SOFTWARE USER INTERFACE AND ALGORITHM DEVELOPMENT FOR SIGNAL AND NOISE CHARACTERIZATION

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A project report submitted in partial fulfillment of the requirements for the award of the degree of Bachelor of Engineering (Hons) Electronic Engineering

Faculty of Engineering and Green Technology
Universiti Tunku Abdul Rahman

September 2015

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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I certify that this project report entitled **"SOFTWARE USER INTERFACE AND ALGORITHM DEVELOPMENT FOR SIGNAL AND NOISE CHARACTERIZATION"** was prepared by **PHOONG WEI SIANG** has met the required standard for submission in partial fulfillment of the requirements for the award of Bachelor of Engineering (Hons) Electronic Engineering at Universiti Tunku Abdul Rahman.

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SOFTWARE USER INTERFACE AND ALGORITHM DEVELOPMENT FOR SIGNAL AND NOISE CHARACTERIZATION

ABSTRACT

Atomic force microscopy (AFM) also known as “Scanning force microscopy (SFM)” is high resolution scanning probe. The resolution of scanning object is reached to the order of fractions of a nanometer. Its advantage is the performance of AFM is better than optical diffraction. The wide application range of AFM include mapping, measuring or scaling in nanometer scale precise state. To construct an AFM, Optical Beam Deflection (OBD) system was always applied. Laser as source to emit light and photodiode as detector to detect the light. The cantilever is scan the object along X-axis direction and Y-axis direction. The light is emit to cantilever and reflect the light to photodiode. The data from photodiode is read by LabVIEW software for further develop to obtain useful output data. The previous task done by senior is I/V converter and algorithm for detect location of photodiode are implement by using LM741 op-amp chip on printed circuit board. The output data display in array is only x-axis direction. In my final year project, the purpose of project is reconstruct the I/V converter by using op-amp chip other than LM741 and the algorithm for detect location of photodiode is implement by LabVIEW software. The output data display in array is implement to display in two dimension array with X-axis direction and Y-axis direction.

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CHAPTER 1

INTRODUCTION

1.1 Background

A scanning tunneling microscope is device to measure forces as small as 10^{-8}N. From this concept, new type of microscope called atomic force microscope (AFM) or scanning force microscopy (SPM) which is capable of investigating insulators surfaces on an atomic scale is design by engineer. Generally, atomic force microscopy is a combination of the principles of scanning tunneling microscope and the stylus profilometer. Gerd Binning and Heinrich Rohrer is founder of this development in 1980s during an IBM research. This invention had helped them to won a Nobel Prize in 1986. After few years which in 1989, AFM was introduced commercially. The first type of AFMs operated in contact mode where tip mounted onto the end of flexible cantilever. Raster scans the surface of the object. The high resolution of result was obtained through the deflection of light beam lie the tip was scanning sample's surface. Samples are analysis in air, vacuum and liquids. However, the problem with contacted AFM is that biological samples are difficult to scan because they are soft and weak to lie on the surface. The problem solved by introduces new type of AFM with non-contacted mode in 1987. Within its resonant frequency, cantilever oscillates above the plane. In 1993, Tapping Mode was introduced where cantilever gently taps the plane during the process of scanning. Reduction of damage at lateral part is greatly improved due to this method applied. In 1996, a smaller cantilever was designed to provide higher resolution and also smaller scanning times.

1.2 Aims and Objectives

The aims and objectives of this final year project with the title of **SOFTWARE USER INTERFACE AND ALGORITHM DEVELOPMENT OF SIGNAL AND NOISE CHARACTERIZATION FOR ATOMIC FORCE MICROSCOPY** are shown as following below:

i) Build an integrated prototype.
ii) Design a user interface and algorithm development for signal and noise characterization through LABVIEW.
iii) Compare and evaluate performance of system with algorithm implement in printed circuit board and LabVIEW software.
iv) To study and understand the algorithm about position of laser emit on quadrant photodiode.
v) To study relate to control receiver and transmitter of NI ELVIS II.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Optical Beam Deflection (OBD)

Atomic Force Microscopy also known as Scanning Force Microscopy (SFM) is a high resolution scanning device to scan the sample that up to nanometer of changes on surface. On the other hand, it able to measure the roughness of sample at a high resolution which is in nanometer.**(Hegner, 2012)**

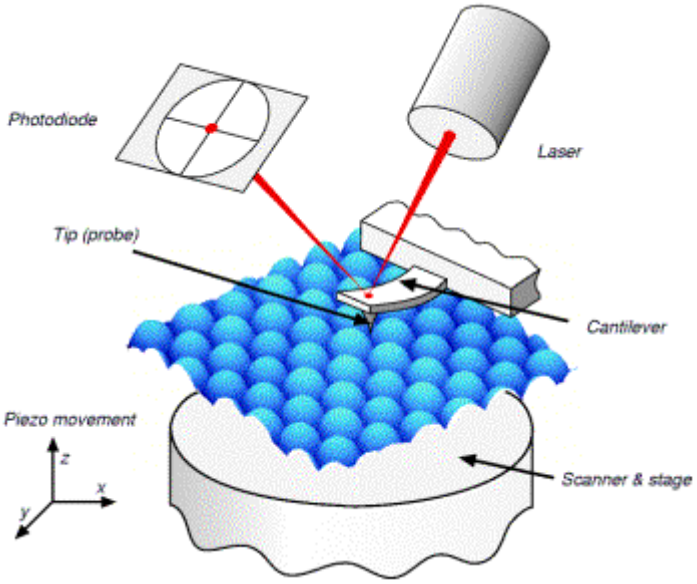


Figure 1: Atomic Force Microscopy

The components of Atomic Force Microscopy consist:

1. Laser
2. Cantilever
3. Tip (Probe)
4. Photodiode
5. Scanner & stage

2.1.1 Operation

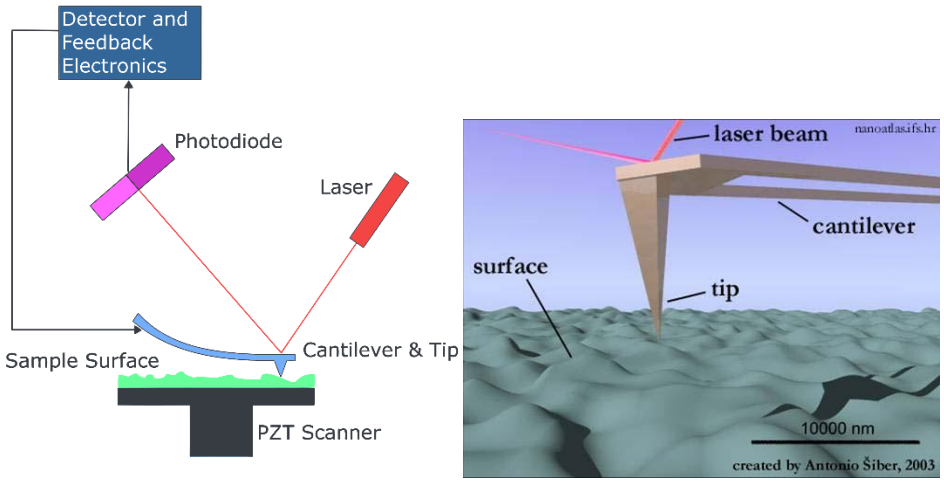


Figure 2: Concept operation

The Figure 2 above show that elastic of cantilever make it able to bend and scan the roughness of sample with a tip at the end of cantilever. Laser is emitting light on the surface of cantilever and reflects to photodiode. With the movement of piezo lead the scanner to scan along the X-axis direction and Y-axis direction, the cantilever is move up and down. The different height of cantilever cause the lights emit to it to produces different reflection angle. Hence, the position detector of photodiode that the light emit on it is depends on the height of cantilever. This is known as "Deflection". Photodiode generate a small current when light is emit on it and this current is send to electronics part to measure and record.

2.2 Laser

Figure 3: Laser

Laser known as “light amplification by stimulated emission of radiation” and it is device that emit light beam by way of process of optical amplification. Area of light beam emit by laser on the junction of photo detector greatly affect the precision of results after measurement.

2.3 Photodiode

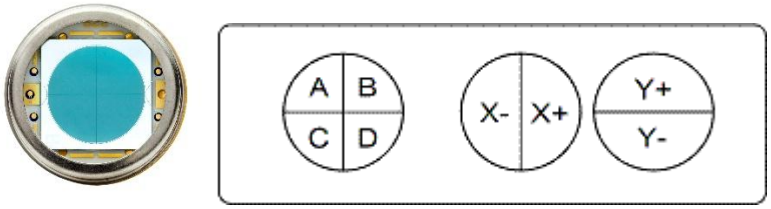


Figure 4: Four quadrant photodiode and properties

To detect the light beam from laser, a four quadrant photodiode is used. The photodiode operate in reverse bias as it consists an active p-n junction. The response of reverse current is proportional to illuminance when the light beam from laser is emit on the junction of photodiode.

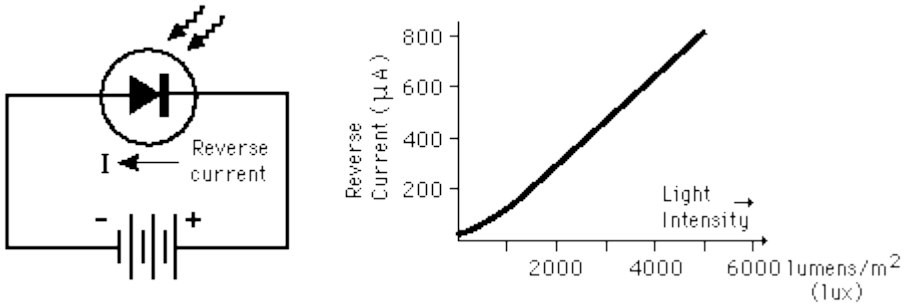


Figure 5: Characteristics of photodiode

2.4 Photodiode Light Detector

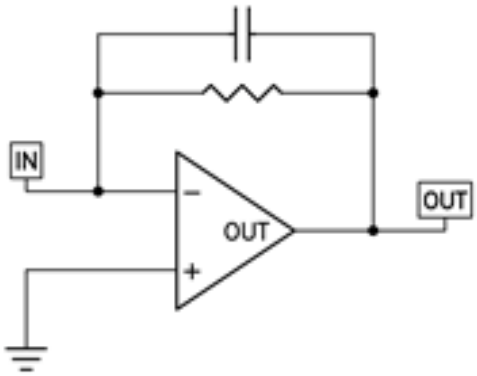


Figure 6: Photodiode Light Detector Circuit

Basiclly, photodiode light detector is a converter that convert the current to voltage. Op-amp IC chip is used as its FET input able to prevents loading of photodiode and the output voltage is directly proportional to current. Therefore, output voltage is proportional to the light beam emit on the junction of photodiode as long as light response of photodiode is linear.In order to filter out noise signals or undesired signals, capacitor is placed across feedback work as to reduce the impedance, so that its output gain relative to dc level signal is reduces.

The following Figure 7 below shown light detector circuit is connected to each pins of photodiode.

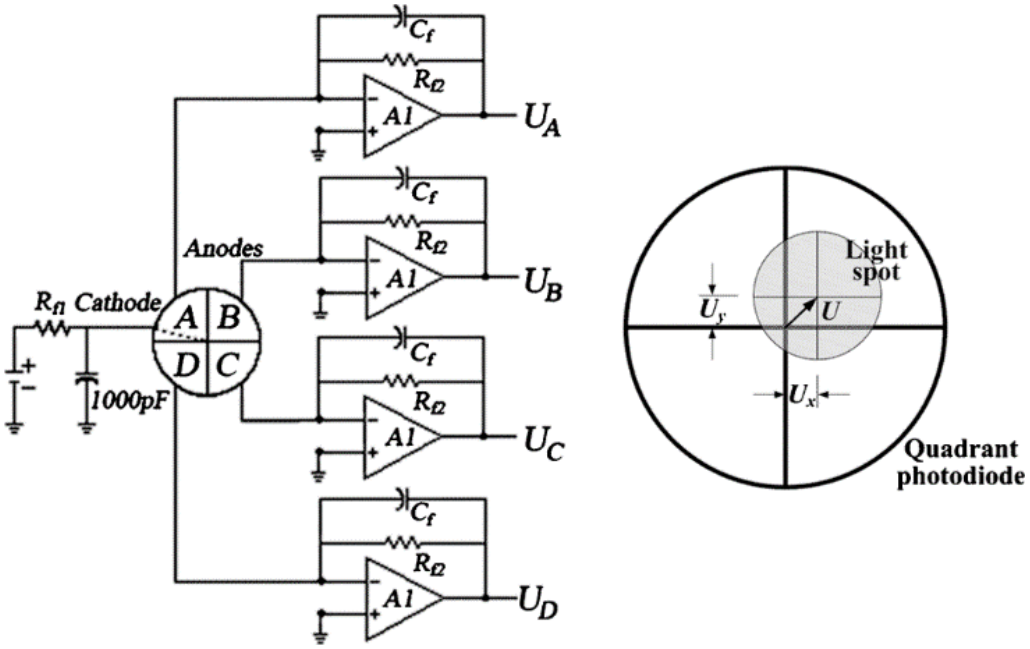


Figure 7: Connection of ligh detector circuit to photodiode

2.5 Location Detection Algorithm

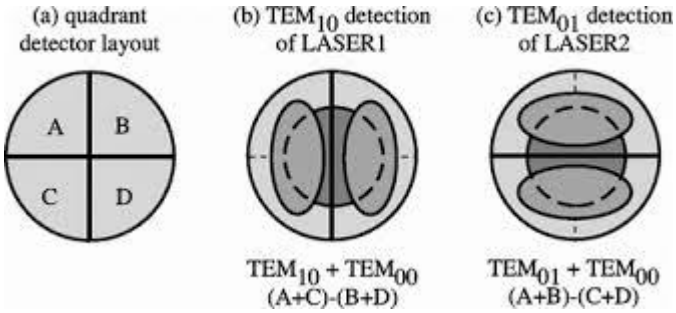


Figure 8: Detector layout and its algorithm

There are two type of light beam emit on the junction of photodiode, which is:

I. Deflection
II. Lateral

To detect the light beam is emit on left side or right side of photodiode. The Figure 8 at above show that (A+C) – (B+D). While the detection of top and bottom is (A+B) + (C+D).

2.6 Buffer

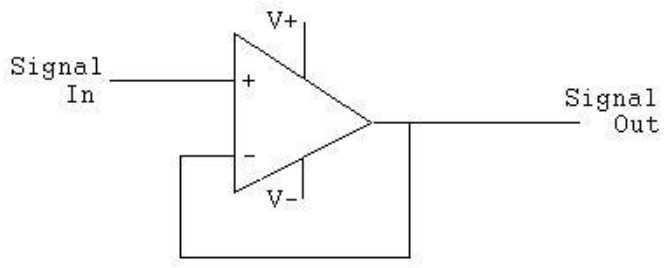


Figure 9: Simple buffer circuit

The purpose of voltage buffer is to prevent the second circuit from loading the first circuit unacceptably and interfering with its desired operation. Besides that, it also increases the current for low impedance input while retaining the voltage level. Hence, signals and data bits can be passing with sufficient drive capability along to a succeeding stage.

2.7 Printed Circuit Board (PCB)

Printed Circuit Board (PCB) is a non-conductive board that become a conductive board by printed or etched the conductive lines on it, so the board can mechanically supports the electrical connection between electronic components. Mount the electronic components on the board by soldering and does not need any wire to connect other components due to conductive lines are the advantage of printed circuit board (PCB). It makes the overall circuit look tidier and systematic. Design the circuit for PCB with double side is the best way to reduce board size used.

Eagle is software that use to implement the circuit which designed in breadboard to printed circuit board (PCB). It provides a components interface to allow user to choose the size and type of components. Auto routing is a function provided by Eagle to sketch the connection layout between components. Before auto routing, Eagle also allow user to setting the width of conductive lines, width between conductive lines and etc.

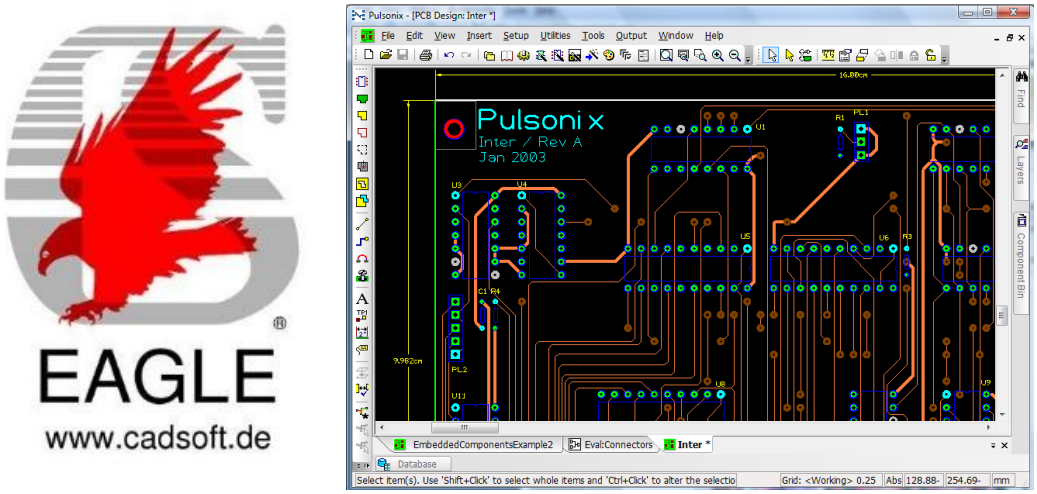


Figure 10: Interface example of EAGLE

2.8 LabVIEW

LabVIEW is a short-form of Laboratory Virtual Instrument Engineering Workbench. It is a software to create custom application for interact with the real world data. LabVIEW provide a different programming language from other software which is graphical dataflow programming model. This type of programming language known as “G programming”. Shorter learning curve and familiar visual to represent processes are the advantage of graphical programming compare to traditional text-based programming.

Graphical programming language is easy to understand and use due to this type of language is focus on the flow of data unlike the text-based programming that need basic knowledge and further study. Besides that, LabVIEW is supported by many hardware devices, including NI ELVIS II, scientific instruments, data acquisition devices, sensors, cameras and etc.

The powerful of LabVIEW is allowing user to create and design their user interface and reporting tools. Button, textbox, decision select box, enum, knob and so on as input to allow user to manipulate the system and display the data in indicators such as table, graph, chart, led and so on. LabVIEW also provide save and read function to store data in varies file types.

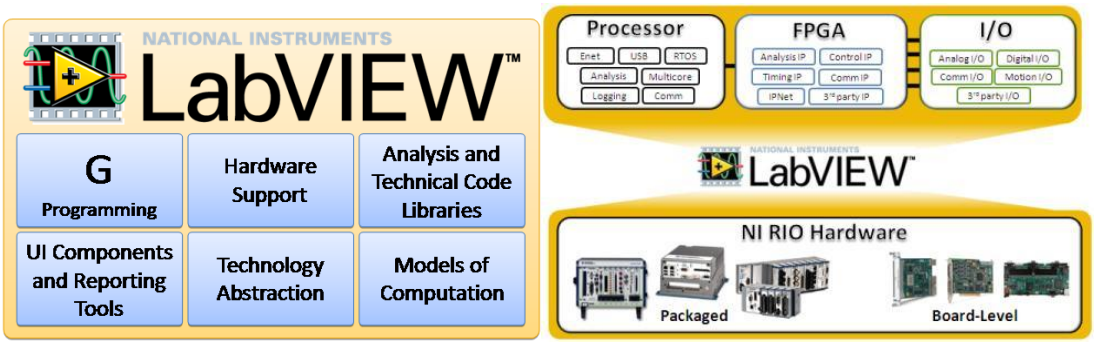


Figure 11: Advantage and properties of LabVIEW

2.9 NI ELVIS II

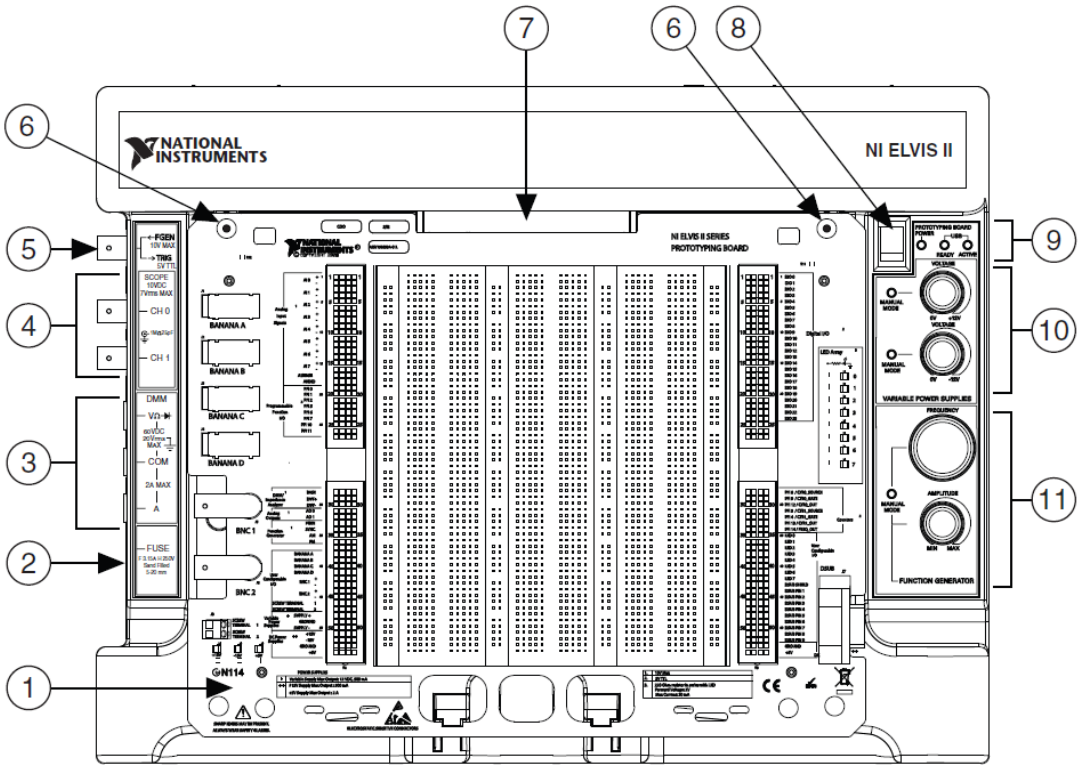


Figure 12: NI ELVIS II

Table 1: Specification of NI ELVIS II

1. NI ELVIS II Series prototyping Board	6. Prototyping Board Mounting Screw Holes
2. DMM Fuse	7. Prototyping Board Connector
3. DMM Connectors	8. Prototyping Board Power Switch
4. Oscilloscope Connectors	9. Status LEDs
5. Function Generator Output/ Digital Trigger Input Connector	10. Variable Power Supplies Manual Controls
	11. Function Generator Manual Controls

The National Instruments Educational Laboratory Virtual Instrumentation Suite (NI ELVIS) is a hands-on design and prototyping platform. It is integrates the commonly used electronics instrument including oscilloscope, digital multi-meter, function generator, bode analyzer, and more. Connect it through USB connection to PC for providing quick and easy acquisition and display of measurements.

Benefit of NI ELVIS:

I. Cost-Effective–integrates of electronics instruments.

II. Easy to Use, Less Time Troubleshooting, More Time Learning

III. Multisim Integration - supplies the necessary components for a wide variety of applications from investigating basic circuit principles to prototyping research projects. Allow user build circuit on a virtual protoboard and view the simulated results with the real-world measurements in the same screen by using the soft front panels.

IV. Flexibility with LabVIEW and Software - electronics instruments of the NI ELVIS platform are accessible through the NI ELVISmx Instrument Launcher.

V. Technical Support – as a member of the NI Developer Zone community and collaborate with professors, enthusiasts, and professionals through discussion forums and instructional material downloads.

2.10 Mechanical Set up (LEGO)

LEGO is a plastic construction toys to let children use their imagination to build something. It is best recommendation when to build a prototype for final year project due to it able to decompose and reconstruct. Each of LEGO brick was designed to a standard dimension so that each of brick can stick together tightly. Different types of brick with different dimension allow to build a complicated design.

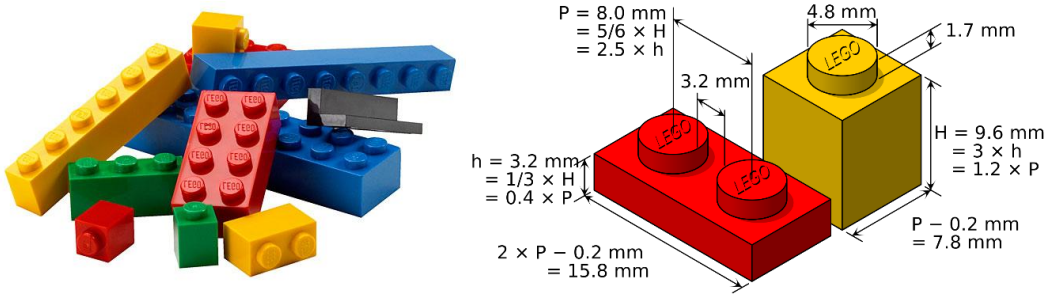


Figure 13: Type and dimension of bricks

2.11 Time Domain and Frequency Domain

Spectrum analyzer is an electronic device or machine that uses to analyze signals, noise and frequency. Most natural way, spectrum analyzer is used to observe signal varies in amplitude as time progress. Secondly, spectrum analyzer provides frequency domain function that use to display amplitude in certain range of frequency. It is useful for communication system because able to observe those unwanted signals which will cause interference to other signals and decrease the performance. Spectrum analyzer allows observing so that ensures the unwanted signals are below acceptable or criteria.(Poole, n.d.)

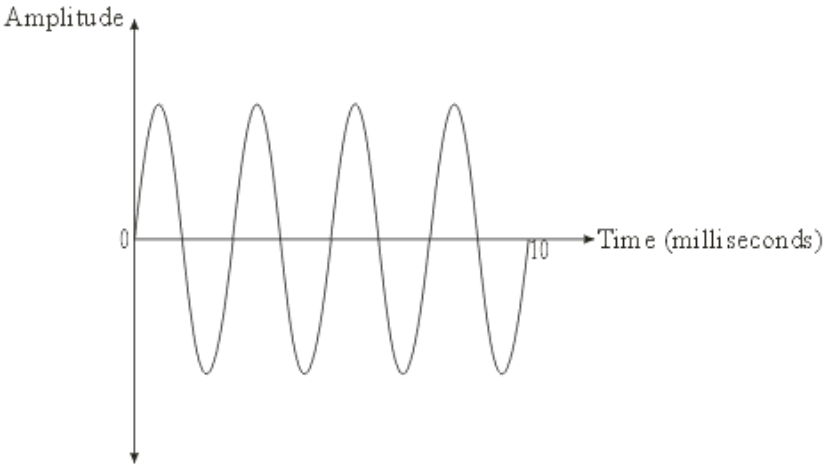


Figure 14: Time domain

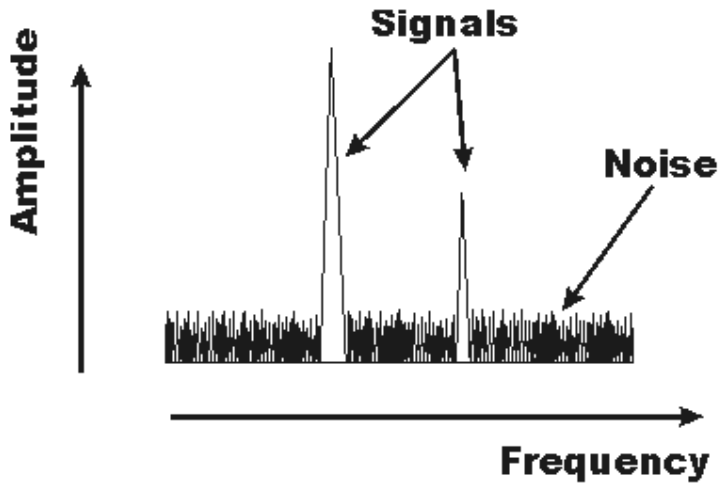


Figure 15: Frequency domain

2.12 Comparison of FIR and IIR Filters

Filter is the function use to filter out the unwanted signals called noise signals in order to ensure the performance. But here, there are two choice of filter which is Finite impulse response filter (FIR) and Infinite impulse response (IIR). The following table below shows the different between FIR and IIR filter. **(FIR filter vs IIR filter, n.d.) (Designing Filters Using the NI LabVIEW Digital Filter Design Toolkit, 2011)**

Table 2: IIR vs FIR Filters

Finite impulse response filter (FIR)	Infinite impulse response filter (IIR)
• Linear phase	• Non-linear phase
• Stable	• Unstable
• No limited cycles	• Limited cycles
• Derived from analog	• No analog history
• Always be made casual	• Polyphase implementation
• More memory require to store data	• Less memory require to store data

From the Table 2 above, FIR filters always have linear phase but IIR filters have non-linear phase and difficult to control. It means all frequencies component of input signals are perfectly shift in time with constant amount for FIR filter whereas there are delay distortions or phase distortion for IIR filter when delay applies to system. FIR filters are always stable whereas IIR filters are not always stable.

From Figure 16, the figure shows that FIR filter is dependent on input only whereas IIR filter is dependent on both input and output. Or we can say that, FIR filters consist only zero (numerators) whereas IIR filters consist of zero and poles (numerators and denominators), and require less memory than FIR filters from difference equation of FIR and IIR. Due to IIR filters have delay and distort adjustments of poles &zeroes problem, so make the filters unstable can become difficult to implement. Therefore IIR filters can be unstable but FIR filters are always stable.

FIR filters have no limited cycles but IIR filters have limited cycles. Limit cycles are instability of a particular type due to quantization, which is severely non-linear. IIR filters make polyphase implementation possible, whereas FIR can always be made casual. Number of multiplications and additions, #MAD used as criterion for comparing different of FIR filters and IIR filters. After the algorithm, IIR filters show that it requires more #MAD than FIR filters due to high order of FIR compare to low order and uses polyphase structures of IIR.(FIR filter vs IIR filter, n.d.)(Jilani, 2011)

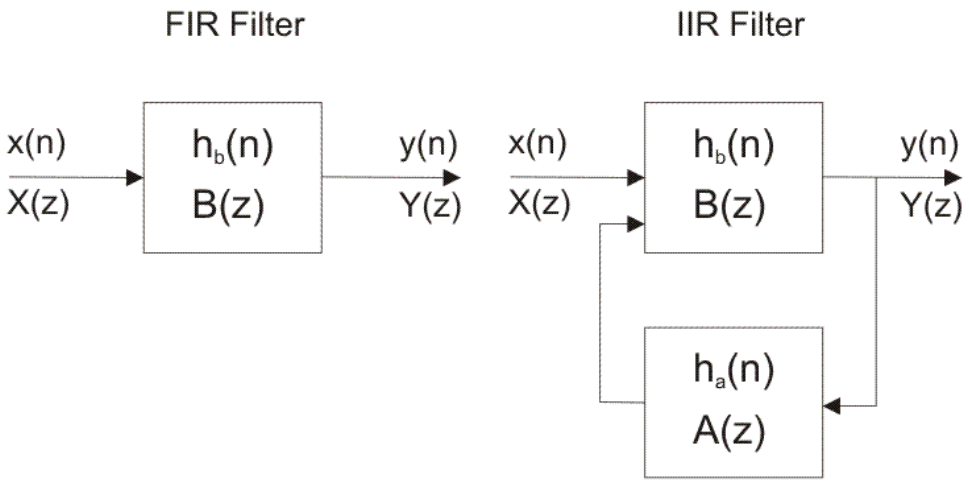


Figure 16: Structure of FIR and IIR Filters

Difference equation for FIR filters

$$y[n] = \sum_{i=0}^{M} b_i x[n-i]$$
$$= b_0 x[n] + b_1 x[n-1] + b_2 x[n-2] + \cdots + b_M x[n-M]$$

Difference equation for IIR filters

$$y[n] = b_0 x[n] + b_1 x[n-1] + \cdots + b_M x[n-M]$$
$$-a_1 y[n-1] - \cdots - y_N x[n-N]$$

Figure 17: Difference Equation of FIR and IIR Filters

2.12.1 Reasons of FIR Filter

From the overall of comparison between FIR filters and IIR filters, FIR filters show it have better performance than IIR filter since FIR filters can have exactly linear phase, stable and don’t have delay distortion problem when shifting the signals in time.

CHAPTER 3

METHODOLOGY

3.1 Flow Chart of Work

The following Figure 18 below is the flowchart that the overall steps or procedure of my final year project for final year project I and II which is 28 weeks.

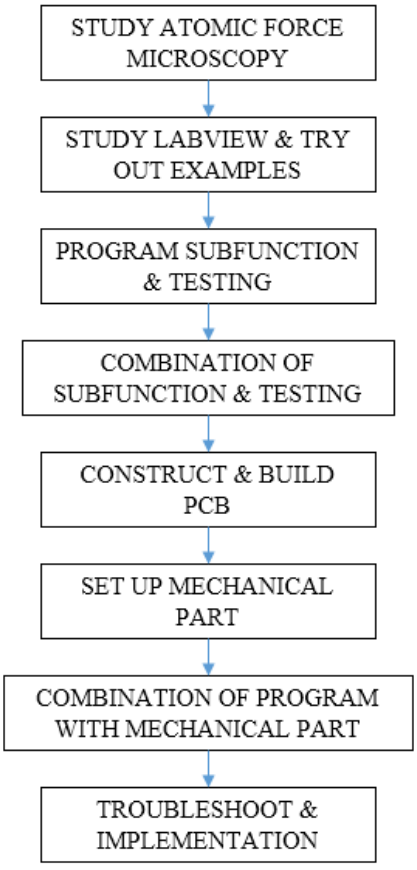


Figure 18: Flow chart of work

3.2 Schedule of Final Year Project

Two semesters are conducted by final year project. Therefore, the following two tables below shown the procedure of work during final year project I and II.

Table 3: Schedule of Final Year Project I

<table>
<tr><th>WEEK</th><th colspan="2">PROCEDURE</th></tr>
<tr><td>1</td><td colspan="2">Choosing Project Title</td></tr>
<tr><td>2</td><td colspan="2">Study & understand about Atomic Force Microscopy</td></tr>
<tr><td>3</td><td rowspan="7">Progress Log Part I</td><td rowspan="7">Study LABVIEW &Try out all the tutorials from book, website and YouTube</td></tr>
<tr><td>4</td></tr>
<tr><td>5</td></tr>
<tr><td>6</td></tr>
<tr><td>7</td></tr>
<tr><td>8</td></tr>
<tr><td>9</td></tr>
<tr><td>10</td><td colspan="2">Arrangement of study & Report writing</td></tr>
<tr><td>11</td><td colspan="2">Modify flowchart &Prepare slide for presentation</td></tr>
</table>

Table 4: Schedule of Final Year Project II

<table>
<tr><th>WEEK</th><th colspan="3">PROCEDURE</th></tr>
<tr><td>1</td><td rowspan="8">Progress Log Part II</td><td rowspan="2">Program sub-function& Testing</td><td rowspan="8">Analysis & Troubleshoot</td></tr>
<tr><td>2</td></tr>
<tr><td>3</td><td>Combination of sub-function& testing</td></tr>
<tr><td>4</td><td>Reconstruct & Build PCB</td></tr>
<tr><td>5</td><td>Program algorithm for position of photodiode</td></tr>
<tr><td>6</td><td>Mechanical part set up</td></tr>
<tr><td>7</td><td>Combination of mechanical part with program</td></tr>
<tr><td>8</td><td>Further implementation</td></tr>
<tr><td>9</td><td colspan="3">User interface decoration & Record results</td></tr>
<tr><td>10</td><td colspan="3">Data arrangement & Report writing</td></tr>
<tr><td>11</td><td colspan="3">Design poster & Report writing</td></tr>
</table>

3.3 Hardware Part

The purpose of hardware circuit in this project is to convert the signals from hardware components to signals that can be understand by program or system. Hardware circuit is dividing to two parts:

I. Photodiode Light Detector
II. Buffer

3.3.1 Photodiode Light Detector

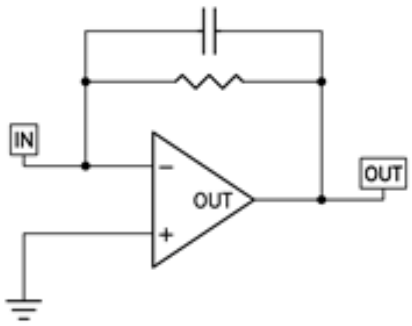


Figure 19: Op-amp I/V converter

Photodiode Light Detector is a circuit that uses to convert current to voltage. The “IN” from the Figure 19 represent to input current that the photodiode pin as input pin connect to it directly while the “OUT” represent output in voltage.

One resistor, one capacitor and Lm324 op-amp is used to design I/V converter. 10kohm of resistor is connecting the output and feedback to inverting input. And 10pF of capacitor is connecting parallel with resistor. Due to Lm324 has 4 internal op-amp circuits, the 10kohm of resistor and 10pF of capacitor is connecting to pin 1 and pin 2 of Lm324 which the pin 1 represent to OUT A and pin 2 represent to inverting input A. Non-inverting input A is connecting to ground. Pin 4 and pin 11 of Lm324 is connecting to +15V and -15V to power on the op-amp chip.

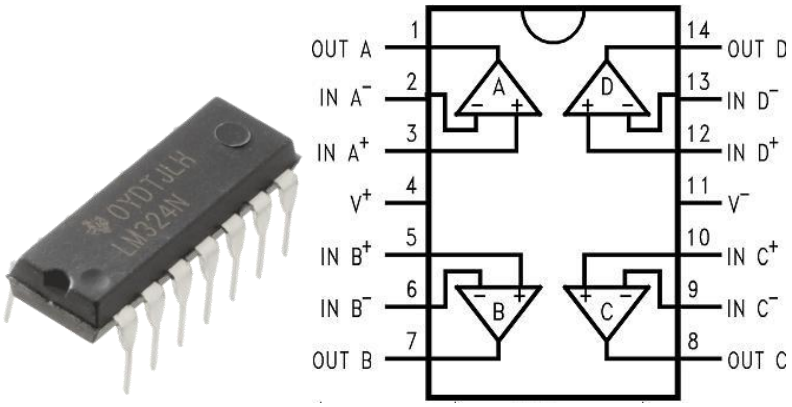


Figure 20: Lm324 and its internal circuit design

There are 4 pins to detect different detector plate for photodiode. Each pin of photodiode must connect light detector circuit to convert current to voltage. Therefore, 4 pins of photodiode mean need 4 light detector circuit. Lm324 has great benefit because it has 4 internal op-amp circuits. The following Figure 21 below shown the 4 pins of photodiode as input connect to inverting port of Lm324 op-amp.

Figure 21: 4 internal op-amp for 4 pins of photodiode

3.3.2 Buffer

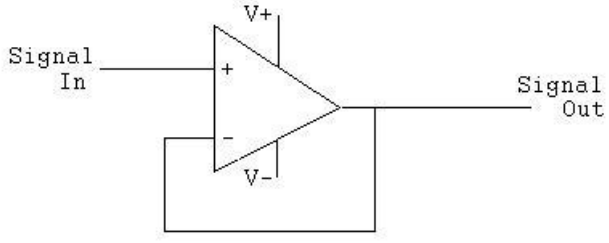


Figure 22: Simple buffer circuit

The output of I/V converter is directly connect to non-inverting input port to prevent loading of circuit and retaining voltage level. The buffer circuit is just simple connect its output feedback to inverting input port. Also, the IC chip used for buffer is Lm324. The following Figure 23 below shown the buffer is highlight with a red box.

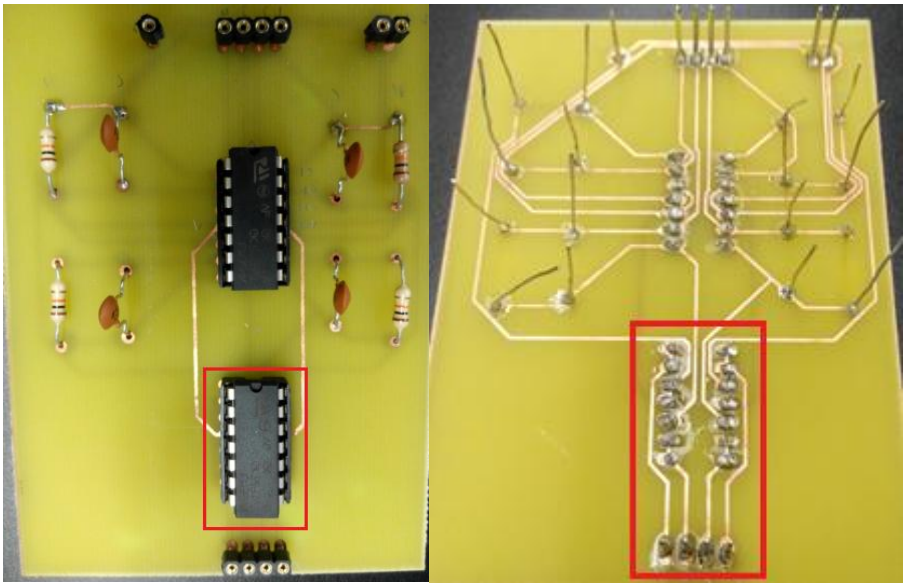


Figure 23: Buffer

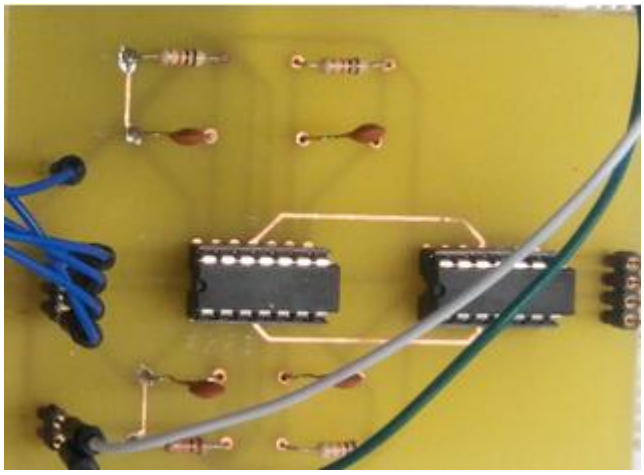


Figure 24: Overall view of I/V converter and buffer

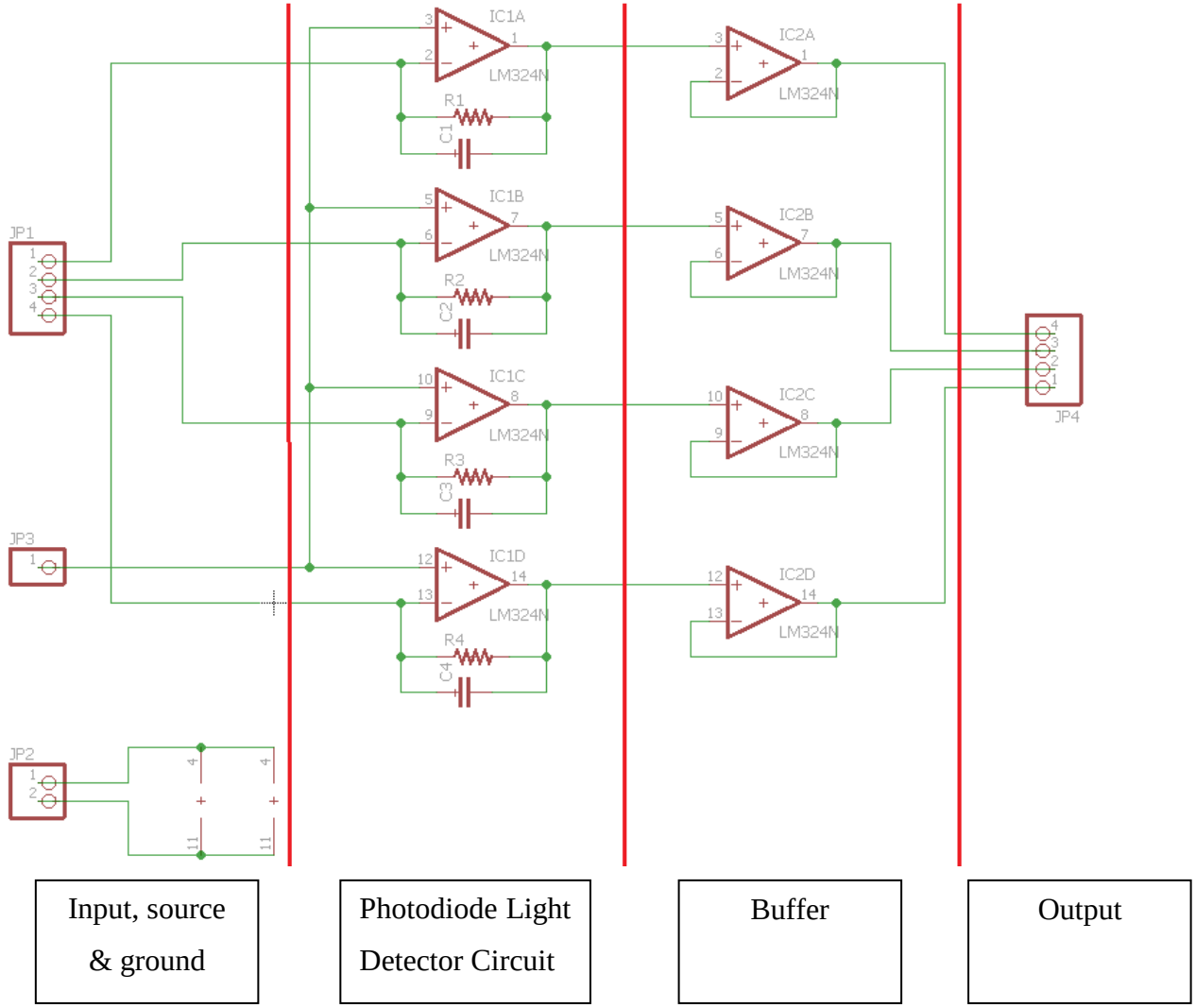


Figure 25: Schematic view of connection of part

From the schematic circuit diagram from Figure 25 above, the amount of components used for photodiode light detector circuit and buffer is list at below:

Photodiode light detector circuit:
1 Lm324 op-amp IC chip, 4 resistors with resistance of 10kohm, 4 capacitors with capacitance of 10pF

Buffer:
1 Lm324 op-amp IC chip

3.3.3 Implement to Printed Circuit Board

Electronic components design in breadboard look messy due to the wire connection and longer of components legs. Implement the circuit to printed circuit board and mount electronic components on board by soldering has benefit to reduce number of wire connection, reduce space usage and make the circuit look tiny.

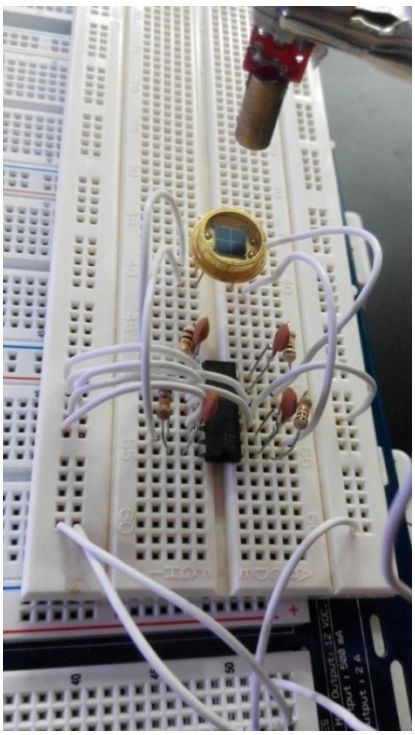


Figure 26: Photodiode Light Detector design on breadboard

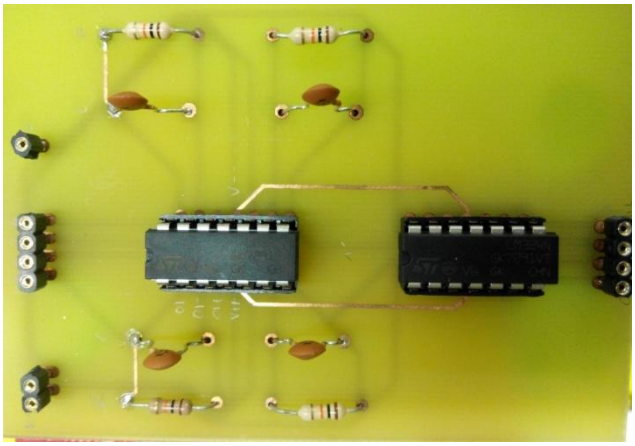


Figure 27: Overall view circuit design on printed circuit board

To design a printed circuit board, “EAGLE” software provide a features and virtual environment of designing. EAGLE is freeware and can be download from website. Create a new project for the schematic design and board design. Firstly, design the schematic circuit, so that the schematic circuit can switch to board design. EAGLE provide a large library that consists of most of components. The components can be add from library.

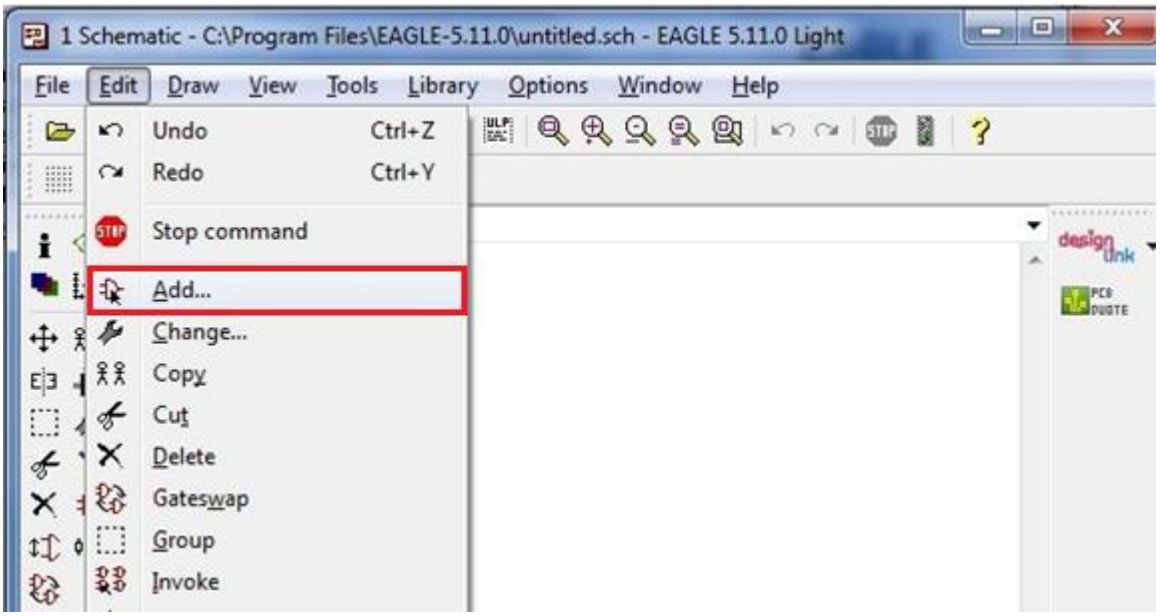


Figure 28: Add components from library

The components view in schematic diagram and board diagram will shown in component properties. Always observe the component view on board diagram due to same type of component may have different shape or design. Therefore, the same component may has a same component view on schematic diagram but different component view on board diagram.

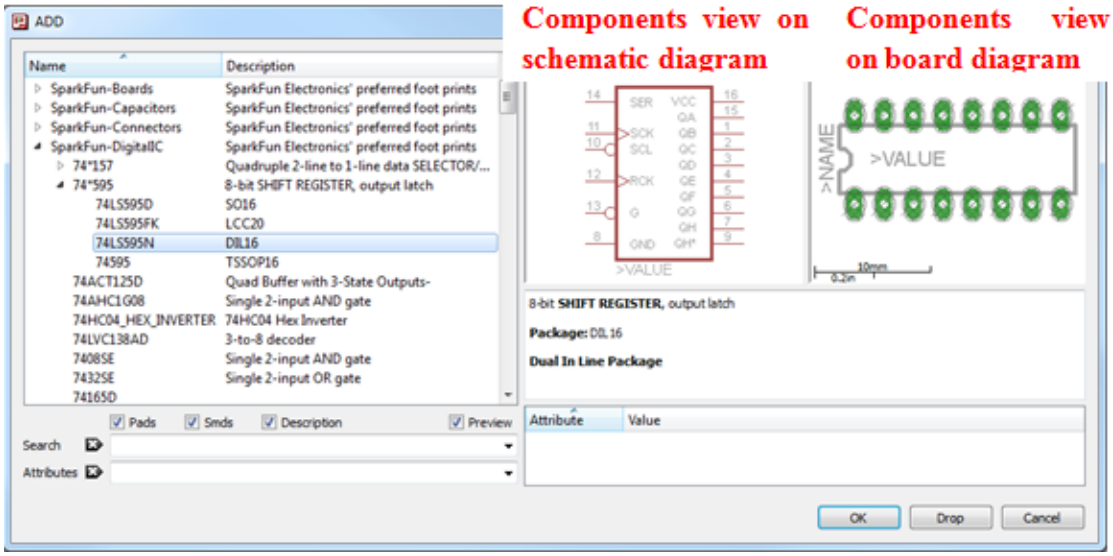


Figure 29: Component selected

Change the name and value from properties of component to convenient to distribute the components belong to the part of whole design.

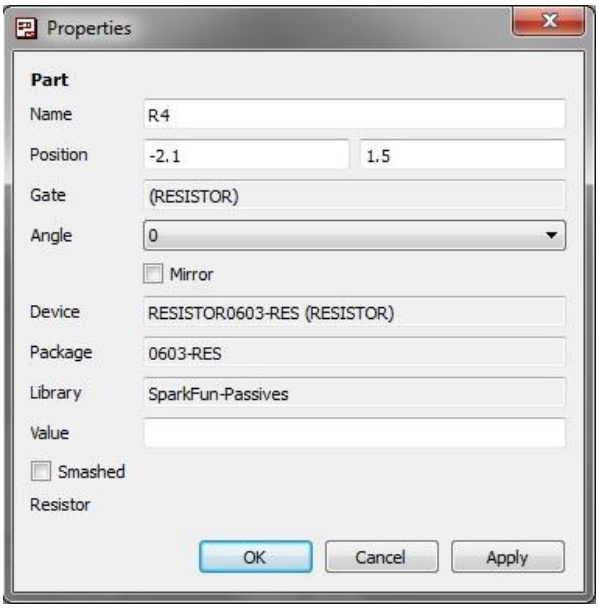


Figure 30: component properties

After placed and arrange all the components, connect them with wire.

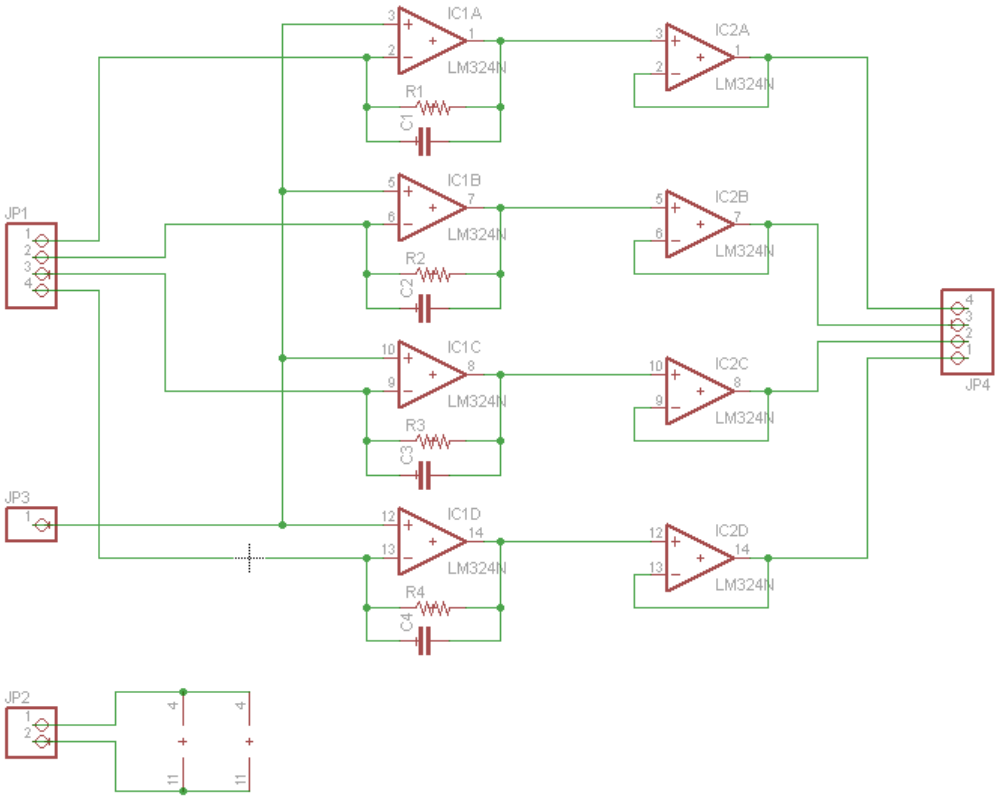


Figure 31: Overall view of schematic diagram

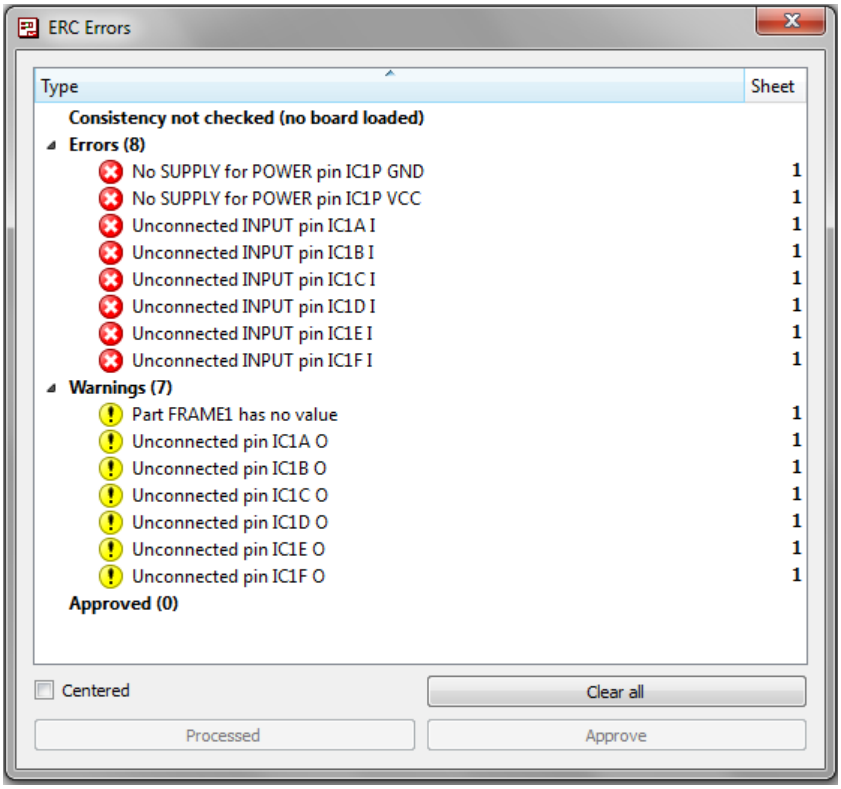


Figure 32: Electrical Rule Check (ERC) errors checking

Apply Electrical Rule Check (ERC) errors checking to check the connection error. After fix all of error and switch the schematic circuit to board diagram when the schematic design is done. The components add from library in schematic diagram will directly create a component board design in board diagram.

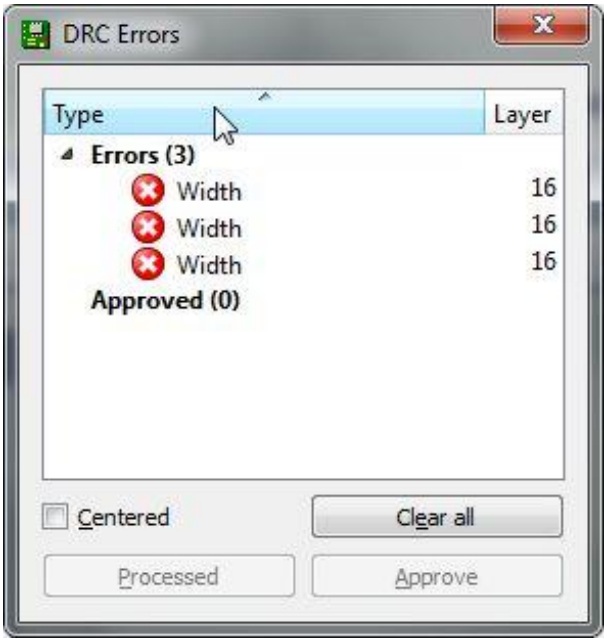


Figure 33: Design Rule Check (ERC) errors checking

The components in board diagram is arrange randomly at the beginning. Therefore, the components have to be rearranging again. After that, open DRC to set the design rule. The width of wire connection, hole size, spacing between components and so on is set in DRC for auto routing. The value of 16mil is set for properties of wire and distance.

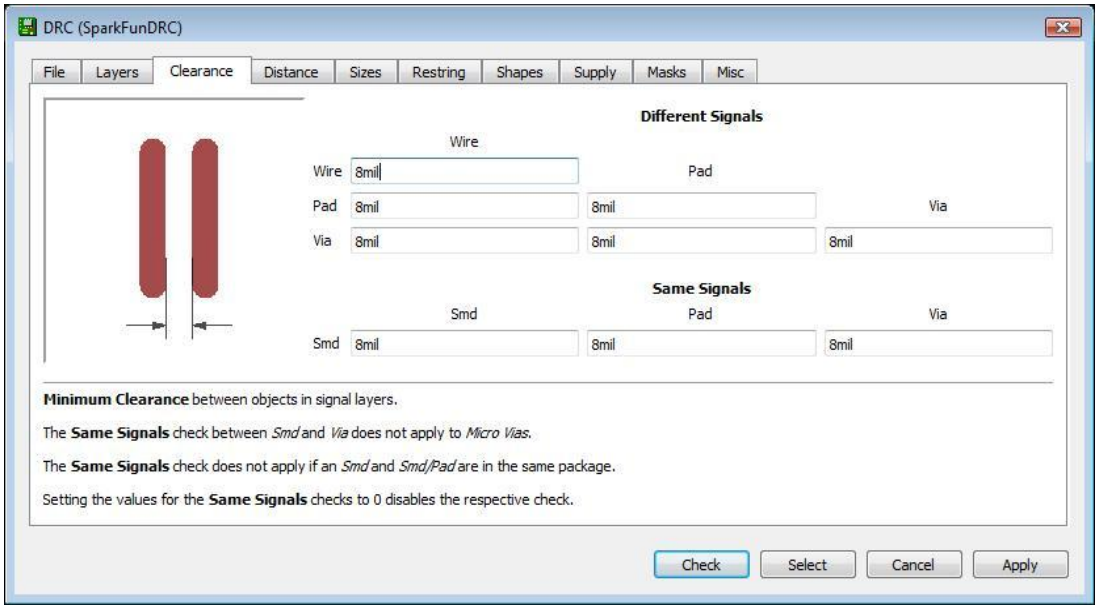


Figure 34: Design rule setting

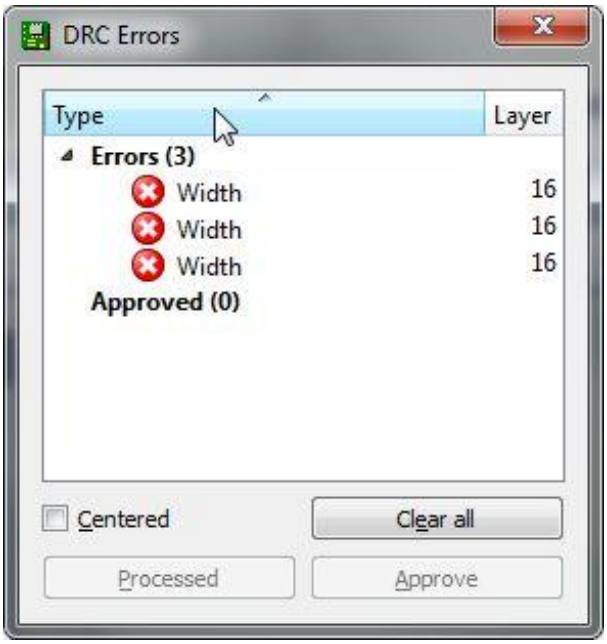


Figure 35: Design Rule Check (DRC) errors checking

Apply Design Rule Check (DRC) errors checking to check whether the setting that the in design rule setting can apply to the board design. The last step is auto-router setup. Select symbol “ * ” to apply connection and select “NA” to apply no application when auto routing. For example, select “ * “ for top and bottom, connection will be on both size of board. Select “ * ” for bottom and “NA” for top, connection will be on bottom layer only.

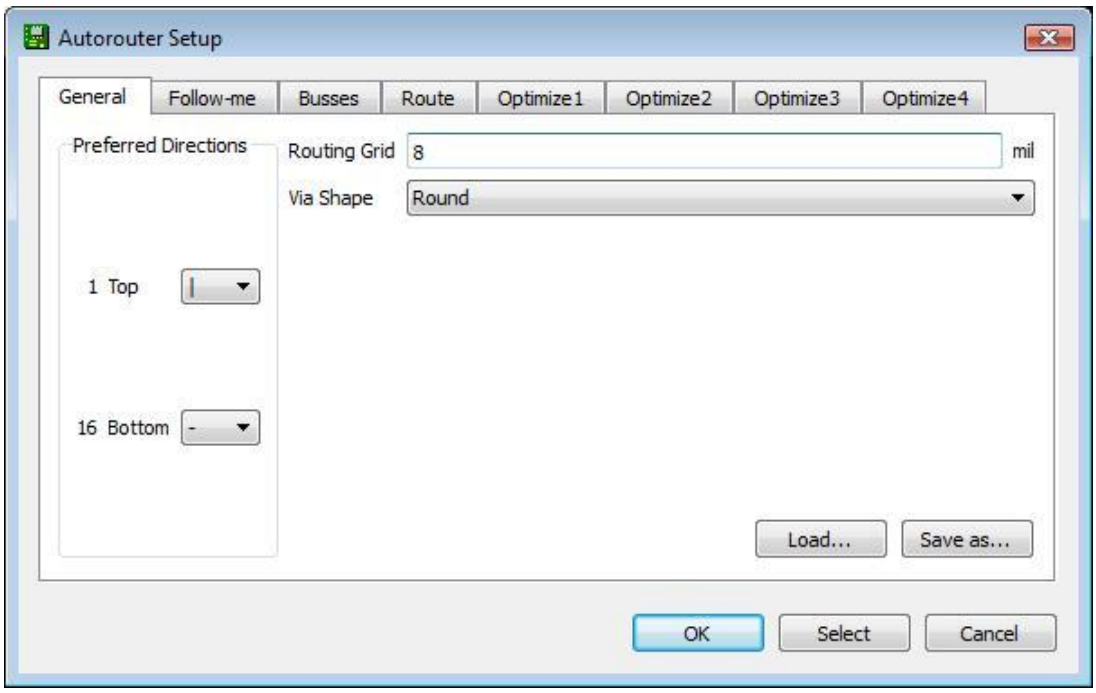


Figure 36: Auto-router Setup

EAGLE software proceed routing automatically once the ok button from auto-router setup is pressed.1 side printing is prefer due to there are no conductive lines on top side and this make the board look tiny and easy to track the connection. More than 10 times tried to adjust the components to obtain 1 side printing when auto routing. But still have 4 wires crashed with other connection. Lastly, connect those 4 wires go through top layer of board by manually.

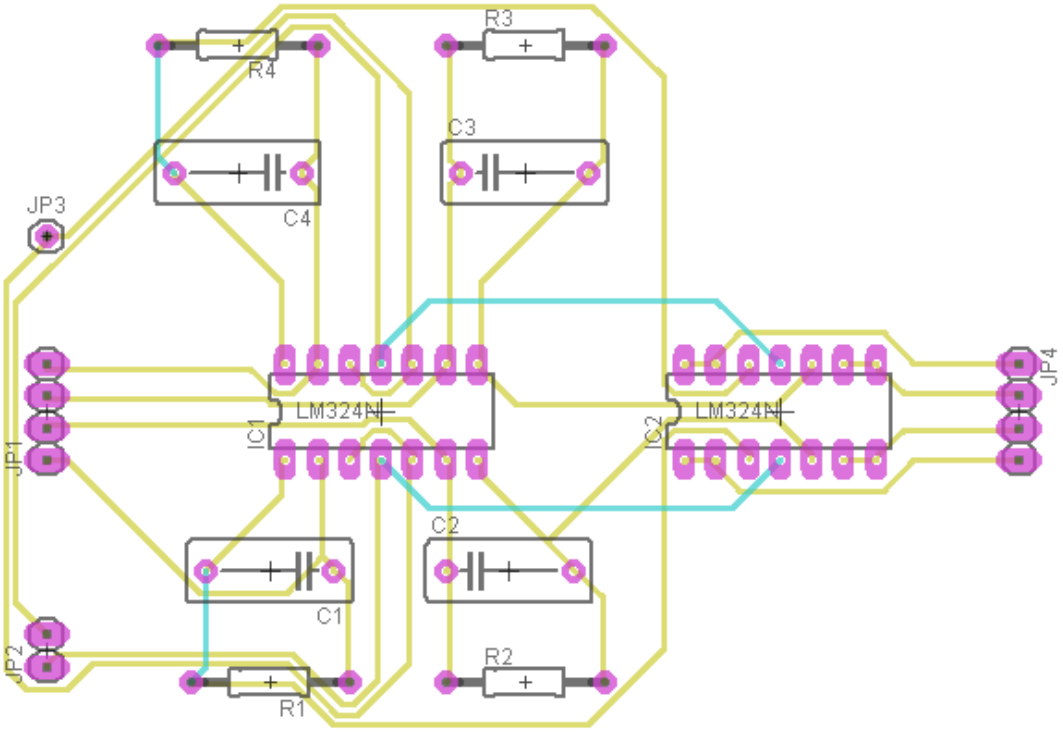


Figure 37: Board diagram

Double checking the board design and printed out for fabrication. After the printed circuit board fabrication completed, the electronics components are mount on the board and solders them by soldering gun and lead.

Figure 38: Solder iron and lead

The following Figure 39 below shown the soldering work.

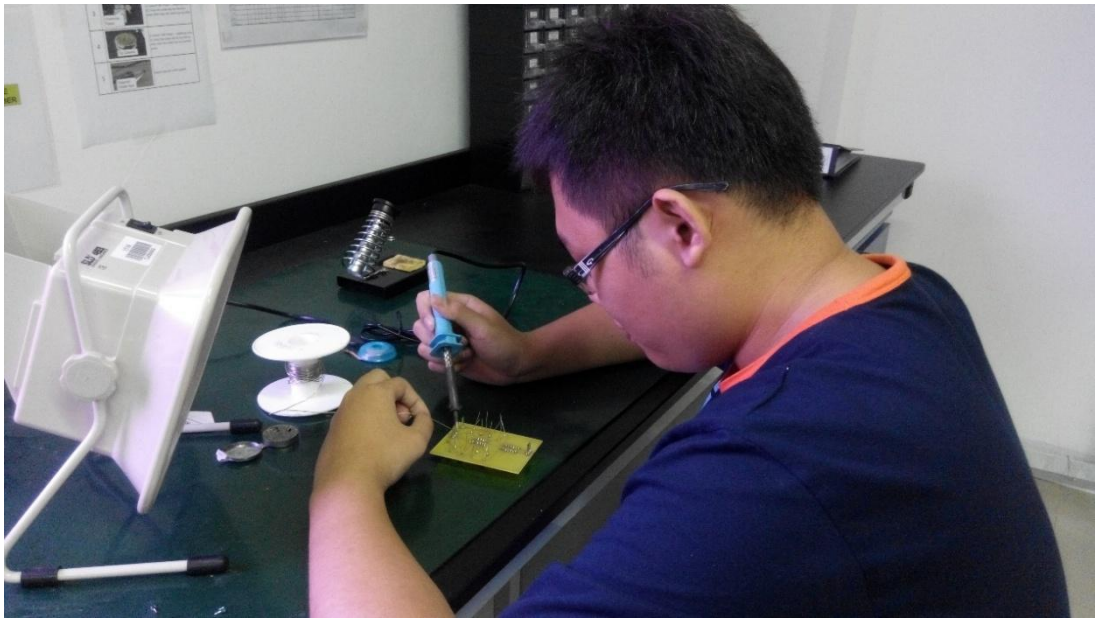


Figure 39: Soldering work

After the components are mount on the board and fix it by soldering. The legs are cut by using cutter.

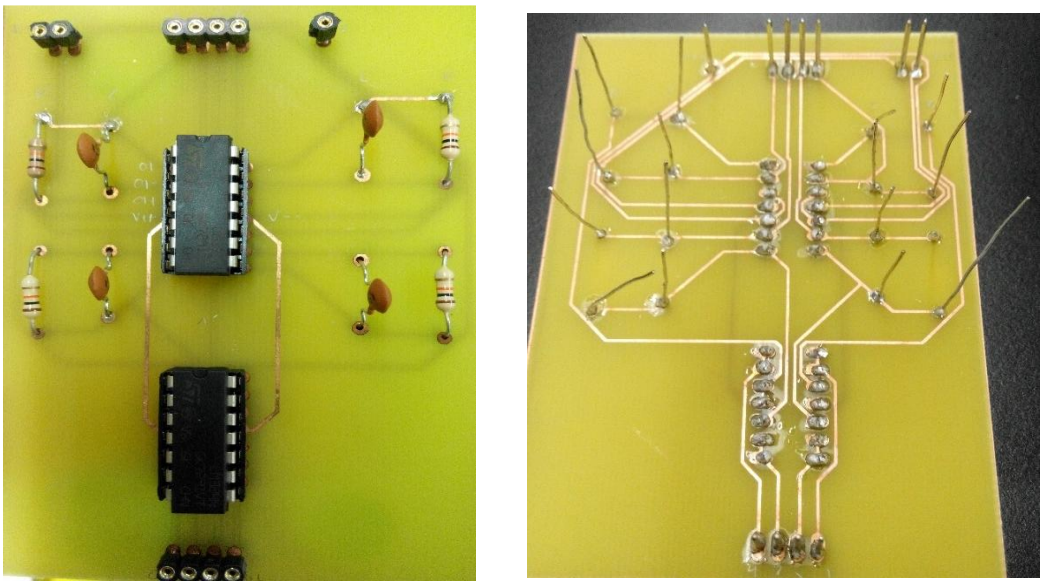


Figure 40: Top and bottom view of PCB

3.3.4 Mechanical Set Up

The basic concept is the laser beam emits light to cantilever and reflect the light with certain angle to center of detector. Therefore, mechanical set-up are support to hold the laser, detector and cantilever.

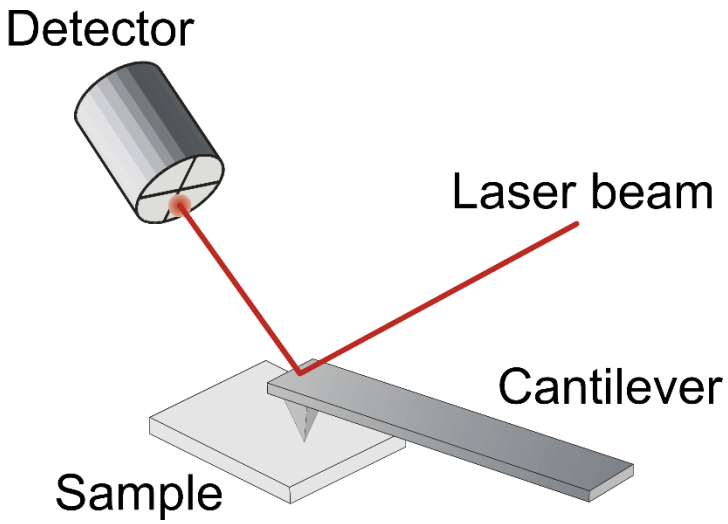


Figure 41: Basic concept of AFM

First of all, cantilever is made by an elastic material for bending easily. Due to the limitation of material and material characteristics, ruler is deciding used as cantilever. But the problem is the ruler cannot bend easily due to the thickness of ruler is quite thick. Hence, the thickness of ruler was cut in half by using knife.

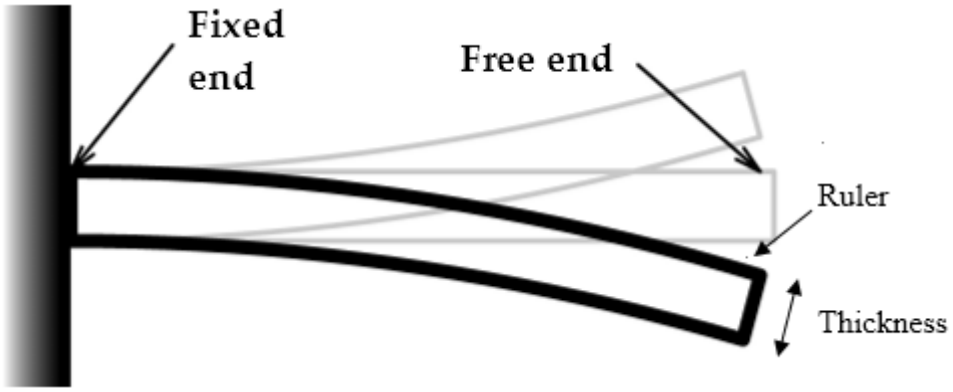


Figure 42: Thickness of ruler

The tip is replaced by tooth of comb because the tip is costly material and it is revolt the objective which is low cost. A hole was drill at the end of ruler and the tooth of comb is passing through the hole. Fix the tooth of comb by using hot glue gun.

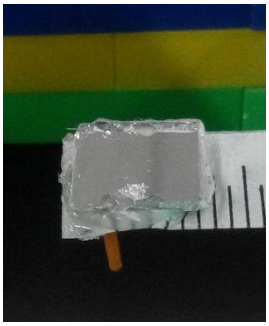


Figure 43: Fix the tooth of comb on ruler

After that, place a mirror on top of ruler to reflect the light. Also, use hot glue gun at this time to fix the mirror. Now, mechanical part was set up and shown in following figure below.

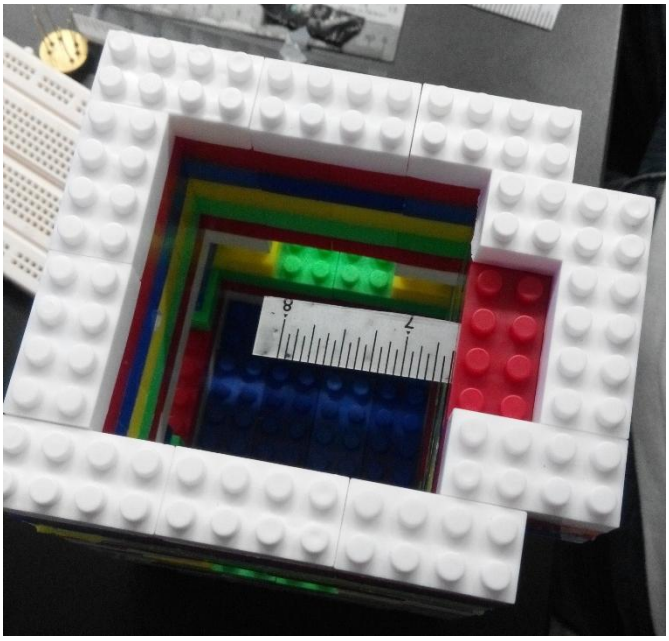


Figure 44: Mechanical set up

Use clay paste to the bottom of ruler to maintain the level of ruler to 90 degree. This work is necessary because it will bend toward downward and make the light cannot reflect to origin or center of junction of photodiode.

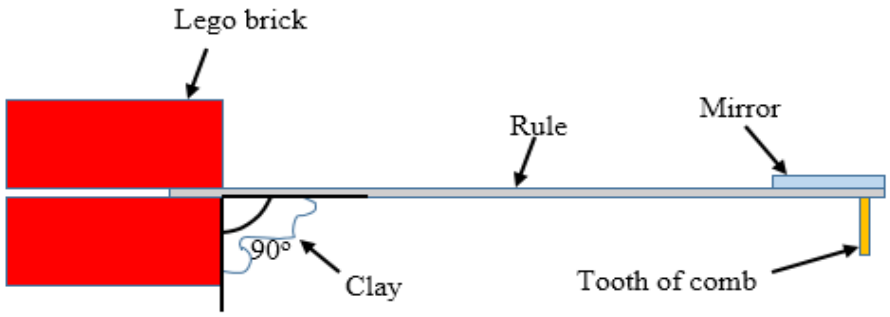


Figure 45: Fix level of rule

The next step is difficult part due to need take angle of the reflection light into consideration. The angle "α" from laser to mirror and from mirror to photodiode must be the same, so that the light will emit to the center of junction of photodiode.

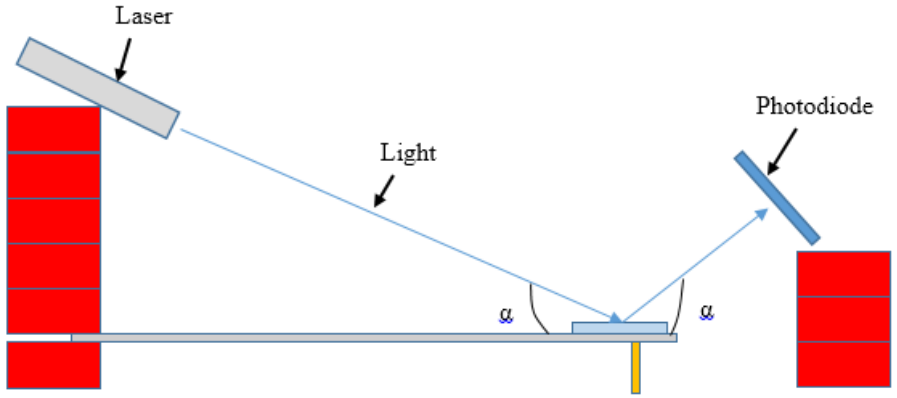


Figure 46: Angle of reflection

To make sure the light emit from laser is reflect to the center of junction of photodiode, laser must keep turn on when adjust the position of photodiode. When the light is reflecting to the center of junction of photodiode perfectly, use hot glue gun to fix the position of laser and photodiode. It is difficult because need keep focus on the light on photodiode to make sure it still in center position when fix the laser and photodiode by hot glue gun. Therefore, two person are needed to done this work,

one person hold the laser and photodiode and another person use hot glue gun to fix the laser and photodiode.

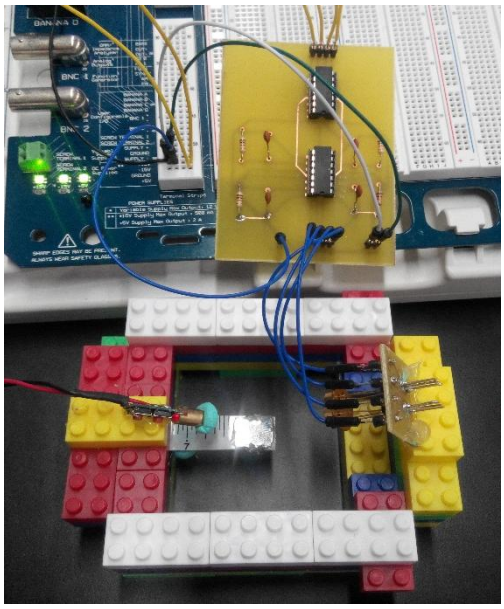


Figure 47: Fixing of laser and photodiode when light emit to center of photodiode

After fixing the laser and photodiode on LEGO brick, continue construct AFM using LEGO brick until the height of wall is totally higher than the laser and photodiode in order to construct a cap of AFM.

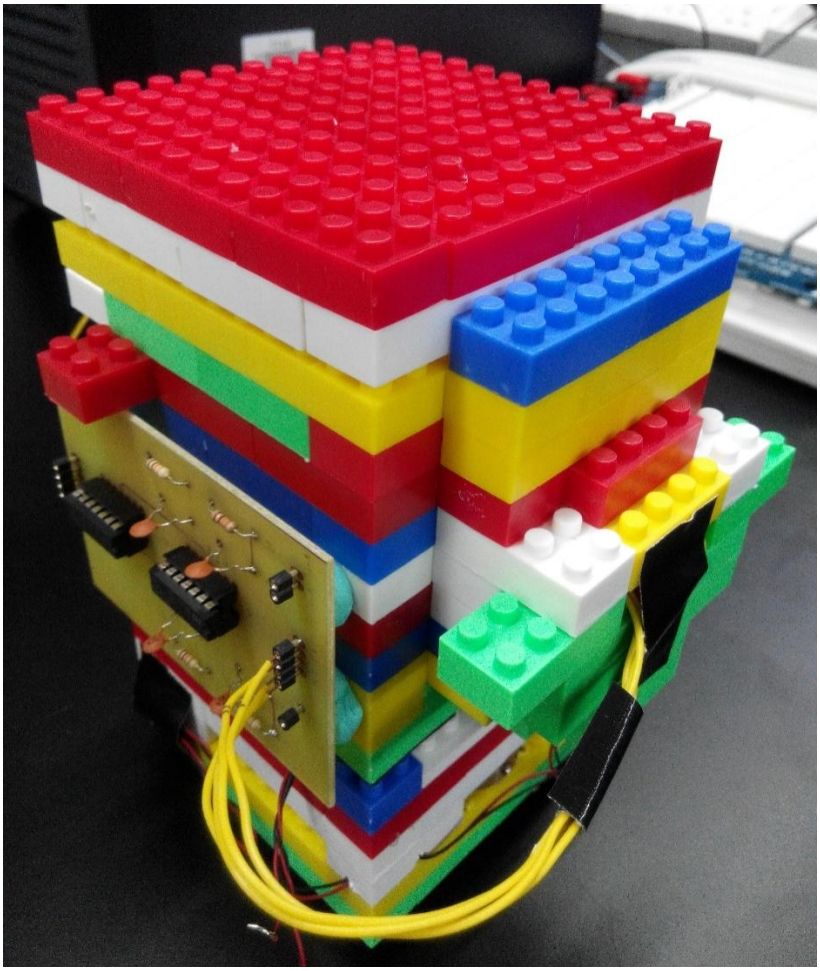


Figure 48: Overview of AFM

From the Figure 48 above, the printed circuit board is paste on the side of AFM by using clay and the wires from photodiode are arrange and connect to printed circuit board.

3.4 Software Part

The objectives of this process are to create a platform in order to observe and analysis the output of hardware in computer. LabVIEW software was introduced to create a user interface to allow user manipulate system and display output. LabVIEW is best recommendation software due to it provides a virtual environment for designing analysis operation.

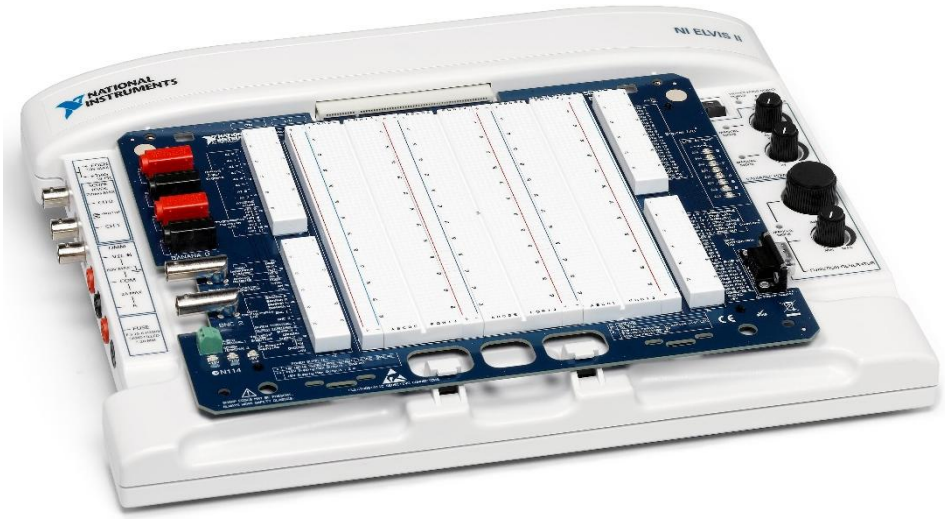


Figure 49: NI ELVIS II

In the other hand, LabVIEW is support with an NI instrument called NI-ELVIS II. NI ELVIS II is a powerful device due to it is combination of electrical instrument. It can represent all others instruments like function generator, multi-meter, voltage generator, oscilloscope and others. All of function can be getting from NI ELVIS II and this has the benefit to reduce work place. From the Figure 49, NI ELVIS II has built in a big breadboard on the printed circuit board. The circuit construct on it can easily obtain power supply or other measurement instrument by simply connect a jumper wire to circuit.

The concept of execution by using LabVIEW is reading the voltage values from printed circuit board through port AI of NI ELVIS II. Some detail need to take into account is the sampling rate, number of sample taken per seconds and type of signals. In printed circuit board, the circuit is design to convert the current to voltage, so signals should be read by NI ELVIS II in analog voltage type. Sampling rate is set in high constant value to capture precise results.

Due to testing different design of printed circuit board, the project has to select. Graphical code for read analog input values was design to read sample with multiple channel due to used four port from analog input of NI ELVIS II. For “Senior Project” project, only one analog input port used that is port 0.

But for “My Project”, four analog input ports are used that is port AI0, port AI1, port AI2 and port AI3. Because there are 4 detectors plate in photodiode to detect position of top left, top right, bottom left and bottom right. Four I/V converter in printed circuit board means four output voltage are generated which each represent one position. Therefore, those four output voltage as analog input connect to port AI0, port AI1, port AI2 and port AI3 of NI ELVIS II. There also has other setting to let user manipulate the input values. The following below shown the project select and NI setting.

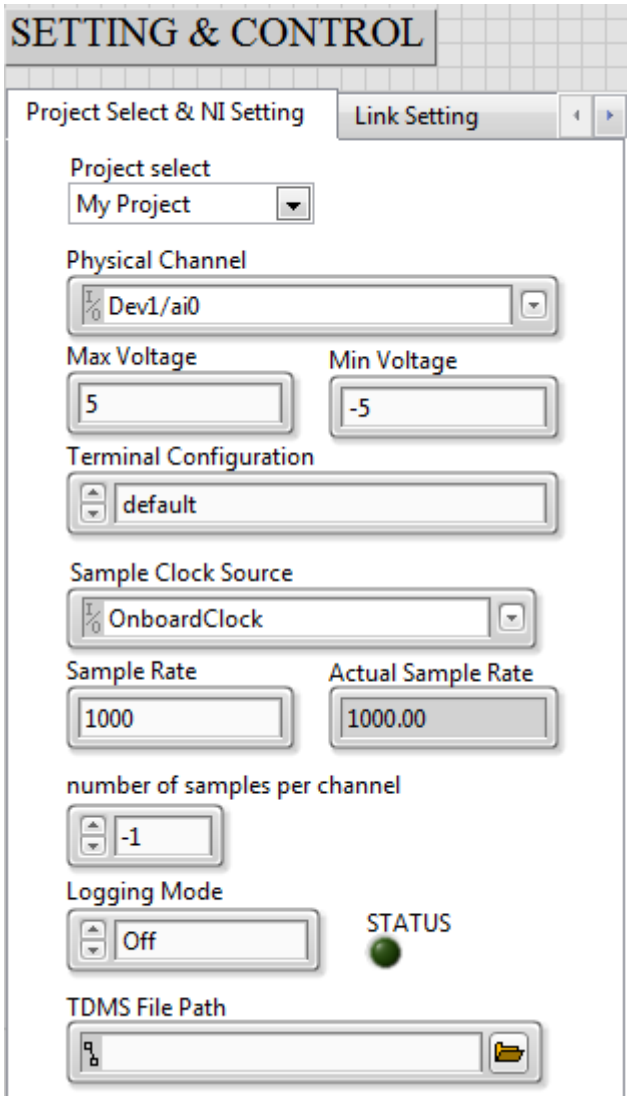


Figure 50: Project select and NI setting

The purpose of design photodiode position detector viewer is allow user know the location of light from laser is emit on detector plate of photodiode. The either position will give a negative values when the light in emit on it. Therefore, this is convenient to let user to know the light is emit to which position of photodiode.

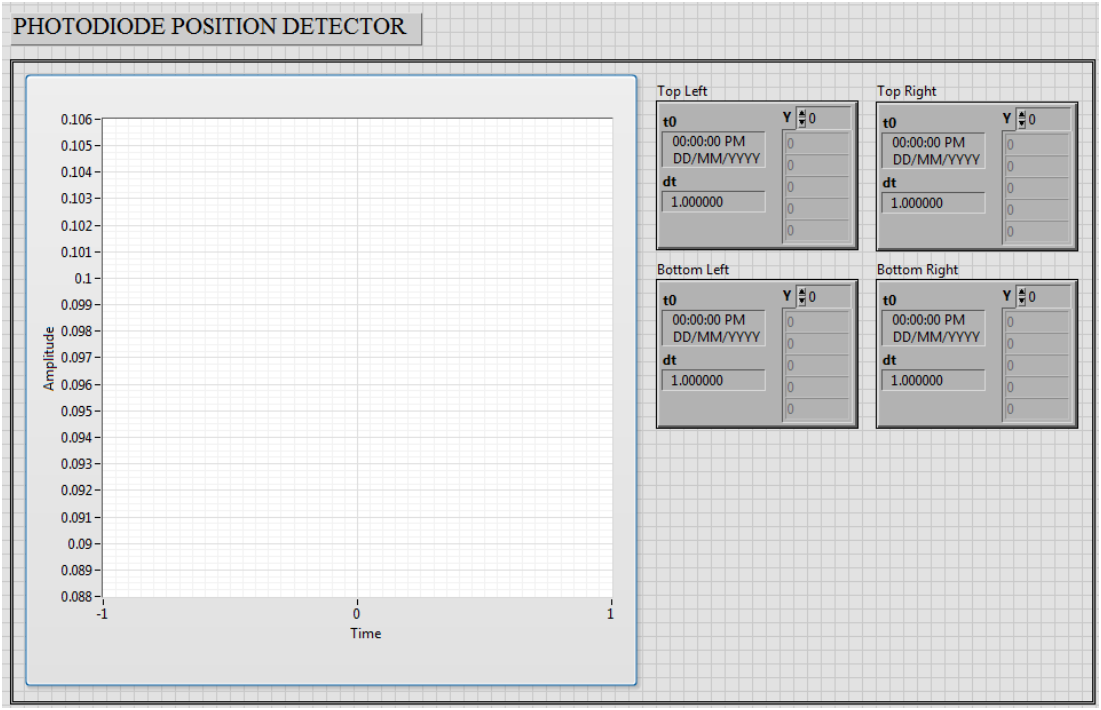


Figure 51: Input data info

The values from port was read by LabVIEW software and execute it to generate desired output which is location detected. The location detector algorithm is applying and design by using math graphical components from function panel of LabVIEW software. The following Figure 52 below shown the coordinate detector info to check the light is on left or right, and top or bottom sides.

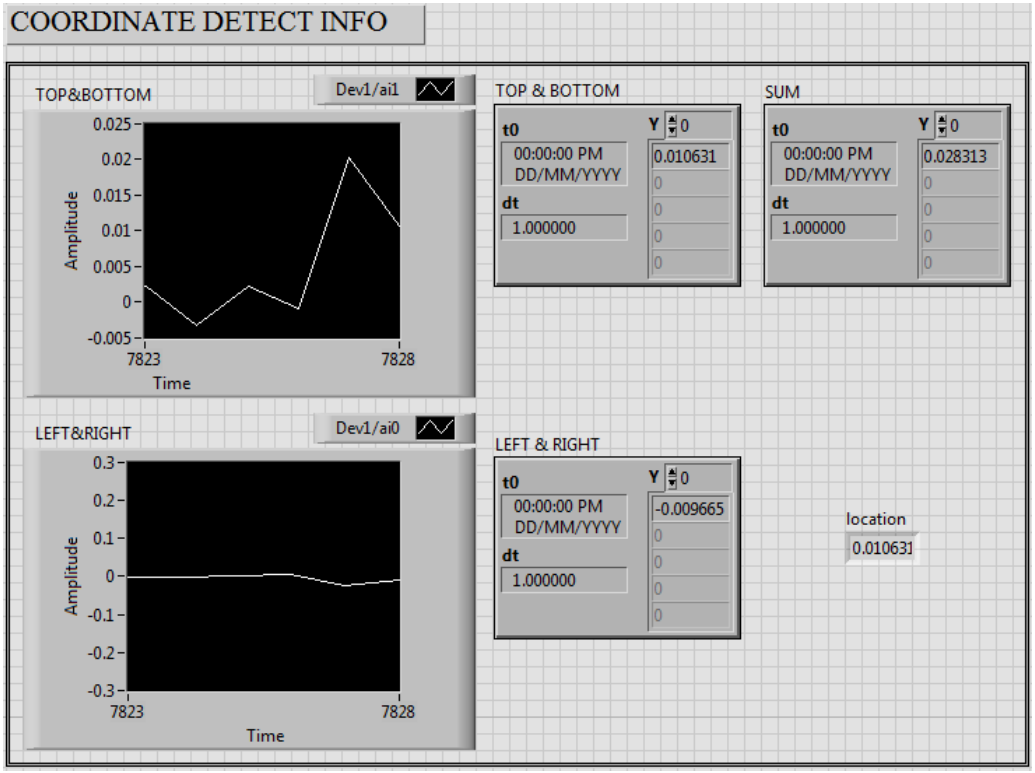


Figure 52: Coordinate detector Info

An array was design in front panel to display the output values. Instead of one dimension array, two dimension array type are used because of values will display in y_0 and x_i. This make difficult to observe the output when there has continuous values display in one dimension array. For example, if there has 100 samples of output values display in one dimension array. The output display in array is y_0 and $x_{0\text{-}99}$, shown in Figure 53. Display in two dimension array can greatly reduce the space in front panel and able to show more output data.

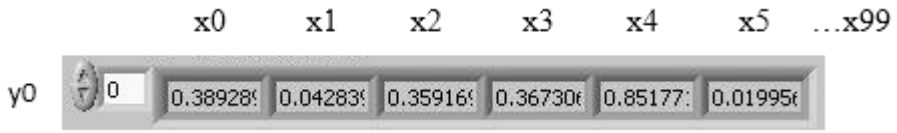


Figure 53: Example of one dimension array

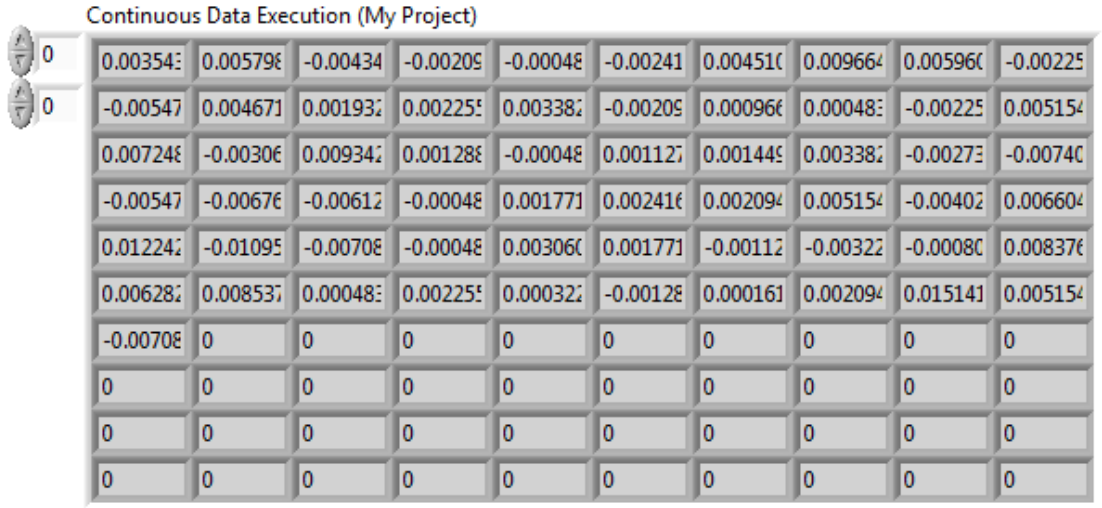


Figure 54: Example of two dimension array

The following Figure 55below showed the scanner info. The output data from algorithm display in two dimension array. The array 1 show the data execution, the continuous data from algorithm will load into array directly. Once the data is fill the blank of array, array 2 will refresh the new data. “Milliseconds to wait” function to slow down the execution. It allows switching to “Senior Project” project to observe the results when “Senior Project” project was select.

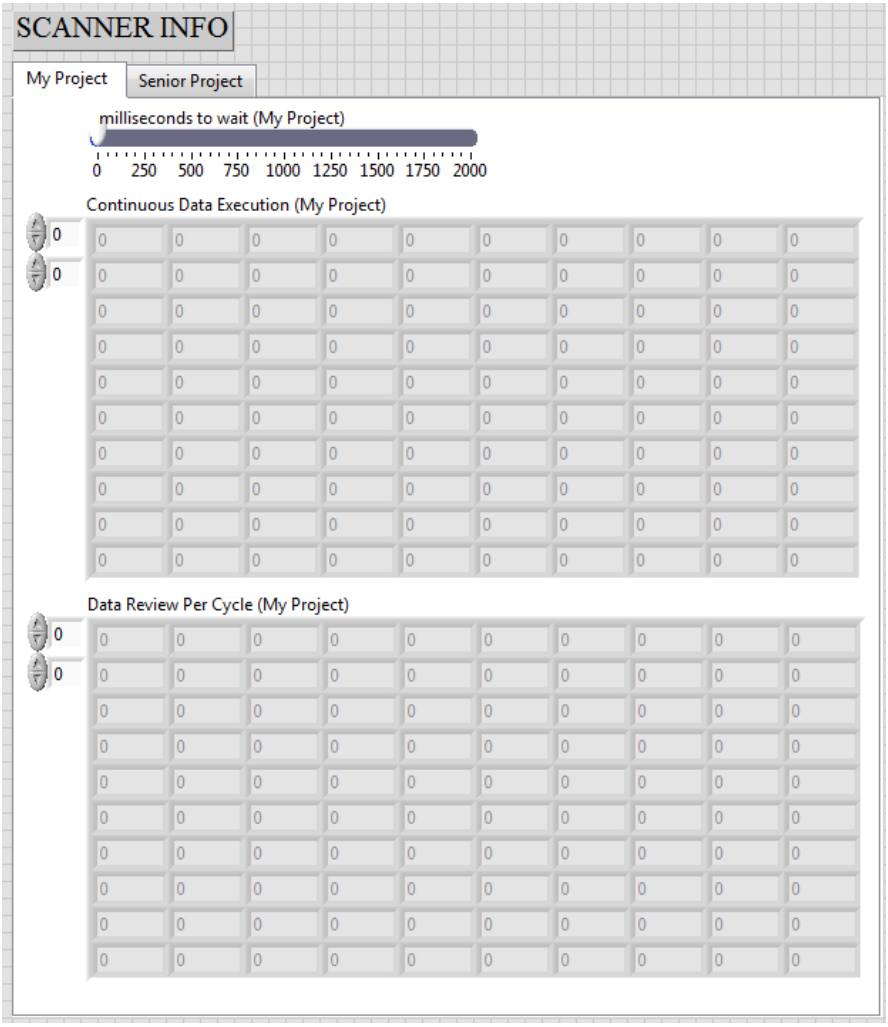


Figure 55: Scanning info

Save function was designed to save the array data in excel file. The file part was designed to allow user to key in file location when save the data. Besides that, view data function also designed to load the data which in excel format and display in front panel.

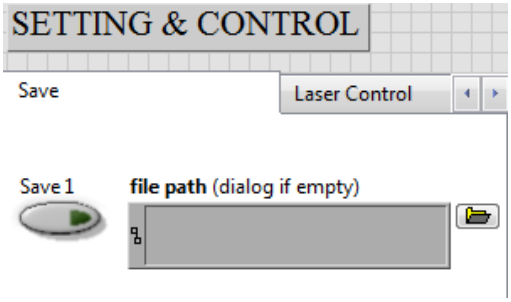


Figure 56: Save data function

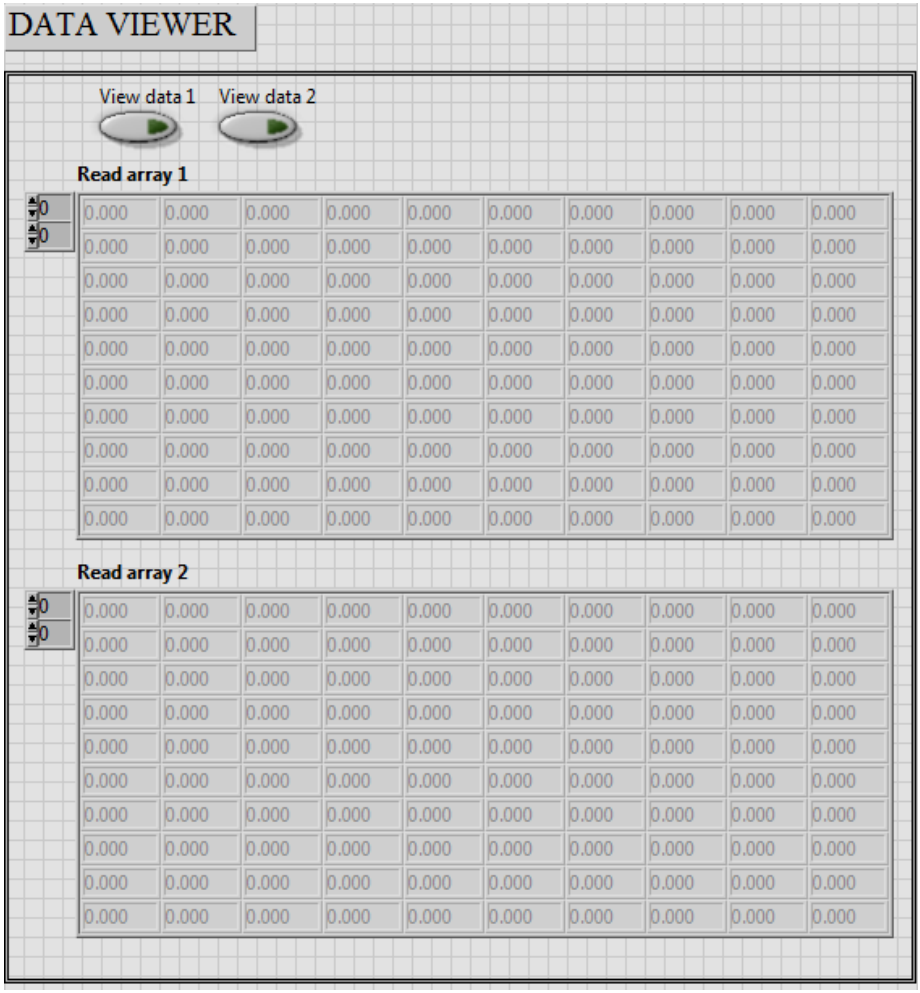


Figure 57: View data function

The graphical code for sending output values was designed to send the output values from location detector algorithm to (TYH) part for further implementation. There are two analog output port which is AO0 and AO1 from NI ELVIS II. Hence, select physical channel to generate the output for (TYH) part or laser.

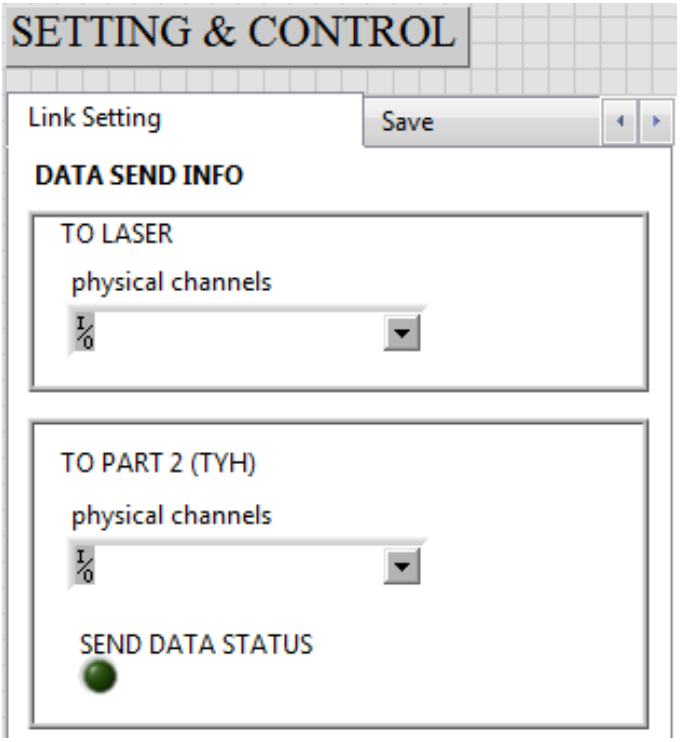


Figure 58: Send data function

The power source for laser is cell battery. It is replaced by the power supply from NI instrument because the running out of electric. Turn the laser on for a certain period of time, running out of electric make intensity of laser decrease gradually and this affect the performance of scanning. Three way to allow user control the laser which is pre-set values, knob and manual key in. Toggle switch was designed to turn on laser and clear button for reset the laser back to default mode.

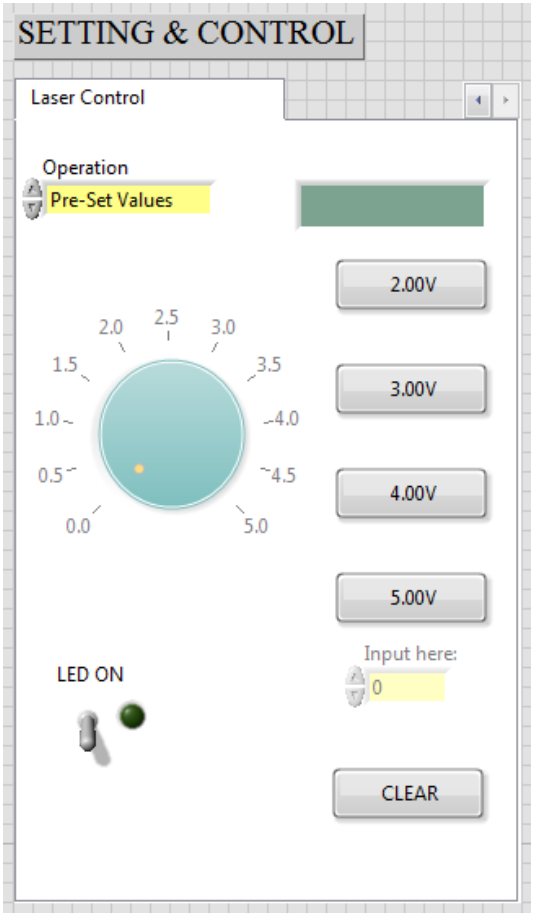


Figure 59: Laser control function

Moreover, a finite impulse response filter was designed for future use. Currently the filter might not work in this project due to the output current from photodiode before apply I/V converter is direct current (DC). This direct current (DC) cause voltage becomes direct current voltage. The without frequency of direct current voltage is the main factor to cause the filter won't work in this project. But, it may work when the object is in sine wave shape being scan by AFM. The filter was tested successfully by apply signal generation. The following Figure 60 below shown the overview of finite impulse response (FIR). The toggle button is design to display the frequency domain of signals and frequency domain of signals after apply filter. **(Ambler, n.d.)**

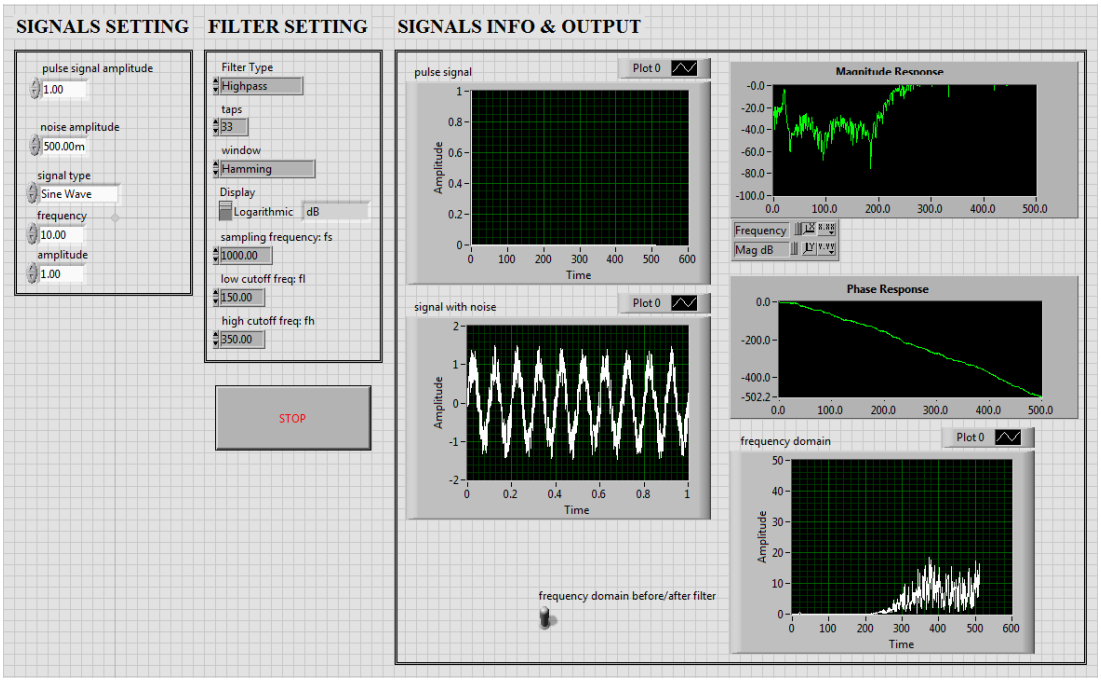


Figure 60: Front panel of finite impulse response filter

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Photodiode Light Detectors

Photodiode light detector is a converter circuit to convert current to voltage. It also known as “Pre-amplifier”, because op-amp chip was used. In senior project, LM741 op-amp chip was used to design I/V converter.

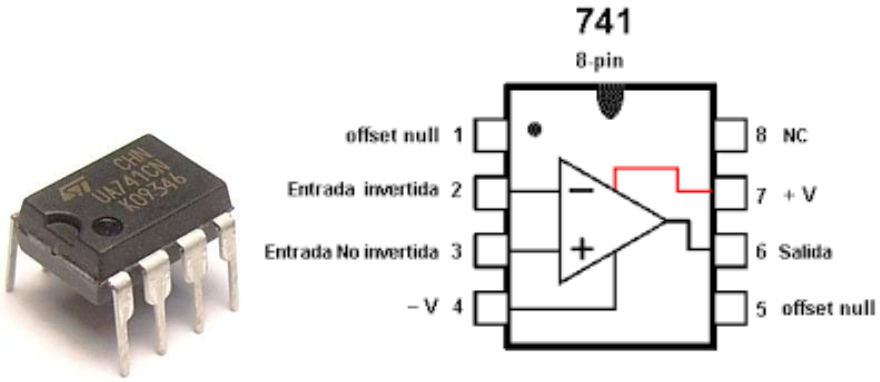


Figure 61: Lm741 and its internet circuit design

Four pins of photodiode means need four LM741 op-amp chips. It is quite waste the place when implement the circuit from breadboard to printed circuit board (PCB). The red box highlight is I/V converter show in following Figure 62 below.

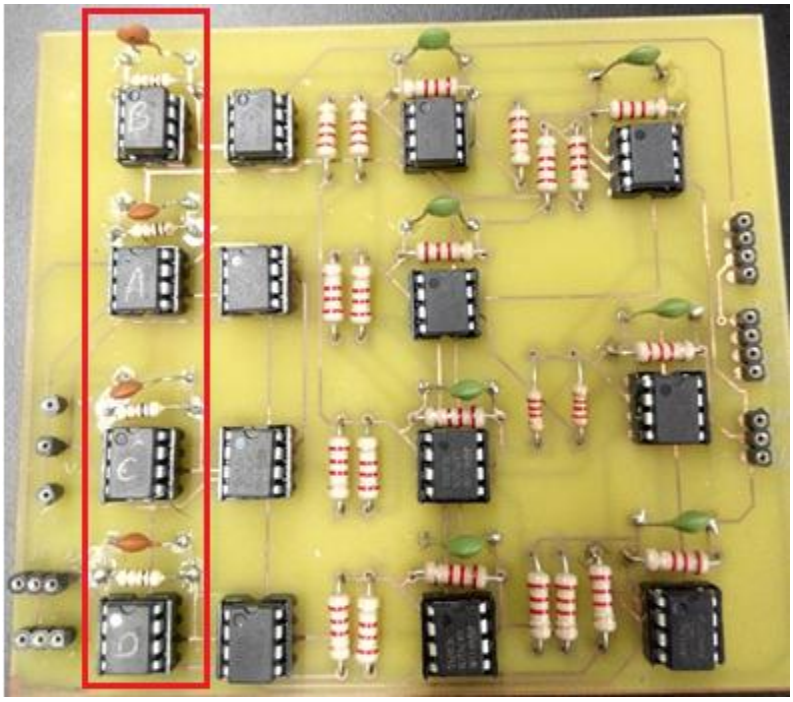


Figure 62: I/V converter for “Senior Project”

Lm324 has same function with Lm741, the only different is that Lm324 has 4 internal op-amps circuit but Lm741 has only 1 internal op-amp circuit. Due to photodiode has 4 pieces of detector plate, so that 4 pins for 4 positions which is top left, top right, bottom left and bottom right. In this case, Lm324 is best recommending connecting 4 pins of photodiode to a single op-amp chip. The following Figure 63 below shown LM741 op-amp chip is replaced by LM324.

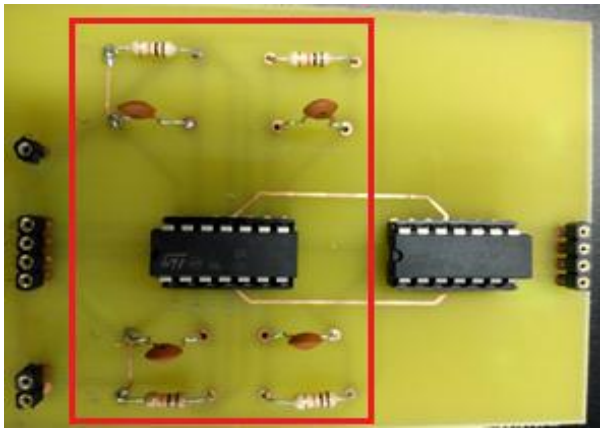


Figure 63: I/V converter for “My Project”

4.2 Buffer

Buffer is design to prevent the second circuit from loading the first circuit unacceptably and interfering with its desired operation. It support signals and data bits can be passing with sufficient drive capability along to a succeeding stage. Same as photodiode light detector circuit, same type of op-amp chip is used to design a buffer. For “Senior Project”, four of LM741 op-cap chip are used for output of four I/V converters. Output of I/V converter is simply connect to non-inverting input and output of buffer is feedback to inverting input. For “My Project”, LM324 op-amp chip is used for design buffer circuit. The following Figure 64 below shows the different of “My Project” and “Senior Project”.

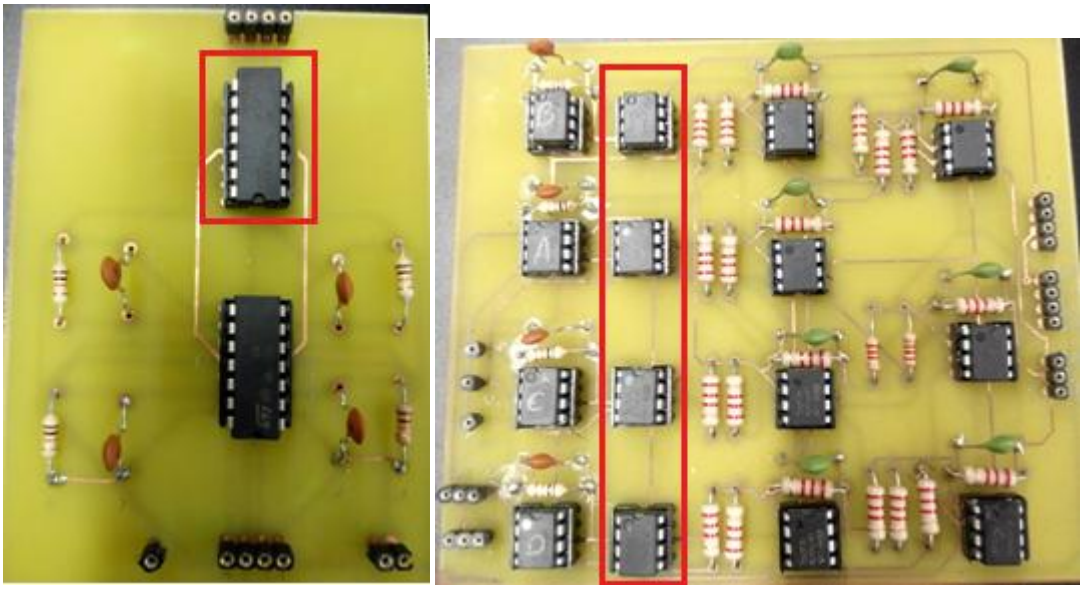


Figure 64: Left for “My Project”; Right for “Senior Project”

Compare the both picture from Figure 64 above, the space is greatly reduce when using LM324 op-amp chip to replace four LM741 op-amp chip.

4.3 Read Data

To obtain the data first from NI ELVIS II, reading data part was design. The important thing is “acquire data” must set to 2D DBL of analog input in multiple channel and multiple samples.**(Learn 10 Functions in NI-DAQmx and Handle 80 Percent of Your Data Acquisition Applications, 2015)**

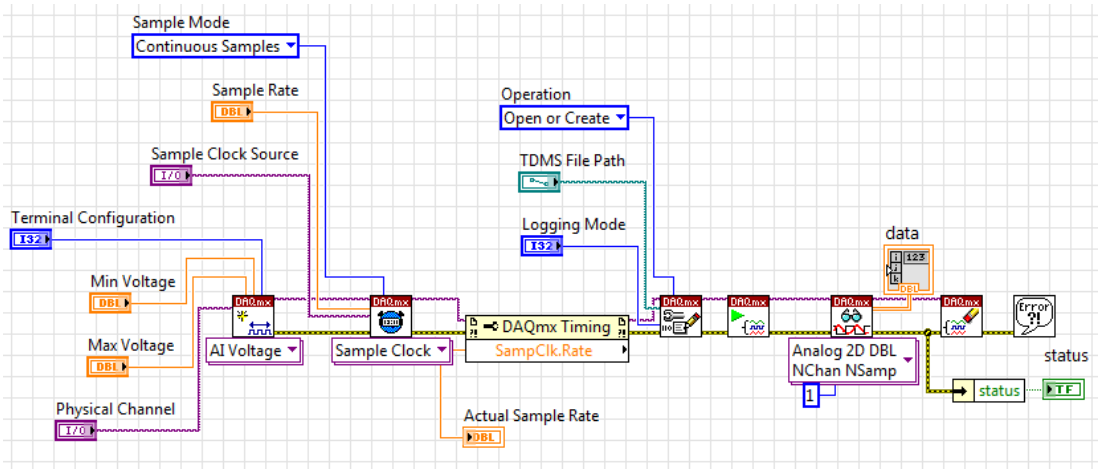


Figure 65: Read data code in block diagram

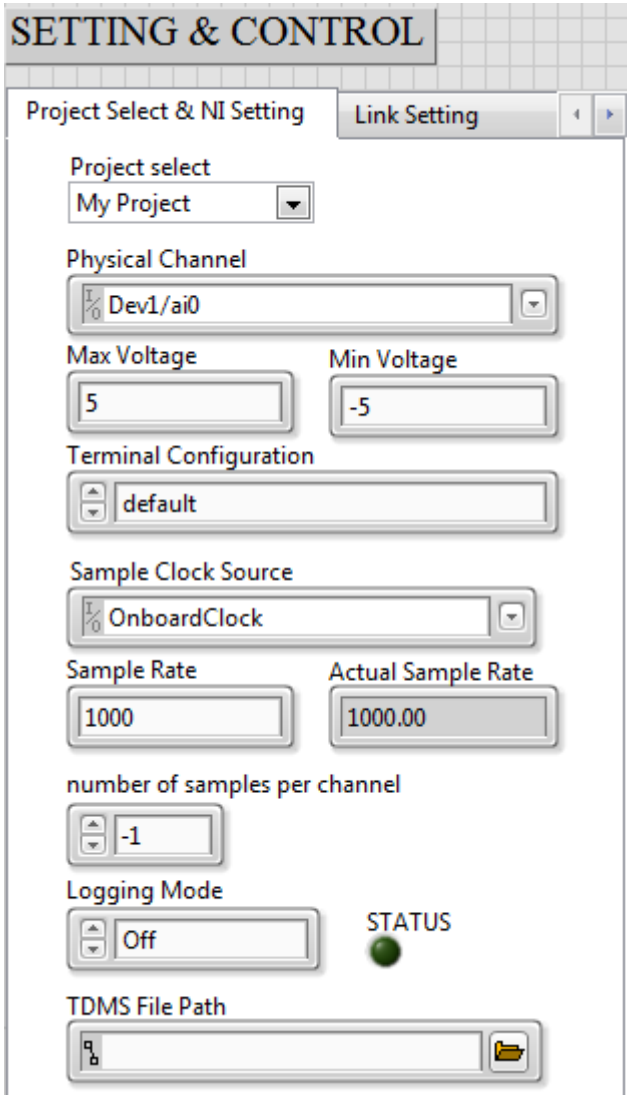


Figure 66: Read data setting in front panel

The data read from NI ELVIS II is in four dimension array data type. To observe the values, split array graphical code from array panel is use. The constant value of "1" is set to split one dimension from four dimension. Hence, the output will only display the first one dimension array values on waveform chart or indicator.

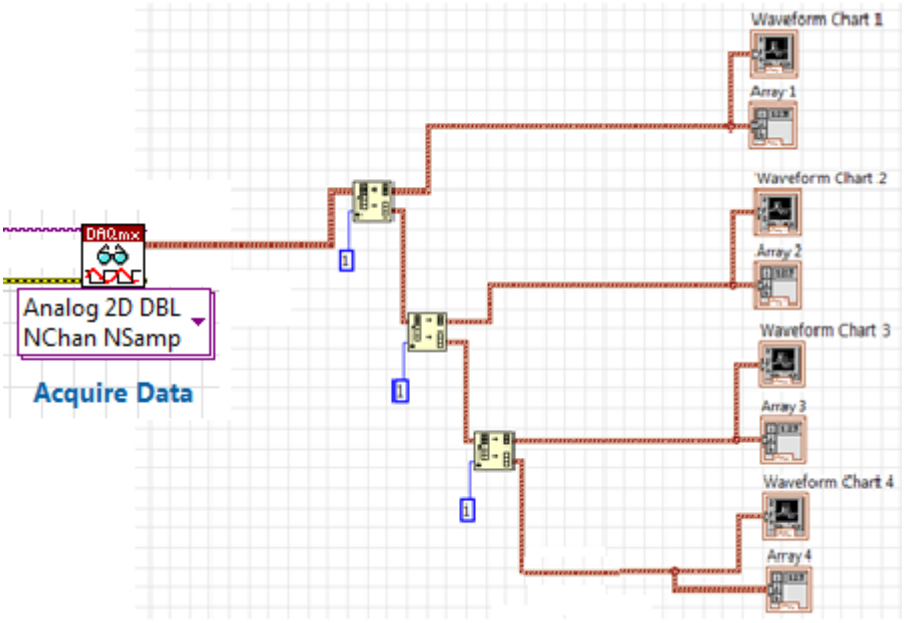


Figure 67: Split array function

After that, it is implement by using "Index Array" code to read array data show in Figure 68. Index 0 to read first array data; index 1 to read second array data; index 2 to read third array data and index 3 to read forth array data.

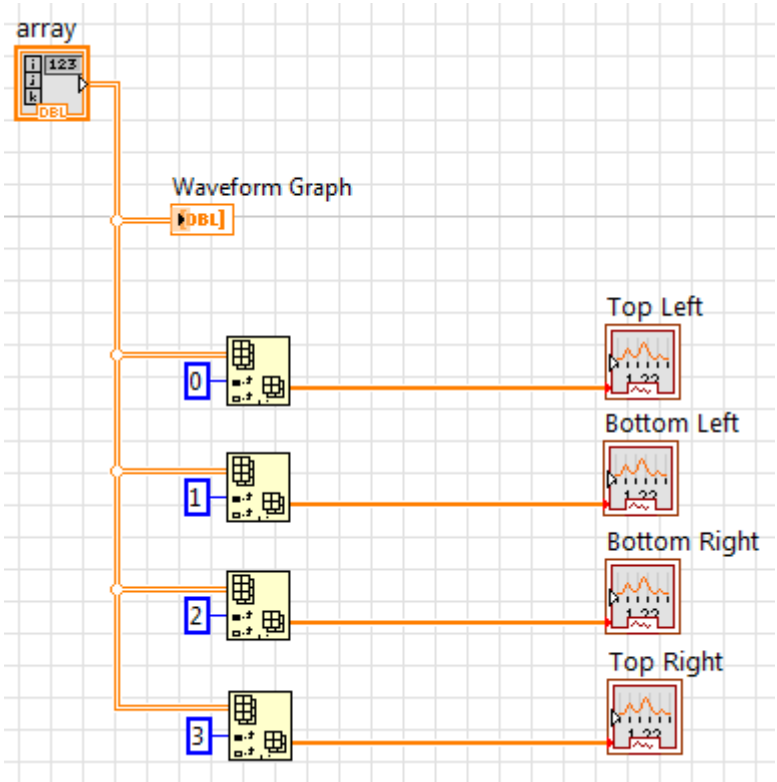


Figure 68: Index Array

4.4 Location Detection Algorithm

4.4.1 Senior Project

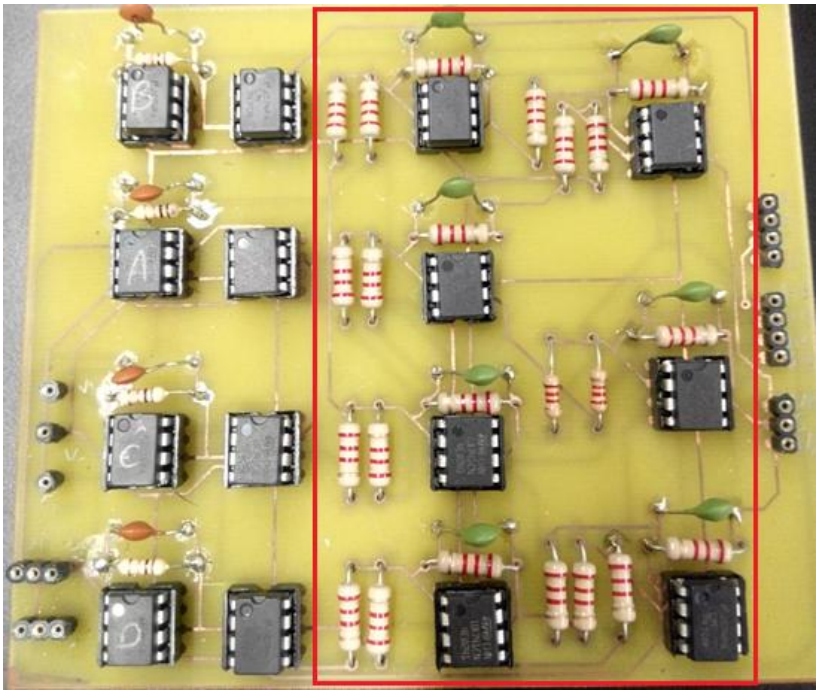


Figure 69: Algorithm for location

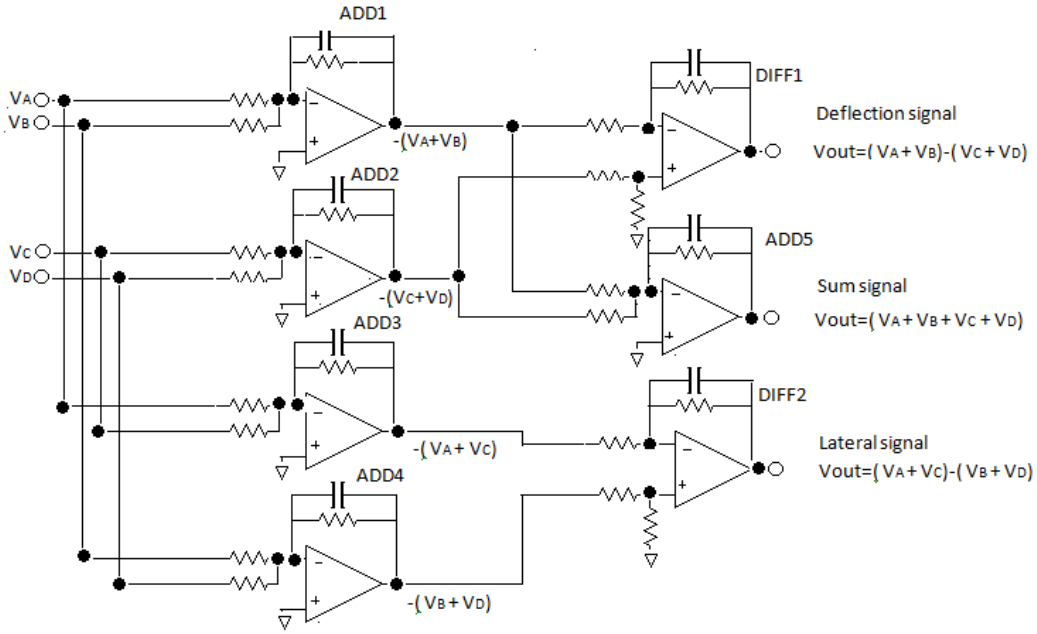


Figure 70: Combination of adder and differential amplifier circuit

From the Figure 70 above, the algorithm part is done by using LM741 op-amp chip for “Senior Project”. Two signals are parallel each other and connect to inverting input of op-amp to apply addition. To apply subtraction, first signal has to connect to inverting input while the second signal is connect to non-inverting input of op-amp.

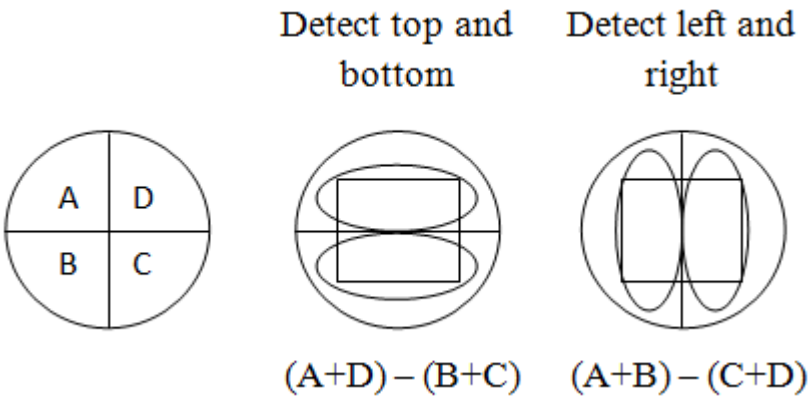


Figure 71: Detector layout and its algorithm

The algorithm is done in PCB, so there is only 1 output is send to LabVIEW through NI ELVIS II port.

4.4.2 My Project

For “My Project”, the hardware algorithm was done by LabVIEW software. The algorithm is simply put a addition and subtraction from boolean panel.

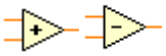


Figure 72: Addition and subtraction component

The data input from different position of photodiode is read and apply the addition and subtraction to execute.

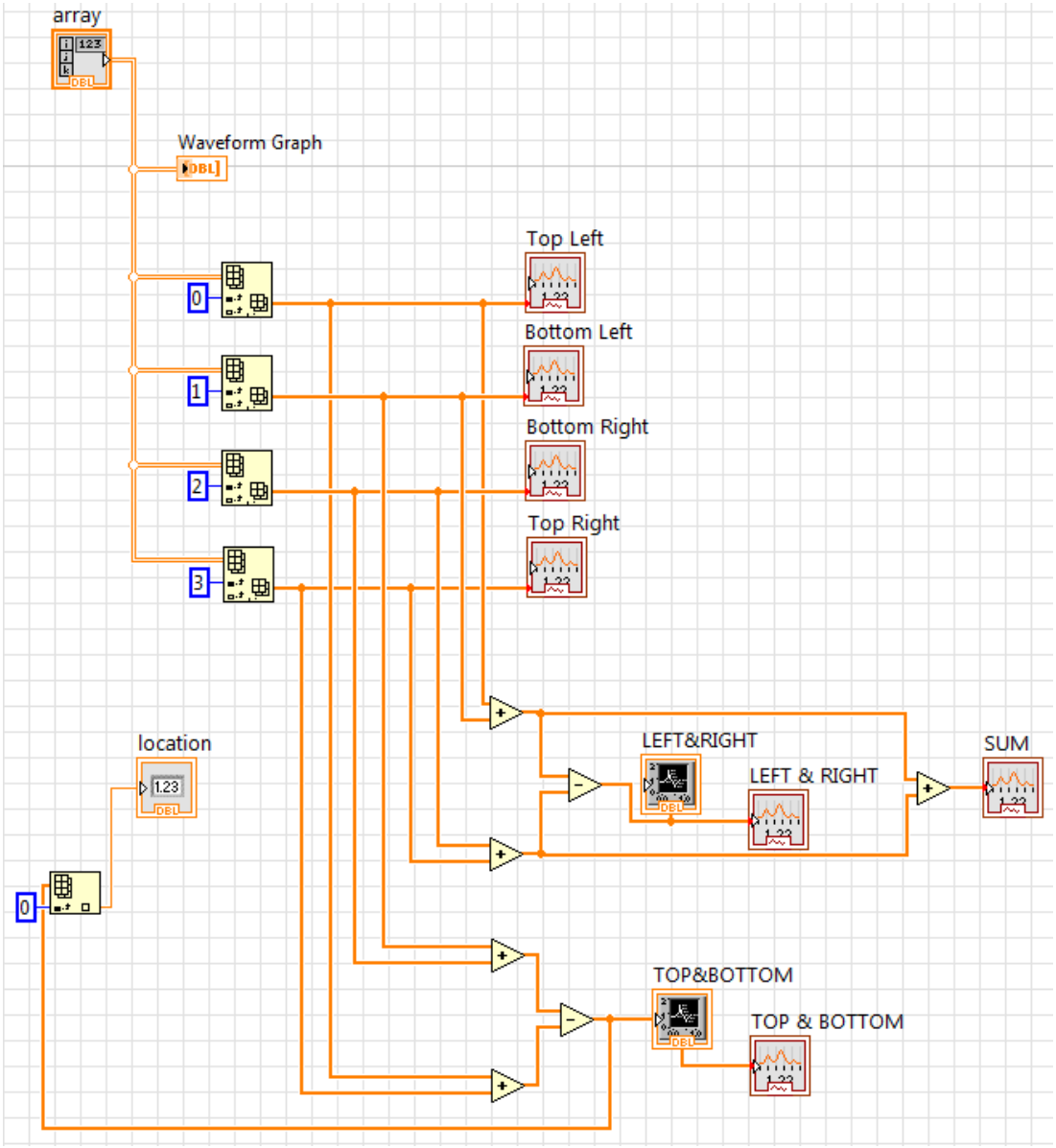


Figure 73: Algorithm

4.5 Output Fed Into Array

4.5.1 My Project

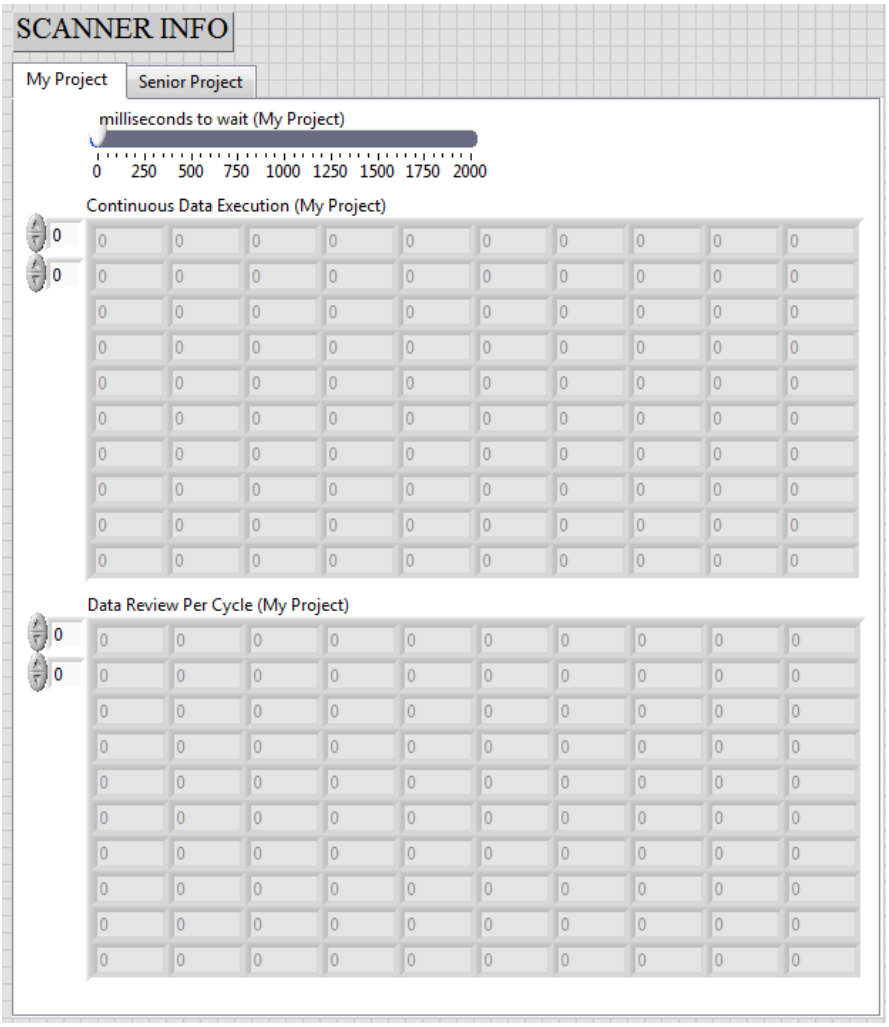


Figure 74: Overview of Scanning info

In Figure 74 above, the miliseconds to wait is a function to slow down the execution, so that user able to observe the flow of data in array.

From the Figure 75 below, the output of algorithm part is convert from DBL data type to element data type and fed in to “Replace Array Subset”. “Replace Array Subset” is use replace the value in array by set index value to choose the cell.

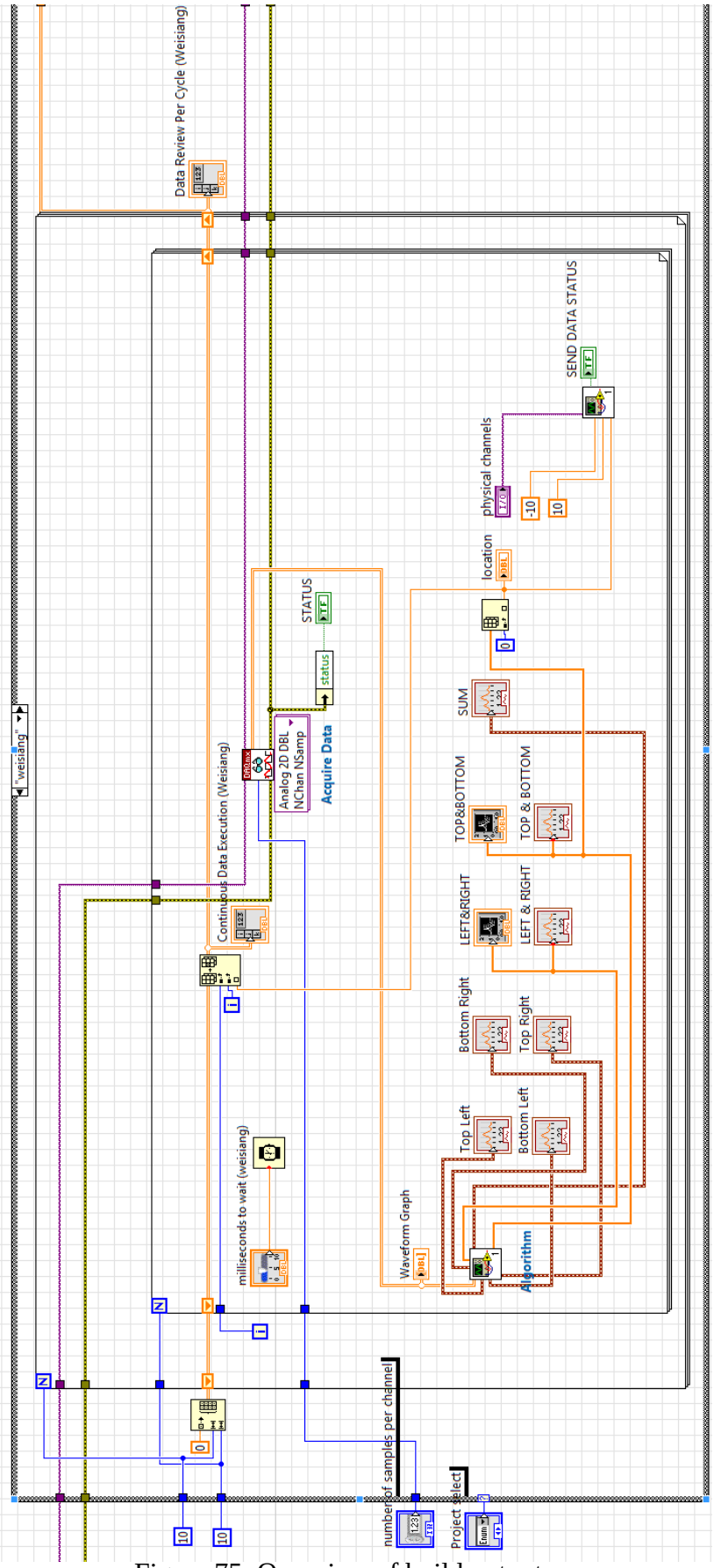


Figure 75: Overview of build output array

Figure 76: Replace Array Subset

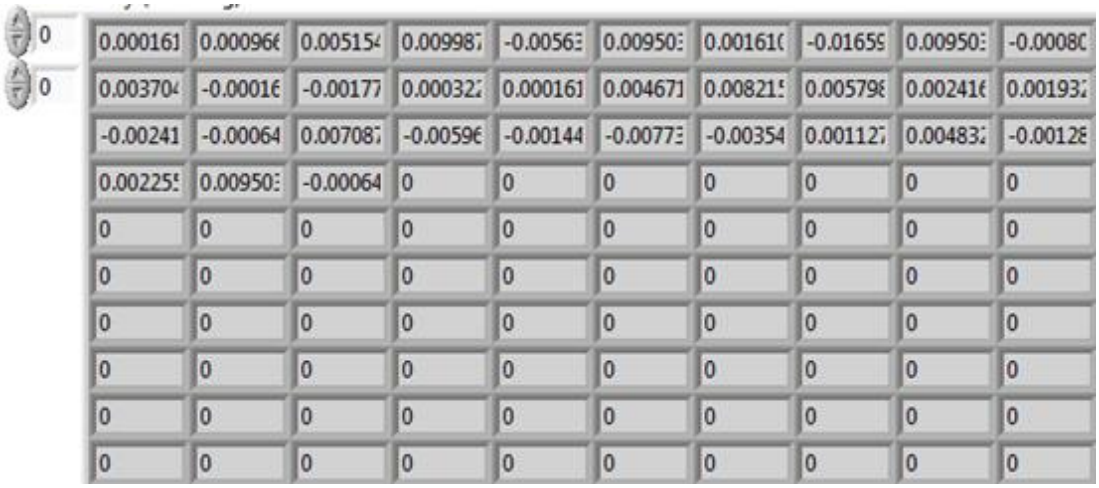
But before that, an two dimension array with values of 0 for all cell must be create. To create a two dimension array, build array graphical code is used by set the value to index. For example, set value of 15 for index x and index y, the array has size of 15 x 15. In Figure 75, array size is 10 x 10 with the value of 0 for all cell initially. To display the output of algorithm in two dimension array with constant index y value and keep increasing index x value of array, two for loop are needed. The inner for loop for keep increasing the index x value while the outer for loop increasing when inner loop is done their task. **(Tutorial: Arrays and Clusters, 2015)**

Therefore, the iteration "i" of inner for loop is connect to index x of "Replace Array Subset" which the iteration will keep increasing from 0 to the maximum number of loop which is 10. The output of algorithm will keep insert its values to the array with increasing the index x. Let say the output of algorithm given (23,56,1,5,8), insert to array with increasing index x will give the result of

23	56	1	5	8

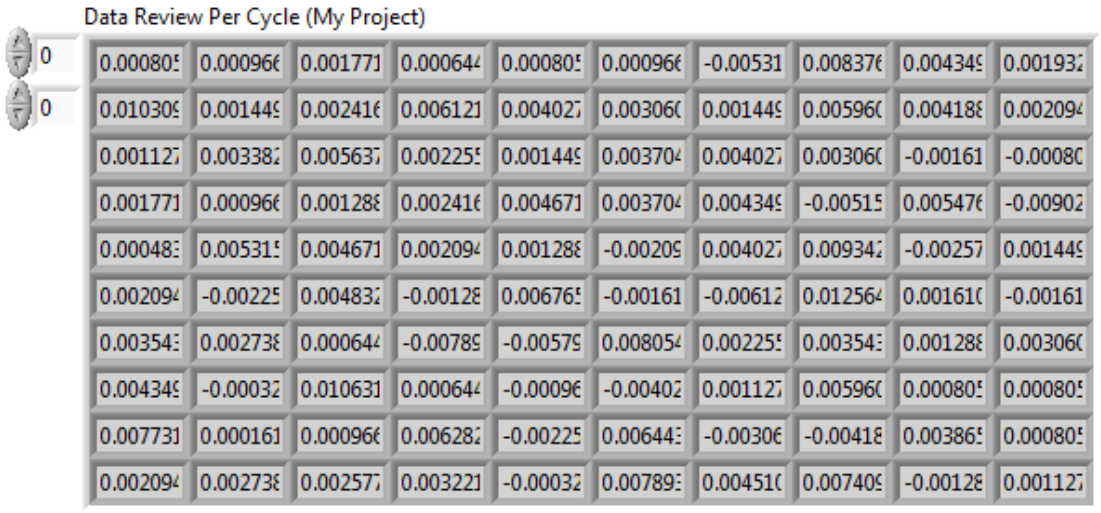
The outer for loop is increasing when the loop of inner for loop reach its maximum number of loop. Iteration of outer while loop is connect to index y of "Replace Array Subset". Hence, it works like values keep insert to cell of array with constant y and keep increasing value of x_i. Once the x_i meet its maximum number of loop, y increasing by 1 and again execute the inner for loop till the y meet the its maximum number of loop.

The continuous data execution in Figure 77 is to observe how the values is insert into array. And the data review per cycle is design to display the values in the array once the values in done insert into array. It works like refresh and display the last data in array. The following Figure 77 and Figure 78 below show the example execution of values insert into array and data review per cycle.



0	0.000161	0.00096	0.00515	0.00998	-0.0056	0.00950	0.00161	-0.0165	0.00950	-0.0008
0	0.00370	-0.0001	-0.00177	0.00032	0.00016	0.00467	0.00821	0.00579	0.00241	0.00193
	-0.00241	-0.00064	0.00708	-0.0059	-0.00144	-0.0077	-0.00354	0.00112	0.00483	-0.0012
	0.00225	0.00950	-0.00064	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0

Figure 77: Example execution of values



Data Review Per Cycle (My Project)

0	0.00080	0.00096	0.00177	0.00064	0.00080	0.00096	-0.00531	0.00837	0.00434	0.00193
0	0.01030	0.00144	0.00241	0.00612	0.00402	0.00306	0.00144	0.00596	0.00418	0.00209
	0.00112	0.00338	0.00563	0.00225	0.00144	0.00370	0.00402	0.00306	-0.00161	-0.0008
	0.00177	0.00096	0.00128	0.00241	0.00467	0.00370	0.00434	-0.00515	0.00547	-0.0090
	0.00048	0.00531	0.00467	0.00209	0.00128	-0.0020	0.00402	0.00934	-0.00257	0.00144
	0.00209	-0.00225	0.00483	-0.00128	0.00676	-0.00161	-0.00612	0.01256	0.00161	-0.00161
	0.00354	0.00273	0.00064	-0.00789	-0.00579	0.00805	0.00225	0.00354	0.00128	0.00306
	0.00434	-0.00032	0.01063	0.00064	-0.0009	-0.00402	0.00112	0.00596	0.00080	0.00080
	0.00773	0.00016	0.00096	0.00628	-0.00225	0.00644	-0.00306	-0.00418	0.00386	0.00080
	0.00209	0.00273	0.00257	0.00322	-0.00032	0.00789	0.00451	0.00740	-0.00128	0.00112

Figure 78: Data review per cycle

4.5.2 Senior Project

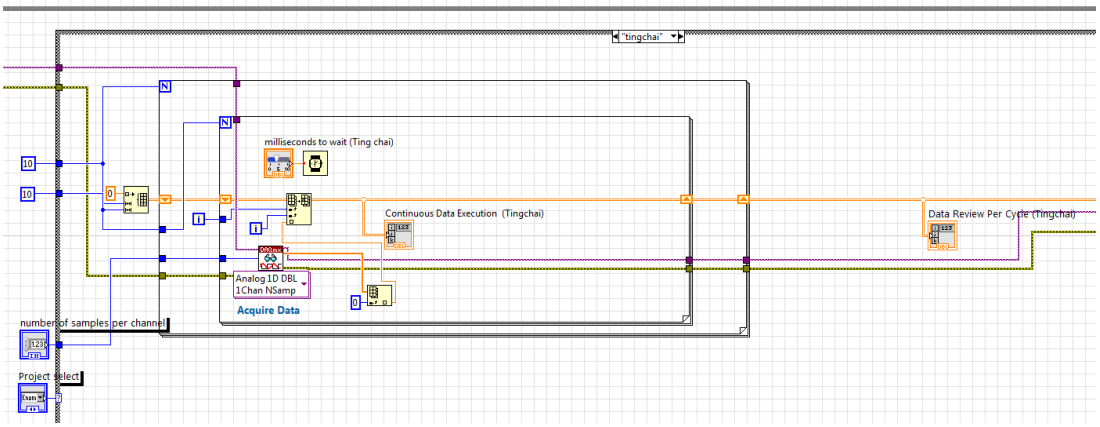


Figure 79: Block diagram of senior project

When the project is switch to senior project, the overall thing is almost the same compare to previous part which is “4.5.1 My Project”. The different thing is algorithm is done in LabVIEW for “My Project” while the “Senior Project” is done in PCB. It is same concept to display the data in two dimension array.

4.6 Store Data

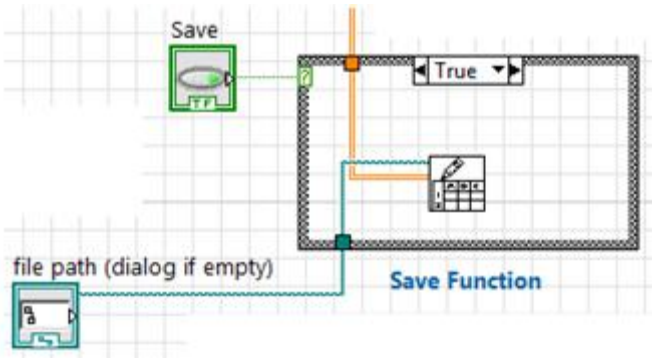


Figure 80: Storing data

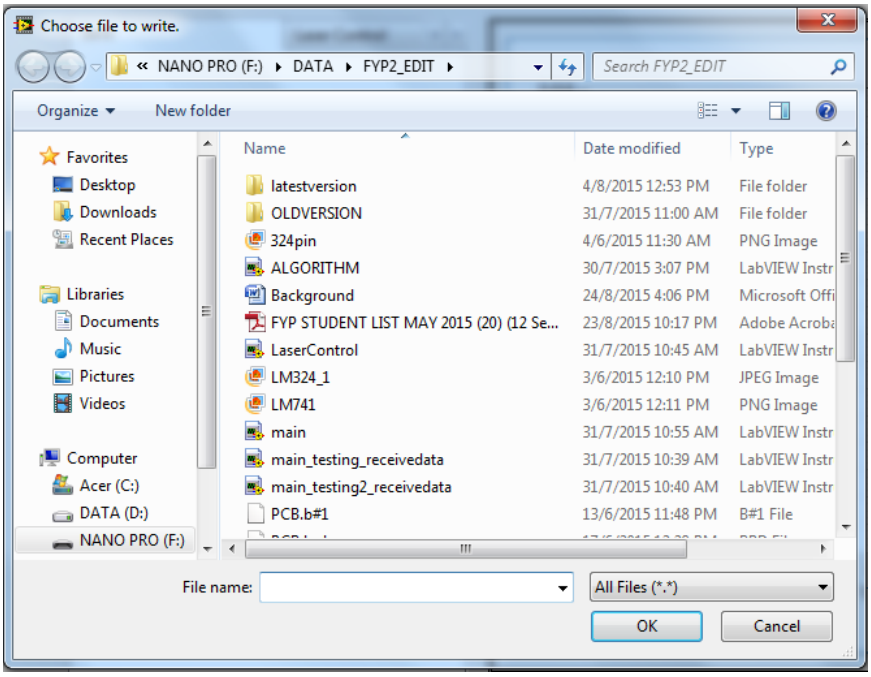


Figure 81: Location for storing

Store function allow user to save the data in excel file. The message box will prompt out to ask user to key in choose location and key in file name when the save button is pressed. To save the data in excel file format, ".csv" must type after the file name to set the file format to excel format.

4.7 View Data

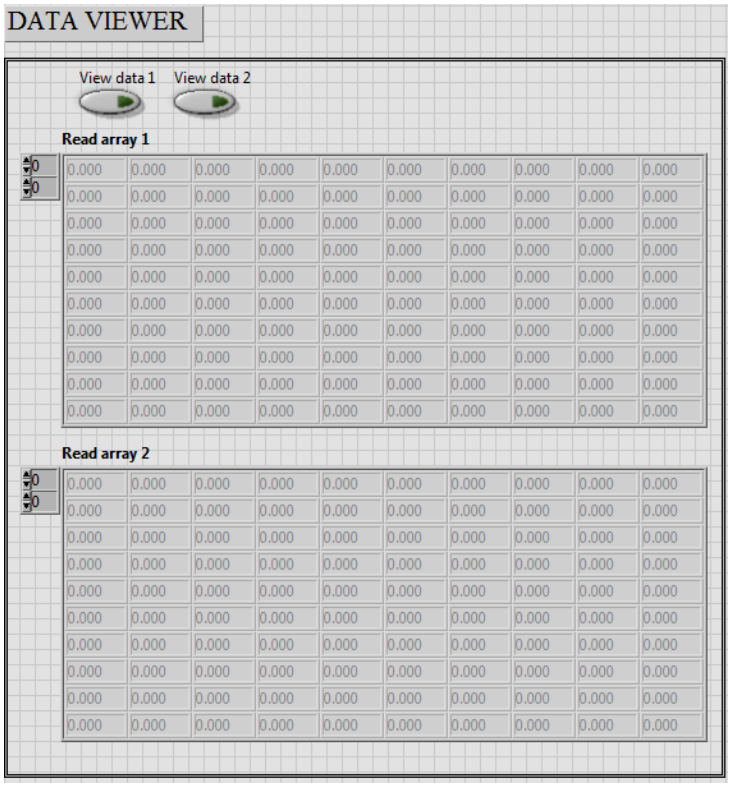


Figure 82: Data viewer

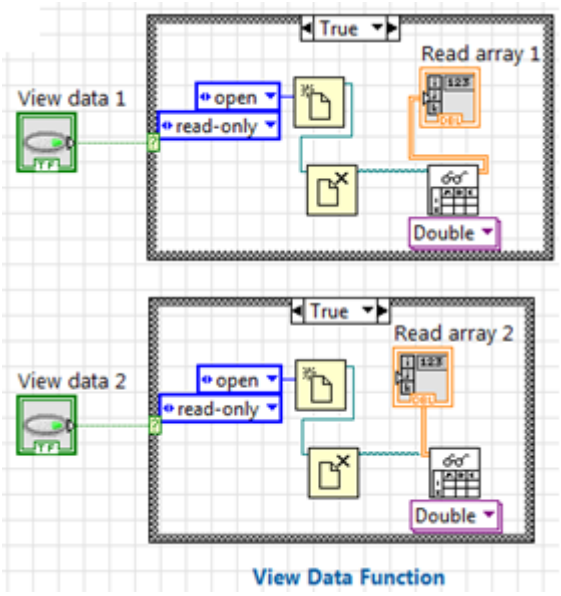


Figure 83: Block diagraom of view data function

The both Figure 82 and Figure 83 above show the front panel and block diagram of view data function. Function of data viewer is to display the data that had save in excel file format. For display more than 100 of data, enlarge the size of array manually.

4.8 Link Data

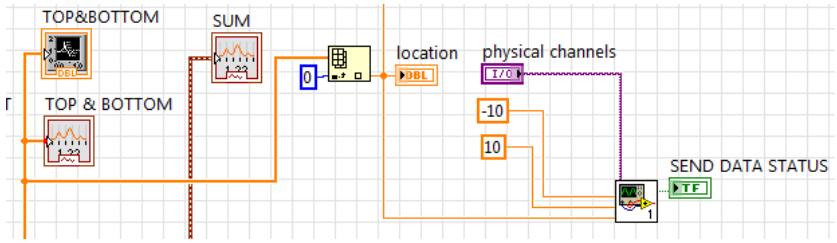


Figure 84: Send Data with sub-vi icon

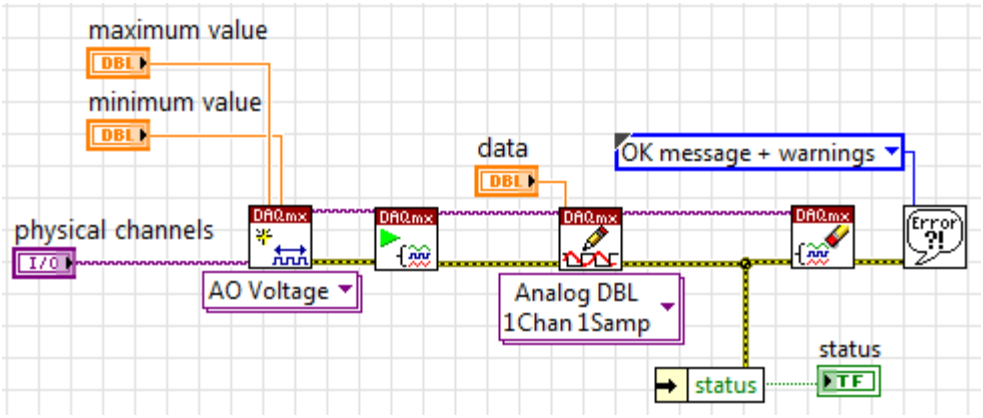


Figure 85: Send data

The Figure 84 and Figure 85 above show the output of algorithm is connect to send data sub-vi to send the data to (TYH) part for further development. NI ELVIS II has two analog output port to sending data, so the physical channels must set either AO0 or AO1. The following Figure 86 below show the physical channel is located in link setting which highlight in red box.

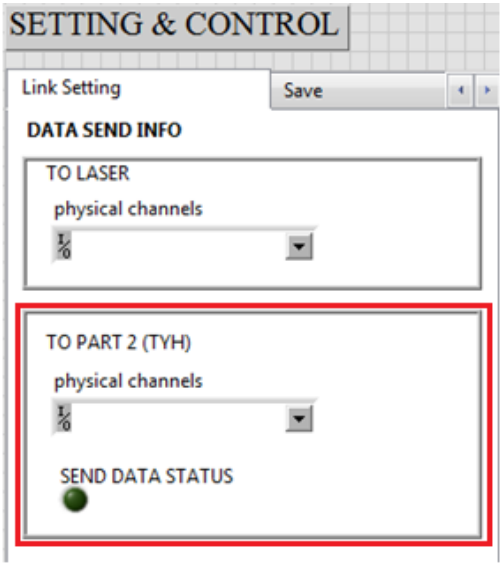


Figure 86: Channel for send data

4.9 Laser Control

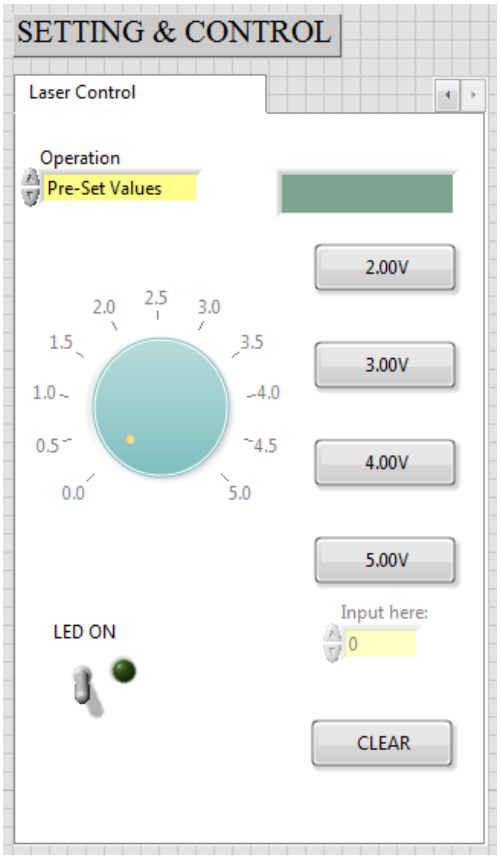


Figure 87: Front panel of laser control

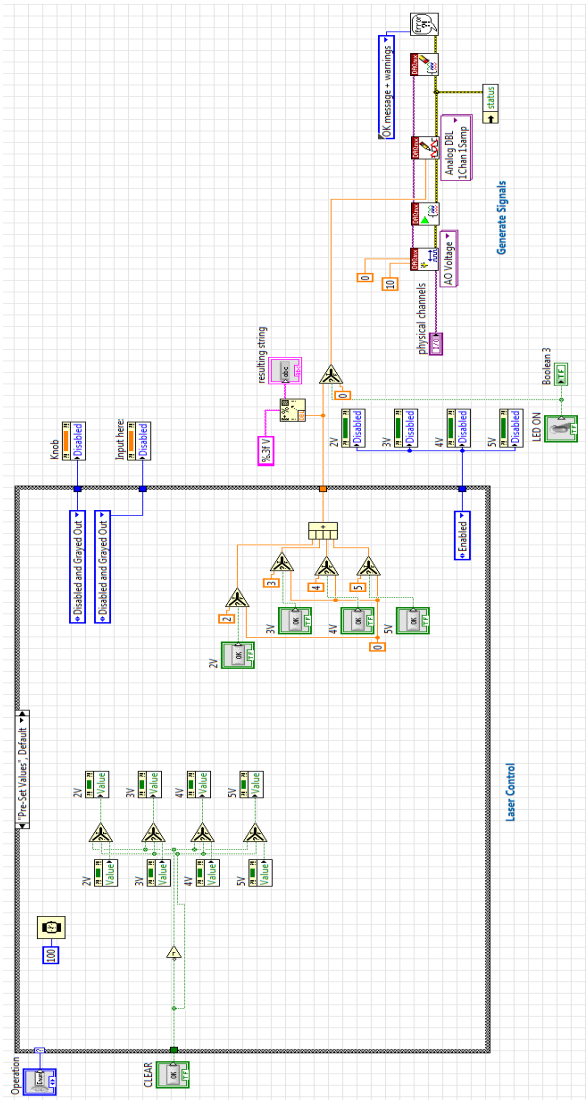


Figure 88: Block diagram of Pre-set values

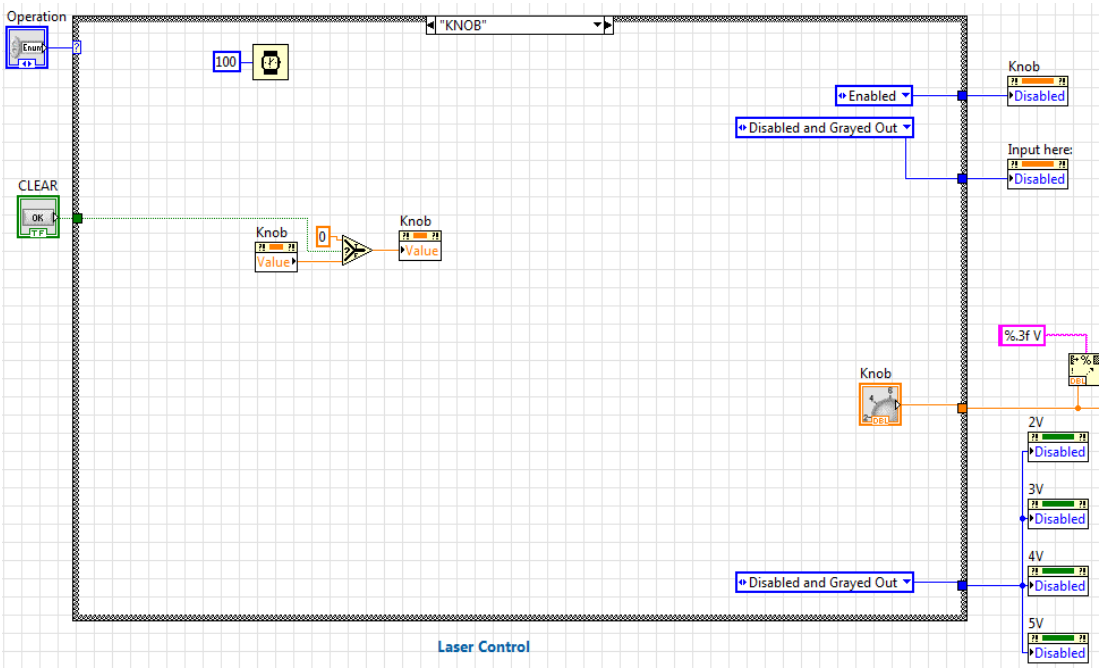


Figure 89: Block diagram of knob

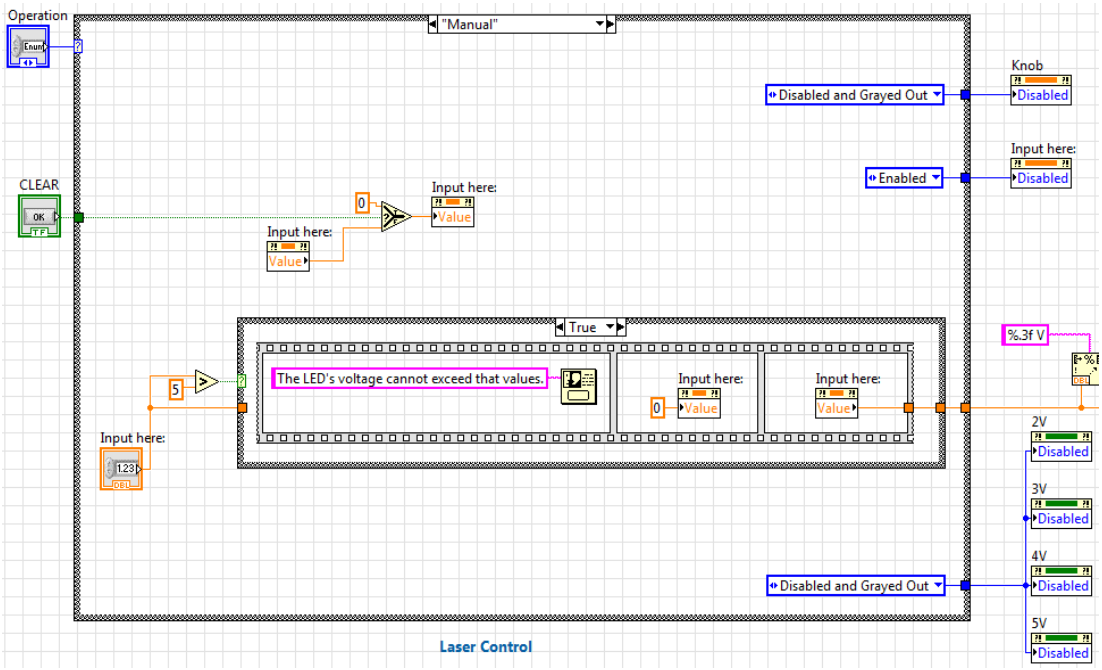


Figure 90: Block diagram of manual

There are 3 types of choice to control the laser which is pre-set values, knob and manual set. The Figure 88, Figure 89 and Figure 90 above show the graphical code for pre-set values, knob and manual set. In block diagram, a case function is used to switch these choices. Clear button connected for overall part and zero value will send to their properties node when it is pressed.

The key's properties node "disabled" was written at the end of the case for each case. This is to make sure that the others key will not operate when anyone of the key is working. Therefore, there is only single output.

There is a protection was design to protect the laser. Limit the voltage send to laser in manual only since other choice to control the laser already set to maximum 5V. Error message will pop out when it is exceed 5V which may cause damage to laser.

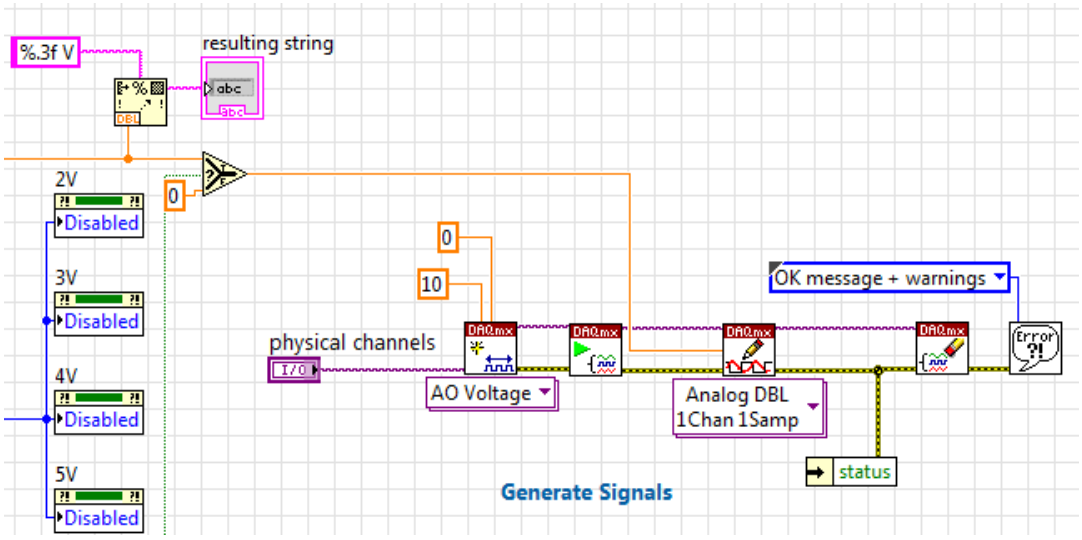


Figure 91: Resulting value setting and send signals

The resulting string shown in Figure 91 above is display the voltage apply to laser currently. To display 3 decimal point, (%.3f V) is set as constant. The "Generate signals" function is to generate the analog voltage from analog output port of NI ELVIS II. Select the channels either AO0 or AO1 to supply voltage for laser.

4.10 Testing &Results

The following Figure 92 below show the light is emit to bottom right side because the value is in negative sign. This design is convenient for user to observe the position of photodiode that the light emit to.

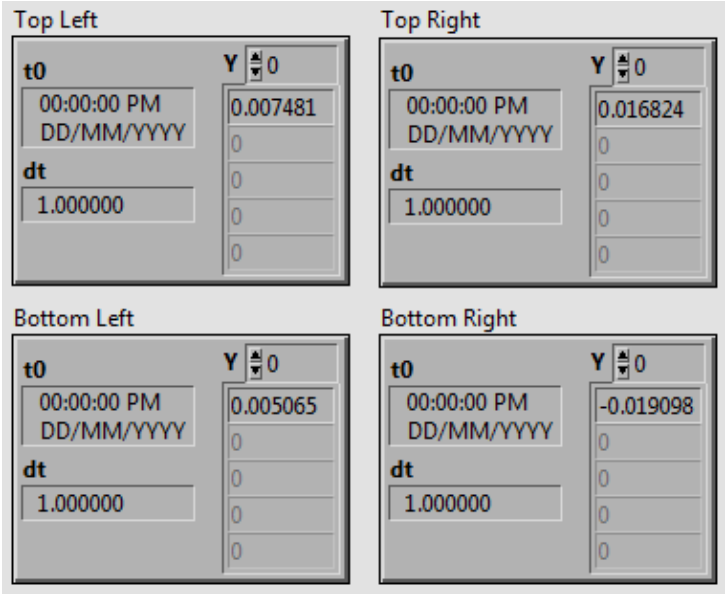


Figure 92: Light on the bottom right side

More example of result, light emit to position top right side of photodiode.

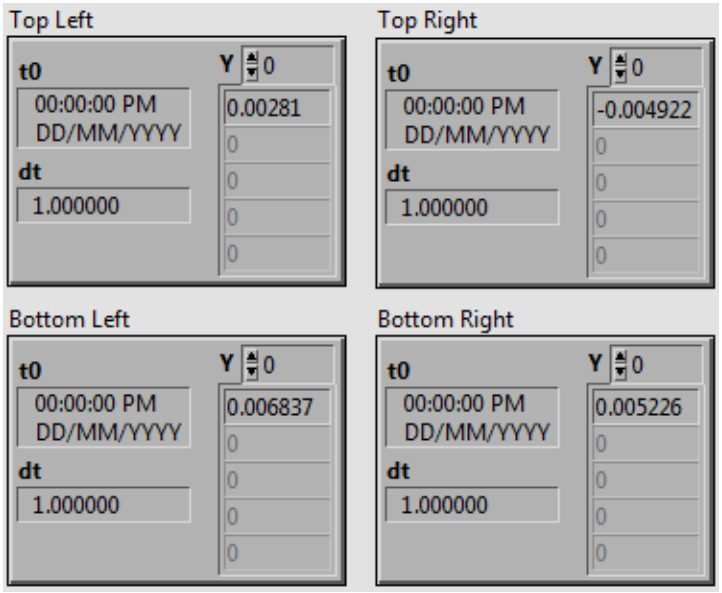


Figure 93: Light on the top right side

Proceed algorithm to obtain deflection signals when input is detected. It will get a positive value of result if the light is on top side while obtain a negative value of result if the light is on bottom side.

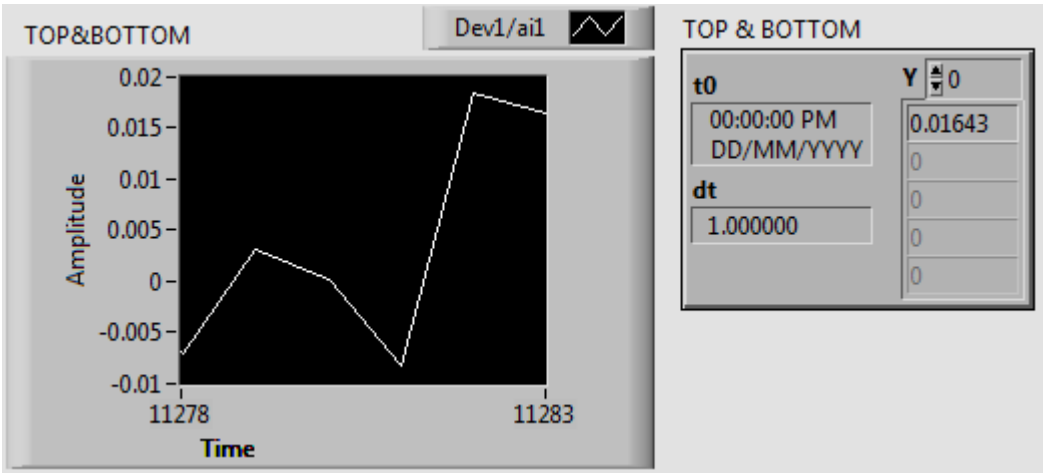


Figure 94: Light on top side

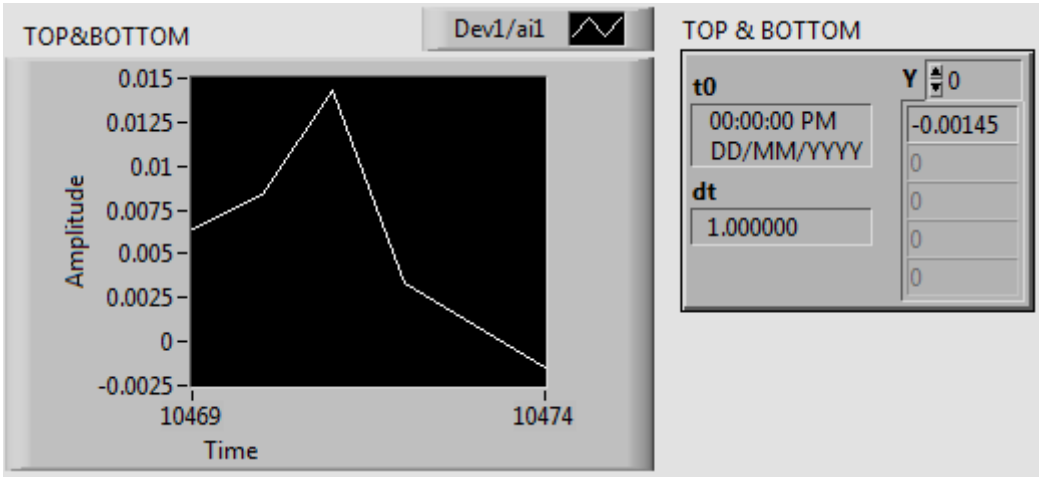


Figure 95: Light on bottom side

4.11 Finite Impulse Response (FIR)

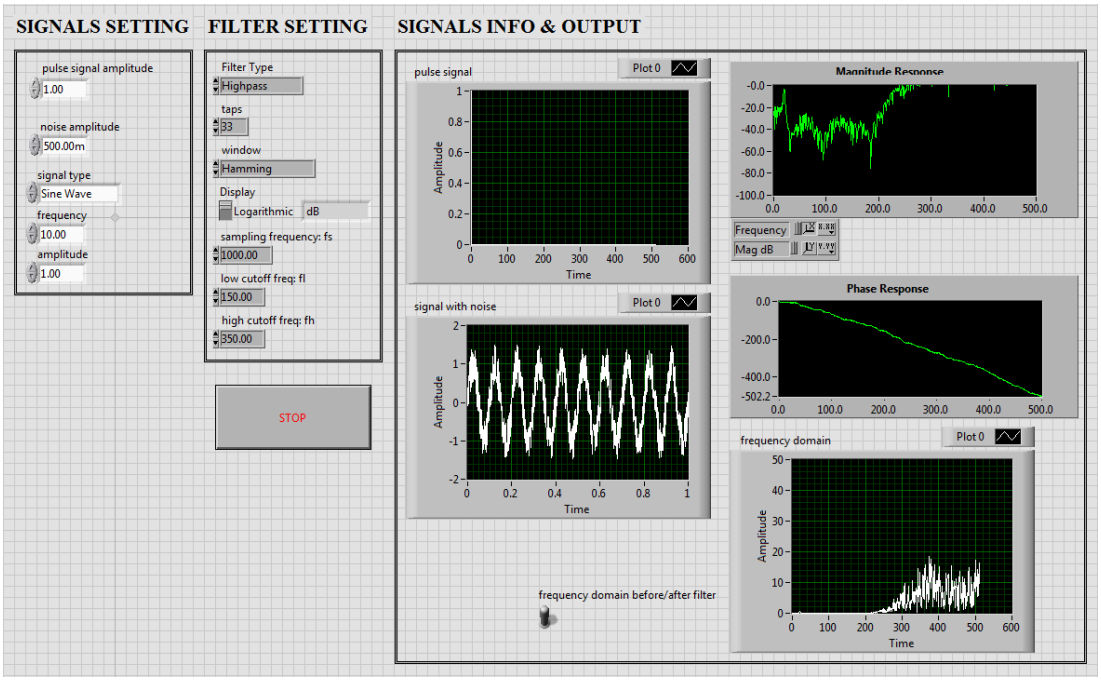


Figure 96: Front panel of FIR

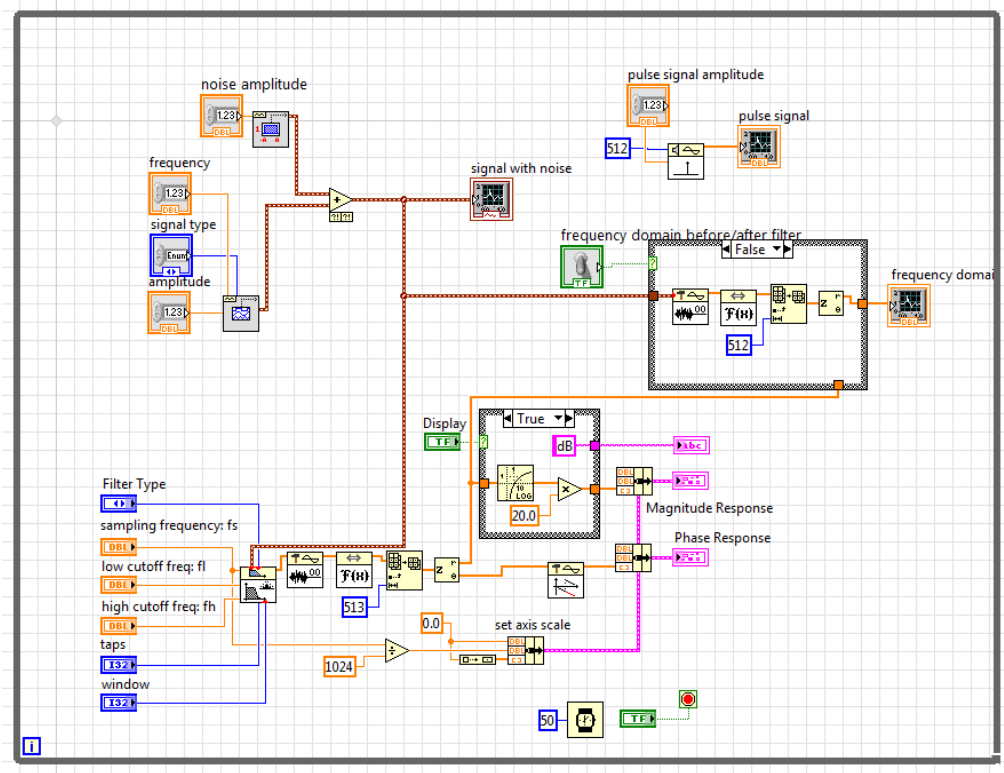


Figure 97: Block diagram of FIR with frequency domain before filter

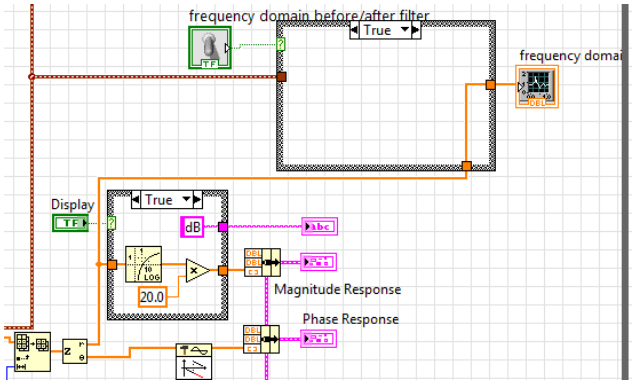


Figure 98: Block diagram of FIR with frequency domain after filter

For future use, filter was design. It can be use when scanning a sine wave shape or triangle wave shape of object. The input signal is apply manually to observe its performance. Create a signals and add with noise signals to obtain a signals with noise. Set the filter setting and observe the output waveform.

The “frequency domain before/ after filter” button was design to observe the different between the frequency domain before go through filter and after go through filter. The following Figure 99 and Figure 100 below show the results.

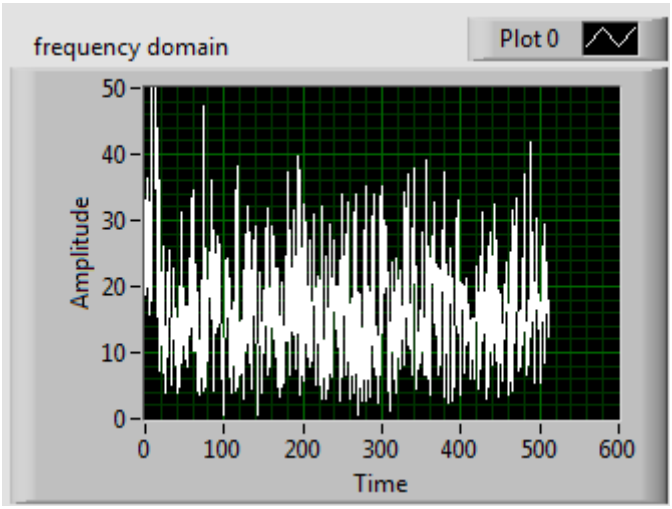


Figure 99: output before filter

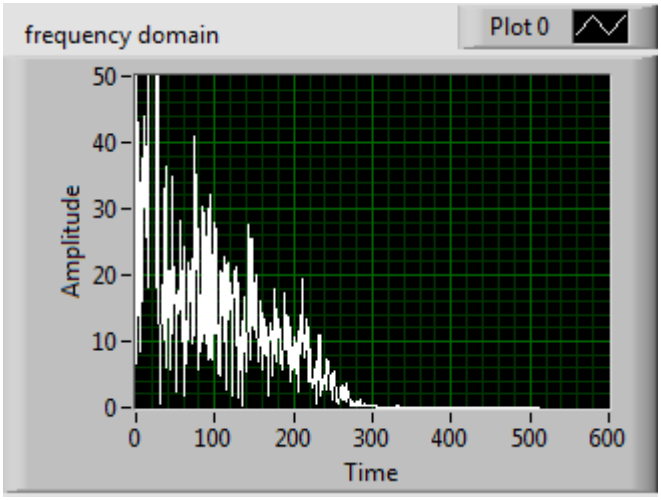


Figure 100: output after filter

From two figure above, the both Figure above prove that the results is correct since the frequency domain give more noise signals before apply filter compare to the frequency domain after apply filter.

4.12 Flow Chart

4.12.1 Optical Beam Deflection

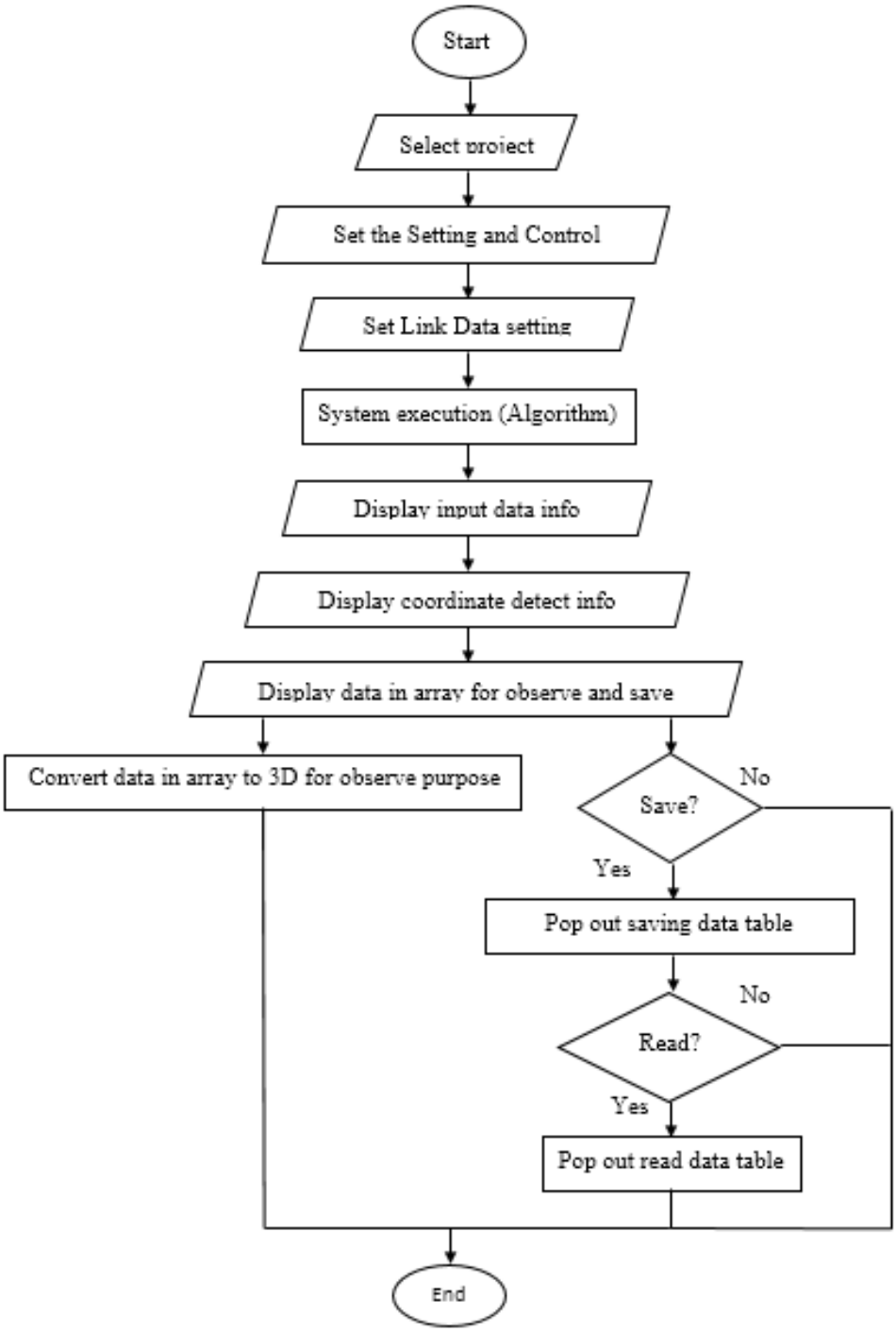


Figure 101: Operation flow of OBD

4.12.2 Filter

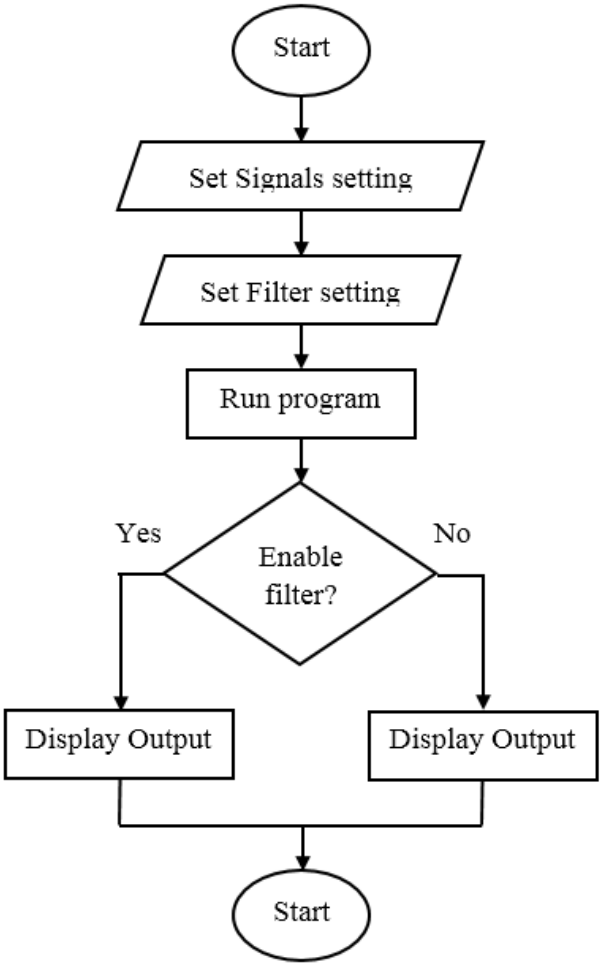


Figure 102: Operation flow of filter

4.13 Problem Faced

The first problem I faced is printed circuit board (PCB) design. For better track the connection, 1 layer printing is preferred. But, no matter how I arrange the electronic components, there still has some of wire is unable to connect after apply auto-routing. The black color wire shown in Figure 103 below is broken wire.

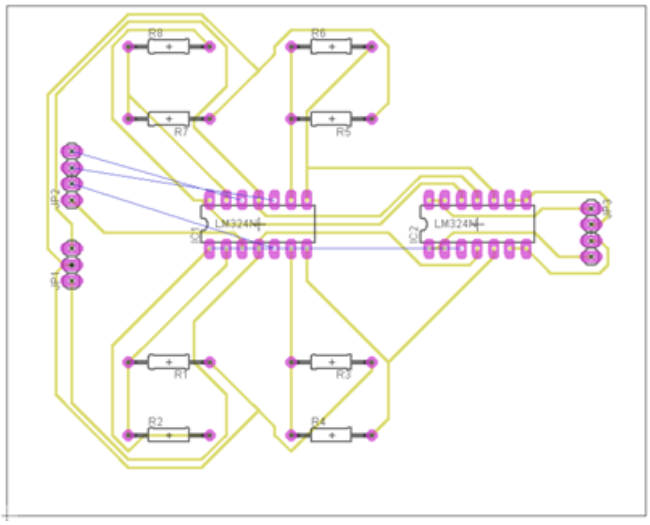


Figure 103: Block diagram after auto-routing

The second problem is data cannot display in array along x-axis and y-axis increment by 1 when x-axis reach the limit of cell. The following Figure 104 below show the data display in wrong cell of array. The problem solved by place the acquire data code in inner for loop shown in Figure 105 below, so that the array able to display new updated data.

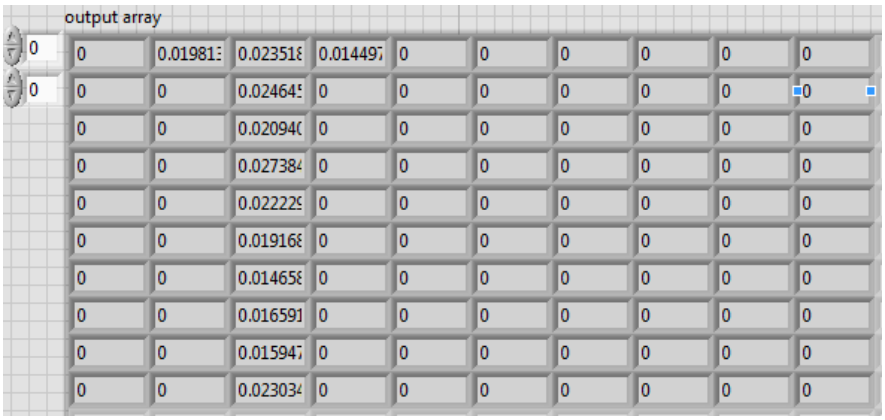


Figure 104: Error of display

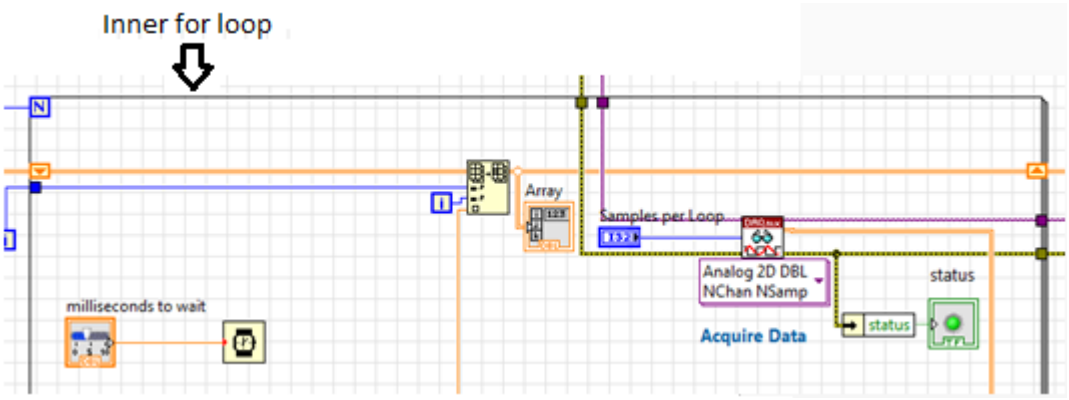


Figure 105: Acquire data code in inner for loop

The third problem is the overall execution rate of system start to slow down after few seconds of running. It can be seen when scroll down to observe results in front panel after the program is start running. It operate smoothly at the beginning, but it start to hang up. Few way was tried, but fail to solve the problem.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

An atomic force microscopy is split to 3 part to develop. My final year project is mainly to improve senior project to design prototype for optical beam deflection system and communicate with LabVIEW software. The algorithm design in printed circuit board (PCB) is design by using LabVIEW. Hence, the optical beam deflection system become more programmable. Design and keep improve the small parts of project to obtain desired results. Assemble those small parts and further testing the stability of system. Keep troubleshooting and implement to obtain better results.

From the project, I had learning and understanding the characteristics and limitation of component like LM324 op-amp chip. It replace the LM741 op-amp chip so the space is greatly reduce. I had learn to use EAGLE software to design a printed circuit board (PCB). The reduce use of wire make the project look more tiny and systematic.

Characteristics of material and material cost always the limitation of mechanical part. Limited resources become an obstacle to achieve better results. The hardest for mechanical part is adjust the angle of laser and photodiode. It cannot be done by myself due to need another person to fix the laser and photodiode on LEGO by using hot glue gun when holding the laser and photodiode.

In software part, connection between different data type data is the challenges. Data type converter solve a lot of problem in this task. Although LabVIEW provides an easy view for coding, but sometimes the concept in C programming cannot apply in G programming. Further testing and research to try out different way to solve the problem become main issues of time management.

5.2 RECOMMENDATIONS

The first recommendation is about the photodiode. The surface of photodiode is reflective material which will spread the light. To obtain more precise results, choose photodiode with unreflective material surface.

Last recommendation is about the laser. High quality of laser always the first choice. In my project, the light is too thick when it emit to photodiode. The movement of light on photodiode cannot be see when scanning. It give almost the same results.

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APPENDICES

APPENDICES A: Lm324 op-amp Chip

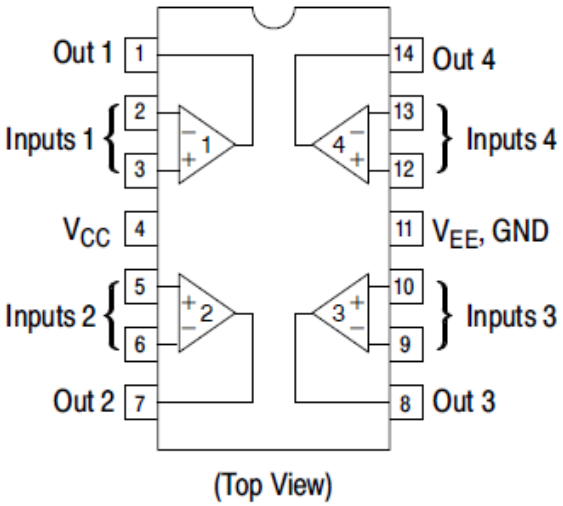


Figure 1: Structure of Lm324 op-amp chip

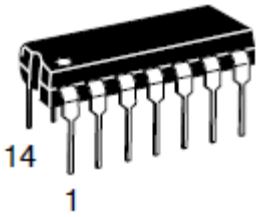


Figure 2: PDIP-14 N SUFFIX CASE 646

Figure 3: SOIC-14 D SUFFIX CASE 751A

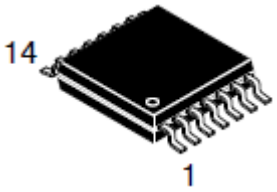


Figure 4: TSSOP-14 DTB SUFFIX CASE 948G

MAXIMUM RATINGS (T_A = +25°C, unless otherwise noted.)

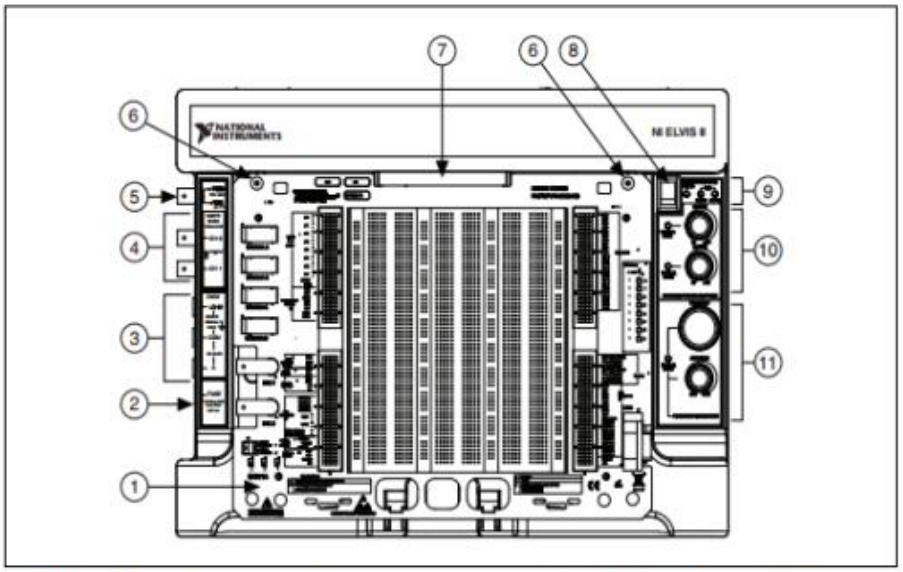
Rating	Symbol	Value	Unit
Power Supply Voltages Single Supply Split Supplies	 V_{CC} V_{CC}, V_{EE}	 32 ±16	Vdc
Input Differential Voltage Range (Note 1)	V_{IDR}	±32	Vdc
Input Common Mode Voltage Range (Note 2)	V_{ICR}	−0.3 to 32	Vdc
Output Short Circuit Duration	t_{SC}	Continuous	
Junction Temperature	T_J	150	°C
Thermal Resistance, Junction−to−Air (Note 3) Case 646 Case 751A Case 948G	$R_{\theta JA}$	118 156 190	°C/W
Storage Temperature Range	T_{stg}	−65 to +150	°C
ESD Protection at any Pin Human Body Model Machine Model	V_{esd}	 2000 200	V
Operating Ambient Temperature Range LM224 LM324, 324A LM2902 LM2902V, NCV2902 (Note 4)	T_A	 −25 to +85 0 to +70 −40 to +105 −40 to +125	°C

Stresses exceeding Maximum Ratings may damage the device. Maximum Ratings are stress ratings only. Functional operation above the Recommended Operating Conditions is not implied. Extended exposure to stresses above the Recommended Operating Conditions may affect device reliability.

1. Split Power Supplies.
2. For supply voltages less than 32 V, the absolute maximum input voltage is equal to the supply voltage.
3. All $R_{\theta JA}$ measurements made on evaluation board with 1 oz. copper traces of minimum pad size. All device outputs were active.
4. *NCV2902 is qualified for automitive use.*

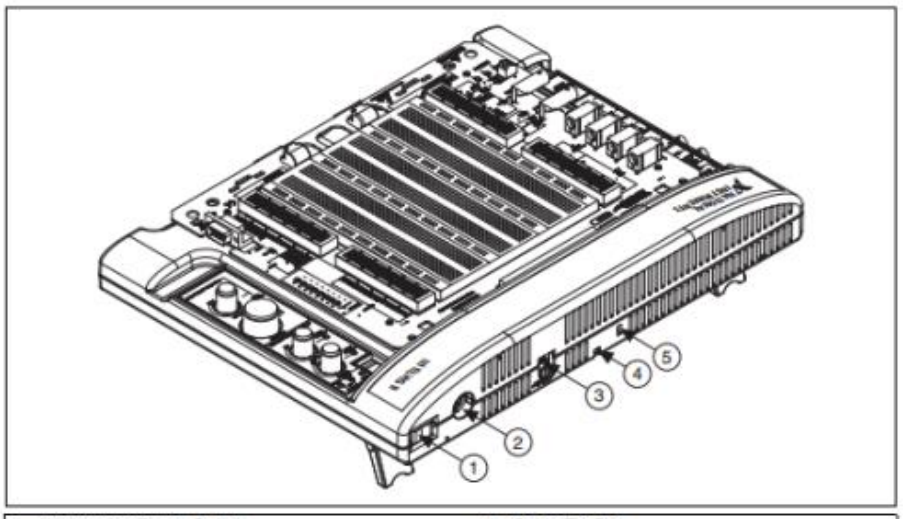
APPENDICES B: NI-ELVIS II data sheet

Figure 2-2 shows the workstation parts locator diagram.



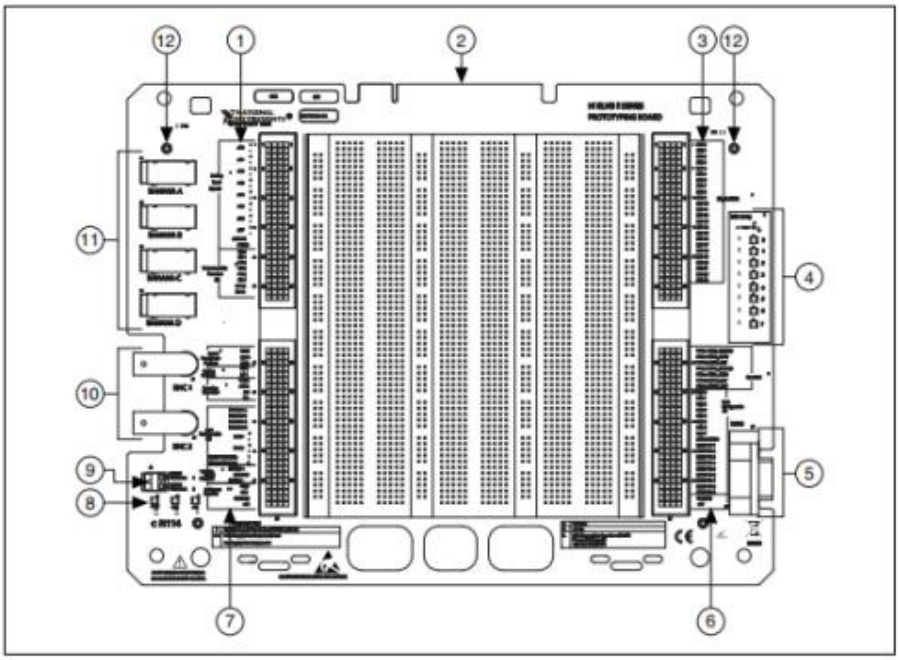
1	NI ELVIS II Series Prototyping Board	6	Prototyping Board Mounting Screw Holes
2	DMM Fuse	7	Prototyping Board Connector
3	DMM Connectors	8	Prototyping Board Power Switch
4	Oscilloscope Connectors	9	Status LEDs
5	Function Generator Output/Digital Trigger Input Connector	10	Variable Power Supplies Manual Controls
		11	Function Generator Manual Controls

Figure 2-2. Top View of NI ELVIS II Workstation with Prototyping Board (NI ELVIS II shown)



1	Workstation Power Switch	4	Cable Tie Slot
2	AC/DC Power Supply Connector	5	Kensington Security Slot
3	USB Port		

Figure 2-3. Rear View of NI ELVIS II Series System (NI ELVIS II shown)



1 AI and PFI Signal Rows
2 Workstation Interface Connector
3 DIO Signal Rows
4 User-Configurable LEDs
5 User-Configurable D-SUB Connector
6 Counter/Timer, User-Configurable I/O, and DC Power Supply Signal Rows
7 DMM, AO, Function Generator, User-Configurable I/O, Variable Power Supplies, and DC Power Supplies Signal Rows
8 DC Power Supply Indicators
9 User-Configurable Screw Terminals
10 User-Configurable BNC Connectors
11 User-Configurable Banana Jack Connectors
12 Screw Positions for Locking

Figure 2-5. NI ELVIS II Series Prototyping Board

Table 2-2. Signal Descriptions (Continued)

Signal Name	Type	Description
SCREW TERMINAL <1..2>	User-Configurable I/O	Connects to the screw terminals.
SUPPLY+	Variable Power Supplies	Positive Variable Power Supply—Output of 0 to 12 V.
GROUND	Power Supplies	Ground.
SUPPLY–	Variable Power Supplies	Negative Variable Power Supply—Output of –12 to 0 V.
+15 V	DC Power Supplies	+15 V Fixed Power Supply.
–15 V	DC Power Supplies	–15 V Fixed Power Supply.
GROUND	DC Power Supplies	Ground.
+5V	DC Power Supplies	+5V Fixed Power Supply.
DIO <0..23>	Digital Input/Output	Digital Lines 0 through 23—These channels are general purpose DIO lines that are used to read or write data.
PFI8 / CTR0_SOURCE	Programmable Function Interface	Static Digital I/O, line P2.0 PFI8, Default function: Counter 0 Source
PFI9 / CTR0_GATE	Programmable Function Interface	Static Digital I/O, line P2.1 PFI9, Default function: Counter 0 Gate
PFI12 / CTR0_OUT	Programmable Function Interface	Static Digital I/O, line P2.4 PFI12, Default function: Counter 0 Out
PFI3 / CTR1_SOURCE	Programmable Function Interface	Static Digital I/O, line P1.3 PFI3, Default function: Counter 1 Source
PFI4 / CTR1_GATE	Programmable Function Interface	Static Digital I/O, line P1.4 PFI4, Default function: Counter 1 Gate
PFI13 / CTR1_OUT	Programmable Function Interface	Static Digital I/O, line P2.5 PFI13, Default function: Counter 1 Out
PFI14 / FREQ_OUT	Programmable Function Interface	Static Digital I/O, line P2.6 PFI14, Default function: Frequency Output
LED <0..7>	User-Configurable I/O	LEDs 0 through 7—Apply 5 V for 10 mA device.
DSUB SHIELD	User-Configurable I/O	Connection to D-SUB shield.
DSUB PIN <1..9>	User-Configurable I/O	Connections to D-SUB pins.
+5 V	DC Power Supply	+5V Fixed Power Supply.
GROUND	DC Power Supply	Ground.