MEASUREMENT OF FINE MOTOR MOVEMENTS OF HANDS IN AID OF FINE MOTOR SKILLS DEVELOPMENT

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Biomedical Engineering

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January 2020

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 **"MEASUREMENT OF FINE MOTOR MOVEMENTS OF HANDS IN AID OF FINE MOTOR SKILLS DEVELOPMENT"** was prepared by **JUSTIN YIP YUEN KIT** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Biomedical Engineering at Universiti Tunku Abdul Rahman.

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ABSTRACT

Providing the most suitable or customised rehabilitation therapy for individual stroke patient is a common challenge to therapists. Most therapies focus on overall gross movements which is not specific enough to aid in full functional recovery of fine motor movements in hands. With the present difficulty, the aim this project is to design and develop a non-invasive wearable device (MSR glove) which can detect electromyography (EMG) signals from hand movements. This was achieved using a wearable device with the presence of electronics such as MyoWare Muscle Sensor, programmable Arduino UNO microcontroller, a Bluetooth module and a mobile app. The placement of sensors was performed on different muscle locations to observe the threshold of signals generated. Data generated was portrayed in the form of EMG can be easily accessed and monitored by the users via PC, laptop or smartphone. The device developed is also able to provide real-time measurements of other parameters such as body temperature, room temperature, skin humidity and muscle movement. Testing performance indicated that this development could provide reliable data on muscle action potential generated by individual finger motions. Subsequently, therapist may use these data as a reference to device treatment plan that targets specific inactive or weak muscles which is responsible for fine motor movements of patients that have been affected neurologically therefore aiding in fine motor skills development.

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LIST OF SYMBOLS / ABBREVIATIONS

°C	degree Celsius
aMSS	active muscle stiffness sensor
ASL	American sign language
CDC	centers for disease control
DALYs	disability adjusted life years
EMG	electromyogram
FES	functional electrical stimulation
FSR	force sensitive resistor
GBD	global burden of disease
LED	light emitting diode
MCO	Movement Control Order
MMG	mechanomyogram
MSR	Muscle Signal Receiver
NMES	neuromuscular electrical stimulation
PPG	photoplethysmogram
TES	therapeutic electrical stimulation
TIA	transient ischemic attack
USB	universal serial bus
WSO	World Stroke Organisation

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

The occurrence of stroke in patients doubles every decade with increasing age. This usually happens to older adults after the age of 55 years old. Adults with ages between 35 to 44 has an incidence of stroke approximately of average 30 to 120 of 100,000 per year while in elderly within the ages of 65 to 74, has a higher probability of stroke with the incidence of 670 to 970 of 100,000 per year (Ovbiagele and Nguyen-Huynh, 2011). In Malaysia, stroke is among the top five leading causes of death among citizens. In addition, stroke also has the greatest burden of disease with reference to disability-adjusted life years (Loo and Gan, 2012). Pathophysiology associated with stroke can be divided into several types of disabilities that include hemiparesis, complete paralysis, problems controlling movement, sensory disturbances, thinking, memory effects and affective disorders (National Institute of Neurological Disorder and Stroke, 2009). Currently, common approaches used to treat patients after experiencing stroke are such as physiotherapy. Physiotherapy can be divided into several approaches based on motor learning, neurophysiology and orthopaedic principles but it would depend on the condition of patient as some may require more than a single approach of treatment to be able to relearn movements to obtain recovery (Pollock *et al.*, 2008).

Besides, other forms of therapy used to treat patients of stroke are speech, occupational and physical therapy. Each of these methods would depend on the affected region of the body due to stroke. For example, speech therapy focuses on aiding patients that have lost their memory or ability to communicate and swallow effectively whereas occupational therapy helps patients to regain their ability to perform daily routines such as dressing up, toileting and bathing. Physical therapy is more towards enhancing strength and mobility of muscle movements to ensure patients have the correct posture, balance, endurance and strength (Sponholz, 2020). When comparison is made between the recovery time of gross motor and fine motor skills, there is no doubt that gross motor skill recovery is much faster as it involves larger muscles of the body to perform movements such as standing or walking whereas fine motor skills require much more coordinated muscle controls which involves smaller muscles to perform activities such as writing (MedlinePlus, 2020). During treatment process, the upper extremities such as the hands are usually a target of focus because movement involving the hands are able to perform much more work. In addition, learning of hand motions are able to strengthen patients' capabilities in fine motor skills hence enable them to be coordinate finger movements more effectively.

The selection of this project is mainly to study the various types of muscles involved in the motion of the palm as well as to improvise a non-invasive method to quantify the activity of fine muscle in the hands of stroke patients. The achievement of this project would enable therapist/medical professional to identify the specific muscle fibres most affected by stroke and thus enabling therapist to customise the most suitable treatment or rehabilitation programme for individual patient.

1.2 Importance of the Study

An action potential, also known as nerve impulse, can be classified as a transient alteration of a voltage across a membrane in an excitable cell which is triggered by the flow of ions into and out of ion channels present in the membrane. These potentials act as signals from the muscles to the brain and vice versa. Presence of action potentials enables movements with coordination and extreme precision. The occurrence of a stroke causes damage to the neuronal pathway depending on its severity which affect the pathway of neural transmission thus causing muscle disability and spasticity (DuBois, 2010).

Learning of action potentials in correspondences to hand motion can definitely aid in better recovery towards stroke patients. This is because when we identify the muscles which exhibit a little or no action potentials, special treatments or exercises can be directed towards that muscle or region with the focus of training to relearn its motion. This study enables the exploration of methods to improve hand motion of stroke patients focusing on the palm. Furthermore, the outcome of this project would be to develop a device which is able to detect action potential of muscles involved in fine motor movement of the hands of stroke patients. When this project is compared with other methods of measurement using invasive sensors and imaging, an advantage this project has is that it is non-invasive thus does not cause any harm to patient. Besides, this device is also mobile and can be home-based thus patients need not to visit healthcare centers to have their muscle activity examined through methods such as electromyogram (EMG). With the data from this device, it would allow therapist/medical professional to identify the specific muscle fibers most affected by stroke and propose the best route of therapy or rehabilitation to help individual patients regain their fine motor functions in the shortest time thus regaining their abilities to perform activities of daily living.

1.3 Problem Statement

Asia Pacific Stroke Conference classified stroke as a major life-threatening neurological disorder as well as a primary cause of disabilities in adults. Different attempts of clinical trials and therapies have been performed by medical personals, but it is still insufficient to provide full functional recovery for fine motor movements from a stroke. Existing methods such as repetition of exercises, rehabilitation therapies and neuroprotection medication has been performed but results shown were not too promising as none of them has been proven useful in aiding towards full functional recovery of an ischemic stroke (Qureshi, 2002). The limitation of these methods is due to the inability to detect and target specific muscles responsible for the movement of fine motor skills. The absence of this knowledge has prolonged rehabilitation therapist and doctors to rely on methods as mentioned above which is time-consuming and requires patient discipline for better results.

1.4 Aim and Objectives

This project aims to study and design a non-invasive or minimally invasive method to quantity the activity (action potential) of fine muscle of hands of stroke patients. With the data attained, therapist/medical professional will be able to identify the specific muscle fibers most affected by stroke (which show least activity or action potential) and customize better therapy regime or rehabilitation program for individual patients.

Three objectives have been set to achieve the aim of this study. The primary objective is to analyze the hand anatomy with focus on kinesiology of the palm. The second objective is to design a wearable device that detects action potentials of muscles during hand motion activity. The third objective towards the performance of this project is to develop a multi-sensor functional monitoring system that can perform measurements linked to smartphones for real-time measurements and monitoring.

1.5 Scope and Limitation of the Study

In this project, a simplified measurement model using sensors to detect muscle movement were used to measure motions of the fingers. The signal data collected were then analysed using programming in the form of electromyogram (EMG). Hence, the scope of this project performs muscular detection and measurement only at the area of the hand without the involvement of other parts of the body. Besides, another limitation is that the testing of device is only done on healthy subjects as stroke patients could not be approached for trial run due to the Movement Control Order (MCO) since March 2020. This study uses a non-invasive method despite it is believed that invasive method can result in higher accuracy. Compared to the conventional electromyogram (EMG) system, the device was developed in a much more simplified design and sensor due to limited resources and time constrains.

1.6 Contribution of the Study

In this project, an assistive device towards measurement of EMG signals was developed and tested in its functionality and limitations. The problems faced during result testing were discussed in this report. The EMG envelope signals collected from individual finger movements were recorded to study the stiffness of the finger. With this, the relationship between the EMG signals collected and the condition of movement while performing finger movements towards fine motor activities could be investigated. In addition, this measurement device would also be able to be used through a smartphone device via Bluetooth connectivity and is able to measure other parameters such as body temperature, humidity, surrounding temperature and muscle signals all at once.

1.7 Outline of the Report

There is a total of five chapters in this report which discusses every stage throughout this project. Chapter 1 presents information on stroke which leads towards the importance of this study and describes the focus of this project. Chapter 2 summarizes the relevant journals and articles to be used to support the ideas of this project which ultimately aids in producing the final product with higher success. Chapter 3 explains on the methodology and work plan which includes software and hardware design of the Muscle Signal Receiver (MSR) Glove Device. Chapter 4 portrays and discusses the results obtained from every component of this project with actual comparison and analysis. Lastly, chapter 5 of this written report concludes the outcome of this project and the recommended possibilities of future work to improve the overall prototype.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

The Secretary General of Asia Pacific Stroke Organization stated that the burden of stroke is enormous in various aspects that results in handicap of bodily functions or incapability of an individual, resulting in impacts towards familial, social and economic status of a person in society (Tay, 2020). According to Holland (2018), stroke can be defined as a condition whereby bleeding occurs in the brain caused by the rupture of blood vessel or when there is an occurrence of blockage in any blood vessels which supply blood to the brain. Blood and oxygen access are inhibited into the brain tissues when this blockage occurs. Hence, it can be said to be an interruption towards blood supply of the brain (Holland, 2018).

A total of three types of stroke has been classified up to this date. Firstly, ischemic stroke, which occurs due to blockage of arteries leading towards the brain. Ischemic stroke is the most common stroke to occur, taking up almost 87% of stroke incidents. The second type of stroke is known as hemorrhagic stroke which is caused by the rupture of blood vessel, causing bleeding and thus blood flows into the brain tissue (Southwestern Medical Centre, 2020). Brain cells are pressurized by the presence of leaked blood causing damages. Hemorrhagic stroke can be classified into two types which are intracerebral haemorrhage and subarachnoid haemorrhage. Intracerebral haemorrhage occurs when an artery in the brain ruptures and floods surrounding tissue with blood. It is also the most common type of hemorrhagic stroke. Subarachnoid haemorrhage rarely occurs but is caused by bleeding within the brain and the thin tissue that surrounds it. The third type of stroke is known as transient ischemic attack (TIA) or sometimes called as “mini-stroke.” This is because unlike the ischemic and hemorrhagic strokes, the blood flow of TIA is blocked temporarily, not longer than a period of 5 minutes. Nevertheless, it is a warning sign of a future stroke (Mozzafarian *et al.*, 2016).

Figure 2.1: Ischemic Stroke. Source: Southwestern Medical Centre (2020)

Figure 2.2: Intracerebral Hemorrhage. Source: Southwestern Medical Centre (2020)

Figure 2.3: Subarachnoid Hemorrhage. Source: Southwestern Medical Centre (2020)

The presence of several risk factors causes an individual to be much more susceptible to stroke. The National Heart, Lung, and Blood Institute states that the higher the risk factors one has, the larger the probability that he/she may get a stroke. Among the risk factors that causes stroke include diet, inactivity, alcohol consumption, tobacco usage, personal background and health history. An unhealthy diet consisting of salt, cholesterol, saturated and trans fats increases the risk of stroke. Inactivity in this context can be defined as the lack of exercise. The Centers for Disease Control (CDC) recommends that adults should perform at least 2.5 hours of aerobic exercise every week through simple activities such as walking or cycling. Alcohol consumption should be controlled as overconsumption leads to the rise of blood pressure levels. In this context, the usage of tobacco also increases the risk for a stroke as it damages blood vessels and heart. Further damages would be caused through smoking due to the rise in blood pressure due to the presence of nicotine in cigarettes. The last two risk factors for stroke which are personal background and health history is much more complex to be controlled. This is because it can be linked to family history, sex, age, race, medical conditions and etc (Holland, 2018).

2.2 Literature Review

2.2.1 Stroke Occurrence

Occurrence of stroke in many countries has been unavoidable and is a major cause of disability and death. In the year of 2016, the World Stroke Organisation (WSO) a total number of 116 million cases related to stroke patients losing their healthy life was reported globally. From the reported cases, about five and a half-million people have died due stroke where 53% of all deaths from stroke are in men and the remaining 47% are women of all ages (World Stroke Organisation, 2019). About 60% of world population is from Asia and stroke is a serious highlight in Asia due to its higher rate of occurrence compared to Western Europe, Australasia and the Americas (Venketasubramanian, 2017).

According to Keats research on stroke occurrence in Malaysia, his article has proven that stroke is among the top five leading causes of death among citizens of Malaysia. In addition, stroke also has the greatest burden of disease with reference to disability-adjusted life years. The primary factor contributing to stroke in Malaysians is due to hypertension and victims of stroke usually have the mean age between 54.5 and 62.6 years. Stroke is the third in rank to affect Malaysians after ischemic heart disease and pneumonia as shown in Table 2.1. Analysis of death reports caused by stroke ranged from 6.6% to 8.4% since the year of 2005 and is expected to increase due to rise of population. Estimation of life expectancies in Malaysia for male is about 72 years old and female up to 76 years old respectively, which accounts for a total average of 5.5 death rate per 1000 population (Loo and Gan, 2012).

Table 2.1: Data Collection of Top Five Causes of Death Among Males and Females in Malaysia. Source: Loo and Gan (2012)

Rank	**Disease**	**Percentage (Male)**	**Percentage (Female)**
1	Ischemic heart disease	16.3%	13.9%
2	Pneumonia	8.9%	9.5%
3	Cerebrovascular disease	7.7%	9.2%
4	Septicemia	5.8%	6.5%
5	Chronic lower respiratory disease	4.6%	2.0%
6	Others	56.7%	58.9%
Total Cases		**17935**	**14808**

Data collection from Venketasubramanian *et al*. (2017) consists of people which originate from South and East of Asia. Their study was performed with the objective to review recent epidemiology of stroke which covers parameters such as age-sex standardized mortality, incidence, prevalence and Disability-Adjusted Life Year (DALYs) lost. The tabulation of data collected consisting of mortality, incidence, prevalence and DALYs lost due to stroke is as follows:

Table 2.2: Data collected consisting of mortality, incidence, prevalence and DALYs lost due to stroke in Asia. Source: Venketasubramanian *et al.* (2017)

Countries	**Age sex standardized mortality /100 000 person-years**	**Incidence /100 000 person-years**	**Prevalence /1000**	**DALYs lost /100 000 people**
South Asia				
Bangladesh	54.8	-	9.4	888.1
India	82.4	119-145	0.84 – 4.24	1420.3
Pakistan	83.3	250	191	1467.2

Sri Lanka	65.4	-	0.1	1073.6
East Asia				
China	126.9	116 - 219	2.6 – 7.2	2101.5
Japan	43.4	422 (Male), 212 (Female)	27.0 (>65 years)	706.6
Korea	77.4	216	15.9	1117.8
Taiwan	56.8	330	19.3	992.1
Mongolia	222.6	326	71.3 (>55 years)	4409.8
South-East Asia				
Indonesia	193.3	-	0.2 - 8.0	3382.2
Malaysia	84.3	67	-	1480.4
Myanmar	165.4	-	-	2971.3
Philippines	109.6	-	9.0	2171.9
Singapore	47.9	180	36.5 (>50 years)	804.2
Thailand	62.8	-	18.8 (>45 years)	1108.1

When mortality is compared within the three regions of Asia, it is generally lower in South Asia and high-income countries in East Asia. The difference in incidents portrays the quality of healthcare and ability of doctors or physicians to combat the severity of the disease. Mortality rate is the lowest in Malaysia (67/100,000 person-years) while the highest rate is observed in Japan (422/100,000 person-years among men and 212/100,000 person-years among women).

Occurrence of stroke reflects balance between incidence and mortality. In other words, a low occurrence shows low incidence or high mortality or both and similarly, a high occurrence is because of high incidence or low mortality or both at the same time. The usage of DALYs lost due to stroke is the best method to analyse the burden of stroke. DALYs rate is the lowest in Japan (706.6 /100,000 people) and Singapore (804.2/100,000 people). DALYs lost tends to have a higher number in low-income countries and lower in more developed countries such as countries in South-East Asia. Thus, from these comparison, we can use to indicate the effects of stroke severity and rehabilitation services (Venketasubramanian *et al.*, 2017).

2.2.2 Effect of Stroke on Motor Control

Stroke in patients commonly causes disabilities in terms of paralysis or difficulties in motor or movement control (National Institute of Neurological Disorders and Stroke, 2009). In this context, motor control can be described as the ability of a person to perform voluntary movements using the direct muscle functions. The term "motor skills" is related to motor control as it is referred to as specific physical movements performed using muscle with precise coordination. Motor control can be classified into gross motor control and fine motor control. The definition of gross motor control refers to motions performed by a large muscle group in the anatomy. On the other hand, fine motor control is classified as the ability of a person to accurately perform precise movements such as writing and typing. Both these motor controls are the integrated output of three different aspects of the human anatomy which are nervous system, muscles and bones. A common effect towards patients suffering from stroke is known as hemiparesis which is the inability of the body to control half a side. This causes difficulties towards the performance of daily activities such as eating, writing, lifting objects and etc (World of Sports Science, 2020).

2.3 Rehabilitation

According to William (2017), rehabilitation can be classified as the aid provision towards a patient that has experienced an injury or disease to recover their lost skills and be independent once again. Rehabilitation can include different types of therapy such as physical, speech, occupational or recreational. Each of these includes many different techniques such as therapeutic exercise, manual therapy, neurological re-education or pain- relief technique and etc.

Stroke rehabilitation is a type of treatment which overcome complications caused due to the damage of brain tissue by aiding patients to relearn their lost skills. Among these skills are such as hand movement coordination to hold, lift and move objects involved in any activity. Rehabilitation also guides patients' on new methods to perform daily task to replace or as an alternative for any residual disabilities such as learning to use only one hand to complete activities such as bathing or dressing or on how to communicate effectively when their ability of speech is compromised (National Institute of Neurological Disorders and Stroke, 2019).

2.3.1 Physical Rehabilitation Therapies

Rehabilitation therapies for stroke are usually performed by physicians and rehabilitation nurses, but some activities may be performed by the patients themselves. The three types of physical rehabilitation currently available are physical therapy, occupational therapy and home-based therapy. Each of these form of rehabilitation serves a different method in aiding towards patient recovery (MedlinePlus, 2020).

Physical therapy for stroke is a type of treatment that focuses towards recovering body strength and movements. The purpose for this therapy is to enable stroke patients to relearn motor activities such as standing, sitting, walking or switching movement from one type to another (National Institute on Aging, 2017). Physicians here usually would analyse the patient's musculoskeletal capabilities before coming with their treatment plan and establish continuous exercise programs which aid stroke patients to relearn the necessary skills. Besides, physical treatments using pain-relieving techniques may combine with exercises which aid patients to build up their strength and range of motion while fighting off existing discomfort during movements. This will greatly help to reduce pain faced by patients in their muscles or joints (Sanchez, 2016).

Occupational therapy focuses more towards improvement of sensory abilities with motor functions to relearn and perform much more coordinated activities. Examples of such activities would include eating, dressing, reading and writing. Occupational therapy comes with the purpose of helping stroke patients to become independent or semi-independent on their own. Therapist here would guide patients to learn suitable self-care methods such as the one-handed method to improve impaired limb coordination as well as to cope for limited range of movements (National Institute on Aging, 2017).

Home-based therapy as the name suggests is a type of rehabilitation that allows patient to perform at home at their convenience. This rehabilitation focuses more towards stroke patients that have discharged from a hospital. In this rehabilitation, therapists come directly to the patient's home to guide patients to work on exercises that can help them strengthen muscles and movement coordination while at the same time retraining healthy brain tissue. Patients can also perform exercises on their own after learning it from therapists. This method of treatment is much convenient as patients need not to travel distances to a hospital or rehabilitation centre for therapy as well as having a much more comfortable environment to perform the activities at their own home (Hoffman, 2016).

2.3.2 Current Rehabilitation Device on Muscle Detection

2.3.2.1 Wearable Arm Rehabilitation Device

Researchers of various institutions and companies started the study and development various design devices and training procedures comprising of advanced technologies which are able to aid patients with disabilities and injuries. In any type of environment, the developed devices are able to be used on patient via attachment of device on the affected human limbs for motion improvement. Systems which are able to provide constant monitoring and requires no supervision is essential towards improving the methods of rehabilitation and to act as a medium that has the ability to portray results of a specific task that could possibly contribute towards the motivation of patients to continue rehabilitation process.

Ambar and his team (2012) designed a wearable arm rehabilitation device which monitors post-stroke patients upon usage during rehabilitation. In the construction of this device, components such as an accelerometer, a flex sensor and two force sensitive resistors were equipped. This enables their device to be closely and neatly designed, light in weight, does not limit or restrict movements upon usage and easy to attach onto the arm with minimal external resistance. In addition, the device consists of its own data logging system which is stored into a computer and the data can be used for diagnosis by therapist or clinicians for further analysis. Being a low-cost device, this system is able to be fully utilized by patients at their home without any needs of supervision from doctors or clinicians (Ambar *et al.*, 2012).

2.3.2.2 Neuromuscular Electrical Stimulation

Kotaro *et al.* (2017) published an article based on a review for equipment implemented in neuromuscular electrical stimulation (NMES) focusing on stroke rehabilitation. NMES is a stimulating equipment which artificially controls the human muscles or muscle nerves. In clinical rehabilitation, NMES is widely implemented for the treatment of stroke cases which causes paralysis to the upper and lower limbs due to the impairment of neuronal pathways from upper motor neurons to lower motor neurons. Analysing into stroke, patients which survive a stroke usually experiences unilateral paralysis or a condition known as hemiparesis. The amount of time required for recovery of motor impairments may take up to weeks and months. Currently, post-stroke recovery is complicated based on factors such as pathophysiology, genetic and clinical factors. Hence, NMES was developed with the purpose of inducing motor recovery through the stimulation of neuromuscular activity of the paretic limbs. The usage of NMES can be further narrowed into two categories which are functional electrical stimulation (FES) and therapeutic electrical stimulation

(TES). FES requires implantation and functions to compensate for voluntary motions. On the other hand, TES does not require implantation and is often applied for muscle strengthening purposes or for recovery of paralysis through the usage of surface electrodes for stimulation (Takeda *et al.*, 2017)

Figure 2.4: NMES Usage via Surface Electrode Attachment.
Source: Takeda *et al.* (2017)

2.3.2.3 Electromyogram

Electromyogram (EMG) can be classified as a test performed to record electrical activities of muscles. An electrical current is produced when muscles are active and the current is equal to the muscular activity. This test is often used on patients experiencing unexplained muscle weakness and as an aid to distinguish muscle conditions due to nerve disorders. In addition, EMG is also be used for determining a level of nerve injury as well as to detect abnormality in electrical activity in a muscle caused by diseases which includes inflammation of muscles, muscular dystrophy, peripheral nerve damage and etc (Shiel, 2016).

Klein *et al.* (2007) implemented EMG into their research for detection of muscular activity known as Cyberglove. They managed to obtain quality data via fingerspelling, an activity that enables the portray of a rich variety of postural transitions. Dynamic movements were mainly focused on, as it is rhythmic and complex. The purpose of rhythmic is for the alignment and scaling of EMG data into discrete segments for analysis while complexity ensures that it will cover a realistic amount of individuation of the finger motions. American Sign Language (ASL) was used to record muscular activity in the EMG. The system comprises of small bipolar silver chloride electrodes that are placed on the skin of hand. The disk centers are placed 10mm apart from each other and the conductive surfaces are 2mm in diameter.

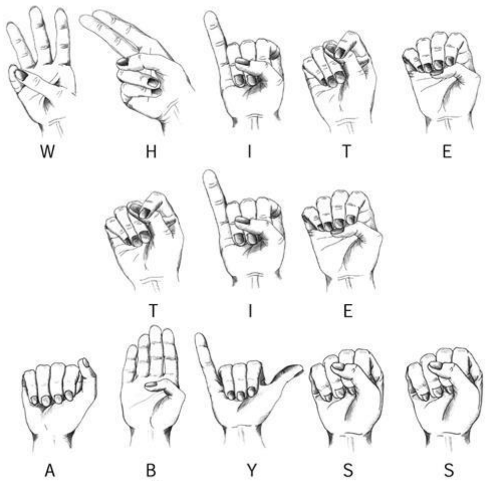


Figure 2.5: Illustration of ASL Using Finger Movements.

Source: Klein *et al.* (2007)

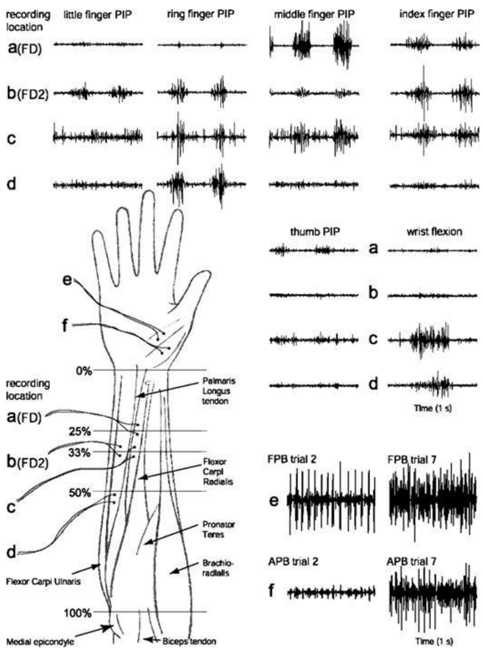


Figure 2.6: EMG Data Collected via ASL Finger Movements.

Source: Klein *et al.* (2007)

Compared to conventional EMG systems, the usage of bipolar silver chloride electrodes is small and closely spaced. Hence, it was assumed the experience of exponential decay for the data recorded during measurement by the electrode was due to the distance in positioning. Data collected from the Cyberglove was used in two methods. Firstly, the checking of words performed were correctly spelled, which means the correct hand shapes were produced, in this case was the word “ABYSS”. The second usage is by pausing after the subject performs each individual letter in order to segment the signals into letter transmissions. The performance of this is illustrated in Figure 2.7 below. A total of 100 normalized samples was performed for each letter transition (Klein *et al.*, 2007).

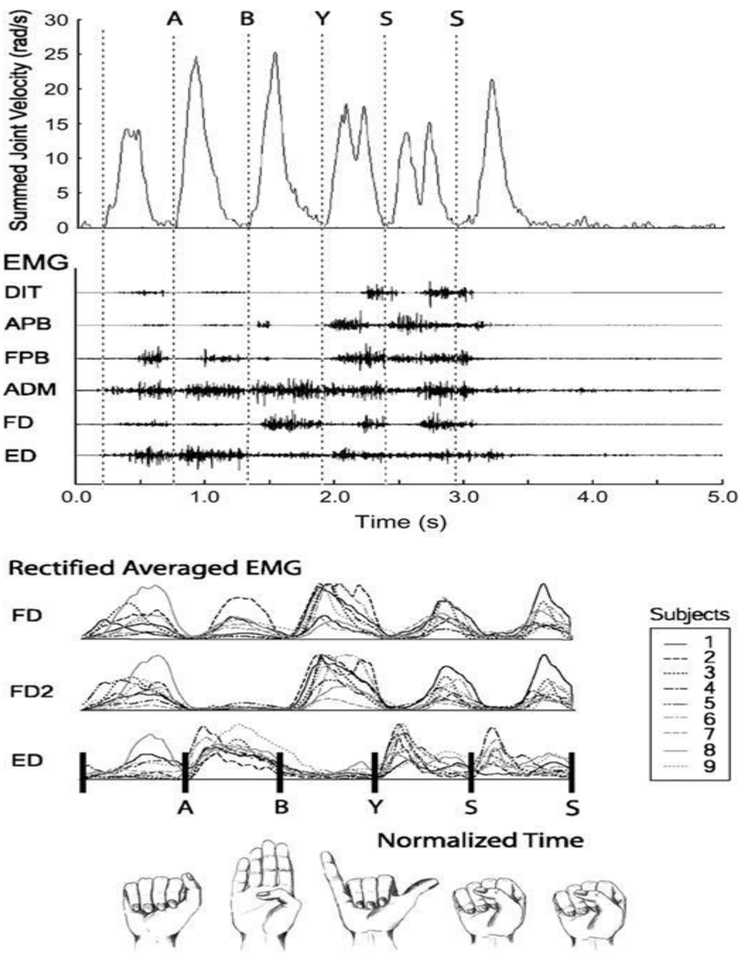


Figure 2.7: Illustration of Data Collected by Cyberglove.

Source: Klein *et al.* (2007)

2.3.2.4 Detection of Muscle Activity with Piezoresistive Sensor and Mechanomyography.

Although electromyography (EMG) is a popular area of interest for biomedical applications for measurement of muscle contraction, it has some drawbacks which includes cost, invasiveness, complexity and compatibility. Esposito *et al.* (2018) devised another alternative towards the measurement of muscle activities which occurs during contraction whereby its mechanical variations are monitored through the usage of simple and non-invasive sensor based on force-sensitive resistor (FSR) capable for measurements of muscular contractions. This method detects muscle activity with piezoresistive sensor and mechanomyography in terms of the exertion of mechanical force by underlying contracting muscles. FSR creep causes an output drift which can be conditioned through the setting of a constant voltage across the FSR which generates a voltage output proportional to the force. Furthermore, this sensor has an additional feature that enables it to detect mechanomyogram (MMG), which is the occurrence of soft or small vibration during muscle contraction.

In general, FSR is a type of conductive polymer which is able to change its resistance during the detection of a force. The sensor is relatively low in cost and can be made small in size but able to provide resistance towards shock and operate in hostile environments. However, FSR can only detect a concentrated and uniformly distributed force for a much more reliable data. Placement of sensor should be on the surface of patient’s skin. During operation, the dome creates little subsidence that firmly holds onto the surface of skin. The back of the sensor is attached with a rigid plastic to avoid improper bending. A mechanical coupler is present to provide accurate and reliable muscle force transmission towards the FSR (Esposito *et al*.,2018).

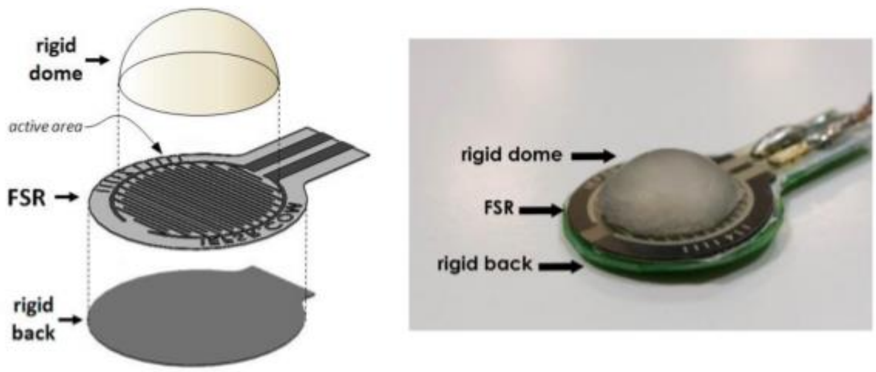


Figure 2.8: Detailed View of FSR sensor. Source: Esposito *et al.* (2018)

MMG is a type of test which functions to record muscle vibrations that an active muscle is said to generate. This feature is useful as it is able to monitor muscle stiffness and muscle force exertion. Presence of active motor units would affect the amplitude of the MMG signal depending on their numbers. Sensors which are able to detect MMG signals are such as piezoelectric sensors, accelerometers and laser distance sensors which is positioned on individual's skin (Esposito *et al.*, 2018).

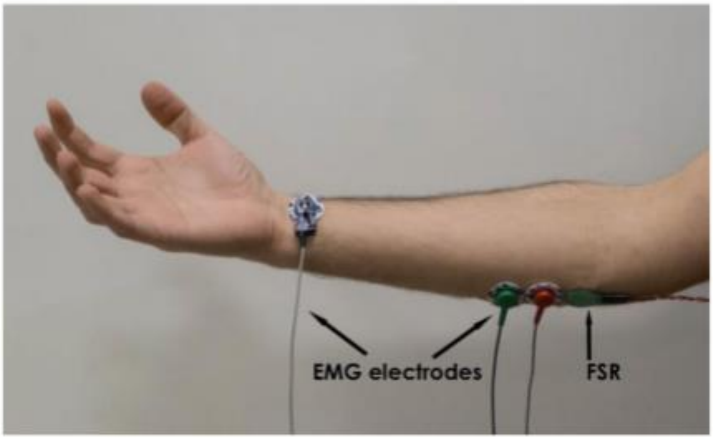


Figure 2.9: Placement of EMG Electrodes and FSR Sensor.
Source: Esposito *et al.* (2018)

2.3.2.5 Devices for Detection of Muscular Contraction

With the latest advancements of sensors, muscular contractions are able to be analysed using numerous numbers of methods. Among these sensors currently available are such as strain gauges, muscle circumference sensor, ultrasound scanners, resonance-based active muscle stiffness sensor (aMSS) and optical sensors.

Strain gauge is a type of sensor which is able to alter its resistance based on the amount of applied force. It is capable of converting measurements of force, pressure, weight and etc. into impedance which can be recorded. This can be applied in muscular contraction which causes direct stretching of the sensor (Woodford, 2019). Muscle circumference sensor is used to detect internal muscle activity. This sensor is placed at the changing cross-sectional area of muscle which is proportional to muscular contraction.

Ultrasound scanners via the usage of ultrasound probes function to evaluate morphological changes during muscle movements by analysing muscle thickness and displacement. Besides, another sensor currently available is known as resonance-based active-muscle stiffness sensor (aMSS) which is a special sensor that operates through the usage of piezoelectric probes built specifically to test and measure muscle stiffness. An advantage towards aMSS usage is that it is able to measure muscle contractions through clothing and its method of operation does not necessary require direct contact with the skin (Han and Kim, 2013).

Optical sensors with the combination of LEDs and photodiodes function to detect muscular contractions through the measurement of backscattered light from the muscle tissue (Woodford, 2019).

2.3.2.6 Multiple EMG Positions to Detect Finger Movement

Junlasat *et al.* (2019) implemented the MyoWare muscle sensor which is able to obtain data of EMG signals. Their published paper represents data collected from finger movements based on multiple EMG positions that are then processed in a low computational processing unit. During testing of their prototype, a healthy volunteer not having any problems involving muscles and nerve in the forearm was selected. While performing data measurements, the volunteer was in a relaxed state while sitting on an insulated seat to ensure the absence of metals and conductors which may cause error in data collection. A total of three EMG Foam Solid Gel Electrodes were placed on the volunteer's arm and collected to the MyoWare Muscle Sensor for measurement of voltage generated by the muscles when muscular activity is present. This sensor comprises of a middle muscle electrode and an end muscle electrode for voltage detection and a reference electrode which is used as a reference voltage from the volunteer.

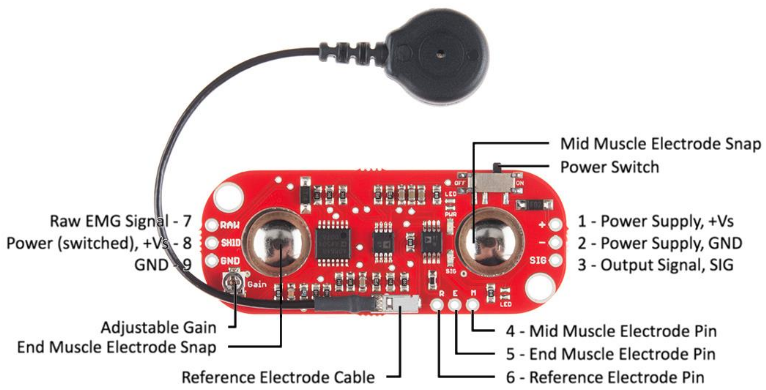


Figure 2.10: Illustration of MyoWare Muscle Sensor. Source: Brent (2020)

EMG signals obtained from the sensor were then processed by an open-source microcontroller board known as Arduino UNO via Jumper. Various patterns of finger movements are performed, each having their EMG signals recorded and processed afterwards. Five positions are selected for the attachment of electrodes mainly on the superficial flexors of the forearm. Studies of up to 100 positions was performed but it was concluded that only these 5 positions as illustrated below are the best for the detection of finger movements.

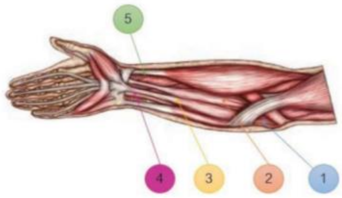


Figure 2.11: EMG Sensor Attachment Positions. Source: Junlasat *et al.*, (2019)

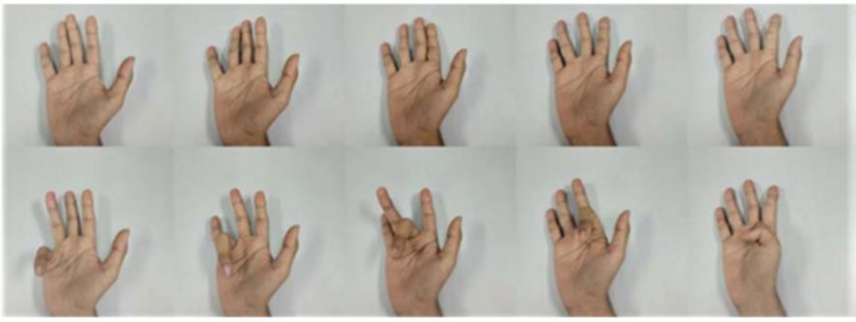


Figure 2.12: Finger Movement Pattern Tested. Source: Junlasat *et al.*, (2019)

The EMG signals generated were then processed using MATLAB programming which shows maximum and average values between 1 – 160 milliseconds. The graphical EMG data was then tabulated with Peak to Average, Increasing/Decreasing and Overall Judging Criteria in response of the analysis between EMG positions and finger movement. This hence enables their device to find and detect movement of each finger through the aid of this MyoWare sensor (Junlasat *et al.*, 2019).

Table 2.3: Response Analysis Between Various Finger Movement. Source: Junlasat *et al.*, (2019)

Data Type	Peak to Average					Increasing and Decreasing					Overall Judging Criteria				
Finger Movement	Little	Ring	Middle	Index	Thumb	Little	Ring	Middle	Index	Thumb	Little	Ring	Middle	Index	Thumb
Position 1	No	No	Yes	No	No	Yes	Yes	Yes	Yes	No	No	No	Yes	No	No
Position 2	No	Yes	No	No	No	No	Yes	No	No	No	No	Yes	No	No	No
Position 3	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Position 4	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No
Position 5	No	No	Yes	No	Yes	No	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes

2.3.2.7 Types of EMG Signals

Action potentials which are generated by muscles and motor units can be collected using EMG electrodes which are capable of detecting these signals generated which it is placed on. The sensitivity of EMG detection by electrodes can be affected by various factors which are classified as intrinsic and extrinsic factors. Intrinsic factors are differences which occur in the muscle such as the physiological, anatomical and biochemical characteristics of the muscle. Due to different individual having different types of muscular characteristics such as muscle fiber diameter, number of active motor units and distance between active fibers between the electrode placement and the muscle, any result collected will show slight dissimilarity as these factors could vary among different individuals, between days within an individual and within a day in an individual if the electrode was interrupted.

On the other hand, extrinsic factors are influenced by the experimenter such as electrode configuration, electrode placement, location of muscle and its orientation, skin impedance, perspiration and temperature. Hence, with the presence of various factors which could affect the data collection of EMG signal, the voltage recorded would be difficult to describe if there is an absence of reference value to perform comparison. Interpretation of amplitude of raw EMG signal is required through a process known as normalization which can be defined as the process of converting a signal to a scale relative to a known and repeatable value (Reaz *et al*, 2006).

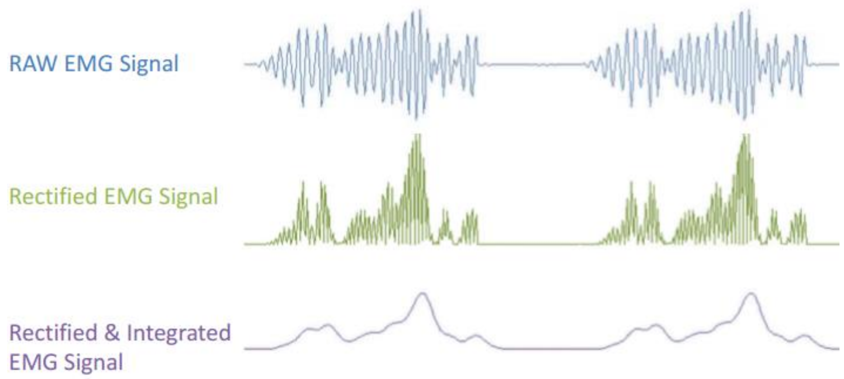


Figure 2.13: Types of EMG Signal. Source: armMBED (2020)

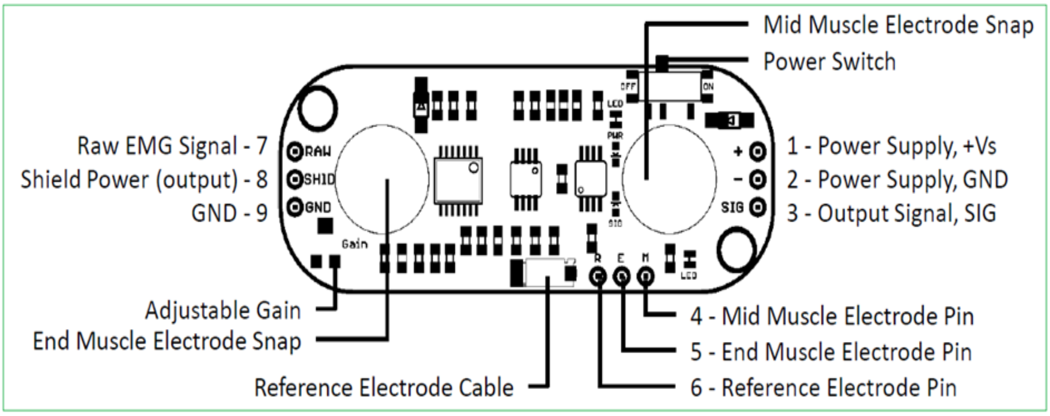


Figure 2.14:Detailed Representation of MyoWare Muscle Sensor.
Source: armMBED (2020)

The MyoWare Muscle Sensor is designed in such a way that it can be used in various types of wearable devices that comes in contact with the human body. There is a total of three electrodes present where two of it are EMG surface electrodes and one reference electrode which is used to obtain EMG signals from muscle movements. For example, placement of the electrode can be applied onto the bicep muscle of the hand where the two EMG surface electrodes are in contact with it while having the reference electrode placed on a bony part of the wrist to act as a ground or reference for the circuit (Novak, 2011). The presence of reference electrode to be placed on a non-adjacent muscle is crucial to obtain a much clearer and accurate signal (Cochrane et al., 2016).

There are several factors to be taken into consideration while operating with this muscle sensor such as electrode placements, muscle size and skin moisture as it could affect the accuracy of reading. Orientation of electrode also affects the strength of signal and thus for this case, the best placement of electrode should be directly in the middle of the muscle and aligned with the alignment of muscle fiber for the best and accurate reading. The reason behind this placement is that motor units are greater in numbers in the centre of the muscle.

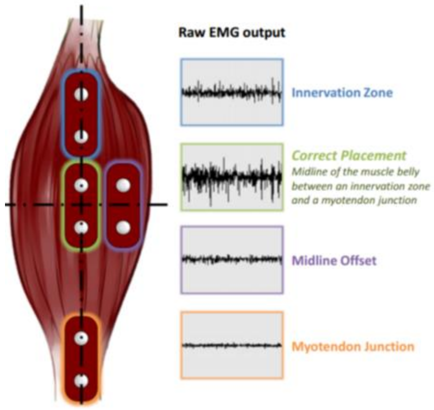


Figure 2.15: Signal Received by Electrodes at Different Position of Muscle.
Source: Advancer Technologies (2015)

Cochrane *et al.* (2016) performed an expriment using this sensor to determine the best location for the placement of reference electrode in the hand. The MyoWare muscle sensor was placed on two different locations which is in the inner elbow (Figure 2.16) and the inner forearm (Figure 2.17). From the data collected, it was concluded that the reference electrode that was placed on the inner elbow was much more readable and distinguishable when the signals are compared with the one placed at the inner forearm. Thus, placement of reference electrode of the muscle sensor should be at inner elbow.

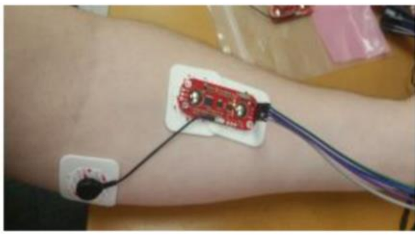


Figure 2.16: Position of Reference Electrode on Inner Elbow.
Source: Cochrane *et al.* (2016)

Figure 2.17: Position of Reference Electrode on Inner Forearm.
Source: Cochrane *et al.* (2016)

2.4 Human Hand Anatomy

2.4.1 Bone Anatomy of Hand

Bones are framework of the body that allows movement while providing support and protection for muscles and soft internal organs. The skeletal anatomy of the hand, is classified under the appendicular skeleton and is connected to the pelvic girdle, consisting of humerus, radius, ulna and phalanges (McMillan, 2012). The wrist and hand are constructed by a total of 27 bones. The wrist contains eight small bones known as carpals (proximal). The palm of the hand is constructed by five metacarpals which connects to the carpals. Each finger is connected by one metacarpal. Small bone shafts known as phalanges (distal) connects in a line to form each finger (Oliver, 2019).

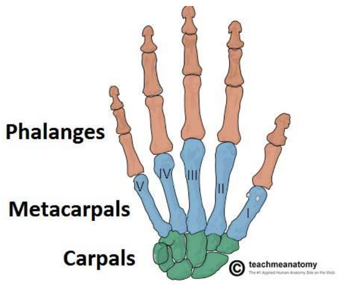


Figure 2.18: Bone Anatomy of the Hand. Source: Oliver (2018)

2.4.2 Nerve Anatomy of Hand

The nerve system of the arm consists of three major nerves which are known as the median, radial and ulna nerves. These nerves function to control the muscles of the forearm and hand as well as provides sensational feel such as touch, pain and temperature (McMillan, 2012). The median nerve functions to control muscles needed for coordination of precise hand movements. The ulnar nerve is the second type of nerve present in the palm. It functions to provide sensation on the palm as well as enables grasping motion. The third nerve connecting to the palm is classified as radial nerve. This nerve functions to control the hand’s ability to extend its wrist and have a complete control of hand positioning (Summit Orthopedics., 2015). When nerve cells present in the brain becomes injured due to stroke, the nerve cells lose the ability to communicate with other cells leading towards impairment of bodily functions (Cleveland Clinic, 2018).

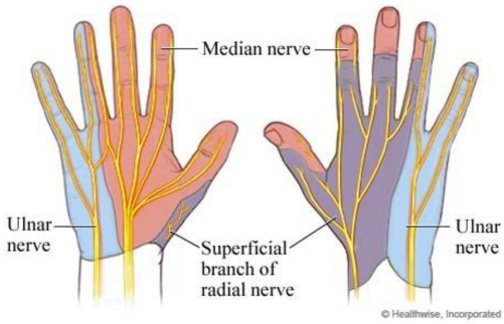


Figure 2.19: Region of the Palm Controlled by Responsible Nerves.

Source: Degamo (2020)

2.4.3 Muscle Anatomy of Hand

The muscular structure of the hand comprises of two groups which are extrinsic and intrinsic muscles. The main function of extrinsic muscles is to control crude movements and to enable gripping force while intrinsic muscles functions to enable the hand to perform fine motor functions. Intrinsic muscles located in hand includes thenar muscles, hypothenar muscles and lumbricals. Thenar muscles enables the thumb to move closely to the palm (adduction) of the hand which is crucial for gripping as well as enables flexing of the metacarpophalangeal (MCP) joint at the thumb area (Healthline, 2014). Hypothenar muscles produce muscular protrusion on the medial side of the palm which is located near the little finger around its base area and it is commonly known as hypothenar eminence. These muscles contribute towards the motion of our little finger and the mound-like structure at the palmar side of the hand (Nguyen, 2019).

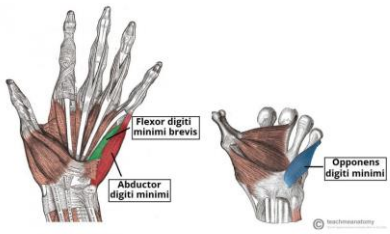


Figure 2.20: Superficial and Deep Layer View of the Hypothenar Muscles.

Source: Oliver (2018)

Lumbrical muscles comprises of four short muscles each located in the metacarpus deep to the palmar fascia. These muscles are unique as it does not attach to bones but rather to tendon sheets that originates from the flexor digitorum profundus. Lumbricals enables flexing motion and extension of fingers in which these actions are similar to the toes. Nevertheless, lumbricals only perform movements from the second to the fifth finger. The combination of both flexion and extension of lumbrical muscles enables the support of a strong hand grip (Bengochea, 2020).

Figure 2.21: Structure of Lumbrical Muscles Attached in the Palm.
Source: Bhimji (2020)

2.5 Basic Motions of Hand Kinesiology

Pronation is defined as a motion of rotation by the forearm. During this motion, palm of the hand faces a posterior direction while observing in anatomic position. Supination can be described as the turning motion of the palm anteriorly. The usage of both these motions enables movements such as grasping and holding of objects in the palm. Thus, we can classify pronation as turning the palm to face downward while supination is the opposite which is to turn the palm of the hand upwards (Mansfield and Neumann, 2019).

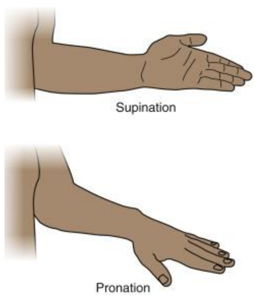


Figure 2.22: Illustration of Supination and Pronation. Source: Mansfield and Neumann (2019)

Another hand motion which bends and contracts the hand upward causing the palm to be pulled towards the individual is known as dorsiflexion. This enables extension of the hand at the wrist. Dorsiflexion can also be performed at the fingers which is usually referred towards the wrist. This motion occurs when the wrist joint back is flexed toward the lower arm which can be performed by the extension of arm and hand in front of the individual. On the other hand, palmar flexion is the downward movement of the hand which relaxes the hand. This movement usually faces the palm towards the arm (Cronkleton, 2017).

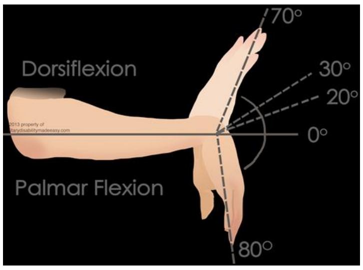


Figure 2.23: Illustration of Dorsiflexion and Palmar Flexion. Source: Biking (2018)

Adduction is defined as a motion which pulls any body parts that are outwards from the middle line of the body. For fingers, if an individual has his fingers widely spread, closing and contact them towards each other would be described as a motion of adduction. An adduction of the wrist occurs when the hand is moved towards the body when the arm is at the individual's side. This is known as ulnar deviation and the muscles which are responsible for this motion are known as adductors. Abduction is the reverse towards adduction as it spreads the fingers away from the middle line of the hand. Wrist abduction occurs when the hand is moved away from the body at the wrist when the arm is positioned at the individual's side. This is known as radial deviation and the muscles responsible for these actions are called abductors (Mraz, 2014).

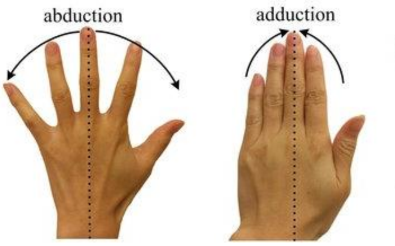


Figure 2.24: Illustration of Abduction and Adduction. Source: Wang (2017)

2.6 Summary

This literature review explores the past research works done and developments by various researchers towards stroke occurrence, measurements of muscle activities, engineering designs with applications of sensors and EMG on muscle activity detection and the human hand focusing on the palm anatomy. From the data collection of stroke occurrence, it is undeniable that the numbers increase every year due to rise of population. This hence lead engineers, researchers and inventors to develop new solutions of development towards aiding post-stoke patients to identify their muscle activity which enables clinicians or doctors to help provide the suitable course of treatment. From the works reported, it was seen that EMG was mostly utilized to provide readings of muscle activity. With this concept in mind and with the study of the human hand anatomy which focuses mainly on the palm, it can definitely serve as a driving force of this project towards the development of a device which is able to measure muscular activities during the performance of fine motor skills.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

Before constructing the actual prototype, planning was necessary to achieve the project's aim and objectives within the given constraints of time. The planning process includes material selection, cost estimation, conceptual design and a work plan. This process helps to avoid future complications while producing the prototype, which means every step and detail should be well prepared and understood to ensure the project runs smoothly. In this chapter, coverage on project milestone planning, background research, material planning and acquisition, the cost estimation of the selected materials and conceptual design of prototype was performed.

3.2 Project Task and Activities

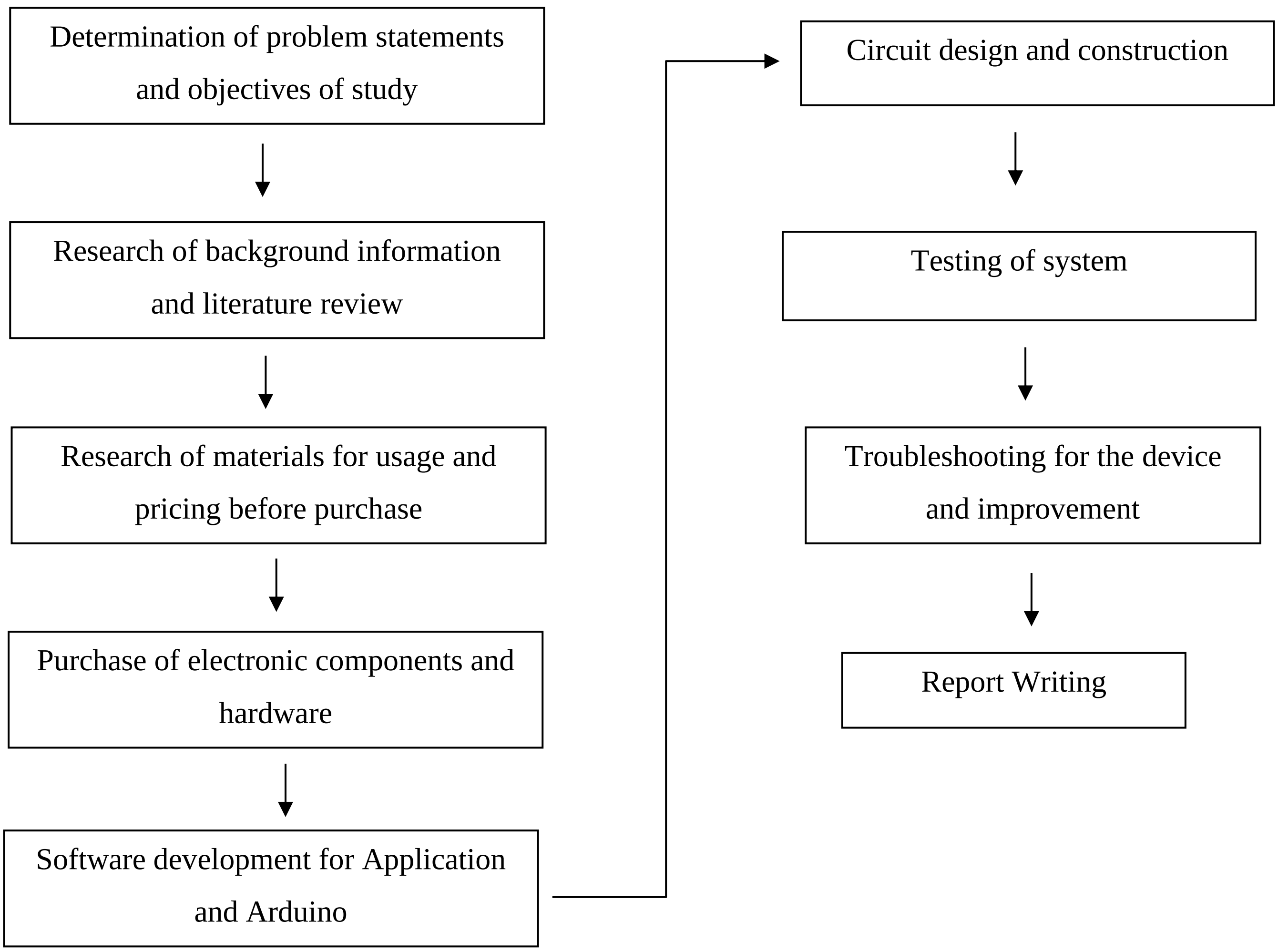
3.2.1 Gantt Chart (FYP Part 1)

Project Activities	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Identification of problem statement and objectives.														
Data gathering of articles in relation to title and writing for literature review and methodology														
Proposal of development system														
Report Writing and Preliminary Testing														

3.2.2 Gantt Chart (FYP Part 2)

Project Activities	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Software Writing to Interface with Muscle Sensor and Preparation of Circuitry for Muscle Sensor														
Preliminary Testing of Muscle Sensor on Detection of EMG signals														
Modification and Troubleshooting of Sensors in Data Collection														
Report Writing														

3.2.3 Flow Chart for Project Methodology



3.2.4 Material Selection

A muscle sensor known as the MyoWare Muscle Sensor was used in this development with the purpose of measuring electrical activities of a muscle. The generation of electrical signals from muscle activity was then converted into an analog output signal which is read by a microcontroller in this case, an Arduino UNO. When attached on a muscle, the sensor's output voltage increases when the target muscle group flexes. An on-board gain potentiometer was present to fine-tune the relationship between output voltage and muscle activity. Electrodes used to aid in measurement of the EMG levels are Biomedical Sensor Pads which are a type of disposable electrodes. These little pads are suitable for short-term monitoring of neurofeedback and biofeedback purposes. Each pad used was able to adhere well to the skin without the presence of liquid agent or electrode gel thus preventing risk of allergies or discomfort as well as ease the electrode lead to be pushed or removed without any issues.

An LM35 body temperature sensor was used together with this device in order to obtain body temperatures of the subject during the time of use. This sensor is capable of measuring body temperature when in contact with the skin and the results are displayed in Fahrenheit which will be converted into Celsius using software coding. In addition, a DHT11 temperature and humidity sensor was included in the hardware design in order to detect surrounding temperature and the skin humidity of the user. This is essential as an increase in humidity via sweat can cause disruption in measurements and therefore the presence of this sensor can act as a safety precaution of the device.

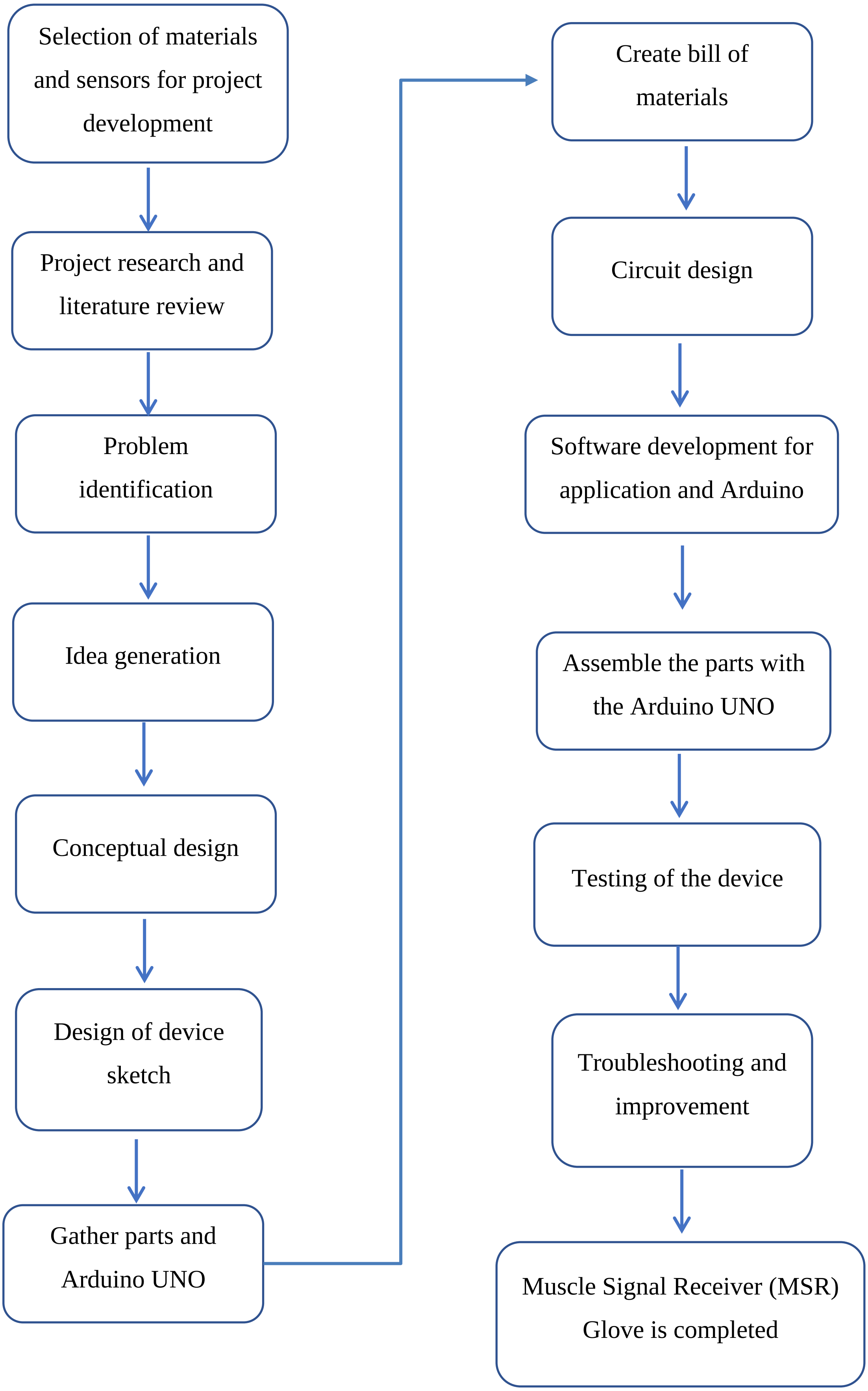
HC-05 Bluetooth Module was programmed with the Arduino UNO microcontroller board to be used for establishing connections with any smartphone device in order to observe real-time measurements recorded by the system. The reason for this selection was due to its low cost and its small size for convenience. However, a limitation to this Bluetooth module is that the receiving signal would decrease as with increasing distances. Therefore, caretakers of the patient cannot be too far and should be within the range of 10 meters for intake of best results.

A subsystem used for the development of this project is an electronic component known as the Arduino Uno R3. Arduino is a microcontroller board that consists of 14 digital input/output pins, 6 analogue inputs, a 16 MHz quartz crystal, a USB connection, a reset button, a power jack and an ICSP header. All these components serve to support a microcontroller (Arduino, 2019). The Arduino UNO uses its own specific language known as the Arduino Language for programming. Hence, to programme the device, the usage of multiple libraries is included in order to operate the various components such as electrodes and temperature sensors as well as the heart rate pulse detector. Specifications for the Arduino Uno used is tabulated in Table 3.1 as follows:

Table 3.1: Specifications for the Arduino Uno Used. Source: Arduino (2019)

Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	20V
Digital I/O Pins	14
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	20 mA
Flash Memory	32 KB (ATmega328P)
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
Clock Speed	16 MHz
Length	68.0 mm
Width	53.4
Weight	25 g

3.3 Project Planning (Flow Chart)



3.4 Conceptual Design

On the first phase of project, the idea of designing a device for the measurement of fine motor movements of hands in aid of fine motor skills development portrays a similar concept towards an electromyography (EMG) system but is more simplified and focused towards patients recovering from stroke. The device would include various sensors such as the MyoWare muscle sensor, LM35 body temperature sensor and DHT11 humidity and temperature sensor. After the sensors acquired the data respectively, all the data will go across a set of algorithms to process the raw data and the final data will be displayed on a screen. This feature enables the user and the person monitoring to analyze muscular activity when the patient performs finger movement to test for the muscle's activeness. Direct placement of sensor would be tested on 5 different positions as illustrated in Figure 3.1 and a single built-in snap connector for electrodes is available on the sensor itself.

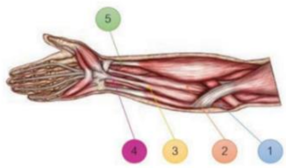


Figure 3.1: Five Positions Selected for Sensor Attachment. Source: Junlasat *et al.*, (2019)

The components require a sort of control and power up in order to fully function, hence a microcontroller was used. On the other hand, choosing the right microcontroller was essential for the whole project. This is because the selection of a bad or wrong microcontroller would affect the device performance, functionality and also the relation between components and microcontroller. On the other hand, different microcontrollers have different programming languages to program and control. For the programming language, Arduino IDE will be used as it is the main language for controlling the Arduino UNO and is much beginner friendly. Application of other programming languages such as python and C++ will not be a good choice here as it requires more time for learning and the usage of harder languages would affect the progress of project. This is because it is time consuming as a deeper understanding of the command languages are required. Due to all those reasons, it shows apparently that relatively simple program language, suitable storage capacity as well as processing speed of a microcontroller would be the best choice of the device, thus Arduino UNO microcontroller board was introduced in the project because it matches the requirements as stated above for data transmission (Figure 3.2).

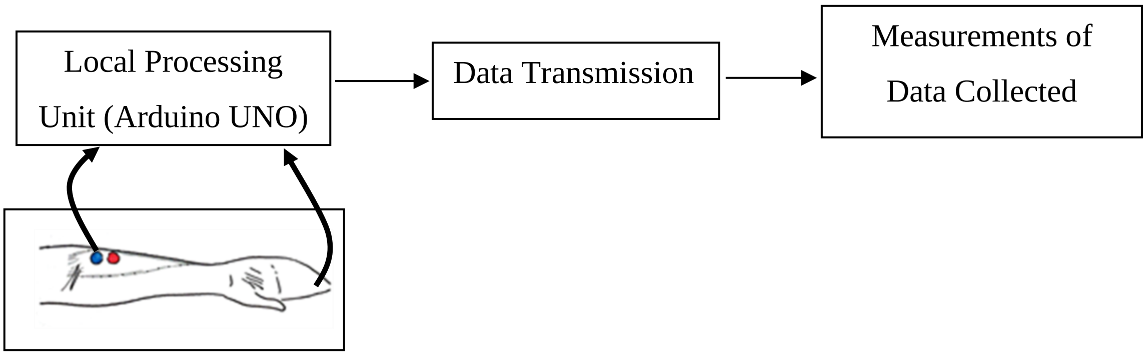


Figure 3.2: Schematic flow of data collection by sensors and Arduino.

In addition, the device was further modified using various sensors such as body temperature sensor (LM35) and humidity and temperature sensor (DHT11). After data was acquired by the sensors, all of the data undergoes a set of algorithms in order to process the raw data and the final data produced will be sent through Bluetooth then received by the smartphone. This feature enables the user or their respective caretakers to monitor patient condition at any corner of the house with minimal disturbances to the patient. In order to achieve this, a mobile application was created via coding in order to establish Bluetooth connection with the module. This application was designed in a way which notifies the user if parameters of data obtained was out of the normal range.

Furthermore, the device was planned to have a casing in order to protect all its circuitry. The muscle sensor will be placed at the forearm location of the glove while the temperature sensor will be placed at the palm of the glove. The DHT 11 sensor will be positioned near to the muscle sensor for detection. This means that these three sensors will not be inside the casing but connected externally with wires. The components that are placed in the casing are Bluetooth module and Arduino UNO microcontroller.

3.5 Cost Estimation

Before purchasing the materials needed for this project, a survey was made among various online shopping websites to get the lowest price with the same quality. For the purchase of MyoWare Muscle Sensor, price comparison was compared between multiple online stores before purchase at a price of RM252.04. Disposable biomedical sensor pads (10 units) were also purchased through online shopping at the price of RM46.50. These sensor pads were used as an adhesive source towards the muscle sensor and subject skin during data collection.

An Arduino microcontroller board was chosen for this project compared to other boards such as Raspberry Pi was due to Arduino UNO being much more beginner friendly. The Arduino UNO can also be powered using batteries unlike the Raspberry Pi which requires more power. A few other minor components such as jumper wires, headers and precision screw were purchased from physical visits in local stores. Table 3.2 below shows the material cost for each material purchased for usage in this project.

Table 3.2: Table for Material Cost.

Arduino Uno	RM42.90
Jumper Wire	RM18.36
Header Single Row L-Type 1X40	RM1.80
Biomedical Sensor Pad (10 units)	RM46.50
MyoWare Muscle Sensor	RM 252.04
6pcs Precision Screwdriver Set	RM6.50
TOTAL	**RM368.10**

3.6 Device Design for Measurement of EMG Signals and Other Measurements

The overall design of this project focuses towards designing a non-invasive method of measuring muscular signals by using a sensor known as MyoWare Muscle Sensor which is able to detect EMG signals from muscles. The sensor was stitched on to a glove which covers from the palm up to the elbow of the hand. Other sensors were also included but the primary focus was directed towards collection of muscle signals. The LM35 body temperature sensor was positioned near the palm whereas the DHT11 was stitched beside the muscle sensor.

3.6.1 Glove Selection and Design

For glove selection, a satin glove as shown in Figure 3.3 was selected for the designing of this project due to its long length which is able to cover up to the length of the elbow. The material is made of tightly woven polyester and nylon which provides comfort to users. In addition, it can be easily cleaned thus oil, smudges, dust and dirt can be easily wiped off maintaining the surface clean and safe. It is also tight fit which means that it firmly covers the hand which enables sensors to be held with much more grasp onto the surface of the skin by the material.

Figure 3.3: Image of Glove Used for Attachment of Sensors.

3.6.2 Circuit Design

A programmable microcontroller known as the Arduino UNO was used in the design of circuitry. The Arduino comprises of 14 digital pins which starts from 0 to 13 and 6 analog pins starting from A0 to A5. Both the digital and analog pins have their own function but, in this context, the analog pins were used due to its ability to read analog voltages and converts them into digital values for analysis which is also known as analog to digital converter. The muscle sensor was connected into one of the analog pins as an input which send information and data to the Arduino that can be analysed using the program. A schematic layout of the MyoWare muscle sensor attached with the microcontroller is shown in Figure 3.4 below.

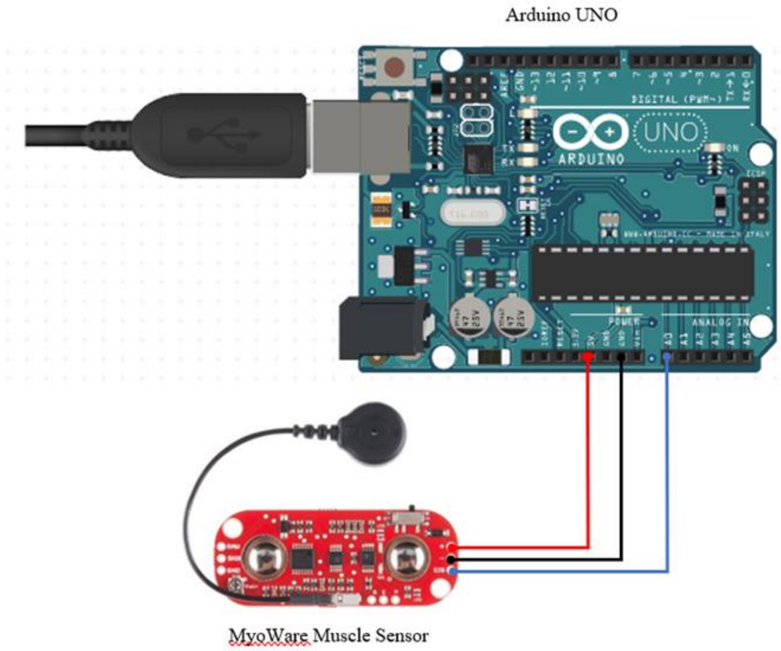


Figure 3.4: MyoWare Muscle Sensor Attached to the Microcontroller.

3.6.3 Software Coding

3.6.3.1 Coding to Interact Specifically Towards Muscle Sensor for Data Collection

In this project, the device was planned to have the capability to operate two different ways which are firstly only specifically to the muscle sensor for only EMG signal collection and secondly to the entire monitoring system. The setup of MyoWare Muscle Sensor was program written using manual algorithms without the presence of libraries. In the first part of the program, the purpose of the algorithm was to establish a friendly interface with the user, welcoming any user which uses the Muscle Signal Receiver (MSR) Glove Test to read their EMG signals generated through muscle movement. The software also displays an instruction which notifies the user to remain calm and avoid any motions other than movement of the palm to reduce distortions and inaccuracy as shown in Figure 3.5.

```
int x = 0;
int temPause= 2500;
int waitTime = 1500;

// the setup routine runs once when you press reset:
void setup() {
  // initialize serial communication at 9600 bits per second:
  Serial.begin(9600);

Serial.println("************************ MSR GLOVE TEST ************************");
Serial.print(" Hello User!!!");
delay (temPause);
Serial.print(" Welcome to MSR GLOVE TEST. ");
delay (temPause);
Serial.println(" For The Best Results,");
delay (temPause);
Serial.println(" Remain Calm and Avoid Motions Excluding the Moving Palm. ");
delay (5000);
```

Figure 3.5: Coding for Interface with User.

The second part of the program is to notify that the measurements were commenced after the countdown reaches zero which was displayed as wordings on the serial monitor of the Arduino IDE as shown in Figure 3.6.

```
Serial.println (" Measurements Will Begin In ");
delay (temPause);
Serial.print(" Three......");
delay(waitTime);
Serial.print("  Two.......");
delay(waitTime);
Serial.println("  One.........");
delay(waitTime);

}
```

Figure 3.6: Coding for Notifying Start Time.

The third part of the program algorithm serves the function to detect, read and display the signals collected by the MyoWare muscle sensor which was connected to the Arduino UNO. In here, the specific pin of A0 was noted as the analog input to be read by the microcontroller which the values were printed and display into the serial monitor. A small delay has to be introduced at the end of every reading intervals to ensure stability of the sensor as shown in Figure 3.7.

```
// the loop routine runs over and over again forever:
void loop() {
  // read the input on analog pin 0:
  int sensorValue = analogRead(A0);
  // print out the value you read:
  Serial.println(sensorValue);
  delay(50);        // delay in between reads for stability
}
```

Figure 3.7: Coding Which Collects Sensor Value from Muscle Sensor.

3.6.3.2 Coding to Interact with All Sensors for Data Monitoring

3.6.3.2.1 Libraries

In this section of software writing in the Arduino IDE, two libraries were imported into the program for usage which is the DHT sensor library (DHT_U.h) and the HC05 Bluetooth module library (SoftwareSerial.h). Other sensors such as muscle sensor and LM35 body temperature sensor were written with manual algorithm. The presence of libraries in this programming acts as a collection of codes for a specific component, which means completed algorithms or routines has been made beforehand in C or C++ language and represented in the form of functions on other programming software. The libraries used in the coding are shown in Figure 3.8 below.

```
#include <DHT_U.h>                    // libraries
#include <SoftwareSerial.h>
```

Figure 3.8: Libraries Included in Arduino Coding.

The command “#include” is the command code of Arduino programming to apply library into the whole algorithm. Besides that, the term “.h” represents the single respective library. “DHT.h” is a library which setup and controls the DHT11 humidity and temperature sensor. The library has some function keyword for user in order to setup sensor and obtain data from sensor, such as “.readHumidity()” and “.readTemperature()”. These keywords will be described more in detail on the respective sensor algorithm part. For “SoftwareSerial.h”, it is a library to help setting up the Bluetooth module only for the model of HC-05 Bluetooth module.

3.6.3.2.2 LM35 Body Temperature algorithm

The first step of the algorithm is to set up necessary variables as shown in Figure 3.9 below.

```
#define LM35 A5
float tempC;
float tempF;
float lmValue;
```

Figure 3.9: Variables for Body Temperature Algorithm.

From Figure 3.9 above, the set-up variables are “tempC”, “tempF” and “lmValue” and the input analog pin of temperature sensor is A5 are variables that provide final output data which is in degree Celsius. The “lmValue” is the variable which collects raw data from the LM35 temperature sensor output. The data type of the variable is shown in blue coloured word, ‘float’ is a data type that functions to input a number that has decimal point. After setting up all the variables, a calculation algorithm must be performed as the raw signal collection will be in Fahrenheit. The variable of “tempr” was set to represent the final calculated output after calculation has been performed as shown in Figure 3.10.

```
float lmvalue = analogRead(LM35);
float tempr = (lmvalue* 500)/1023;
```

Figure 3.10: Calculation Algorithm of Body Temperature.

3.6.3.2.3 DHT11 Humidity and temperature sensor algorithm

For the algorithm of humidity and temperature sensor, since the library for the sensor has been included, the algorithm was relatively easy to be designed by just using the function given in its library and does not require any calculation. But there are still some important steps required to setup the sensor.

```
#define Type DHT11
int sensePin=2;
DHT HT(sensePin,Type);
```

Figure 3.11: DHT11 Setup Command.

As shown in Figure 3.11 above, the DHT11 sensor output pin was declared to connect to digital port pin 2, also the sensor model was declared as DHT11. Next, by insert the keyword function from its library (orange coloured word), a function name declared as “HT” with the pin where the sensor is connected to with sensor model. After the sensor is set up, the next step is to get reading from the sensor.

```
humidity = HT.readHumidity();
tempC = HT.readTemperature();
tempF = HT.readTemperature(true);
```

Figure 3.12: Data reading Command from DHT11.

The sensor library provided some functions to obtain and process humidity data and temperature data (Figure 3.12), which are ".readHumidity()" and ".readTemperature()". By calling these two functions, the data of humidity with % in unit was stored in to "H" variable, and the data of surrounding temperature with degree Celsius was stored in "T" variable.

3.6.3.2.4 Bluetooth module setup

For Bluetooth module setup, because the library "SoftwareSerial.h" library for Bluetooth has been included in the program, hence by using the function provided in the library, the program was able to be setup much easier with a single command for connecting with the HC05 Bluetooth module as shown in Figure 3.13.

```
SoftwareSerial Bluetooth(10, 9);
```

Figure 3.13: Bluetooth Setup.

The function from the library was used (orange coloured wording). Then a variable name "Bluetooth" was declared to the function for future steps. In the bracket, the first digit refers to the transmission pin of the Bluetooth module connected to, whereas the second digit refer to the receiving pin of the Bluetooth module connected to on the Arduino UNO microcontroller. This means that, the function has commanded the Arduino UNO to setup the digital port no.10 as transmission output and digital port no.9 as receiving input of the Bluetooth module.

3.6.3.2.5 Output parameters data

```
Bluetooth.print(tempr);
Bluetooth.print(tempC);
Bluetooth.print(humidity);
Bluetooth.print(EMGVal);
delay (500);
```

Figure 3.14: Data Output to Bluetooth Coding.

From Figure 3.14 above, the coding was to send all the final data collected in a form of line string to the Bluetooth module. The reason the parameters data was placed into a string line was to allow the mobile application to receive the parameters easier and more accordingly by breaking down the string line into 4 different segments. A delay has to be introduced here to ensure the stability of sensors and Bluetooth module.

3.7 Design and Creation of Mobile Application

In this project, a mobile application was built to display all the parameters, including muscle signal, body temperature, room temperature and skin humidity. The mobile application works by acquiring a string data sent from the Bluetooth module which was connected to Arduino UNO and then breaks down the string data into 4 different parameters as stated above before displaying them in layout. In order to create this application, MIT App Inventor software was used. The icons used for this mobile application were created using an icon creator application known as LogoMakr.

3.7.1 Mobile Application Icon

A suitable icon of mobile application was necessary because it represents the image of the mobile application. The idea of the concept of icon design was through the project name MSR Glove. Since the user will operate the device wearing a glove, thus the icon of a glove labelled M.S.R was the best to relate to this device as shown in Figure 3.15 below.

Figure 3.15: Mobile Application Icon.

3.7.2 Mobile Application Layout

For application layout, the design is structured in such a way much makes it tidy and easy for the user to avoid confusion and complexity. The four parameters are shown in four rows with respective name and picture to represent. Also, above the layout of parameter display has an icon and application name called M.S.R Glove Device (Figure 3.16). A total of two buttons were placed at the bottom as shown in layout 2 (Figure 3.17) for Bluetooth connection purposes.

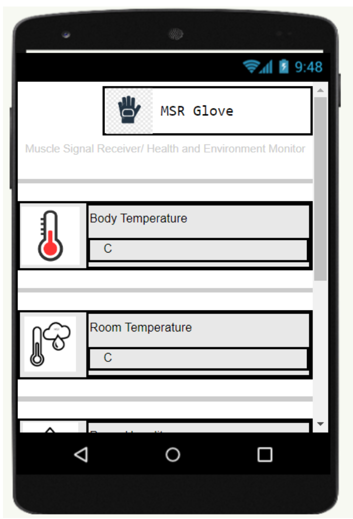


Figure 3.16: Application Layout 1.

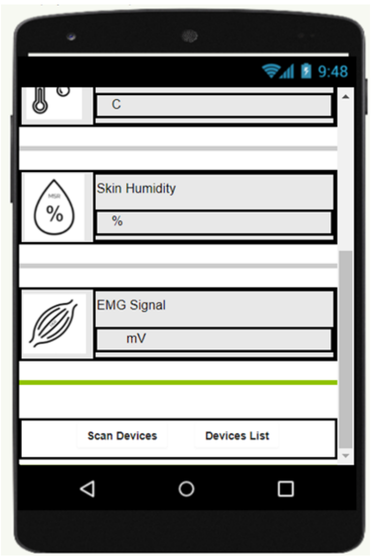


Figure 3.17: Application Layout 2.

From Figure 3.16 and Figure 3.17 above, the application layout was displayed as follows where four parameters were shown in four different rows. In each row, a respective name of parameter and picture with data labels were placed to display the data parameters. Specific icons were created for each parameter and added through the MIT App Inventor. The construction of layout was performed through usage of multiple layout functions such as horizontal and vertical layouts. The horizontal layout functions to display every element in a horizontal manner, whereas vertical layout will display every element in a vertical manner. In addition, in order to create spacings within the structure of display for better represented layout, blank labels were added. Two buttons were added into the application and renamed in the settings column of the MIT App Inventor. The first button named as “Scan Devices” is a button which functions to scan the available Bluetooth devices when pressed while the second button named as “Device List” is a button to show the available Bluetooth devices in list form upon press.

3.7.3 Mobile Application Coding

MIT App Inventor uses a special form of coding known as block programming. As its name states, block programming is achieved by dragging a block of command and assemble them together into a complete code capable of performing specific functions towards the build desired. In this project, the coding for mobile application was constructed in a way which enables the application to perform some essential functions required by the glove such as data acquisition, data display, data processing and Bluetooth connection establishment.

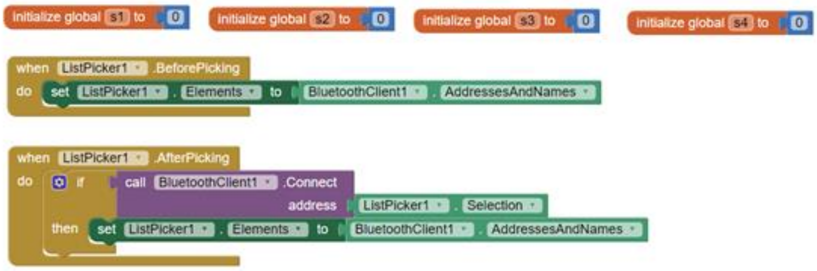


Figure 3.18: Bluetooth Connection Setup.

From Figure 3.18 above, the block codes constructed together function to collect all the available Bluetooth devices name and address before displaying them in a list when the button “Device List” is pressed. When a Bluetooth device is chosen to be connected, the coding will control the Bluetooth in Android phone to connect to the Bluetooth address chosen.

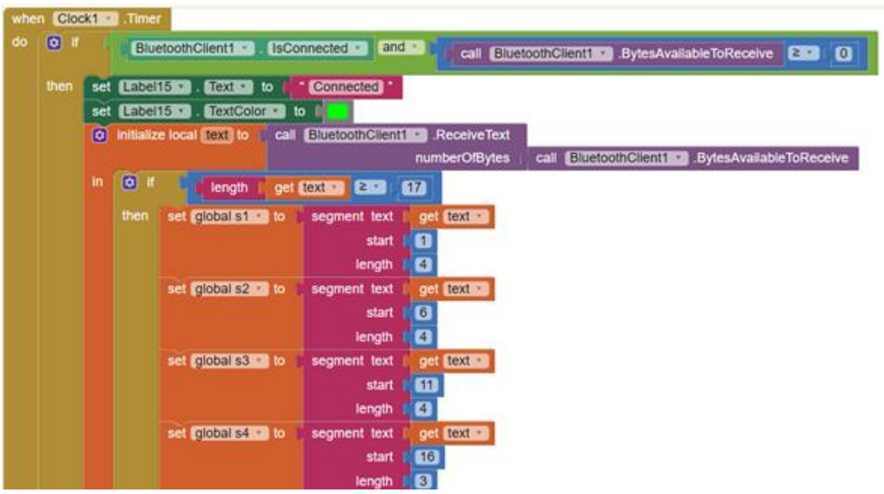


Figure 3.19: Data Acquisition Block Code.

After the Bluetooth device is connected, a label text will display "Connected" in the application layout with green text colour (Figure 3.19). Next, the mobile application needs to obtain data from the connected device the data is stored in a variable called "text". After that, the data is broken down into 4 segments and stored in 4 global variables. The Arduino output coding was arranged in such a way that the first segment will be the body temperature data, second segment will be room temperature data, third segment is skin humidity data, and the last segment is muscle signal data.

Figure 3.20: Data Processing Block Code.

Figure 3.20 above portrays all the data which have been stored into global variables is ready to be displayed and process by adding abnormal range condition of parameters data respectively. In order to display parameter data, the data in global variable will be stored to the display label variable for example as shown above in the "Data_Btemp" which is the display label variable. Then if body temperature is greater than 40°C, the display label text of body temperature will turn red and at the same time shows an alert notification that shows "Abnormal Patient's Body Temperature Detected". This algorithm was applied similarly to the rest of the parameters.

Figure 3.21: Button for Bluetooth Establishment Block Code.

Figure 3.21 above shows the functions of “scan device” button. When the button is pressed, the device list will prepare all the available Bluetooth devices and the “Device List” button changes into “List Ready”.

3.8 Summary

In summary, the conceptual design of this project mainly utilizes Arduino UNO and a muscle sensor for the detection of muscular activity. From the data obtained, programming software was used to analyze the EMG signals received for determination of types of active muscle involved during the movements of fingers. The developed device was tested onto three healthy subjects to determine its effectiveness and accuracy. Initially, this project was targeted to be tested on stroke patients, but this was not achieved due to the implementation of the movement control order (MCO) imposed by the government. The hand motions performed were simple movements such as the formation of a fist and individual contraction of the thumb, index finger, middle finger, ring finger and the little finger. Each set of motion was to be repeated six times or more depending on the results obtained. The cost estimation performed was based on real prices from online stores and a survey of price is made to ensure minimal spending for the development of this project. The project flow is made for better project structure before the initiation of building prototype. Other parameters such as temperature measurement and humidity sensors are introduced so that the device has more unique features for monitoring and usage. The mobile application layout and function coding has been successfully constructed with very good stability and tidy looks. The basic function of this mobile application is to receive parameters data from the MSR Glove device then display them accordingly with proper layout style. Also, all the abnormal condition has been set to all parameters data and will send out an alert notification to user if the parameter is out of normal range. the project flow is made for better project structure before the initiation of building prototype.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Muscle Signal Receiver (MSR) Glove was the name given to this project development where a glove capable of detecting muscle signals generated from finger motions was developed using sensor and program coding. In addition, the device also has added features such as body temperature detection, skin humidity and surrounding temperature sensing as well as a Bluetooth feature for connectivity. The model was tested with its functionality and limitation. Hence, this chapter focuses on discussion towards assembling, data collection, functionality, reproducibility and accuracy of the MSR Glove during application.

4.2 Assembly of Circuit

4.2.1 MyoWare Muscle Sensor Connection

The circuit design of this device involved the usage of soldering pen to attach a L-type single row Header (1x3) towards the sensor and jumper wires as shown in Figure 4.1. Soldering iron was used as the fusible metal alloy in order to enable strong adherence towards the sensor and wires to prevent disconnection during usage.

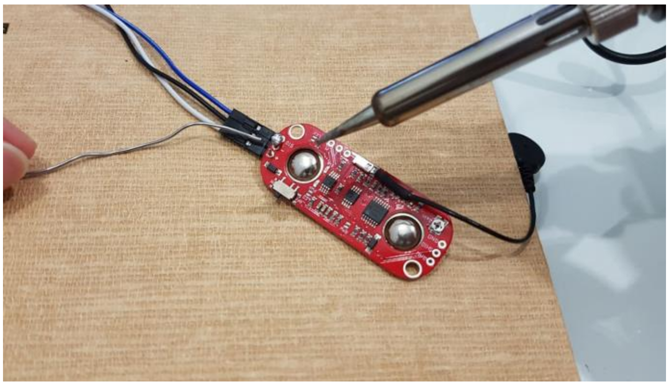


Figure 4.1: Soldering of Iron onto L-type Header for Adherence.

Jumper wires were then used to connect the MyoWare Muscle Sensor and the microcontroller board via the L-type header which was soldered. Three terminals of the Arduino UNO were used for this construction which are the 5.0V terminal which was connected to the positive head of the sensor to receive power, a ground terminal which is connected to the negative head of the sensor to direct any excess electrical charges away from the user safely and an analog pin (A0) which is to receive signals from the sensor to be displayed in the serial monitor. The connections between the muscle sensor and Arduino are shown in Figure 4.2.

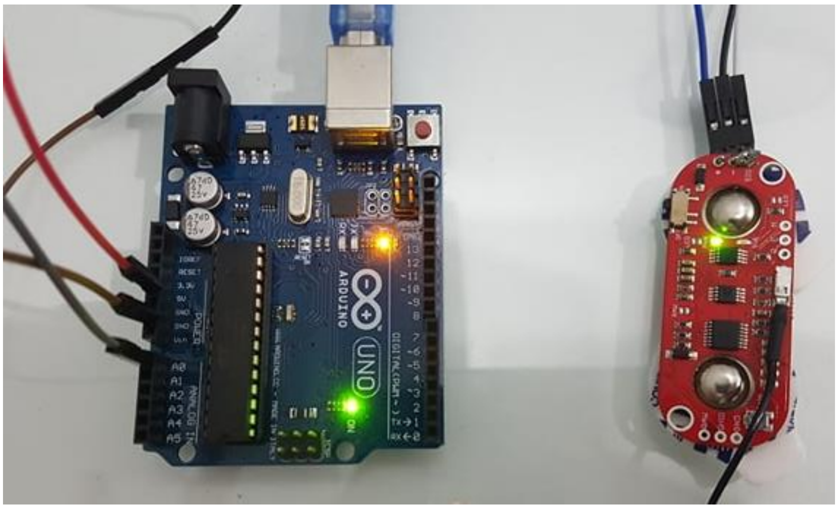


Figure 4.2: Arduino UNO connection to MyoWare Muscle Sensor.

4.2.2 Placement of Electrodes

The MyoWare Muscle Sensor is capable of measuring signals from many types of muscles which is close to the surface of skin. Placement of electrode must be along the length of muscle, with the primary electrode which is closest to the jumper wire, placed at the middle of the muscle and the secondary muscle placed towards the end of the muscle. An external electrode which is connected at the top of sensor through the black wire which is referred to as the reference electrode and should be placed as far as possible from the muscle being sensed. For the start, biomedical sensor pads are required to the attached into the electrode snap of the muscle sensor for measurement and adherence to the skin while testing. The paper which is placed behind the biomedical sensor pads should be removed in order for usage as shown in Figure 4.3.

Figure 4.3: Removal of Paper Backing the Biomedical Sensor Pads.

In this project, movements performed was more focused towards motion of the palm and from the study conducted by Cochrane et al. (2016) as explained in the literature review, the best placement of the muscle sensor to detect finger activity is to position the electrode which reference electrode is placed on the inner elbow. Therefore, once the paper is removed, the sensor should be placed as firmly as possible to the muscle as shown in Figure 4.4.

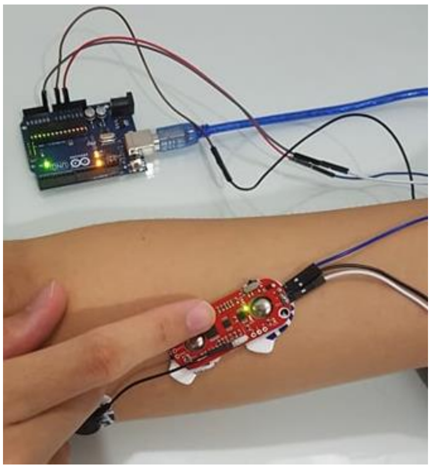


Figure 4.4: Placement of Sensor on Muscle.

4.2.3 Data Streamer Using Microsoft Excel

Once the sensor was able to detect signals without difficulties, the sensor was then stitched onto the glove and data samples from individuals were recorded. The data signals received from the sensor were streamed into Microsoft Excel as portrayed in Figure 4.5. A graphical representation of the EMG signal received was plotted using the streamed data collected by the sensor and shown in Figure 4.6 below.

3	Current Data										
4	Time	CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8	CH9	CH10
5	13:36:46.68	343 mV									
6	Historical Data										
7	Time	CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8	CH9	CH10
8	13:36:32.69	343 mV									
9	13:36:33.69	343 mV									
10	13:36:34.69	343 mV									
11	13:36:35.69	343 mV									
12	13:36:36.69	343 mV									
13	13:36:37.69	343 mV									
14	13:36:38.69	342 mV									
15	13:36:39.69	342 mV									
16	13:36:40.69	342 mV									
17	13:36:41.69	342 mV									
18	13:36:42.69	342 mV									
19	13:36:43.69	343 mV									
20	13:36:44.69	343 mV									
21	13:36:45.69	343 mV									
22	13:36:46.68	343 mV									

Figure 4.5: Data Streamer View Through Microsoft Excel.

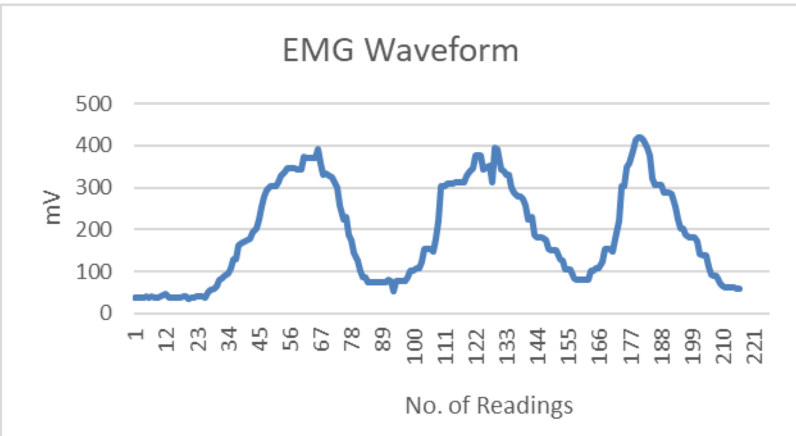


Figure 4.6: Graphical Representation Through Data Streamer in Microsoft Excel.

4.3 Hardware

4.3.1 Hardware Results

Before the assembly of circuit was performed, a schematic sketch of the circuit was drawn as shown in Figure 4.7 below for a clearer view. Once the schematic circuit was completed, the actual assembly of circuit was then constructed as shown in Figure 4.8.

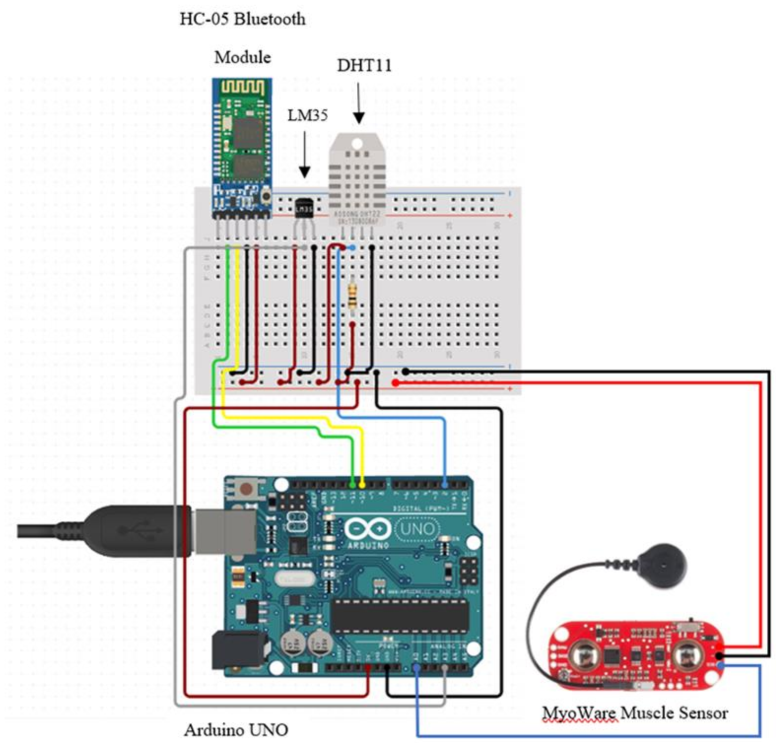


Figure 4.7: Schematic Drawing of Circuit.

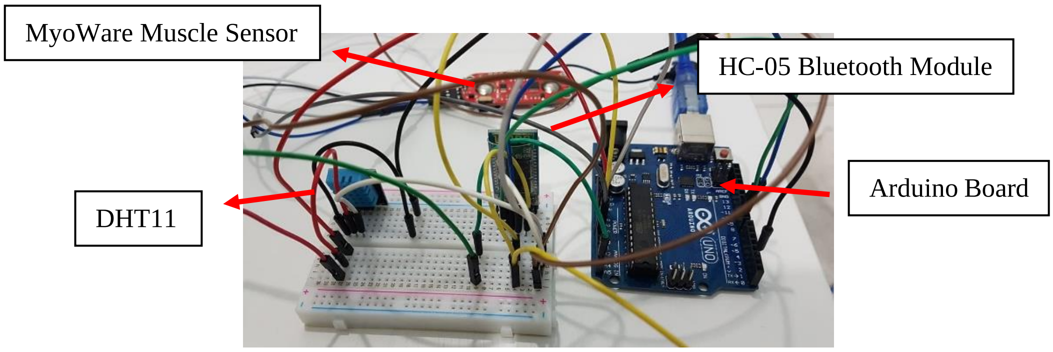


Figure 4.8: Circuit Board Connected to Arduino UNO, DHT11, HC05 Bluetooth Module and MyoWare Muscle Sensor.

Once the circuit was successfully assembled and tested for its functionality, sensors such as the MyoWare muscle sensor, LM35 temperature sensor and DHT11 humidity and temperature sensor were transferred and stitched onto a glove as shown in Figure 4.9 to Figure 4.11 below.

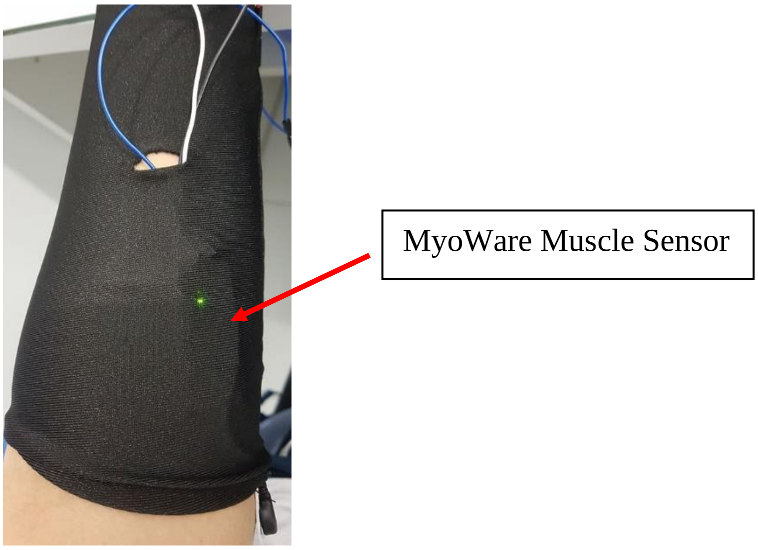


Figure 4.9: MyoWare Muscle Sensor with Green Light at Forearm.

Figure 4.10: LM35 Temperature Sensor.

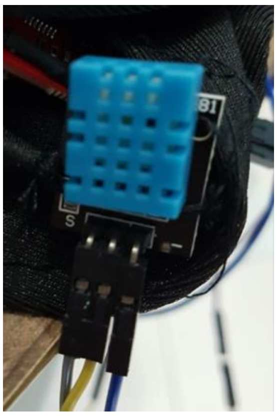


Figure 4.11: DHT11 Humidity and Temperature Sensor.

With the sensors placed onto the glove, the remaining external circuitry such as the HC-05 Bluetooth Module, the Arduino UNO microcontroller and the breadboard were then encased with a casing made from cardboard in order to protect its circuitry from damage. Figure 4.12 to Figure 4.15 shows the HC05 Bluetooth Module and the overall structure view of the casing protecting the circuit board.

Figure 4.12: HC05 Bluetooth Module.

Figure 4.13: Back View of Casing Protecting the Internal Circuit Board.

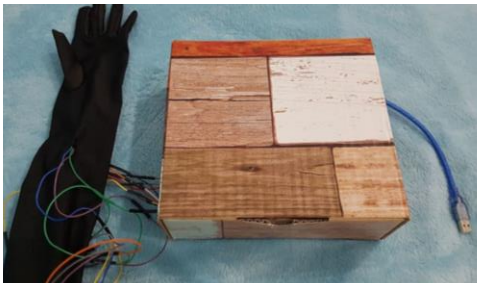


Figure 4.14: Front View of Overall Device.

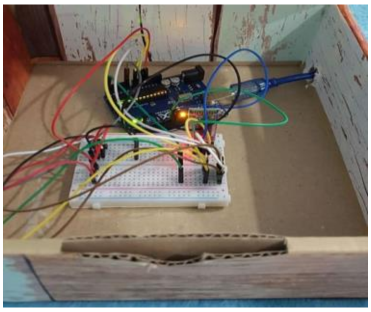


Figure 4.15: Interior View of Overall Device.

In an overall summary of the hardware design through Figure 4.7 to Figure 4.15, the MSR Glove was originally designed for measuring muscle movements in a non-invasive manner without the need of visiting healthcare centres frequently to check their EMG by using the MyoWare muscle sensor. In addition, the device also includes several sensors which are LM 35 temperature sensor to detect body temperature, DHT 11 humidity and temperature sensor to detect humidity and surrounding temperature. After sensors received the data respectively from the sensor, all of the data will go through a set of algorithms to process the raw data and the final data will be sent through Bluetooth via HC-05 Bluetooth module which will eventually be received by the smartphone. All the sensors and Bluetooth were connected to the Arduino Uno. The device was placed into a casing in order to protect all its circuitry.

4.4 Testing of Software for Collection of EMG Signals from Different Individuals.

A total of 3 healthy subjects with different age were tested using the MSR Glove Test in order for comparison and to investigate the relationship between the muscle size and EMG signal generated by the muscle during its contraction. A total of 6 different motions were performed which was firstly, the flexion and extension of all fingers at once to form a fist, followed by the thumb, index finger, middle finger, ring finger and little finger. Illustration on the performance of finger activity are shown in Figure 4.16 below for clearer picture.

Figure 4.16: Fine Finger Movements Used to Detect Muscle Activity.

The output was displayed in the serial monitor from the Arduino and the data was then streamed into Microsoft Excel for the plotting of graph if needed. A snapshot of data was taken for each individual while performing a single contraction with different motions and is attached in Figure 4.17 to Figure 4.22. For simplicity of analysis, the parameters of body temperature, skin humidity and surrounding room temperature was temporarily removed in this section to avoid confusion. The measured data frequency set for sampling and data collection was fixed at 2 Hertz.

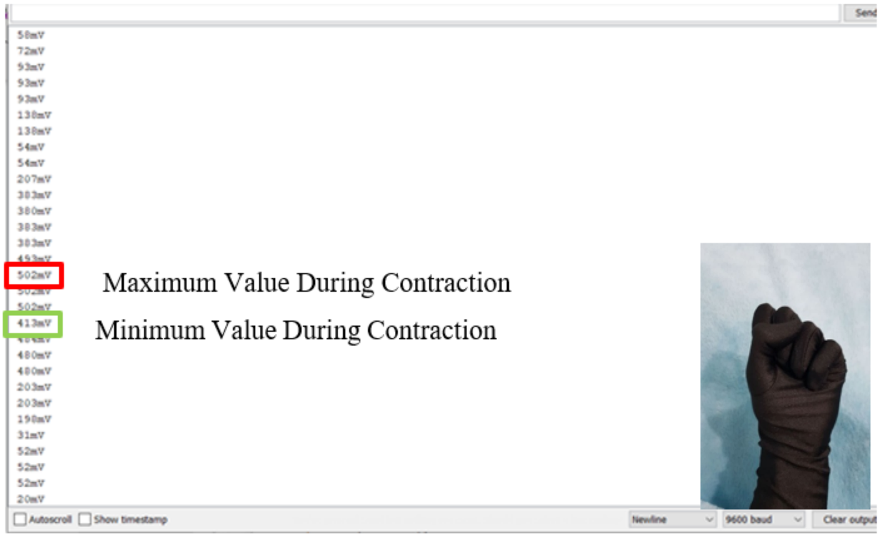


Figure 4.17: Maximum and Minimum EMG Signal While Forming a Fist of Subject A.

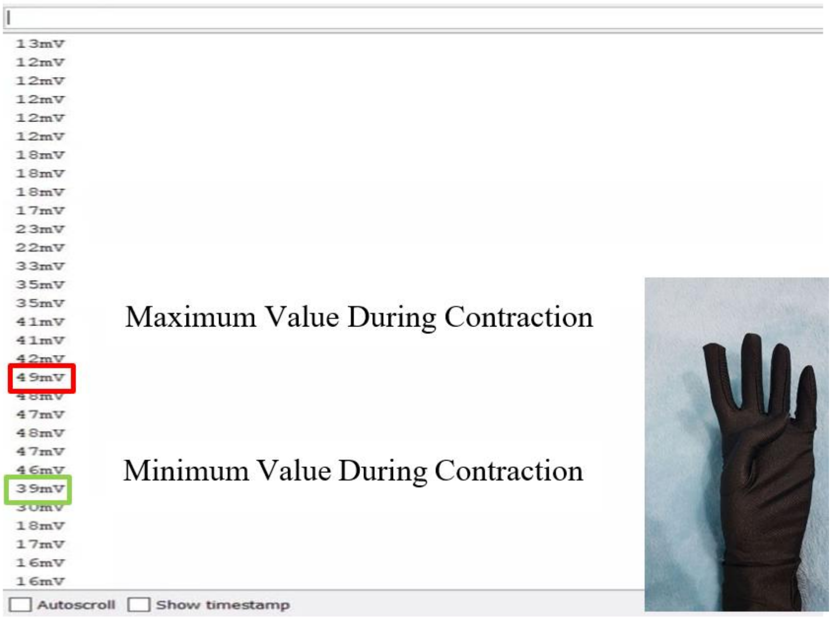


Figure 4.18: Maximum and Minimum EMG Signal While Contracting Thumb of Subject A.

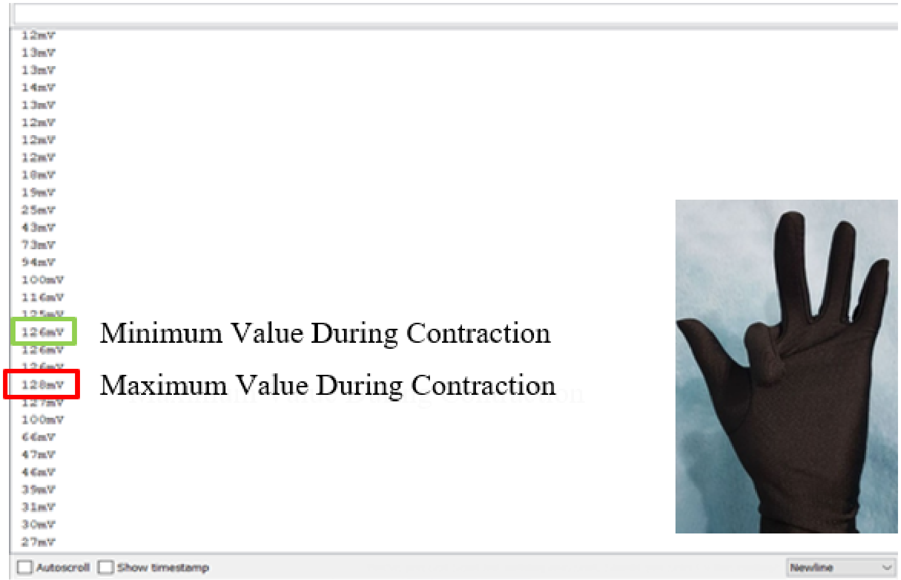


Figure 4.19: Maximum and Minimum EMG Signal While Contracting Index Finger of Subject A.

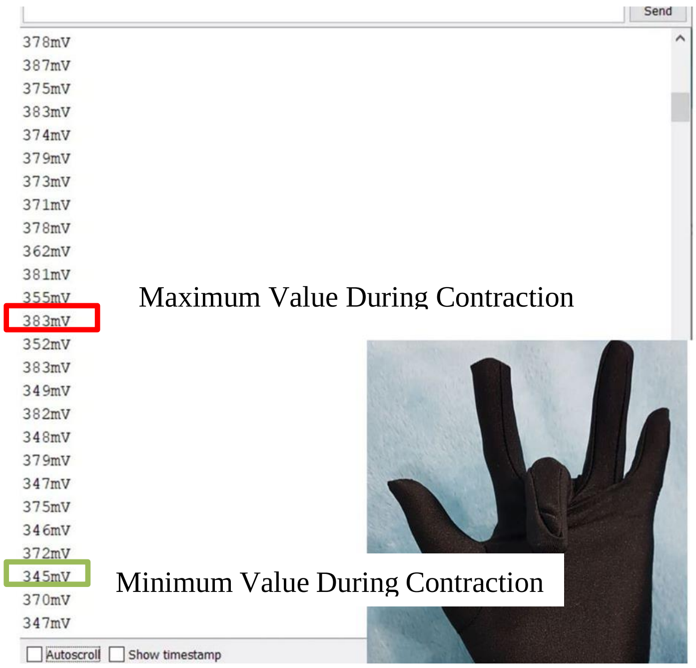


Figure 4.20: Maximum and Minimum EMG Signal While Contracting Middle Finger of Subject A.

Figure 4.21: Maximum and Minimum EMG Signal While Contracting Ring Finger of Subject A.

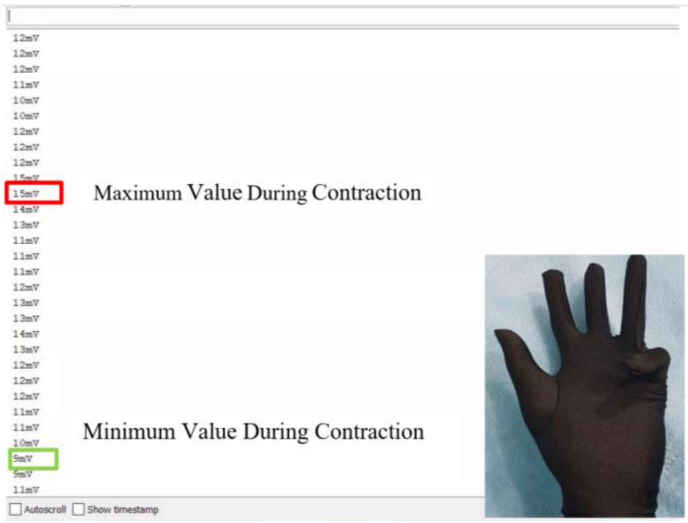


Figure 4.22: Maximum and Minimum EMG Signal While Contracting Little Finger of Subject A.

From the collection of data through repetition of the specific finger movement, a table was constructed between the subjects A, B and C for observation and comparison of data. The recorded data was then presented as shown in Table 4.1 to Table 4.3.

Table 4.1: EMG Values from Subject A.

Subject	A					
Gender	Male					
Age	22					
Weight (kg)	73					
Height (cm)	181					
Motion	Fist	Thumb	Index Finger	Middle Finger	Ring Finger	Little Finger
Minimum EMG signal during finger contraction (mV)	413	35	126	345	98	9
Maximum EMG signal during finger contraction (mV)	502	49	128	383	106	15
Minimum EMG signal during finger relaxation (mV)	12	12	12	11	10	11

Table 4.2: EMG Values from Subject B.

Subject	B					
Gender	Female					
Age	25					
Weight (kg)	61					
Height (cm)	170					
Motion	Fist	Thumb	Index Finger	Middle Finger	Ring Finger	Little Finger
Minimum EMG signal during finger contraction (mV)	299	40	83	101	112	10
Maximum EMG signal during finger contraction (mV)	325	44	101	131	120	14
Minimum EMG signal during muscle relaxation (mV)	12	12	16	15	12	9

Table 4.3: EMG Values from Subject C.

Subject	C					
Gender	Female					
Age	50					
Weight (kg)	67					
Height (cm)	165					
Motion	Fist	Thumb	Index Finger	Middle Finger	Ring Finger	Little Finger
Minimum EMG signal during finger contraction (mV)	183	22	50	81	20	7
Maximum EMG signal during finger contraction (mV)	221	33	103	155	47	12
Maximum EMG signal during finger relaxation (mV)	11	14	11	13	15	8

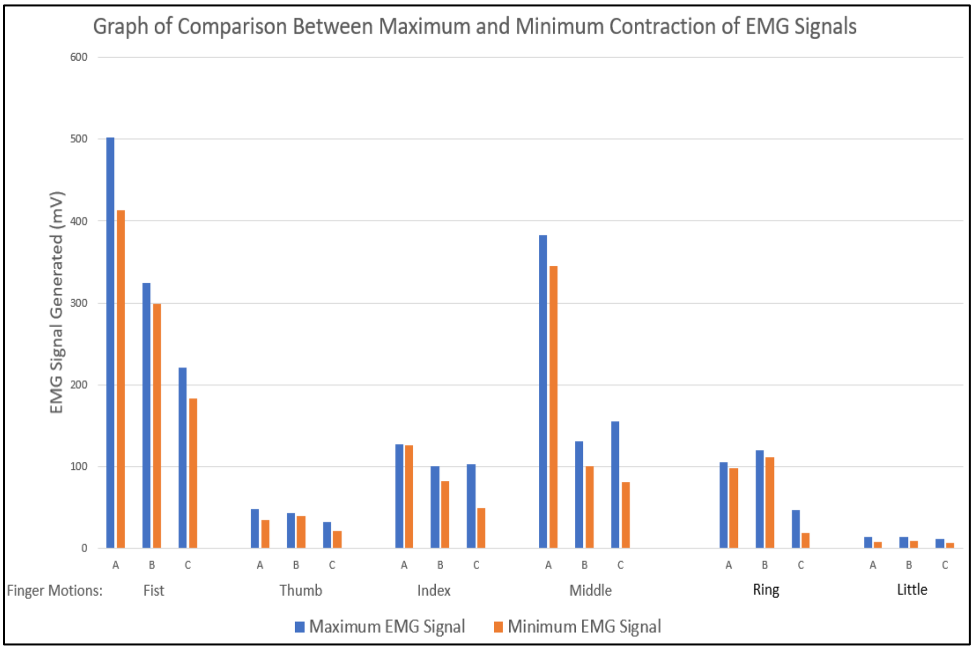


Figure 4.23: Comparison of Maximum and Minimum Contraction EMG Signals.

From the results obtained via the three different healthy individuals, it was noted that subject A has the highest EMG readings for all fine movements of fingers when compared to subjects B and C (Figure 4.23). This was due to subject A having a larger muscle mass and size which is a gender characteristic as males would usually have greater muscle-mass to ratio compared to females. The results of fist clenching were highest for subject A at 502mV followed by subject B at 325mV and subject C at 221mV. When comparison is made between subjects B and C with the same gender, the reason for this difference can be caused by age factor where the strength levels are typically higher for younger adults with an active lifestyle compared to a working adult. Looking into the little finger, the EMG signal collected by the sensor for all three subjects are similar and relatively low. This could be due to the inaccuracy of sensor to detect smaller forces compared to when larger forces are exerted which requires greater muscular activity.

However, the collection of data was not tested on stroke patients due to the movement control order (MCO) imposed by the government to contain the pandemic. This has led to difficulties in visiting care centres in search of suitable test subjects. Nevertheless, from the results obtain there are positive benefits and potential applications to which the data collected can be of use. A major benefit from the data collection is that it is capable of aiding therapists to detect and identify inactivity of muscles responsible for specific finger contraction in stroke patients. A higher magnitude of EMG value will indicate that action potentials are present to enable that specific finger motion while at the same time a smaller or no EMG value will result in the absence of action potentials which causes the inability to perform that specific finger motion.

With these data collection, therapists can draft out and perform special treatments and exercises of rehabilitation on stroke patients with emphasis on the targeted muscle which is responsible for fine motor movements. This will in return aid patients that have been affected neurologically to regain their fine motor skills over time. In addition, these data are not only limited to the treatment of post-stroke patients but also can be used on individuals suffering from upper extremities disability often caused by muscle weakness or spasticity. Therefore, by targeting the specific muscles, the process of recovery will definitely require a shorter amount of time for recovery in patients.

4.5 Testing of Full Device for Monitoring Purposes

4.5.1 Arduino Code Results

After the coding has completed, it was uploaded into the Arduino UNO for testing. The parameters output was displayed in serial monitor of Arduino IDE. From Figure 4.24 below, the shown data is tested from an individual with the MSR Glove Device, the first column is the body temperature data, followed by room temperature data, skin humidity data, and muscle signal. From the data collected, the LM35 and DHT11 sensor were compared with actual devices where the body temperature sensor was compared to a common thermometer and the DHT sensor was compared to actual room thermometer and surrounding weather forecast.

```
36.4C 32.1C 74.0%  33.0mV
36.4C 32.1C 74.0%  33.0mV
36.1C 31.1C 74.0%  33.0mV
36.4C 31.1C 74.0%  33.0mV
36.4C 31.1C 74.0%  155.0mV
36.1C 31.1C 74.0%  125.0mV
36.1C 31.1C 74.0%  131.0mV
36.4C 31.1C 74.0%  107.0mV
36.4C 31.1C 74.0%  107.0mV
36.1C 31.1C 74.0%  106.0mV
36.4C 30.9C 74.0%  86.0mV
36.6C 30.9C 74.0%  54.0mV
```

Figure 4.24: Parameter Data in Serial Monitor.

4.5.2 LM35 Temperature Sensor Results

Table 4.4: Body Temperature Result Comparison.

Number of Data Collected	LM35 Body Temperature Sensor	Actual Thermometer
1	36.4 °C	36.7 °C
2	36.4 °C	36.7 °C
3	36.1 °C	36.7 °C
4	36.4 °C	36.7 °C
5	36.4 °C	36.9 °C
Average	36.3 °C	36.7 °C

After the comparison has been made, the error percentage was calculated.

$$error\ percentage = \left|\frac{measured\ value - exact\ value}{exact\ value}\right| \times 100\%$$

$$error\ percentage = \left|\frac{36.3 - 36.7}{36.7}\right| \times 100\%$$

$$error\ percentage = 1.09\%$$

The percentage error gives a result of 1.09% which is considerably low. The reason of this error might be due to the LM35 temperature sensor having an output accuracy fluctuation range of $\pm 0.5℃$ (Projects, 2020), hence minor error occurs in output.

4.5.3 DHT 11 Temperature and Humidity Sensor Results

Table 4.5: Room Temperature Result Comparison.

Number of Data Collected	DHT11 Room Temperature Sensor	Common thermometer
1	32.1^{o}C	30.8 ^{o}C
2	32.1^{o}C	30.8^{o}C
3	32.1^{o}C	30.7^{o}C
4	31.1^{o}C	30.7^{o}C
5	31.1^{o}C	30.8^{o}C
Average	31.7 ^{o}C	30.8 ^{o}C

$$error\ percentage = \left|\frac{measured\ value - exact\ value}{exact\ value}\right| \times 100\%$$

$$error\ percentage = \left|\frac{31.7 - 30.8}{30.8}\right| \times 100\%$$

$$error\ percentage = 2.92\%$$

From the percentage error of room temperature shown above, the room temperature measured from DHT11 sensor varies slightly towards the actual room thermometer but is still pretty accurate, having an overall percentage error of 2.92%.

The accuracy of the DHT11 in sensing humidity was also measured to check its consistency. Although the actual purpose of this function was to measure skin humidity, the accurateness was difficult to determine as different individuals would have different skin humidity depending on their location, surrounding environment and skin moisture. Hence, to determine its accuracy on humidity detection, the DHT11 sensor was compared to actual humidity data online in Penang on the same day at 5:47pm as shown in Figure 4.25. The compared result (Table 4.6) and percentage error calculated are shown below.

Figure 4.25: Online Humidy Result. Source: timeanddate (2020).

Table 4.6: Room Humidity Result Comparison.

Room Humidity data	DHT11 Humidity Sensor	Online Humidity Data
Average	74%	66%

$$error\ percentage = \left|\frac{measured\ value - exact\ value}{exact\ value}\right| \times 100\%$$

$$error\ percentage = \left|\frac{74 - 66}{66}\right| \times 100\%$$

$$error\ percentage = 12.12\%$$

With the percentage error determined as shown above, the room humidity was not very accurate due to the high percentage error of 12.12%. After some analysis, the high error was probably due to the online humidity data covering the whole state of Penang and the big coverage causes difficulty to be compared towards a small area which the DHT11 sensor is in. Hence, the room humidity data was not confirmed on its accuracy during actual application.

4.5.4 Mobile Application Results

Once the block program was written and overall layout constructed, the application was downloaded and installed into an Android smartphone to test the overall performance of the application.

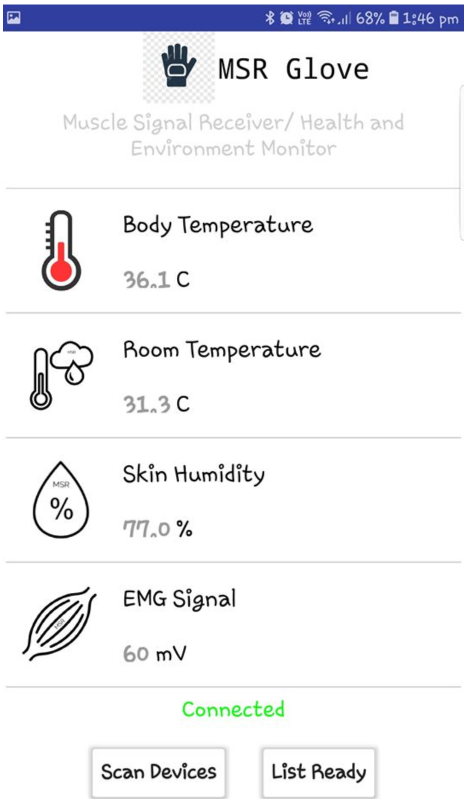


Figure 4.26: Mobile Application Layout Result.

From Figure 4.26 above which shows the application layout, it can be seen that values recorded from the sensors of MSR Glove Device were successfully directed into the smartphone application and displayed clearly. The application interface is neat, clean and tidy. The icons are also arranged in symmetry and when a Bluetooth connection is successfully established between the MSR Glove Device and mobile application, the application is able to show the info “Connected”.

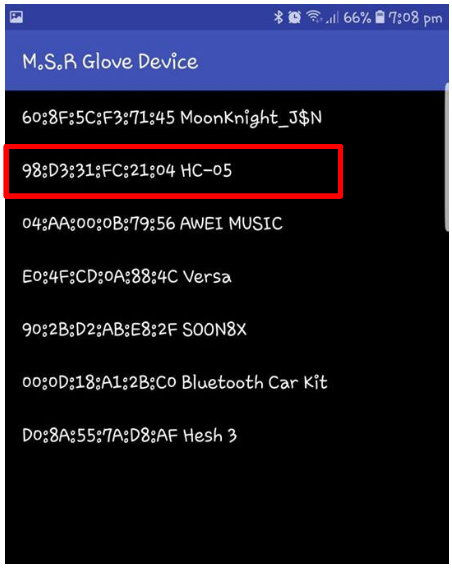


Figure 4.27: Device List Displayed.

From Figure 4.27, it can be clearly seen that the device list button is performing well, and it was able to show all nearby available Bluetooth devices ready for connection. Most importantly was the application being able to detect the HC05 Bluetooth module of MSR Glove Device which was at the second position of the list and is boxed in red for clearer view.

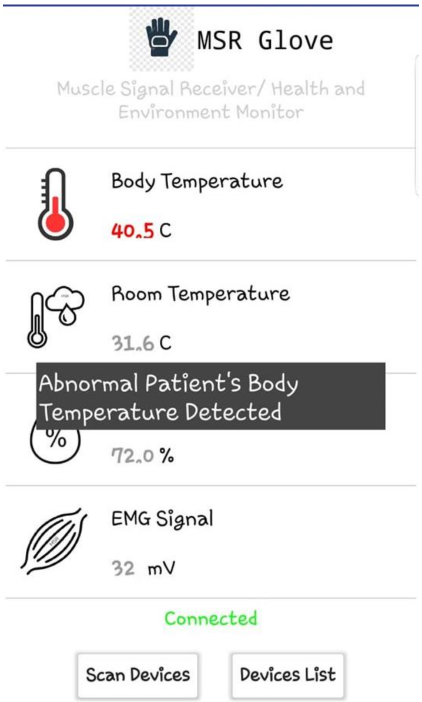


Figure 4.28: Alert Notification.

To test if the application was able to display an alert reading when a value exceeds a certain threshold point, all the sensors were taken into testing. For the LM35 temperature sensor, the threshold was set to 40 °C to indicate that a person is experiencing fever. As shown in Figure 4.28, a temperature higher than 40 °C will trigger an alert response through the application. The alert notification also triggers with room temperature exceeding 34 °C, humidity exceeding 85% and when there is no muscle signal received, 0 mV.

When usage was compared between the mobile application to the PC/laptop, the data collection method was different on both. In the PC/laptop, data collection is recorded and can be stored as a file for future references. At the same time, data can be streamed into Microsoft Excel using Data Streamer in order for analysis and representation of the data graphically. However, indication of any values exceeding threshold will not be displayed. At the same time, the user of this device must be present in front of the PC/laptop at all times as the device is connected using wires from the glove worn by the patient to the PC/laptop.

While operating using the mobile application, the downsides of PC/laptop can be solved. This is because the application is capable of providing an immediate pop-up alert notification which specifies if a specific threshold was exceeded during the period of measurement. Having the mobile application installed in smartphones also enables the user to move around much more freely as consistent real-time monitoring results can be displayed on their smartphone via Bluetooth connectivity. Nevertheless, the mobile application can only act as a device for monitoring as it is unable to store and display data graphically unlike through using the PC/laptop. When both the PC/laptop and mobile application usage are combined, both devices can operate at the same time therefore providing constant measurement of the patient over time while providing real-time data monitoring though the mobile application in case of incidents where an exceed of threshold value of any parameters were to occur. Hence, by combining the usage of both, therapist can access the same app synchronously to monitor the progress of patient.

4.6 Problems Faced and Solution

While using the MSR Glove Device, the main problem encountered was during data collection for receiving muscle signals through the MyoWare Muscle Sensor. At times, the muscle sensor would not be able to pick up or only detects very small signals. This problem was found during the testing and troubleshooting period of this project to which the data was obtained by the muscle sensor and plotted in the serial monitor as shown below in Figure 4.29.

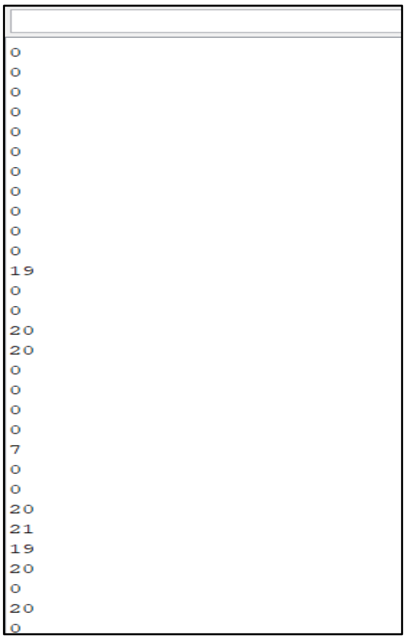


Figure 4.29: Incorrect Muscle Signal Received by Muscle Sensor.

Through analysing and research, it was found that placement of electrodes of the MyoWare Muscle Sensor would vary between individuals. According to Junlasat *et al*. (2019), a total of 5 different positions can be used in order to determine results of finger movements (Junlasat *et al*., 2019). When the sensor was placed closer to the palm, it was found that no muscular activity was detected as shown in Figure 4.29, where the EMG signal received was 0mV and maximum is only up to 20mV. This is because the electrode placement was not meeting the criteria of placement where the sensor should be directly in the middle of muscle which in this case, the flexor carpi radialis with the reference electrode attached to the inner elbow. Figure 4.30 below shows signal collection through incorrect placement of electrodes.

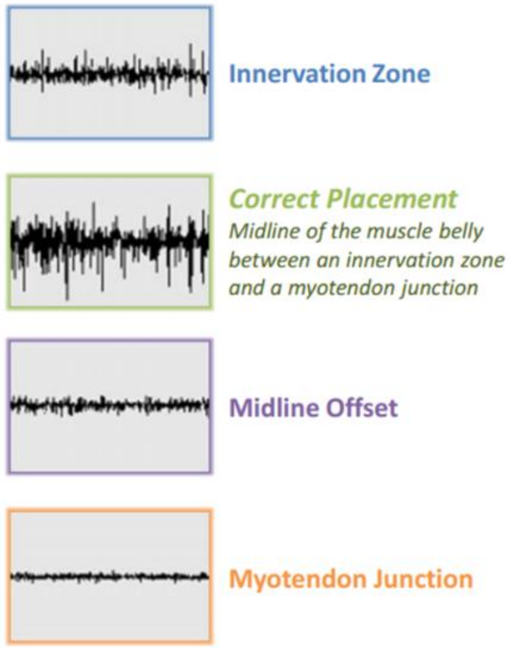


Figure 4.30: Different EMG Output with Different Placement on Muscle.
Source: Advancer Technologies (2015)

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, the MSR Glove was developed to be a multi-sensor measurement and monitoring device with the capability to measure EMG signals from muscular activity of individuals as well as taking measurements of body temperature, skin humidity and surrounding temperature. The price of the materials used to build the device cost about RM368.10 and is relatively easy to use. The device was also linked with a smartphone to be able to monitor the readings obtained from the MSR Glove without the need to be close to the device via Bluetooth. Besides, the limitation and functionality of the overall device, including its accuracy were tested and analysed in order for the correct setting of alert parameters to identify users if the set threshold has been exceeded. Through the completion of this project, the implementation of academic knowledge into practical application to develop a measuring device has been achievable even with the constraints of time and resources.

5.2 Recommendations for Future Work

The MSR Glove Device was far from perfect and has several limitations that has to be improved. The first limitation of this device is in its sensitivity. Due to the device measuring signals in a non-invasive manner, accuracy and precision of data collection would definitely be less accurate when compared to the typical EMG measurements which requires insertion of needle electrodes into muscle for detection. In order to improve accuracy while maintaining a non-invasive concept, amplifiers and filters can be applied in order to generate a stronger muscle signal for better detection.

The second limitation of this glove is towards the sensor. Operating the device for extended periods of time causes overheating towards the

MyoWare Muscle sensor. In a long run, this could affect user comfort as the heat may result in discomfort or pain which causes interruptions towards the ability of the sensor to detect EMG signals effectively. Hence, the best solution towards this is to apply gel or gel pads towards the base of the sensor which does not interrupt EMG signals while maintaining user comfort within the testing period. The period of test should also not exceed a certain amount of time as heat may also damage the sensor instead.

Another room for improvement of the prototype would be the time taken for the results to be calibrated on the mobile application. For the patient to be able to get accurate readings for the health measurements, the readings have to be stabilised for around 30 seconds. This weakness is only present for LM35 body temperature sensor as the MyoWare muscle sensor and DHT11 sensor readings are constantly updated without any data needed from the user. To combat this weakness, we could use a better sensor to measure the body temperature. Aside from hardware, another technique to obtain better result accuracy is by increasing the sampling frequency of the sensor data. Some of the sensors on the market provide faster calibration than the sensors that are chosen for this project. However, these sensors typically cost more than the sensors used in this prototype. Hence, to keep the costs down, I have decided to use sensors that are available with a good cost to performance ratio.

Another improvement that can be done on the prototype would be the improvement of range and accessibility of the data collected through the device. The HC-05 Bluetooth module has a limited connection range of up to 10 meters and is unable to place any data collected online. Thus, for future improvements, a more expensive Wi-Fi Module can be used for establishing connection with unlimited range as long as Internet was present as well as to enable data access through the Internet via a cloud storage. This will be beneficial especially to health caretakers where they are able to analyse readings without the need of being present near the patient hence may reduce the risk of disease transmission, if any.

The next modification to improve the weakness of the prototype would be the fragility of the casing structure. This was due to the choice of material used for the casing of the prototype, which is cardboard. Cardboard is very affordable and light, but it has low durability and resistance to impact making it fragile to drops or accidental damage. Cardboards are also not waterproof and will lose its structural integrity if it is in contact with water. A good alternative to this problem would be by using a solid plastic casing to contain the components. Solid plastics are strong and water-resistant, solving the issues that are present with the usage of cardboard casing. However, a cardboard casing is much easier to produce than a solid plastic casing, with the cardboard being able to be cut into different shapes to accommodate the components. To solve the problem of customisation of the casing, Perspex can be used and cut into different shapes and sizes then joined together with hot glue. This allows the components of the prototype to be visible and also allows the prototype structure to be more rigid.

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APPENDICES

APPENDIX A: Program Codes

```
void loop() {
  // read the input on analog pin 0:
  int sensorValue = analogRead(A0);
  // print out the value you read:
  Serial.print(sensorValue);
  Serial.println("mV");
  delay(50);          // delay in between reads for stability
}
```

Figure A-1: Code to Read and Print EMG Value from the Muscle Sensor.

```
int x = 0;
int temHold = 5000;
int temPause= 2500;
int waitTime = 1500;

// the setup routine runs once when you press reset:
void setup() {
Serial.begin(9600);     // initialize serial communication at 9600 bits per second

Serial.println("*********************** MSR GLOVE TEST ***********************");
Serial.print(" Hello User!!!");
delay (temPause);
Serial.print(" Welcome to MSR GLOVE TEST. ");
delay (temPause);
Serial.println(" For The Best Results,");
delay (temPause);
Serial.println(" Remain Calm and Avoid Motions Excluding the Moving Palm. ");
delay (temHold);
Serial.println (" Measurements Will Begin In ");
delay (temPause);
Serial.print(" Three......");
delay(waitTime);
Serial.print("  Two.......");
delay(waitTime);
Serial.println("  One.........");
delay(waitTime);
}

// the loop routine runs over and over again forever:
void loop() {

  int sensorValue = analogRead(A0);   // read the input in analog pin 0:
  Serial.print(sensorValue);        // display the EMG values measured in Serial Monitor
  Serial.print(" mV")
  delay(50);                          // delay in between reads for stability
```

Figure A-2: Full Program Code for Muscle Sensor.

```
#include <DHT_U.h>                    // libraries
#include <SoftwareSerial.h>
#define MyoWare A0                    // Muscle Sensor Input
#define LM35 A5                       // LM35 Input
#define Type DHT11                    // DHT Input
int sensePin=2;
DHT HT(sensePin,Type);
SoftwareSerial Bluetooth(10, 9);   // RX, TX

float humidity;
float tempC;
float tempF;
int EMGVal;


void setup() {
  // put your setup code here, to run once:
Bluetooth.begin(9600);
Serial.begin(9600);
HT.begin();

delay(500);
}

void loop() {

humidity = HT.readHumidity();
tempC = HT.readTemperature();
tempF = HT.readTemperature(true);

float lmvalue = analogRead(LM35);
float tempr = (lmvalue* 500)/1023;                //conversion of Fahrenheit to Celcius
float EMGVal = analogRead(MyoWare);


Serial.print(tempr);
Serial.print(" C ");
Serial.print(tempC);
Serial.print(" C ");
Serial.print(humidity);
Serial.print(" % ");
Serial.print(EMGVal);
Serial.println(" mV ");


Bluetooth.print(tempr);
Bluetooth.print(tempC);
Bluetooth.print(humidity);
Bluetooth.print(EMGVal);
delay (500);
```

Figure A-3: Full Program Code with Multi-Sensor Function