation in the kinematics of whole body movement derived from marker locations, global optimization procedures with a chain model have been developed.<br><br>Joint centres are defined from static data acquisitions or from measurements on the participant. For the marker sets, the joint centre location is estimated with a predictive approach based on anthropometrical measurement or the midpoint of two markers.<br><br>**Global optimization procedure**<br>- Reduce skin movement artefacts and apparent joint dislocations.<br>- Applied to computer simulated movements of the lower limbs and the upper limbs. |

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| | | | Three or more markers per segment is impractical for whole body sports movements because of increased marker occlusion, increased soft tissue movement and increase marker detachment during dynamic movements.<br><br>**Methods**<br>- A member of the Great Britain Men's Senior Gymnastics Squad.<br>- 21 technical and anatomical reflective markers were used to define the chain model.<br>- The model implementation and the kinematics optimization from real data were performed using the HuMAnS toolbox under Scilab.<br>- All trials were captured using 18 Vicon cameras operating at 100Hz and positioned on a hemisphere on the left side of the subject. |
| 8 | **Title:**<br>The accuracy of measuring the kinematics of rising from a chair with accelerometer s and gyroscopes<br><br>**Authors:**<br>Boonstra, M.C. et.al | - 2 uni-axial / 1 bi-axial accelerometers<br>- 1 gyroscope | Assess the accuracy of measuring angle and angular velocity of the upper body and upper leg during rising from a chair with accelerometers, using low-pass filtering of the accelerometer signal.<br><br>Improvement in accuracy of the measurement with additional use of high-pass filtered gyroscopes was assessed.<br><br>Two uni-axial accelerometers and one gyroscope per segment were used to measure angles and angular velocities of upper body and upper leg.<br><br>**Accelerometer**<br>- Small in size, very accurate, solid and inexpensive.<br>- Analysis of the accelerometer signal has been problematic because consists of 2 components<br>a. Position of the acceleration relative to gravity used for assessing angles of body segment.<br>b. Linear acceleration<br>- Linear accelerations occur in a higher frequency domain than the gravitational component. |

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| | | | **Gyroscopes**<br>- To increase the accuracy, additional use of gyroscopes because relative angles can be calculated by integration of the gyroscope signal.<br>- Drift in time results in large errors for orientation after integration.<br>- Compensated the integration drift of the gyroscopes by adding the low-pass filtered accelerometer signal to the high-pass filtered gyroscope signal.<br><br>**Methods**<br>- 5 healthy subjects participated.<br>- Movements of both the upper body (thorax and pelvis) and upper leg were determined, using gyroscopes, accelerometers and an optical motion analysis system (Optotrak).<br>- Matlab 6.0 was used for all signal processing.<br>- For the pelvis, the sensors were placed in a box, which was attached to the waist with a neoprene belt.<br>- The sensors for the thorax and upper leg were placed on metal strips, which were attached to sternum and frontal side of upper leg, with double-side tape.<br>- Gyroscopes measured the movements in the sagittal plane.<br>- Data were collected with the maximum sample rate of 32Hz.<br>- Opotrak sampled with a rate of 64Hz.<br><br>**Method 1: Accelerometer**<br>- Accelerometer and gyroscope signal were resampled to 64Hz.<br>- Raw accelerometer signals were low-pass filtered.<br><br>**Method 2: Combined accelerometers and gyroscopes**<br>- For combined signal, both the accelerometers and gyroscope signal were used.<br>- To derive the orientation of the sensors, the gyroscope signal was integrated.<br>- A high-pass Butterworth filter was used on the raw gyroscope data, to correct for the internal drift. |

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| | | | - However, high-pass filtering caused loss of a part of the signal, which results in underestimation of the angle.<br>- To compensate for the loss, the accelerometer signal was low-pass filtered and added to the filtered gyroscope signal. |
| 9 | **Title:**<br>A triaxial accelerometer and portable data processing unit for the assessment of daily physical activity<br><br>**Authors:**<br>Bouten, C.V.C., Koekkoek, K.T.M., Verduin, M., Kodde, R. & Janssen, J.D. | Accelerometer | - Describes the development of a triaxial accelerometer (TA) and a portable data processing unit for the assessment of daily physical activity.<br><br>**Sources of accelerometer output**<br>- Acceleration due to body movement<br>- Gravitational acceleration<br>- External vibrations not produced by body itself<br>- Accelerations due to bouncing of sensor<br><br>**Methods**<br>- Body-fixed accelerometers must be able to register accelerations within the amplitude range of -12g to +12g and with frequencies up to 20Hz.<br>- Combination with a high-pass filter to eliminate any resulting dc component during the registration of human movement, while retaining a very low frequency cut-off (about 0.1Hz).<br>- Data are stored in a 512kB, 16 bit data memory chip that can be read out with the serial interface to a computer.<br>- Batteries, data logger, and other electronic components for data processing are built in a housing of PVC. |
| 10 | **Title:**<br>Accelerometer-based human abnormal movement detection in wireless sensor networks | Wireless biomedical sensor network (WBSN)<br>- IEEE 802.15.4<br>- ZigBee<br>- Microelectromechanical systems (MEMS) | **Applications**<br>- Biomedical patient telemetry-monitoring tool<br><br>**Major constraints for WBSN**<br>- Processing speed<br>- Memory<br>- Power consumption<br>- Data transmission capacity<br>- Battery life |

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| | **Authors:**<br>Burchfield, T.R. & Venkatesan, S. | Standard radio communication module (RCM) in the Ember EM2420 based development kit<br>- Atmel controller<br>- 3V battery<br>- 2 momentary press buttons for programmable action upon user input.<br>- Pin-outs for signal I/O and debugging<br>- An auditory buzzer<br>- 3-axis accelerometer<br><br>3 –axis accelerometer for this project is Freescale semiconductor MMA7260Q | **Methods**<br>- Placement: small wireless node with an accelerometer is attached to human wrist.<br><br>**Algorithms**<br>- 2 threshold-based algorithms used to classify the subject's movement into one of a few categories.<br>a. Identify rapid shaking movements that usually accompany myoclonic, clonic and tonic-clonic seizures.<br>b. Generate an alarm when a patient has sustained an extended period of inactive of coma onset or loss of consciousness triggered by an acute brain injury.<br>- Upon detecting an abnormal event, both algorithms sound an auditory alarm from the wrist-device and transmit an alarm message through a ZigBee multi-hop wireless network to a patient monitoring station staffed by medical personnel.<br><br>**Signal processing**<br>- Sample rate of 20Hz<br>- g conversion<br>- signal aggregation<br>- calculation for Δg-rms<br>- Average calculation.<br><br>**Rapid shaking detection (RSD) algorithms**<br>- 2 criterion conditions trigger an alarm<br>a. Drastic movement - require an upper threshold of activity that must be exceeded for some small threshold period.<br>b. Sustained movement - An elevated activity level for a prolonged duration of time.<br><br>**Application**<br>- Applied to fragile shipment monitoring. (instantaneous impact of excessive g-force, prolonged exposure to excessive vibration & excessive tilt)<br>- ShockWatch shock and tilt indicator. |

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| 11 | **Title:** Kinematical models to reduce the effect of skin artifacts on marker-based human motion estimation<br><br>**Authors:** Cerveri, P., Pedotti, A. & Ferrigno, G. | | The estimation of the skeletal motion obtained from marker-based motion capture systems is known to be affected by significant bias caused by skin movement artifacts, which affects joint center and rotation axis estimation.<br><br>During skeleton motion, muscle deformations and skin sliding, which cause the markers to move non-rigidly with respect to the underlying bones, introduce orientation artifacts.<br><br>Muscle deformations cannot be eliminated by simply low-pass filtering. Some techniques were proposed to reduce marker local motions:<br>- Estimation of the unobservable bone motions from the motion of the markers attached to the body surface<br>- Investigation of the correlation between kinematical variables and local trajectories of the markers<br>- Determining a correction table, estimated for prototypical movements<br>- Model-based filtering method, named interval deformation technique<br>- Using extended Kalman filters and biomechanical models<br>- Local motion estimation (LME)<br><br>**Local motion estimation (LME)**<br>- Reducing the effects of skin artifacts and the local movement of joint centres<br>- Stimulate movements of virtual human models were designed and implemented to prove the capability to prove the capability of the proposed technique.<br>- Utilize virtual humans and extended Kalman filter to solve in bundle the problem of marker tracking and kinematical estimation<br><br>The solution to minimize the effects of artifacts<br>- Adopted in the most of marker protocols consisted in locating the markers on bony protuberances, which are less affected by soft tissue artifacts, or upon support structures rigidly linked |

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| | | | to the body surface<br>- Adopted dynamics filter approach and a priori kinematical models with constraints on kinematics and changes in the local coordinates taking into account prior knowledge about motion artifacts |
| 12 | **Title:**<br>Effect of treadmill walking on the stride interval dynamics of human gait<br><br>**Authors:**<br>Chang, M.D., Shaikh, S. & Chau, T. | Force sensitive resistor (FSR) | Study the disruptions in the natural neuromuscular rhythms of gait during treadmill walking (TW). Treadmill walking is a widespread rehabilitative tool.<br><br>To investigate the impact of treadmill walking without using a handrail on stride interval dynamics as compared to over ground walking.<br><br>To examine the effect of employing a handrail during treadmill walking on stride interval dynamics.<br><br>**Detrended fluctuation analysis (DFA)**<br>- Stride interval defined as the time between consecutive heel strikes of the same foot.<br>- The statistical persistence of an individual's gait is commonly measured by α, also known as a scaling exponent, and derived from a DFA of an individual's SI time series.<br>- Able-bodied individual typically exhibits an α value ranging from 0.8 to 1.0.<br>- Individuals exhibiting lower α values were more prone to falling.<br>- Parkinson's disease and Huntington's disease typically present with significantly lower values closer to 0.5.<br><br>**Methods**<br>- 16 able-bodied participants had normal or corrected-to-normal vision and were a right foot dominant.<br>- Walked for 15min in 3 different conditions at a self-selected comfortable walking speed:<br>a. Over ground walking<br>b. Treadmill walking without holding a |

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| | | | handrail<br>c. Treadmill walking while holding a front handrail<br>- Ultra-thin, force-sensitive resistor (FSR) was taped below the heel of the participant's right shoe.<br>- Each time the FSR made contact with the ground, a change in voltage occurred. These voltages were directly captured by a CompactFlash data acquisition card (CF-6004).<br>- The wiring was clipped to clothing along the lateral side of the right leg and the fanny packs was centered at the front of the participant's waist to ensure that the instrumentation did not interface with natural gait.<br>- Footswitch signals were sampled at 200Hz and subsequently uploaded to a PC for data analysis.<br>- Kruskal-Wallis test was used to determine significant differences between three walking conditions in terms of α, means stride interval, gait speed and stride interval variability.<br>- Wilcoxon Rank Sum test was used to calculate significance between groups. Spearman's correlation coefficient was used to quantify the correlation of α with gait speed.<br>- Statictical analysis was performed using MATLAB for windows.<br><br>Without handrail, dynamic stability is achieved by controlling a multi-segment system and coupling interlimb motion to maintain the centre of mass within the medial border of each support foot.<br><br>When handrail is used, forces on arm and hands, shoulders extension, and angle of the lower body with respect to the upper body additionally assist in maintaining body stability.<br><br>Treadmill walking at a self-selected comfortable pace did not diminish the intrinsic stride dynamics as compared to natural over ground gait. |

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| 13 | **Title:**<br>Design of multipurpose sensing system for human gait analysis<br><br>**Authors:**<br>Che, D.W., Kwon, O., Shim, J., & Park, J.H. | Multipurpose sensing system<br>- 6 absolute encoders<br>- 8 FSR sensors<br>- FPGA board for data processing<br><br>Gait phase analysis algorithms<br>- 2 major categories for analyzing walk behaviours and stand behaviours.<br>- 4 subordinate phases for standing, lift, swing and landing. | Multipurpose sensing system and fast phase analysis algorithms to predict and estimate behaviours of human being in advance.<br><br>**Multipurpose sensing system**<br>- Lightly<br>- Simply to minimize data acquisition errors<br>- Cheap and exact<br>- Can get much information of gait<br><br>**Gait analysis method**<br>a. Video motion capture<br>- Get joint information and motion classifies<br>- Receives the effect of circumference environment a lot and the reliability of information due to image analysis.<br>b. Accelerometer<br>- Can divide stance motion and walking motion.<br>c. Surdilovic<br>- 4 FSR and 1 position sensor and a fibre sensor.<br>- Uses fibre sensor to measure knee bending, so cannot get exactly joint information.<br>- Can divide 4 phases.<br>d. 3 FSR<br>- Measure external force and used chip gyro to get rotation information of ankle.<br>- Exact and simple<br>- Not sufficient to measure each joint value.<br><br>**Components**<br>a. Absolute encoder<br>- Is robust to noise because it is digital sensor and it is needless to adjust zero, which can find out subject's initial standing habit easily.<br>- Attached in ankle, knee and hip joint.<br>b. FSR<br>- Attach position is toe, ball of foot (in and out) and heel.<br>- Can't get exactly value because it has basically linearity errors and its value change a lot by following contact |

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| | | | situation like slant of contact, foot positions.<br>c. Field-programmable gate array (FRGA)<br>- ALTERA EP1S10 TQFP100<br>- To manage data<br>- To manage encoder data to PC<br><br>**Gait phase analysis algorithms**<br>a. Main category<br>- Walk-behavior<br>If there is front-rear body movement in motions.<br>- Stand-behavior<br>If there is no front-rear body movement in motions<br>b. Subordinate phase<br>- Standing<br>Toe-FSR often doesn't detected by human's stand habit<br>- Lift<br>Hip joint angular velocity must be negative<br>- Swing<br>Hip joint angular velocity must be detected<br>- Landing<br>Hip joint angular velocity must be positive<br>Knee joint angular velocity is negative<br>- Sit-down (at stand-behavior)<br>- Stand-up (at stand-behavior)<br><br>**Experimental study**<br>a. Walking motion<br>- The division is generally well and misses division point are located at double support phase which is none swing point.<br>- Single support phase and double support phase are exactly divided.<br>b. One leg swing in the stand motion<br>- Can divide each phase well and misses division in major category like walk motion case<br>- Single support phase and double support are exactly divided.<br>- Subordinate phases are exactly divided. |

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| | | | c. Sit-down and stand-up<br>- There is no swing phase and the motion tendency of both leg are almost same.<br>- Can divide each phase well but some miss divisions in major category and subordinate phases.<br>- Subordinate phase error is due to condition confusion.<br><br>**Applications**<br>- Usefully to targets like biped robot or exoskeleton system.<br>- Can observe the leg motion under 2 leg motions and it gives to more exact and various information of human motions. |
| 14 | **Title:**<br>A six-degree-freedom marker set for gait analysis: Repeatability and comparison with a modified Helen Hayes set<br><br>**Authors:**<br>Collins, T.D., Ghoussayni, S.N., Ewins, D.J. & Kent, J.A. | | Evaluate performance of a 6 degrees-of-freedom (DOF) set based largely on calibrated anatomical systems technique (CAST) and International Society of Biomechanics (ISB) recommendations, through comparison with a conventional set and assessment of repeatability.<br><br>Major limitations in kinematic gait analysis result from soft tissue artefact (STA) and landmarks identification.<br><br>For STA, movement over bone violates a rigid body assumption and for some cases the errors can be as large as the range of movement (ROM) of the joint.<br><br>For landmark identification, it is difficult to place markers accurately because anatomical landmarks tend to be large curved areas and this variability contributes to errors in joint angles.<br><br>**Methods**<br>- 10 able-bodied subjects with no musculoskeletal injuries or disorders that affect walking ability.<br>- Data collection and data analysis were carried out by the same assessor for all subjects.<br>- Each subject was recorded in 2 sessions, approximately 1 week apart. |

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| 15 | **Title:**<br>Inertial sensor-based knee flexion / extension angle estimation<br><br>**Authors:**<br>Cooper, G. et.al. | IMU<br>- 3 single axis rate gyroscopes<br>- 1 three-axis accelerometer | A new method for estimating knee joint flexion / extension angles from segment acceleration and angular velocity.<br><br>**Sensor systems**<br>a. MEMS inertial sensors<br>- Measure acceleration or angular velocity<br>- Lightweight<br>- Low power<br>b. Accelerometers and rate gyroscopes<br>- Used to estimate orientation relative to an inertial frame<br>- High accuracy estimation of inclination<br>- Relative orientation is possible by integration of gyro signals in this plane, but susceptible to drift.<br><br>**Calibration procedure**<br>a. Static calibration<br>- When subject stands in a defined pose<br>b. Dynamics calibration<br>- When subject rotates their leg about the hip while maintaining a “stiff” knee, which imposes the same angular velocity on both IMU.<br><br>**Methods**<br>- Data from the sensors were logged on a SD-micro card integrated into each IMU unit.<br>- Estimation of joint angle is split into 2 parts:<br>a. Kalman filter estimates the 2 components (roll and pitch) of the Euler angles of each IMU.<br>b. The information is used to estimate knee joint angle.<br>- A 10 camera Qualysis system was used to provide independent reference measurements of the IMUs’ orientation.<br>- IMU and reflective markers attached to a test subject’s right leg.<br>- The IMU and camera data were captured at 100Hz.<br>- Roll, pitch and yaw angles exacted from the Qualysis camera data using Visual 3D.<br>- The outputs of the estimation were |

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| | | | saved in a text file to be read by the knee joint angle estimator.<br><br>**Knee angle estimator**<br>- Assume that the knee can be represented as a pure hinge joint.<br>- With the joint constraint in place, there are only 3 important degree of freedom (DOF): inclination of the thigh (2 DOF) and the hinge joint angle (1 DOF), making the problem solvable.<br>- Knee angle is estimated using an analytical chi-squared minimization method.<br><br>**Absolute estimator errors**<br>- Accuracy decreases as the speed increases.<br>- Loss of accuracy may be partly due to the duration of the measurement as well as the increase in dynamics.<br><br>**Application of IMU and Kalman filter**<br>- Estimate orientation of the trunk, pelvis and forearm.<br>- Estimate elbow joint orientation<br>- Measured knee angle during walking<br><br>**Limitation**<br>- Knee is assumed to be a perfect hinge joint.<br>- Not well tested such as response of the system when the user is turning (walking or running round a corner).<br><br>**Further work**<br>- Eliminate the need for a camera system for calibration.<br>- Improved the accuracy. |
| 16 | **Title:**<br>Application of optimal and robust design methods to a MEMS accelerometer<br><br>**Authors:** | MEMS accelerometer | - Objective functions are created to optimize each performance aspect and to penalize designs that are not sufficiently robust to manufacturing variations.<br>- Two optimization studies: to maximize the full-scale range and to minimize the threshold acceleration while meeting or exceeding a range of strict |

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| | Coultate, J.K., Fox, C.H.J., William, S.M. & Malvern, A.R. | | specifications. |
| 17 | **Title:** Functional calibration procedure for 3D knee joint angle description using inertial sensor<br><br>**Authors:** Favre, J., Aissaoui, R., Jolles, B.M., Guise, J.A. & Minian, K. | 2 inertial measurement units (IMU) fixed on the thigh and shank segments | **Inertial measurement units (IMUs)**<br>- High precision<br>- Moderate accuracy<br>- Used in unconstrained environments<br>- Small and lightweight enough to be fixed on the body segments without interfacing with the execution of movements.<br><br>**Magnetic and inertial measurement unit (MIMU)**<br>- Orientations are calculated relative to an earth-fixed frame defined by the gravity and local magnetic field.<br>- Sensitive to magnetic field distortions.<br>- Use in clinical setting environments is limited.<br><br>**Methods**<br>- Joint coordinate system (JCS) was used to describe the knee joint angles. Three clinical rotations normally occur: flexion/extension, abduction/adduction and finally internal/external rotation.<br>- The wearable system was made up of 2 small IMUs connected to a portable data-logger.<br><br>**Reference measurement system**<br>- Several calibration protocols were proposed for the knee joint, none is currently adopted as a 'good standard' by the community.<br>- Used 2 magnetic markers fixed on the thigh and shank parts of the harness.<br>- The data were recorded with a sampling frequency of 240Hz.<br><br>**Validation protocol**<br>- Subjects: 8 healthy men<br>- After few minutes to accustom, the subjects were asked to walk seven meters along a pathway. |

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| 18 | **Title:** Predicting lower limb joint kinematics using wearable motion sensors<br><br>**Authors:** Findlow, A., Goulermas, J.Y., Nester C., Howard, D. & Kenney, L.P.J. | MT9 Xsens units<br><br>Vicon motion capture system | Estimate sagittal plane ankle, knee and hip gait kinematics using 3D angular velocity and linear acceleration data from motion sensors on the foot and shank.<br>- Hip, knee and ankle kinematic data were collected using reflective markers<br>- Foot and shank angular velocity and linear acceleration data were collected using small integrated accelerometers / gyroscope units.<br><br>**Wearable measurement systems**<br>- Require too many sensors on the body.<br>- Not accepted by potential users.<br><br>**Approach**<br>- Reduce the size and weight of sensors.<br>- Improve the physical integration of the sensors and associated microelectronics with garments.<br>- Reduce the number and complexity of sensors.<br>- Predicting rather than directly measuring the required data.<br><br>**General regression networks (GRNN)**<br>- Performed best among the 7 algorithms tested.<br>- Used to characterize the relationship between the kinematic data from the reflective marker approach (the gold standard) and the sensor derived acceleration and angular velocity signals.<br><br>**Methods**<br>- Subjects: 8 participants completed 10 walking trials at their self-selected speed.<br>- Foot and shank angular velocity and linear acceleration data for both limbs were collected using MT9 Xsens Units.<br>- Simultaneously, foot, shank, thigh and pelvis kinematic data for the both limbs were collected using surface mounted reflective markers and a Vicon motion capture system.<br>- Both datasets were collected at a frequency of 100Hz.<br>- To describe joint kinematics, local |

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| | | | coordinate systems (LCS) for each body segment were defined using the CAST approach with rigid plastic plates attached to the pelvis, thighs and shanks.<br>- The inputs to the GRNN were the 24 signals, where there was one acceleration and one angular velocity signal for each of the 3 axes of a sensor box, and 4 sensor boxes (left and right, foot and shank).<br>- The outputs from the GRNN were the 6 sagittal plane angles for the hip, knee and ankle joints on the left and right sides.<br>- 4 measures:<br>(a) Correlation coefficient<br>(b) Percentage of variance<br>(c) Mean absolute deviation<br>(d) Threshold absolute deviation<br><br>**Future work**<br>- Inter-subject predictions of lower limb kinematic data remain the greatest challenge for this approach to utilizing wearable motion sensor system. The sample size required to reduce inter-subject predictions.<br>- Further training data is required for GRNN to test whether is robust for other activities such as stair climbing. |
| 19 | **Title:**<br>A wireless motion sensing system using ADXL MEMS accelerometers for sports science applications<br><br>**Authors:**<br>Fong, D.T.W. et.al | WMOSS<br>- 2 low-cost and micro accelerometers | An acceleration-based wireless motion sensing system (WMOSS) was developed for sports science applications.<br><br>**Low-power wireless motion sensing system (WMOSS)**<br>- A sensing device for wireless acceleration measurement with high sensitivity.<br>- Uses 2 low-cost and micro accelerometers to detect acceleration.<br>- Accelerations, the forces, vibrations and directions of motions can be obtained.<br>- Velocity and displacement information can also be obtained by integration,<br>- Small and handy, and can be easily carried around.<br>- Easily installed because a user only |

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| | | | needs to carry the sensing module and run software to receive transmission data.<br>- Localized vibrations can be directly detected. This may help to determine which motion is potentially harmful to athletes.<br>- Consists of a motion sensing module, a wireless receiving module, and an interface program.<br>(a) Motion sensing module is able to detect acceleration, vibration, force, and send data wirelessly.<br>(b) Interface program collected all the sensor data and can store and display those data instantaneously with some post-processing functions.<br>- Motion sensing module includes 2 dual-axial MEMS accelerometers, a microprocessor and a wireless transmitter.<br>- Microprocessor which is used for signal encoding and conversion.<br>Wireless receiver receives and decodes all the signals. |
| 20 | **Title:**<br>A review of the evolution of microcontroller-based machine and process monitoring<br><br>**Authors:**<br>Frankowiak, M., Grosvenor, R. & Prickett, P. | | Reviews the evolution of intelligent, distributed, microcontroller based machine and process monitoring systems.<br><br>**Importance for effective monitoring**<br>- Support cost reduction and efficiency improvement strategies.<br>- Running equipment longer at optimum levels<br>- More energy efficient<br>- Environmentally friendly industrial processes.<br>- Provide key information that is necessary to plan, implement and manage production in a strategic and effective way.<br><br>**Different monitoring process**<br>- Intelligence system based approaches<br>- Sensor-based machine monitoring systems<br>- Integrated monitoring systems<br>- Distributed monitoring systems |

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| | | | - Embedded and microcontroller based monitoring systems |
| 21 | **Title:**<br>Soft-tissue artefact assessment during step-up using fluoroscopy and skin-mounted markers<br><br>**Authors:**<br>Garling, E.H. et.al. | Fluoroscopy<br><br>Skin-mounted markers<br>- Plate-mounted marker<br>- Strap-mounted marker | Accurately quantify the soft-tissue artefacts and to compare 2 marker cluster fixation methods by using fluoroscopy of knee motion after total knee arthroplasty during a step-up task.<br><br>The most widely accepted non-invasive method to study knee kinematics is stereophotogrammetry using skin-mounted markers. However, soft tissue and structures surrounding the knee interfere with the actual underlying kinematics.<br><br>Soft-tissue artefacts can be reduced when plate-mounted markers or marker trees defining the individual body-segments are used instead of individual unconstrained mounted markers.<br><br>The most accurate measurement technique for in vivo performance of total knee replacement prosthesis is 3-D fluoroscopic analysis. The position and orientation of 3-D computer models of total knee components are manipulated so that their projections on the image match those captured during the in vivo knee motion.<br><br>**Methods**<br>- Subjects: 10 patients were included 6 months after a total knee arthroplasty.<br>- Patients were randomized into 2 groups:<br>(a) Plate-mounted marker group<br>- Received the contour-mounted Thermoplast marker-plates which containing six 3-mm stainless steel beads, mimicking the normally used reflecting markers, at the lateral side of the femur and the medial-frontal border of the tibia.<br>- The marker plates were attached with Velcro straps.<br>(b) Strap-mounted marker group<br>- Received 2 polystyrene squares |

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| | | | attached to elastic straps containing six 2mm RVS beads.<br>- Straps were positioned at the distal part of the lateral femur and at the proximal part of the lateral tibia.<br>- Perform a step-up task in front of the fluoroscope and the knee was positioned in front of the image intensifier.<br>- Data analysis<br>(a) The 2-D positions of the marker projections in the fluoroscopy images were automatically detected with an algorithm based on the Hough-transformation for circle detection.<br>(b) Marker configuration model-based roentgen fluoroscopic analysis was used to estimate the pose of the marker configurations from this 2-D data. This method requires the 3-D models of the defined rigid bodies.<br>- Non-parametric Mann-Whitney U-test was used to compare the differences in anthropometric data between the SM group and the PM group.<br><br>**To avoid the error component of soft-tissue artefacts** in kinematic analyses, kinematic data have been obtained via<br>- Invasive techniques<br>- Exoskeletal attachment systems<br>- Computed tomography<br>- Magnetic resonance imaging<br>- Elimination of error through mathematical correction<br>- Roentgen Stereophotogrammetric Analysis (RSA)<br>- Fluoroscopy<br><br>**Disadvantages**<br>- Risk of infection pain<br>- Loss in freedom of movement<br>- High exposure to radiation<br>- Inaccuracy of the method<br>**Fluoroscopy**<br>- Most accurate and accepted method to study kinematics after total knee replacement |

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| | | | - Exposure to radiation<br>- Limitation of analysis to a single joint<br>- Extensive image data processing<br><br>**Further study**<br>- Expanding the patient group may reveal systematic errors allowing mathematical correction for the skin artefacts in specific tasks<br>- Developed technique for fluoroscopy using digital reconstructed radiographs will provide accurate data for the in vivo kinematics of healthy subjects. |
| 22 | **Title:**<br>Direct measurement of human movement by accelerometry<br><br>**Authors:**<br>Godfrey, A., Conway, R., Meagher, D. & Olaighin, G. | Accelerometers<br><br>Current commercial technologies<br>- RT3 trial research tracker kit<br>- activPAL™ Professional<br>- AntiGraph GT1M<br>- Cyma StepWatch3<br>- Dynastream AMP331<br>- Ossur PAM: Prosthetic Activity Monitor™<br>- IDEEA: Intelligent device for energy expenditure and physical activity | **Application**<br>- Assess human movement in many illnesses.<br><br>**Advantages of accelerometers**<br>- Low power.<br>- Low cost electronic sensors.<br>- Low current draw.<br>- High resolution at typical sampling frequencies used for ambulatory detection.<br>- Small size<br>- Continuous, unobtrusive and reliable method in human movement detection and monitoring.<br><br>**Accelerometers**<br>- Used to measure the rate and intensity of blood movement in up to 3 planes.<br>- Measure tilt (body posture)<br><br>Advances in integrated microelectronic systems (iMEMS)<br><br>**Classification of accelerometers**<br>- Piezoelectric accelerometers.<br>- Piezoresistive accelerometers.<br>- Differentiable capacitor accelerometers.<br><br>**Accelerometer placement**<br>- Ankle and shin (leg movement during walking)<br>- Wrist (study of Parkinsonian tremor)<br>- Close to the center of mass (COM) of the body. |

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| | | | **4 factors to be considered:**<br>- Position at which it is placed.<br>- Its orientation at this location.<br>- Posture of the subject<br>- Activity being performed by the subject.<br><br>**Translating accelerometry data for clinical purposes**<br>- Common analytical and mathematical techniques<br>a. Frequency spectrum analysis<br>b. Multi-resolution analysis<br>c. Wavelets<br>d. Continuous wavelet transform (CWT)<br>e. Discrete wavelet transform (DWT)<br>- Activity determination - classifiers<br>a. Decision trees: Classification and regression tree (CART), ID3 & C4.5<br>b. Naive Bayes Classifies<br>c. Neural networks<br><br>**Factors that affect the choosing an effective motion sensor.**<br>- Reproducibility<br>- Validity<br>- Sensitivity<br>- Feasibility<br>- Cost<br><br>**Limitations**<br>- Algorithms should always be validated in the elderly to account for slow and erratic movement.<br>- Multiple accelerometer arrangements impractical for long-term monitoring because involve numerous cables running across the joints and along the body. |
| 23 | **Title:**<br>Gait dynamics, fractals and falls: Finding meaning in the stride-to-stride fluctuations of human walking | | The magnitude of the stride-to-stride fluctuations and their changes over time during a walk-gait dynamics-may be useful in understanding the physiology of gait, in quantifying age-related and pathologic alterations in the locomotor control system, and in augmenting objective measurement of mobility and functional status.<br><br>Gait dynamics has meaning and may be |

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| | **Authors:** Hausdorff, J.M. | | useful in providing insight into the neural control of locomotion and for enhancing functional assessment of aging, chronic disease, and their impact on mobility. |
| 24 | **Title:** Test-retest reliability of trunk accelerometric gait analysis<br><br>**Authors:** Henriksen M., Lund, H., Nilssen, R.M., Bliddal, H. & Samsoe, B.D. | Tri-axial accelerometer | Determine the test-retest reliability of a trunk accelerometric gait analysis in healthy subjects.<br><br>**Methods**<br>- 20 volunteered and none of the subjects reported previous or present diseases or injuries associated with gait or balance impairments.<br>- Piezoresistent tri-axial accelerometer was secured onto an elastic belt worn by the subjects in a way that the three axes were aligned close to the anatomical axes.<br>- 10 m walking distance on a flat floor with no obstacles nearby was arranged in an indoor hospital environment.<br>- All subjects wore their own comfortable clothing and were barefoot during tests. |
| 25 | **Title:** Video-based human movement analysis and its application to surveillance system<br><br>**Authors:** Hsieh, J.W., Hsu, Y.T., Liao, H.Y.M. & Chen, C.C. | Video-based analysis | Triangulation-based system that analyzes human behavior directly from videos:<br>- Background subtraction to extract body postures from video sequences.<br>- Derive their boundaries by contour tracing.<br>- Delaunay triangulation technique is used to divide a posture into different triangular meshes.<br>- From the triangulation result, two important features, the skeleton and the centroid context (CC), are extracted for posture recognition. |
| 26 | **Title:** Gait event detection using linear accelerometers or angular velocity transducers in able-bodied | Sensor pack<br>- One rate gyroscope<br>- Two biaxial accelerometers | 3 different methods of gait event detection (toe-off and heel strike) using miniature linear accelerometers and angular velocity transducers in comparison to using standard pressure-sensitive foot switches.<br>Compare the identification of IC and EC events in both healthy normal and spinal-cord injured (SCI) individuals with |

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| | and spinal-cord injured individuals<br><br>**Authors:**<br>Jasiewicz, J.M. et.al. | | abnormal gait using either foot linear accelerations, or foot sagittal angular velocity, or shank sagittal angular velocity data.<br><br>A central requirement of any gait analysis system is the ability to accurately and reliably detect foot end contact (EC) and initial contact (IC) events. EC and IC are referred to as toe-off and heel strike, respectively; they are the beginning of swing and stance phases.<br><br>**Foot contact switches**<br>- Consist of force sensitive resistors that are integrated into shoe inserts or taped to the soles of shoes.<br>- Inexpensive and easy to use, these are prone to breakage.<br><br>**Linear accelerometers or rate gyroscopes**<br>- Mounted on the body.<br>- IC event can be extracted from linear accelerometers.<br>- EC events can extracted from linear accelerometers or rate gyroscopes.<br><br>**Methods**<br>- 26 healthy volunteers, 14 SCI individuals and 1 person with Charcot-Marie-Tooth (CMT) Syndrome.<br>- Subjects were asked to walk 8m at their normal self-selected pace.<br>- All event detection and analysis software were developed in Labview.<br><br>**a. Sensor systems**<br>- Sensor pack contained one rate gyroscope to record angular velocity about y-axis, two biaxial linear accelerometers (ADLX202) and a programmable 4-MHz 10 bit-microprocessing chip with three analog inputs.<br>- Sampling rate to 25Hz occurred.<br>- Attached using hypoallergenic double-sided tape to ensure minimum movement of the sensor relative to the skin. |

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| | | - 4 sensor locations: dorsal surface of the left and right shoes and ventral surface of the left and right mid-shank.<br>- An assistant held the PDA and used it to start data collection.<br><br>**b. Foot switches**<br>- 2 pairs of heel and toe foot switches (MIE) were attached to the soles of walking shoes using double-sided tape.<br>- Sampled as analog voltages simultaneously with sensor signals at 25Hz. |
| 27 | **Title:**<br>Classification of posture and movement using a 3-axis accelerometer<br><br>**Authors:**<br>Jeong, D.U., Kim, S.J. & Chung, W.Y. | MMA 7260Q Tri-axial accelerometer | - The present study implemented a small-size and low-power acceleration monitoring system for convenient monitoring of activity volume and recognition of emergent situations such as falling during daily life.<br>- Developed a wireless transmission system based on a sensor network.<br>- Developed a program for storing and monitoring wirelessly transmitted signals on PC in real-time.<br><br>**Methods**<br>- MMA7260Q accelerometer measured acceleration information of axis X, Y and Z according to the subject's posture and activity.<br>- TIP710M, a Zigbee compatible wireless sensor node.<br>- Implemented a monitoring program using LabView8.0.<br>- Filter circuit to each output terminal of the sensor to remove noise.<br>- Buffer circuit was designed using OP-Amp in order to prevent impedance. |
| 28 | **Title:**<br>Design and analysis of an orientation estimation system using coplanar gyro-free inertial measurement | 7 single-axis linear accelerometers and 3-axis magnetic sensors. | 2 ways to determine the **orientation angles** of an object:<br>(a) Uses 3-axis accelerometers and 3-axis magnetic sensors<br>- Often contaminated by the sensor noise and drift.<br>- Often interrupted by the surroundings<br>- Inaccuracy of the angle determination |

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| | unit and magnetic sensors.<br><br>**Authors:**<br>Kao, C.F. & Chen, T.L. | | (b) uses additional 3-axis gyroscopes<br>Then integrated by the "Sensor fusion" techniques to improve the accuracy of the angle estimation.<br><br>2 ways to measure **3-axis angular velocity** using inertial sensors.<br>(a) 3 gyroscopes<br>(b) linear accelerometers together with signal processing techniques (referred to gyro-free Inertial measurement unit, IMU)<br>- Expensive<br>- Susceptible to the alignment error that would deteriorate its sensing accuracy. |
| 29 | **Title:**<br>A new type of model-based Roentgen stereophotogrammetric analysis for solving the occluded marker problem.<br><br>**Authors:**<br>Kaptein, B.L., Valstar, E.R., Stoel, B.C., Rozing P.M., & Reiber, J.H.C. | Roentgen stereo-photogrammetric analysis (RSA)<br><br>Marker Configuration Model-based RSA (MCM-based RSA) | **Convectional: Roentgen stereo-photogrammetric analysis (RSA)**<br>- Measures micromotion of an orthopaedic implant with respect to its surrounding bone.<br>- Accurate three-dimensional (3-D) measurement technique.<br>- Implant and the surrounding bones are marked with tantalum beads.<br>- From the projections of these markers, detected in a stereo-pair of roentgen images, their 3-D positions are reconstructed.<br>- Difficulty of RSA is markers that are attached to the implant or inserted close to the implant may be over projected by the implant itself.<br>- Marker positions are calculated as the crossing point of 2 corresponding projection lines.<br><br>**New Model: Markers configuration model (MC-model)**<br>- Estimate the pose of the rigid body.<br>- Describes the positions of the markers in the rigid body relative to each other.<br>- The positions of the markers in the rigid body relative to each other.<br>- Projection lines that have no corresponding marker occasionally need to be removed from the matching procedure by a human operator.<br>- In order to project each marker to its |

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| | | | corresponding projection line, the markers are sorted based on their distances and a number of markers is selected that is equal to the number of projection lines, leaving out the markers with larger distances.<br><br>**Methods:**<br>- The migration of the tibial component of the interax total knee prosthesis related to the tibia was measured.<br>- Validated using collected data from double examinations obtained from 15 patients.<br>- RSA radiographs were digitized by a Vidar VXR-12 CCD scanner at 150 DPI and a grey-scale resolution of 8 bits, and processed using the conventional RSA-software package RSA-CMS.<br>- Occlusion of markers was stimulated by excluding one or more detected markers from the pose estimation. |
| 30 | **Title:**<br>Accelerometry: A technique for quantifying movement patterns during walking<br><br>**Authors:**<br>Kavanagh, J.J. & Menz, H.B. | Accelerometer-based systems | **Advantages of accelerometer**<br>- Low cost and small<br>- Relatively unrestricted<br>- Eliminate errors associated with differentiating displacement and velocity data<br>- Offer diversity of dynamic range<br>- Sensitivity<br><br>Conventional gait analysis are optoelectronic and force plate motion analysis<br><br>**Classification of accelerometers**<br>- Strain gauge<br>- Piezoresistive<br>- Capacitive<br>- Piezoelectric<br><br>**Calibration**<br>- Static calibration<br>- Periodic calibration<br><br>**Optimal conditions for use**<br>- Elastic bandages and Velcro straps to ensure a firm skin-marker fixation<br>- To avoid amplifying noise during |

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| | | | differentiation procedures, substantial low-pass filtering may be necessary.<br>- Triaxial accelerometer attached over the L3 spinous process is suggested to closely to reflect actual lower trunk accelerations.<br><br>**Signal Processing**<br>- Frequency-domain analysis of the acceleration signal provides additional insight about how the locomotion system organises movement, attenuates vibration, and accommodates to perturbation.<br>- Transfer functions provide measure of attenuation that accounts for both the amplitude and frequency of movement.<br><br>**Applications**<br>- Examine features of the walking pattern.<br>- Provide useful insights into the motor control of normal walking. |
| 31 | **Title:**<br>Reliability of segmental accelerations measured using a new wireless gait analysis system<br><br>**Authors:**<br>Kavanagh, J.J., Morrison, S., James, D.A. & Barrett, R. | Wireless gait analysis<br>- Near real-time data transmission via a Bluetooth network<br>- Accelerometer-based systems | To determine the inter- and intra-examiner reliability, and stride-to-stride reliability, of an accelerometer -based gait analysis system which measured 3D accelerations of the upper and lower body during self-selected slow, preferred and fast walking speed.<br><br>**Accelerometer-based systems**<br><br>**Advantages**<br>- Lightweight<br>- Portable<br>- Unencumbered movement of the subject<br>- Do not confine data collection to the laboratory environment<br>- Easy to use<br>- Cost effective<br>- Able to capture data from many gait cycles<br>- Avoid errors associated with differentiation of raw displacement data<br>- Sufficiently sensitive to detect rapid movements even when the corresponding displacements are small |

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| | | | **Limitations**<br>- Not straightforward to distinguish between the inertial and gravitational components of the signal without additional information describing the orientation of the device.<br>- Difficulties relating acceleration data to a global reference frame since the acquired data's frame of reference is continually moving.<br>- Skin motion artefact due to impact loading and muscle activation can readily contaminate signals.<br>- Location and orientation of the attached accelerometers can also have a substantial influence on the output signal.<br><br>**Methods**<br>a. Subject: 8 healthy male subjects with no history of neurological disorder or musculoskeletal pathology or injured.<br>b. Experimental design<br>- Perform 5 straight-line walking trials along a 30m level walkway at self-selected slow, normal and fast walking speed conditions during 2 testing sessions.<br>- For inter-examiner, the walking protocol was repeated after the accelerometers were reattached by a different examiner.<br>- For intra-examiner, 1 examiner from the initial testing session repeated the test in another session conducted within 24 hours.<br>- Gait velocity was monitored by 3 pairs of Omron (E3JK-R4M2) photoelectric light gates spaced at 5m intervals in the middle of the walkway.<br>c. Instrumentation<br>- 4 accelerometer nodes were attached to each subject to measure 3D accelerations during walking.<br>- An individual accelerometer node consisted of 2 biaxial accelerometers (ADXL202) mounted perpendicular to each other.<br>- Accelerometer nodes attaches over (1) |

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| | | occipital pole of the head with a firm fitting elastic headband (2) the neck (C7 spinous process) (3) the trunk (L3 spinous process) and (4) the right shank with rigid sports tape.<br>- Each accelerometer node was connected to processor box fixed to the subject's waist.<br>- Processor box contained a Hitachi microprocessor (H8/300H), a Bluetooth Personal Area Network device for external communications, 2 AAA batteries and a power regulation module.<br><br>Reliability was assessed using the coefficient of multiple determinations (CMD), a waveform similarity statics that indirectly quantifies the percentage variance accounted for within the data.<br><br>CMD's for stride-to-stride reliability were not significantly different from inter-or intra-examiner reliability due to the errors associated with the reapplication of accelerometers by the same or different examiners were minimal.<br><br>The test-retest reliability of accelerations was significantly influenced by the location and direction of accelerations, as well as walking speed. |
| 32 | **Title:**<br>Gait analysis system for assessment of dynamic loading axis of the knee<br><br>**Authors:**<br>Kawakami, H. et.al | Computer-assisted gait analysis system | Demonstrate a computer-assisted gait analysis system.<br><br>Precise estimation of the loading axis of the lower limb on the knee joint is important for patients with knee osteoarthritis (OA).<br><br>**Computer-assisted gait analysis system**<br>- Uses skeletal structure data, motion capture data and force plate data.<br>- 6 plastic ball markers that reflect infrared light were attached to the lower limb surface of the subjects.<br>- Examine the accuracy of this system using open MRI. |

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| 33 | **Title:**<br>Wireless MEMS inertial sensor system for golf swing dynamics<br><br>**Authors:**<br>King, K., Yoon, S.W., Perkins, N.C. & Najafi, K. | Wireless six-degree-of-freedom MEMS inertial measurement unit (IMU) | Highly accurate, portable and inexpensive sensor system to support golf swing training, custom club fitting and club design.<br><br>MEMS inertial sensors system consists of a complete six-degree-of0freedom IMU composed of MEMS accelerometers and angular rate gyros with an integrated microprocessor and RF transceiver.<br><br>Enables the computation of the position, velocity and orientation of the club head at the opposite end of the shaft during the entire putting stroke.<br><br>**Common swing measurement system**<br>- High speed video<br>- Optical tracking systems<br>- Camera-based systems<br>- Marker-based systems<br><br>**Limitation**<br>- Extensive set-up and alignment<br>- Restriction to indoor use<br>- High cost<br>- Lack of portability<br>- Placement of instruments (marker) on or near the head of the club<br>- Time consuming data processing and analysis. |
| 34 | **Title:**<br>Inertial gait phase detection for control of a drop foot stimulator inertial sensing for gait phase detection<br><br>**Authors:**<br>Kotiadis, D., Hermens, H.J. & Veltink, P.H. | Accelerometer and gyroscope | An inertial gait phase detection system was developed to replace heel switches and footswitches currently being used for the triggering of drop foot stimulators.<br><br>Capacitive accelerometers and vibrating element gyroscopes provide us with accelerations and angular velocity is used in the system.<br><br>The design of the system using simple threshold settings allows for the signals to be used after simply low-pass filtering for the accelerometers and no pre-processing for the gyroscopes and requiring only a low performance processor to run the algorithm. |

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| | | | The small number of components, single gyroscope and two accelerometers is also a plus in terms of power and size. Although gyroscopes use more power than accelerometers, they also produce better results. |
| 35 | **Title:**<br>Determination of location and orientation of 3-axis accelerometer for detecting gait phase, duration, and speed of human motion for development of prosthetic knee<br><br>**Authors:**<br>Kumar, N., Kunju, N., Kumar, A. & Sohi, BS. | ADXL 330 accelerometer | - Prosthetic control, an intelligent prosthetic device like electronic knee requires knowing in real time the activity of amputees so as to control the prosthetic device to match his gait close to normal.<br>- Control of knee is divided into swing phase control and stance phase control.<br><br>**Methods**<br>- Placing sensor at thigh and shank of lower limb simultaneously.<br>- Walk on level surface (bare footed) with slow, normal & fast speed according to their own comfort level.<br><br>Help amputee patient to walk more near natural gait. |
| 36 | **Title:**<br>A portable system for the measurement of the temporal parameters of gait<br><br>**Authors:**<br>Kyriazis, V., Rigas, C. & Xenakis, T. | Portable system<br>- Transmitter<br>- 4 electrical sensor<br>- Receiver<br>- Personal computer (PC) with appropriate software<br><br>Transmitter logic circuit<br>- 2 Aurel Totem Line Radiofrequency transmitter modules, a TX-433-SAW and a TX-224- | **Limitations of gait analysis techniques**<br>- Assessment in footfall timing<br>- Carry heavy attachments or accessories and wires at their trials<br>- Complexity of construction<br>- Not portable, requiring a special room for gait tests<br><br>**Advantages of portable system**<br>- Low-cost<br>- Easy to use<br>- Easily reproducible<br>- Frees the subjects from wires that may affect or hinder their gait.<br>- Portable<br>- Can be perfectly used in at least 30 passes<br>- On-line system |

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| | | SAW module.<br>- Two 9V batteries used for supply<br>- 2 resistances of 10KΩ<br>- 2 antennas for signal transmission<br><br>Receiver circuit<br>- 2 antennas for signal detection<br>- 2 Aurel Totem line adapter STD-RS 232 modules.<br>- 2 4N28 photocouplers serve the isolation of the receivers' ground and the PC's ground.<br>- 9V battery | **Methods**<br>- Sensors are taped under the subjects' shoes, one under front and one under the back part of each shoe.<br>- Sensors require 10N minimum force to detect input.<br>- 2 sensors connected parallel and are used as inputs to the transmitter modules placed at the waist.<br><br>**Software**<br>- Designed in the laboratory to read the card's inputs<br>- Analyse the data and present out results<br>- Written in Visual Basic<br><br>**Validation of system**<br>- Tested with a layout, which consists of a piston that moves vertically and repeatedly presses the object beneath.<br>- Validated with a group of 20 healthy adults and perform 3 passes with self-selected fast speed. |
| 37 | **Title:**<br>Development of low cost motion-sensing system<br><br>**Authors:**<br>Lan, J.H., Nahavandi, S., Yin, Y.X. & Lan, T. | Micro-electro-mechanical system (MEMS) technology<br>- Accelerometer<br>- Gyroscopes | Develops a low cost motion-sensing system to track the 6 degrees of the object of interest.<br><br>**Applications**<br>- Military<br>- Space exploration<br>- Industrial intelligent robots<br>- Vehicles<br>- Toys<br><br>**Inertial sensors**<br>- Effective type of motion sensor<br>- Accelerometers and gyroscopes comprise inertial sensing<br>- Attaches directly to the moving body of interest<br>- Operate regardless of external references, friction, winds, directions and dimensions<br><br>**Principle of the system**<br>- Measurement of 6 dimensional |

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| | | | movement parameters<br>- Combination of micro accelerometers, gyroscopes, signal processing circuits and signal conditioning circuits<br>- Angular rate information is gained by micro gyroscopes<br>- Acceleration information is gained by micro accelerometers.<br><br>**Principle of inertial sensors used in the system**<br>(a) MEMS gyroscopes<br>- Typically use vibrating structures because of the difficulty of micromachining rotating parts with sufficient mass to be useful. Their current structure consists of a quartz and silicon vibrating beam.<br>- The difference among different MEMS gyroscopes lie in the vibrating device such as electro-static, electromagnetic and piezoelectric vibrating devices.<br>- The principle of vibrating gyroscope is based on the Coriolis effect.<br>(b) MEMS accelerometers<br>- Several types such as piezoresistive, capacitive, resonant beam, piezoelectric sensors and so on.<br><br>**Constitution of the system**<br>- 2 dual-axis solid-state micro rate gyros<br>- 2 dual-axis micro accelerometers<br>- Amplifier<br>- Conditional circuits<br>- Filter<br>- Voltage regulator<br>- A/D converter (12 bits, 32 channels & 100KHz)<br><br>**Software of the system**<br>- A user interface of the system is designed through the use of MFC software<br>- System data, velocity and motion and attitude display different values of various information |

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| | | | **Future work**<br>- Close integration of the inertial sensor and the algorithms<br>- Continuous current trend in miniaturizing sensors, reducing costs and provide sensors with accuracy. |
| 38 | **Title:**<br>Graphical programming based biomedical signal acquisition and processing<br><br>**Authors:**<br>Lascu, M & Lascu, D. | LabVIEW | - Describes a computer based signal acquisition, processing and analysis system using LabVIEW, a graphical programming language for engineering applications.<br><br>**Data Acquisition**<br>- Used National Instruments PCI-6023E board from the 6023E, 6024E and 6025E family.<br>- NI-DAQ has an extensive library of functions that you can call from your application programming environment. These functions include routines for analog input (A/D conversion), buffered data acquisition (high-speed A/D conversion), analog output (D/A conversion), waveform generation (timed D/A conversion), digital I/O, counter/timer operations, SCXI, self-calibration, messaging, and acquiring data to extended memory. |
| 39 | **Title:**<br>The reliability of using accelerometer and gyroscope for gait event identification on persons with dropped foot<br><br>**Authors:**<br>Lau, H.Y. & Tong, K.Y. | Accelerometer and gyroscope | A threshold detection method for identifying gait events and evaluating the reliability of a system on subjects with dropped foot and three non-impaired controls.<br><br>This system comprised three sensor units of accelerometers and gyroscopes attached at the thigh, shank and foot of the impaired leg in subjects with dropped foot, and the dominant leg in the controls.<br><br>**Methods**<br>- 3 non-impaired subjects and 10 hemiparetic patients with dropped foot following stroke were recruited.<br>- The non-impaired subjects reported no musculoskeletal condition or injury that could affect their gait.<br>- Each sensor units comprised one dual- |

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| | | | axis accelerometer and one single-axis gyroscope.<br>- The gyroscope was orientated to measure the segmental rotation about the hip, knee, and ankle joints in the sagittal plane.<br><br>**Applications**<br>- Detected stair climbing and level ground walking events using a gyroscope attached on the shank with good reliability.<br><br>**Future work**<br>- Evaluate the senor system in other walking conditions, such as walking on a slope, or stair climbing. |
| 40 | **Title:**<br>Wearable accelerometer system for measuring the temporal parameter gait<br><br>**Authors:**<br>Lee, J.A.,<br>Cho, S.H.,<br>Lee, J.W.,<br>Lee. K.H. &<br>Yang, H.K. | Wireless accelerometer system was built using two 3-axis accelerometers | Measurements of temporal parameters of gait are used for the quantification of their subsequent improvement after therapeutic exercise.<br><br>Accelerometers and footswitches had high consistency in the temporal gait parameters.<br>**Gait analysis**<br>- Investigate the features of normal or abnormal gait<br>- To quantify subsequent improvement after the lower-extremity operation<br>- To assess balance and mobility monitoring<br><br>**Instruments assist in the study of human gait**<br>- Motion analysis system and force plates ( cost and intricate setting have limited those to use them for large trials and daily life)<br>- Foot switches or pressure sensors attaches to the sole (provide unsatisfactory results for abnormal walking and sensor attachment.<br>- Accelerometer sensors<br><br>**Methods**<br>a. Subject: 8 subjects (5 men & 3 women) without lower limb abnormalities, previous lower limb surgery and lower |

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| | | | pain as well as with neurological or surgical abnormalities on clinical examination.<br>b. Implementation of accelerometer system<br>- Using 3-axis accelerometer (MMA7260, Freescale, TX)<br>- Sensitivity of accelerometers is calibrated by rotating device with variable speed and measured to calibrate the accelerometer signals in gravitational constant g as a unit.<br>c. Data sampling<br>- Data from the pair of ankle devices were A/D converted and transmitted wirelessly to PC-side receiver.<br>- Acknowledge 3.7.3 program (BIOPAC) read-in the data to determine its frequency domain and apply low pass filter.<br>d. Gait analysis<br>- Accelerometer system was attached to the lateral side of the both ankles.<br>- Two footswitches sensors were placed inside each sole of a foot, under the heel and the first metatarsal.<br>- Acknowledge 3.7.3 program was used for the visual peak detection while comparing it with simultaneous footswitch data and the following gait parameters were determined for the each gait cycle: stance time, swing time, single support time and double support time.<br>e. Statistical Analysis<br>- Interclass correlation coefficients (ICC) were used for each gait parameters.<br>- ICC $< 0.75$ was considered as ‘poor to moderate’.<br>- ICC $> 0.75$ was considered as ‘good’.<br>- ICC $> 0.90$ was considered as ‘excellent’.<br>f. Results<br>- The temporal parameters detected by the footswitches and those from the accelerometers matched well. |

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| | | | 2 peaks of acceleration for each gait cycle from the accelerometers could be found in normal gait. The first accelerometer peak meaning heel contact and the second peak meaning toe off.<br><br>**Limitations of this study**<br>- Accelerometer signal analysis by visual inspection and small number of subjects.<br>- For the visual inspection, only 20 steps from each subject were selected by the examiner.<br><br>**Further work**<br>- Automatic peak detection and phase measurement program should under development. |
| 41 | **Title:**<br>The concurrent validity of the body center of mass in accelerometric measurement<br><br>**Authors:**<br>Lee, H.K., Cho, S.P., You, J.H. & Lee, K.J. | Accelerometric measurement<br>- 3 AMTI force plates<br>- Piezoresistant accelerometer, CXL02LF3.<br><br>VICON motion analysis system measurement<br>- 6 optical camera motion capture system | 2 computational estimation methods of body center of mass (COM)<br>- Accelerometric measurement computed via trapezoidal double integration methods.<br>- VICON motion analysis system measurement computed via VICON polygon.<br><br>Falls are the 6$^{th}$ leading cause of death therefore importance to better understand underlying neuromechanical mechanism and to accurately detect gait instability associated with elderly falls.<br><br>**Methods**<br>a. Subjects: 4 healthy young adults and were free from any neuromuscular and cardiopulmonary system disorders.<br>b. Data acquisition:<br>- 32 reflective markers were placed on each subject's body landmarks based on Helen-Hayes marker set.<br>- Piezoresistant accelerometer secured on the surface on the 2$^{nd}$ sacrum.<br>- Subjects walked on the 6m long walkway at their self-selected speed.<br>- After signal processing and analysis were performed on Matlab 7.0.<br>c. Signal Processing:<br>- COM data signals obtained from |

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| | | | VICON were automatically processed with the VICON polygon software.<br>- COM data signals obtained from accelerometric using the trapezoidal double integration computation method.<br>- The heuristic signal processing method was used to filter unwanted noise.<br>- Least-squares polynomial curve fitting method was employed to remove cumulative noise resulting from the double integrated signal processing of the acceleration data to avoid integration drift and velocity signals.<br>- Processed with the $60^{th}$ order finite impulse response (FIR) low pass filter at a cut-off filter at a cut off frequency of 5Hz to remove high frequency noise associated with movement-related artefact.<br>a. Data analysis<br>- Correlation statistics was used to determine the concurrent validity of the accelerometer measurement.<br><br>Accelerometric measurement and signal processing methods for the body COM was as accurate and reliable as the conventional motion analysis method using VICON.<br><br>**Further study**<br>- To optimize signal processing method<br>- Enhance the ability to detect the body COM with greater precision using a portable and inexpensive accelerometric measurement system. |
| 42 | **Title:**<br>Physical activity recognition using a single tri-axis accelerometer<br><br>**Authors:**<br>Lee, M.H.,<br>Kim, J.C., | ADXL330 Accelerometer | - Present a method to convenient monitoring of detailed ambulatory movements in daily life, by use of a portable measurement device employing single tri-axis accelerometer.<br><br>**Methods**<br>- Wearable device consisted of Micro SD-Memory card connector with mini USB socket. |

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| | Lee, I.H., Jee, S.H. & Yoo, S.K. | | - ADXL330, Li-ionic batteries & microprocessor units is needed.<br>- Sampling frequency was 100Hz.<br>- Data was downloaded via USB and processed offline by a PC.<br>- Mean and standard deviation of acceleration and correlation features were extracted from acceleration data.<br><br>**Limitations**<br>- Collected data was from younger subjects.<br>- Single accelerometer of placed on body waist typically do not measure ascending and descending stairs walking.<br><br>**Future direction**<br>- Implementation of real-time processing firmware and encapsulation of the hardware. |
| 43 | **Title:** Development of a wearable sensor system for quantitative gait analysis<br><br>**Authors:** Liu, T., Inoue, Y. & Shibata, K. | Gyroscopes (ENC-03J) and 2-axis ADXL202 accelerometers | Development of a wearable sensor system for quantitative gait analysis using inertial sensors of gyroscopes and accelerometers.<br><br>**Multi-camera systems** and reaction force measurement using force plates to tracking human body parts and performing dynamics analysis of their physical behaviours in a complex environment.<br><br>**Optical motion analysis methods**<br>- Needs considerable work space<br>- Needs high-speed graphic signal processing devices<br>- Expensive<br>- Pre-calibration experiments and off-line analysis of recorded pictures are especially complex<br>- Time consuming<br>**Magnetic or sonic technologies**<br>- Limited to laboratory research<br>- Difficult to be applied in daily life applications or complex environments.<br><br>**Wearable sensor system**<br>- Lower cost |

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| | | | - Friendly operation<br>- Less effect to human<br><br>Analysis of human walking pattern by phases more directly identifies the functional significance of the different motions accruing at the individual joints and segments.<br><br>Normal walking gait cycle is divided into 8 different **gait phases**<br>- Initial contact<br>- Loading response<br>- Mid stance<br>- Terminal stance<br>- Pre-swing<br>- Initial swing<br>- Mid swing<br>- Terminal swing<br><br>**Sensor system**<br>- 3 gyroscopes are used to measure angular velocities of leg segments of foot, shank and thigh.<br>- In local coordinates of 3 segments, sensing axis of the gyroscopes is along y-axis, and the z-axis is along leg-bone.<br>- 2-axis accelerometer is attached on the side of the shank to measure 2-directional accelerations along tangent direction of x-axis and sagittal direction of z-axis.<br><br>**Hardware system design**<br>- 8-channel data recorder can be pocketed by the subject<br>- A gyroscope and accelerometer combination unit located on shank<br>- 2 gyroscope units attached on foot and thigh<br>- The signal from the gyroscopes and accelerometer is simplified and low-filtered by cut off frequency 25Hz to remove electronic noise.<br>- Micro-computer PIC (16F877A) is used to develop the pocketed data recorder, and sampling data from the inertial sensors can be saved in SRAM.<br>- Off-line motion analysis can be performed by feeding data saved in the |

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| | | | SRAM to a personal computer through a RS232 communication module or a wireless module.<br>- Experiments data were processed using MATLAB, in which a direct integral calculation was designed to estimate orientations of the 3 leg segments.<br>- Low energy consumption which can be powered using a rechargeable battery of 300mAh.<br><br>**Calibration of sensor units**<br>- A/D card, a potentiometer, a reference angle finder and a clamp.<br>- The calibration of the accelerometer sensor is carried out during the static state.<br>- The dynamic calibration is completed to calibrate the gyroscopes and test the accelerometer in a moving condition.<br><br>**Optical motion analysis system**<br>- To validate the sensor system performance<br>- Hi-Dcam tracked and measured the 3D trajectories of retro-reflective markers placed on the subject's body.<br>- 2 high-speed cameras with sampling frequency 50Hz are used to track the marker positions with accuracy of 1mm.<br><br>**Performance analysis of the sensor system**<br>- The motion analysis results of the 2 systems should be identical in a time domain and therefore the correlation coefficient should approach 1.<br>- The motion analysis results of the 2 systems should be quantitatively identical and therefore the root means squared error (RMSE) should be approach 0.<br><br>**Future study**<br>- Develop a wearable sensor system for estimating muscular tensions instead of EMG<br><br>**Application**<br>- In the study of robotics, this wearable |

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| | | | sensor system is applied for real-time control of humanoid robot which may walk in the same phase as human walking. |
| 44 | **Title:** Accuracy of an optical active-marker system to track the relative motion of rigid bodies<br><br>**Authors:** Maletsky, L.P., Sun, J.Y. & Morton, N.A. | Optical active-marker system | **Methods to measure the relative motion of 2 bones**<br>- Goniometers<br>- Video cameras<br>- Electromagnetic sensors<br>- Optical devices<br>- Fluoroscopy<br><br>**Electromagnetic kinematic measurement system**<br>- The position and orientation of a receiver is described relative to a transmitter.<br>- Metal in the measurement area cause field distortion that decreases the accuracy.<br>- Noise increase and signal quality decreases as the distance between the sensor and transmitter increase beyond the suggested range.<br><br>**Optical systems**<br>**a. Passive marker**<br>- Using passive markers typically have a series of cameras that triangulate the position of a retroreflective ball in space.<br>- Accuracy values dependent on factors such as<br>➢ The location of the cameras relative to each other<br>➢ The distance from the cameras to the markers<br>➢ The motion of the markers in the viewing volume.<br>**b. Active marker**<br>- Use infrared light-emitting diodes (IRED) that are triangulated in space using a set of cameras, typically in a fixed orientation to each other.<br>- Accuracy of a single marker position is affected by<br>➢ The distance and the angle from the camera to the marker.<br>- Optotrak® 3020 active-marker |

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| | | | optical system was used.<br><br>**Methods**<br>- To quantify static noise, data continuously sampled at 30Hz was collected at seven different positions.<br>- To examine the effect of distance from the cameras to the rigid body, five camera distances were selected between 1.75 and 4.75m.<br>- NDI ToolBench was used to calculate the position and orientation of the rigid body relative to each other.<br><br>Increasing the camera distance increased the measured noise. A static position the noise can be minimized by averaging over a short duration, but this solution is not possible when dynamic measurements are required.<br><br>The accuracy of the Optotrak rigid body seems to be slightly better than that of the electromagnetic system and typically much better than that of the passive marker systems. |
| 45 | **Title:** Accelerometer and rate gyroscope measurement of kinematics: An inexpensive alternative to optical motion analysis systems<br><br>**Authors:** Mayagoitia, R.E., Nene, A.V. & Veltink, P.H. | Body-mounted sensor consisted of 4 uniaxial seismic accelerometer and 1 gyroscope per body segment. | **Advantages of body-mounted sensors**<br>- Accurate<br>- Inexpensive<br>- Portable<br>- Allow long-term recordings in clinical, sport and ergonomics settings<br>- More cumbersome than the markers but does not alter movement<br><br>**Advantages Optic motion analysis**<br>- Expensive<br>- Restricted volume<br>- Markers are easily obscured from vision resulting in incomplete data<br><br>**Methods**<br>- Instrumentation: 4 pairs of uniaxial accelerometers were mounted on 2 aluminium strips & gyroscope was attached to the midpoint of each aluminium strip to measure the angular velocity.<br>- Subjects: 10 normal males aged |

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| | | | between 23 and 27 years.<br>- Test protocol: performed ten 10s or 12s treadmill walking trials consisting of 2 repetitions at 5 speeds wearing their usual shoes.<br>- Data analysis:<br>a. Matlab was used for all signal processing<br>b. 6th order Butterworth low-pass filter with a cut-off frequency of 3Hz was used to remove noise from all the raw data.<br>c. Optic data were gathered simultaneously using a Vicon® System.<br>d. Coefficient of multiple correlations (CMC) was used to look at the closeness in the shape of the 2 signals.<br><br>**Discussion**<br>- Body-mounted sensors give results that are very close to those of Vicon® presenting small RMS and large CMC values.<br>- Errors do increase at the highest speed for the accelerometer data due to the sensors being hit or vibrated during heel strike.<br>- The rate gyroscopes were not affected. |
| 46 | **Title:** Objective monitoring of physical activity in children: considerations for instrument selection<br><br>**Authors:** McClain, J.J. & Tudor-Locke, C. | Accelerometer & pedometer | - Provide a primer to guide selection of instruments for the objective monitoring of children's physical activity.<br>- Instrument selection is further complicated for those who study children's physical activity due to:<br>(1) The challenge associated with detecting the typically short and sporadic nature of children's physical activity patterns.<br>(2) The diversity of developmental maturity/age among potential participants.<br>(3) Children's inherent curiosity regarding wearable technologies and the associated potential for reactivity to monitoring. |

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| | | | **Pedometers**<br>- Simple and low cost.<br>- Yamax pedometer to determine free-living physical activity in youth.<br>- Generally not designed to detect time in specific categories.<br>- More delimited activity time.<br><br>**Accelerometer**<br>- Detect accelerations at specific attachment points on the body.<br>- The most widely used and extensively validated accelerometer for assessment of physical activity among children is the ActiGraph.<br>- Range in price from $50 to over $400 per unit.<br><br>**Methods**<br>- Participant burden during objective physical activity assessment is comprised of 2 primary factors:<br>(1) Ease and comfort of instrument wear<br>(2) Data recording requirements<br>- Affixing instruments to elastic belts may actually allow children to more quickly and independently prepare, attach, and wear the instrument; and may reduce the chance of a child inadvertently losing the instrument. |
| 47 | **Title:**<br>Recovery of walking speed and symmetrical movement of the pelvis and lower extremity joints after unilateral THA<br><br>**Authors:**<br>Miki, H. et.al. | 3D-optical analyzer and 15 surface markers | Determine how much THA could restore the preoperative primary impairment of hip motion.<br><br>17 patients with unilateral hip disease who underwent total hip arthroplasty (THA), the gait was analyzed preoperatively and 1, 3, 6 and 12 months after unilateral THA using a Vicon system to assess the recovery of walking speed and symmetrical movement of the hip, knee, ankle and pelvis.<br><br>The impairment of hip function in patients with coxoarthropathy not only has a harmful influence on the walking speed but also affects the motion of the pelvis and knee. |

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| | | | **Methods**<br>- Subjects: 17 patients who underwent unilateral total hip arthroplasty.<br>- Implantable systems:<br>(a) BHR system ( 9 patients)<br>(b) ANCA fit system (4 patients)<br>(c) Versys Hip system<br>(d) Perfix system<br>(e) SROM system<br>(f) Partnership system<br>- The gait was analyzed preoperatively and at 1, 3, 6, and 12 months postoperatively.<br>- Movements of the bilateral lower extremity joints were measured with a 3D-optical analyzer and 15 surface markers.<br>- Kinematic data were collected at a sampling rate of 60Hz.<br>- 2 Kistler force plates were used to measure the ground reaction force with sampling rate of 600Hz.<br>- Vicon clinical manager software was used to calculate the<br>(a) relative angles between coordination systems of each segment in the lower limb<br>(b) absolute angles between a coordination system of pelvis and the laboratory coordination system<br>(c) the moment of force in each joint from the kinematic data<br>(d) Ground reaction force<br>- Basic gait parameters, including cadence, stride length, and step length, were measured directly on each side by the Vicon system.<br>- Analysis:<br>(a) Statistical analysis – Stat View 4.58 software<br>(b) Student's t-test<br>(c) I-factor repeated ANOVA and paired student's t-test<br>(d) Fisher's r to z test<br><br>The greatest improvements of gait symmetry and of both temporal and spatial gait parameters occurred within the first 6 months after unilateral THA. |

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| 48 | **Title:**<br>Wireless sensor networks for personal health monitoring: Issues and an implementation<br><br>**Authors:**<br>Milenkovic, A., Otto, C. & Jovanov, E. | Wearable wireless personal/body area network (WWBAN) | Discusses implementation issues and describes the wearable wireless body/personal area network (WWBAN) for health monitoring that utilizes off-shelf 802.15.4 compliant network nodes and custom-built motion and heart activity sensors.<br><br>**Wireless personal or body networks (WPANs or WBANs)**<br>- Inexpensive<br>- Non-invasive<br>- Continuous<br>- Ambulatory health monitoring with almost real-time updates of medical records via the internet.<br><br>**Wearable health monitoring devices**<br>- Simple pulse monitors<br>- Activity monitors<br>- Portable Holter monitors<br>- Implantable sensors<br><br>**Wireless sensor networks applications**<br>- Habitat monitoring<br>- Machine health monitoring and guidance<br>- Traffic pattern monitoring and navigation<br>- Plant monitoring in agriculture<br>- Infrastructure monitoring<br>- Health monitoring<br><br>**WWBAN architecture**<br>- Encompasses a number of wireless medical sensor nodes, personal server (PS) and a medical servers accessed via the internet.<br>- Each sensor node can sense, sample, and process one or more physiological signals.<br>- The PS application running on a Personal Digital Assistant (PDA), a cell phone or a home personal computer.<br>- PS providing a transparent interface to the wireless medical sensors, an interface to the user and an interface to the medical server.<br>- Medical serves sets up a communication channel to the user’s PS, collects the |

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| | | | reports from the user and integrates the data into the user's medical record.<br><br>**Requirements for wireless medical sensors**<br>- Wearability<br>- Reliable communication<br>- Security<br>- Interoperability<br><br>**WWBAN Prototype**<br>- Consisted of multiple ACtiS sensor nodes that are based on a commonly used sensor platform and custom sensor boards.<br>- A sensor node that monitors both ECG activity and the upper body trunk position.<br>- 2 motion sensors attached to the ankles to monitor activity.<br>- ActiS node utilizes a commercially available wireless sensor platform Telos from Moteiv and a custom intelligent signal processing daughter card attached to the Telos platform.<br>- Daughter boards interface directly with physical sensors and perform data sampling.<br>- Pre-processor data is then transferred to the Telos board. Telos platform perform additional filtering, characterization, feature extraction, or pattern recognition and responsible for time synchronization, communication with the network coordinator, and secure data transmission.<br>- 2 custom boards specifically for health monitoring applications, an ISPM and an IAS (Intelligent Activity Sensor).<br>- ISPM board adding 2 perpendicular dual axis accelerometers, a bioamplifier with signal conditioning circuit, and a microcontroller MSP430F1232.<br>- The user's physiological state can be monitored using an on-board bioamplifier implemented with an instrumentation amplifier and signal conditioning circuit. It also could be used for electromyogram or electrocardiogram monitoring. |

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| | | | - IAS board is a stripped-down version of the ISPM with only accelerometer sensors and signal conditioning for a force-sensing resistor that can be used as foot switch. |
| 49 | **Title:**<br>Analysis of stroke patient walking dynamics using tri-axial accelerometer<br><br>**Authors:**<br>Mizuike, C., Ohgi, S. & Morita, S. | Wireless tri-axial accelerometer<br>- Piezoresistive type tri-axial accelerometer (RF-H48C, Japan, Hitachi Metals.Ltd)<br>- Signal was samples at a rate of 200Hz using inbuilt 10 bit analogues to digital converter.<br>- Stored in a personal computer | **Application**<br>- Measure trunk acceleration.<br>- Discriminate between the stroke patients and the control group.<br><br>**Advantages of accelerometers**<br>- Analyze spatiotemporal<br>- Reliable assessment tools<br>- Non-invasive<br>- Small and light<br>- Do not require manipulation during use.<br><br>**Methods**<br>- Subjects: 63 stroke hemiplegic patients and 21 age-matched healthy elderly persons as control group.<br>- Motor function:<br>  - Recovery was evaluated with the Brunnstrom recovery assessment, which is widely used to determine motor functional recovery of stroke patients.<br>  - Perform voluntary movements of lower limbs.<br>  - Qualitatively classified into 6 stages.<br>- Procedures:<br>  - 10m walk test was performed twice.<br>  - Walk straight at a self-selected comfortable speed towards a target green line on the floor.<br><br>**Analysis data**<br>- Acceleration time-series data<br>- Acceleration data were analysed by linear analysis and the following tools:<br>  - Root mean square (RMS)<br>  - Auto correlation (AC)<br><br>**Discussion**<br>- Normalised RMS values were significantly higher at all axes in stroke patients due to stroke patients exhibited |

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| | | | greater fluctuation of trunk.<br>- Lower AC values indicate that the stroke patients was characterised by inconsistent walking patterns.<br>**Limitations**<br>- Classification by Brunnstrom stages may not be sufficiently sensitive to assess the motor function recovery.<br>- The design was cross-sectional.<br>- Values of raw RMS and AC seem to be weekly correlated with motor recovery and gait capacity in stroke patients. |
| 50 | **Title:** Application of principal component analysis in vertical ground reaction force to discriminate normal and abnormal gait<br><br>**Authors:** Muniz, A.M.S. & Nadal, J. | Principal component analysis (PCA) | Testing the application of PCA to discriminate the vertical component of GRF pattern between normal subjects and patients with lower limb fractures and also applying the principal components coefficients to obtain a standard distance as a score to classify as normal and abnormal GRF.<br><br>**Analyze normal and pathologic gait**<br>- Parameterization techniques<br>- Extract instantaneous values of amplitude from ground reaction force curve and pattern of movement is ignored.<br>Statistical techniques are available to reduce data and extract useful information.<br><br>**Principal component analysis (PCA)**<br>- Reducing dimensionality and analyzing waveforms in gait analysis.<br>- Reduced set of uncorrelated variables, which retaining maximally the variances from the original data.<br>- Used to develop a measure of how closely an individual gait pattern approaches normal.<br>- Extractions of components that carry information from the complete times series, instead of focusing on only isolated peaks.<br>- Quantify the relative contributions of the original aGRF and the distribution on loading factors along the time. |

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| | | | **Method**<br>- Subjects:<br>(a) 13 subject with unilateral lower limb fracture.<br>(b) 38 normal subjects without physical lesions, neurological or skeletal muscle disorders participated in the study.<br>(c) 5 subjects in unilateral lower limb fracture underwent physiotherapeutic treatment 3 times a week for about 4 months.<br>- Walked on an instrumented treadmill Gaitway at a controlled speed (4km/h) with their regular walking shoes.<br>- GRF was collected with sampling frequency of 300Hz during 10s.<br>- Advantages of treadmill analysis<br>(a) Acquiring larger datasets<br>(b) Obtaining a representative gait pattern<br>- All signal processing and statistical analysis procedures were implemented with the software Matlab 6.5.<br>- To minimize the effect of random noise, the data were filtered using a low pass, second order Butterworth filter, with cut-off frequency at 30Hz.<br>- To prevent phase drifting, the filter was applied in forward and backward directions.<br>- Principal component coefficients (PCCs) were obtained by singular value decomposition using GRF of complete stride.<br>- Wilcoxon Rank Sum test was used to compare differences between principal component coefficients (PCCs) from control group and patients with lower limb fractures. |
| 51 | **Title:**<br>Review of physical activity measurement using accelerometers in older adults: | Accelerometers | To provide researchers with a guide to some commonly-used accelerometers in order to better design and conduct physical activity (PA) research with older adults.<br><br>**Physical activity**<br>- PA is often assessed using self-report measures. These measures are easy to |

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| | Considerations for research design and conduct<br><br>**Authors:**<br>Murphy, S.L. | | administer and can provide information on the types of activities performed, but may not capture activity patterns throughout the day.<br>- Accelerometry provides information on the amount, frequency and duration of PA. It also provides only crude information on the types of activity in which people participate.<br><br>**Older adults and physical activity**<br>- Older adults spend a higher percentage of their day performing low intensity activities and a low percentage performing high intensity activities.<br>- Loss of flexibility, decreased bone and muscle mass, and decreased ability of the cardiac and respiratory systems.<br>- Age-related in basal metabolic rate and decreased fat free mass may contribute to errors in energy expenditure calculations.<br>- Chronic conditions increase in prevalence with aging and can affect physical activity levels.<br>- Memory and recall among older adults may affect compliance of wearing monitors over a series of days.<br><br>**Accelerometer types**<br>- Piezo-electric sensors measure acceleration due to the movement and there are 2 main types, the cantilever beam and the integrated circuit (IC) chip.<br>- The cantilever beam technology is named for the beam that is attached to a support at one side that contains a piezoelectric element and a seismic mass. When acceleration is detected by the seismic mass, it causes the piezoelectric element in the beam to bend and record a voltage signal.<br>- The IC chip technology also has a piezoelectric element and seismic mass that detects acceleration, but the sensor is fully enclosed in a package that is directly affixed on an electronic circuit board. This can enhances durability and repeatability of the monitors. |

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| | | | - Important enhancement<br>  - Have a rechargeable battery<br>  - Skin conductance feature that can help researchers distinguish sedentary activity from not wearing the monitor.<br>- Most literature on daytime PA using accelerometry involves the use of the Actigraph (Actigraph LLC) brand monitors, where most literature on nighttime activity and sleep patterns involves the use of the Actiwatch (Mini Mitter Co) brands.<br>- The cantilever beam accelerometers have the potential to break or become less reliable over time. So, when using a cantilever beam accelerometer, it is recommended that researchers have a calibration protocol in place.<br><br>**Placement of monitors**<br>- The output of an accelerometer depends on the position at which it is placed, its orientation, posture, and activity being performed.<br>- Sleep and wake patterns are often measured using wrist worn activity monitors. However, wrist worn accelerometers are not recommended to approximate energy expenditure.<br><br>**Number of days worn**<br>- The number of days sampled depends on the outcome of interest although typically the sampling period is between 3 and 7 days.<br><br>**Limitations of accelerometers**<br>- Do not capture the full energy cost of certain activities, such as walking while carrying a load or walking uphill.<br>- Financial cost of monitors, staff time to process and analyze data, and problems with monitor placement when data are collected over a number of days.<br><br>**Other methods of assessment**<br>a. Pedometers<br>  - Inexpensive<br>  - Easy to use<br>  - Provide participants with feedback |

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| | | | about their performance<br>- Main PA outcome using pedometers is step counts.<br>- Inaccuracy in measurement of daily energy expenditure<br>- Lack of ability to measure PA patterns<br>- Accuracy is reduced for people who have variable gait patterns and for obese individuals.<br>b. Pedometer with a piezoelectric components<br>- Can measure physical activity patterns<br>- More accurate than other pedometers at slow speeds<br>- More expensive<br>- Requires a docking station and software<br>c. Heart rate monitoring<br>- For approximating energy expenditure<br>- Inexpensive<br>- Provide information about activity duration and intensity<br>d. SenseWear WMS armband<br>- A monitor that combines accelerometry with other physiologic measures device.<br>- For example, heart rate, galvanic skin response<br><br>**Choosing an accelerometer**<br>- Feasibility may include the size of the study, the memory capacity of the monitor, and practical considerations such as equipment, supply costs, and technical support available for data processing.<br>- Participant burden is also important to consider when determining whether to use one or more monitors, placement and length of view. |
| 52 | **Title:** Review of physical activity measurement using | Accelerometer | - Provide researchers with a guide to some commonly-used accelerometers in order to better design and conduct physical activity research with older adults. |

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| | accelerometers in older adults: considerations for research design and conduct<br><br>**Authors:**<br>Murphy, S.L. | | **Older adults and physical activity**<br>- Higher percentage performing low intensity activities.<br>- Low percentage performing high intensity activities.<br>- Loss of flexibility<br>- Decreased bone and muscle mass<br>- Decreased ability of the cardiac and respiratory systems<br>- Declines in basal metabolic rate<br>- Decreased fat free mass<br>- Chronic conditions increase in prevalence with aging and can affect physical activity levels.<br>- Memory and recall among older adults may affect compliance of wearing monitors over a series of days.<br><br>**Sensor placement**<br>- Upper extremity movement of stroke survivors has been assessed using wrist-worn monitor.<br>- Gait and balance has been assessed using hip or trunk worn accelerometers and a combination of monitors have been used to distinguish sit to stand movements in the clinic.<br>- Sleep and wake patterns are often measured using wrist-worn activity monitors.<br>- Wrist-worn accelerometers are not recommended to approximate energy expenditure.<br><br>**Number of days worn**<br>- Another consideration for using accelerometers is the length of time they are worn.<br>- If night time activity, such as sleep patterns, is of interest, recent practice parameters recommended at least 3 days of monitor wear.<br><br>**Limitations of accelerometers**<br>- Do not capture the full energy cost of certain activities, such as walking while carrying a load or walking uphill, because acceleration patterns do not change under these conditions.<br>- Financial cost of monitors, staff time to |

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| | | | process and analyze data, and problems with monitor placement when data are collected over a number of days.<br><br>**Future directions**<br>- Need to examine the generation comparability under different conditions. |
| 53 | **Title:** Acceleromete r use in a physical activity intervention trial<br><br>**Authors:** Napolitano, M.A., Borradaile, K.F., Lewis, B.A., Whiteley, J.A., Longval, J.L., Parisi, A.F & etc. | Accelerometer | - Describes the application of best practice recommendations for using accelerometers in a physical activity intervention trial.<br><br>**Methods**<br>- Participants for the parent intervention trial were recruited through newspaper advertisements, radio advertisements, email notices and postings on a worksite website.<br>- Participating in moderate for less than 90 min per week.<br>- ActiGraph was selected for the study.<br>- 22 consecutive days.<br><br>**ActiGraph**<br>- Can be effectively implemented in physical activity intervention trials.<br>- Effective tool for objectively measuring activity and complementing self-report methodology.<br>- An intervention study requires an initial investment in the devices, appropriate data management support, and proper oversight to monitor the integrity of the data.<br><br>For the assessment of physical activity in clinical trials, a combination of ActiGraph monitoring for seven days and properly administered interview-based measures incorporating the same period is recommended. |

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| 54 | **Title:**<br>Foot kinematics during walking measured using bone and surface mounted markers<br><br>**Authors:**<br>Nester, C. et.al. | Markers<br>- 9mm reflective markers<br>- 5mm reflective markers | Compare kinematic data from an experimental foot model comprising 4 segments (heel, navicular/cuboid, medical forefoot and lateral forefoot) to the kinematics of the individual bones comprising each segment.<br><br>Collect and compare 3 data sets describing foot kinematics from bone anchored markers, markers mounted directly onto the skin surface and using the markers attached to plates mounted on the skin surface.<br><br><br>**Rigid segment models of the foot** have been used to reduce the complexity of the foot for experimental. 2 sources of error<br>- The simplification of the foot anatomy into rigid segments which in reality are not rigid<br>- Skin movement artifact<br>**Method**<br>- Subject: 6 male volunteers.<br>- In the skin condition, 9mm reflective markers were attached directly to these sites.<br>- For the plate condition, 9mm markers were mounted on the rigid plastic plates directly over the same sites.<br>- Prior to collection of kinematic data each subject performed barefoot walking trials to determine their starting position, self-selected speed and preferred cadence.<br>- 10 ProReflex cameras were used to record kinematic data (240Hz) during 10 walking trials for each participant.<br>- Intra cortical pin surgery: surgical pins were inserted under local anaesthetic infiltration into 9 bones and arrays of 5mm markers attached to the pins.<br>- Stance time, ground reaction and tibial kinematics were compared.<br><br>A large difference between skin and plate and bone pin data could be due to a difference in the relaxed standing position of the foot in each session, not necessarily the effect of the protocol. |

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| 55 | **Title:**<br>A wearable system for pre-impact fall detection<br><br>**Authors:**<br>Nyan, M.N., Tay, F.E.H. & Murugasu, E. | A wearable pre-impact fall detection prototype.<br><br>Torso and thigh wearable inertial sensors (3D accelerometer and 2D gyroscope) are used and the whole system is based on a body area network (BAN). | In fall intervention strategies, one of the key concerns in preventing or reducing the severity of injury in the elderly is to detect the fall in its descending phase before the impact (pre-impact fall detection).<br>- Inflatable hip protectors to cushion the fall prior to impact.<br>- Implemented pre-impact fall detection by thresholding the horizontal and vertical velocity profiles of the trunk using motion analysis system.<br>- Used 3 gyroscope sensors at 3 different locations, the sternum, front of the waist and under the arm.<br>- An optical motion capture system and an inertial sensor unit consisting of a tri-axial accelerometer and a tri-axial gyroscope were used.<br><br>**Methods**<br>- Hardware setup<br>a. Thigh sensor set (MMA7260Q tri-axial micromachined accelerometer and 2 analog devices ADXRS150)<br>b. Waist sensor set (single tri-axial accelerometer)<br>c. Data processing unit<br>- Filters<br>a. Acceleration data are low pass filtered with cutoff frequency of 0.5Hz<br>b. Gyroscope signals are band-pass filtered between 0.5 and 2.5Hz.<br>- RC low-pass and band-pass filters are used in implementation to avoid time delay and phase shift in digital filtering.<br>- Chipcon CC2420 Zigbee transceivers are used for data communication between the sensor sets and data processing unit.<br>- Intel PXA255 processor (400MHz) is used in the data processing unit.<br>- Sensor data is sampled at sampling rate of 47Hz.<br>- Medium access control (MAC) designed mainly for the multi-transmitter BAN systems requiring the continuous transfer of data at a central processing point. |

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| | | | - Fall is confirmed<br>a. If 1 or 2 dimensional angular signals of the thigh segment intersects the threshold levels, ± 10º.<br>b. If the correlation coefficient between the band-pass filtered gyroscopes segment and its corresponding reference template is greater than or equal to 0.8.<br>- 13 male and 8 female volunteers participated in the clinical trial to perform the stimulated fainting incidents on a 6in thick soft foam mattress.<br>- Validation: Each activity was conducted twice and recorded using a camcorder with a frame rate of 30 frames/s.<br><br>**Limitations**<br>- Further tests are needed for other types of falls such as falls preceded by walking such as tripping and slipping.<br>- Temperature compensation strategy is also required as temperature drift may affect the performance of the system during a long term implementation.<br><br>Lead-time of 700ms before impact occurs to the vulnerable areas of the body is the longer lead-time achieved so far in pre-impact all detection. |
| 56 | **Title:**<br>An inertial and magnetic sensor based technique for joint angle measurement<br><br>**Authors:**<br>O'Donovan, K.J., Kamnik, R., O'Keffe, D.T. & Lyons, G.M. | Kinematic sensor based 3D joint angle measurement techniques<br>- Rate gyroscope<br>- Accelerometer<br>- Magnetometer sensor | This technique is not dependent on a fixed reference coordination system and thus may be suitable for use in a dynamic system such as a moving vehicle.<br><br>**Applications**<br>- Monitoring of lower leg activity in persons with limited mobility that are at risk of remaining inactive for prolonged periods.<br>- Measure of balance dorsiflexion in drop foot correction application.<br>- Monitoring of foot function rotation in clinical trials.<br><br>Joint angles are determined from the orientation of one segment relative to another and are not concerned with |

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| | | | absolute segment orientation.<br><br>**Sensor design**<br>- 2 acceleration, angular rate and magnetic (AARM) sensors are used.<br>- One attached to the foot segment and the other attached to the lower leg segments.<br>- Each AARM sensor contains a tri-axial accelerometer, rate gyroscopes and magnetometer configuration.<br>- Tri-accelerometer is formed from the combination of two bi-axial Analog Devices ADXL210E accelerometer.<br>- Tri-axial rate gyroscope consists of 3 uni-axial Analog Devices ADXRS510 rate gyroscopes.<br>- Tri-axial magnetometer used is the Honeywall HMC2003 magnetic sensor.<br><br>Three different angles of rotation at the ankle joint<br>- Dorsiflexion / plantar flexion<br>- Internal / external rotation<br>- Inversion / eversion<br>Are calculated using a Joint Coordinate System (JCS).<br><br>**Experiment**<br>- Subjects: 2 healthy male subject<br>- 13 exercises cover a wide spectrum of 3D lower leg movements were investigated<br>- Tested by comparison with the laboratory based Evart 3D motion analysis system<br>- Three markers and a single AARM sensor unit were attached to each pad.<br>- A modified shin pad was attached at the front of the lower leg and a second pad was attached to the superior surface of the foot.<br>- Sensor signals were low-pass filtered with a cut-off frequency of 15Hz.<br><br>**Analysis**<br>- The MATLAB computing program was used for all post-trial data processing and analysis.<br>- Both the sensor and marker data were |

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| | | | low-pass filtered at 5Hz using second order Butterworth filter.<br>- Joint angle measurements were calculated based on the Joint Coordination System (JCS).<br>- Root mean squared error (RMSE) of the angles measured by the sensor-based system when compared with the angles measured by the Evart motion analysis system was used to compared the two methods.<br><br>Strong correlation between the joint angles measured using the AARM sensor based technique and the Evart motion analysis system.<br><br>**Sensitivity of the joint angle measurement technique**<br>- Flexion rotations were generally performed about an axis approximately orthogonal to the 2 reference vector, thus resulting in the most accurate measurements.<br>- Internal/external rotations were generally performed about the acceleration reference vector, thus resulting in the least accurate measurements.<br>- Inversion/eversion rotations were generally performed about neither an axis which was neither a reference vector nor an axis approximately orthogonal to the two reference vectors and the accuracy is lying approximately in between the accuracy of the other two.<br><br>**Limited**<br>- The investigation of the performed of the technique in this study was limited to a static system.<br><br>**Future work**<br>- A future study should seek to investigate the performance of the technique in a dynamic system. |

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| 57 | **Title:**<br>Motion analysis system for identification of 3D human locomotion kinematics data and accuracy testing<br><br>**Authors:**<br>Papic, V., Zanchi, V. & Cecic, M. | Optical motion capture based system | Procedure for acquisition and processing of the human locomotion system kinematics data is presented.<br><br>A different family of motion data acquisition systems is based on the **camcorder and framegrabber concept**.<br>- Provide real-time data acquisition<br>- Easier manual intervention in resolving possible ambiguities in marker association.<br>- Easier application to outdoors motion capture.<br>- Much cheaper<br><br>In order to synchronize the data sets obtained with the two or more cameras, a method based on minimizing average direct linear transformation (DLT) reconstruction error estimate of a single marker.<br><br>The movement measurement and data processing procedure was carried out in 6 basic steps<br>- Video tape recording of the moving object in the laboratory.<br>- Transferring recorded movement to PC as AVI files for each camera.<br>- Extracting calibration coordinates.<br>- Extracting coordinates from the markers positioned on the moving object.<br>- Software program execution for camera data synchronization and calculating 3D coordinates by DLT.<br>- Graphical presentation of the result. |
| 58 | **Title:**<br>Dynamics and control of a MEMS angle measuring gyroscope<br><br>**Authors:**<br>Park, S.S., Horowitz, R. & Tan, C.W. | MEMS angle gyrocopes | Algorithms for controlling vibratory MEMS gyroscopes so that can directly measure the rotation angle without integration of the angular rate, thus eliminating the accumulation of numerical integration errors incurred in obtaining the angle from the angular rate.<br><br>**MEMS angular rate gyroscopes**<br>- Typically the angular rate gyroscopes that are designed to measure the angular rate.<br>- In order to obtain the rotation angle, it is |

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| | | | required to integrate the measured angular rate with respect to time.<br>- The integration process, however, causes the rotational angle to drift over time and therefore the angle error to diverge quickly due to the presence of bias and noise in the angular rate signal.<br>- Effects more severe for low cost MEMS rate gyroscopes.<br>- A common technique used to bind the error divergence is to fuse rate gyroscopes with accelerometers and magnetometers.<br>  - Steady-rate pitch and roll angles can be obtained using accelerometers<br>  - Yaw angles can be obtained using magnetometers.<br>  - Magnetometer signal can be severely distorted by unwanted magnetic field in the vicinity of the sensors.<br><br>**MEMS angle gyroscopes**<br>- Can be implemented by the 2-DOF mass-spring-damper system whose proof mass is suspended by spring flexure anchored at the gyro frame.<br>- Same structure as a vibratory rate gyroscope.<br>- Consists of a weighted energy control, a mode turning control and an initial calibration stage.<br>- An adaptive controller to compensate for damping terms and mismatches in natural frequencies by performing 2 tasks:<br>  a. Initiating oscillation and maintaining total energy level<br>  b. Tuning any mismatch in the natural frequencies of both axes.<br>- Energy control should be to maintain at certain level so that the damping is compensates without interface with the angular rate.<br>- If the energy level is larger than the current energy level, then the magnitude of energy control is chosen to be positive for growing the oscillation and conversely for damping the oscillation. |

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| 59 | **Title:** Utility of the RT3 triaxial accelerometer in free living: An investigation of adherent and data loss<br><br>**Authors:** Perry, M.A. et.al | RT3 triaxial accelerometer | Investigated user perceptions, adherence to minimal wear time and loss of data when using the RT3 activity monitor.<br><br>Occupational activity and occupational inactivity has been shown to influence the risk of musculoskeletal work related disorders. Musculoskeletal work related disorders are thought to arise from prolonged periods of exposure to repetitive specific high or low load tasks causing tissue fatigue, coupled with a combination of other psychological and sociological factors.<br><br>**Methods**<br>a. Participants<br>- 24 participants were of good health with no current or past medical conditions limiting PA<br>b. Procedure<br>- Each participant's sex, height and weight were downloaded onto the RT3 via the Stayhealth software.<br>- RT3 was clipped onto their belt or waistband in the centre of the lower back.<br>- If the monitor caused the discomfort in this position participants were advised to shift it to the lateral right pelvis.<br>- Record the primary activity for each walking hour in an activity diary.<br>- Record the time and reason for removal of the RT3 in the diary.<br>- After one week the RT3 was collected and data downloaded to a computer using the Stayhealth software.<br>c. Measurement<br>- The accelerometer in the RT3 is sensitive to 3 orthogonal axes and has 4 modes of recording and storing.<br>- The utility questionnaire asked participants to comment on the convenience and acceptability of the RT3 and any difficulties associated with wearing the activity monitor.<br>d. Data treatment and statistical analysis<br>- Descriptive statistics were used to |

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| | | | analyse: wear hours from the RT3, the reasons for data loss and to summarise responses from the utility questionnaire.<br><br>**RT3**<br>- Acceptable to wear for 7 days, corroborated by the high hours of daily wear.<br>- The percentage hours of data loss is relatively small, the combined loss of data due to either forgetfulness (adherence) or battery malfunction increased over time.<br>- Other reasons for non-recording of data included misplacement, removal for sporting activity, discomfort, appearance, and fear of losing the activity monitor.<br>- Sitting or driving with the monitor on the central lumbar spine was uncomfortable and necessitated removal in some occupational situations.<br>- Most participants reported that the RT3 was acceptable to wear; application was easy to remember and did not interfere with daily activities.<br><br>Careful consideration of the requirements of specific populations and occupational groups when determining minimally acceptable hours of wear time and placement site of the monitor prior to data collection. |
| 60 | **Title:** Determination of the optimal locations of surface-mounted markers on the tibal segment<br><br>**Authors:** Peters, A., Sangeux, M., Morris, M.E. & Baker, R. | Thirty-six retro-reflective markers | Determine optimal locations on the lower limbs for skin-mounted markers representing the tibial segment in three-dimensional gait analysis.<br><br>**Methods**<br>- Subjects: 20 able-bodied young adults without history of musculoskeletal injuries or disorders.<br>- Instrumentation: 10 camera Vicon motion capture system. The system used MX40+ cameras sampling at 100Hz using VICON Nexus software.<br>- Marker Locations: Thirty-six 14mm diameter retro-reflective markers. 10 |

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| | | | marker locations used to define the tibia were assessed.<br>- Procedure: wore loose fitting clothing and walked in bare feet. Performed isolated knee flexion/extension, ankle plantar flexion/dorsiflexion and walk a comfortable speed along the walkway.<br>- Test duration: 60 min / 1 hour.<br>- Data analysis and modelling:<br>a. Data were filtered using a Woltring filter (MSE15)<br>b. Bodylanguage® model was used to determine distance between marker pairs.<br>c. Data were processed using Vicon® software to determine the displacements between marker pairs and joint angles.<br><br>TIAP and TIAD pairs to be highly rigid and ideal because the tibial crest is unimpeded by muscle or fatty deposits.<br>TIAP2 and TIAD2 were to provide alternatively markers if cameras are unable to sufficiently track the medially located tibial crest markers.<br><br>4 marker locations that are optimal for defining the tibia are the proximal anterior tibial crest, the distal anterior tibial crest, the lateral malleolus and the medial malleolus. |
| 61 | **Title**<br>Agreement between an electrogoniometer and motion analysis system measuring angular velocity of the knee during walking after stroke<br><br>**Authors**<br>Pomeroy, V.M., Evans, | Eelctroniometer and motion analysis system | Measurement quality of movement to assess effectiveness of physical therapy interventions after stroke.<br><br>Investigate the concurrent validity of using an electrogoniometer and a laboratory-based movement analysis system, Vicon to measure knee angular velocity.<br><br>**Methods**<br>- 15 subjects aged over 18 years, at least 6 months post stroke and able to walk at least 4.5m, with or without assistance, on a flat surface indoors.<br>- Captured speed of Vicon 512 motion analysis system was set to 120Hz.<br>- Biaxial electrogoniometer was |

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| | E. & Richards, J.D. | | connected into the Vicon workstation analogue channels and data were collected at 1080Hz.<br>- To measure knee angular velocity, the electrogoniometer and a Vicon retroreflective marker both require placement over the estimated knee joint centre.<br>- Spherical, retroreflective markers were placed on anatomical landmarks and a electrogoniometer was placed on the lateral side of each subject's right knee.<br><br>The angular velocity of Vicon values was found to be higher than electrogoniometer values, particularly during knee extension. A possible reason for the discrepancy in angular velocity values could be the nature of the application of the different measuring techniques. The markers used with the Vicon system were placed on the knee joint line, whereas the electrogoniometer was placed over the knee joint with the 'arms' fixed with double-sided tape on the soft tissue proximal and distal to the knee.<br><br>There is an unacceptable level of disagreement between measurement of knee angular velocity by the Vicon system and an electrogoniometer. |
| 62 | **Title:** Biomedical signal analysis by a low-cost accelerometer measurement system<br><br>**Authors:** Quagliarella, L., Sasanelli, N., Cavone, G. & Lanzolla, A.M.L. | ADXL210E Accelerometer | - Movement functional analysis of vertical jump allows to quantify the motor capabilities of lower limbs and to determine the performance level and the effectiveness of the trial programs.<br><br>**Tri-axial accelerometer**<br>- Centre of mass is one of the most representative points of human body, controlled by the central nervous system to ensure the stability of the movements.<br>- Positioned on the dorsal area, at the level of L4-L5.<br>- Acceleration signal needs to be low-pass filtered, in order to perform noise reduction and anti-aliasing.<br>- Cut-off frequency of 200Hz. |

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| | | | - Noise power of 3.58mg.<br>- Analog filter was made using a 27nF capacitor.<br>- Sensor was connected to a simple and inexpensive, 8 bit portable data logger (SARI).<br>- Acquisition frequency of each signal was set to 1000Hz.<br><br>**Methodology**<br>- 124 subjects (74 normal subjects and 70 athletes, age 17±8 years).<br>- Fit and injury free.<br>- Performing five countermovement jumps with arms akimbo, at maximal intensity.<br>- Different phases of the jump movement: upward propulsion, flying and landing.<br>- Flight duration of the jump, a performance parameter related to the flight height, can be directly computed by the platform data, considering that the signal is equal to zero during the flying phases.<br><br>Accelerometric system is able to differentiate the best performance of practiced athletes. |
| 63 | **Title:** Experimental identification and analytical modeling of human walking forces: Literature review<br><br>**Authors:** Racic, V., Pavic, A. & Brownjohn, J.M.W. | | Basic concepts and terminology in human gait analysis.<br><br>Modeling of human walking force.<br><br>Kinematics and kinetics of human body motion.<br><br>Synchronization phenomenon in human-structure dynamic interaction.<br><br>Anthropometry: Body segment parameters.<br><br>Indirect measurement of human loading. |

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| 64 | **Title:**<br>Assessment of 3D dynamic interactions between backpack and bearer using accelerometers and gyroscopes<br><br>**Authors:**<br>Ren, L., Jones, R., Liu, A., Nester, C. & Howard, D. | 3 MT9<br>- 3D accelerometers<br>- 3D gyroscopes | **Method**<br>- Subjects: 4 male subjects walked indoors along a walkway at 3 speeds (slow, normal and fast) and with 2 different pack loads (11.5 kg and 23.0 kg).<br>- 3 miniature MT9 (Xsens) sensors, combining both 3D accelerometers and 3D gyroscopes, were firmly mounted on the aluminum frame, and one MT9 sensor was attached to the bearer's sternum.<br>- 3 coordinate system: global coordinate system, backpack coordinate system and bearer's torso coordinate system.<br>- 3D interaction forces and moments between the pack and the bearer were derived using Newton-Euler equations.<br><br>**Multiple-sensor method**<br>- Does not require a gait laboratory environment<br>- Can be used for field studies with an untethered, completely body-mounted recording system.<br>- Improve calculation accuracy<br>- Gait cycles may be recorded.<br><br>**Future work**<br>- Involve assessment of pack interaction forces under various conditions, such as running, jumping or climbing. |
| 65 | **Title:**<br>Ambulatory position and orientation tracking fusing magnetic and inertial sensing<br><br>**Authors:**<br>Roetenberg, D., Slycke, P.J. & Veltink, P.H. | Portable magnetic system combined with miniature inertial sensors for ambulatory 6 degrees of freedom (FOC) human motion tracking. | **Portable magnetic system**<br>- Requires a substantial amount of energy<br>- Easily be disturbed by ferromagnetic materials or other sources<br>- Errors were higher during movements with high velocities due to relative movement between source and sensor within one cycle of magnetic actuation.<br><br>**Accelerometers and gyroscopes**<br>- Measures fast changes in position and orientation.<br>- Requires less energy<br>- Not sensitive for magnetic disturbances<br><br>Inertial sensors for accurate reconstruction of the movement of a body |

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| | | | segment, but restricted to time-limited.<br><br>Portable magnetic system is designed and used to measure relative positions and orientations on the body.<br><br>**System Design**<br>- Magnetic Tracking comprised of 3 essential components: an actuator, 3-D magnetic sensors and a processor.<br>- Inertial tracking<br>- Sensor fusion |
| 66 | **Title:**<br>A portable magnetic position and orientation tracker<br><br>**Authors:**<br>Roetenberg, D., Slycke, P., Ventevogel, A. & Veltink, P.H. | Portable magnetic trackers system | Design and testing of a portable magnetic system for human motion tracking.<br><br>**Magnetic trackers system**<br>- Use an electromagnetic field generated at some point in space and detected at a remote segment.<br>- 3 essential components:<br>a. 3D source, which generates a magnetic field.<br>b. 3D sensor, which is fixed at a remote body segment and measures the fields generated by the source.<br>c. Processor, whose function is to relate the signals from source and sensor.<br>- Commercially available magnetic trackers such as Fastrak and Flock of Bird are provided with so-called long or extended range sources offering a tracking range of several meters.<br>- Small weight and size, no impediment of functional mobility, and operating time should be at least half an hour on a set of batteries, but preferably longer.<br>- Can fully wear on the body without the need for an external reference.<br>- 3D source is constructed as a three orthogonally sided pyramid and is mounted on the back of the body and sensors placed at remote body segments.<br>- Transmitter driver provides controlled pulsed dc current to 3 coils having orthogonal axes.<br>- 3-axis magnetic sensor measures the strengths of the magnetic pulses that are functions of the distance to the |

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| | | | transmitter.<br>- Vulnerable for magnetic disturbances.<br>- Limited to a restricted measurement volume and have large and heavy sources which do not allow for ambulatory purpose.<br><br>**Methods**<br>- An electrical circuit was designed to drive the coils b means of 4 AA batteries.<br>- Magnetometers in a MTx sensor module were used to measure the strength of the pulses and the earth magnetic field in 3D.<br>- Sample frequency of the sensors was 120Hz with 15bits resolution.<br>- Vicon 470 system consisting of 6 cameras operating at 120Hz was used as a reference. |
| 67 | **Title:**<br>A wearable acceleration sensor system for gait recognition<br><br>**Authors:**<br>Rong, L., Zhou, J.Z., Liu, M. & Hou, X.F. | - Tri-axial accelerometer (MMA7260, Freescale)<br>- MCU with high speed 12-bit ADC<br>- 32M bytes of RAM<br>- Data transfer module for data transfer | Portable microprocessor-based data collection device was designed to measure the 3-D gait acceleration signals during human walking.<br>**Gait collection device**<br>- MMA7260 low cost capacitive micromachined accelerometer features signal conditioning and provides a sleep mode that ideal for battery operated products.<br>- 1-pole low pass filter<br>- Temperature compensation<br>- g-selectivity which allow for the selection among 4 sensitivities.<br><br>**Data collection process**<br>- Output of accelerometer were analog signal<br>- Transformed to digit signal via the built in ADC<br>- Used potentiometer resistance for the voltage matching<br>- In the interface of accelerometer and microprocessor, RC filters were used to minimize clock noise<br>- Output data of the microprocessor were stored in the RAM<br>- Transfer to a personal computer via data transfer module for further processing |

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| | | | **Methods**<br>- Subjects: 21 volunteer healthy subjects<br>- Placement: Placed in a waist belt and located on the user’s back, close to the center of gravity of the body in the standing position<br>- Walked naturally along in the hallway, wearing their own flattie<br>- Duration: total recoding time does not exceed 5 minutes<br>- The template generated from the training set (21 set) were compared against the verification samples in the test set (84 set)<br><br>**Signal processing**<br>- Measured acceleration signals are low-frequency component.<br>- Wavelet analysis / wavelet transform uses a nonlinear threshold method for noise reduction in raw gait signal.<br>- Among the wavelet-packet-based methods, Daubechies wavelet of order 8 is seen to remove the noise more effectively than others.<br><br>**Gait recognition methods**<br>a. Time domain analysis<br>  - Acceleration signal in vertical and anteroposterior directions were used.<br>  - In order to identifying different individuals, dynamic time warping (DTW) methods was used to normalize the gait cycles, so that the step length is equal and used for matching.<br>  - K-nearest neighbour is also applied for recognition.<br>  - Correlation coefficient can be used to measure the similarity.<br>b. Frequency domain Analysis<br>  - 3-Dimension acceleration signals are combined for frequency analysis.<br>  - Use discrete Fourier Transformation (DFT) to turn the gait acceleration signal of time domain into frequency domain. |

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| | | | - Method of plural correlation to measured the similarity.<br><br>**Results**<br>- Combine the 2 analysis methods, the accuracy of individual recognition can improve a little.<br><br>**Applications**<br>- The gait recognition method can be applied to smart interface, access control, and protection of mobile and portable electronic devices. |
| 68 | **Title:**<br>Methods for gait event detection and analysis in ambulatory system<br><br>**Authors:**<br>Rueterbories, J., Spaich, E.G., Larsen, B. & Andersen, O.K. | Sensors<br>-Goniometers<br>-Accelerometers<br>-Angular rate meters<br>-Inclinometers<br>-Force sensing resistors (FSR) | **Sensor used for gait cycle analysis**<br>- Goniometers<br>- Accelerometers<br>- Angular rate meters<br>- Inclinometers<br>- Force sensing resistors (FSR)<br>Suitable for determining joints angles, body-segment acceleration, tilt angle, and times of foot contact, respectively.<br><br>**Methods to measure gait**<br>a. Force based measurements<br>- Based on the force exerted by the body to the ground.<br>- An alternative to switches is the use of force sensitive insoles composed of a matrix of sensors covering the entire sole of the foot.<br>- The second alternative is based on a pressure sensor connected to a small tube, glued to the outer perimeter of the sole of the shoe.<br>- The accuracy and reliability of such systems depend mainly on mechanical wear, as the contact sensors are exposed to repetitive force changes up to 2.2kN.<br>- Force sensing resistors (FSR)<br>b. Angular rate measurement<br>- Angular rate sensors (gyroscopes) provide the angular displacement.<br>- Does not affected by gravitation<br>- Vibration of sensors during heel strike does not affect the gyroscope output<br>- Less sensitive to positioning on the |

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| | | | body<br>- Movements in other planes are not captured.<br>c. Angular rate and force measurements in combination<br>- A Functional Electric Stimulation (FES) foot drop system composed of 3 FSR sensors detecting vertical load combined with a gyroscope that measured the rotational velocity to detect the heel off and heel strike events.<br>- The FSRs were placed under the heel and the first and fourth metatarsal heads. The uni-axial gyroscope was attached to the heel. This system was capable of detecting the stance and swing phases in real-time.<br>- Reliability and robustness.<br>- Did not generate false triggers.<br>d. Accelerometry<br>- Micro-Electro-Mechanical Systems (MEMS) allow development of miniature, low powered, accelerometer devices that are suitable for monitoring over ground walking.<br>- An ideal choice to analyze locomotion.<br>- The sensor units measured accelerations in two and three dimensions. Either composed by several single axis sensors or dual axis sensors or tri-axial sensors.<br>- In order to measure rotational and translation acceleration, typical sensor positions were shank, thigh, shank and thigh, shank and thigh and pelvis, foot and shank and thigh and pelvis, or trunk.<br>- In general, the use of accelerometers requires additional signal processing and means to compensate the influence of gravity.<br>- Drift problems may occur with integration of the acceleration data.<br>- Imprecision due to the movement of muscles during walking<br>e. Accelerometry and angular rate measurements |

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| | | | - For 2D models, the sensor units are comprised of one 1D gyroscope and two 1D inertial sensors or one 2D inertial sensor.<br>- For 3D models, the sensor units are comprised of one 3D inertial sensor and one 3D gyroscope or alternatively several uni- or dual axis sensors.<br>- The additional use of gyroscopes reduced the error caused by accelerometer vibration.<br>f. Accelerometry, angular rate and magnetic field<br>- Capable for determine 3D inter-joint angles via off-line data analysis or in real-time.<br>- Capable of detecting 5 gait phases.<br>- The additional measurement of the earth magnetic field vector provides a second non-gravity affected reference which may increase the measurement accuracy.<br>g. Inclinometry<br>- A tilt sensor that uses inertial can be used for detection of body tilt.<br>- Rarely been used for gait detection in FES systems.<br>- The shank or the thigh was found to be suitable positions for attachment of tilt sensors.<br><br>**Gait detection methods**<br>- The challenge of gait detection is to develop algorithms that determine gait events while the person is walking.<br>- Functional analysis comprise mathematical methods for curve sketching to exact features that corresponds to or indicate certain gait phases or events.<br>- Inductive machine learning is a branch of artificial intelligence and comprises the design of algorithms that allow a system to learn by extracting rules and pattern out of a set of data.<br>- Commercial machine learning programs based on RoughSets™ and Adaptive Logical Networks have been used with accelerometer data in real-time. |

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| 69 | **Title:**<br>In-use calibration of body-mounted gyroscopes for applications in gait analysis.<br><br>**Authors:**<br>Scapellato, S., Cavallo, F., Martelloni, C. & Sabatini, A.M. | Inertial measurements unit (IMU) for advanced footwear<br><br>Inertial measurement unit (IMU)<br>- 2 biaxial accelerometers (ADXL210)<br>- 1 gyroscope (Murata ENC-03J) | Propose an in-use calibration procedure and standard calibration procedures for gyroscopes are analyzed and discussed.<br><br>**Inertial measurement units (IMU)**<br>- Embody inertial sensors such as gyroscopes and/or accelerometers<br>- Signals produced from the sensors can be angular velocity and linear acceleration<br>- Can be processed to sense movement and orientation of the moving body.<br>- Sense motion and orientation without the restrictions.<br>- Attached to the body of tested subjects in several anatomical positions such as head, chest, trunk, thigh, shank and foot.<br>- Influenced by:<br>a. Sensor bias<br>b. Sensitivity drifts<br>c. Environmental conditions<br>- Calibration procedures which can be used to check and verify the sensor offset and sensitivity during normal use of IMU.<br>- Application:<br>a. Quantitative motion analysis as applied in biomedical and rehabilitation engineering.<br>b. Monitor activities of daily living<br>c. Estimate the energy expenditure incurred during a functional activity.<br><br>**Instruments:**<br>- Estimate:<br>a. Stride time / length<br>b. Cadence<br>c. Walking speed<br>d. Inclination<br>- IMU board are integrated 2 simple driver circuits to interface sensor analog outputs:<br>a. Accelerometric signal is sent directly to a buffer<br>b. Gyroscopic signal is sent to an analog filtering stage<br>- Both buffer and filtering circuits are made using a dual low-cost, rail-to-rail and single supply operational amplifier. |

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| | | | - Before sampling, all the signals were single-stage low-pass filtered at 50Hz and amplifier.<br>- 12-bit sampling was performed at 1KHz by using PCMCIA card which controlled by NI's LabView v.6.1 software for data acquisition and storage.<br>- Matlab v.6.0 (MathWorks) was used for off-line signal processing.<br>- Second-order forward-backward low-pass Butterworth filter was applied to sensor signals with cut-off frequency of 15Hz.<br><br>**Methods:**<br>a. Standard calibration procedure<br>- For the triaxial accelerometer was based on its sensitivity to Earth gravitational field.<br>- Performed by placing the accelerometer sensitive axes in line with gravity, when the nominal output were +1g and -1g.<br>- For the gyroscopes, the signal was integrated to measure the angular excursion.<br>- Sensitivity was estimated from comparison between the estimated from comparison between the estimated rotation angle and the true one.<br>b. In-use calibration procedure<br>- Healthy male subject was fitted with the IMU strapped to the foot instep and perform a series of 6 movements.<br>- Gyroscope offset was estimated when the subject stood still before stepping.<br>- After subtracting the gyroscope offset, from the gyroscope signal the trajectory of the foot instep was reconstructed by strap down integration. |

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| 70 | **Title:**<br>Defining the knee joint flexion-extension axis for purpose of quantitative gait analysis: An evaluation of methods<br><br>**Authors:**<br>Schache, A.G, Baker, R. & Lamoreux, L.W. | | Compare 3 different methods of defining the knee-joint flexion-extension axis:<br>- Knee alignment device (KAD) method<br>- Transepicondylar axis (TEA) method<br>- Alternative numerical method / Optimization procedure (Dynamics)<br><br>**Methods**<br>- 20 adults exhibited normal knee function.<br>- Kinematic data were acquired using a three-dimensional motion analysis system (VICON) with 6 cameras operating at a sampling rate of 120H.<br>- 3D hip and knee joint angular kinematic data were obtained by tracking the trajectories of spherical retro-reflective markers mounted over the five body segments (pelvis, left and right thighs, left and right shanks).<br>- Three different methods of defining the knee joint flexion-extension axis were evaluated.<br>Dynamic method was found to display the highest level of repeatability of hip axial rotation measurements during gait and the lowest degree of knee joint angle cross-talk.<br><br>A major disadvantage of the KAD and TEA-based methods is that they are both highly dependent upon the precise identification of axes of rotation and/or anatomical landmarks by the tester. |
| 71 | **Title:**<br>Design, geometry evaluation, and calibration of a gyroscope-free inertial measurement unit<br><br>**Authors:**<br>Schopp, P., Klingbeil, L., Peters, C. & | Gyroscope-free inertial measurement unit (GF-IMU)<br>- accelerometers | Gyroscope-free inertial measurement unit (GF-IMU) that only comprises linear accelerometers in order to directly measure the transversal acceleration as well as the angular acceleration and velocity.<br><br>**IMU**<br>- A sensor unit that measures the relative movement of body<br>- Conventional IMU comprises three accelerometers, measuring the transversal acceleration, and three gyroscopes, measuring the angular velocity. |

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| | Manoli, Y. | | - However, gyroscopes high bias drift, low shock resistance and bad durability.<br><br>**Previous work**<br>Minimum number of accelerometer axes to determine the relative body movement is 6. However by using 6 accelerometers only the transversal and the angular acceleration of the body can be determined. The angular velocity cannot be determined directly and has to be calculated via an integration step.<br>a. 9 accelerometers in total<br>- The angular acceleration can be determined directly with out of the knowledge of the angular velocity<br>b. 6 sensors is the arrangement of the accelerometers in a special cube configuration<br>- Angular velocity is always zero<br>- Angular acceleration can be obtained independently of the angular velocity.<br>c. Coplanar setup of 9 accelerometers<br>- Detect the angular and transversal acceleration<br>d. Three dual-axes accelerometers<br>- Used for sensing tremor in hand-held microsurgical instruments<br><br>Minimum number of accelerometers necessary to directly calculate the angular velocity for a 6D motion of a body is 12.<br>- It is not possible to determine the direction of the angular rotation using only accelerometers.<br>- The sign of the angular velocity is lost.<br>- In contrast, applied an Unscented Kalman filter to determine the correct angular velocity and provides great robustness and noise cancellation.<br>- Unscented Kalman filter (UKF) is applied to merge the information of the angular acceleration and the angular rate and thus robustly estimate the sign of the body rotation. |

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| 72 | **Title:**<br>Instrumented orthopaedics Analysis system<br><br>**Authors:**<br>Senanayake, S.M.N.A., Chong, Y.Z., Chong, Y.S., Chong, J. & Siringhae, R.G. | Instrumented orthopaedics analysis system<br>- Gait analysis system<br>- Gait pattern recognition system<br><br>Gait analysis system<br>- Attaching force sensing resistors into insole for foot analysis<br>- Wireless sensors are attached on ankle, kneecap (patella) and hip (pelvis) for lower extremity. | Responsible to recognize features of orthopaedics issues of soccer players.<br><br>**Prototype consists of 2 subsystems**<br>a. Gait analysis system<br>- Attaching force sensing resistors into insole for foot analysis.<br>b. Leg movements systems<br>- Wireless sensors are attached on ankle, kneecap (patella) and hip (pelvis) for lower extremity.<br><br>**Gait analysis system**<br>a. Foot movements analysis system<br>- Consists of FSRs which located in the area of calcaneus and phalanges region of the foot.<br>- Total number of sensors located in the insole is 20.<br>- ADC11 data acquisition system<br>- Data logger provides interface to the computer systems via the printer port, shoe insole, PC and data-logging recording software.<br><br>b. Leg movements analysis system<br>- Wireless tri-axial accelerometers<br>- Base station is used for communication between accelerometers and the PC.<br>- Accelerometers are capable for doing a real time data-logging and also non-real time data-logging.<br>- The PC is also used to communicate with the wireless sensors by attaching the USB base station to it.<br><br>**Criteria used to select the experimental human subjects**<br>- Age of the focus group is between 20-55 years old.<br>- Children and elderly person are not considered in the experiment.<br>- Gender<br>- Weight<br>- Ethnicity<br><br>**Gait pattern recognition system**<br>a. Creating the recurrent neural network architecture |

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| | | | - Done using Elman Neural Network (ENN) architecture.<br>- ENN architecture is built using Java Neural Network Simulator (JavaNNS)<br>- User-interface easier and more intuitive to use.<br>b. Real-time data logging<br>c. Recognition of real time patterns |
| 73 | **Title:**<br>Two types of micromachined vibratory gyroscopes<br><br>**Authors:**<br>Shkel, A.M., Acar, C. & Painter, C. | Micromachined vibratory gyroscopes (MVG)<br>- Type I: Angle gyroscopes<br>- Type II: Rate gyroscopes | **Gyroscopes**<br>- Designed for operation under constant rate conditions and since the natural frequencies of gyroscopes are typically in the range of $1\times10^4$ to $1\times10^5$ rad/sec.<br><br>**Angle gyroscopes**<br>- Measure absolute angles of rotation, eliminating the need for numerical integration of the angular rate signal.<br>- Implemented using conventional micromachining technologies.<br>- Required the free oscillation of the mass.<br>- Utilizing an energy sustaining feedback control which cancels the effects of damping.<br>- Assumption of a zero damping condition, the only perturbations is Coriolis force.<br>- Hemispherical Resonance Gyroscopes (HRG) operating on the principle of elastic waive precession. The sensing element of HRG is a precision shell made out of quartz.<br>- 2D isotropic resonators that are designed to transfer the energy between its principal axes of elasticity.<br>- New, unexplored and may potentially enable high performance micro-scale gyros.<br><br>**Rate gyroscopes**<br>- Measure rotational rate.<br>- Operate on the Coriolis principle of a vibrating proof mass suspended above the substrate.<br>- Designed to operate at or near the peak of their resonance curve, which makes the system to be very sensitive to |

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| | | | variations in system parameters.<br>- Already commercially successful.<br>- Can be effectively achieved structurally, shifting the complexity from the control electronics.<br><br>**Shell and Resonator**<br>- In the case of a shell a standing waive is excited on the surface of the shell and precession of the elastic waive is detected and related to the object rotation.<br>- In the case of the resonator, standing waive is replaced by vibration of the resonator itself and the transfer of energy, or precision of the vibration pattern, is used for detection of the object rotation. |
| 74 | **Title:**<br>Performance of orientation sensors for use with a functional electrical stimulation mobility system<br><br>**Authors:**<br>Simcox, S., Parker, S., Davis, G.M., Smitch, R.W. & Middleton, J.W. | 5 sensor packs<br>-Rate gyroscope<br>-Two 2-D accelerometers | Verify the performance of recently developed body-worn sensor packs against 3-D motion analysis of trunk and lower-limb movements.<br><br>Artificial sensors provide feedback for neuroprostheses used by paraplegic individuals to restore lower limb functional movements.<br><br>Electrogoniometers, potentiometers, FSR and manual switches have been previously used as sensory inputs for closed-loop control of neuroprostheses.<br><br>5 sensor packs, each consisting of rate gyroscopes and two 2-D accelerometers controlled by a microprocessor were attached to the trunk, thighs, and shanks of an able bodied subject.<br>- Provide real-time kinematic data in the sagittal plane.<br>- Worn under clothing, attached and removed easily.<br>- Do not encumber normal movements.<br><br>**Sensor packs**<br>- A uni-axial rate gyroscope (ENC-03JA, Murata) and two 2D accelerometers (ADLX202, Analog Devices) were used to derive the kinematics signals for a |

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| | | | sensor pack.<br>- The raw signals from the transducer outputs were sampled by an on-board 4MHz micro-controller (AT-Mega103L, ATMEL) at a rate of 800Hz.<br>- Embedded C software combined information from both the accelerometers and the gyroscope to calculate the angular orientation of the sensor packs.<br>- Each sensor was uniquely identifiable with an electronic serial number allowing for multiple sensors to transmit information on a single bus.<br><br>**Sensor calibration**<br>- Calibration of each pack involved a two-step process to verify the accelerometers and gyroscope outputs.<br>- First step: placing the sensor on a calibration jig made level with respect to the ground by a bubble level and comparing the output of each accelerometer with respect to the gravity vector, either +1g or -1g depending on the orientation of the sensor.<br>- Second step: calibrate the gyroscopes by placing the sensor in a movable arm, holding the sensor still so that the accelerometer could measure the tilt angle, then moving the arm while a software routine measured the time.<br>- Frequent recalibration of the devices is unnecessary because the calibration values are stored in the sensor microprocessor EEPROM.<br><br>**Trial protocol**<br>- A 3D motion analysis system (MAS) was used to evaluate the dynamic performance of the sensor packs during each trial.<br>- 6 video cameras were used to record trunk and lower limb movements in the visual space at 60Hz.<br>- Completed 3 trials of sit-stand-sit transitions and walking each.<br>- For walking trial the subject was asked to walk again at a self-selected pace, in |

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| | | | a straight line approximately 10m through the center of the camera recording space.<br>- Sensor pack was fixed to each thigh and trunk of the subject.<br><br>**Data analysis**<br>- Data from the motion analysis system (MAS) was later analysed with a biomechanical software package to produce absolute 3D angular information of the lower limb segments and trunk relative to a laboratory coordinate system (LCS).<br>- The segment coordinate system (SCS) was rotated so that its longitudinal axis was aligned with the distal and proximal joint centers that enabled a transformation matrix between the SCS and LCS to be computed.<br>- The Joint coordinates system (JCS) was used to define 3D angular displacements of the segment relative to the laboratory.<br><br>The sensor packs proved to be an accurate method of measuring angles during mobility tasks as compared to the results obtained from a MAS.<br><br>3 gyroscopes and 3 accelerometers could be used to develop an algorithm that provided good accuracy of limb orientation and also minimized integration drift. |
| 75 | **Title:**<br>Variability analysis of lower extremity joint kinematics during walking in healthy young adults<br><br>**Authors:**<br>Son, K., Park, J.H. & Park, | | Determine the kinematic variability of the lower extremity joints using methods from the mathematical chaos theory in a normal walking environment in conjunction with a large population of healthy young adults.<br><br>**Lyapunov Exponent values (LEs)**<br>- Derived from the mathematical theory of Chaos and long-range correlations of stride interval fluctuations from nonlinear fractal dynamics can find subtle differences between healthy and diseased joints.<br>- The method of long range correlations |

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| | S.H. | | has been used as a tool to observe the variability of heart rate oscillations.<br>- For example, patients with Anterior Cruciate Ligament (ACL) reconstruction exhibit an increase in Les as compared with subjects with an intact knee.<br>- Could be clinically applied to the development of rehabilitation strategies by evaluating recovery progress in comparison of healthy subjects.<br>- Indicate sensitive dependence on initial conditions.<br><br>**Methods**<br>**a. Joint motion capture system**<br>- Subjects: 40 young healthy subjects (20 male subjects + 20 female subjects) with no history of joint diseases volunteered.<br>- Procedures: all subjects practice treadmill walking at self-selected walking speeds until they felt comfortable, their joint motions were recorded for 90s using a 3-D motion capture system consisting of 8 video cameras (DCR-VX2100, Sony, Japan).<br>- 24 custom reflective markers were made with their surface covered by reflective film to maximize the reflection of light.<br>- Limited to the analysis of the lower extremity due to large information acquired.<br>**b. Flexion-extension angles**<br>- The 3-D coordinates of virtual markers (secondary markers coordinates) are the temporary centers of joint motions, and should be provided to calculate the flexion-extension angles of joint motions.<br>- These secondary marker coordinates were computed from primary marker coordinates.<br>- Range of motion (ROM) of the joints was calculated from these flexion-extension angles.<br>- The spatial displacement errors of marker were less than 2mm. |

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| | | | **Discussion**<br>- LEs have also been defined as the sensitivity of a system to small perturbations, and these small local perturbations correspond to stride-to-stride variability in normal walking.<br>- Larger values of LEs imply more divergence and variability of a system while smaller values reflect less divergence and variability.<br>- Positive local divergence curves that result in positive LEs are indicative of local instability.<br>- Lower positive LEs imply less sensitivity to perturbations and are also less flexible and adaptable when variations from one stride to another occur. |
| 76 | **Title:**<br>On the sensitivity improvement of CMOS capacitive accelerometer<br><br>**Authors:**<br>Sun, C.M., Wang, C.W. & Fang, W.L. | Capacitive accelerometers | **Standard CMOS process**<br>- Monolithic integration of the IC and MEMS components.<br>- CMOS MEMS process can be categorized as pre-CMOS, intermediate-CMOS and post-CMOS processes.<br>- Post-CMOS is the most popular approach since the changing of standard CMOS process is not required.<br>- Found in various applications in the area of micro sensors, accelerometer, the pressure sensor, the IR sensor, the gyroscope, the gas sensor and others.<br><br>**CMOS MEMS accelerometers**<br>- Integration of sensing circuit and MEMS transducer on the chip.<br>- Hybrid solution of smaller die size, less noise and higher ability to integrate for semi-custom applications.<br><br>**capacitive accelerometer**<br>- Sensitivity of capacitive accelerometer can be improved by increasing the proof mass and the number of sensing fingers, and decreasing the spring stiffness.<br>- CMOS capacitive accelerometer consists of a proof mass, supporting springs, sensing electrodes, self- |

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| | | | diagnostic actuators, and curvature matching frame.<br>- The motion of the proof mass will lead to the capacitance change of sensing electrodes, so as to determine the accelerations.<br>- The present accelerometer designs remove the center part of the proof mass, and replace with the sensing electrode arrays to increase its sensitivity.<br>- The additional springs and anchor-post are exploited I this CMOS accelerometer for electrical routing of sensing finger arrays. |
| 77 | **Title:**<br>Gait analysis using gravitational acceleration measured by wearable sensors<br><br>**Authors:**<br>Takeda, R. et.al | Sensor unit<br>- A tri-axial acceleration sensor<br>- 3 gyro sensors<br>Aligned on three axes.<br><br>7 sensor units worn on the abdomen and the lower limb segments ( both thighs, shanks and feet) | Measure human gait posture using wearable sensor units.<br><br>**Wearable sensors systems**<br>- Cannot provide position data, but only information such as the tilt angle of a body segment.<br>- Can be conducted outside the laboratories to monitor daily human activity.<br><br>**Acceleration and gyro sensors**<br>- Attached on the thigh and shank were used to estimate 3D knee joint angles during walking<br>- Absolute displacement was not considered.<br><br>**Magnetic sensors**<br>- Body segment position and orientation calculated by magnetic sensors to compensate errors calculated by gyro and acceleration sensors.<br>- Attaching a magnetic source to the body, removing surrounding magnetic interference.<br><br>**Method**<br>- Subject: 3 healthy volunteers with no past history of disabilities or injuries.<br>- Walked for 20s on a flat straight floor.<br>- Measurement for the width at the hip, length of hip joint to knee joint and knee joint to ankle joint were taken for |

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| | | | each volunteer.<br>- Sensors are placed on 7 locations: abdomen, left and right thigh, left and right shank and left and right foot.<br><br>**Experiment**<br>- Consisted of 7 sensor units, each containing a data logger and a sensor head.<br>- The sensor head has a tri-axial acceleration sensor (H34C) and 3 gyro sensors (ENC-03M) aligned on the 3 orthogonal axes.<br>- Data logger simultaneously records the acceleration and angular velocity data for a maximum of 150s at a sampling rate of 100Hz.<br>- An automated mechanical turntable was used to derive the offset for acceleration and angular velocity data of each sensor unit.<br>- Reflective markers were placed on the lower body of volunteers and images where captured during the experiment using a digital camera (HDR-SR1).<br>- The camera images were analyzed using motion capture software (DIPP-Motion Pro).<br>- This software automatically detects and gives coordinate data of markers.<br><br>**Limitations of study:**<br>- Results cannot be shown in real time.<br><br>**Contrary to limitations:**<br>- Able to detect differences in joint angles of a healthy leg and an impaired leg.<br>- Can provide quantitative information for constant gait in healthy subjects<br>- The acceleration patterns during gait can be used to estimate lower body posture. |

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| 78 | **Title:**<br>Gait posture estimation using wearable acceleration and gyro sensors<br><br>**Authors:**<br>Takeda, R., Tadano, S., Natorigawa, A., Todoh, M. & Yoshinari, S. | Tri-axial acceleration sensor (H34C)<br><br>Gyro sensors (ENC-03M) | Measure the 3D positions of joint centers of hip, knee and ankle during movement using wearable acceleration sensors and gyro sensors.<br><br>**Gait analysis method**<br>(a) Cameras to track the position of body-mounted reflective markers<br>- Large, expensive and complex<br>- Restricted to indoor laboratories<br>(b) Acceleration sensor<br>- Measurements to be made outside the laboratory environment<br>- Do not measure positions<br>(c) Gyro sensor<br>- Small errors in the angular velocity data accumulate with integration<br>- Restricted to the measurements of cyclic gait<br>(d) Combination of acceleration, gyro and magnetic sensors<br>- Increase the accuracy<br>- Recalibration of the sensors had to be conducted regularly<br>- Careful attention must be given to the magnetic surroundings and even to the storage of the sensors.<br>- Magnetic sensor is not suitable for measurements in home environments.<br><br>Angular velocity was used to calculate the translational acceleration<br><br>Translational acceleration was then subtracted from the measured acceleration data to obtain the gravitational acceleration.<br><br>**Sensor system**<br>- Wearable sensor unit which containing a data logger and a sensor head.<br>- The sensor head has a tri-axial acceleration sensor and 3 gyro sensors.<br>- Data logger can record the acceleration and angular velocity data for a maximum of 160s at a sampling rate of 100Hz.<br>- All sensor units were checked on a mechanical turntable to establish the |

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| | | | offset values for acceleration and angular velocity data, in addition to obtaining the inclination relationships of the measured values.<br><br>**Method**<br>- Subject: 3 healthy volunteers with no past history of disabilities or injuries.<br>- Walking on a 5m flat straight floor for 3 trails.<br>- Walking velocity was fixed to a cadence of 88 steps/min using a digital metronome (TU-80).<br>- Measurement for the length and inclination of each segment was used to calculate the joint positions of both left and right hip, both knees and both ankles during walking.<br>- Sensor units are placed on 4 locations: left and right thigh and left and right shank.<br>- For comparison, a reference motion analysis system (DIPP-Motion Pro) was used to track reflective markers on the volunteers as well.<br>- To prevent sensor attachment errors, measurements of each sensor unit were made before and after the trials of each volunteer.<br><br>**Advantages**<br>- Strong correlation with the camera system data.<br>- Does not require measurements of the cyclic gait over long periods of time.<br><br>**Limitations of study**<br>- Assumption of constant velocity in the walking direction.<br>- Assumption of hip joint movement includes only centripetal and tangential acceleration.<br>- Anterior-posterior acceleration of the trunk segment increased with walking velocity, and as the current work conducted experiments at fairly low velocity, the effect of any anterior-posterior acceleration may not have been apparent.<br>- Error introduced by the attachment of |

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| | | | the sensors is an issue with any kind of wearable sensor.<br><br>**Future work**<br>- Develop a more secure method for fixation of the sensors.<br>- Develop a method for calculating the internal-external rotation of the hip joints to provide more accurate results. |
| 79 | **Title:**<br>GPS analysis of human locomotion: Further evidence for long-range correlations in stride-to-stride fluctuations of gait parameters<br><br>**Authors:**<br>Terrier, P., Turner, V. & Schutz, Y. | Global Positioning System, GPS | **Global Positioning System, GPS**<br>- Consists of 24 operational satellites and provides navigation and surveying capability worldwide.<br><br>**Methods**<br>- Seven healthy young participants.<br>- Conducted in the sport area of the university on an athletic track, 400m oval.<br>- The computing was realized with Matlab to calculate time series of basic gait parameters such as walking speed, step length and step frequency.<br><br>GPS technology appears to be a promising tool to analyze long-term fluctuation dynamics of walking. |
| 80 | **Title:**<br>Analysis of walking improvement with dynamic shoe insole, using 2 accelerometer s<br><br>**Authors:**<br>Tsuruoka, Y., Tamura, Y., Shibasaki, R. & Tsuruoka, M. | Synchronized Accelerometer System (SAS) used two light-weight synchronized, two-axial (2D) accelerometers | The orthopedics at the rehabilitation hospital found that disorders caused by sports injuries to the feet or caused by lower-back are improved by wearing dynamics shoe insole, these improve walking balance and stability.<br><br>Treatment with dynamic shoe insole, which restores the balance of body posture, is known to increase the stability of the rhythm in walking movements and to reduce lower-back pain.<br><br>Dynamic shoe insoles are defined as shoe insoles with various pads attached. They are made by observing movements during actual walking. The various pads are shaped and positioned on the back of the shoe insoles so that they will enable smooth walking. |

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| | | | **Conventional 3D motion capture system**<br>- Measured distance is not enough for the walking analysis because cameras are fixed in place.<br>- More space is needed for setting up a motion capture system.<br>- Sometimes markers on joints during walking seem to disappear suddenly against camera angles.<br><br>**Methods**<br>a. Subjects<br>- 10 females with mild left lower-back pain who had not received any orthopaedic treatment.<br>b. Dynamic shoe insoles<br>- The state of foot alignment, the toes, and the arch of the sole during walking are taken into consideration<br>- Weight-bearing positions and movement patterns are also taken into consideration.<br>- Decides the position and shape of the various pads on the back of the insoles.<br>c. Synchronized accelerometer system (SAS)<br>- Consisted of 2 ADXL accelerometers<br>- Connected to a small wristwatch-type-computer (WPC)<br>- WPC controls the synchronization of 2 accelerometers, contains a ceramic resonator called “CERALOCK”.<br>d. Experimental procedure<br>- WPC was attached to the wrist of the subjects.<br>- 2 accelerometers were attached to the subjects left lower-back and left knee or left lower-back and right knee.<br>- Accelerometer was attached onto the pants not skin but was held stable attached to the knee and pelvis using a strong elastic supporter.<br>- Measured position of the left lower-back was an anterior superior iliac spine.<br>- Measured position of the left or right knee was height between the adductor tubercle of the femur and the knee-gap |

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| | | | (between femur and tibia) and halfway between the front and back of the knee excluding the patella.<br><br>**Data analysis**<br>a. Relative Power Contribution (RPC) analysis<br>- Using the auto regressive (AR) model to study feedback in the body.<br>- When walking without insoles, there is little contribution to movement from left knee relative to the subject's impaired left pelvis.<br>b. Step Response (SR) analysis<br>- Evaluate stability by adding a unit step signal to the system.<br>- When the unit step signal was added to the movement of impaired left pelvis, the waveforms of the responses more smoothly converged when the insole were worn.<br>- SR variance of the right knee greatly decreased, in both directions.<br>- Right knee was more stable with the addition of unit step signal to the left pelvis.<br>c. Statistical analysis<br>- Paired t-tests were performed on all variables to compare data obtained with insoles and without insoles.<br><br>RPC analysis showed that the contribution of both knees clearly increased when patients with lower-back pain wore dynamic shoes insoles. SR analysis showed that the stability of both knees. |
| 81 | **Title:**<br>Recent developments in human motion analysis<br><br>**Authors:**<br>Wang, L., Hu, W.M. & Tan, T.N. | Human movement analysis | - Provides a comprehensive survey of research on computer vision based human motion analysis. The emphasis is on three major issues involved in a general human motion analysis system, namely human detection, tracking and activity understanding.<br><br>**Human Motion Analysis System**<br>- Attempts to detect, track and identify people, and more generally, to interpret human behaviors, from image |

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| | | | sequences involving humans.<br>- Has a wide range of potential applications such as smart surveillance, advanced user interface, motion based diagnosis<br>- Visual surveillance used in the security-sensitive areas such as banks.<br>- Advanced user interface is usually used to provide control and command.<br>- Motion based diagnosis and identification is particularly useful to segment various body parts of human in an image, track the movement of joints over an image sequence, and recover the underlying 3-D body structure for the analysis and training of athletic performance. |
| 82 | **Title:**<br>Integrated sensors, MEMS, and Microsystems : Reflections on a fantastic voyage<br><br>**Authors:**<br>Wise, K.D. | | **Integrated sensors**<br>- High-density non-invasive EEG recording system<br>- Silicon-based multi-site neural probe<br>- Catheter-tip pressure sensor<br>- Gas chromatograph<br>- Integrated silicon microcolumns<br>- Silicon image sensors<br>- Direct translation optical to tactile reading aid<br>- Low-power implantable Doppler Microsystems for blood flow and cardiac imaging<br><br>**New technology and new application**<br>- Anodic silicon-glass wafer bonding<br>- Interface circuitry<br>- Integrated sensors<br>- Solid-state sensors<br>- Three-dimensional semiconductor device structures<br>- Solid-state sensors, actuators, and interface electronics. |
| 83 | **Title:**<br>Measurement of energy expenditure in elite athletes using MEMS-based triaxial accelerometer | | Those markers that demonstrated the least rigidity are KNE, KNM and TTU.<br><br>Functional trials marker pairs associated with KNE, KNM or TTU performed poorly, indicating there may be a greater degree of soft tissue movement. Knee joint line is highly susceptible to |

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| | s<br><br>**Authors:**<br>Wixted, A.J. et.al | | movement.<br><br>Methods aim to determine the pattern, and quantify the magnitude, of soft tissues artefact (STA) during motion.<br>- External fixation devices<br>- Intra-cortical bone pins<br>- Percutaneous skeletal trackers<br>- Roentgen photogrammetry<br>Issues may arise<br>- Changes to usual gait pattern due to analgesic compensations<br>- Objects pinned through skin into bone may affect usual soft tissue movement being measured<br>- Bone pins may not be completely rigid<br>- Small participant numbers<br><br>Lower limb gait models should focus on these tibial markers. |
| 84 | **Title:**<br>Detecting spinal posture change in sitting positions with tri-axial accelerometer s<br><br>**Authors:**<br>Wong, M.Y. & Wong, M.S. | Tri-axial accelerometers (KXM52-Tri-axis) | Using three tri-axial accelerometers for monitoring postural changes in sitting.<br><br>S**pinal motion analysis**<br>- Useful clinical method for quantifying he range of trunk motions and pattern of posture changes by clinicians for diagnosis and outcome evaluation.<br>- Radiographic measurements or optoelectronic motion analysis systems have been used for collecting data in spinal motion analysis; these methods are either invasive or limited to laboratory or clinical environment.<br>- Accelerometers could be considered as an option for spinal motion analysis to collect continuous postural information in daily activities.<br>- Accelerometers can measure acceleration and tilt angle relative to the gravity in quasi-static condition.<br><br>**Methods**<br>- 3 sensor modules and motion analysis system (VICON) in three subjects without back injury and spinal deformity.<br>- At the first 3s of each experimental trial, the subject was requested to sit at a |

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| | | | neural position without back support to initialize the measurements of postural change for zero setting.<br>- A three-dimensional rotation alignment device which can provide actual tilting angle with 1˚ increment was used for static calibration of sensor modules.<br>- The measurements of the sensor modules were compared with those of the Vicon system in both quasi-static and dynamic (postural transition) condition.<br><br>**Tri-axis accelerometer detection**<br>- Able to detect the change in static calibration up to 1˚<br>- Sensitivity is reduced when its sensing axis tends to horizontal.<br>- Able to detect the trunk tilting but not curvature changes because of no references signal from the distal portion of the trunk.<br><br>**Future work**<br>- In combination with gyroscopes, it might give more reliable information in tracking dynamics postural changes in daily activities. |
| 85 | **Title:**<br>Clinical applications of sensors for human posture and movement analysis: A Review<br><br>**Authors:**<br>Wong, W.Y., Wong, M.S. & Lo, K.H. | Image-based methods<br>- Photogrammetry<br>- Optoelectric techniques<br>- Video analysis<br><br>Electronic sensors and systems<br>- Accelerometer<br>- Gyroscopes<br>- Flexible angular sensor<br>- Electromagnetic tracking system<br>- Sensing fabric | **Limitations**<br>**a. Image-based methods**<br>- Complicated to set up<br>- Time-consuming to operate<br>- Only can applied in laboratory environments<br>**b. Electronic sensors and systems**<br>- Environment influence<br>- Signal extraction difficulties<br><br>**Photogrammetric**<br>- Used to record 2- or 3-dimensional image of posture.<br>- Uses either light-reflective markers or light-emitting dioxides affixed to the human body.<br>- Captures data with cameras and films.<br><br>**Optoelectric analysis**<br>- Measure the position of joints and body |

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| | | | segments.<br>- Used to collecting the data instead of films.<br><br>**Video systems**<br>- Capture data with optoelectric units or cameras of higher sampling rate.<br>- Capture and record 3-dimensional body segments.<br><br>**Accelerometer**<br>- Is a position sensor operated by measuring acceleration along sensitive axis of the sensor based on Newton's second law.<br>- Capacitive accelerometers have higher stability, sensitivity and resolution than piezoresistive.<br>- Piezoelectric and capacitive accelerometer consists of 2 components, including a gravitational component and a component from other acceleration force.<br>- Piezoresisitive and capacitive accelerometers are suitable for measuring human posture and movement because they can provide dual acceleration components.<br><br>**Gyroscope**<br>- Is an angular velocity sensor which is commonly used for measurement of human posture and movement.<br>- Angular orientation can be obtained from integration of the gyroscopic signal.<br><br>**Flexible angular sensor**<br>- Is not a type of inertial sensor.<br>- Operated by measuring change of electric output or displacement with respect to angular change.<br>- Strain gauge has been used in flexible electro-goniometer for angle measurement in clinical use.<br>- Flexible electro-goniometer is available commercially for measurement of posture and spinal motion in 2 planes. |

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| | | | **Electromagnetic tracking system**<br>- 3-Dimensional measurement device that has been used in human posture and movement analysis.<br>- Consists of transmitter and receivers.<br>- Low-frequency magnetic field is generated by the transmitter and detected by the receivers.<br><br>**Sensing fabric**<br>- Used to detecting the posture and movement.<br>- Operated by measured the changes of resistance in knitted strips.<br>- Minimally intrusive wearable system consisting of a Lycra leotard with conductive polymer strain sensor.<br>- Other combinations of material and polymers were used to optimize the response time of the sensors.<br>- Polymeric conductors and semiconductors offer several advantages with respect to metal and inorganic conductors: lightness, large elasticity and resilience, resistance to corrosion, high flexibility and impact strength.<br>- Polypyrrole as conducting polymer and Lycra/cotton as fabric is particular effective because of its elasticity, ergonomic comfort and high piezoresistive and thermoresistive coefficients.<br><br>**Clinical applications**<br>a. Analyses of general physical activity<br>  - Accelerometer<br>b. Gait analysis<br>  - Accelerometer, gyroscope & flexible angular sensor<br>c. Posture and trunk movement analysis<br>  - Accelerometer, gyroscope, electro-magnetic sensor, flexible angular sensor & sensing fabrics<br>d. Upper limb movement analysis<br>  - Accelerometer, electro-magnetic sensor & sensing fabrics<br><br>**Advantages**<br>- Miniature in size<br>- Lower power consumption |

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| | | | - portable<br><br>**Limitations**<br>**a. Environment effects**<br>- Sensing fabric's signal could be affected by humidity and temperature.<br>- Accuracy of electromagnetic system can be adversely affected by the presence of metallic objects and used only in the prepared environment without any metallic interference, not suitable for the patient with metallic implants and prostheses.<br>- Flexible strain-gauged electro-goniometer could be limited by exceeding the maximum preset distance between the 2 attachments with linear displacements occurring during flexion and extension of the lumbar spine.<br>**b. Difficulties of extraction of signal**<br>- For sensing fabrics, electrical resistance of the fabrics varies with orientation, stress and temperature.<br>- The manipulation of the sensor signals involved many mathematical methods.<br><br>**Future development**<br>- Compactness in size of sensor.<br>- Advancement of portable data logging device and wireless data transfer system.<br>- Well developed user-friendly computerized interface. |
| 86 | **Title:**<br>A review of accelerometer based wearable motion detectors for physical activity monitoring<br><br>**Authors:**<br>Yang, C.C. & | Accelerometer | - The development of wearable accelerometry-based motion detectors for physical activity monitoring and assessment, including posture and movement classification, estimation of energy expenditure, fall detection and balance control evaluation.<br><br>**Accelerometry-based wearable motion detectors**<br>- Piezoresistive accelerometers<br>- Piezoelectric accelerometers<br>- Capacitive accelerometers |

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| | Hsu, Y.L. | | **Sensor Placement**<br>- Whole body movement: sternum, lower back and waist.<br>- Chest-worn accelerometer was presented to detect respiratory and snoring features for apnoea diagnosis during sleep.<br>- Ankle- attached accelerometers can significantly reflect gait-related features during locomotion or walking.<br>- Loose attachment or unsecured fit causes vibration and displacement of the wearable systems. And this is liable to produce extraneous signal artefacts and to degrade sensing accuracy.<br><br>**Current Products**<br>- SenseWear<br>- CT1 and RT3<br>- AMP331<br>- GT3X, GT1M<br>- StepWatch<br>- ActivePAL<br>- IDEEA |
| 87 | **Title:**<br>Automatic Step Detection in the accelerometer signal<br><br>**Authors:**<br>Ying, H., Silex, C., Schnitzer, A., Leonhardt, S. & Schiek, M. | - ADXL322 dual-axis accelerometer<br>- 1 micro farad and 0.1 micro farad ceramic capacitor<br>- 32KΩ resistor<br>- Voltage regulator TPS77027 | **Applications**<br>- Analysis of vegetative locomotor coordination during monitoring the patients with Parkinson's disease.<br><br>**Three algorithms**<br>- Pan-Tompkins method<br>- Template-matching method<br>- Peak-detection method based on combined dual-axial signals<br><br>**Methods**<br>- Subjects: 8 patients suffering from Parkinson's disease<br>- 4 stages<br>- Total duration: 115 minutes<br>- Sample rate: 200Hz<br>- Accelerometers attaching on the lateral side of the left and right feet.<br><br>**Algorithms**<br>b.Pan-Tompkins method<br>- Used for step detection in the accelerometer signal.<br>- Includes a series of bandpass-filters |

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| | | | and methods that perform low-pass, derivative, squaring, integration for preprocess and adaptive thresholds for peak-searching.<br>c. Template-matching method<br>- Generate a template, which represents a typical step cycle<br>d. Peak-detection method<br>- Based on the coincident negative wave in the x- and z-axial acceleration signal. |

# APPENDIX B: Operators for C Programming

<table>
<tr><th>Operator</th><th>Description</th></tr>
<tr><td>+</td><td>Addition operator</td></tr>
<tr><td>+=</td><td>Addition assignment operator, x+=y, is the same as x=x+y</td></tr>
<tr><td>&=</td><td>Bitwise and assignment operator, x&=y, is the same as x=x&y</td></tr>
<tr><td>&</td><td>Address operator or Bitwise and operator</td></tr>
<tr><td>^=</td><td>Bitwise exclusive or assignment operator, x^=y, is the same as x=x^y</td></tr>
<tr><td>^</td><td>Bitwise exclusive or operator</td></tr>
<tr><td>|=</td><td>Bitwise inclusive or assignment operator, x|=y, is the same as x=x|y</td></tr>
<tr><td>|</td><td>Bitwise inclusive or operator</td></tr>
<tr><td>?:</td><td>Conditional Expression operator</td></tr>
<tr><td>--</td><td>Decrement</td></tr>
<tr><td>/=</td><td>Division assignment operator, x/=y, is the same as x=x/y</td></tr>
<tr><td>/</td><td>Division operator</td></tr>
<tr><td>==</td><td>Equality</td></tr>
<tr><td>></td><td>Greater than operator</td></tr>
<tr><td>>=</td><td>Greater than or equal to operator</td></tr>
<tr><td>++</td><td>Increment</td></tr>
<tr><td>*</td><td>Indirection operator</td></tr>
<tr><td>!=</td><td>Inequality</td></tr>
<tr><td><<=</td><td>Left shift assignment operator, x<<y, is the same as x=x<<y</td></tr>
<tr><td><</td><td>Less than operator</td></tr>
<tr><td><<</td><td>Left shift operator</td></tr>
<tr><td><=</td><td>Less than or equal to operator</td></tr>
<tr><td>&&</td><td>Logical AND operator</td></tr>
<tr><td>!</td><td>Logical negation operator</td></tr>
<tr><td>||</td><td>Logical OR operator</td></tr>
</table>

| | |
|---|---|
| %= | Modules assignment operator x%=y, is the same as x=x%y |
| % | Modules operator |
| *= | Multiplication assignment operator, x*=y, is the same as x=x*y |
| * | Multiplication operator |
| ~ | One's complement operator |
| >>= | Right shift assignment, x>>=y, is the same as x=x>>y |
| >> | Right shift operator |
| -> | Structure Pointer operation |
| -= | Subtraction assignment operator |
| - | Subtraction operator |
| sizeof | Determines size in bytes of operand |

# APPENDIX C: Data Definitions for C Programming

## Basic Types

This section describes what the basic data types and specifies are and how variables can be declared using those types. In C all the variables should be declared before they are used. They can be defined inside a function (local) or outside all functions (global). This will affect the visibility and life of the variables.

| **Type - Specifies** | **Size** | **Range** | | |
|---|---|---|---|---|
| | | **Unsigned** | **Signed** | **Digits** |
| int1 | 1 bit number | 0 to 1 | N/A | 1/2 |
| int8 | 8 bit number | 0 to 255 | -128 to 127 | 2-3 |
| int16 | 16 bit number | 0 to $2^{16}$ | -32768 to 32767 | 4-5 |
| int32 | 32 bit number | 0 to $2^{32}$ | -2147483648 to 2147483647 | 9-10 |
| float32 | 32 bit float | $-1.5 \times 10^{45}$ to $3.4 \times 10^{38}$ | | 7-8 |

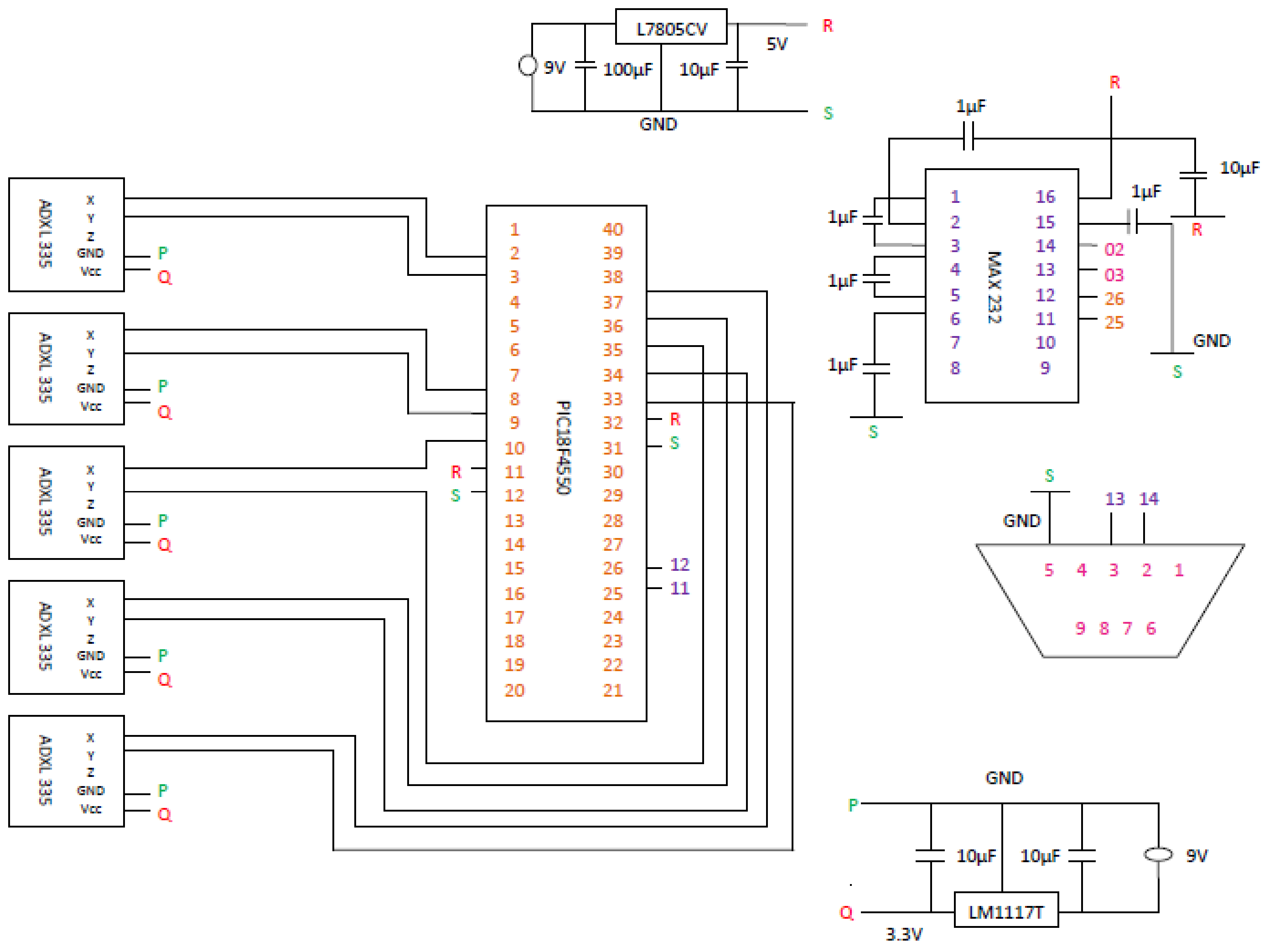
| **C Standard Type** | **Default Type** |
|---|---|
| short | int1 |
| char | unsigned int8 |
| int | int8 |
| long | int16 |
| long long | int32 |
| float | float32 |

Note: All types, except float, by default are unsigned; however, may be preceded by unsigned or signed. Short and long may have the keyword int following them with no effect.

# APPENDIX D: Type-Qualifier for C Programming

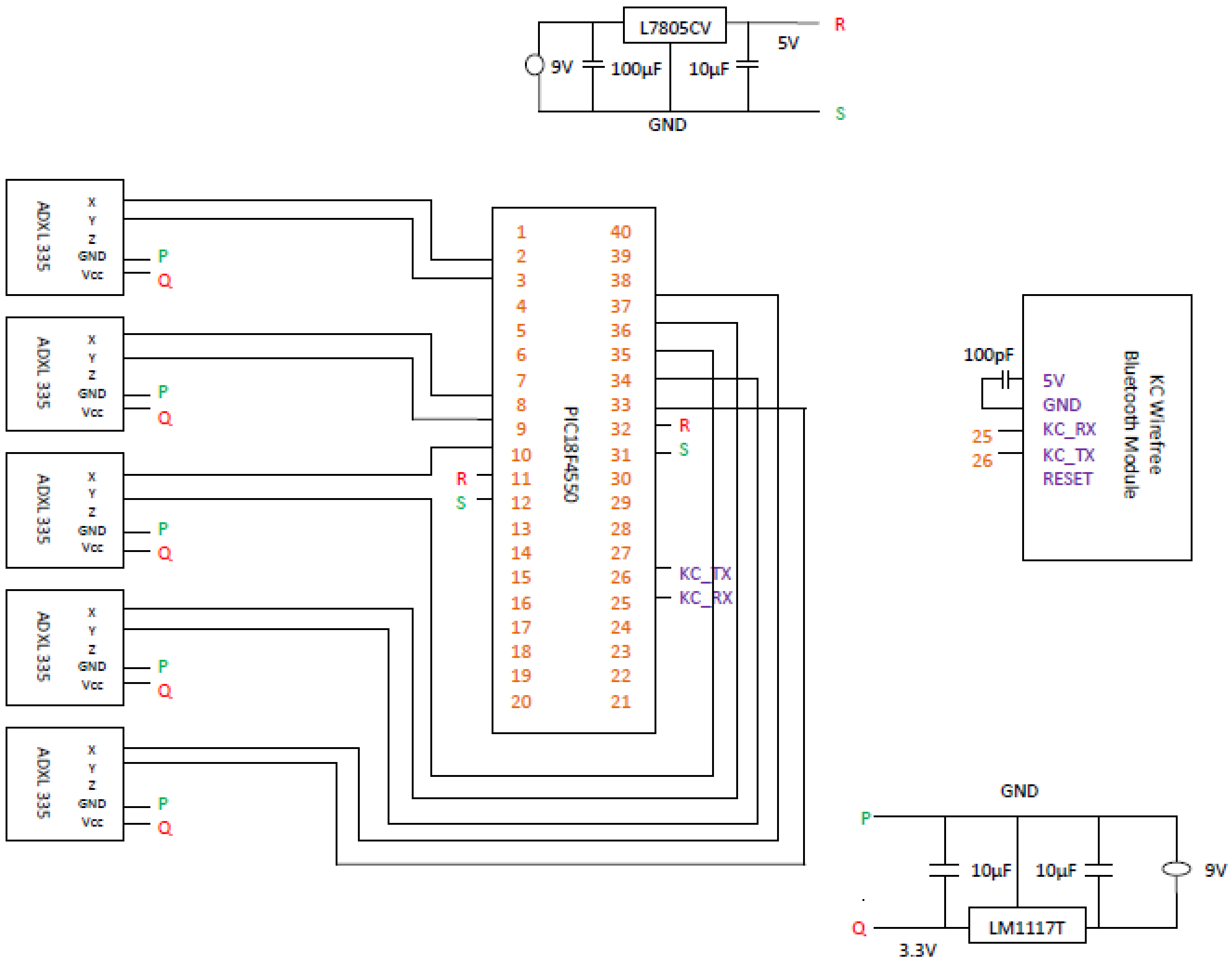
| **Type-Qualifier** | **Descriptions** |
|---|---|
| static | Variable is globally active an initialized to 0. Only accessible from this compilation unit. |
| auto | Variable exists only while the procedure is active. This is default and auto need not be used. |
| double | Is a reserved word but is not supported data type. |
| extern | External variable used with multiple compilation units. No storage is allocated. Is used to make otherwise out of scope data accessible. There must be a non-extern definition at the global level in some compilation unit. |
| register | Is allowed as a qualifier however, has no effect |
| _fixed(n) | Creates a fixed point decimal number where n is how many decimal places to implement. |
| unsigned | Data is always positive. This is the default data type if not specified. |
| signed | Data can be negative and positive. |
| volatile | Tells the compiler optimizer that this variable can be changed at any point during execution. |
| const | Data is read-only. Depending on compiler configuration, this qualifier may just make the data read-only -AND/OR- it may place the data into program memory to save space. |
| void | Built-in basic type. Type void is used for declaring main programs and subroutines. |

# APPENDIX E:
Circuit Diagram for Lower Extremities Human Movement Analysis System with DB9 Connector RS232



L7805CV
9V
100µF
10µF
5V
GND
R
S
ADXL 335
X
Y
Z
GND
Vcc
P
Q
PIC18F4550
MAX 232
1µF
10µF
02
03
26
25
GND
13
14
LM1117T
3.3V
9V

# APPENDIX F:
# Circuit Diagram for Lower Extremities Human Movement Analysis System with Bluetooth Module SKCCA-21


L7805CV
9V
100µF
10µF
5V
R
S
GND
ADXL 335
X
Y
Z
GND
Vcc
P
Q
PIC18F4550
KC_TX
KC_RX
100pF
5V
GND
KC_RX
KC_TX
RESET
25
26
KC Wirefree Bluetooth Module
GND
10µF
9V
LM1117T
3.3V

# APPENDIX G: PIC Microcontroller Programming Code

```
/*****************************************************************
Lower Extremities Movement Analysis Using Accelerometer
**************************************************
This program is designed to obtain the acceleration signal data from accelerometer
which is attached on the human remote body part and transmits to the
microcontroller for further signal processing. After that, the processed signal data
transmit to personal computer for the data analysis.
Programmer: Ms. Chew Kah Mun
File: Human Movement Analysis.C
Date: 15 March 2011
Micro: PIC18F4550
*****************************************************************/
// AN0 for analog input
// RB7 & RB6 for alternating LED blinks
// 20 MHz
// Tx output 9600 baud

#include <p18f4550.h>

#pragma config PLLDIV = 5, CPUDIV = OSC1_PLL2, USBDIV = 2
#pragma config FOSC = HS, FCMEN = OFF, IESO = OFF
#pragma config PWRT = ON, BOR = OFF, BORV = 3, VREGEN = ON
#pragma config WDT = OFF, WDTPS = 32768
#pragma config MCLRE = ON, LPT1OSC = OFF, PBADEN = ON, CCP2MX =
OFF
#pragma config STVREN = ON, LVP = OFF, ICPRT = OFF, XINST = OFF,
DEBUG = OFF
```

```
#pragma config CP0 = OFF, CP1 = OFF, CP2 = OFF, CP3 = OFF
#pragma config CPB = OFF, CPD = OFF
#pragma config WRT0 = ON, WRT1 = OFF, WRT2 = OFF, WRT3 = OFF
#pragma config WRTB = ON, WRTC = OFF, WRTD = OFF
#pragma config EBTR0 = OFF, EBTR1 = OFF, EBTR2 = OFF, EBTR3 = OFF
#pragma config EBTRB = OFF

#define PB7    LATBbits.LATB7

void delayFunc(unsigned int);
void transmit_data(unsigned char* );
void getAcc(unsigned char *);
void conversion(unsigned char, unsigned char, unsigned char*);

static unsigned char channelnumber;
unsigned char head[10]={'A', 'B', 'C', 'D', 'E', 'F', 'G', 'H', 'I', 'J'};        // Data Prefix
unsigned char channel[]={0x00, 0x04, 0x14, 0x18, 0x1C, 0x20, 0x24, 0x28, 0x2C,
0x30};                                  // Channel Address of ADCON0

void main()                             // Main Function
{
        unsigned int delayConst;
        unsigned char acc[4];

        TRISBbits.TRISB7 = 0;           // Set Pin7 of PORTB as output

        ADCON1 = 0x12;                  // Switch AN0/RA0 to analog input
        ADCON0 = 0x00;
        ADCON2 = 0xBE;                  // Right justified and Set Fosc/64

        delayConst = 250;

        UCONbits.USBEN = 0;             // Disable USB
        TXSTA = 0x20;                   // Configure serial port
```

```
        BAUDCONbits.BRG16 = 0;
        BAUDCONbits.TXCKP = 0;
        BAUDCONbits.ABDEN = 0;
        SPBRG = 31;
        RCSTAbits.SPEN = 1;
        TXSTAbits.TXEN = 1;

        channelnumber = 0;                          // Start with Channel 0
        PB7 = 1;                                    // On the LED

        while(1)                                    // Loop Continues
        {
                getAcc(acc);                // Running getAcc(acc) sub-function
                transmit_data(acc);     // Running transmit_data(acc) sub-function

                if(channelnumber == 9)              // If finished all 10 channel
                {
                        channelnumber = 0;          // Return to channel 0

                        delayFunc(delayConst);      // Delay for 250



                } else {
                        channelnumber++;    // If not, continues get and transmit data
                }
        }
}
```

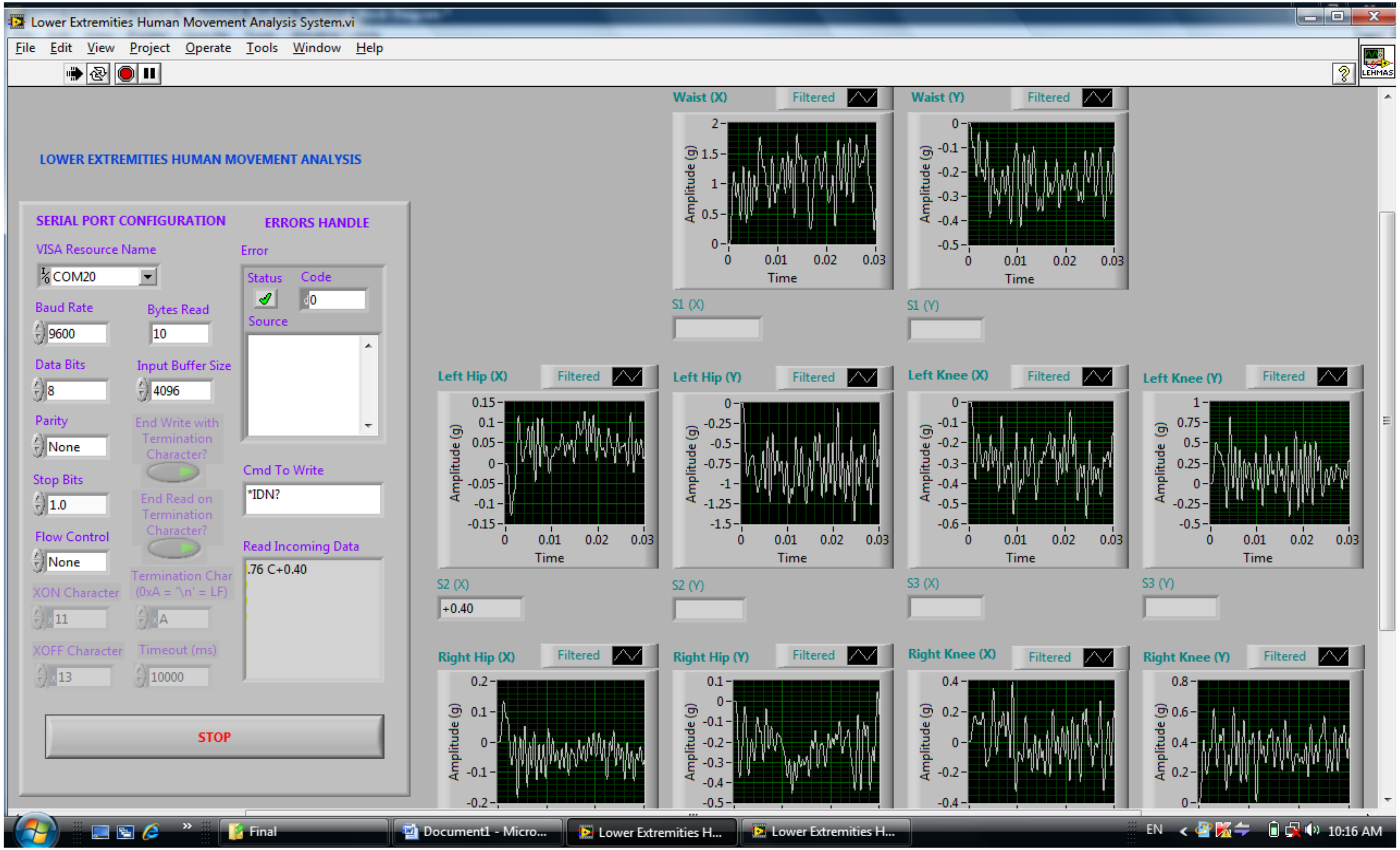
```
void delayFunc(unsigned int delayC)                     // Delay sub-function
{
        unsigned char a, b;                             // Define local variables

        for(a=0; a<delayC; a++)
        {
                for(b=0; b<delayC; b++);
        }
}

void transmit_data(unsigned char *myData)              //Transmit data sub-function
{
        char i;

        while(PIR1bits.TXIF == 0);
        TXREG = head[channelnumber];

        for(i=0; i < 4; i++)
        {
                while(PIR1bits.TXIF == 0);
                TXREG = myData[i];

                if(i==1){
                        while(PIR1bits.TXIF == 0);
                        TXREG = '.';
                }
        }
        while(PIR1bits.TXIF == 0);
        TXREG = '\0';
}

void getAcc(unsigned char * pacc)                       // Get data sub-function
{
        unsigned char accH, accL;
```

```
        ADCON0 = channel[channelnumber];          // Select ADC channel
        ADCON0bits.ADON = 1;                      // Switch on ADC
        ADCON0bits.GO = 1;                        // Start Conversion

        while(ADCON0bits.DONE == 1);
        accH = ADRESH;
        accL = ADRESL;

        conversion(accH, accL, pacc);

        ADCON0bits.ADON = 0;                      // Switch off ADC
}

void conversion(unsigned char addrH, unsigned char addrL, unsigned char *paccVal)
// Sub-function for the conversion of ADC to Hex form and then to ASCII form
{
        int sum = 0x0000, accDeg, accDeg2, accVal[4];
        float fDeg, fSum;
        unsigned char i;

        addrH = addrH & 0x03;
        sum = addrH;
        sum <<= 8;
        sum = sum & 0x0300;
        sum = sum | addrL;

        fSum = sum;
        fDeg = (((fSum / 1024)* 3.3) - 1.62);     // g-Conversion formula

        if(fDeg == -1.62){
                for(i=1; i<4; i++){
                        paccVal[i] = 0x30;
                }
```

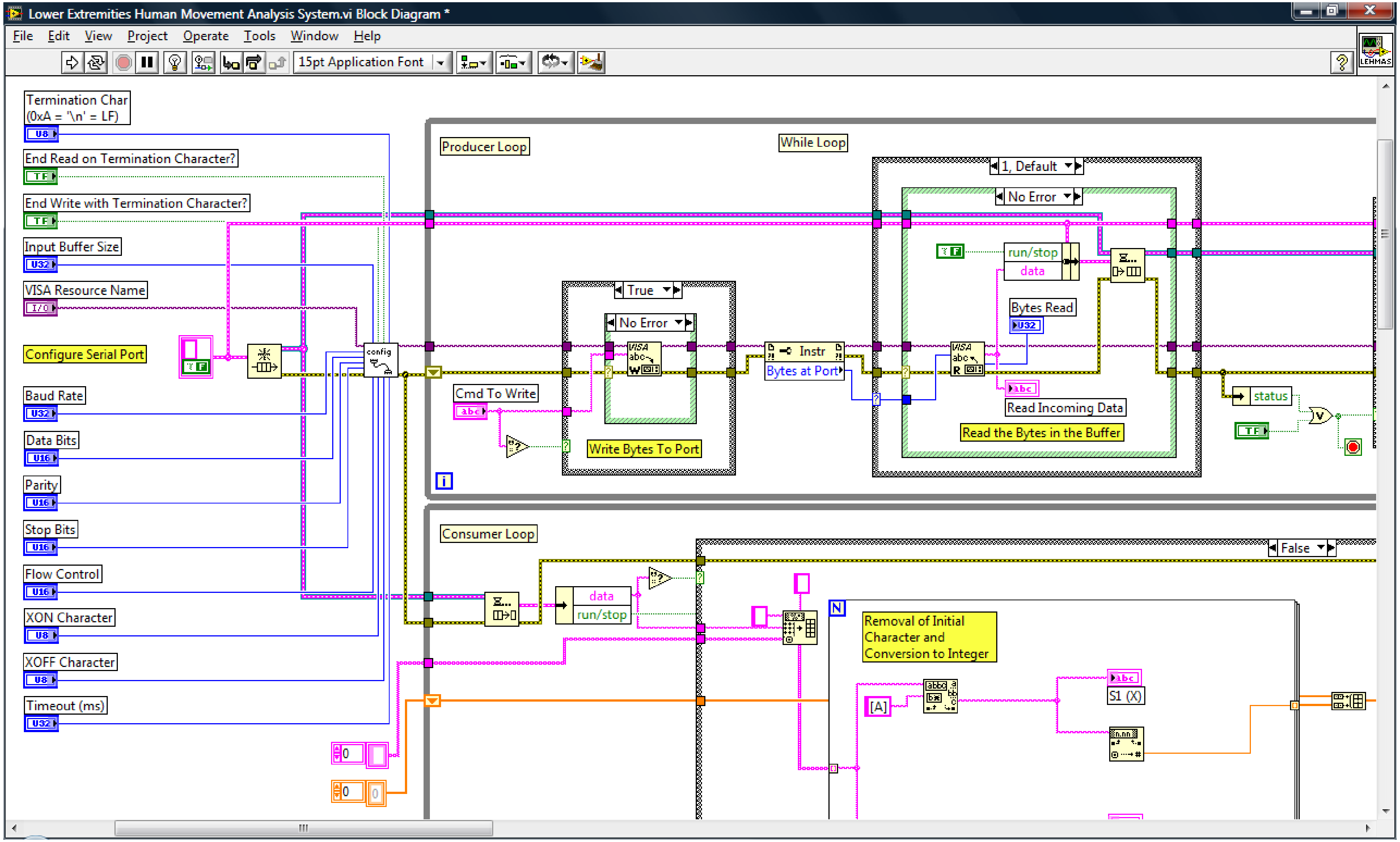
```
        paccVal[0] = '+';
        return;

    } else if(fDeg < 0){
        accVal[0] = '-';
        fDeg *= -1;
    } else if(fDeg >=0){
        accVal[0] = '+';
    }

    fDeg *= 3.03;
    accDeg = fDeg;
    accDeg2 = accDeg;
    accVal[1] = accDeg % 10;

    fDeg = fDeg - accDeg2;
    fDeg *= 10;
    accDeg = fDeg;
    accVal[2] = accDeg % 10;
    fDeg *= 10;
    accDeg = fDeg;
    accVal[3] = accDeg % 10;

    for(i=1; i<4; i++)
    {
        accVal[i] |= 0x30;                  // convert to ASCII form
        paccVal[i] = accVal[i];
    }

    paccVal[0] = accVal[0];
}
```

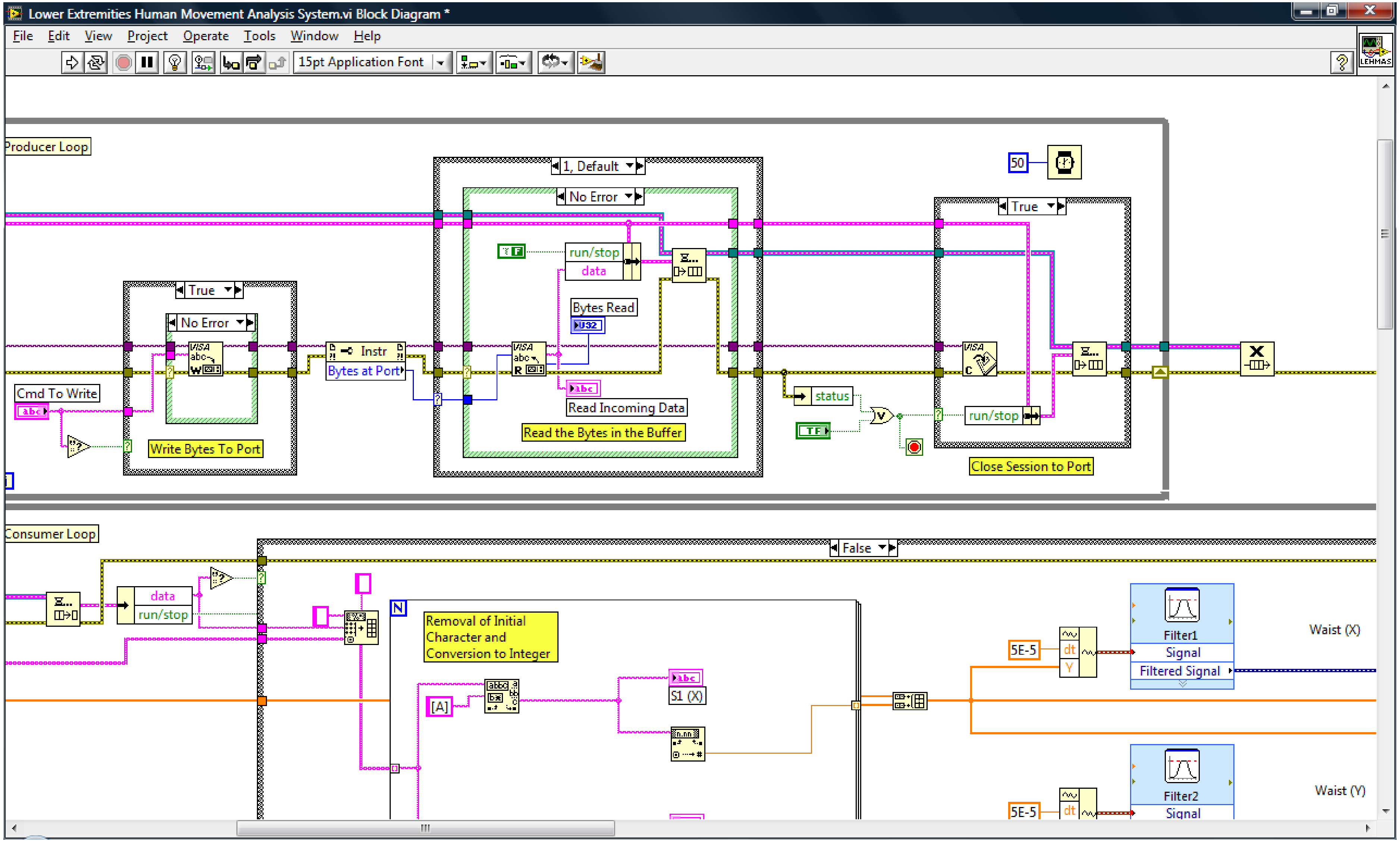
# APPENDIX H: LabVIEW Graphical Programming – Front Panel

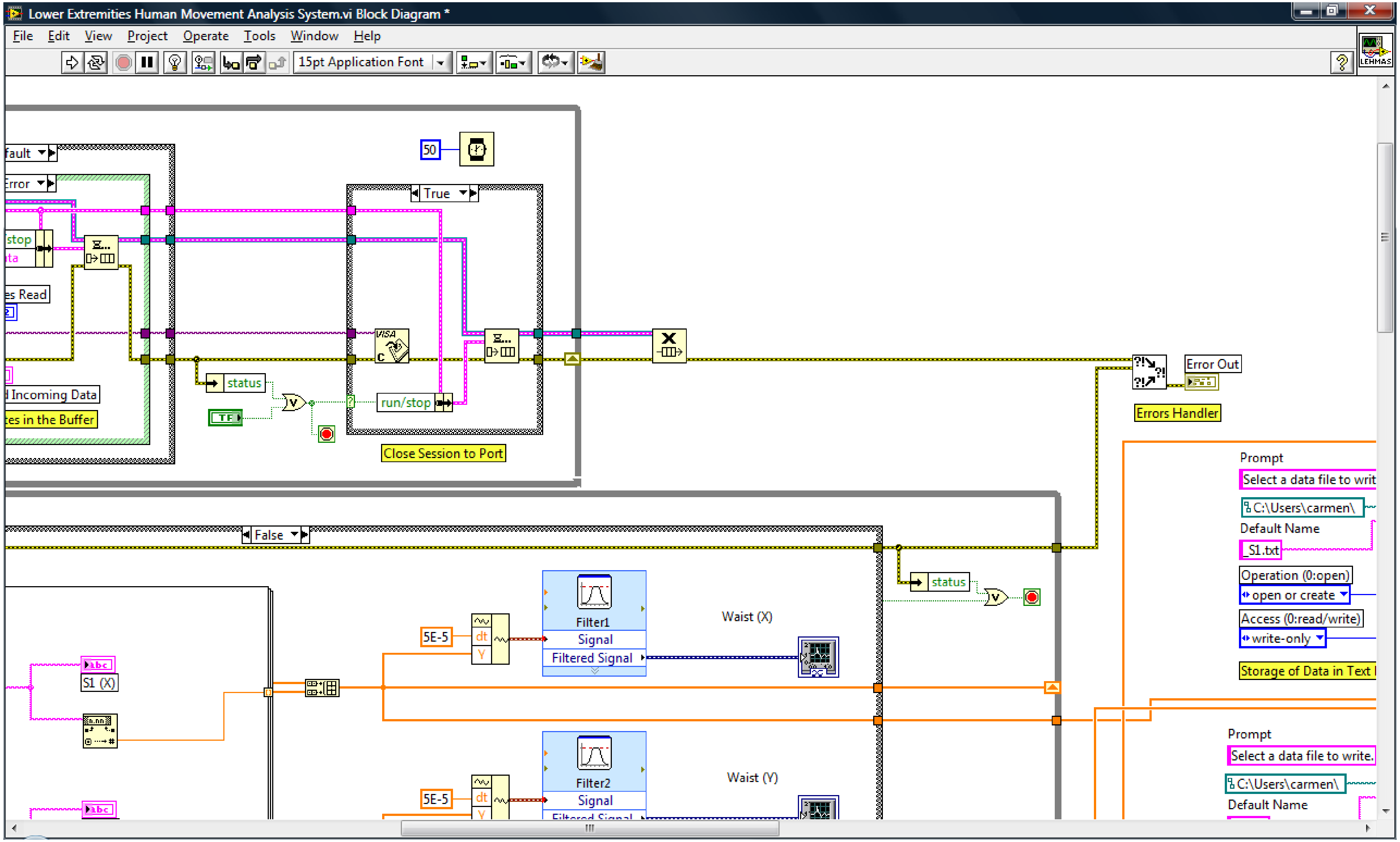

Lower Extremities Human Movement Analysis System.vi
File Edit View Project Operate Tools Window Help
LOWER EXTREMITIES HUMAN MOVEMENT ANALYSIS
SERIAL PORT CONFIGURATION
ERRORS HANDLE
VISA Resource Name
COM20
Baud Rate
9600
Bytes Read
21
Data Bits
8
Input Buffer Size
4096
Parity
None
End Write with Termination Character?
Stop Bits
1.0
End Read on Termination Character?
Flow Control
None
Termination Char (0xA = '\n' = LF)
XON Character
11
A
XOFF Character
13
Timeout (ms)
10000
Error
Status
Code
0
Source
Cmd To Write
*IDN?
Read Incoming Data
+3.23 B-0.79 C-0.38 D
STOP
Waist (X)
Waist (Y)
Filtered
S1 (X)
S1 (Y)
-0.79 C-
Left Hip (X)
Left Hip (Y)
Left Knee (X)
Left Knee (Y)
S2 (X)
-0.38 D
S2 (Y)
S3 (X)
S3 (Y)
Right Hip (X)
Right Hip (Y)
Right Knee (X)
Right Knee (Y)
Amplitude (g)
Time
Final
Lower Extremities H...
10:13 AM

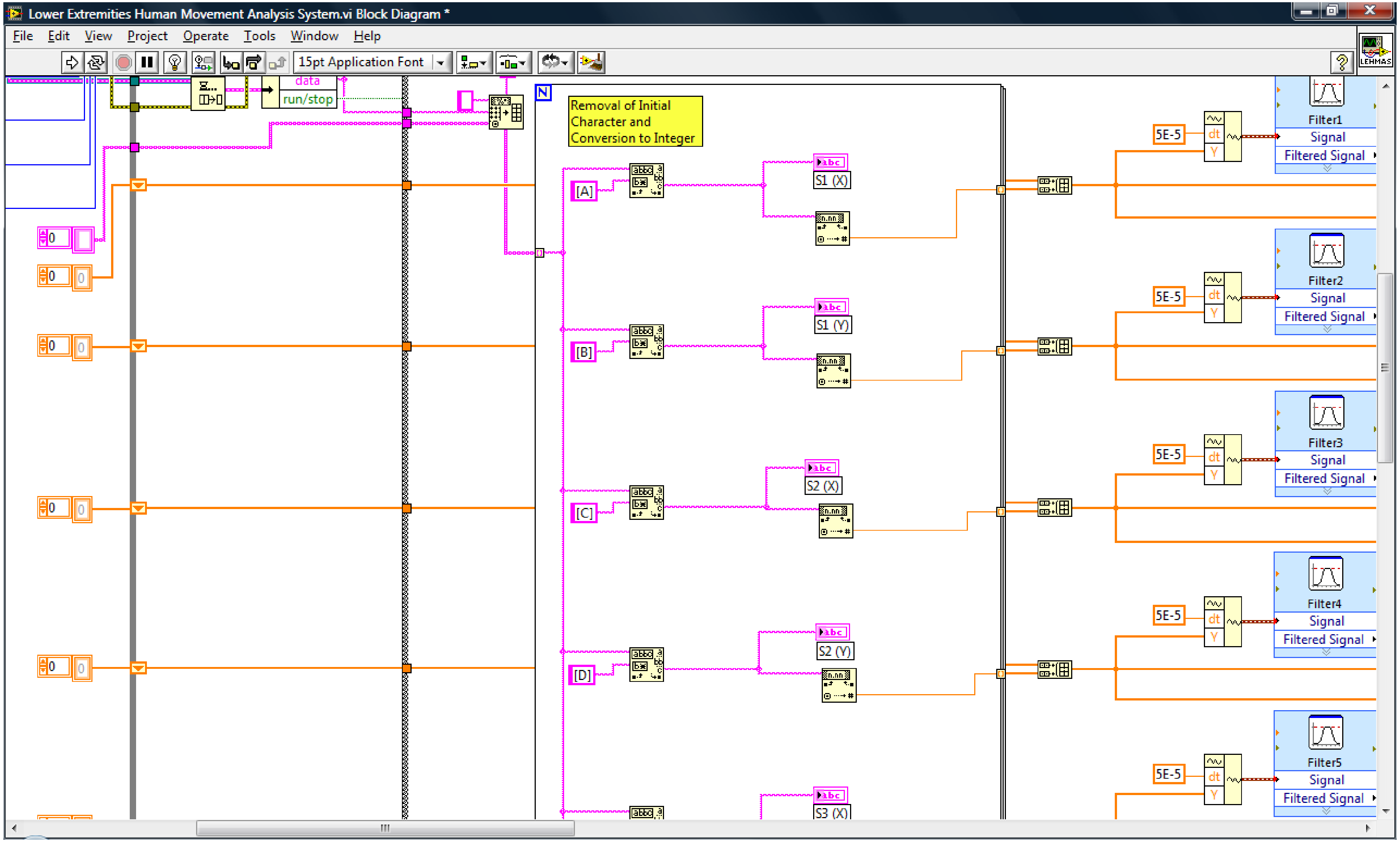

Lower Extremities Human Movement Analysis System.vi
File Edit View Project Operate Tools Window Help
LOWER EXTREMITIES HUMAN MOVEMENT ANALYSIS
SERIAL PORT CONFIGURATION
ERRORS HANDLE
VISA Resource Name
COM20
Baud Rate
9600
Bytes Read
10
Data Bits
8
Input Buffer Size
4096
Parity
None
Stop Bits
1.0
Flow Control
None
End Write with Termination Character?
End Read on Termination Character?
Termination Char (0xA = '\n' = LF)
XON Character
11
A
XOFF Character
13
Timeout (ms)
10000
Error
Status
Code
0
Source
Cmd To Write
*IDN?
Read Incoming Data
.76 C+0.40
STOP
Waist (X)
Waist (Y)
Filtered
Amplitude (g)
Time
S1 (X)
S1 (Y)
Left Hip (X)
Left Hip (Y)
Left Knee (X)
Left Knee (Y)
S2 (X)
+0.40
S2 (Y)
S3 (X)
S3 (Y)
Right Hip (X)
Right Hip (Y)
Right Knee (X)
Right Knee (Y)
Final
Document1 - Micro...
Lower Extremities H...
EN
10:16 AM

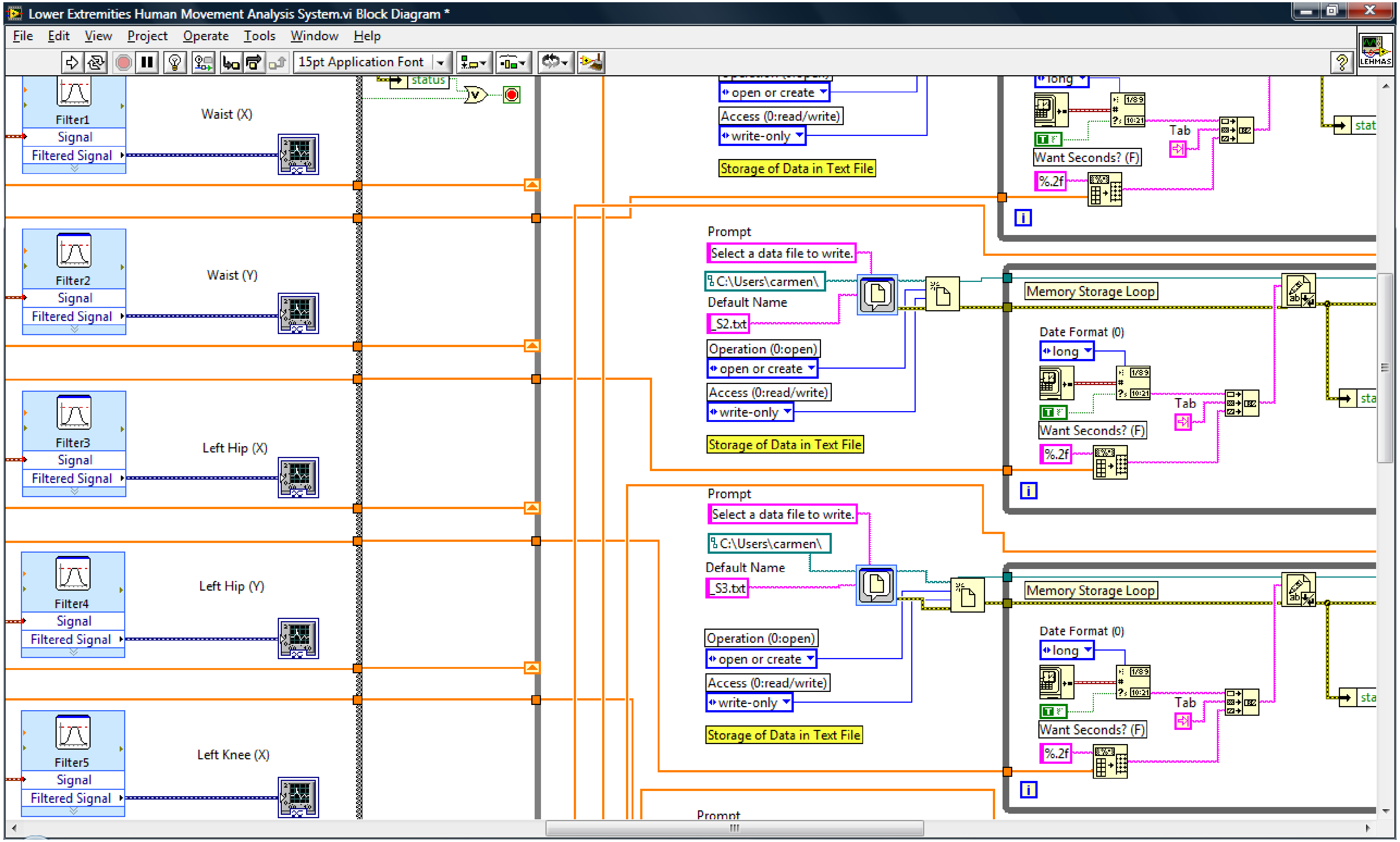
# APPENDIX I: LabVIEW Graphical Programming – Block Diagram


Lower Extremities Human Movement Analysis System.vi Block Diagram *
File Edit View Project Operate Tools Window Help
15pt Application Font
Termination Char (0xA = '\n' = LF)
End Read on Termination Character?
End Write with Termination Character?
Input Buffer Size
VISA Resource Name
Configure Serial Port
Baud Rate
Data Bits
Parity
Stop Bits
Flow Control
XON Character
XOFF Character
Timeout (ms)
Producer Loop
While Loop
True
No Error
Cmd To Write
Write Bytes To Port
Instr
Bytes at Port
1, Default
run/stop
data
Bytes Read
Read Incoming Data
Read the Bytes in the Buffer
status
Consumer Loop
False
Removal of Initial Character and Conversion to Integer
[A]
S1 (X)

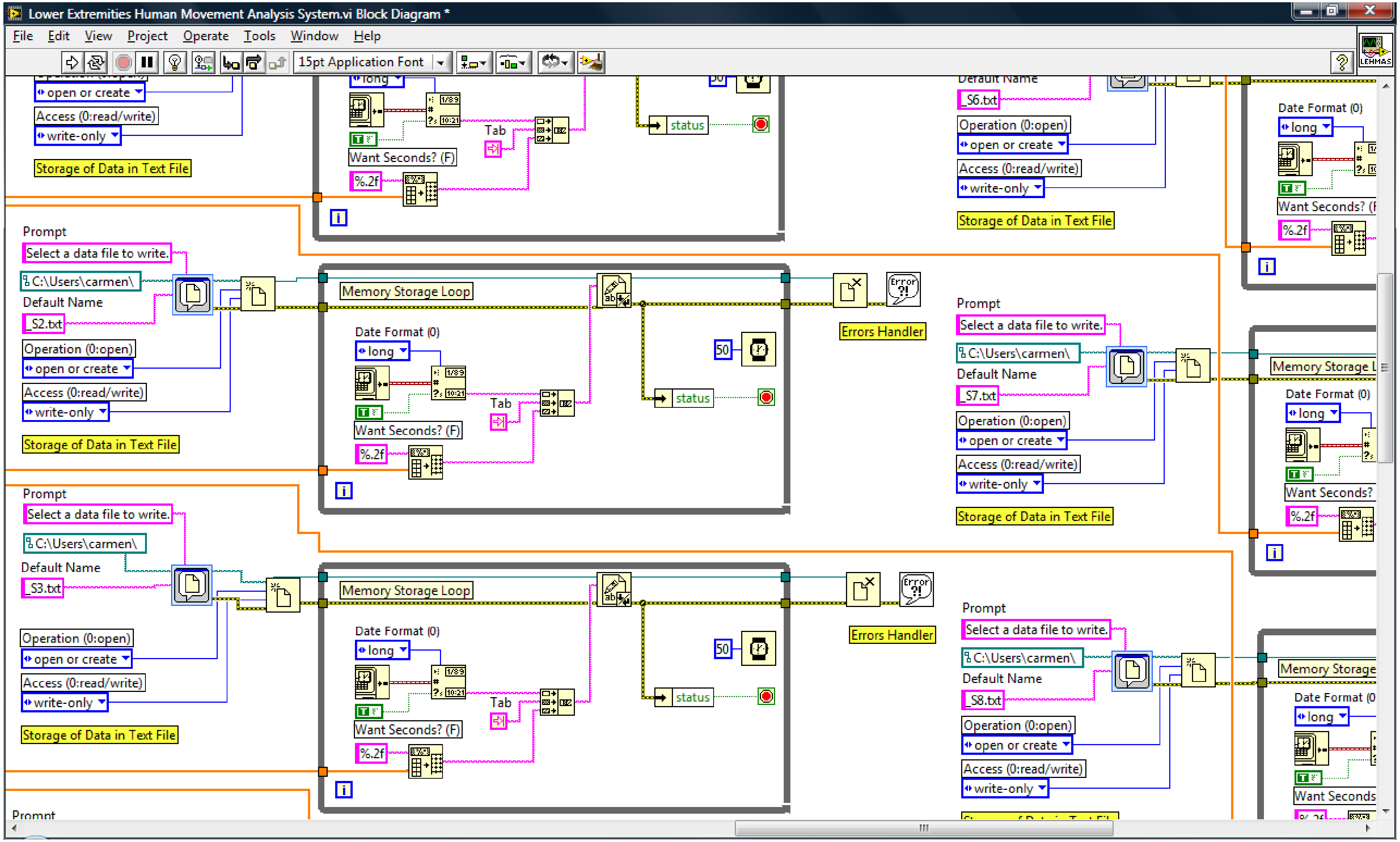

Lower Extremities Human Movement Analysis System.vi Block Diagram *
File Edit View Project Operate Tools Window Help
15pt Application Font
Producer Loop
1, Default
No Error
True
run/stop
data
Bytes Read
True
No Error
Instr
Bytes at Port
Cmd To Write
Read Incoming Data
Write Bytes To Port
Read the Bytes in the Buffer
status
run/stop
Close Session to Port
50
Consumer Loop
False
data
run/stop
Removal of Initial
Character and
Conversion to Integer
[A]
S1 (X)
5E-5
Filter1
Signal
Filtered Signal
Waist (X)
Filter2
Signal
Waist (Y)

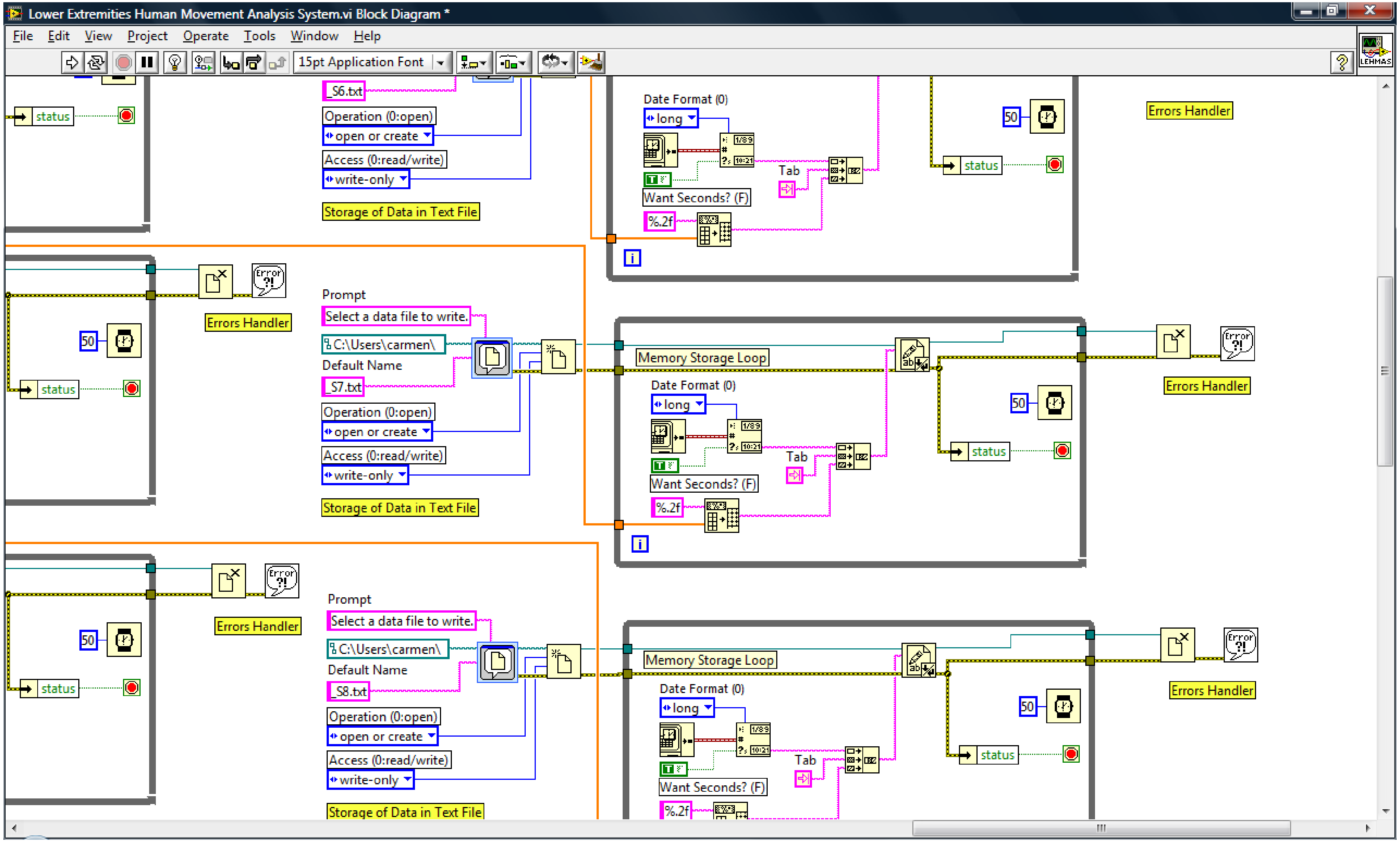

Lower Extremities Human Movement Analysis System.vi Block Diagram *
File Edit View Project Operate Tools Window Help
15pt Application Font
True
50
status
run/stop
Close Session to Port
Error Out
Errors Handler
Incoming Data
es in the Buffer
False
status
5E-5
Filter1
Signal
Filtered Signal
Waist (X)
S1 (X)
Filter2
Waist (Y)
Prompt
Select a data file to writ
C:\Users\carmen\
Default Name
_S1.txt
Operation (0:open)
open or create
Access (0:read/write)
write-only
Storage of Data in Text
Select a data file to write.


Lower Extremities Human Movement Analysis System.vi Block Diagram *
File Edit View Project Operate Tools Window Help
15pt Application Font
data
run/stop
Removal of Initial Character and Conversion to Integer
[A]
[B]
[C]
[D]
S1 (X)
S1 (Y)
S2 (X)
S2 (Y)
S3 (X)
5E-5
dt
Y
Filter1
Filter2
Filter3
Filter4
Filter5
Signal
Filtered Signal

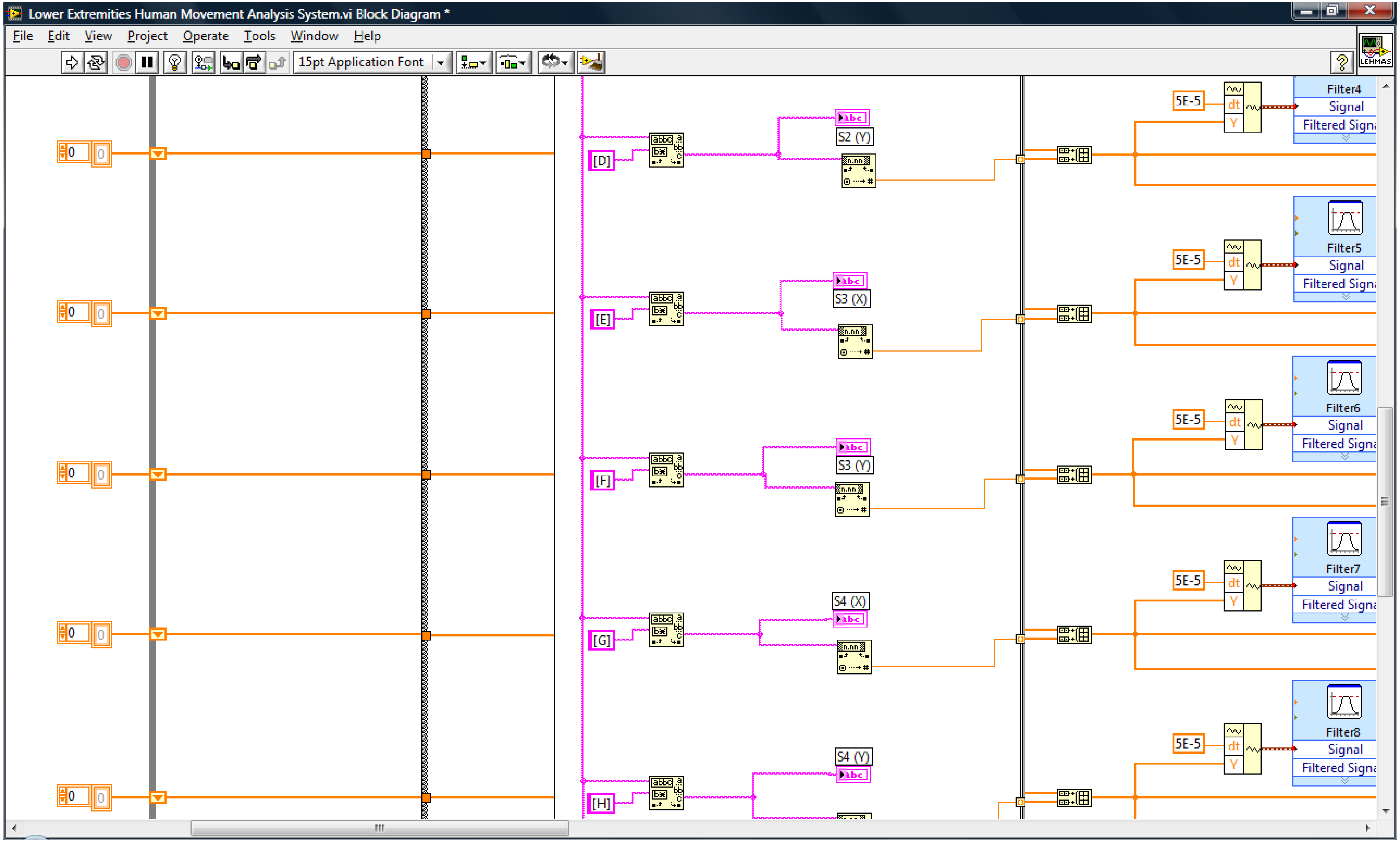


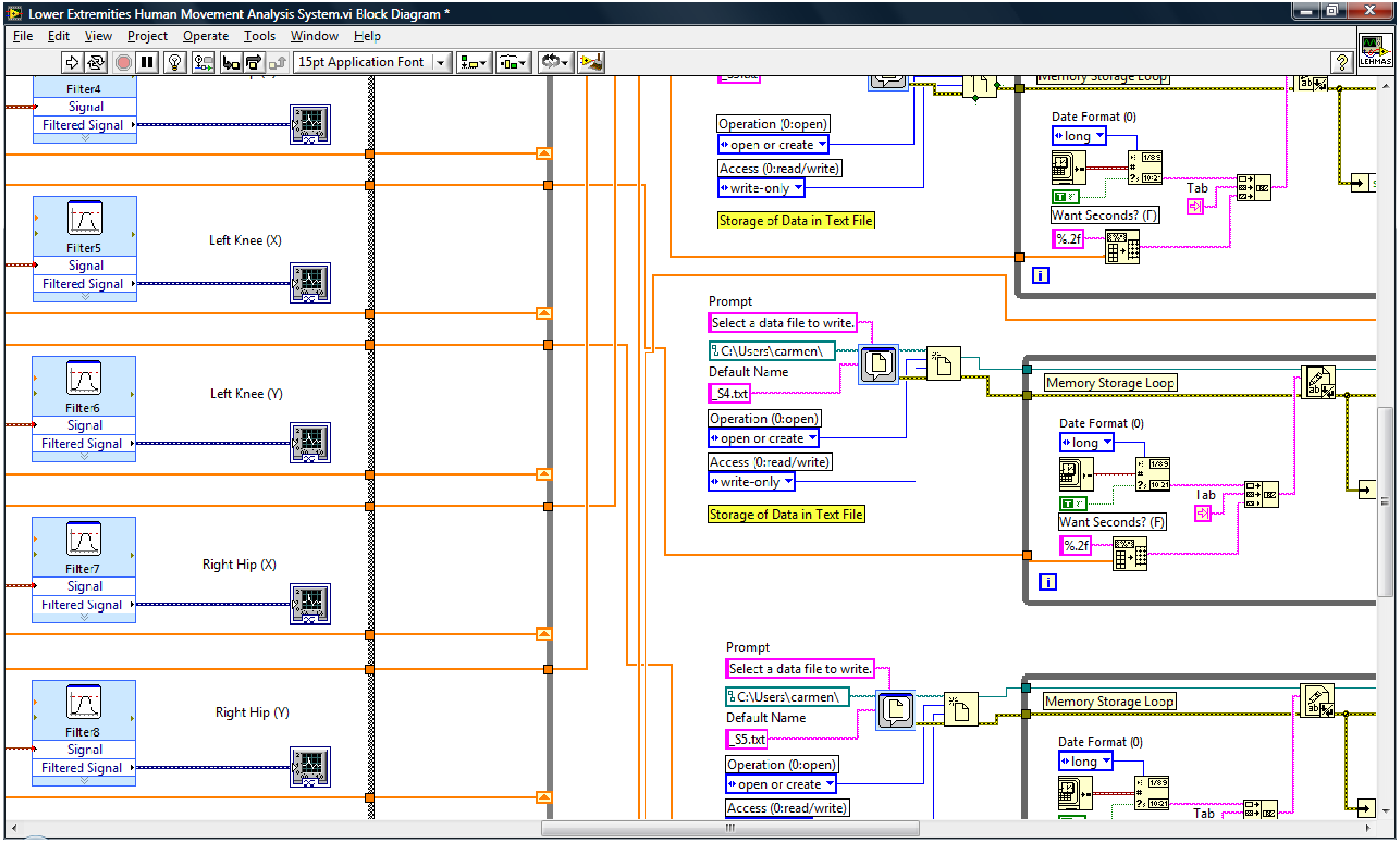
Lower Extremities Human Movement Analysis System.vi Block Diagram *
File Edit View Project Operate Tools Window Help
15pt Application Font
Filter1
Signal
Filtered Signal
Waist (X)
Filter2
Waist (Y)
Filter3
Left Hip (X)
Filter4
Left Hip (Y)
Filter5
Left Knee (X)
status
open or create
Access (0:read/write)
write-only
Storage of Data in Text File
Prompt
Select a data file to write.
C:\Users\carmen\
Default Name
_S2.txt
_S3.txt
Operation (0:open)
Memory Storage Loop
Date Format (0)
long
Tab
Want Seconds? (F)
%.2f

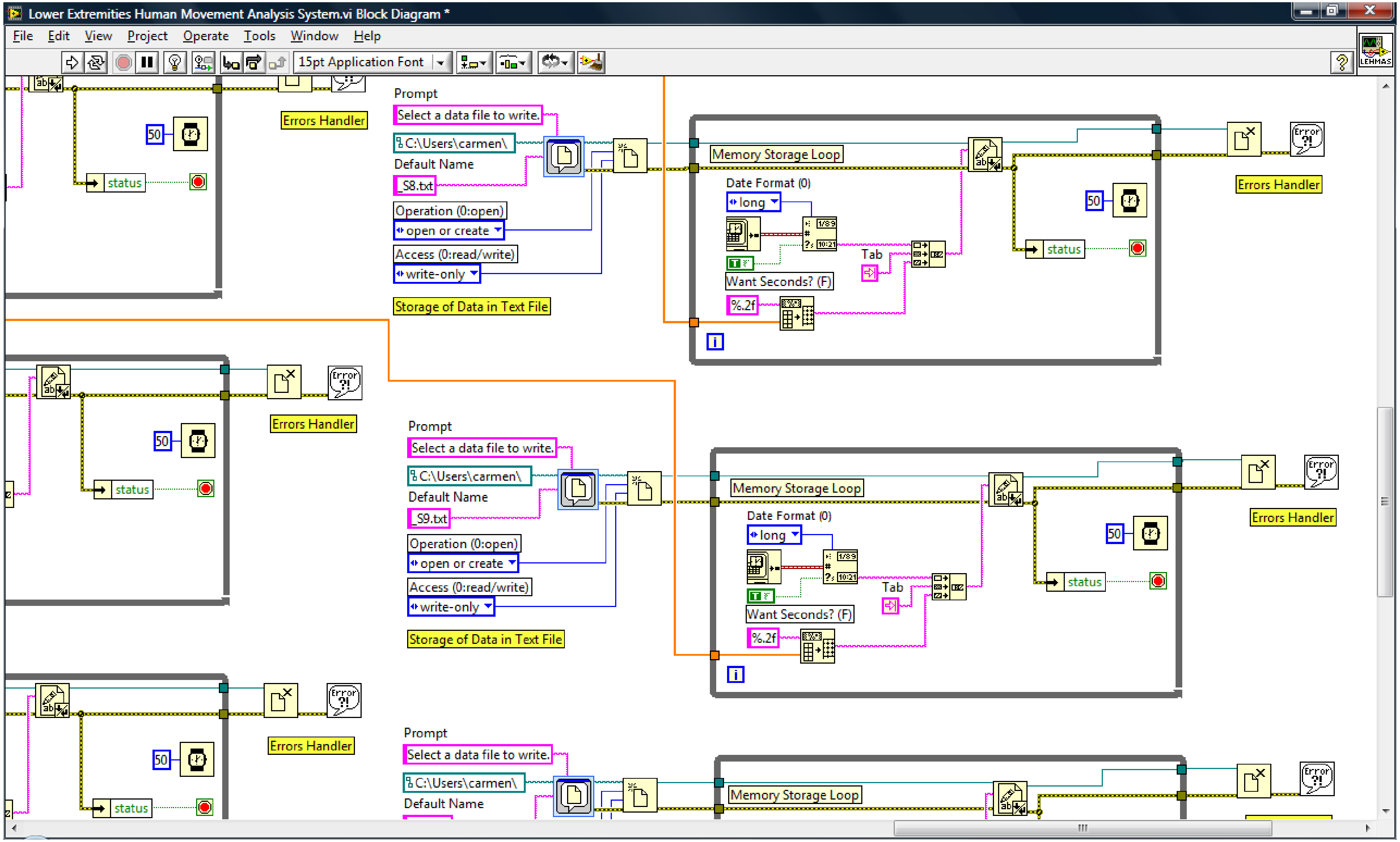

Lower Extremities Human Movement Analysis System.vi Block Diagram *
File Edit View Project Operate Tools Window Help
15pt Application Font
open or create
Access (0:read/write)
write-only
Storage of Data in Text File
long
Tab
Want Seconds? (F)
%.2f
status
Prompt
Select a data file to write.
C:\Users\carmen\
Default Name
S2.txt
Operation (0:open)
Memory Storage Loop
Date Format (0)
50
Errors Handler
S3.txt
S6.txt
S7.txt
S8.txt

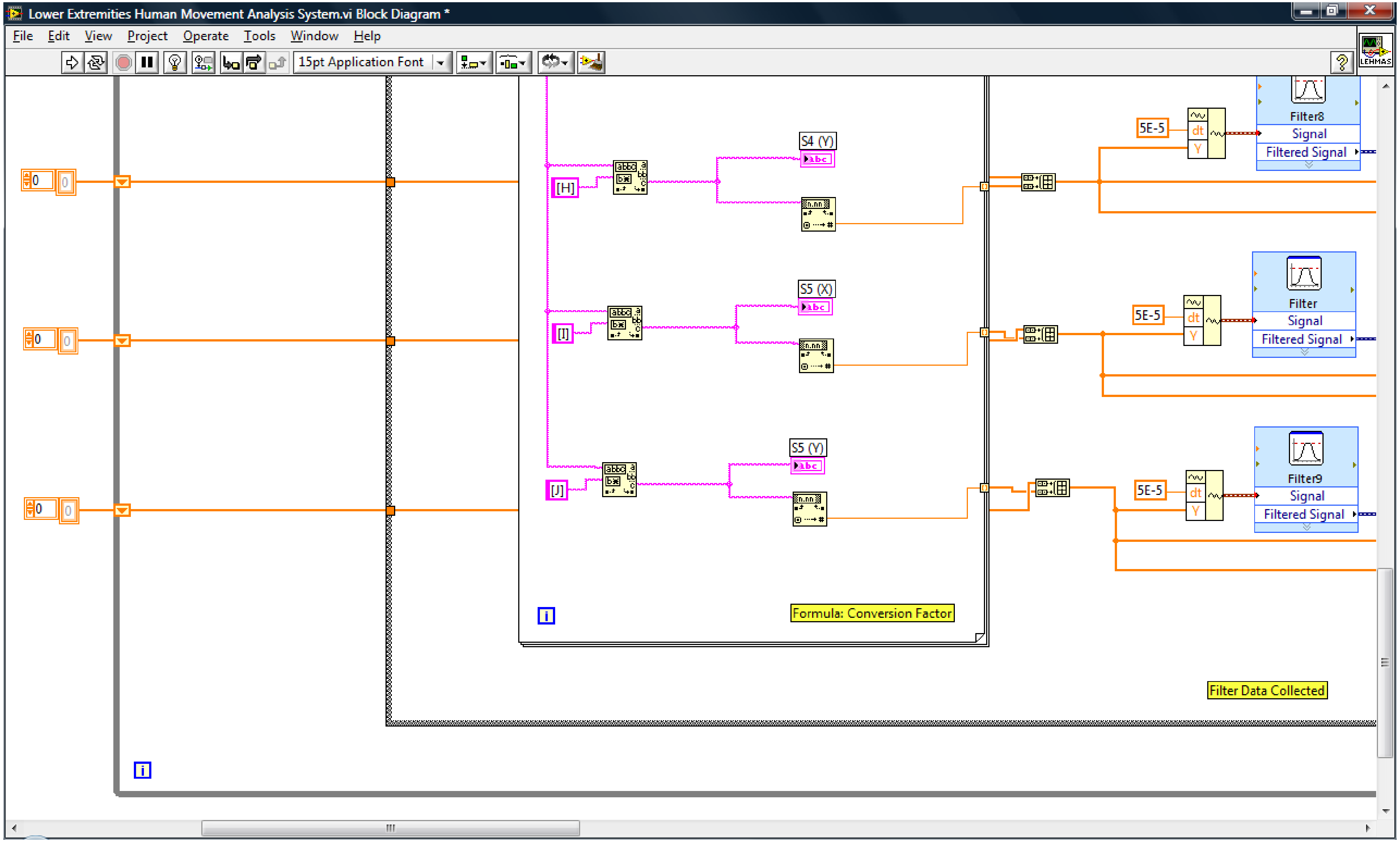


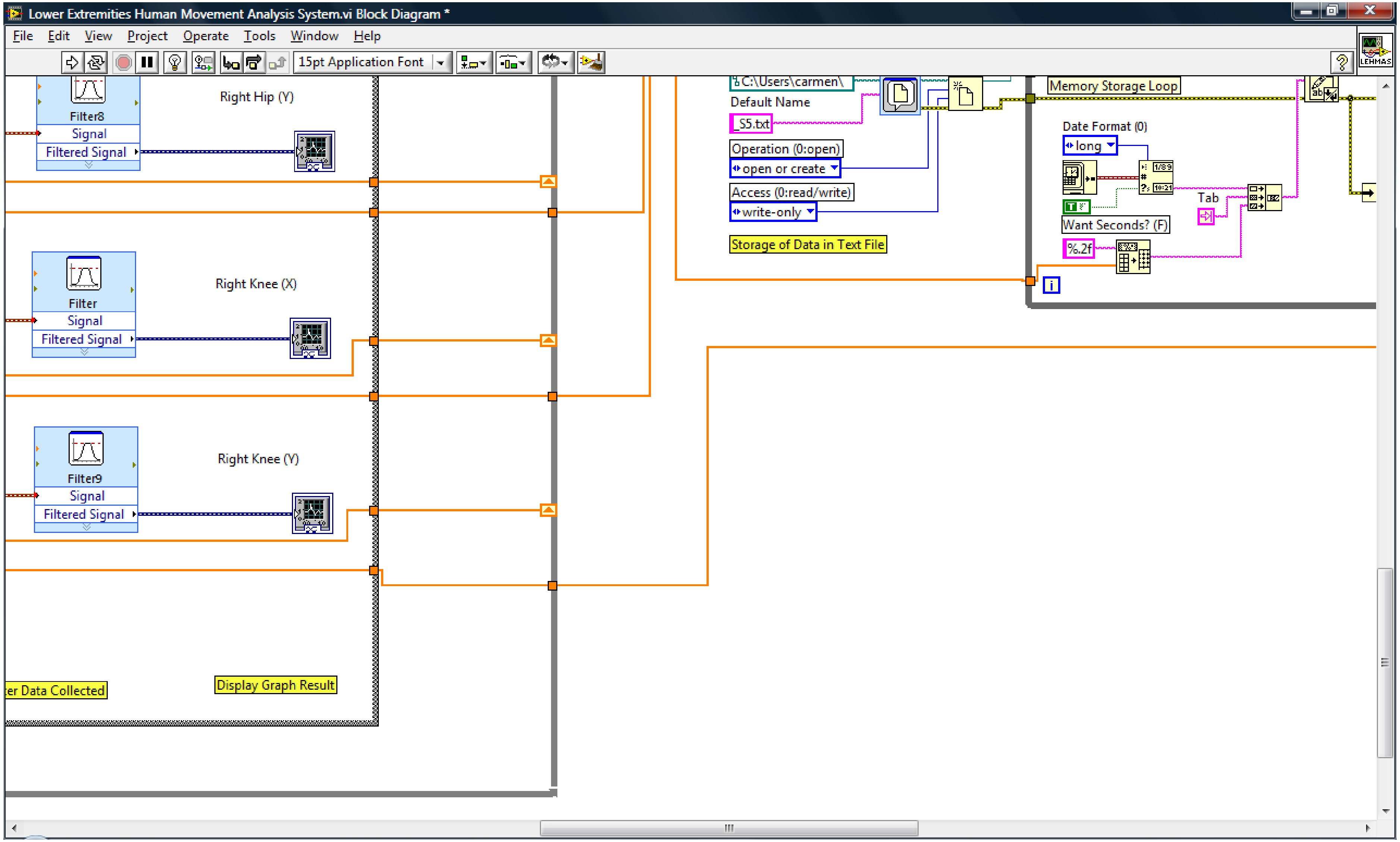
Lower Extremities Human Movement Analysis System.vi Block Diagram *
File Edit View Project Operate Tools Window Help
15pt Application Font
_S6.txt
Operation (0:open)
open or create
Access (0:read/write)
write-only
Storage of Data in Text File
Date Format (0)
long
Tab
Want Seconds? (F)
%.2f
50
status
Errors Handler
Prompt
Select a data file to write.
C:\Users\carmen\
Default Name
_S7.txt
Memory Storage Loop
_S8.txt

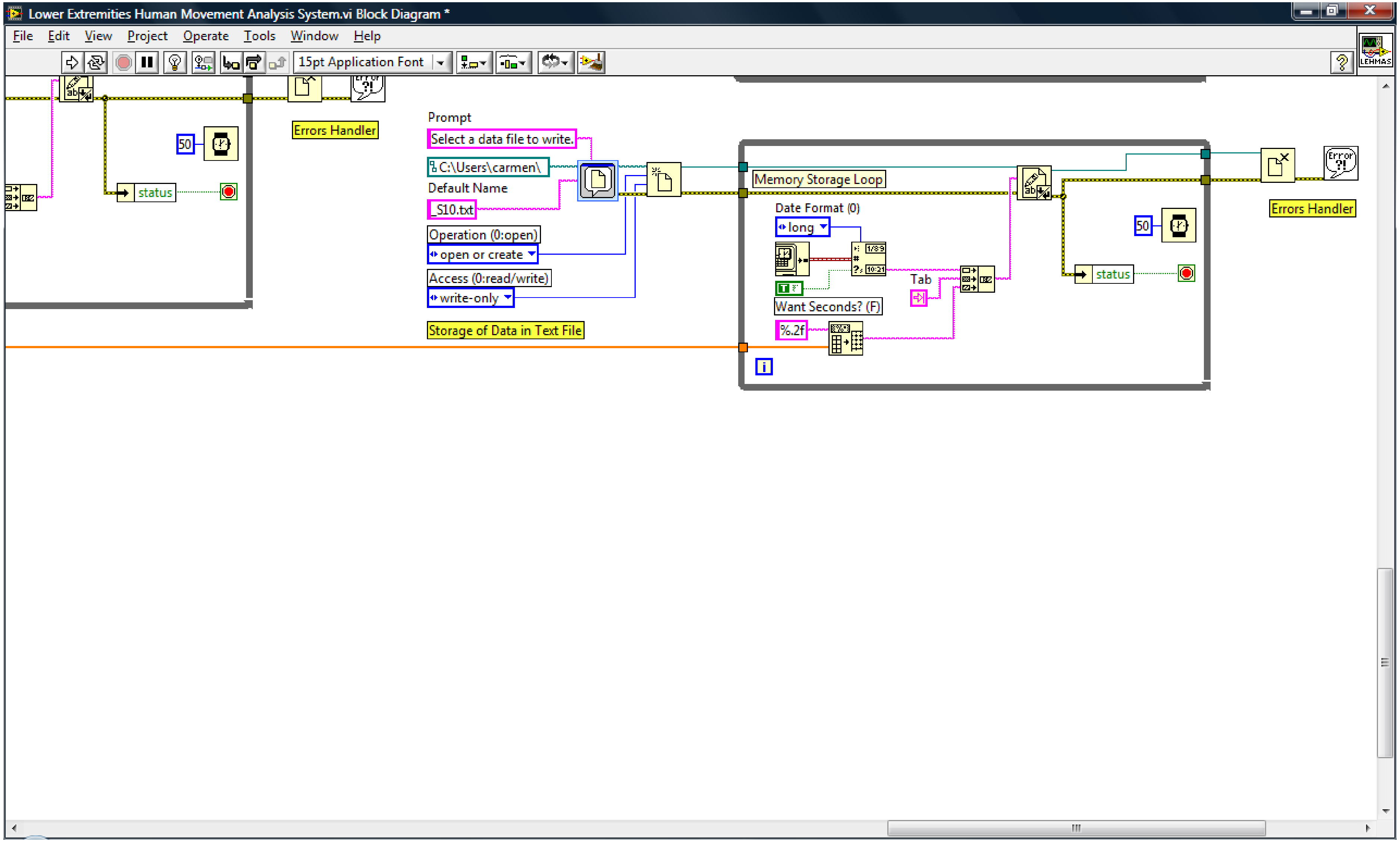

Lower Extremities Human Movement Analysis System.vi Block Diagram *
File Edit View Project Operate Tools Window Help
15pt Application Font
[D]
[E]
[F]
[G]
[H]
S2 (Y)
S3 (X)
S3 (Y)
S4 (X)
S4 (Y)
5E-5
dt
Y
Filter4
Filter5
Filter6
Filter7
Filter8
Signal
Filtered Signal


Lower Extremities Human Movement Analysis System.vi Block Diagram *
File Edit View Project Operate Tools Window Help
15pt Application Font
Filter4
Signal
Filtered Signal
Filter5
Left Knee (X)
Filter6
Left Knee (Y)
Filter7
Right Hip (X)
Filter8
Right Hip (Y)
Operation (0:open)
open or create
Access (0:read/write)
write-only
Storage of Data in Text File
Date Format (0)
long
Tab
Want Seconds? (F)
%.2f
Prompt
Select a data file to write.
C:\Users\carmen\
Default Name
_S4.txt
Memory Storage Loop
_S5.txt


Lower Extremities Human Movement Analysis System.vi Block Diagram *
File Edit View Project Operate Tools Window Help
15pt Application Font
Errors Handler
50
status
Prompt
Select a data file to write.
C:\Users\carmen\
Default Name
_S8.txt
Operation (0:open)
open or create
Access (0:read/write)
write-only
Storage of Data in Text File
Memory Storage Loop
Date Format (0)
long
Tab
Want Seconds? (F)
%.2f
Errors Handler
50
status
Errors Handler
Prompt
Select a data file to write.
C:\Users\carmen\
Default Name
_S9.txt
Operation (0:open)
open or create
Access (0:read/write)
write-only
Storage of Data in Text File
Memory Storage Loop
Date Format (0)
long
Tab
Want Seconds? (F)
%.2f
Errors Handler
Errors Handler
Prompt
Select a data file to write.
C:\Users\carmen\
Default Name
Memory Storage Loop


Lower Extremities Human Movement Analysis System.vi Block Diagram *
File Edit View Project Operate Tools Window Help
15pt Application Font
S4 (Y)
[H]
S5 (X)
[I]
S5 (Y)
[J]
Formula: Conversion Factor
5E-5
dt
Y
Filter8
Signal
Filtered Signal
Filter
Filter9
Filter Data Collected


Lower Extremities Human Movement Analysis System.vi Block Diagram *
File Edit View Project Operate Tools Window Help
15pt Application Font
Filter8
Signal
Filtered Signal
Right Hip (Y)
Filter
Signal
Filtered Signal
Right Knee (X)
Filter9
Signal
Filtered Signal
Right Knee (Y)
er Data Collected
Display Graph Result
C:\Users\carmen\
Default Name
_S5.txt
Operation (0:open)
open or create
Access (0:read/write)
write-only
Storage of Data in Text File
Memory Storage Loop
Date Format (0)
long
Tab
Want Seconds? (F)
%.2f
i



Lower Extremities Human Movement Analysis System.vi Block Diagram *
File Edit View Project Operate Tools Window Help
15pt Application Font
Errors Handler
50
status
Prompt
Select a data file to write.
C:\Users\carmen\
Default Name
_S10.txt
Operation (0:open)
open or create
Access (0:read/write)
write-only
Storage of Data in Text File
Memory Storage Loop
Date Format (0)
long
Tab
Want Seconds? (F)
%.2f
i
50
status
Errors Handler

# APPENDIX J: Participant Characteristics - Mean

| Case | Gender (M/F) | Age (Year) | Height (cm) | Weight (kg) | BMI (kg.m$^{-2}$) |
|---|---|---|---|---|---|
| **1** | M | 24 (1987) | 160 | 63.02 | 24.62 |
| **2** | F | 24 (1987) | 158 | 46.01 | 18.43 |
| **3** | M | 25 (1986) | 180 | 95.00 | 29.32 |
| **4** | F | 24 (1987) | 152 | 53.24 | 23.04 |
| **5** | F | 24 (1987) | 170 | 51.19 | 17.71 |
| **6** | F | 23 (1988) | 168 | 55.59 | 19.70 |
| **7** | F | 24 (1987) | 166 | 76.23 | 27.66 |
| **8** | F | 23 (1986) | 164 | 55.40 | 20.60 |
| **9** | M | 22 (1989) | 170 | 69.55 | 24.07 |
| **10** | F | 24 (1987) | 158 | 45.82 | 18.35 |
| **11** | F | 24 (1987) | 152 | 40.12 | 17.36 |
| **12** | F | 24 (1987) | 167 | 58.91 | 21.12 |
| **13** | F | 23 (1988) | 159 | 47.70 | 18.87 |
| **14** | M | 24 (1987) | 172 | 61.49 | 20.78 |
| **15** | M | 24 (1987) | 178 | 78.10 | 24.65 |
| **16** | M | 23 (1988) | 175 | 56.65 | 18.50 |
| **17** | M | 24 (1987) | 173 | 59.19 | 19.78 |
| **18** | M | 24 (1987) | 180 | 88.40 | 27.28 |
| **19** | M | 23 (1988) | 181 | 86.63 | 26.44 |
| **20** | M | 22 (1989) | 166 | 57.31 | 20.80 |
| | | | | | |
| **Case** | **Gender** | **Mean Age** | **Mean Height** | **Mean Weight** | **Mean BMI** |
| **10** | **F** | 23.70 | 161.40 | 53.02 | 20.28 |
| **10** | **M** | 23.50 | 173.50 | 71.53 | 23.62 |
| **20** | **Total** | 23.60 | 167.45 | 62.28 | 21.95 |

# APPENDIX K: Participant Characteristics – Standard Deviation

| Case | Gender (M/F) | Standard Deviation Age | Standard Deviation Height (cm) | Standard Deviation Weight (kg) | Standard Deviation BMI (kg.m$^{-2}$) |
|---|---|---|---|---|---|
| **1** | M | 0.25 | 182.25 | 72.42 | 1.00 |
| **2** | F | 0.09 | 11.56 | 51.70 | 3.42 |
| **3** | M | 2.25 | 42.25 | 550.84 | 32.49 |
| **4** | F | 0.09 | 88.36 | 0.05 | 7.78 |
| **5** | F | 0.09 | 73.96 | 3.35 | 6.61 |
| **6** | F | 0.49 | 43.56 | 6.60 | 0.34 |
| **7** | F | 0.09 | 21.16 | 538.70 | 54.46 |
| **8** | F | 0.49 | 6.76 | 5.66 | 0.10 |
| **9** | M | 2.25 | 12.25 | 3.92 | 0.20 |
| **10** | F | 0.09 | 11.56 | 51.84 | 3.72 |
| **11** | F | 0.09 | 88.36 | 166.41 | 8.53 |
| **12** | F | 0.09 | 31.36 | 34.69 | 0.71 |
| **13** | F | 0.49 | 5.76 | 28.41 | 1.99 |
| **14** | M | 0.25 | 2.25 | 100.80 | 8.07 |
| **15** | M | 0.25 | 20.25 | 43.16 | 1.06 |
| **16** | M | 0.25 | 2.25 | 221.41 | 26.21 |
| **17** | M | 0.25 | 0.25 | 152.28 | 14.75 |
| **18** | M | 0.25 | 42.25 | 284.60 | 13.40 |
| **19** | M | 0.25 | 56.25 | 228.01 | 7.95 |
| **20** | M | 2.25 | 56.25 | 202.21 | 7.95 |
| | | | | | |
| **Case** | **Gender** | **Standard Deviation Age** | **Standard Deviation Height** | **Standard Deviation Weight** | **Standard Deviation BMI** |
| **10** | **F** | 0.46 | 6.18 | 9.42 | 2.96 |
| **10** | **M** | 0.92 | 6.45 | 13.64 | 3.36 |
| **20** | **Total** | 0.66 | 6.32 | 11.53 | 3.16 |

APPENDIX L: Informed Consent Letter

Universiti Tunku Abdul Rahman
Department of Mechatronic and Biomedical Engineering

**Informed Consent Letter**

**Title of Study**: Development of Lower Extremities Movement Analysis using Accelerometer

**Principal Investigator:**

Name: Mr. Chong Yu Zheng

Department: Department of Mechatronics and Biomedical Engineering

Address: Faculty of Engineering and Science,
Universiti Tunku Abdul Rahman,
Kuala Lumpur Campus,
Jalan Genting Klang,
53300 Kuala Lumpur,
Malaysia.

Phone: 603-41079802 Extension: 178

Email: chongyz@utar.edu.my

## PART I: Information Sheet

### Introduction

We are final year student of Biomedical Engineering from Universiti Tunku Abdul Rahman. We are doing final year project research on the lower extremities movement analysis using accelerometer, which is a most common methods used in the human motion analysis in the recent years.

I am going to give you information and invite you to be part of this research. You do not have to decide today whether or not you will participate in the research. Before you decide, you can talk to anyone you feel comfortable with about the research.

There may be some words that you do not understand. Please ask me to stop as we go through the information and I will take time to explain. If you have questions later, you can ask them of me, the staff or the helper.

Universiti Tunku Abdul Rahman
Department of Mechatronic and Biomedical Engineering

**Purpose**

The main purpose for the research is to develop reasonably reliable, low-cost and accurate two dimensional lower extremities movement analysis using accelerometers.

**Type of Research Invention**

This research will involve seven tri-axial accelerometer together with embed PIC microcontroller attached to the remote body parts, such as waist, hips and knees as well as complete the survey form.

**Participant Selection**

We are inviting all adults had normal or corrected-to-normal vision, the ability to walk unaided, good general health, normal memory function and generally normal cognition. Participants with musculoskeletal injuries or disorders that affect walking ability were excluded from the study.

**Voluntary Participation**

Your participation in this research is entirely voluntary. It is your choice whether to participate or not. Whether you choose to participate or not, nothing will change. You may change your mind later and stop participating even if you agreed earlier.

**Procedures and Protocol**

Before the test is being carried out, initial test will be conducted. This initial test is important to make sure the human movement analysis system can work properly in a good condition and make sure the accelerometers attached on the different body part accurately and tightly. Furthermore, it also make sure the all the embed system instrumented did not interrupt the human movement analysis of the subject.

At the same time, anthropometric measurements, which include height, weight and lower extremities length, would take place. Walking task would be start conducted after the initial test and anthropometric measurements. The Treadmill walk test was performed twice to record definite data on the time-distance gait parameters and lower extremities acceleration. All subjects were instructed to walk straight at 3 different speeds, which are slow walking – 1 km/h, normal walking – 3 km/h and fast walking – 5 km/h on the Treadmill at the Biomechanics facility lab. Test duration was 30 min. Data from the device were recorded in the real-time.

**Duration**

During the research, it will be necessary for you to come to the biomechanics facility lab for around half an hour. We would like to meet with you after the research for filling the survey form. The research will be finished after completed the survey.

**Side Effects**

If you participate in this research, there may not have any side effects for you.

**Risks**

Any exercise program such as walking contains certain risks. Muscle pulls, joint strains, aches, pains and general discomfort from parts of the body.

**Discomforts**

By participating in this research it is possible that you may experience some discomfort such as discomforts, even minor pain for the prolonged period of the research.

**Benefits**

If you participate in this research, there may not be any benefit for you but your participation is likely to help us find the answer to the research question. There may not be any benefit to the society at this stage of the research, but future generations are likely to benefit.

**Incentives**

You will not be given any other money, allowance or gifts to take part in this research.

**Confidentiality**

It is possible that if others in the community are aware that you are participating in this research, they may ask you questions. We will not be sharing the identity of those participating in the research with anyone. The information that we collect from this research project will be kept confidential. Information about you that will be collected during the research will not be identified by your name but by a number. Only the researchers will know what your number is and they will lock that information up with a lock and key. It will not be shared with or given to anyone.

**Sharing the Results**

The knowledge that we get from doing this research will be shared with you before it is made widely available to the public. Confidential information will not be shared. There will be small meetings in the community and these will be announced. After these meetings, we will publish the results in order that other interested people may learn from our research.

**Right to Refuse or Withdraw**

1. You do not have to take part in this research if you do not wish to do so and refusing to participate. You may stop participating in the research at any time that you wish without losing any of your rights as a participant here.
2. You do not have to take part in this research if you do not wish to do so. You may also stop participating in the research at any time you choose. It is your choice and all of your rights will still be respected

**Alternatives to Participating**

If you do not wish to take part in the research, you will be provided with the established standard treatment available at the centre, institute or hospital.

**Person to Contact**

This proposal has been reviewed and approved by Department of Mechatronics and Biomedical Engineering of Universiti Tunku Abdul Rahman, which is a committee whose task it is to make sure that research participants are protected from harm. If you wish to find about more about this research, contact

Name: Ms. Carmen Chew Kah Mun        Phone: 016 - 2823802
Name: Mr. Jason Cheah Soon Keong        Phone: 012 – 3166647
Name: Mr. Fong Suw Wei        Phone: 012 - 2762418

Universiti Tunku Abdul Rahman
Department of Mechatronic and Biomedical Engineering

**PART II: Certificate of Consent**

I have read the foregoing information, or it has been read to me. I have had the opportunity to ask questions about it and any questions that I have asked have been answered to my satisfaction. I consent voluntarily to participate as a participant in this research and understand that I have the right to withdraw from the research at any time without in any way affecting my medical care.

**Name of Participant:** ______________________________

**I/C No:** ______________________________

**Contact Number:** ______________________________

**Email Address:** ______________________________

**Signature of Participant:** ______________________________

**Date:** ____________________ (Day/Month/Year)

# APPENDIX M: Health Information Form

**Universiti Tunku Abdul Rahman**

**Health Information Form**

Please complete this form before taking part in any physical activity program. If you are between the ages of 15 and 70 and do not exercise regularly you are strongly advised to consult your general practitioner. Your signature at the foot of this form confirms you understand the risks involved in exercise, have given your informed consent and are participating at your own free will in a physical activity programmed.

| No | About your general health | Yes / No |
|---|---|---|
| 1 | Have you ever been advised not to take physical exercise? | |
| 2 | Do you ever feel pain in your chest after physical exercise? | |
| 3 | Have you ever had pain in your chest when exercising? | |
| 4 | Do you ever feel faint, dizzy or lose consciousness? | |
| 5 | Do you or your family have a history of heart disease? | |
| 6 | Have you recently had surgery or a serious illness? | |
| 7 | Are you currently taking any medication? | |
| 8 | Are you pregnant or have you recently given birth? | |
| 9 | Do you smoke? | |
| 10 | Do you have high blood pressure? | |
| 11 | Do you have a high cholesterol level? | |
| 12 | Are you diabetic? | |
| 13 | Are you asthmatic? | |
| 14 | Do you exercise regularly? | |
| 15 | How far do you think you can run without stopping? | |

I hereby state that I have read, understood and answered all the questions truthfully. Any queries have been answered to my satisfaction. I also state that I wish to participate in the range of activities including cardiovascular and resistance (weight bearing) exercise. I realize that these activities involve the risk of injury or even death.

Name of Participants: ______________________________

Signature of Participants: ___________________________

Date: _______________________ (Day/month/year)

# APPENDIX N: Anthropometric Measurements

**UNIVERSITI TUNKU ABDUL RAHMAN**

**ANTHROPOMETRIC MEASUREMENTS**

Name of Participant:

I/C No:

Height:

Weight:

| **Segment** | **Length (cm)** | **Centre of Gravity Location (cm)** |
|---|---|---|
| Hip / Waist | | |
| **Right Segment** | | |
| Right Thigh | | |
| Right Shank | | |
| Right Foot | | |
| **Left Segment** | | |
| Left Thigh | | |
| Left Shank | | |
| Left Foot | | |

Signature of Participants

Signature of Person in Charge

________________________ ________________________

# APPENDIX O: Research Survey Form

**Universiti Tunku Abdul Rahman**

**Research Survey Form**

This survey form is designed to improve the further development and performance quality of the accelerometer. In general, accelerometer is a positional sensor operated by measuring acceleration along the sensitive axis of the sensor based on the Principles of Hooke's Law and Newton's Second Law of Motion. Seven accelerometer together with the PIC microcontroller circuit systems attached on the remote body part, such as waist, hips, knees and ankles.

| | | | |
|---|---|---|---|
| **Section 1: Personal Details** | | | |
| Name: | | | |
| Age: | | Gender: | |
| Course: | | | |
| Contact No: | | | |
| Email Address: | | | |
| **Section 2: Habitual Physical Activity** | | | |
| 2.1 | Have you practiced sports or physical exercise in clubs, gyms, parks, street or at home every week? | Y | N |
| 2.2 | If yes, which sport or physical exercise did you practice with most frequency?<br>☐ Cycling ☐ Jogging ☐ Walking ☐ Power lifting<br>☐ Ball sports (Basketball, etc) ☐ Others, please specific ____________ | | |
| 2.3 | How many days per week did you practice this activity? | | |
| **Section 3: Accelerometer** | | | |
| 3.1 | Feeling uncomfortable when the accelerometer attached prolonged period on the remote body parts, such as waist, hips, knees and ankles? | Y | N |
| 3.2 | If yes, which parts of the remote body parts feeling uncomfortable?<br>☐ Waist ☐ Hips ☐ Knees ☐ Ankles ☐ All | | |
| 3.3 | Is the accelerometer together with embedding PIC microcontroller circuit being accountable as lightweight for you? | Y | N |

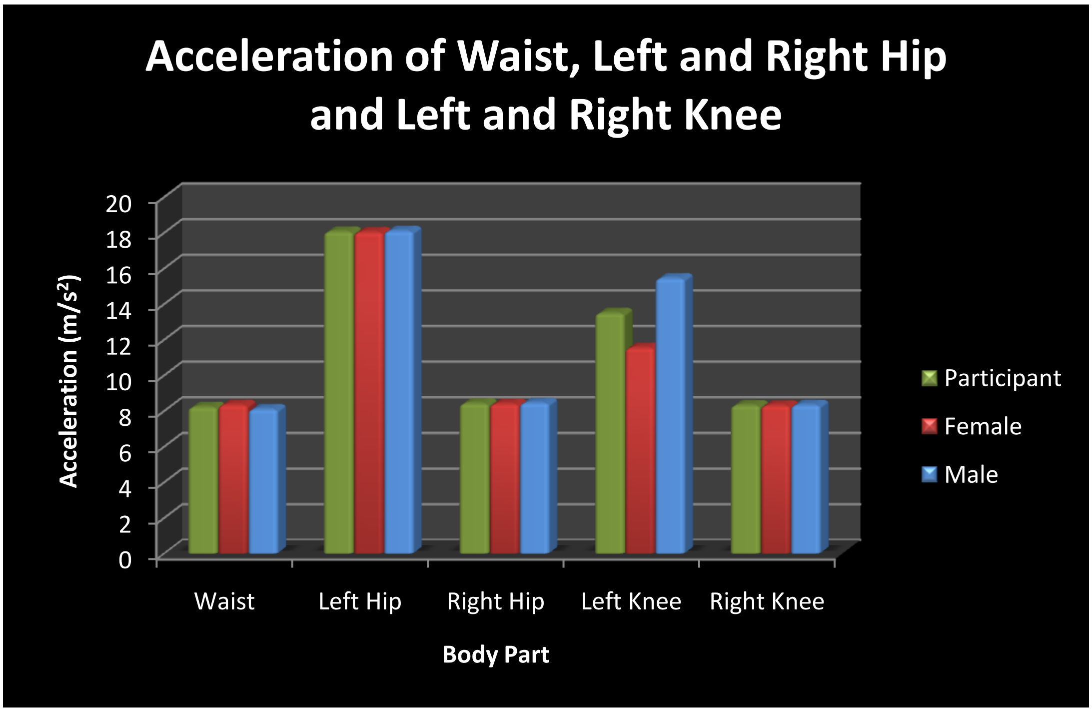
**Any suggestion or comment:**

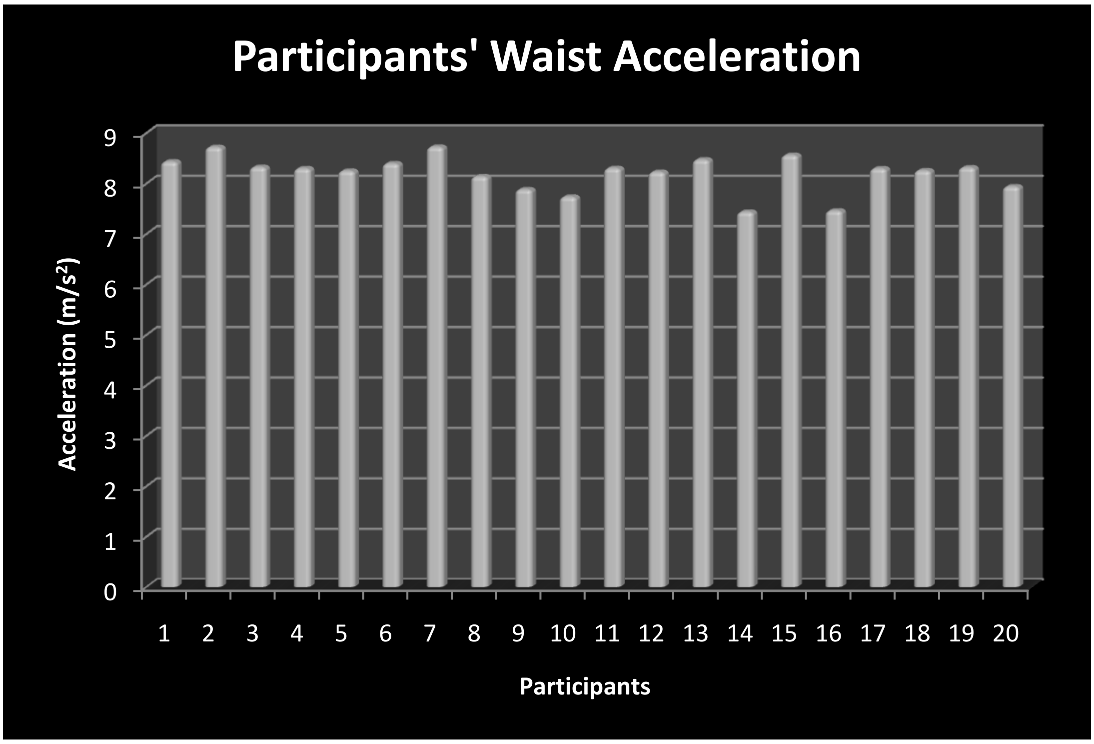
Signature: ______________________________ Date: ______________

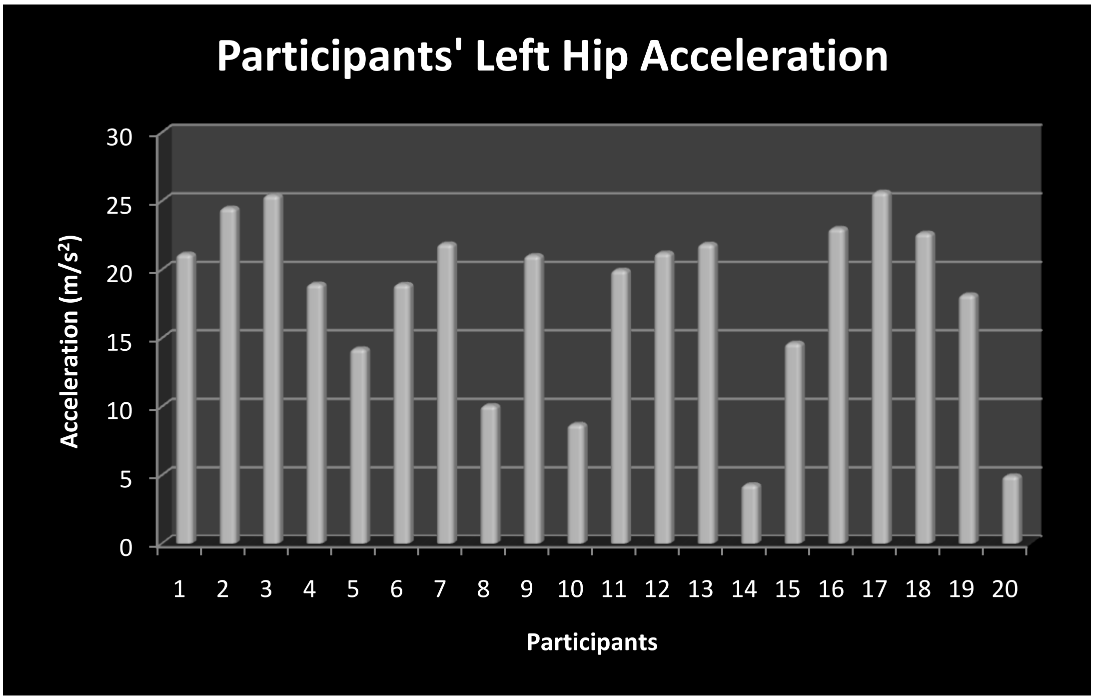
# APPENDIX P:

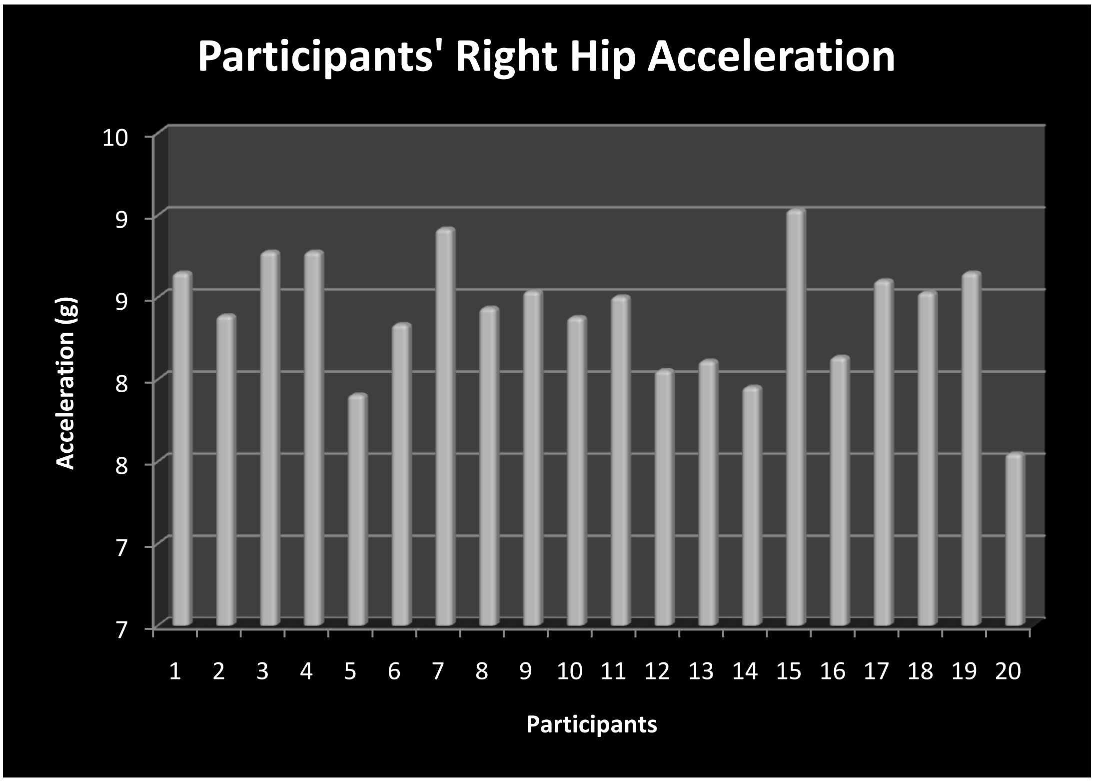
## Data Analysis Graph for Slow Walking – 1 km/h

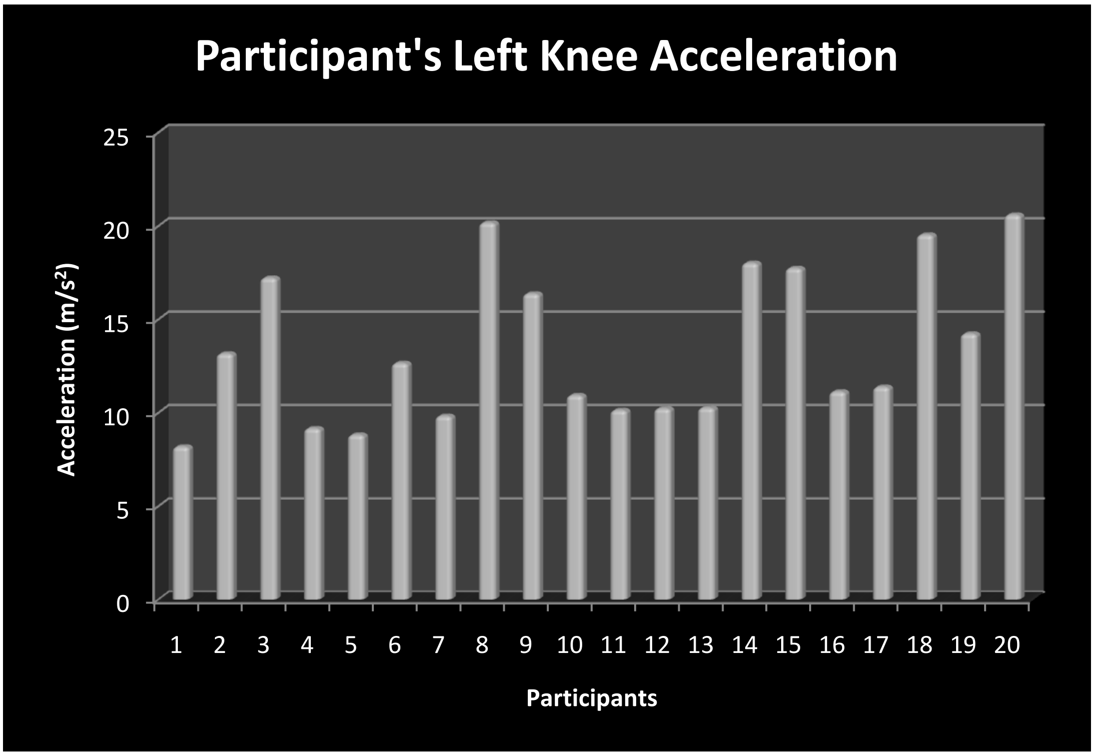
**Average Acceleration**

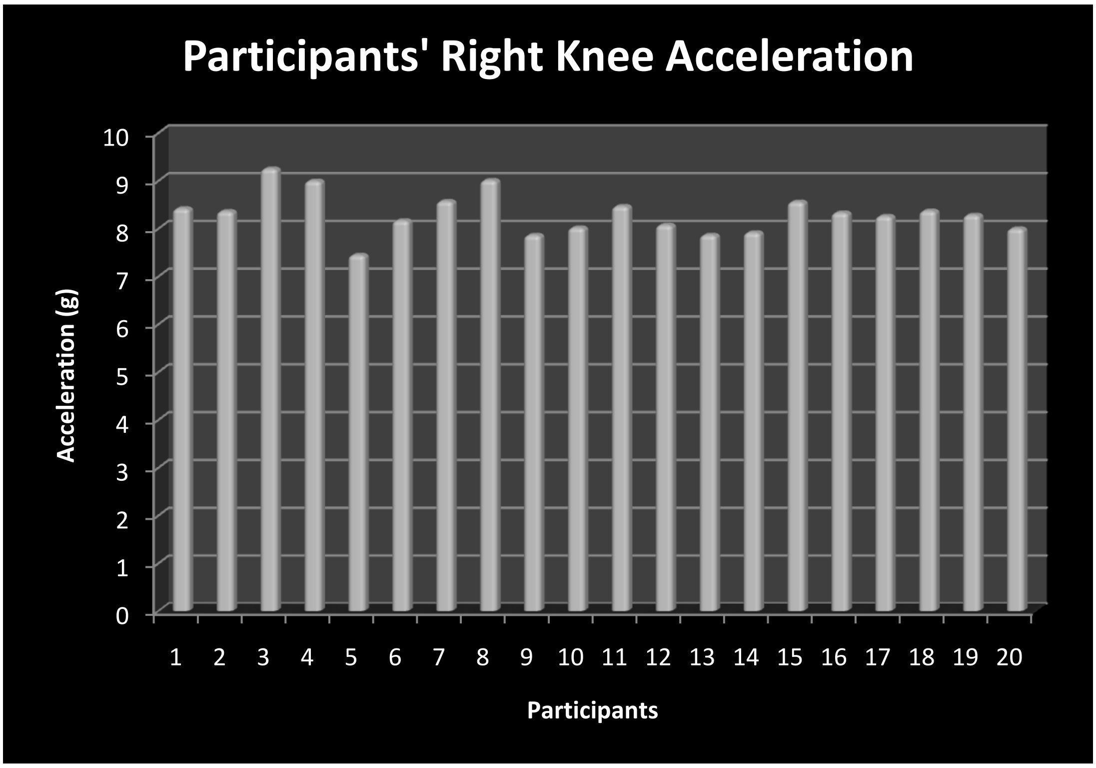


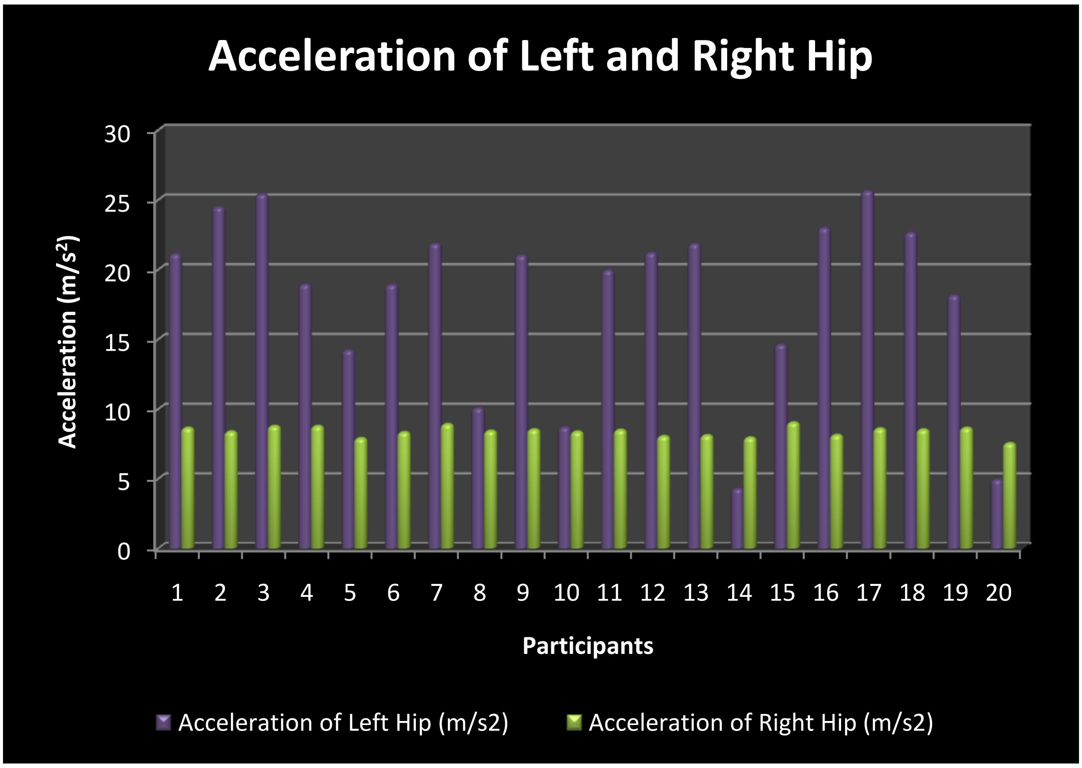



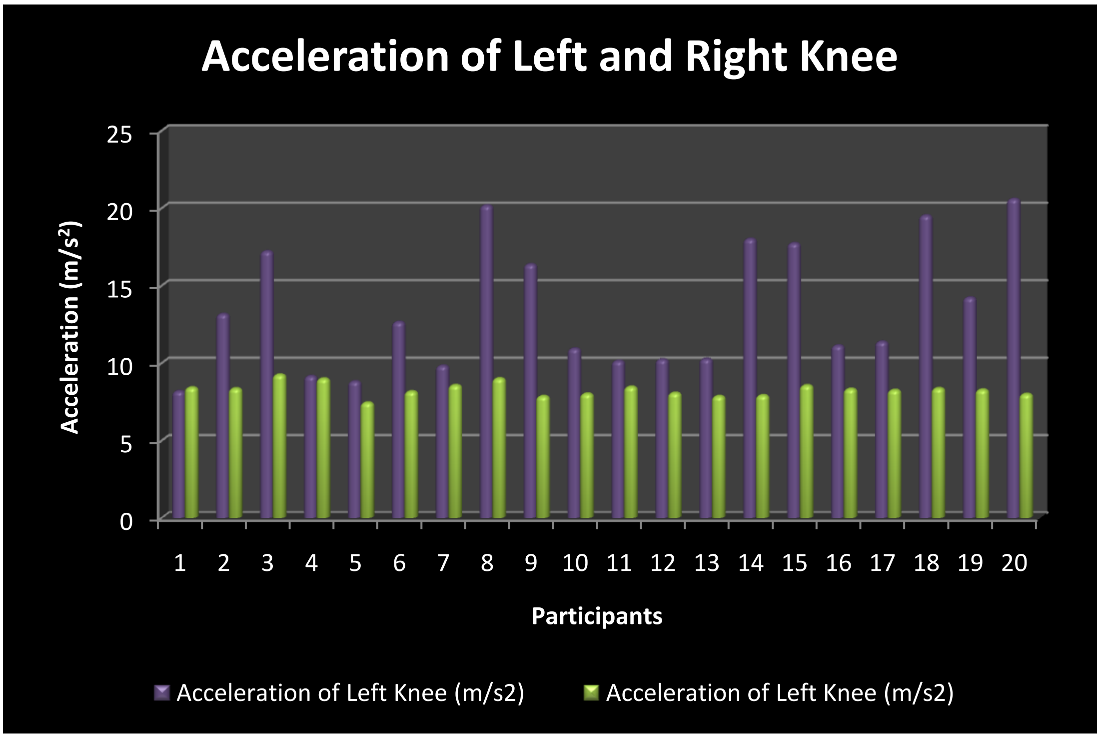

Participants' Left Hip Acceleration
30
25
20
15
10
5
0
Acceleration (m/s²)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Participants


Participants' Right Hip Acceleration
10
9
9
8
8
7
7
Acceleration (g)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Participants


Participant's Left Knee Acceleration
Acceleration (m/s²)
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Participants


Participants' Right Knee Acceleration
Acceleration (g)
10
9
8
7
6
5
4
3
2
1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Participants

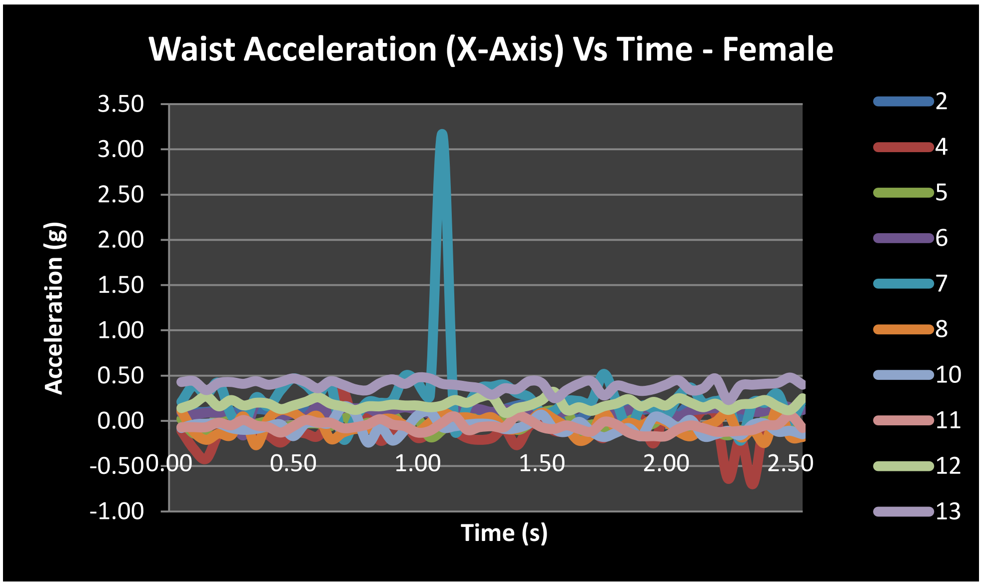

Acceleration of Left and Right Hip
Acceleration (m/s²)
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Participants
Acceleration of Left Hip (m/s2)
Acceleration of Right Hip (m/s2)


Acceleration of Left and Right Knee
Acceleration (m/s²)
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Participants
Acceleration of Left Knee (m/s2)
Acceleration of Left Knee (m/s2)

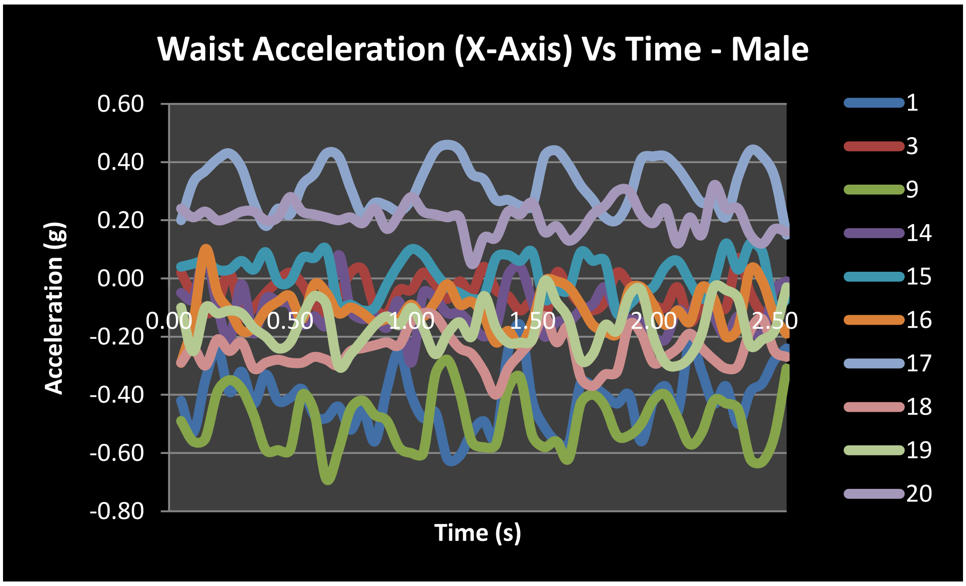
## Acceleration Vs Time Between Female and Male

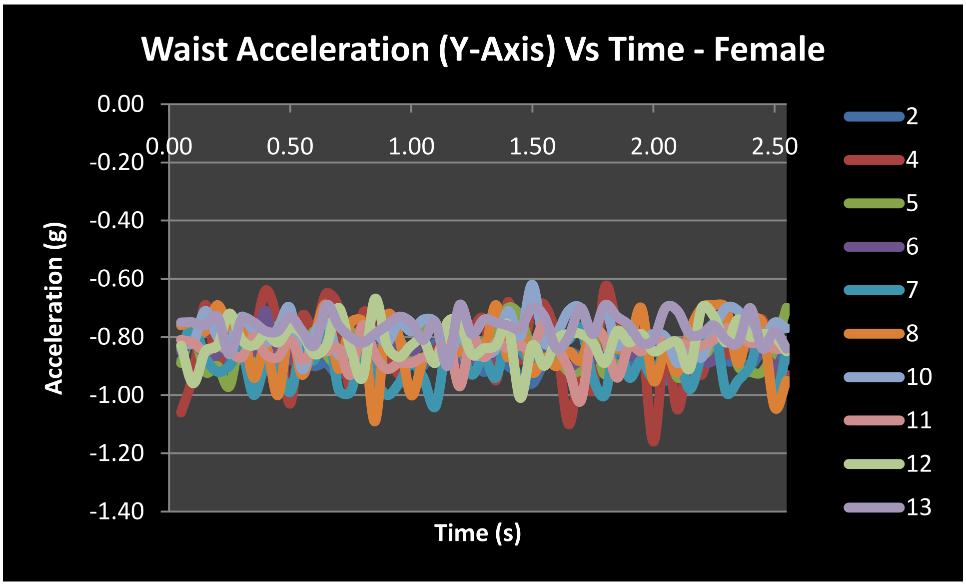
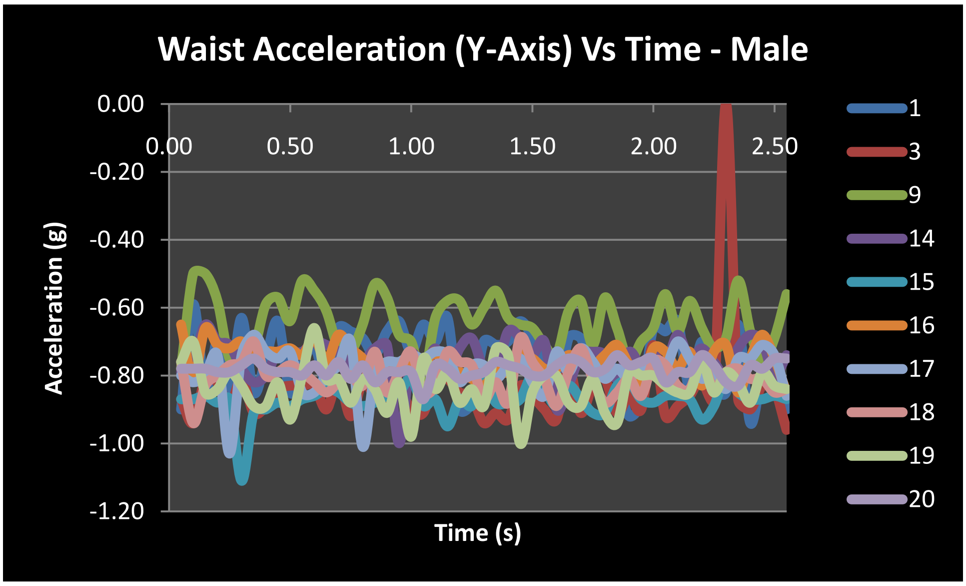
### X-Axis Acceleration of Waist

**Female**



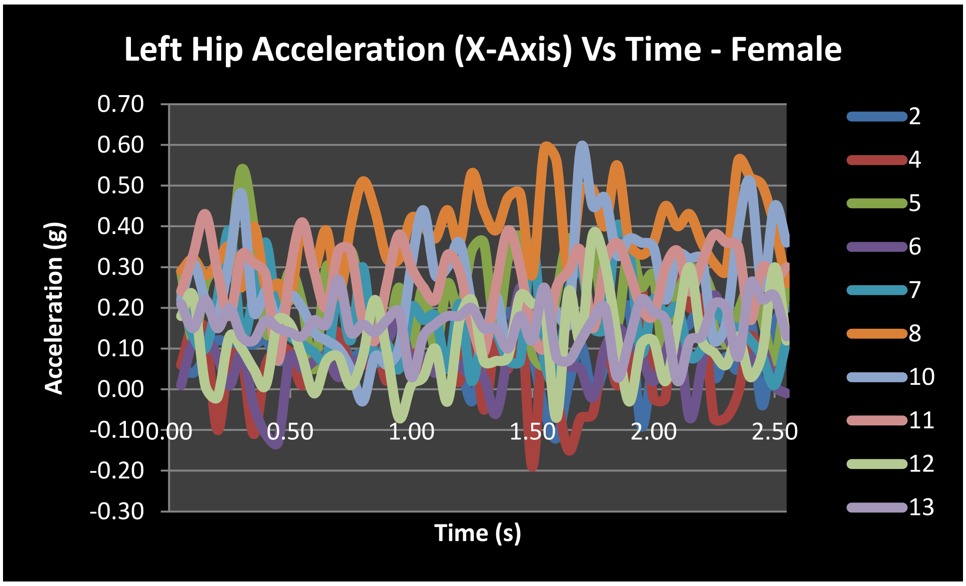

**Male**



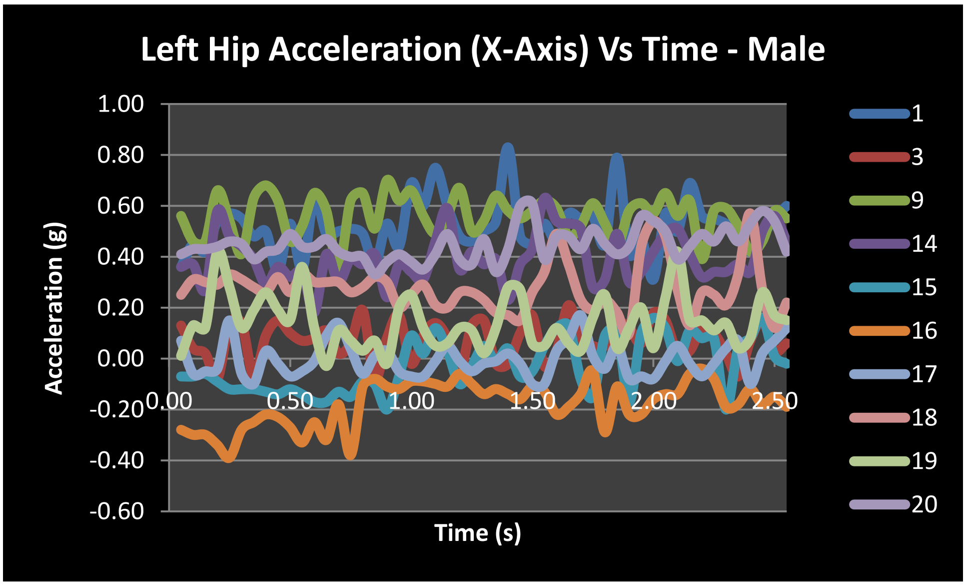
| Y-Axis Acceleration of Waist |
|---|
| **Female**  |
| **Male**  |

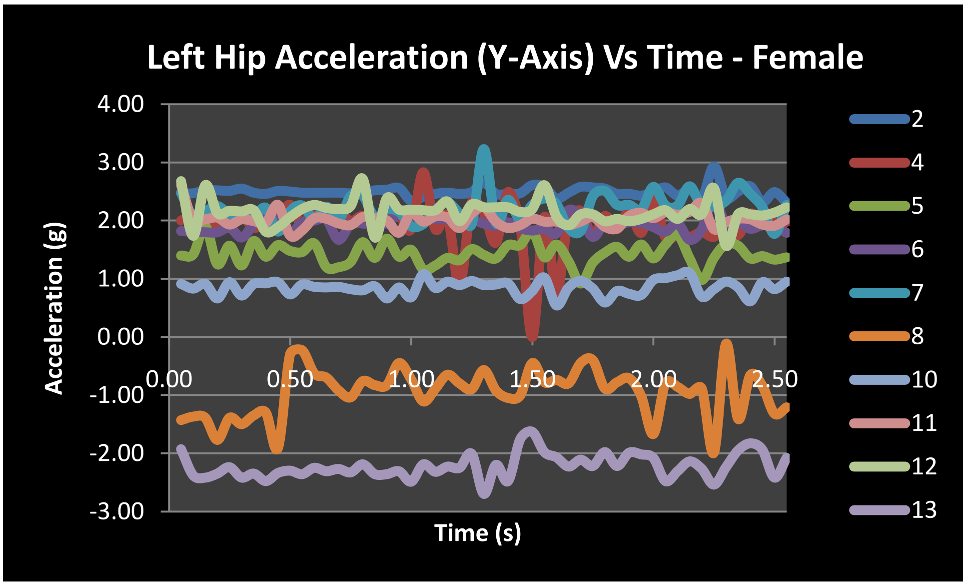
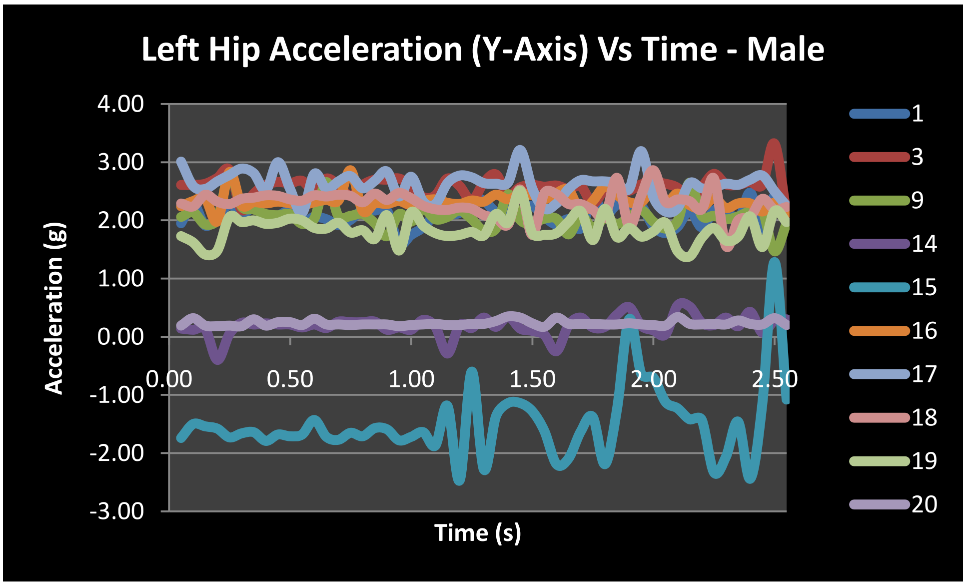
**X-Axis Acceleration of Left Hip**

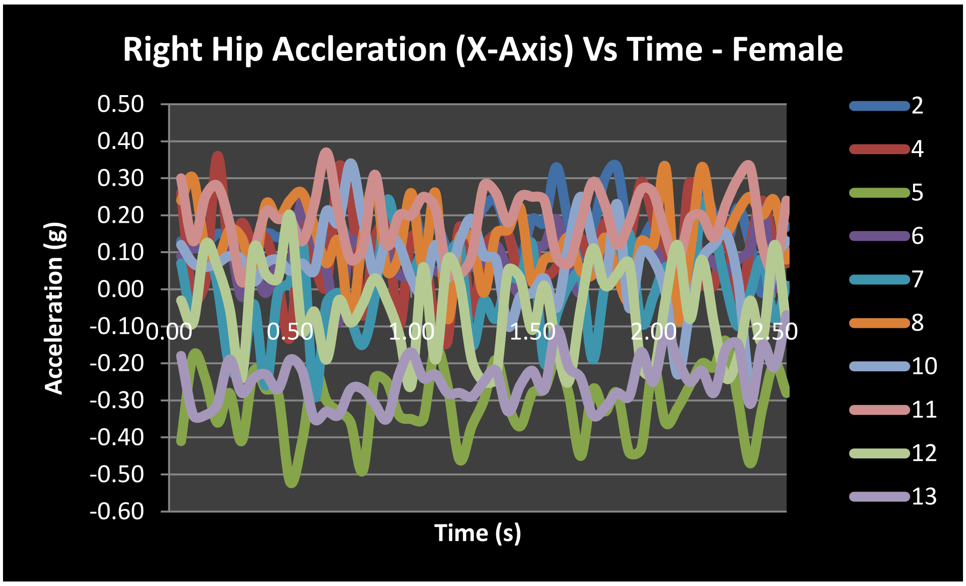
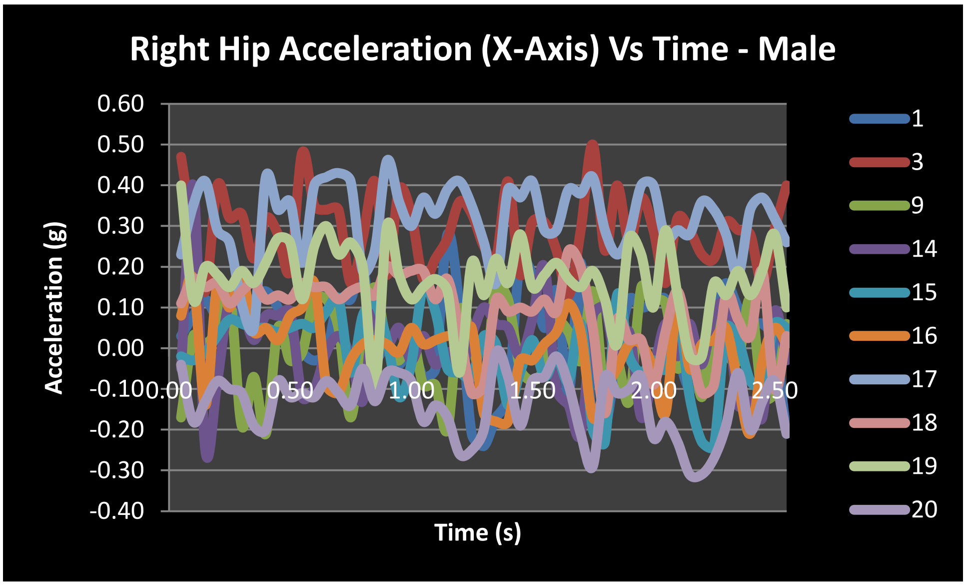
**Female**




**Male**

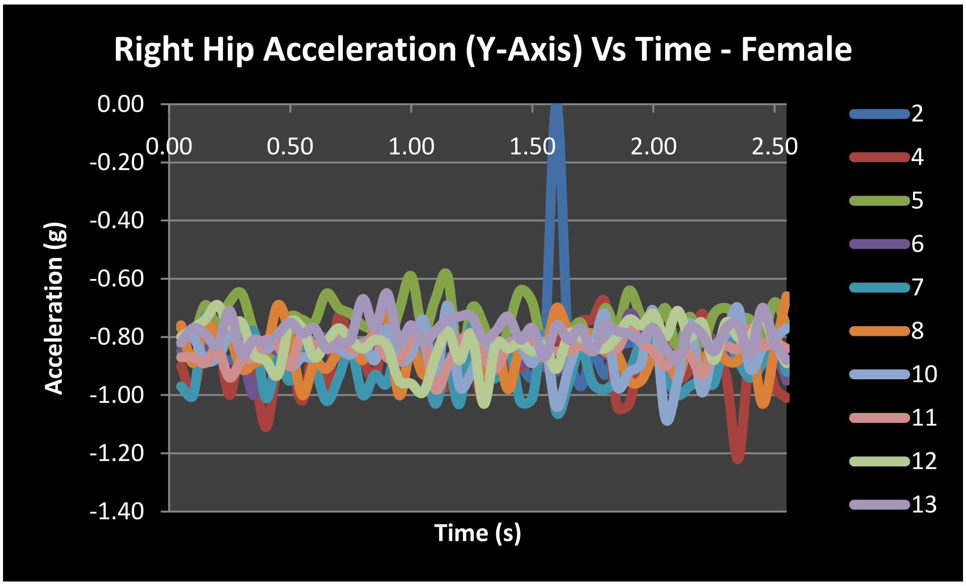


| Y-Axis Acceleration of Left Hip |
|---|
| **Female**  |
| **Male**  |

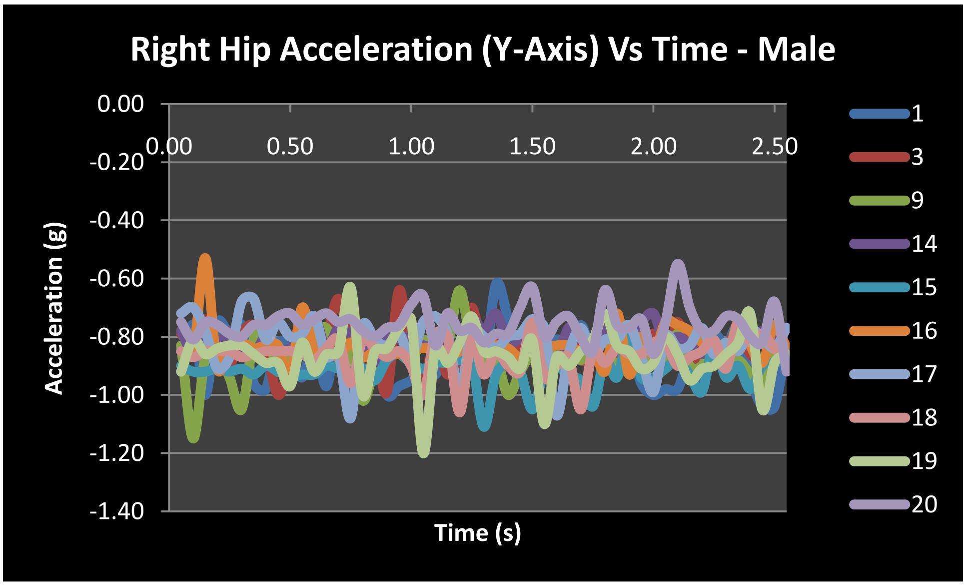
| X-Axis Acceleration of Right Hip |
|---|
| **Female**  |
| **Male**  |

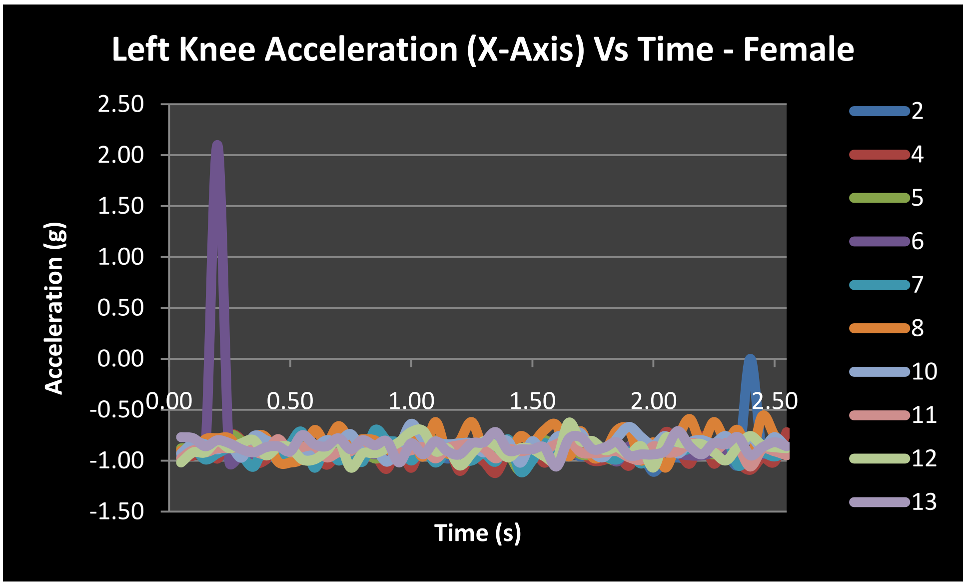
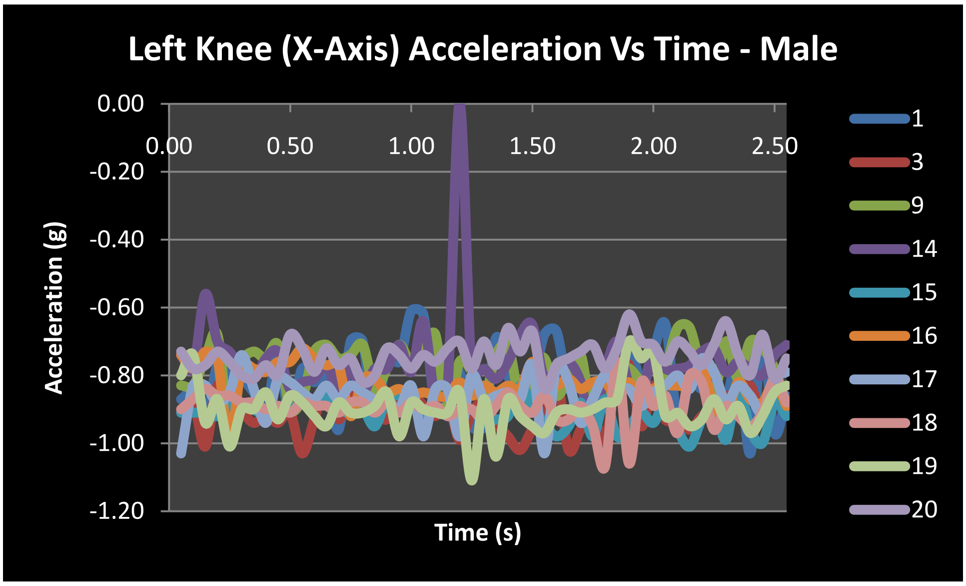
**Y-Axis Acceleration of Right Hip**

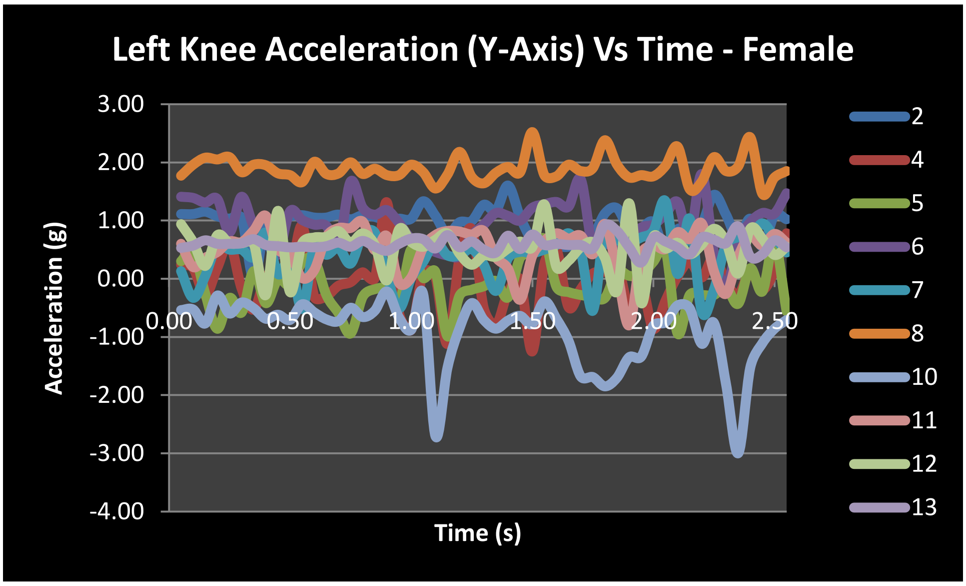
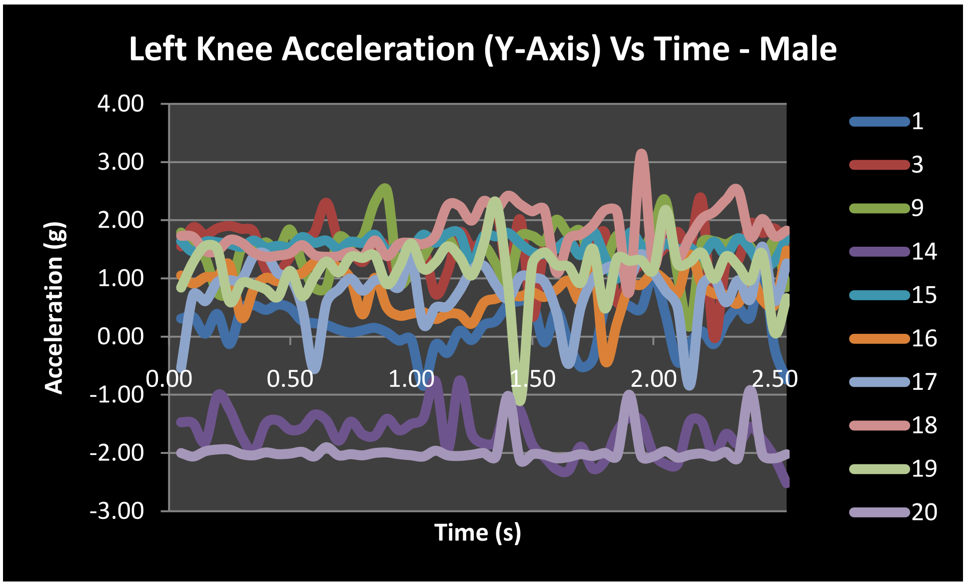
**Female**




**Male**

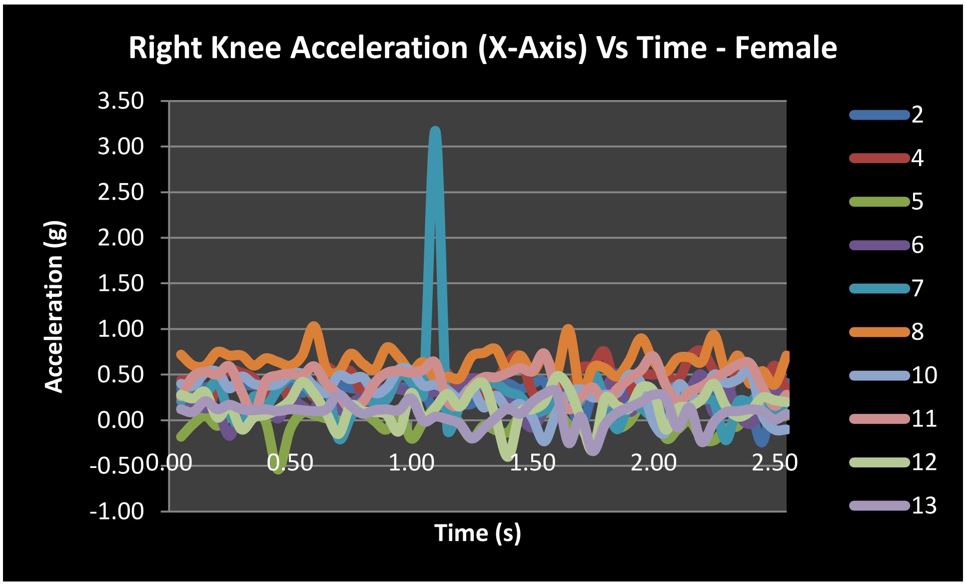


| X-Axis Acceleration of Left Knee |
|---|
| **Female**   |
| **Male**   |

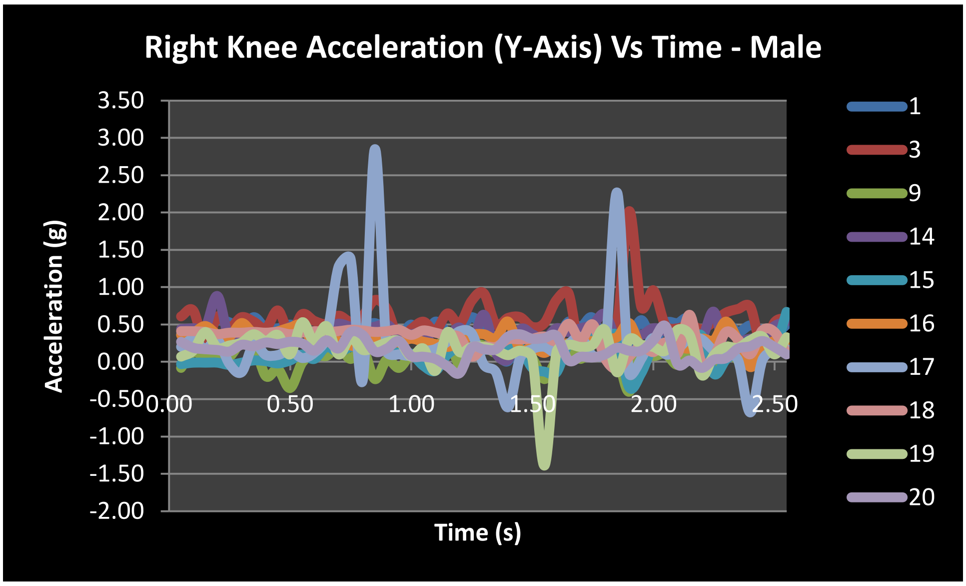
| Y-Axis Acceleration of Left Knee |
| --- |
| **Female**<br> |
| **Male**<br> |

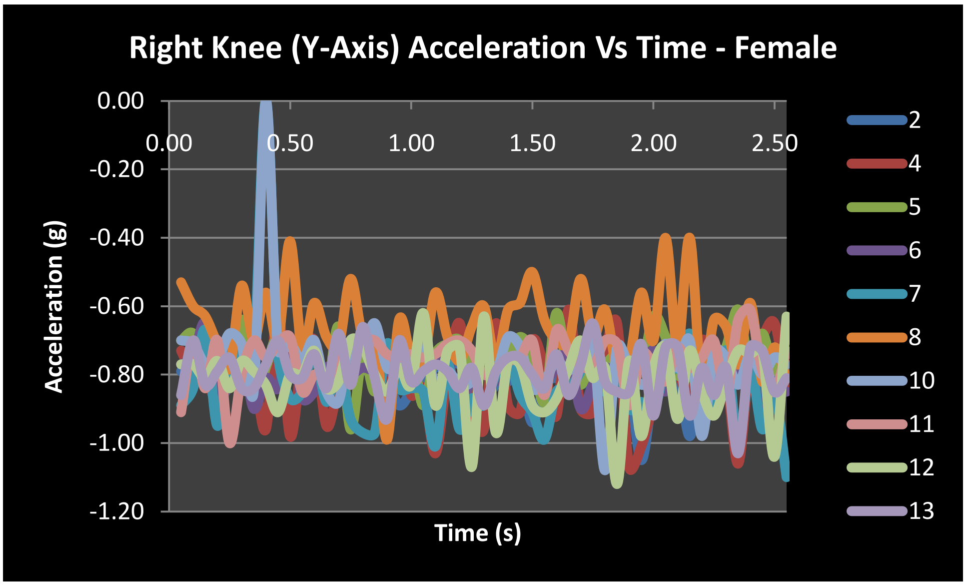
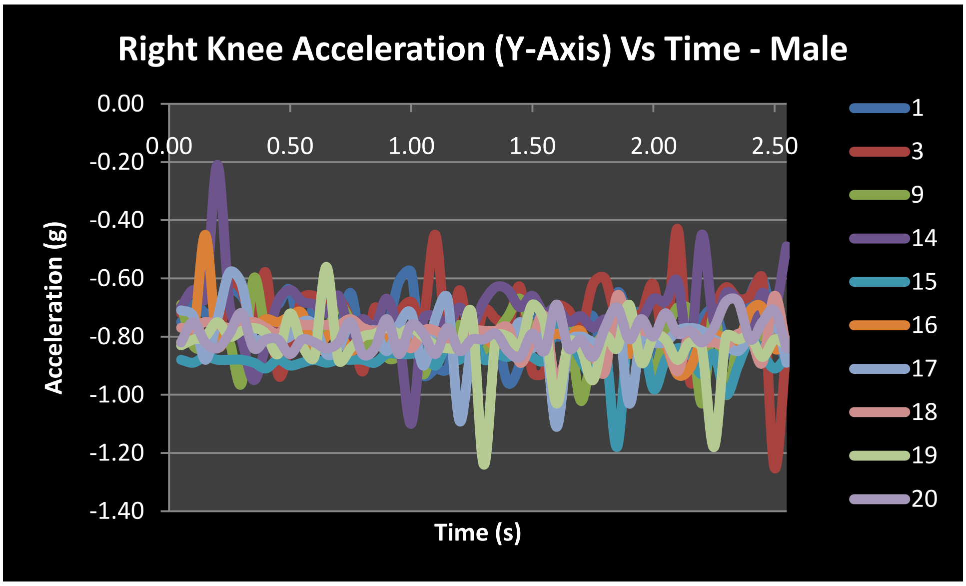
**X-Axis Acceleration of Right Knee**

**Female**




**Male**

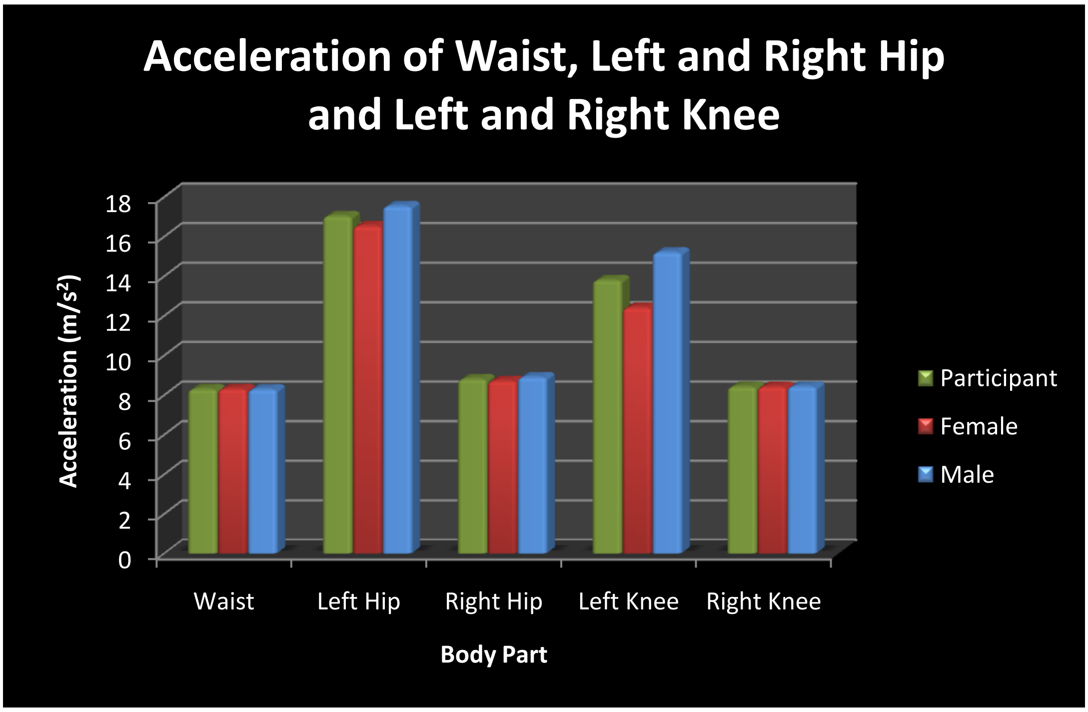


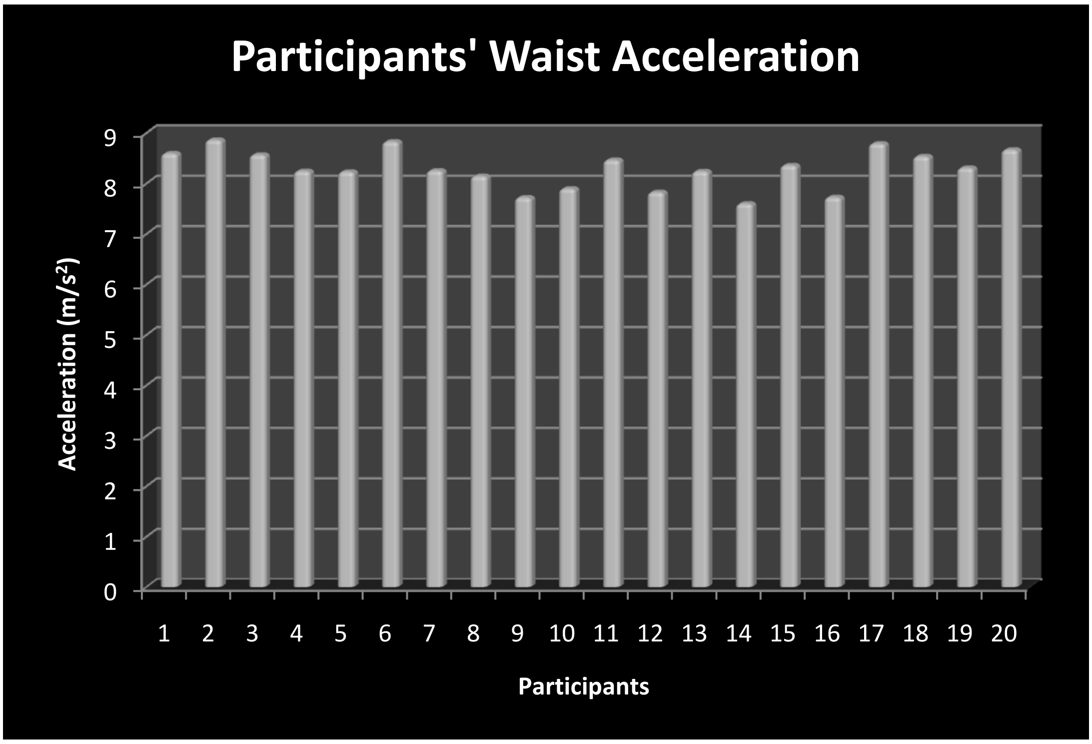
| Y-Axis Acceleration of Right Knee |
|---|
| **Female**  |
| **Male**  |

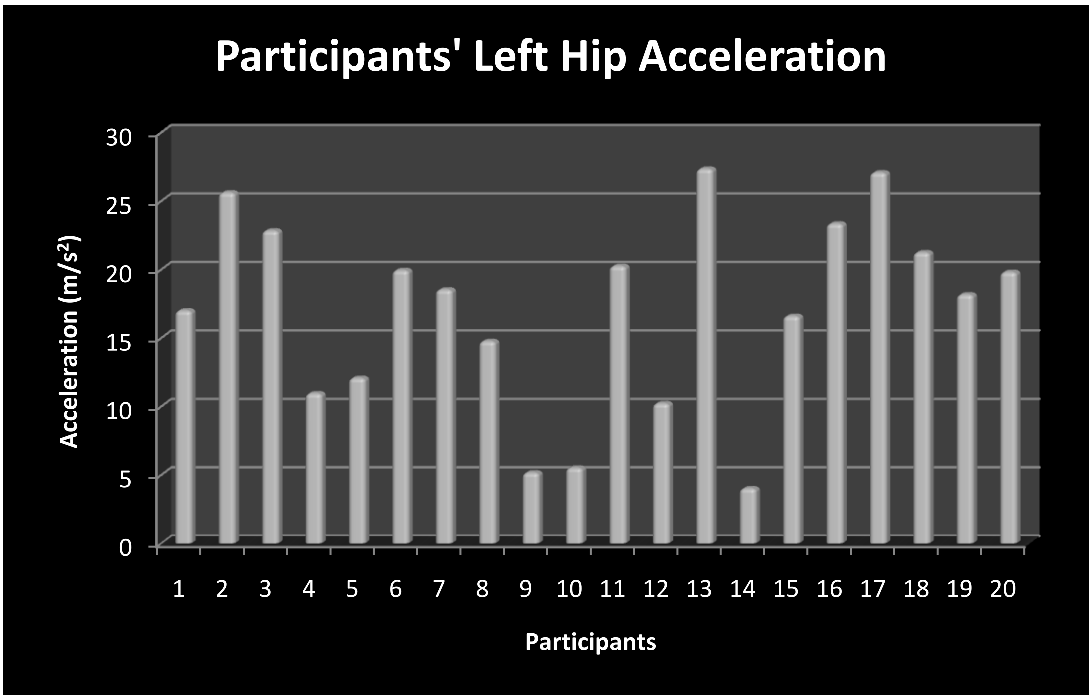
APPENDIX Q:

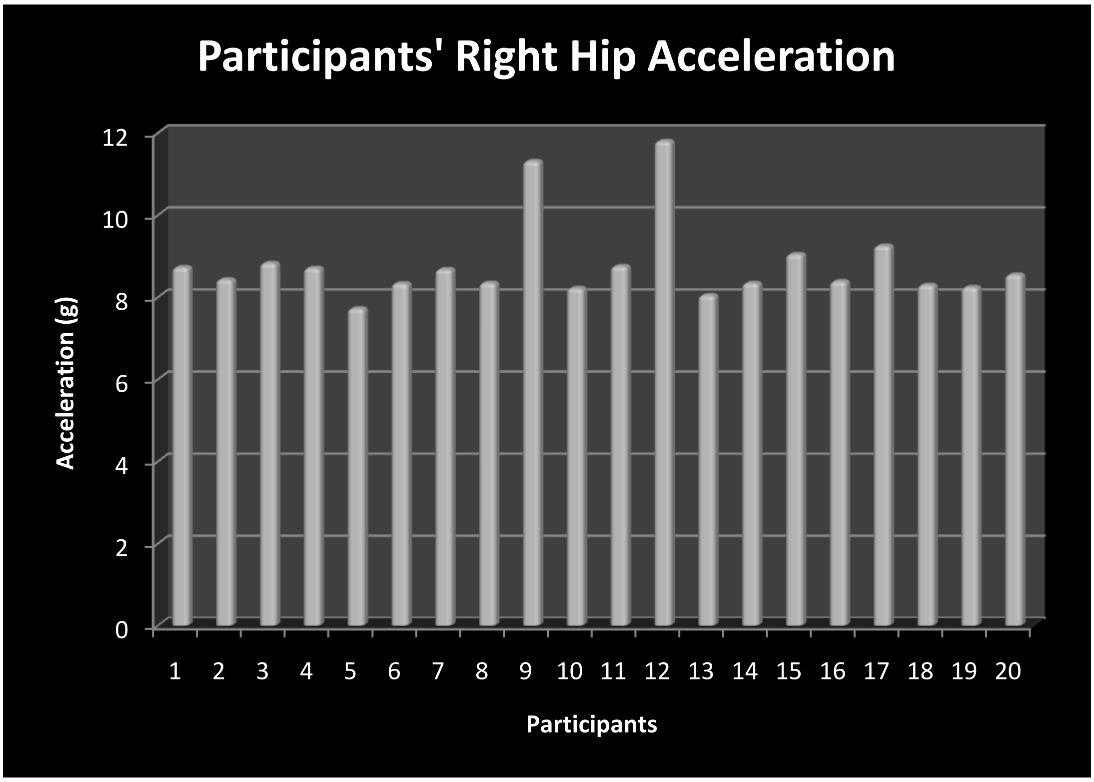
Data Analysis Graph for Comfortable Walking – 3 km/h

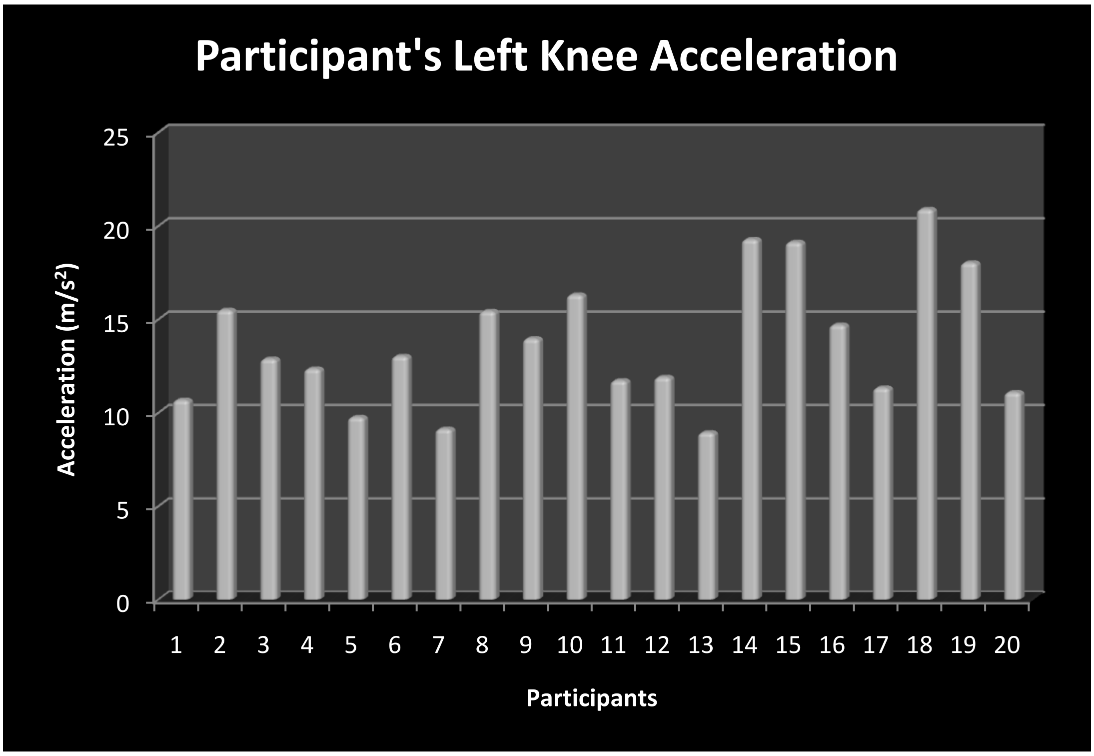
**Average Acceleration**

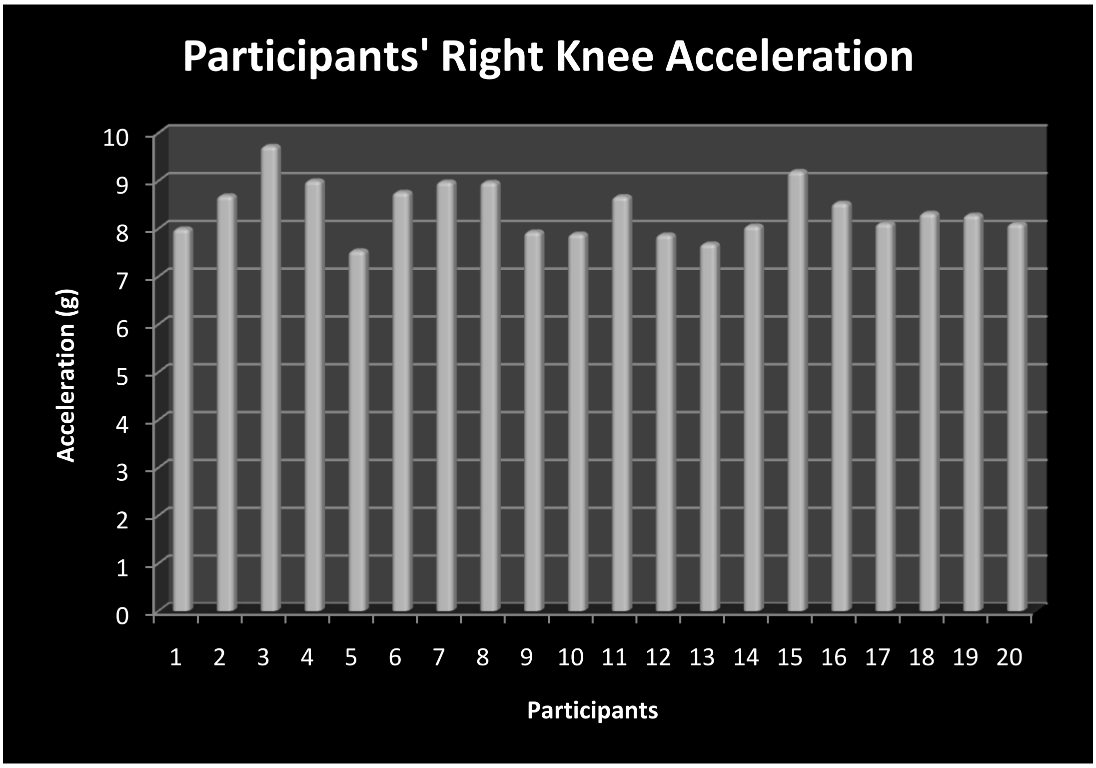


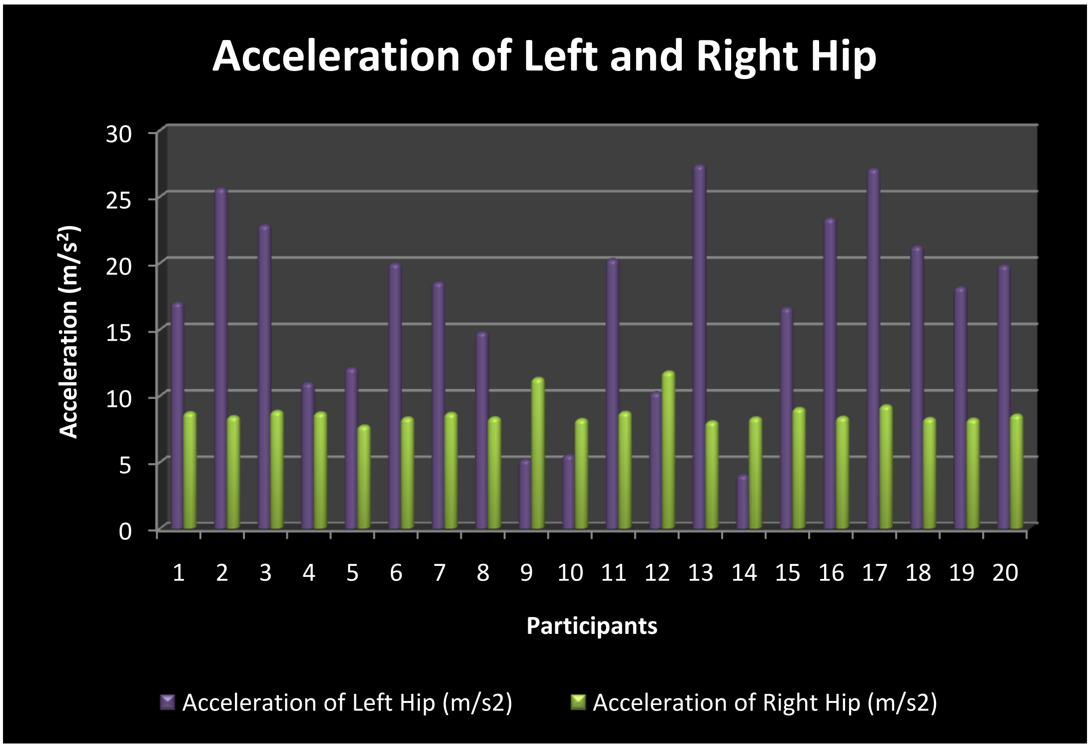



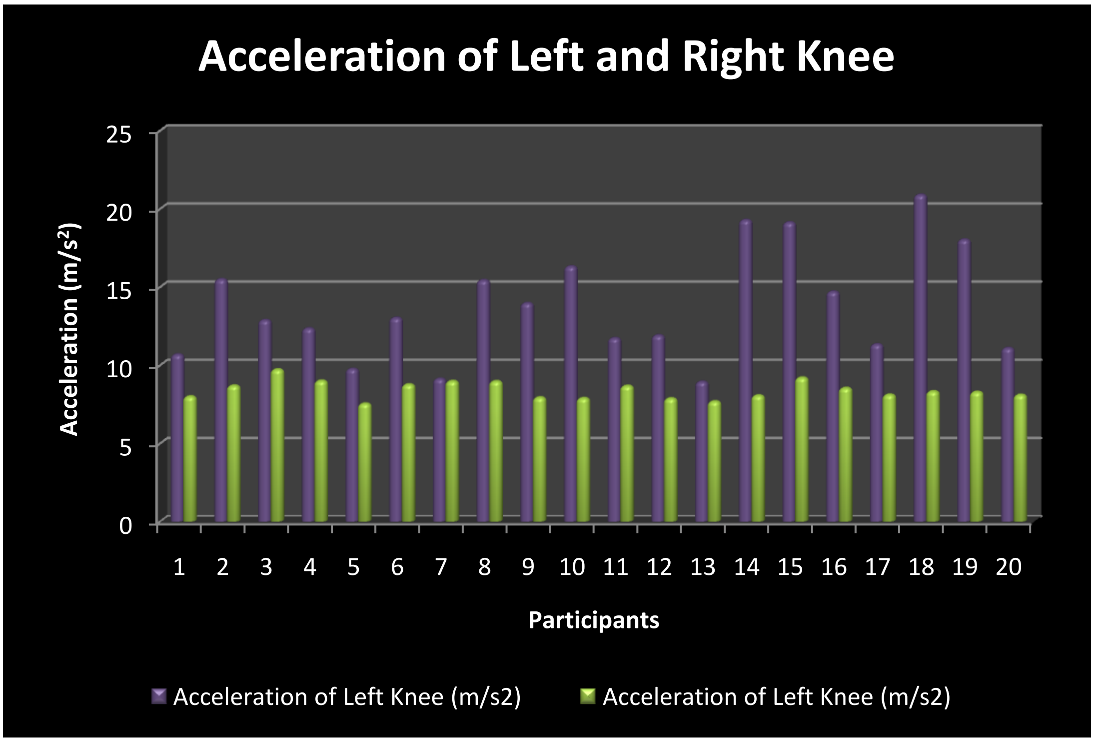

Participants' Left Hip Acceleration
Acceleration (m/s²)
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Participants


Participants' Right Hip Acceleration
Acceleration (g)
12
10
8
6
4
2
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Participants

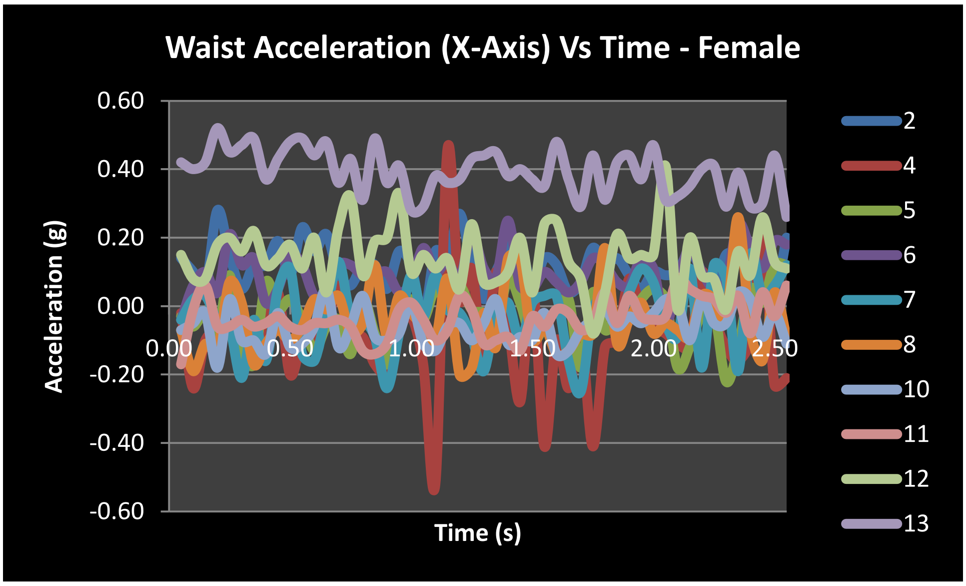
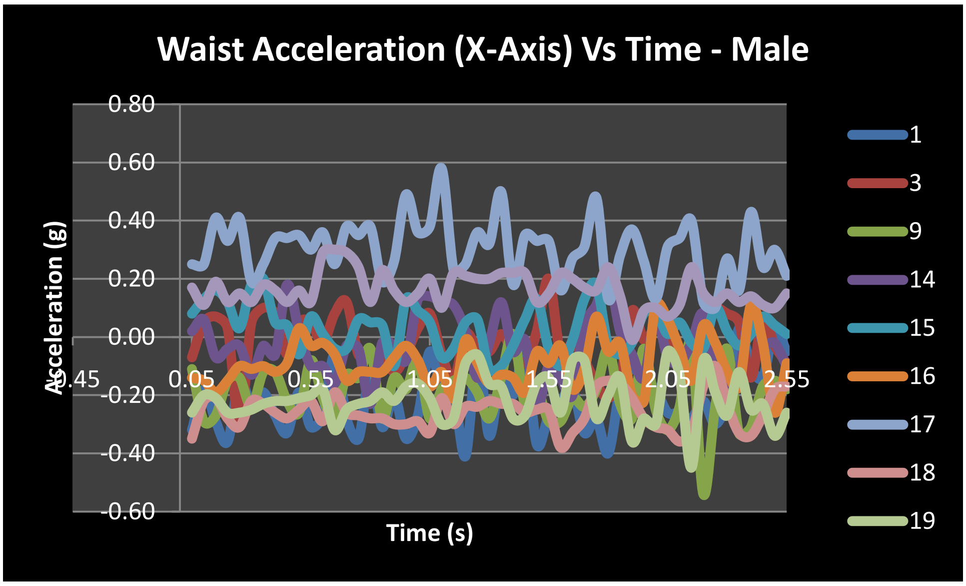

Participant's Left Knee Acceleration
Acceleration (m/s²)
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Participants


Participants' Right Knee Acceleration
Acceleration (g)
10
9
8
7
6
5
4
3
2
1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Participants


Acceleration of Left and Right Hip
Acceleration (m/s²)
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Participants
Acceleration of Left Hip (m/s2)
Acceleration of Right Hip (m/s2)

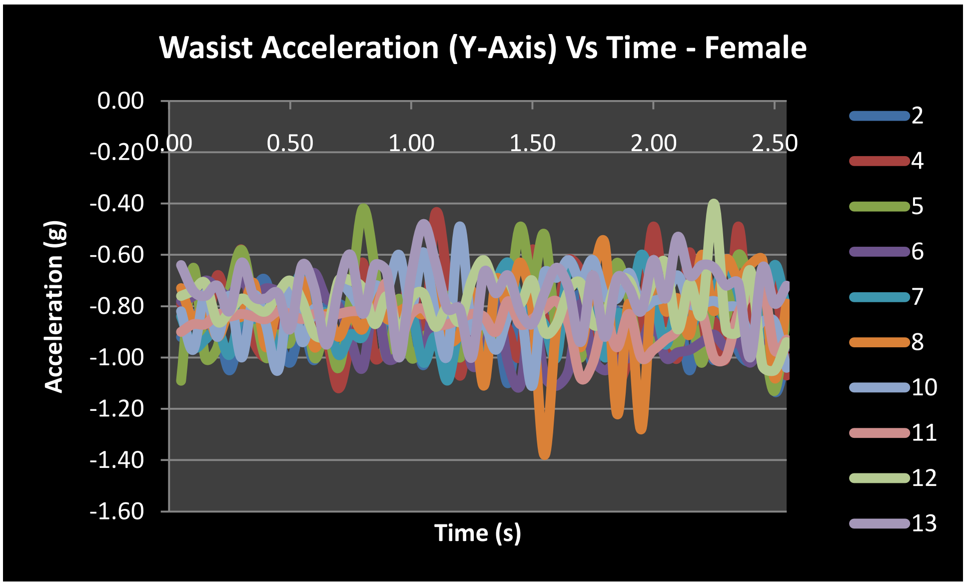

Acceleration of Left and Right Knee
Acceleration (m/s²)
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Participants
Acceleration of Left Knee (m/s2)
Acceleration of Left Knee (m/s2)

**Acceleration Vs Time Between Female and Male**

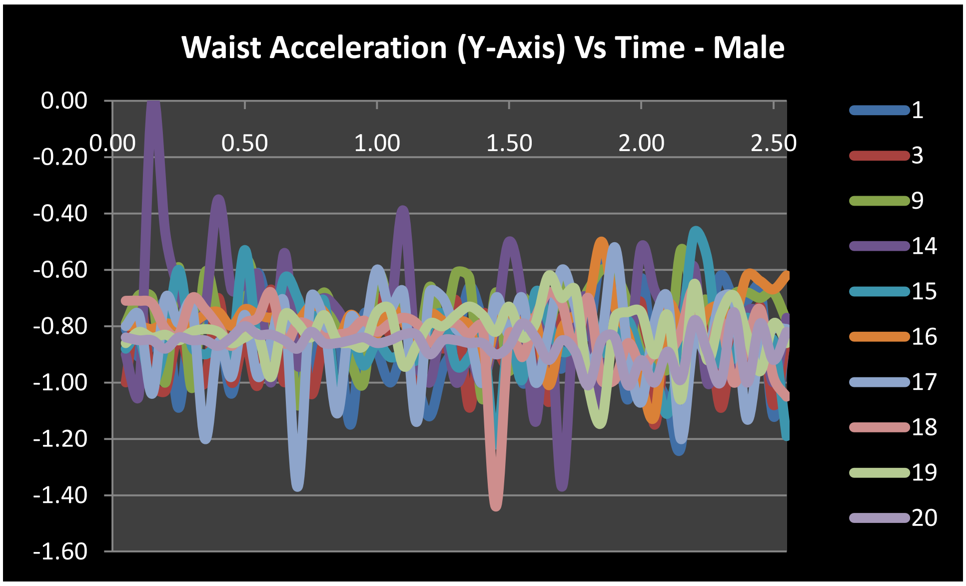
| X-Axis Acceleration of Waist |
|---|
| **Female**  |
| **Male**  |

## Y-Axis Acceleration of Waist

**Female**

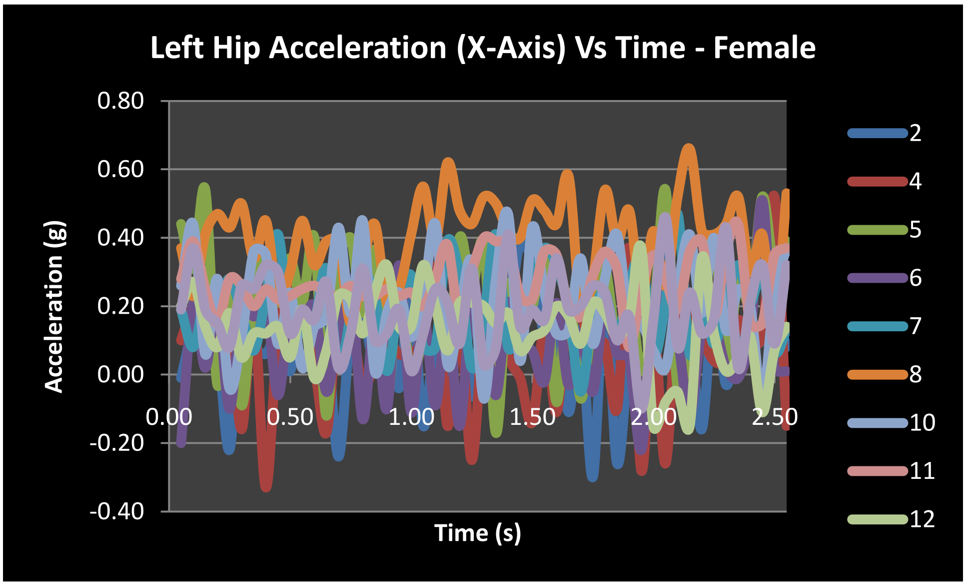



**Male**

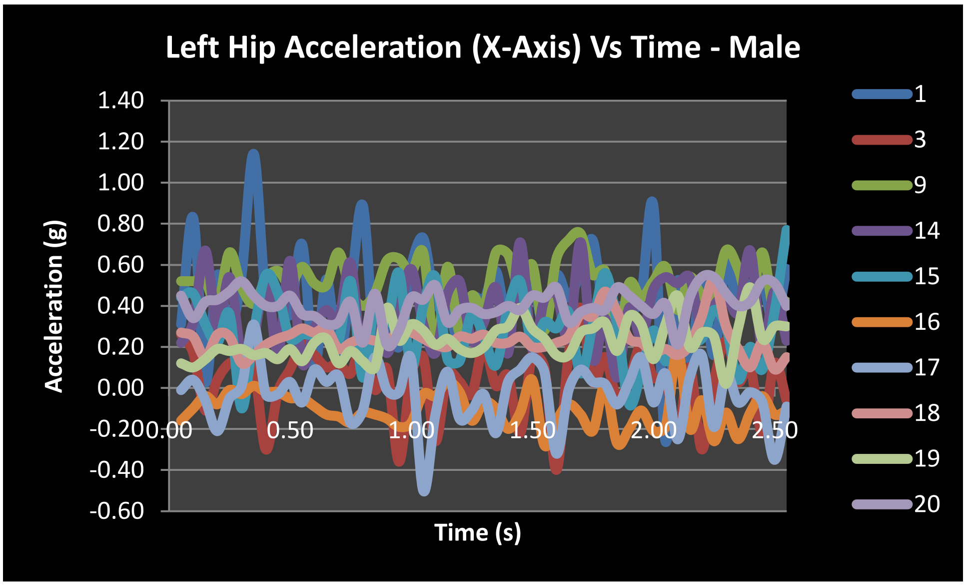


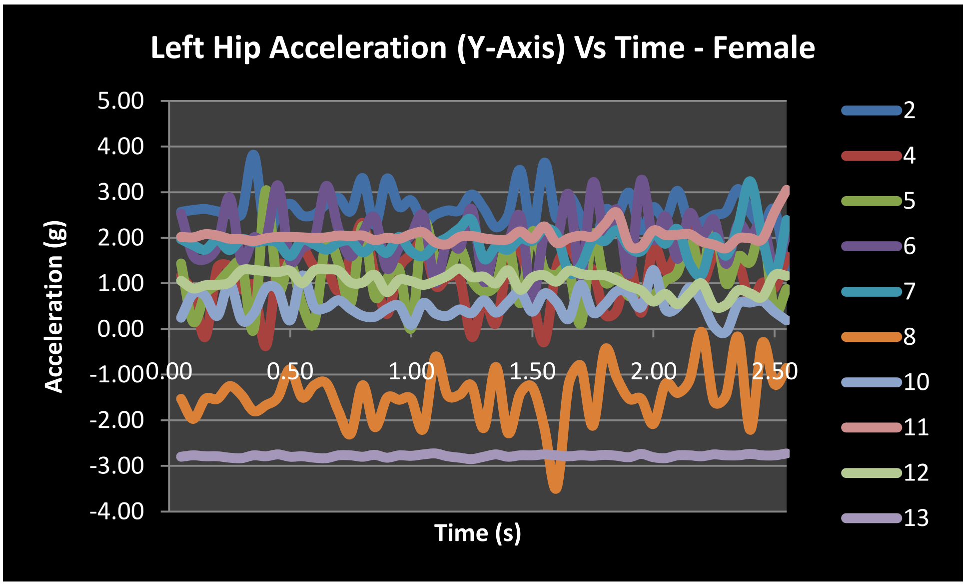
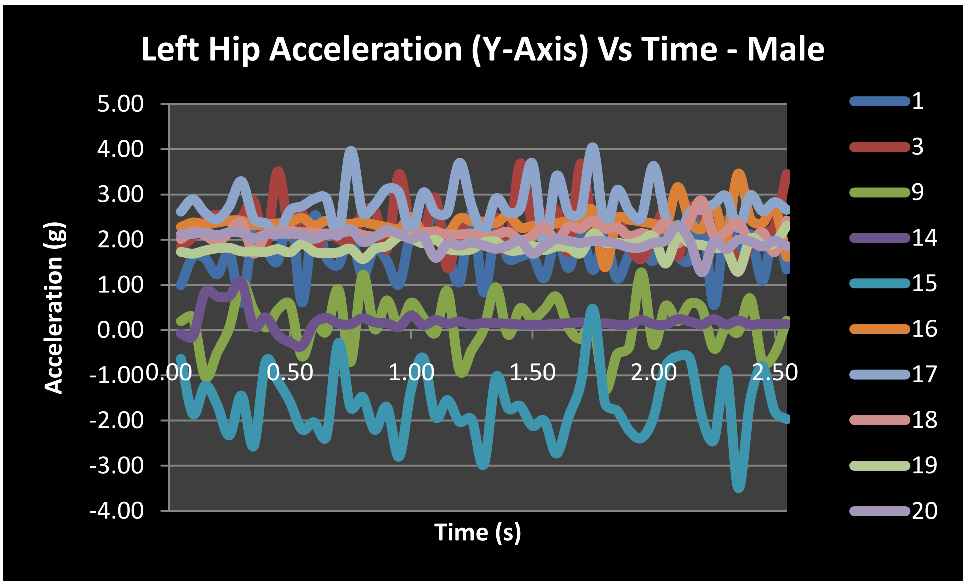
**X-Axis Acceleration of Left Hip**

**Female**



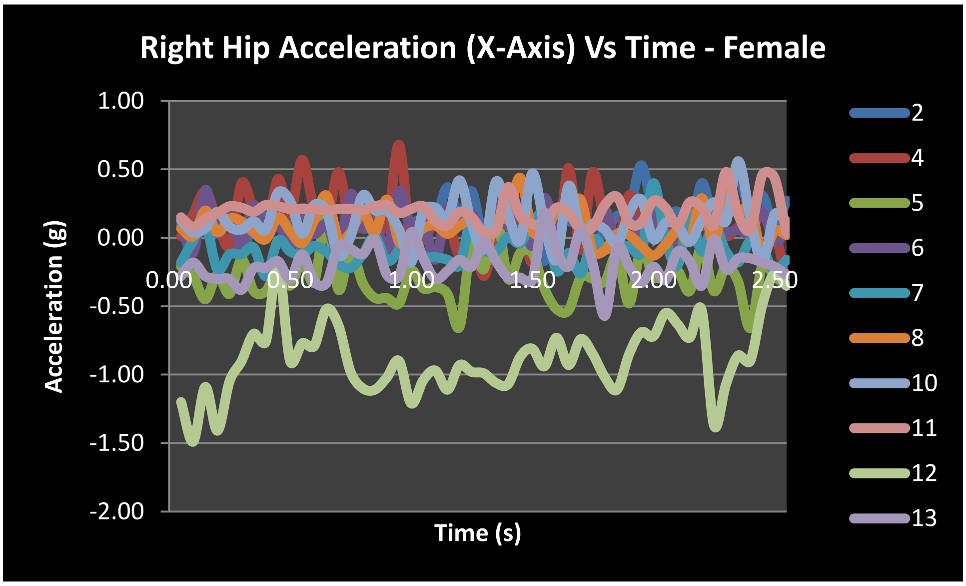

**Male**



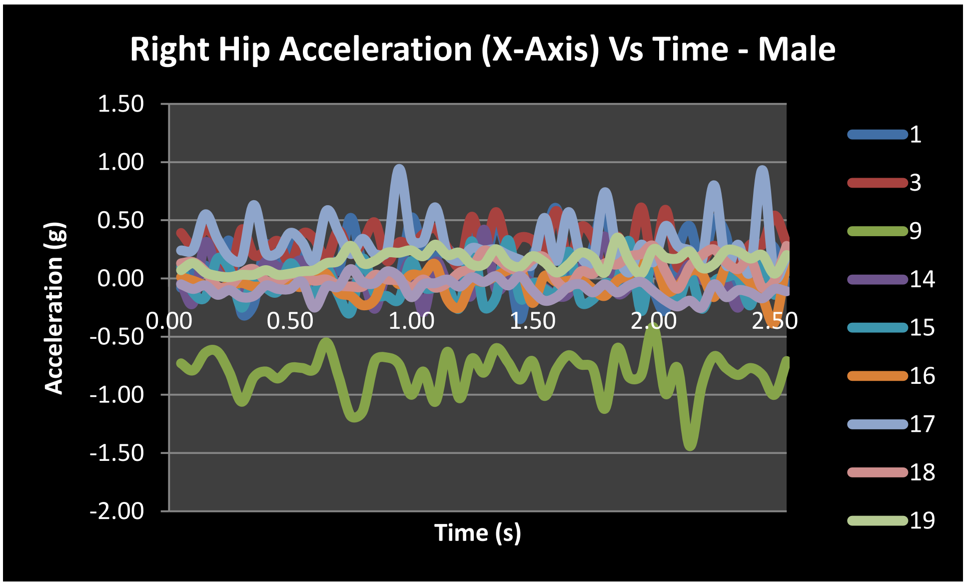
| Y-Axis Acceleration of Left Hip |
| --- |
| **Female**  |
| **Male**  |

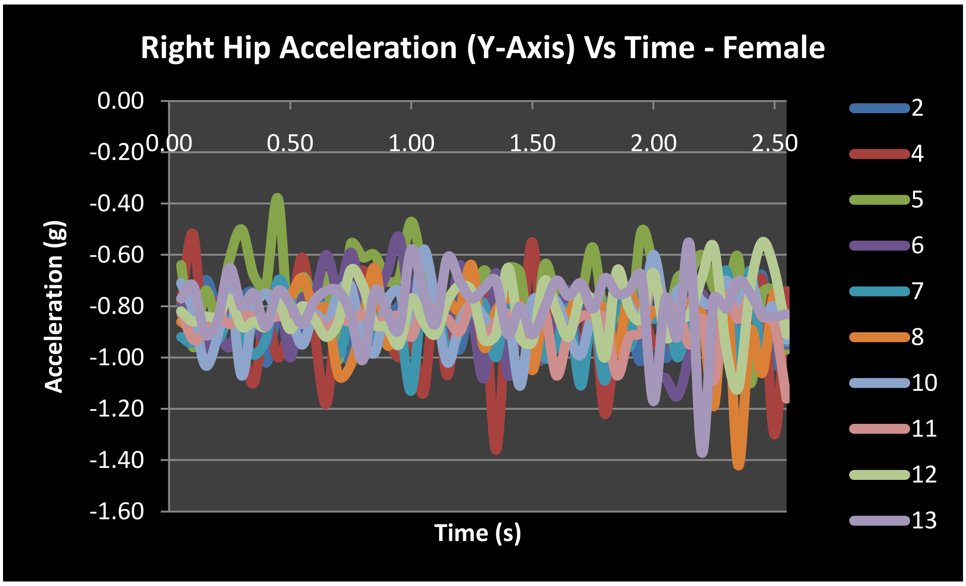
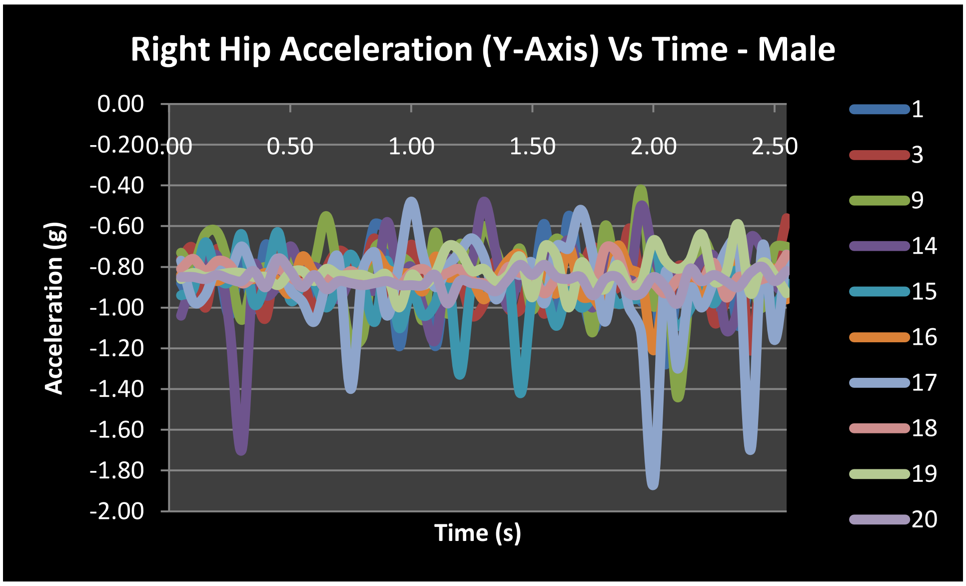
**X-Axis Acceleration of Right Hip**

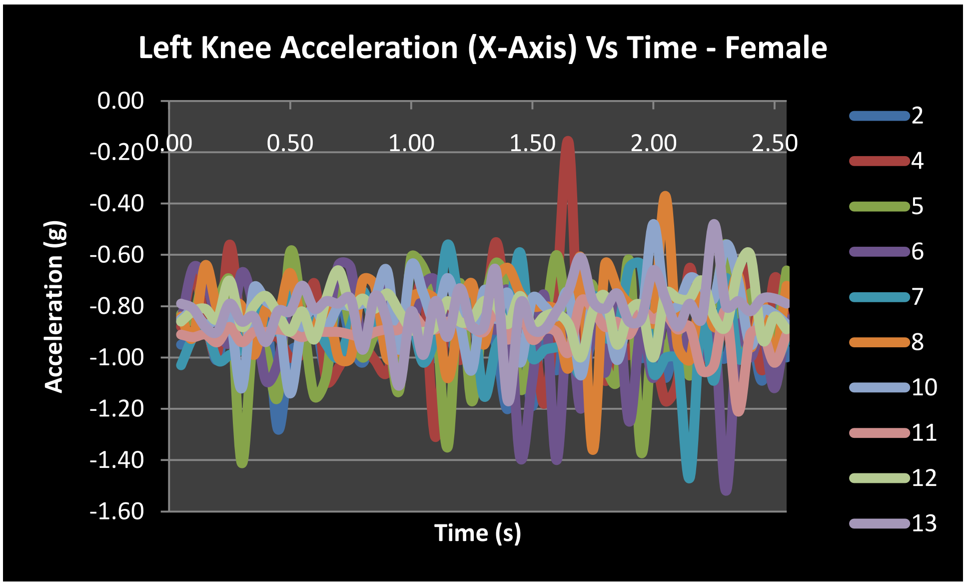
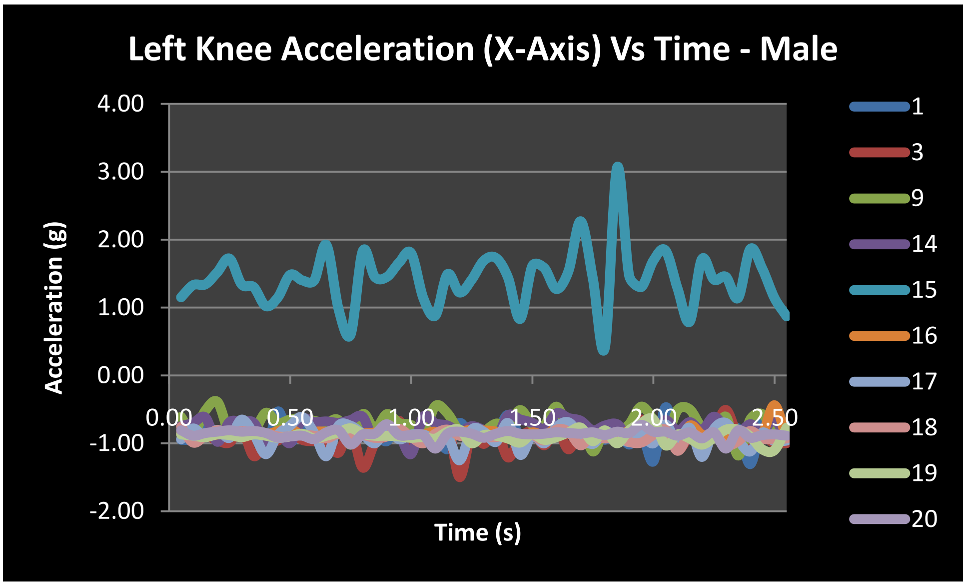
**Female**




**Male**

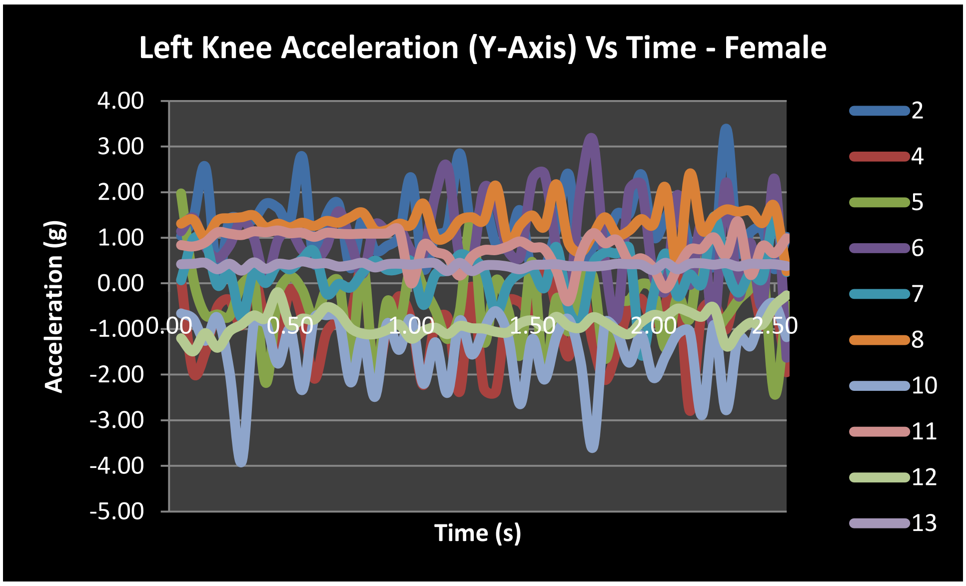


| Y-Axis Acceleration of Right Hip |
| --- |
| **Female**  |
| **Male**  |

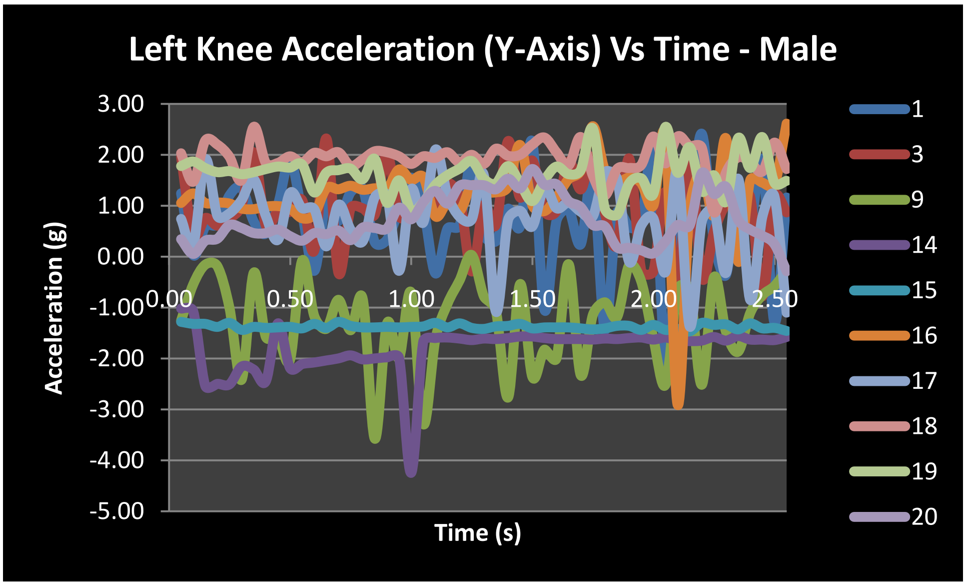
| X-Axis Acceleration of Left Knee |
|---|
| **Female**  |
| **Male**  |

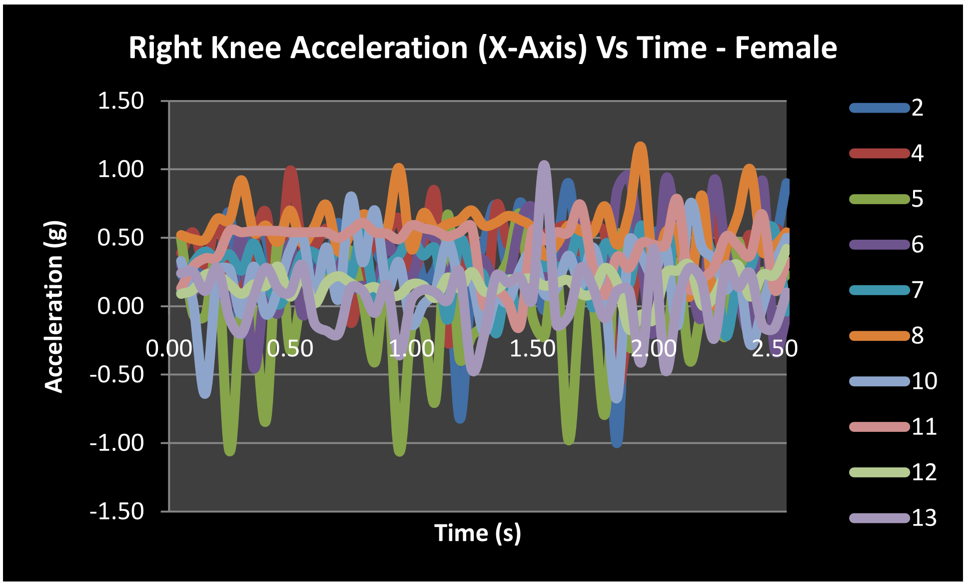
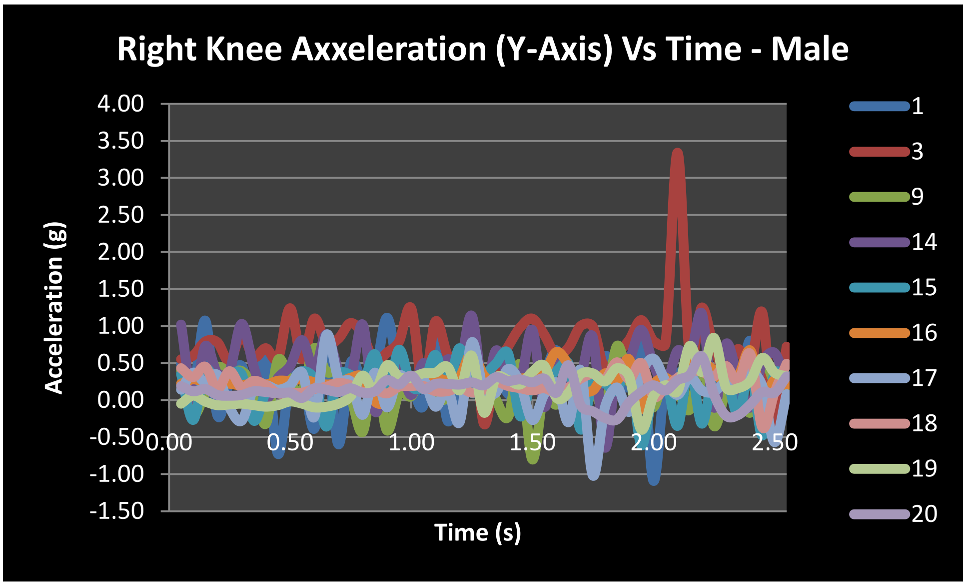
| Y-Axis Acceleration of Left Knee |
|---|

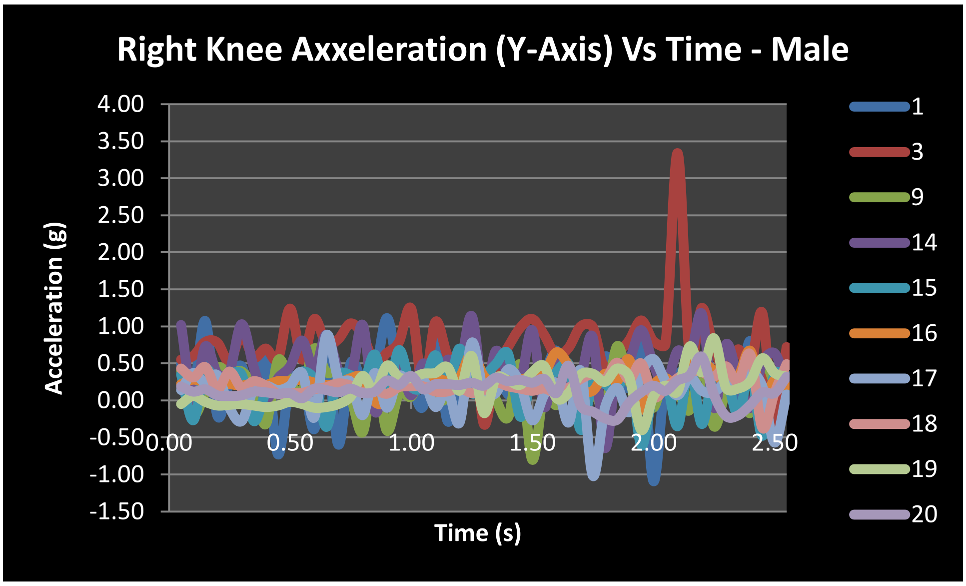
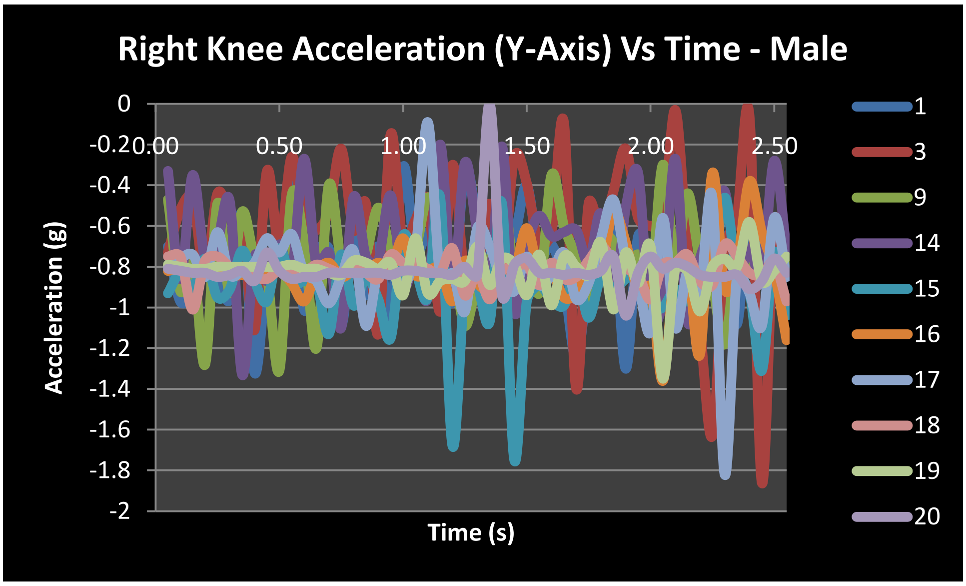
**Female**




**Male**



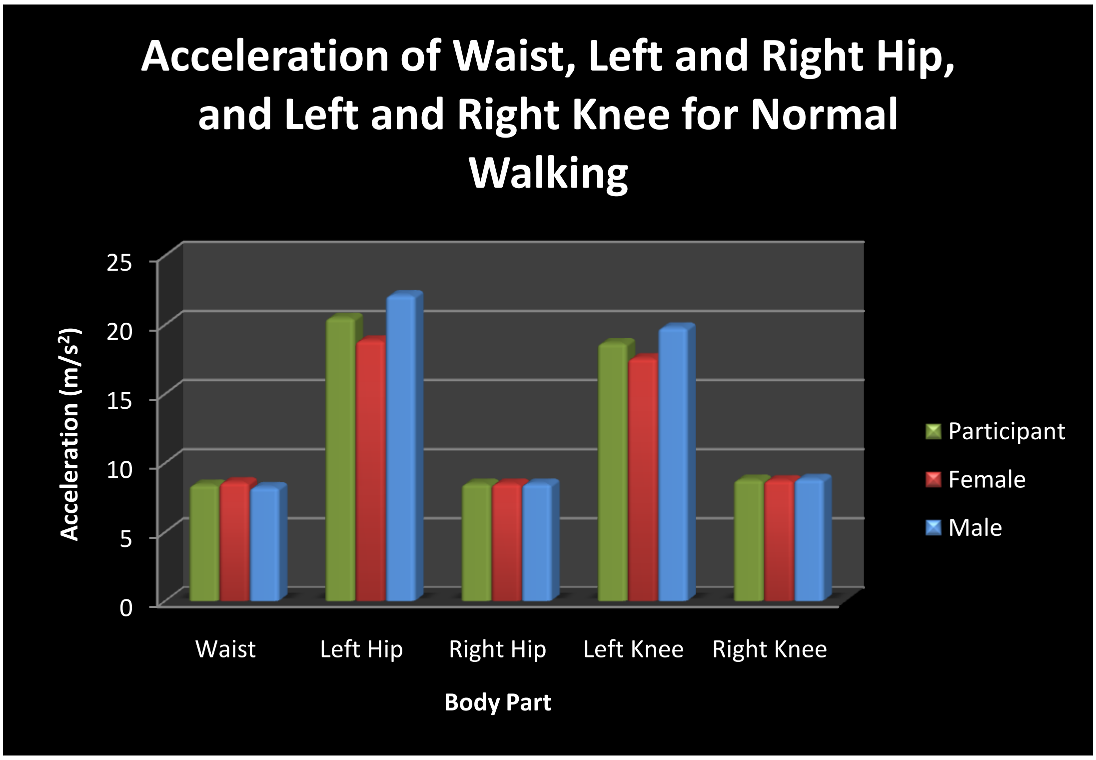
| X-Axis Acceleration of Right Knee |
|---|
| **Female**  |
| **Male**  |

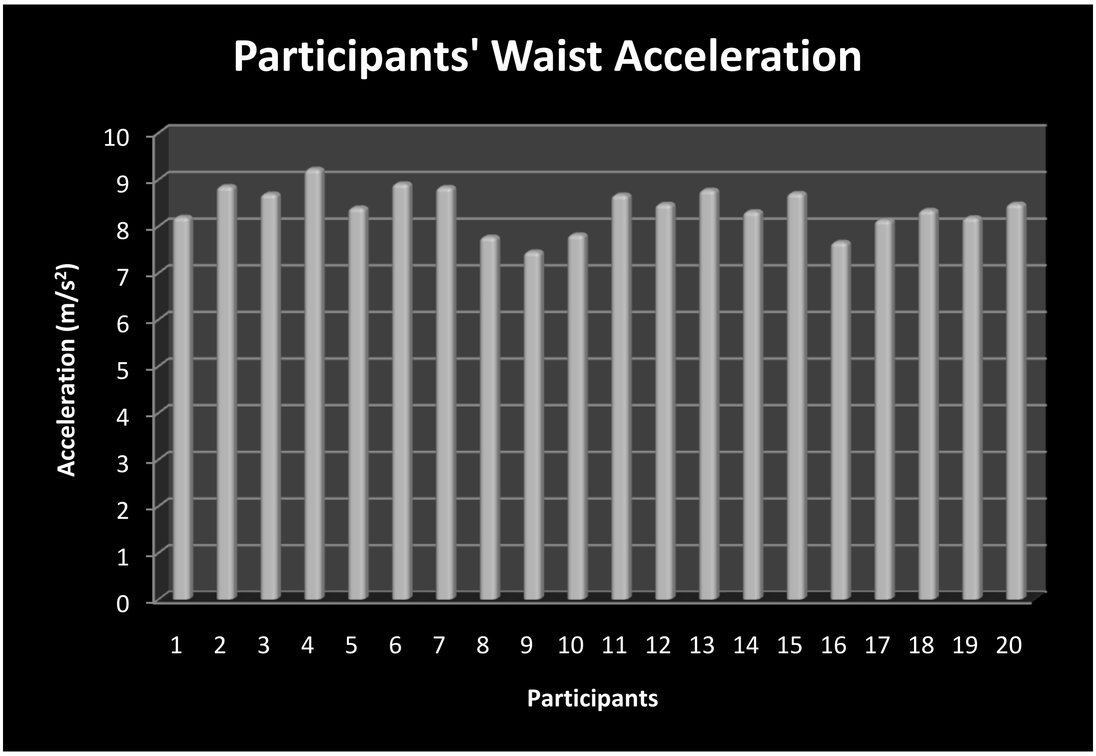
| Y-Axis Acceleration of Right Knee |
|---|
| **Female**  |
| **Male**  |

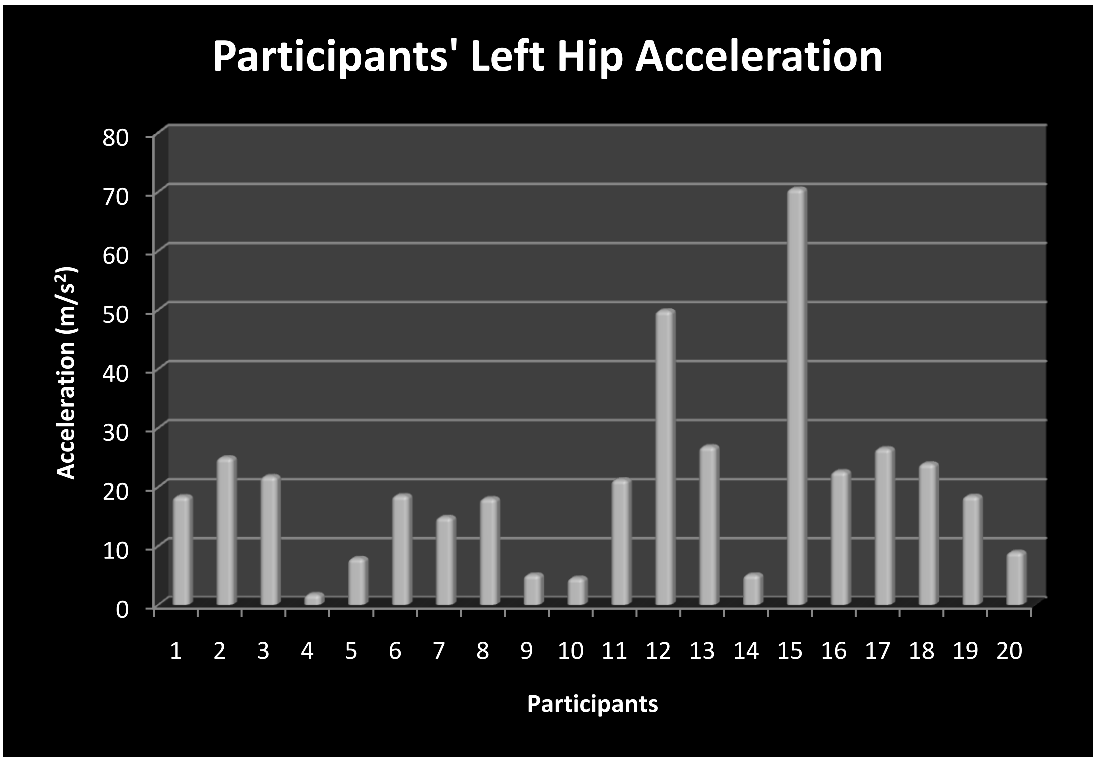
APPENDIX R:

Data Analysis Graph for Fast Walking – 5 km/h

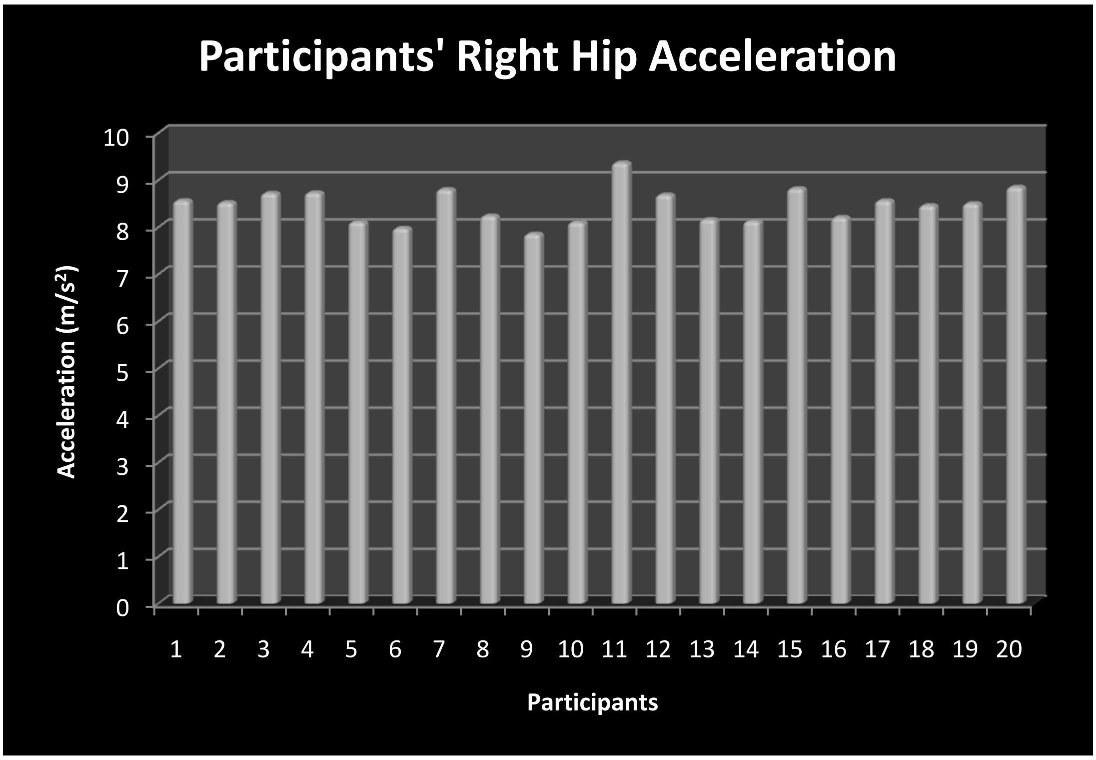
**Average Acceleration**



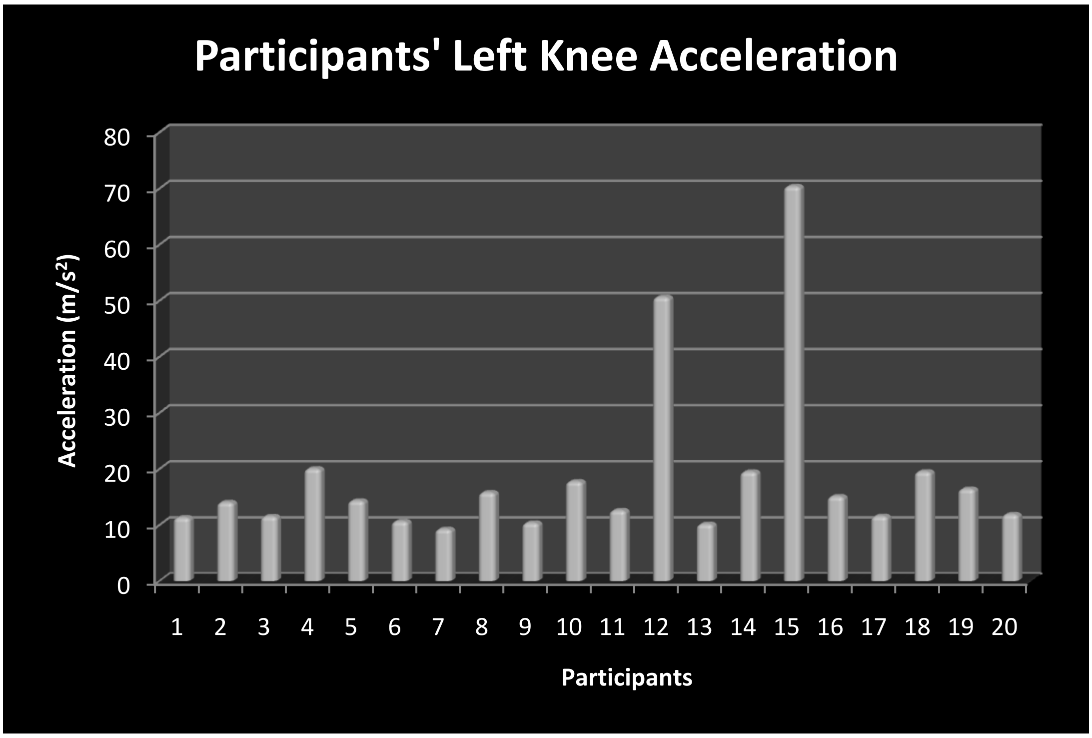





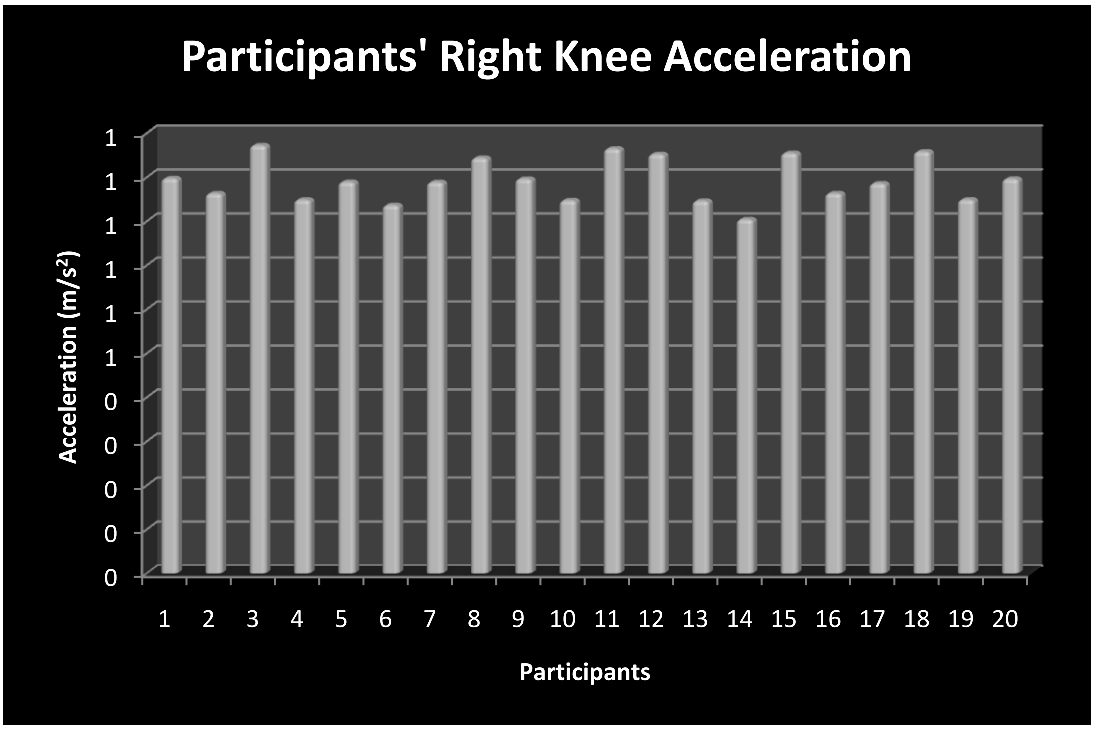
Participants' Left Hip Acceleration
Acceleration (m/s²)
0
10
20
30
40
50
60
70
80
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Participants

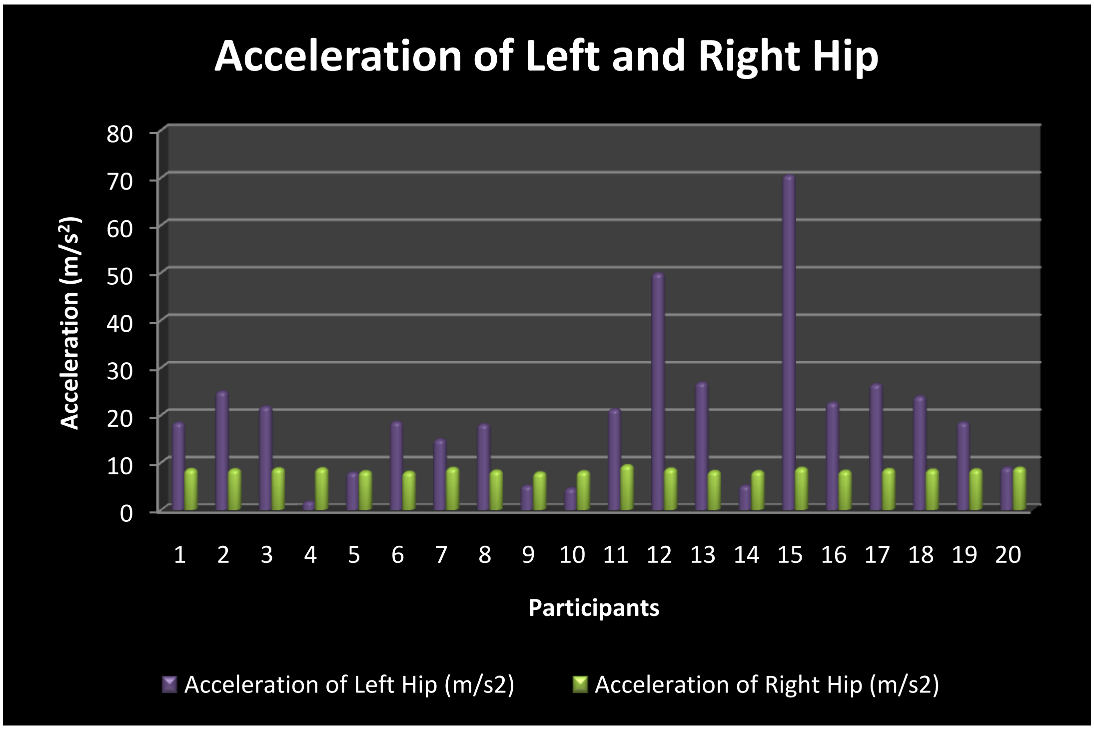
Participants' Right Hip Acceleration
Acceleration (m/s²)
0
1
2
3
4
5
6
7
8
9
10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Participants

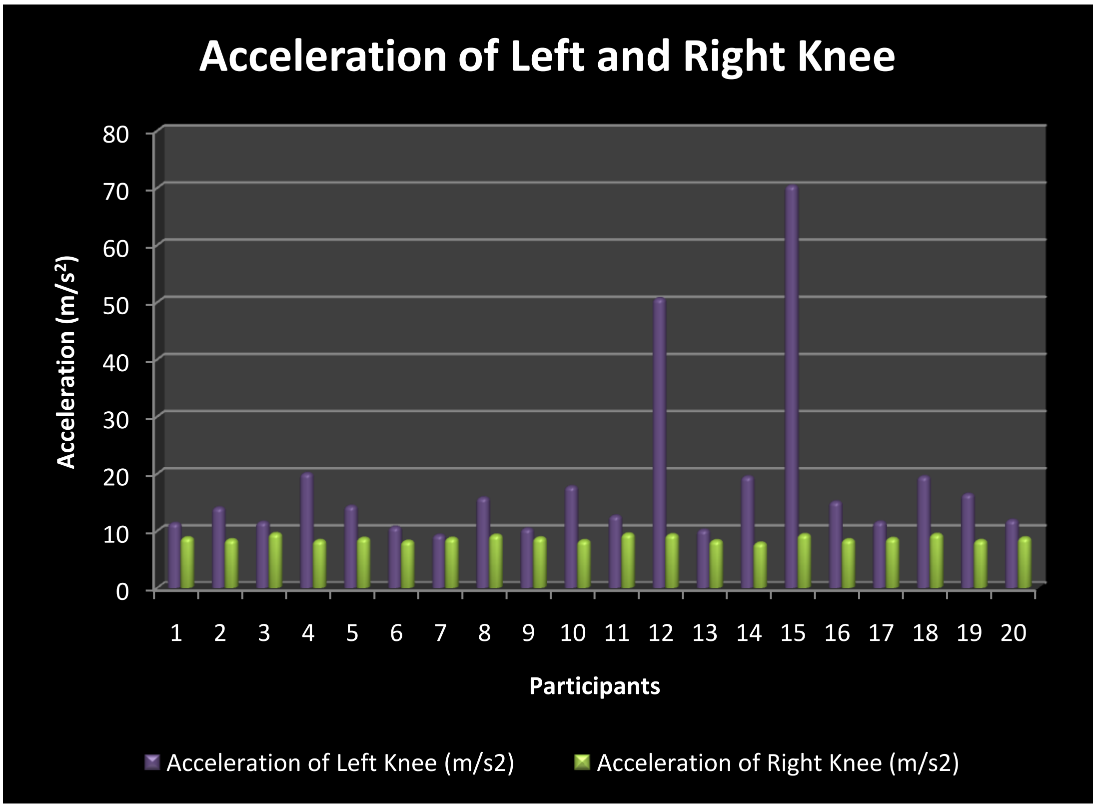


Participants' Left Knee Acceleration
Acceleration (m/s²)
0
10
20
30
40
50
60
70
80
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Participants

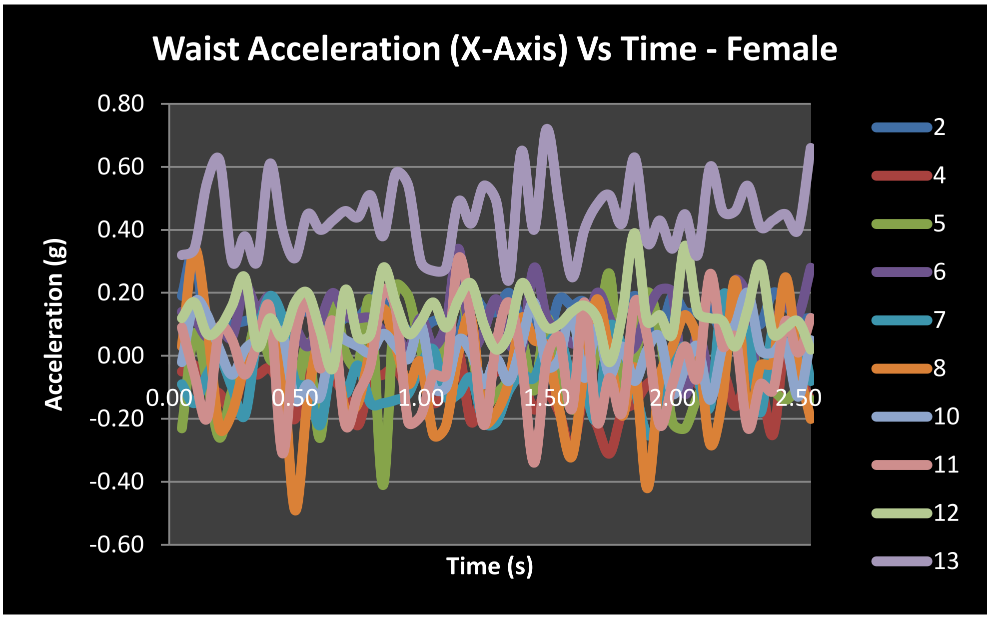
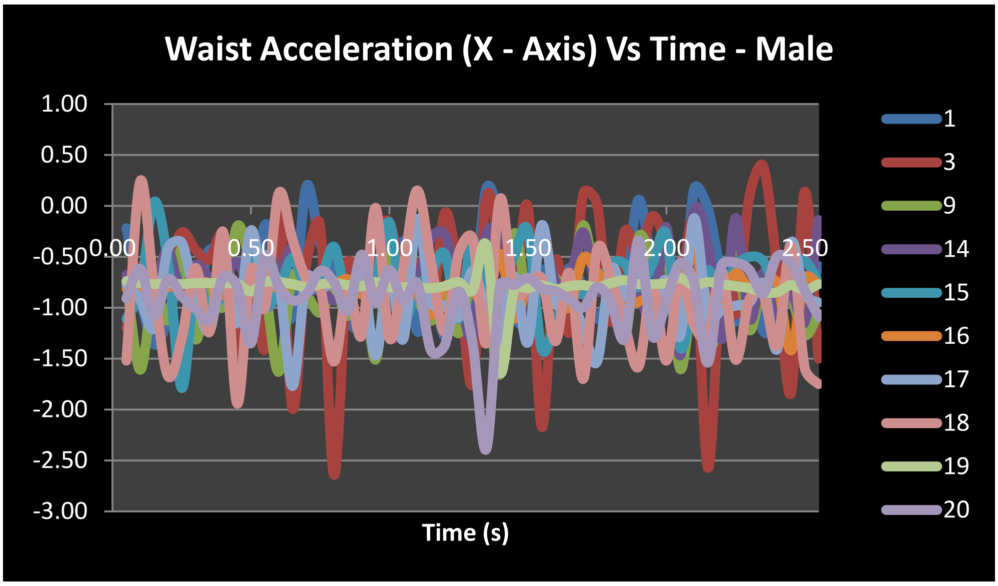



Participants' Right Knee Acceleration
Acceleration (m/s²)
0
0
0
0
0
1
1
1
1
1
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Participants


Acceleration of Left and Right Hip
Acceleration (m/s²)
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Participants
Acceleration of Left Hip (m/s2)
Acceleration of Right Hip (m/s2)

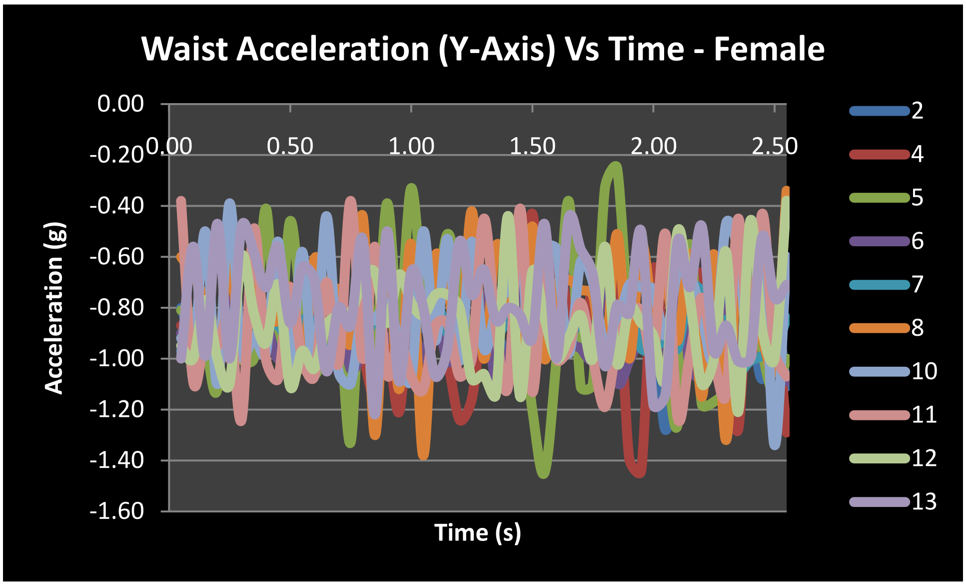

Acceleration of Left and Right Knee
Acceleration (m/s²)
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Participants
Acceleration of Left Knee (m/s2)
Acceleration of Right Knee (m/s2)

**Acceleration Vs Time Between Female and Male**

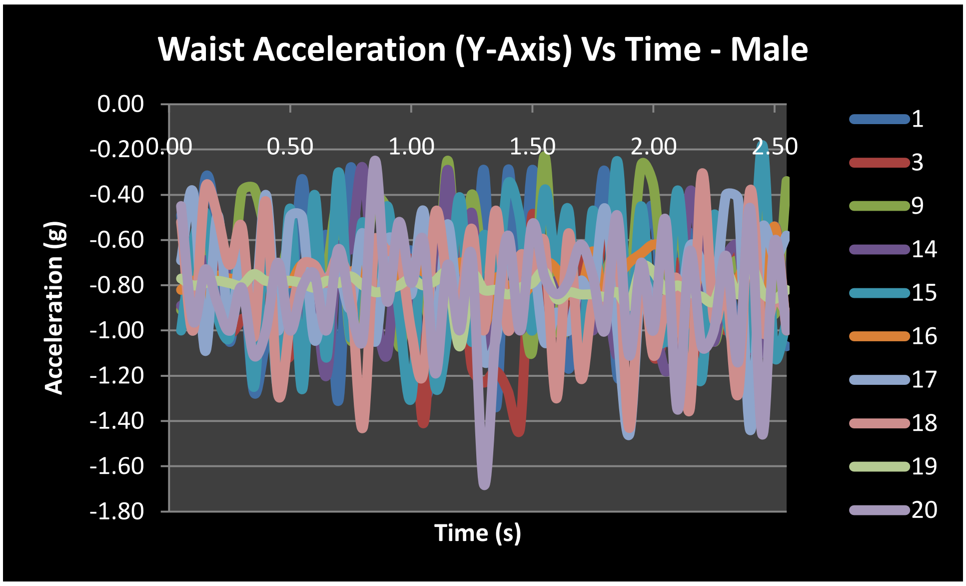
| X-Axis Acceleration of Waist |
|---|
| **Female**  |
| **Male**  |

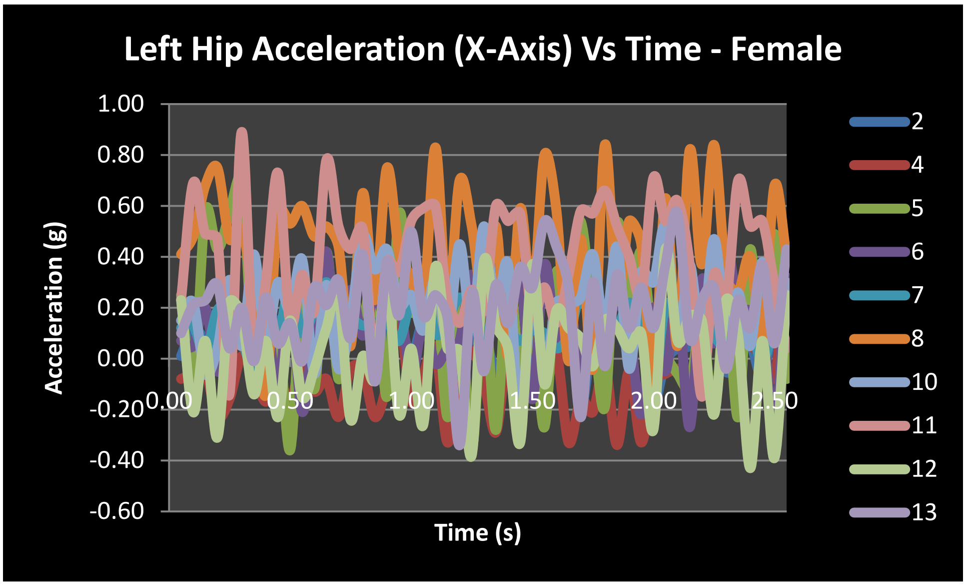
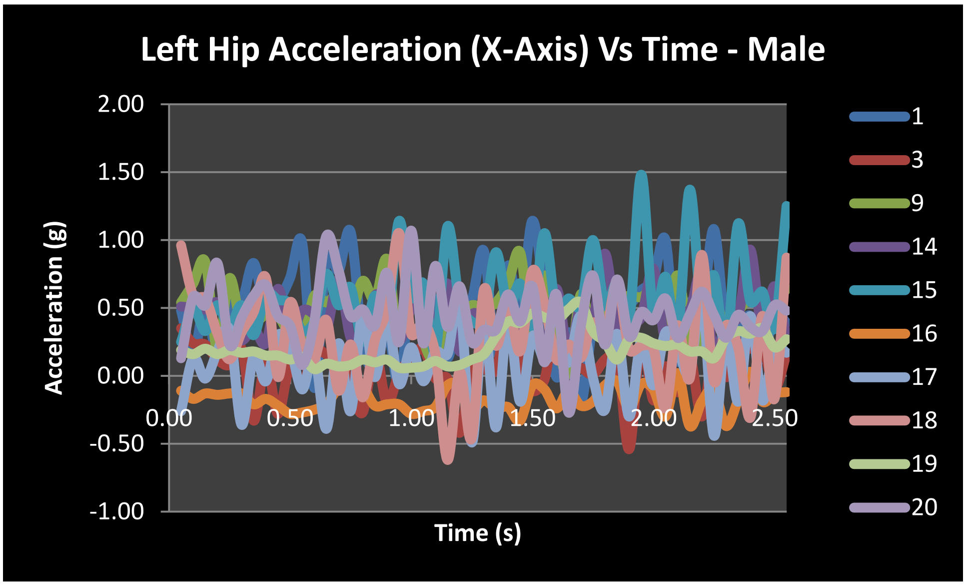
**Y-Axis Acceleration of Waist**

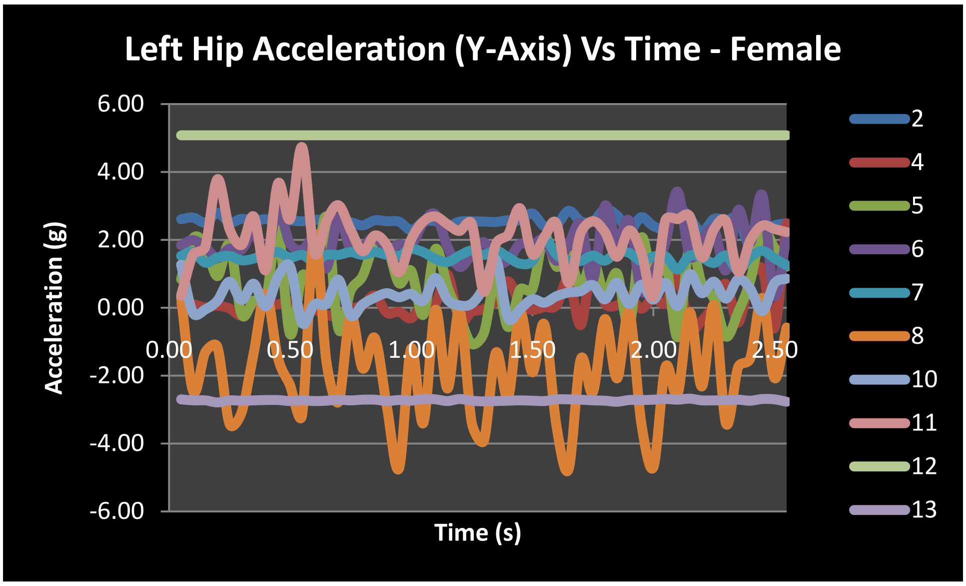
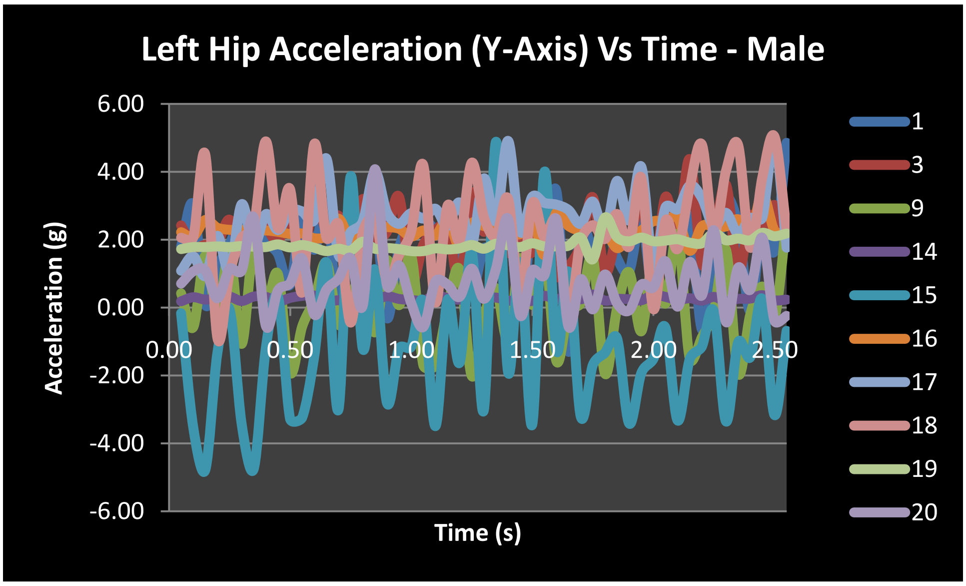
**Female**



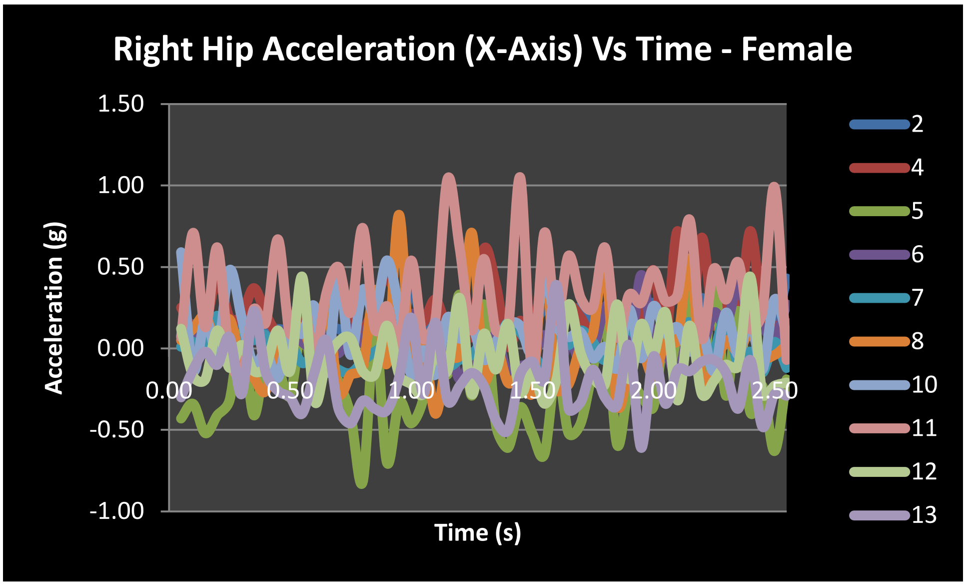

**Male**



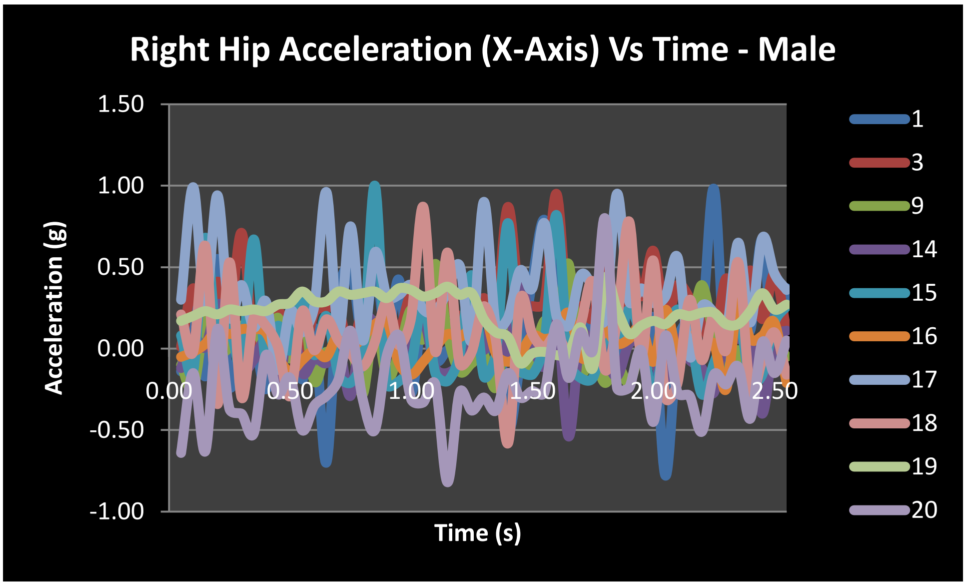
| X-Axis Acceleration of Left Hip |
|---|
| **Female**  |
| **Male**  |

| Y-Axis Acceleration of Left Hip |
| --- |
| **Female**  |
| **Male**  |

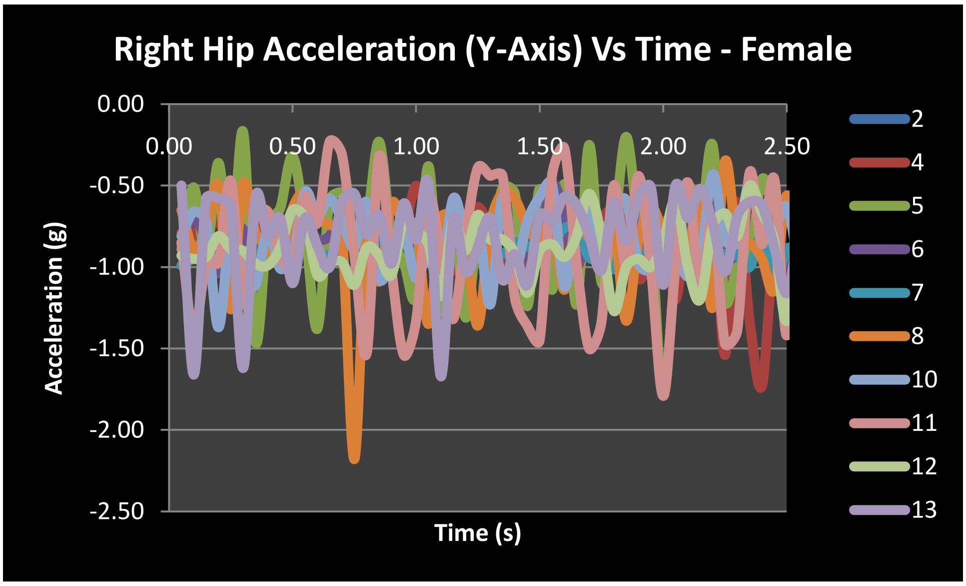
| X-Axis Acceleration of Right Hip |
|---|
| **Female** |



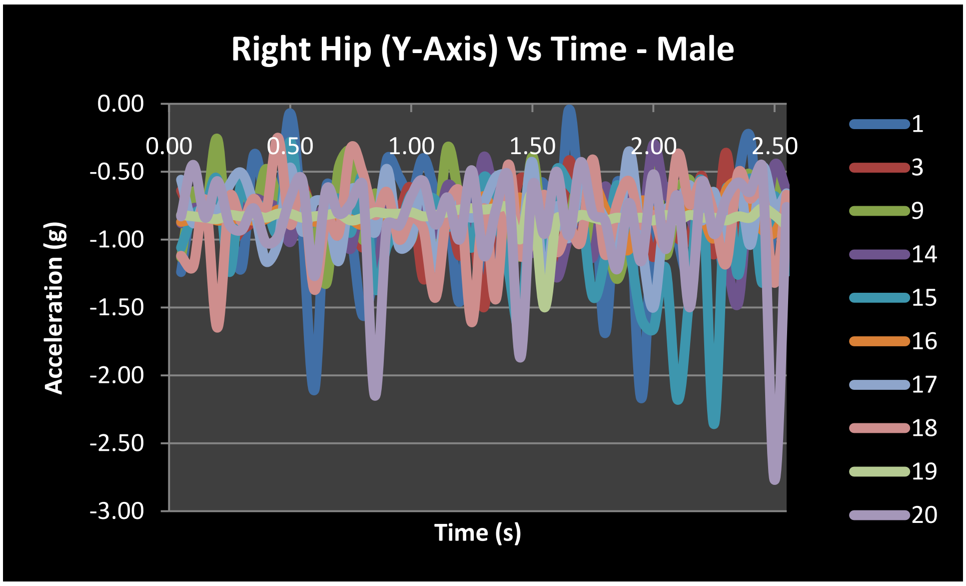

**Male**



| Y-Axis Acceleration of Right Hip |
|---|
| **Female** |

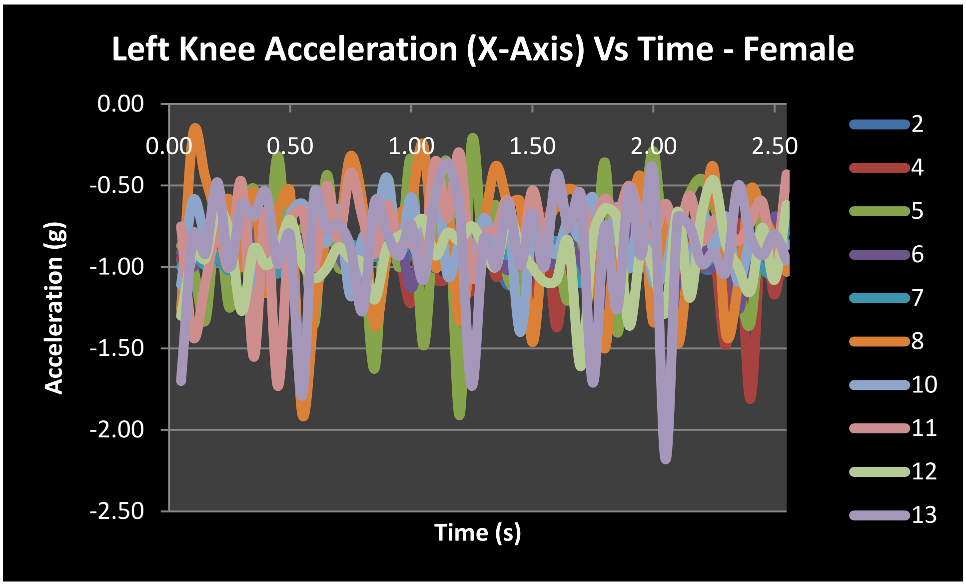



**Male**

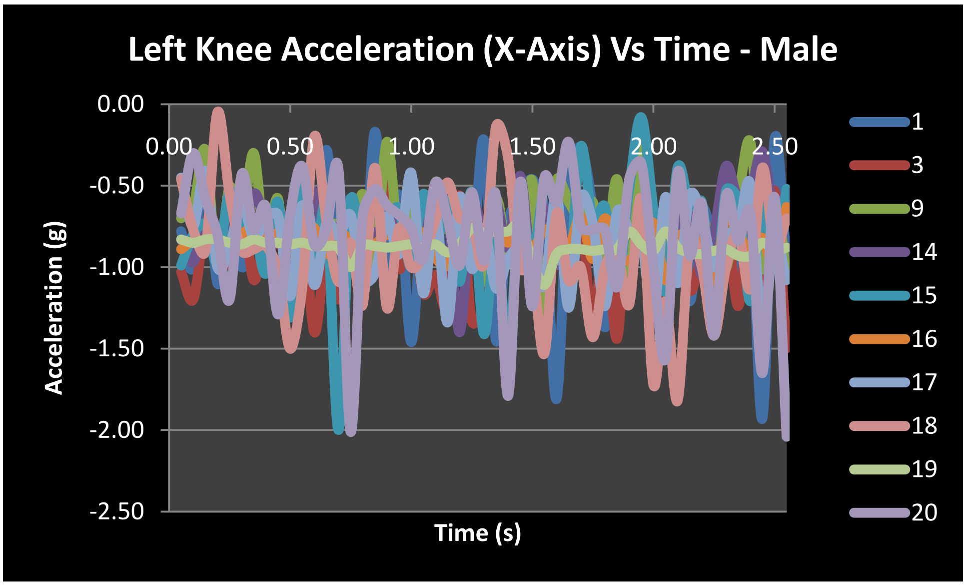


| X-Axis Acceleration of Left Knee |
|---|

**Female**

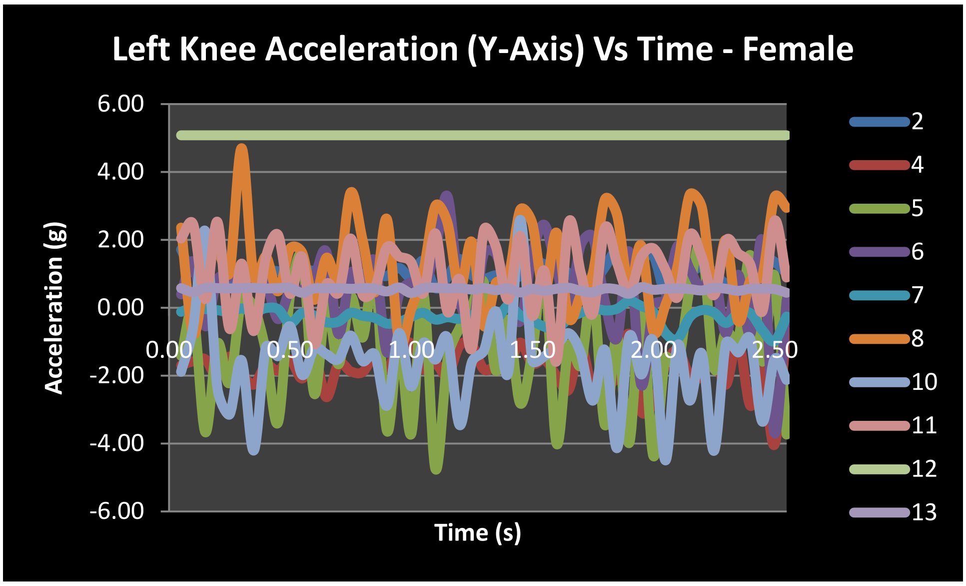



**Male**

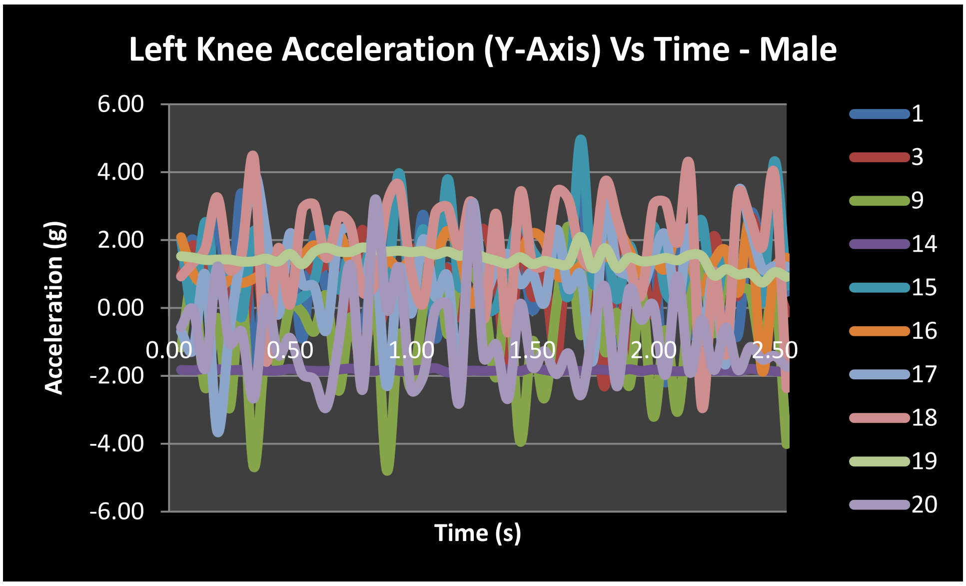


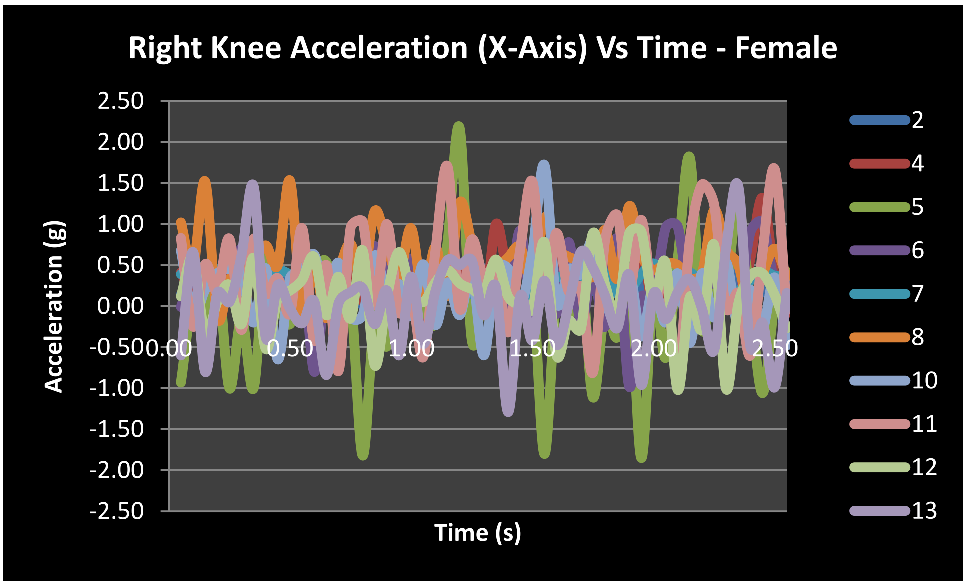
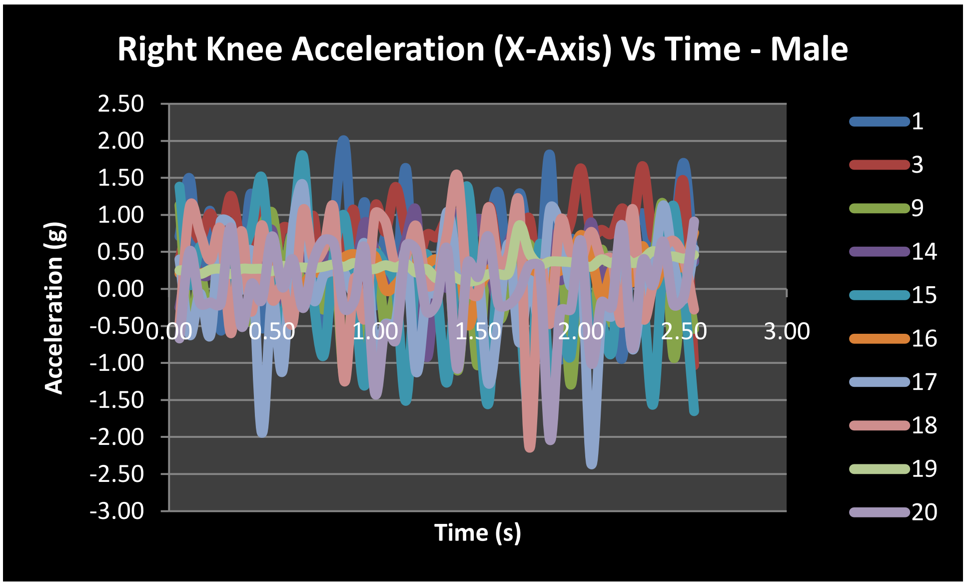
**Y-Axis Acceleration of Left Knee**

**Female**



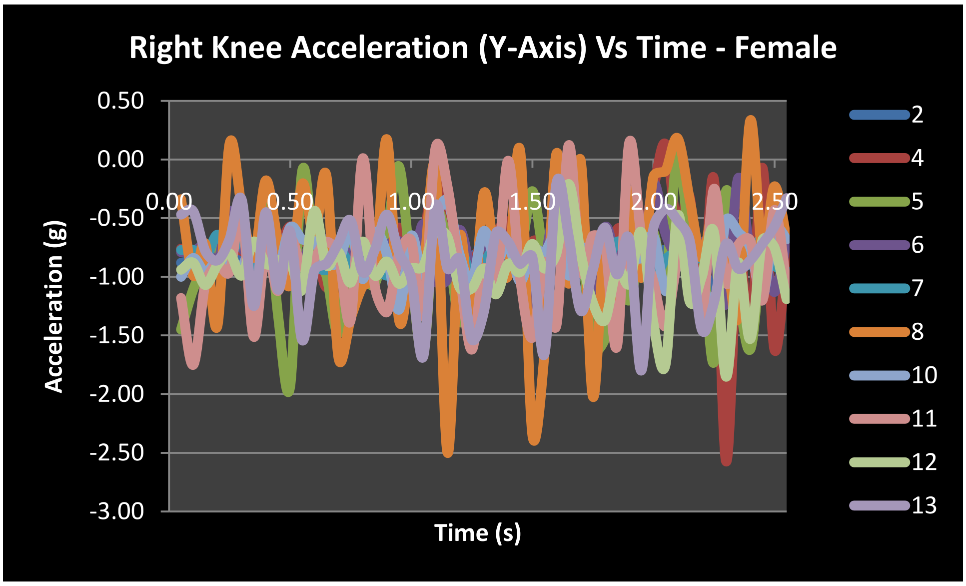

**Male**



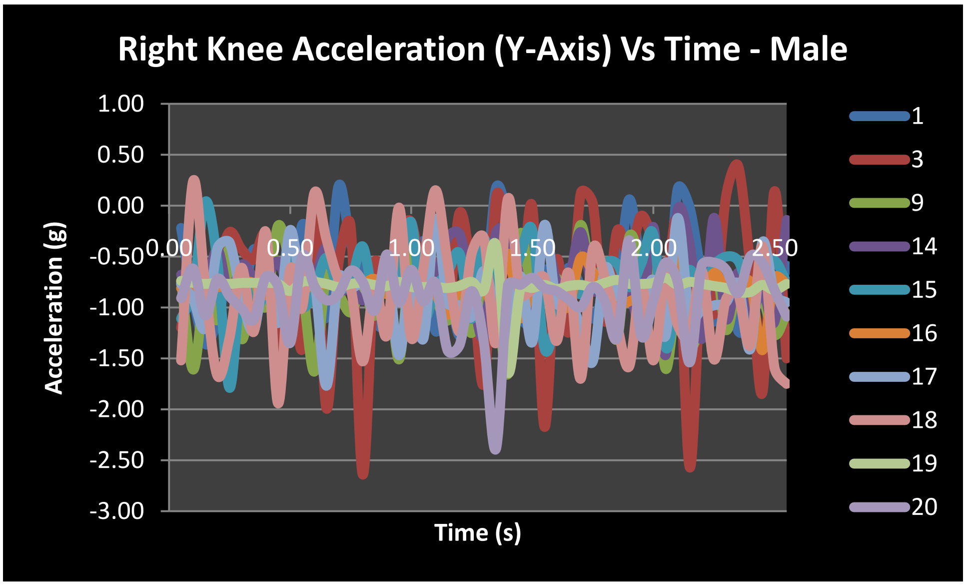
| X-Axis Acceleration of Right Knee |
| --- |
| **Female**<br> |
| **Male**<br> |

**Y-Axis Acceleration of Right Knee**

**Female**

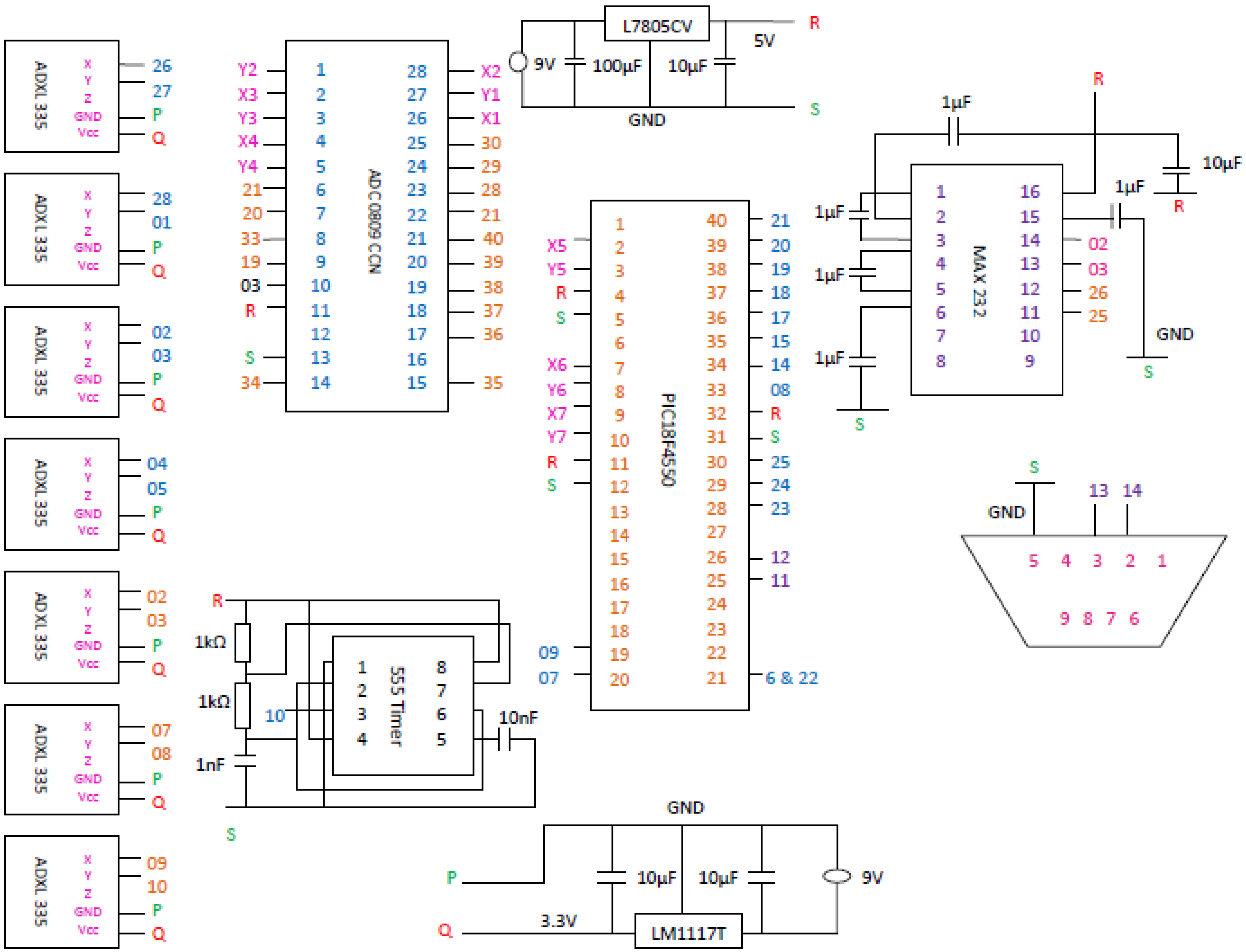



**Male**



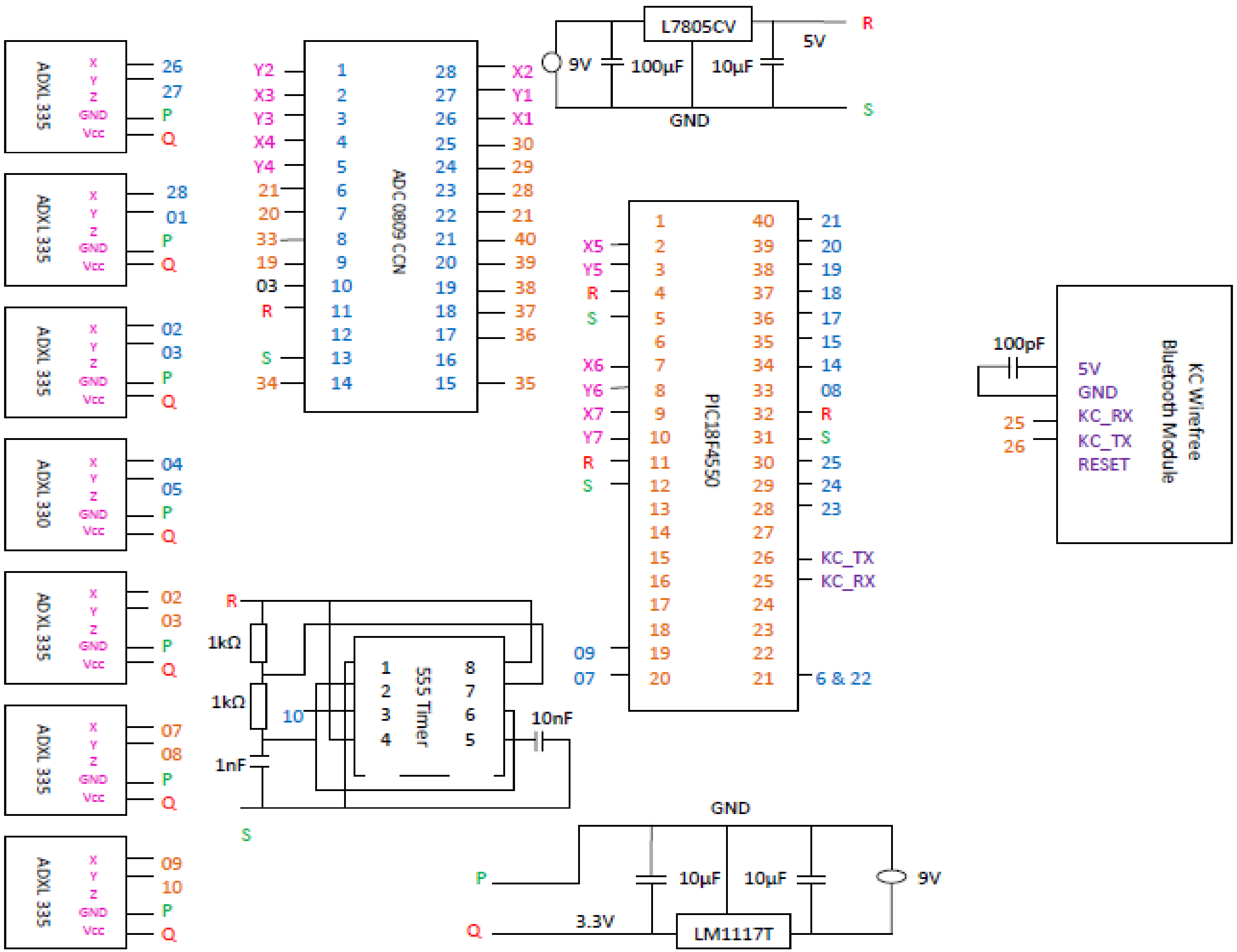
# APPENDIX S:

## Circuit Diagram for Seven Accelerometers with DB9 Connector RS232


ADXL 335
X
Y
Z
GND
Vcc
ADC 0809 CCN
L7805CV
9V
100µF
10µF
5V
GND
PIC18F4550
MAX 232
555 Timer
1kΩ
1nF
10nF
LM1117T
3.3V
6 & 22

# APPENDIX T:

Circuit Diagram for Seven Accelerometers with Bluetooth Module, SKCCA-21



ADXL 335
X
Y
Z
GND
Vcc
26
27
P
Q
28
01
02
03
ADXL 330
04
05
07
08
09
10
ADC 0809 CCN
Y2
X3
Y3
X4
Y4
X2
Y1
X1
L7805CV
9V
100µF
10µF
5V
R
S
GND
PIC18F4550
X5
Y5
X6
Y6
X7
Y7
KC_TX
KC_RX
6 & 22
100pF
5V
GND
KC_RX
KC_TX
RESET
KC Wirefree
Bluetooth Module
1kΩ
1nF
555 Timer
10nF
LM1117T
3.3V
9V