DEVELOPMENT OF LOW-COST PRECISION SCANNER SYSTEM FOR SCANNING PROBE MICROSCOPY APPLICATION

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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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Date : ___________________________

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"DEVELOPMENT of LOW-COST PRECISION SCANNER SYSTEM FOR SCANING PROBE MICROSCOPY APPICATION"** was prepared by **KANG QIN YEE** 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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Approved by,

Signature : _________________________

Supervisor : Dr. LOH SIU HONG

Date : _________________________

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In addition, I also like to thank to my friend, Teh Yong Hui and Phoong Wei Siang that teach me a lot of programming of LabView and how to link NI ELVIS II^{++} and LabView together.

DEVELOPMENT of LOW-COST PRECISION SCANNERSYSTEM FOR SCANING PROBE MICROSCOPY APPLICATION

ABSTRACT

Atomic Force Microscope (AFM), also known as “Scanning Force Microscopy (SFM)”. It is a microscope that can measure up to nanometer technology. In AFM, there is a pin, when this pin touches a bump and the pin will rise up. When the pin rise up, the laser that target to the pin and reflect to photodiode and let photodiode study, measure and decide the pin is rising or dropping. Its advantage is the performance of AFM is better than optical diffraction. To scan the object, we need to move either object or the pin. To move the object, we need some machine that can move in a small scale. The most challenging part is the machine need to move in small range. A small scale motion machine can cost the overall AFM in very high cost. To lower down the cost, we must find some material that is cheaper. After researching, we found that piezoelectric buzzer apply voltage, it will expend and push away the object. In this report, I had done many version of machine to make some motion. To make some motion, I need to apply some programming. I decide to use LabView as software and ELVIS II^{++} board as hardware. The reason of using LabView is because it has a very easy to study, it clear and graphical program. At the same time, ELVIS II^{++} is a test board by using LabView to control. From the programming part, ideally I will let X-axis from left move to right as a cycle and Y-axis will move up one coordinate. To prove this project works, I have to prove both axis can move.

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LIST OF SYMBOLS / ABBREVIATIONS

AFM	Atomic Force Microscopy
2D/3D	2-Dimension / 3-Dimension
EAGLE	Easily Applicable Graphical Layout Editor
PCB	Printed Circuit Board
NI ELVIS II^{++}	National Instruments Educational Laboratory Virtual Instrumentation Suite
DAQ	Data Acquisition

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CHAPTER 1

INTRODUCTION

1.1 Background

Atomic Force Microscopy (AFM) was found in 1986. Bining and Quate presented the ideas of AFM. At that time, they build the ultra-small probe tip at the cantilever.

In 1987, Wickramsinghe et al. was improved the cantilever to vibrate by using light-lever mechanism. Surface profiler was created to improve AFM in 1929 by Schmalz, Figure 1 shown what Schmalz presented. (Zang, 2013)

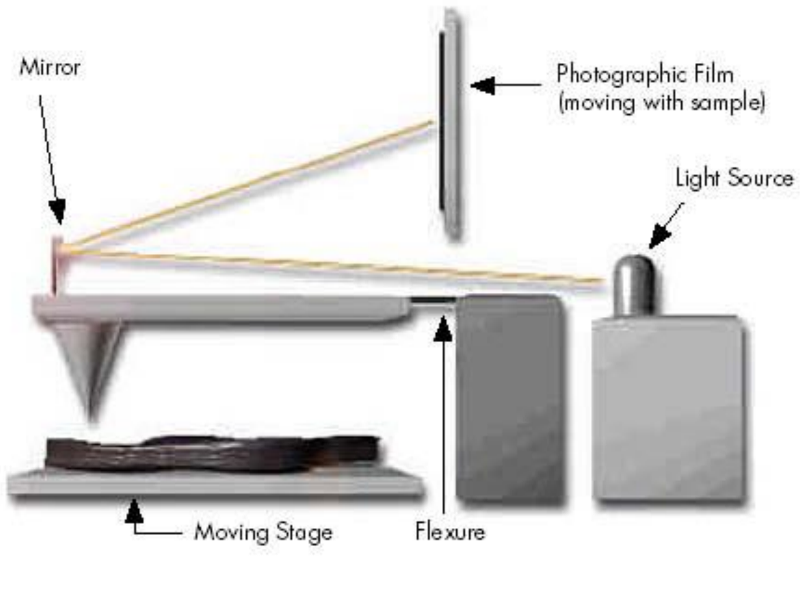


Figure 1-1 Designed By Schmalz

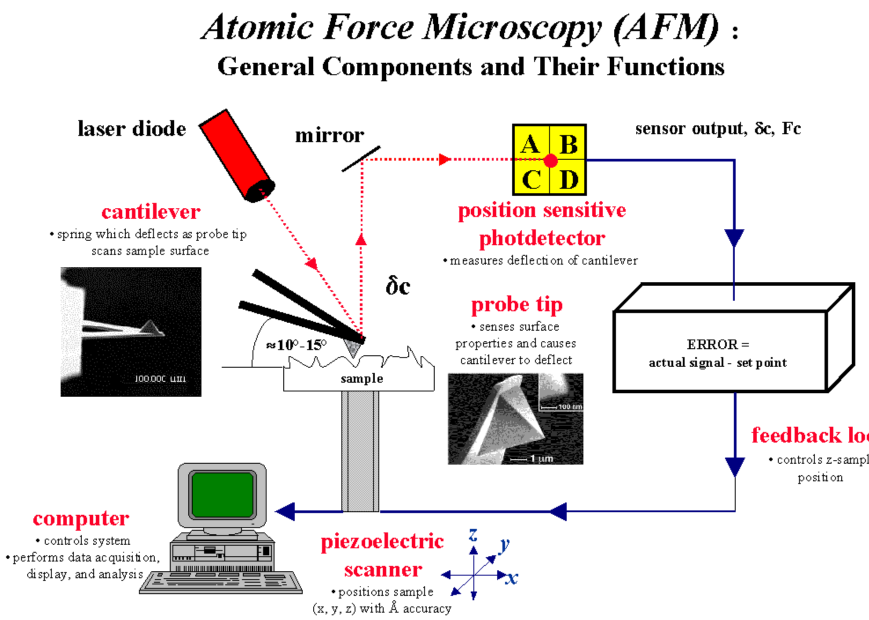


Figure 1-2 Atomic Force Microscope Scanning Process

After that, human try to change the light source to laser source. It is because laser is more focus and more accurate; while the receiving part will use photodiode. Figure 2 shows how AFM works in scanning process. The weakness of this AFM diamond tip is can only scan at a point. So that, we need to build a moving stage which can be considered as a scanning process. Since the moving stage must be designed in such a way that it only move for one or two micrometer. (Zang, 2013)

Nowadays, people create a solution to solve the high power consumption, high cost by replacing piezoelectric buzzer.

1.2 Problem Statements

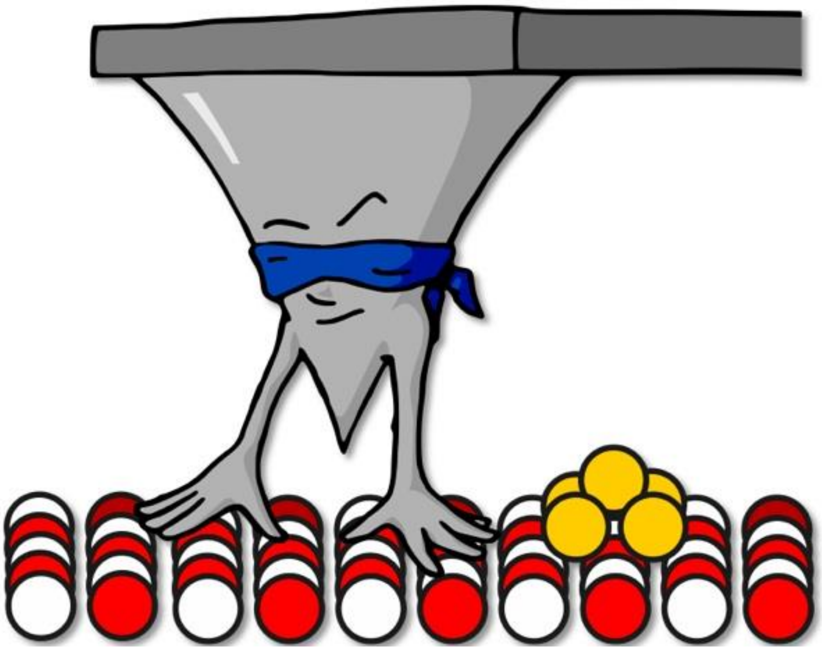


Figure 1-3 Pin is "blink"

When the pin touches an object, it will move up and down. However, I have to move the object or pin to let the pin scan everything. Thus, my project here is to build a machine. The most challenging part is to move in small scale.

1.3 Aims and Objectives

Atomic force microscope (AFM) diamond tip can scan the shape of sample, but it can only stay at point. Thus, what we are going to do is to move the sample let AFM scan it. In conclusion, this thesis is shown the following:-

To build a 2 dimension automation devices.

To build in low cost.

To study the material degradation on the plasma actuator surfaces.

CHAPTER 2

LITERATURE REVIEW

2.1 Material

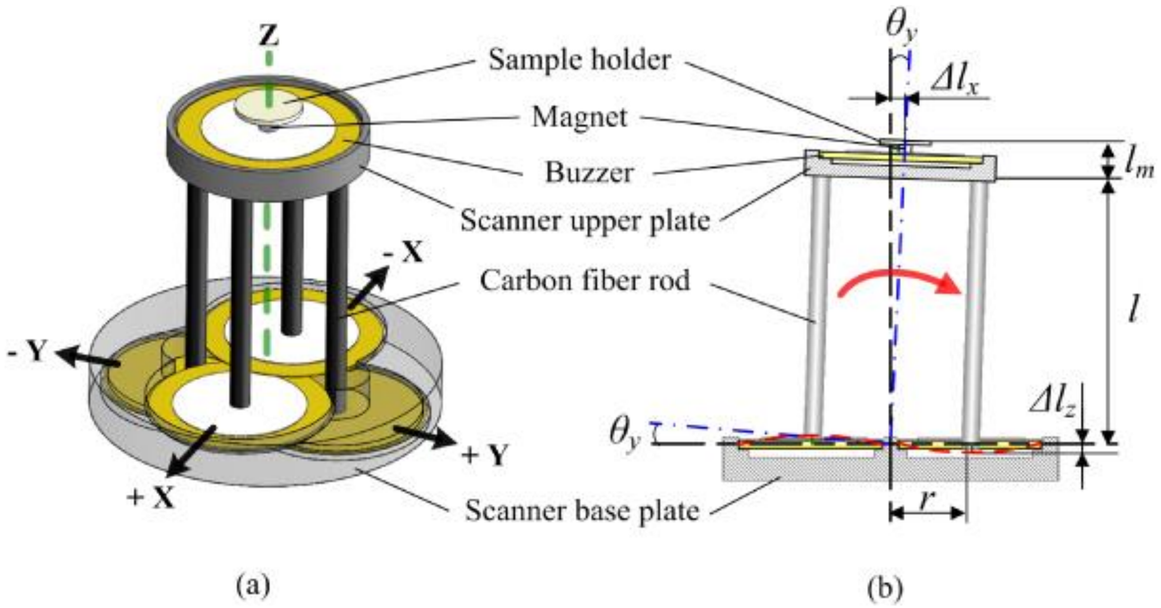


Figure 2-1 Schematic Diagram of Buzzer Scanner (b) Side Vice of Buzzer Scanner

The scanner machine contain of five piezoelectric disk buzzers. The challenging part of the scanner is to move in micrometer. Thus, piezoelectric material can make a move sensitive in micrometer. **In this paper, I found that, there is some improvement from θ_y, because we are how doing 3-dimension, the angle might affect the third dimension measuring.**

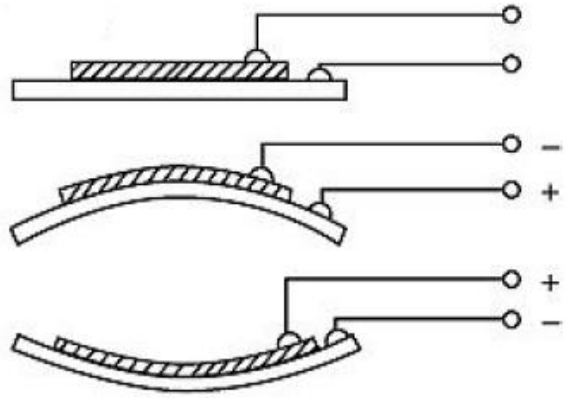


Figure 2-2 Piezoelectric Buzzer

From Figure 4 above, different victor of voltage apply on piezoelectric material, it can expend and move up or down. Piezoelectric can only expend in a few micrometres, so that we decide to use it to turn the direction.

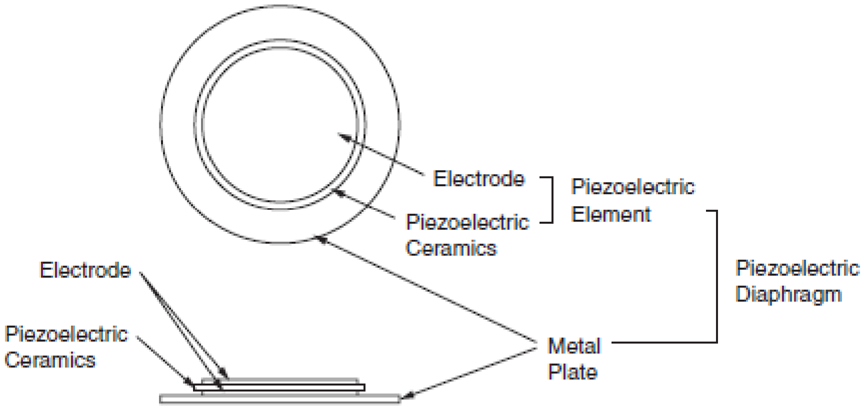


Figure 2-3 Piezoelectric Buzzer Structure

Piezoelectric Buzzer contain of thin metal such as stainless steel (Metal Plate), Silver electrode and piezoelectric Ceramic. The voltage connects to piezoelectric ceramic, it will affect metal plate and electrode expand and thus whole disk band. (Murata, 2012)

2.2 Design

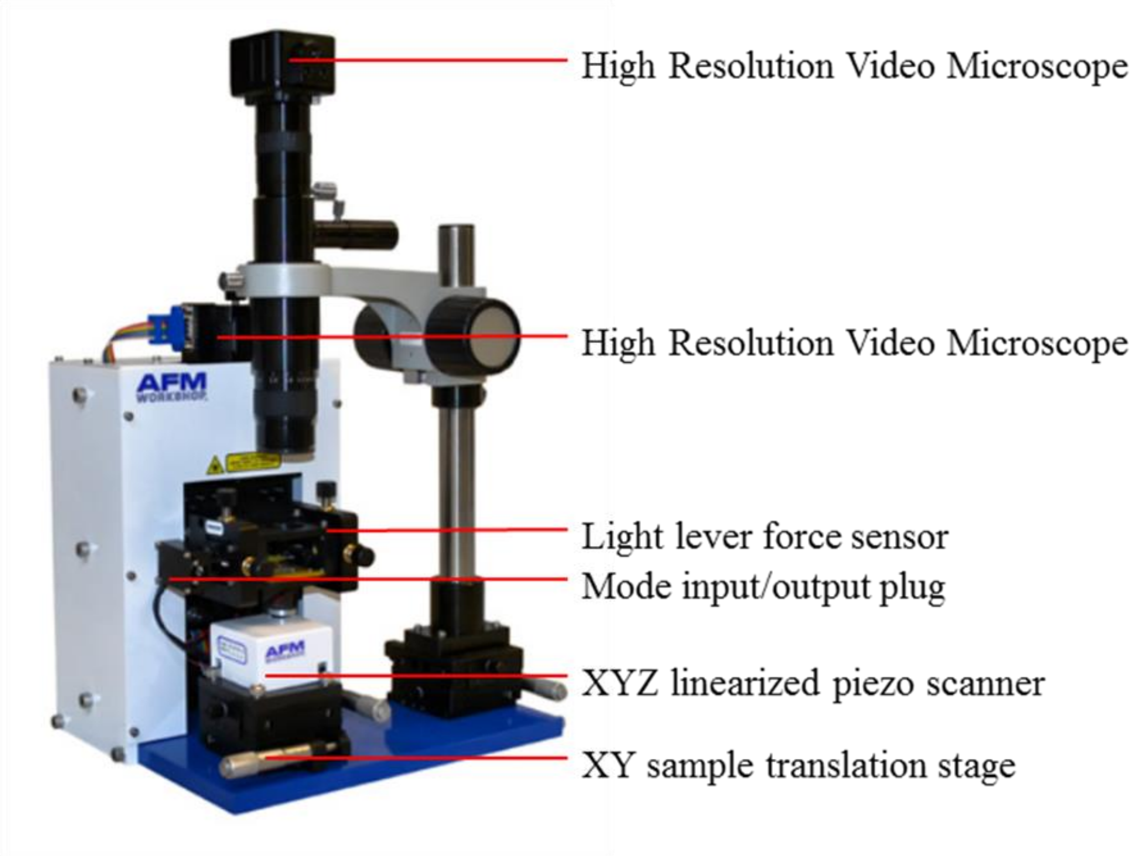


Figure 2-4 Atomic Force Microscope in Market

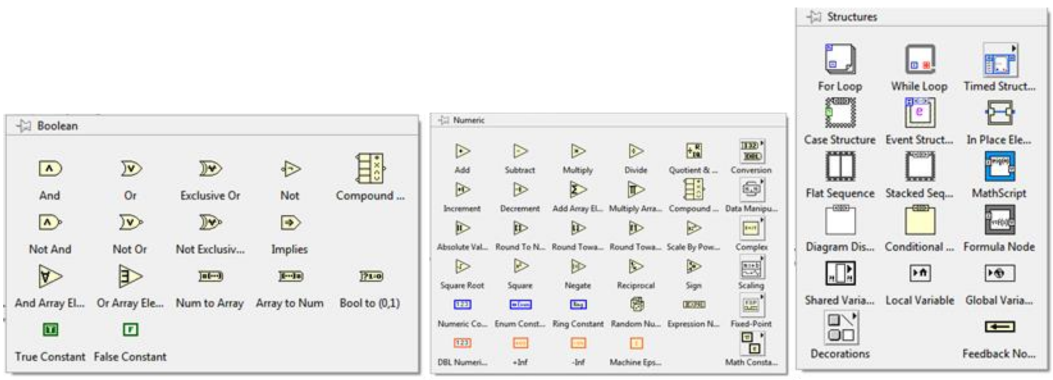
Figure 6 shows the AFM contain with scanner sell in market. This scanner can scan a sample maximum size of $1" \times 1" \times {}^{1}/_{4}"$. This scanner scale can take maximum $50 \times 50 \times 17\mu m$; while minimum is $15 \times 15 \times 7\mu m$. In the other hand, it cost us 31,783USD, thus, we are here to design a low cost AFM. (Workshop, n.d.)

2.3 LabView

Figure 2-5 LabView Logo

LabView is powerful software tool to solve, improved and maintaining any software and hardware effectively and efficiency. It contains of block diagram and front panel to show user high abstraction and much detail function. Block Diagram showed the detail of function. However, Front Panel showed the abstraction part of the function. It considers G programming software. G programming means graphical programming. G programming provide user easy to draw out their ideal programming. G programming is an interesting programming that contain of colourful picture to represent a code, example below shown many picture to represent the code.

In this software, we can learn to build many other components such as logic gates, timer, LED and others. There is not only this few type of component, we still can learn more about high level coding for example like add, subtract, multiply and others.



(a) (b) (c)

Figure 2-6 (a) Logic Gate (b) Mathematical calculation (c) Structures

Other than components, it still has programming function such as, if/else, while loot, for loot and others. Input output ports controller also can be created.

Input output ports named as Acquire Signals (Input ports) and Generate Signals (Output Ports). Acquire signal named as input is because not to confusing user that, it means to receive or get signal from outside to computer; While Generate Signals define as produces or trigger a signal out.

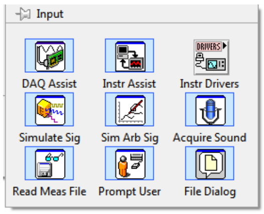


Figure 2-7 Input or output to NI ELVIS II++ board

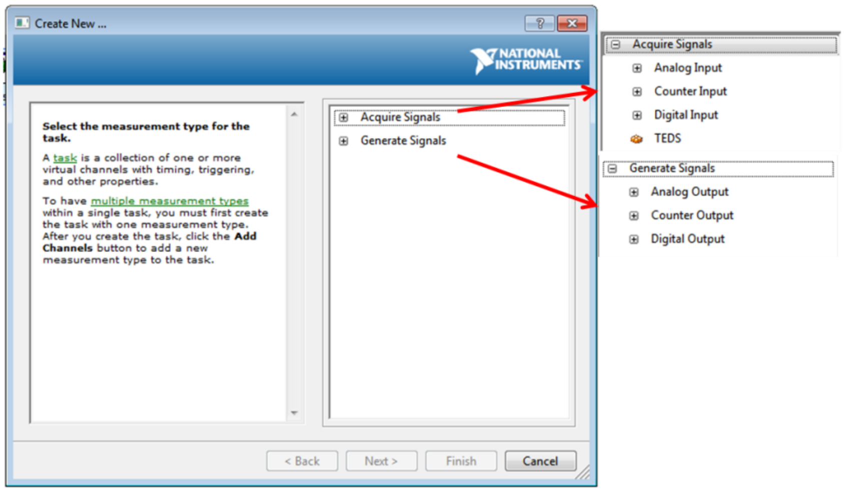
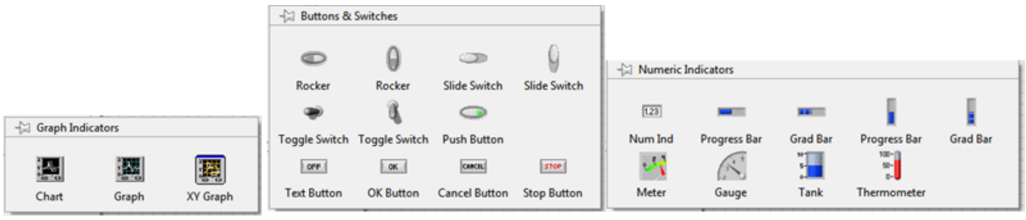


Figure 2-8 Acquire Signal is input signal; Generate Signal is output signal

In addition, it also includes many type of indicator such as 3D/2D graph, 3D/2D array reader, LED and others.



(a) (b) (c)

Figure 2-9 (a) Graphical design (b) Switch and push button (c) Analog measurement

So that, LabView can easily control input and output port. It also can easily run and program the function to test. Thus, it is helpful to test engineer, research and development engineer and others. (LabView, n.d.)

2.4 National Instruments (NI)

Figure 2-10 National Instruments Logo

National Instruments (NI) is powerful instruments. It provides many input output ports and converts to data then study in our computer using either LabView or its own software. Today, I am so proud that, I have a chance to use NI new instruments, NI ELVIS II^+. NI ELVIS II^+ is an education instrument, in this board, it provide many type of input output ports. Figure below shown overall the ports in this instrument.

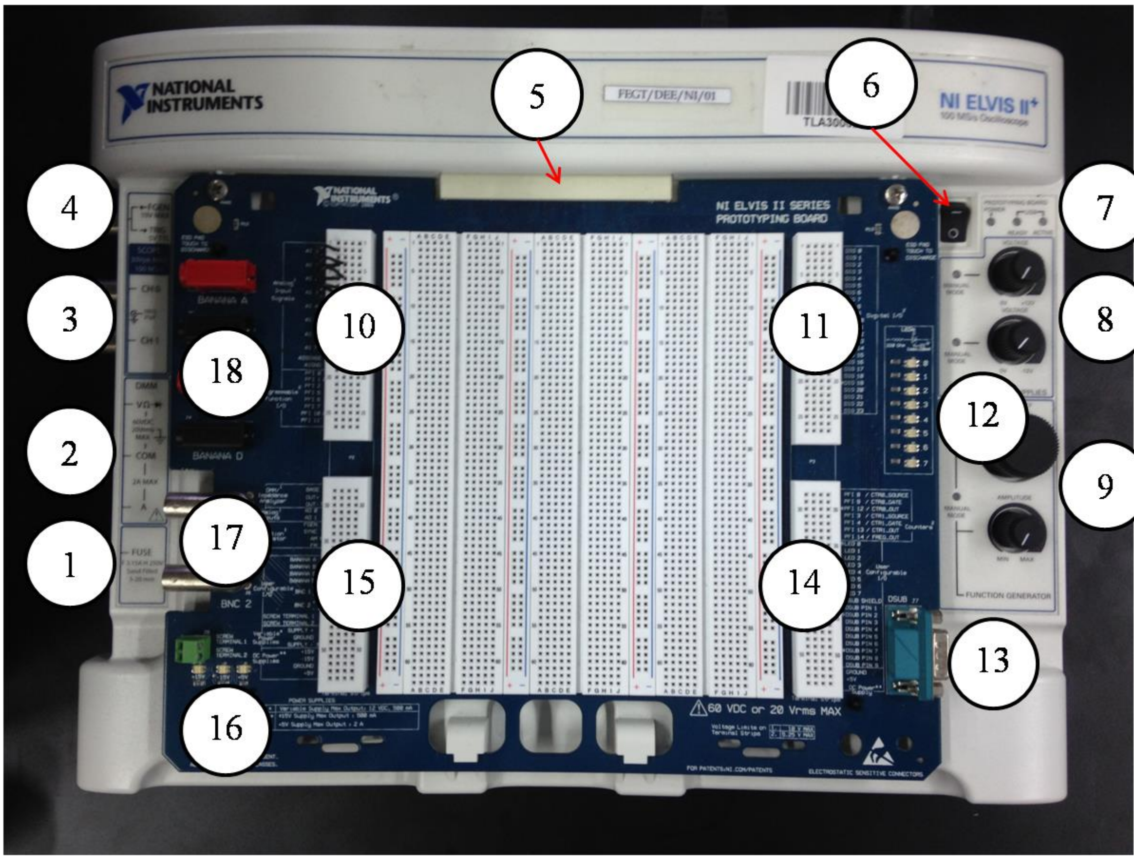


Figure 2-11 NI ELVIS II++ board

Table 2.1 NI ELVIS II++ board

1	DMM Fuse	12	LEDs Output
2	DMM Connectors	13	D-SUB Connector
3	Oscilloscope Connectors	14	Counter/Timer, User-Configurable I/O, and DC Power Supply Signal Rows
4	Function Generator		
5	Prototyping Board Connector	15	DMM, AO, Function Generator, User-Configurable I/O, Variable Power Supplies, and DC Power Supplies Signal Rows
6	Prototyping Board Power Switch		
7	Status LEDs		
8	Variable Power Supplies (Manual Controller)	16	DC Power Supply Indicators
9	Function Generator(Manual Controller)	17	BNC Connectors
10	AI and PFI Signal Rows	18	Banana Jack Connectors
11	DIO Signal Rows		

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In other hand, the software part of NI ELVIS II^{+}, it carry some function such as, DMM (Digital Multimeter), Scope (Oscilloscope), FGEN (Function Generator), VPS (Variable Power Supplies), Bode (Bode Analyzer), DSA (Dynamic Signal Analyzer), ARB (Arbitrary Waveform Generator), DigIn (Digital Reader), DigOut (Digital Writer), Imped (Impedance Analyzer), 2-Wire (Two-Wire Current-Voltage Analyzer) and 3-Wire (Three-Wire Current-Voltage Analyzer).

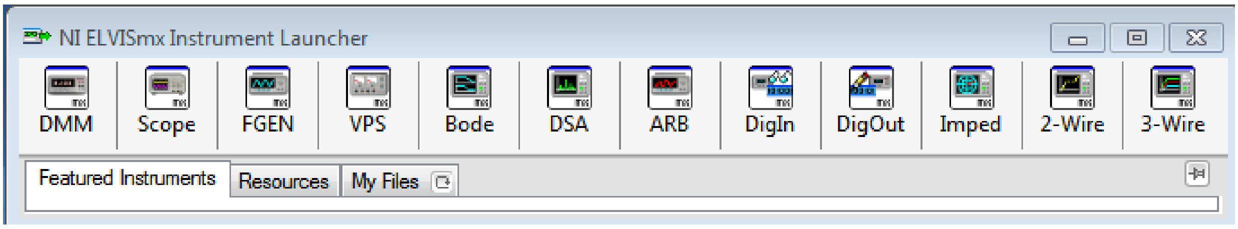
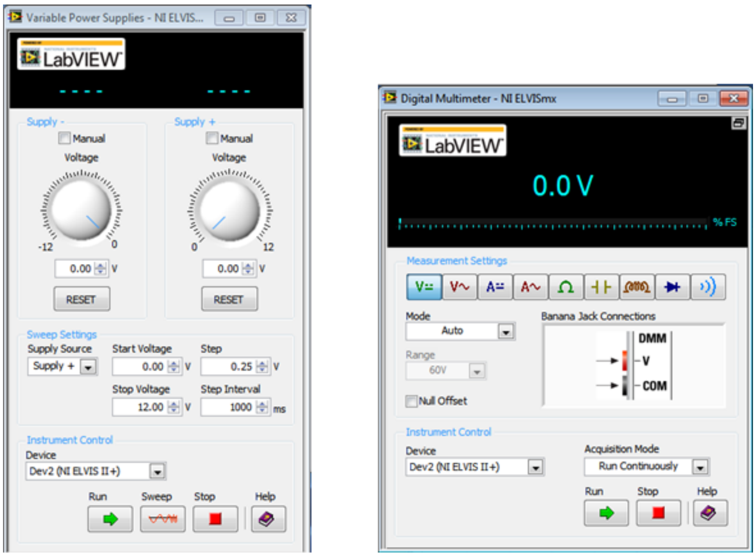


Figure 2-12 Instruments provided for NI ELVIS II++ board

Basically few application only will use, such as Variable Power Supplies. It can supply up to 12V and there are 2 output ports (Supply + and Supply -). Figure below shown VPS software controller.



(a) (b)

Figure 2-13 (a) Power Supply (b) Digital Multimeter

Other than power supply, DMM (digital multimeter) also the main measurement that user needed. In this DMM, We can measure Voltage, current, resistor, capacitor, inductor and many others. Compare to UTAR laboratory DMM machine, it carry more function and occupy less space. But the limitation of the Voltage in is 60VDC, and maximum of 2A current.

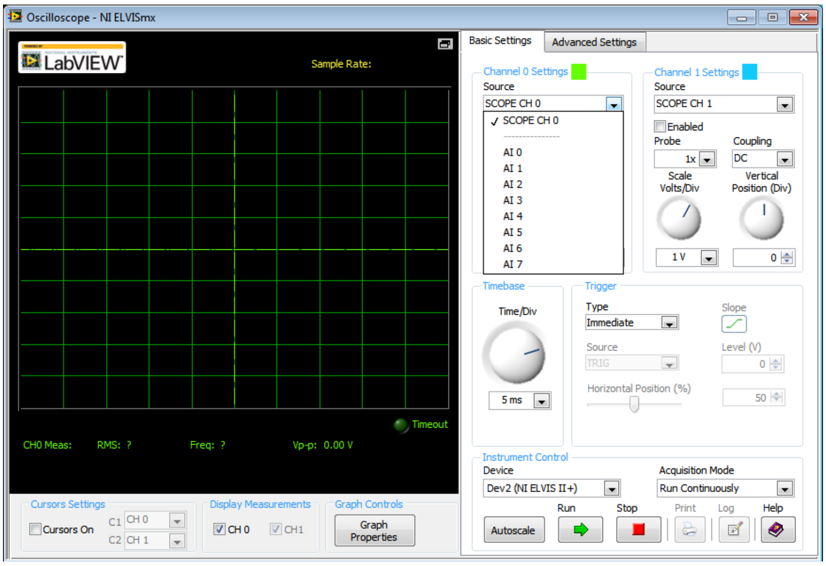


Figure 2-14 Oscilloscope

Oscilloscope also is an important instrument. It helps us to measure the frequency. NI ELVIS II^{+} also contain of oscilloscope. In this software, we can detect the signal or frequency from many different ports, other than only at the specific port.

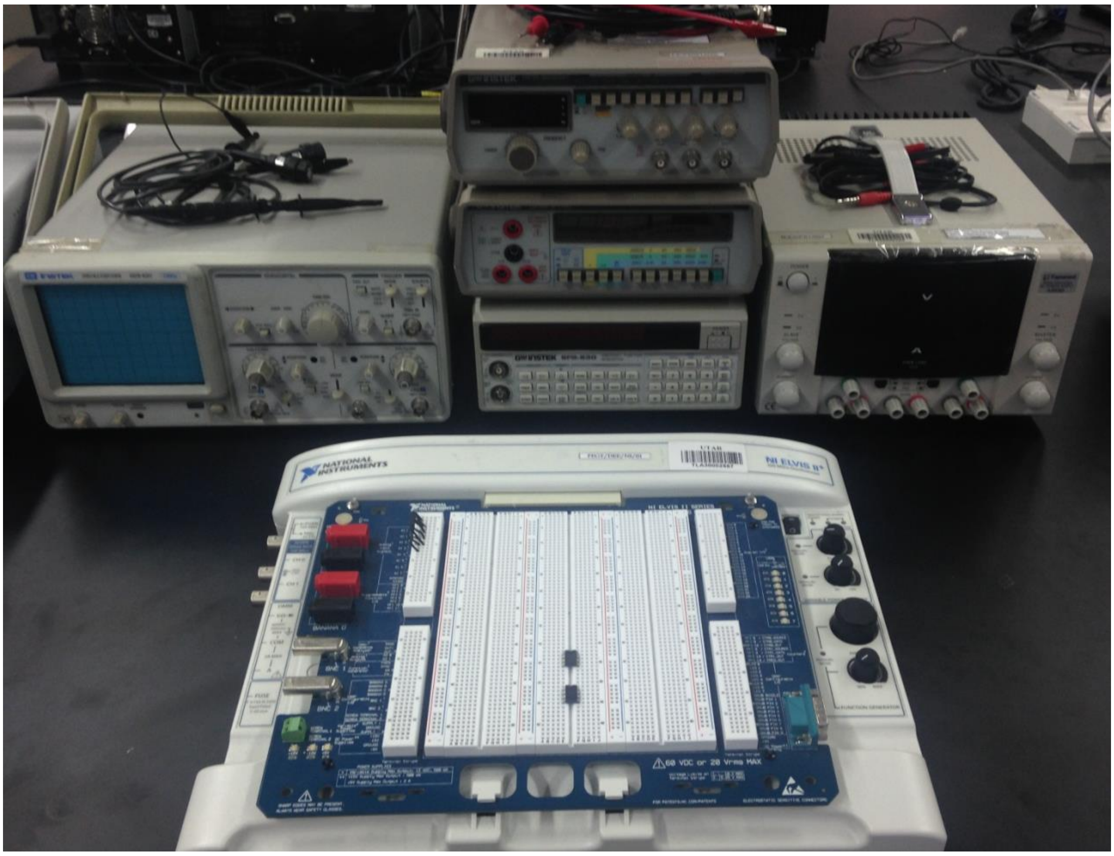


Figure 2-15 NI ELVIS II++ board having five function above with smaller size

NI ELVIS II$^+$ is a powerful and benefits instruments, it got multiple functions in one board. When short circuit, it also will shut down the power supply to protect every port, function and component. It is light to carry anywhere and just plug into computer and control. It occupies less space and it have many ports to run a function. (ELVIS, n.d.)

2.5 LM741 Operational Amplified

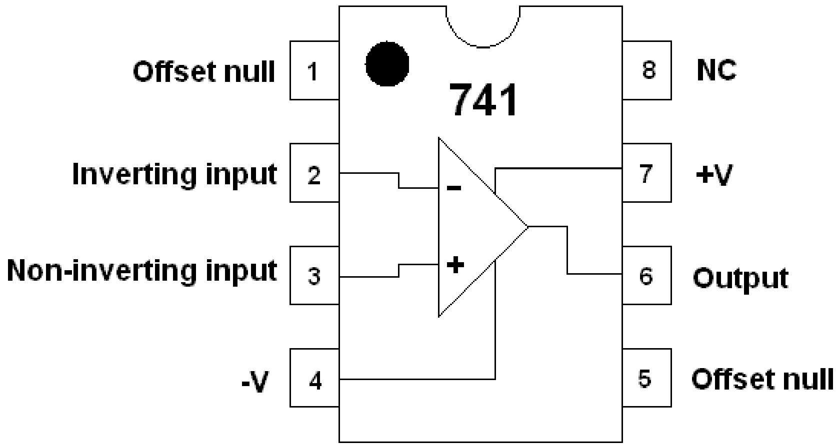


Figure 2-16 LM741 Amplified Circuit designed

LM741 Operation Amplified (Op-Amp) was designed by Texas Instruments (TI). Operational amplifier is a DC-Coupled with high-gain voltage amplifier. Amplifier consis of differential inputs such as non-inverting input (+) and inverting input (-). Output voltage will depends on the difference in voltage between both inverting and non-inverting inputs to calculate using the equation shown below.

$V_{out} = A_{OL}(V_+ - V_-)$, Where A_{OL} is open loop gain.

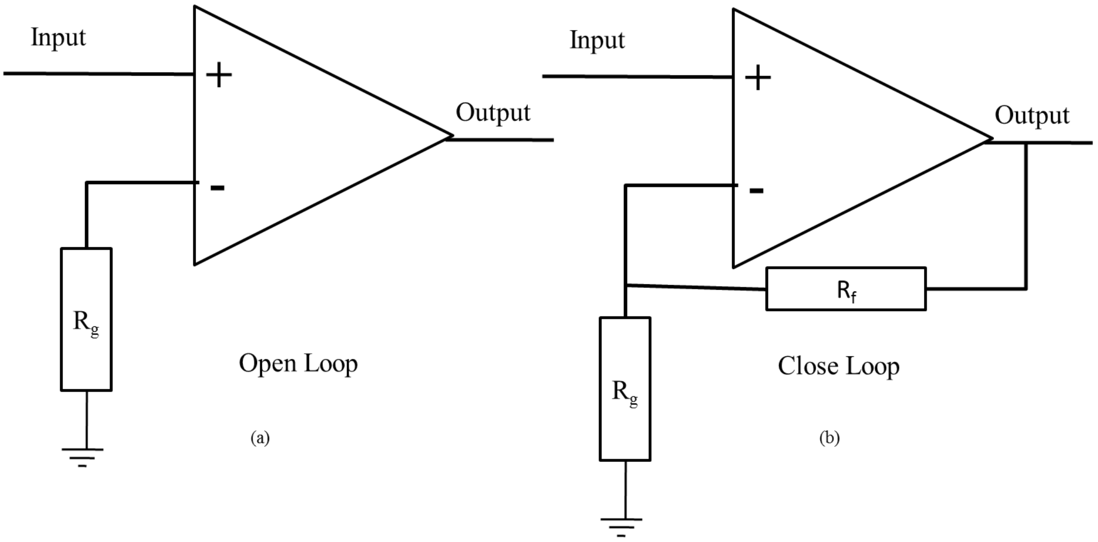


Figure 2-17 (a) Open loop amplifier (b) Close loop amplifier

Besides that, Close loop also is one of the way to amplify. However, the equation used for close loop is slightly different, compare with open loop. $V_{out} = V_{in}A_{CL}$, where A_{CL} is close loop gain that. To calculate close loop gain the formula is $A_{CL} = \frac{V_{Out}}{V_{in}} = 1 + \frac{R_f}{R_g}$.

According to datasheet from Texas Instruments (TI), the most powerful of this component is when there is overloaded of power, there will be a protection to our input and output. Thus, this is the best choice. The important maximum rating in this component is shown below. (LM741, 2013)

Table 2.2: Limitation of LM741

	LM741
Supply Voltage	±22V
Power Dissipation	500mW
Differential Input Voltage	±30V
Input Voltage	±15V

2.6 Printed Circuit Board (PCB)

Printed Circuit Board (PCB), also named "Printed wiring boards" or "Printed Wiring Cards". PCB had developed since 1850s. In 1943, PCB had developed to more than one layer. This is a new and powerful improvement to solve size, spacing and cost problems. PCB main function is to simplify your circuit and compress all the wire become smaller as the figure show in next page.

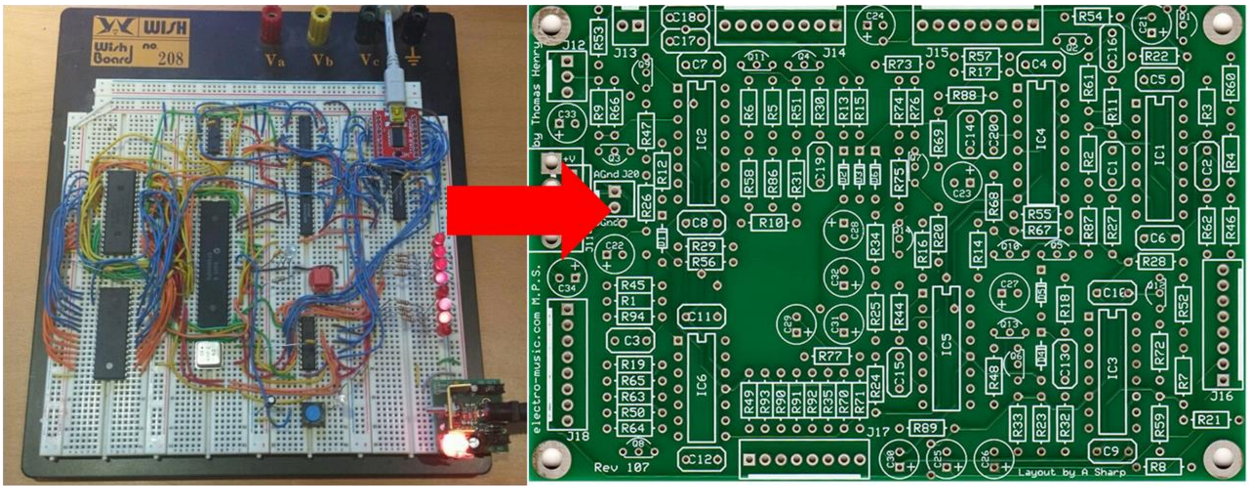


Figure 2-18 Before and after apply in PCB

PCB used to simplified complicated circuit. More complicate circuit, can use more layer to build the circuit. PCB can build in single layer, double layers and multiple layers. (PCB, n.d.)

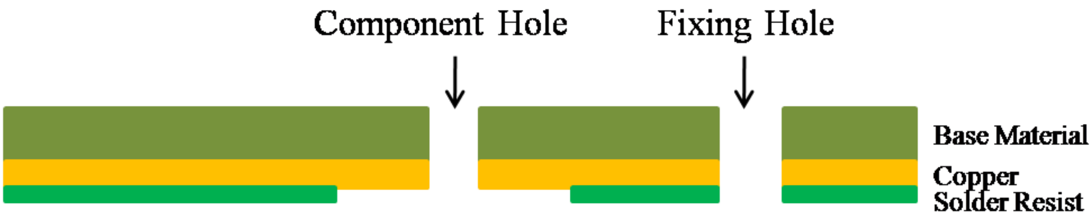


Figure 2-19 PCB Single layer design

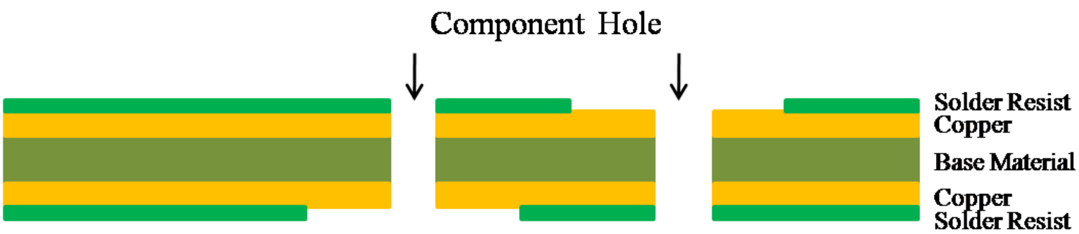


Figure 2-20 PCB double layer design

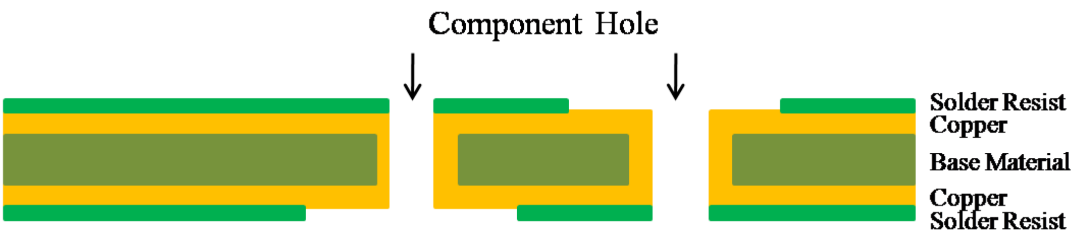


Figure 2-21 PCB double layer with copper through

2.7 EAGLE easily applicable graphical layout editor

Figure 2-22 EAGLE's Logo

EAGLE’s Company founded at 1988 and it named CadSoft. 22nd of November,1988, CadSoft created a software name EAGLE. It is powerful and user-friendly software for PCB design. The most powerful 3 function, Modules schematic editor, layout editor and auto router, every single step also will help you speed up design’s duration, more efficiency and effectively.

Modules Schematic editor, there are more than thousands of components and their size.

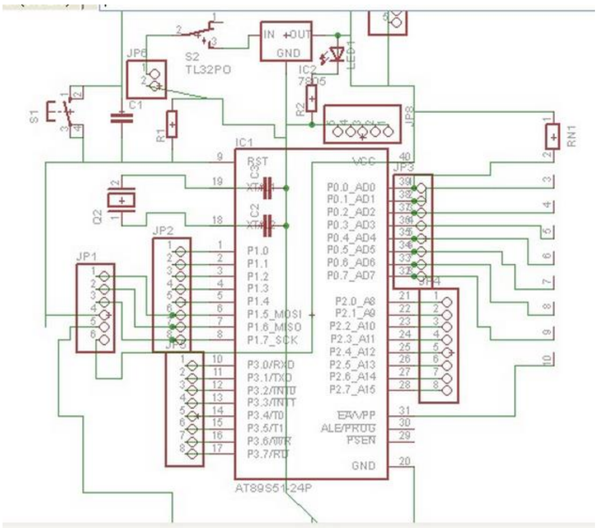


Figure 2-23 Scemathic layout

Layout editor and auto router is the most powerful and intelligent in EAGLE. Figure below shown layout diagram with and without auto router. Figure that without look complicated, if user is going to edit himself, it might took a long time to done it. However, auto router here helps a lot to speed up the time. (EAGLE, 2011)

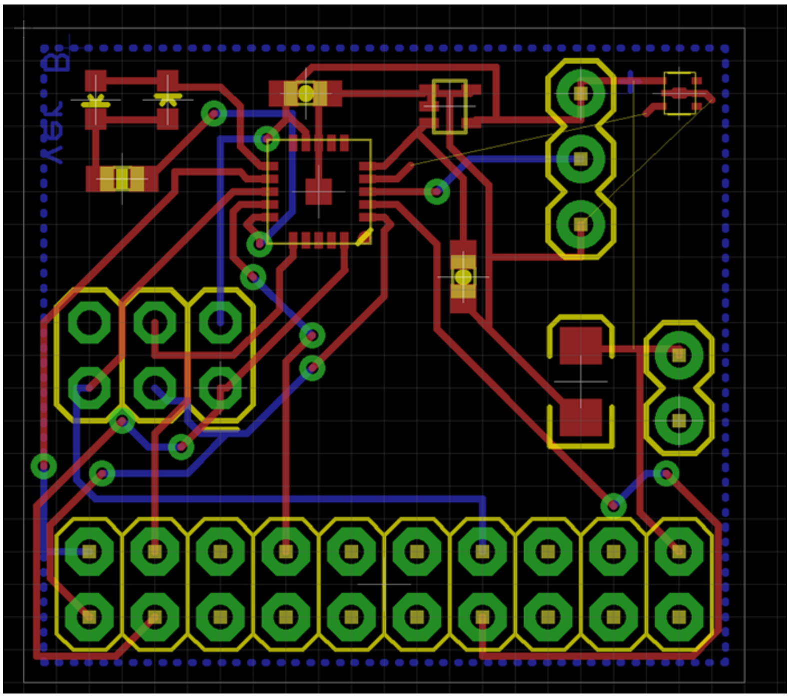


Figure 2-24 Board diagram

2.8 Hot Glue Gun

Hot glue gun is good sticker, it can stick many types of materials together. Once it stick, it hard to remove without heating it. First produced was created at 1940s, hot melts produced liquid-base and exposed to every devices. It is powerful because after it stick, even liquid or water also cannot pass through. Initially of design is only to bond up shoes but after people find out that it can apply in wood working, retail manufacturing, recreational decoration and shipment packaging. Thus, I think it can bond up strongly of lego that I want to build in this project.

Figure 2-25 Quality of hot glue

The best bonding results is the first 30 minutes while start melting. Figure below show the longest time hot glue gun operating, the lowest quality of the glue. (AndyGadget, 2003)

2.9 Soldering Process

Table 2.3 Soldering meterials

	**Chemical Paste** It used to deoxidized soldering iron tips. Once soldering iron tips oxidize, soldering wire cannot stick with it anymore, thus it needs to de-oxidized

	**Soldering Wire (ROHS)** To stick semiconductor.
	**Soldering Iron tip cleaner** To clean up soldering iron tip
	**Desoldering Pump** It use to suck in soldering ROHS Before the ROHS can be suck in, make sure it is melting.
	**Soldering Flux** When the component cannot stick with soldering wire, paste this soldering flux before the soldering process, so that it will stick Caution!!! do not apply too much otherwise it might short circuit.
	**Soldering Exhaust Fan** Once the soldering process start, the fan MUST be open so that, major part of the poison not moving your lungs. For your safety precaution.

2.10 LEGO

Figure 2-26 Logo of LEGO

Lego founded 1932, it main product is toys. After that, they found there is no giving people a chance to build their own imagination toys. Thus, in 1946 they create the first product that can build your own toys called Lego bricks.

In this project, we are going to use Lego bricks to build our project. Lego bricks have a standard size that shown below. It can help us stand up our hardware part. It has strong skeleton, flexible space to build. (TV, 2010)

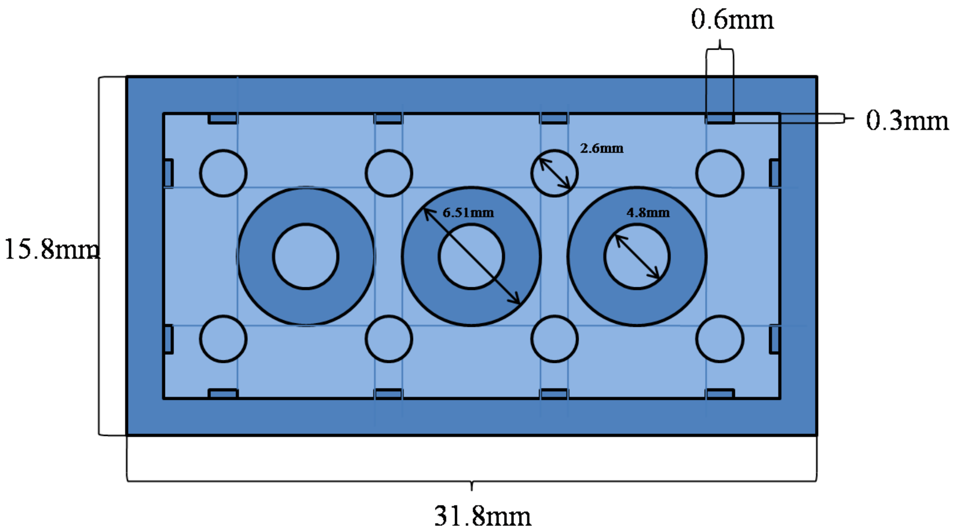


Figure 2-27 Bottom view designs of bricks

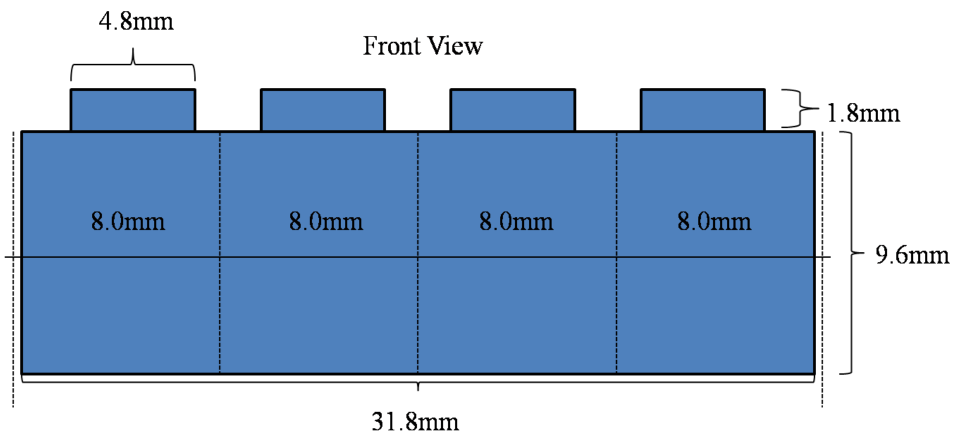


Figure 2-28 Side view of LEGO bricks

CHAPTER 3

METHODOLOGY

3.1 Design

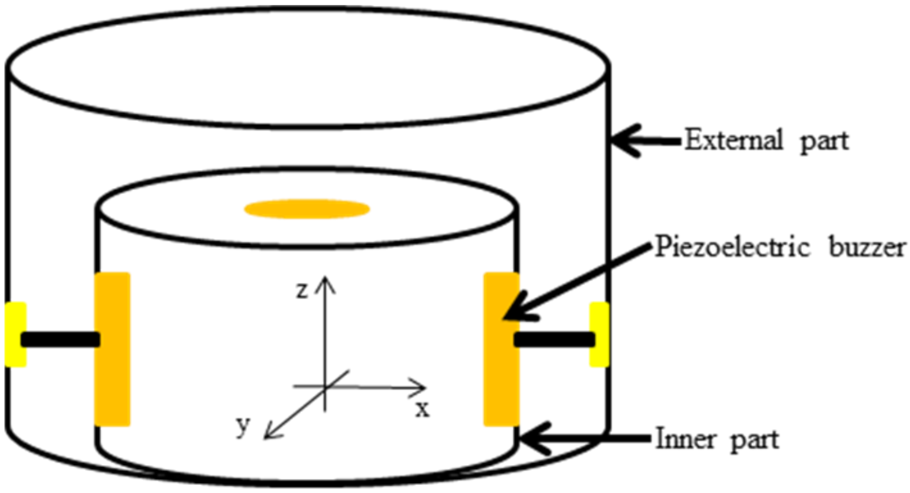


Figure 3-1 Piezoelectric Scanner Blue print

Figure 3.1 shows the blueprint of my scanner. The external part of this scanner must be bigger than inner part, it is because to prevent dust or anything affect the stimulation. Piezoelectric buzzer (X-axis and Y-axis) will put at the side to push or pull the external part.

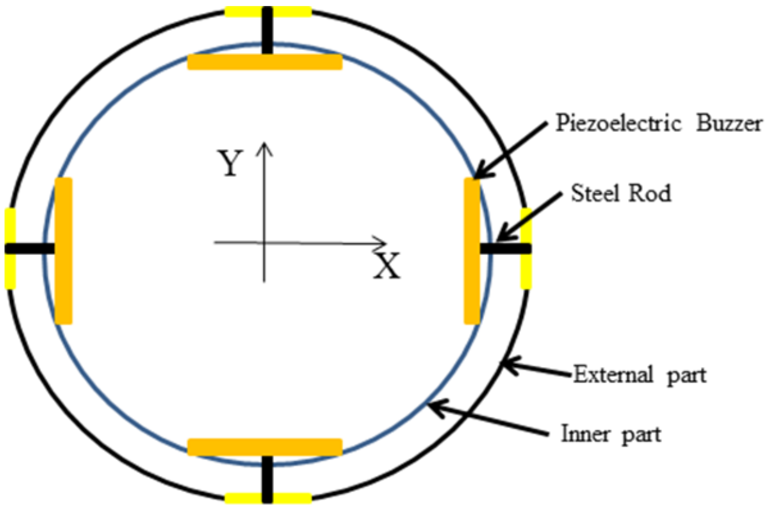


Figure 3-2 Top view of piezoelectric buzzer

Figure 3.2 shows the top view of buzzer scanner. In this project, I am going to design X-Y axis. According to the problem I mention in Chapter 2, θ_y angle might affect third dimension. This will be the best solution to solve the angle problem. Other than that, bright yellow colour part, I will have a space to let the steel rod free moving to prevent the pull and push problem shown in figure below.

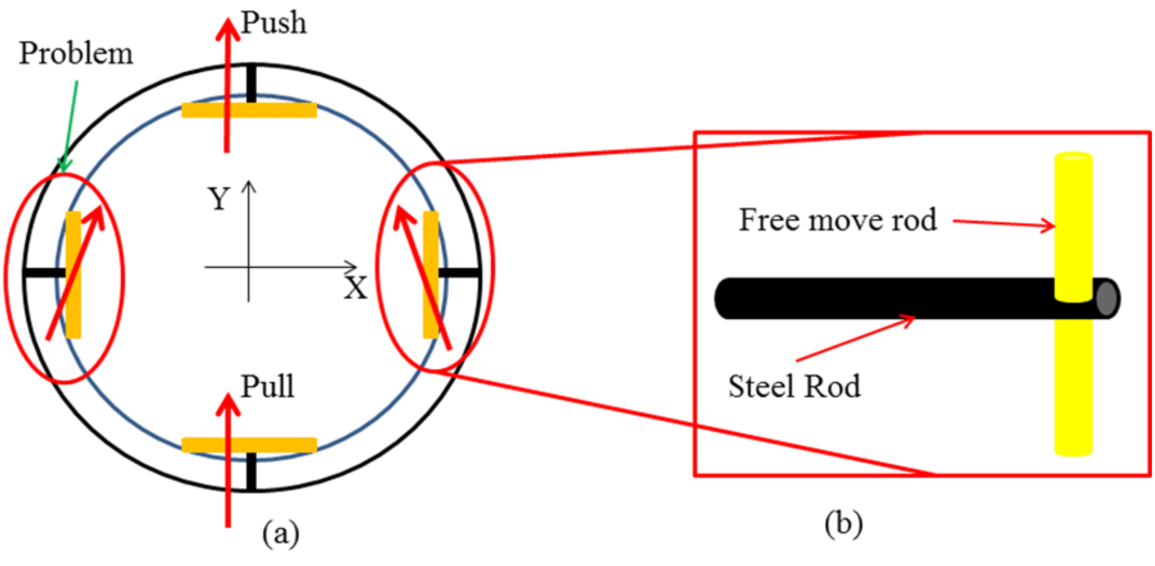


Figure 3-3 (a) Problem of piezoelectric scanner (b) Solution

Figure 3.3 shows the problem of design. When Y-axis is pushing,-Y-axis must be pulling and it will affect X-axis and –X-axis push up. The sticker between the piezoelectric buzzer and steel rod will be break out. Thus, to solve this problem, we need to build the free moving rod in a fixed area.

3.2 Flow Chat

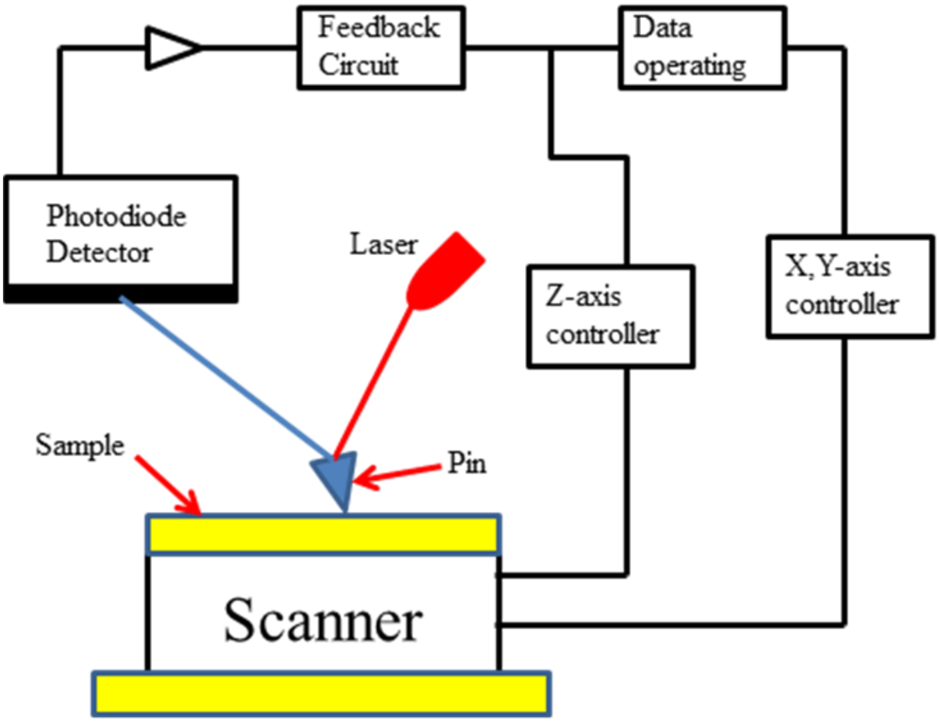


Figure 3-4 Atomic Force Microscope (AFM) flow chat

Figure 10 shows the overall atomic force microscope flow chat. First, laser used to provide more high amplitude and more focusing light source to photodiode detector to detect the angle reflected by the pin. After photodiode detector received the signal, it will send to amplify and then pass through a feedback circuit. Feedback circuit is to make a fast decision for Z-axis to lift up or down. At the same time, the signal will send as DC date to let computer operate and give command to X-axis and Y-axis. (AFM, n.d.)

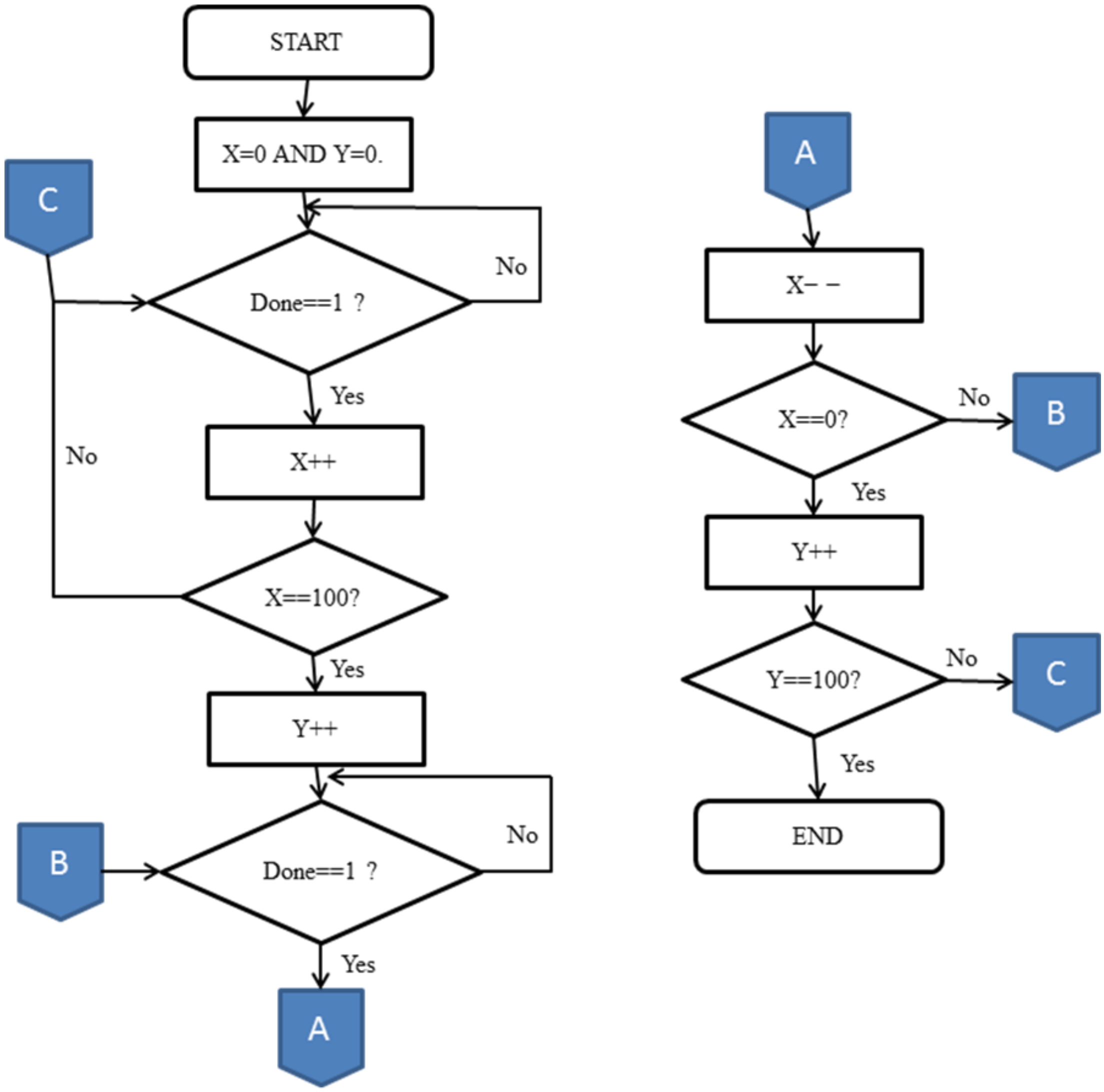


Figure 3-5 Programming for 2-Dimension Moves

Figure 11 shows the flowchart in my X-axis and Y-axis design. First of all, I need an input (Done) to control both output (X and Y). In this design, I will imagine it as a (100, 100) coordinate. The program will start from left-bottom-corner as (0, 0). When X increase until 100 units, consider done the first layer and goes up. To make the scanner faster, I will straight start from X=100 back to 1. It mean (X, Y) = (0, 0) to (100, 0) then (100, 1) back to (0, 1). This will make the scanner take shorter time to finish the journey.

3.3 Circuit Design

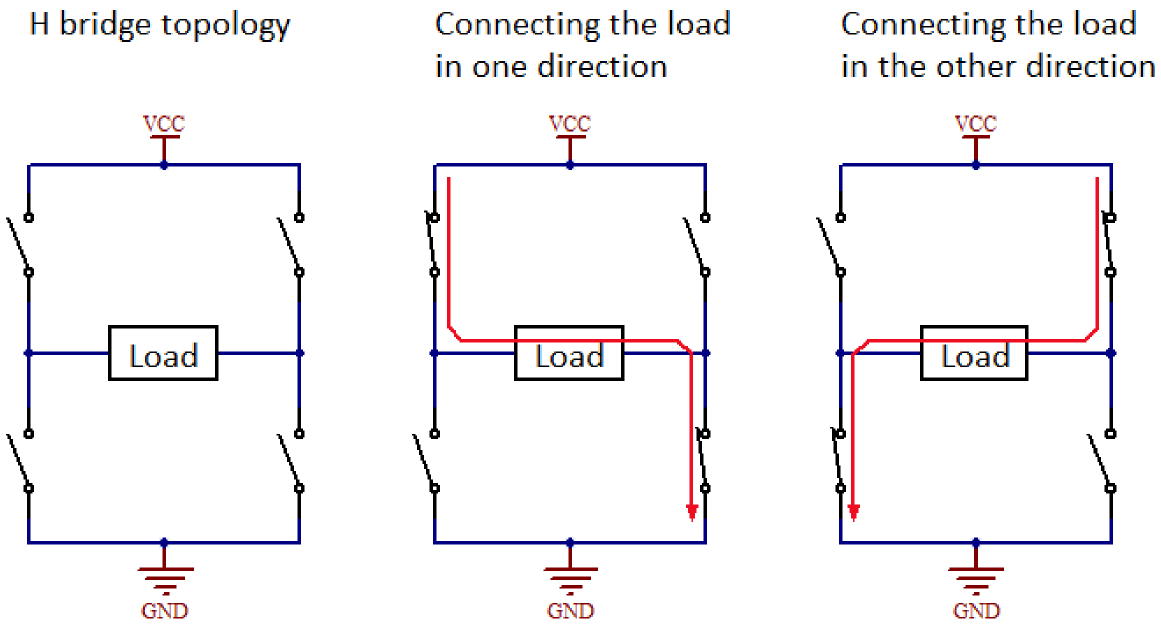


Figure 3-6 Voltage flow

Figure 12 shows the circuit I needed for my piezoelectric buzzer. (Axotron, 2011) However, it is still considering whether this circuit is the best to fill the load as the piezoelectric buzzer. It is because I believe when +voltage apply on the piezoelectric buzzer, the height of expend must not be the same when –voltage is apply. This will affect my result is because +X-axis and –X-axis will connect the same circuit but different direction to make sure when first buzzer is pushing and another is pulling. Pushing distance and pulling distance must be the same else, the steel rod at the middle of operating time, might be lose cause of critical force. (Axotron, 2011)

3.4 Progress

Step 1 – **List and Buy all the material needed.**

Step 2 - **Study the length of expend of piezoelectric buzzer.**

Step 3 – **Looking from Construction Management department for the 3D printer to design the external skeleton.**

Step 4 - **Design the programming and circuit part.**

Step 5 - **Test and stimulate the program.**

Step 6 - **Build the scanner.**

Step 7 - **Combine the program and scanner.**

Step 8 - **Test and stimulate again.**

3.5 Gantt Chart

Table 3.1 Expecting Gantt Chart

Step	Description	May		June				July				August					September	
		18-24th	25-31st	1-7th	8-14th	15-21th	22-28th	29-5th	6-12nd	13-19th	20-26th	27-2nd	3-9th	10-16th	17-23th	24-30th	31-6th	7-13rd
		Tri Break	Tri Break	Tri Break	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14
1	Buy Component	■																
2	Study Piezoelectric buzzer		■															
3	Construct the external skeleton			■	■													
4	Programming and circuit					■	■											
5	Test and Stimulate							■	■									
6	Build hardware									■	■							
7	Combine											■						
8	Test and Stimulate												■					
9	Modified Report													■	■	■		
10	Poster presentation																■	
11	ViVa																	■

Table 3.2 Practivally Gantt Chart

Step	Description	May		June				July				August					September	
		18-24th	25-31st	1-7th	8-14th	15-21th	22-28th	29-5th	6-12nd	13-19th	20-26th	27-2nd	3-9th	10-16th	17-23th	24-30th	31-6th	7-13rd
		Tri Break	Tri Break	Tri Break	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14
1	Buy Component		■															
2	Study Piezoelectric buzzer			■	■													
3	Construct the external skeleton Version 1					■												
3	Construct the external skeleton Version 2					■												
3	Construct the external skeleton Version 3						■											
3	Construct the external skeleton Version 4							■										
3	Construct the external skeleton Version 5								■									
3	Construct the external skeleton Version 6									■								
3	Construct the external skeleton Version 7										■							
4	Programming and circuit				■													
5	Test and Stimulate Programming				■													
7	Combine					■	■	■	■	■	■							
8	Test and Stimulate					■	■	■	■	■	■							
9	Modified Report			■	■	■	■	■	■	■	■	■	■	■	■	■		
10	Poster Preparation															■		
11	Slide Preparation															■		

3.6 Material Used

Used to move in small scale

Push and pull a sample

Cheap (fulfill my objective)

RM2.50

Figure 3-7 Piezoelectric Buzzer

Holding to test

Holding Laser

Holding the fixed angle

Hold strongly and fixed

RM26.00

Figure 3-8 Electronic retort stand

Figure 3-9 Hot Glue Gun

Glue up to hold piezoelectric buzzer

Glue up to link it stronger

RM15.50

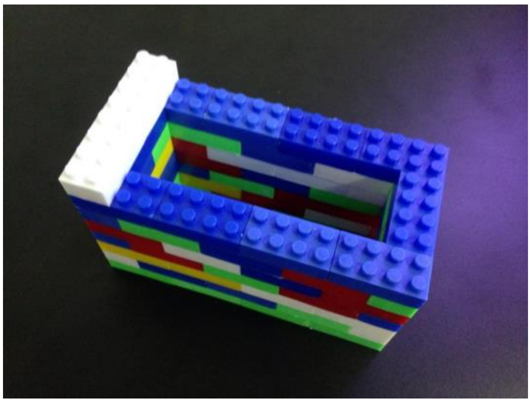


Figure 3-10 Bricks

To build up external skeleton

Build everything easily

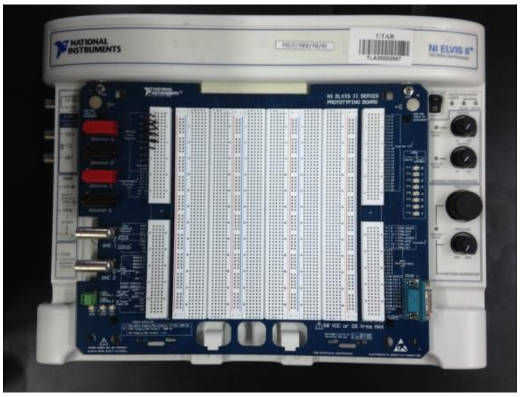


Figure 3-11 NI ELVIS II++

To program input and output

To measure voltage.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Understanding Piezoelectric Buzzer

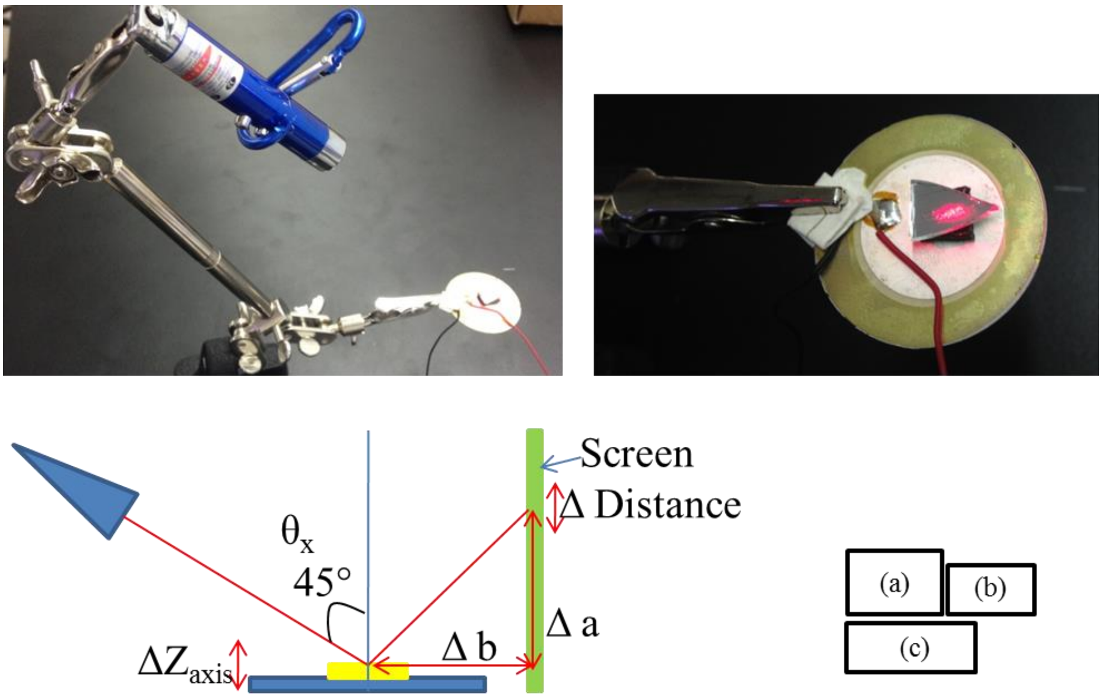


Figure 4-1 (a) Laser is fixed degree away normal target at piezoelectronic buzzer (b) Above the piezoelectric buzzer stick with a mirror (c) The Ideal of this measuring in 45

This is how Teh Yong Hui and me started to test the banding level of piezoelectric buzzer. Mirror plate put horizontally and laser target 45 degree from normal. By using trigonometry method, it proves that $\Delta Z_{axis} = \frac{\Delta Distance}{2}, if\ \theta_x 45^{\circ}$.

Figure 4-2 Measuring the expending distance

Figure above shown how we try to measure. Other then θ_x must be 45 degree, we still need to take care distance a and distance b. We set the distance as 100cm.

4.2 Calculation part

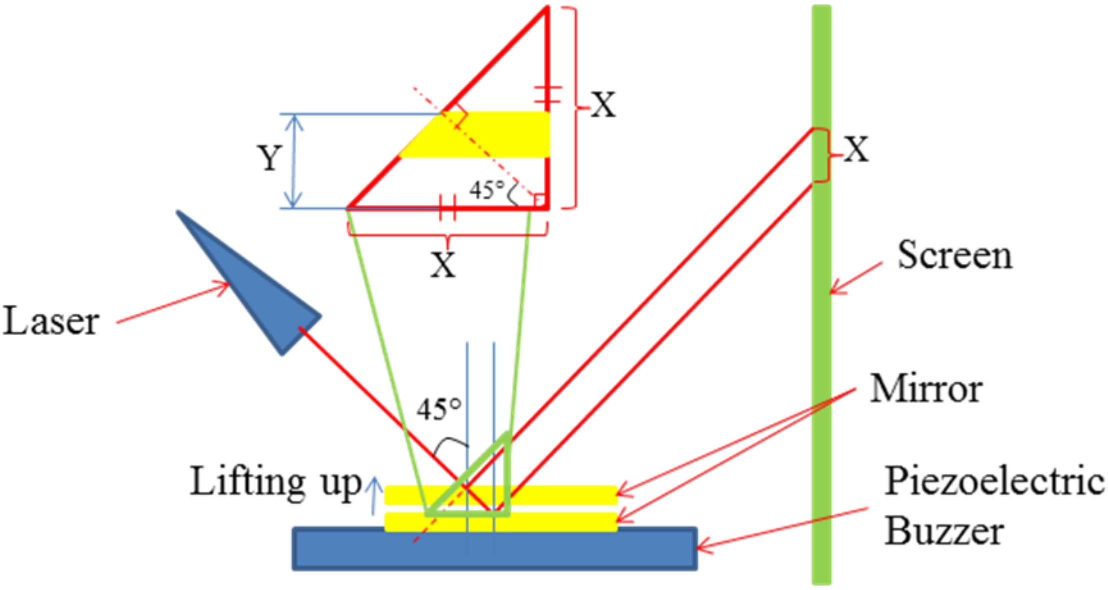


Figure 4-3 Ideal case of measuring and calculating in trigonometry method

Assume Screen is parallel with normal and the light that had reflected is parallel. Thus, distance between two lines will be equal. Adjust the laser target to mirror with 45 degree away normal. A right angle triangle carry with another 45 degree it means isosceles right triangle. Now, vertical distance X is equal to horizontal as show in figure above.

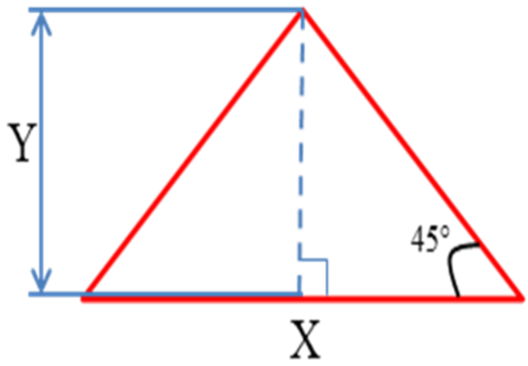


Figure 4-4 Trigonometry calculation

$$\tan 45° = \frac{Y}{\frac{X}{2}} = 1 \; ; \qquad Y = \frac{X}{2}$$

In conclusion, the distance of lifting up, Y is equal to half of the distance measure from the screen.

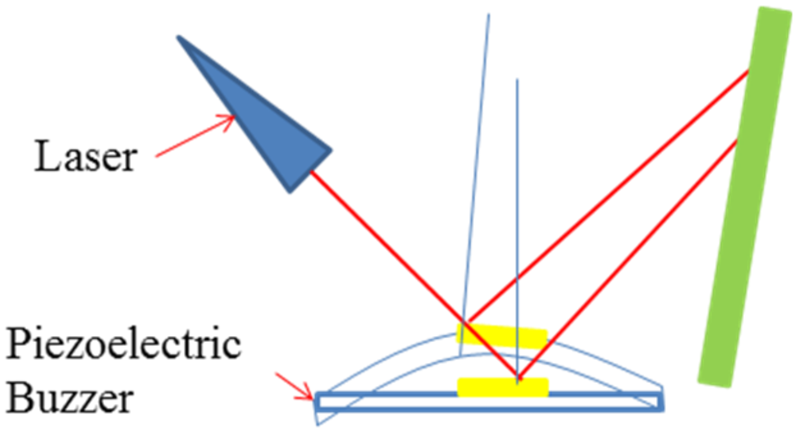


Figure 4-5 Problems that facing

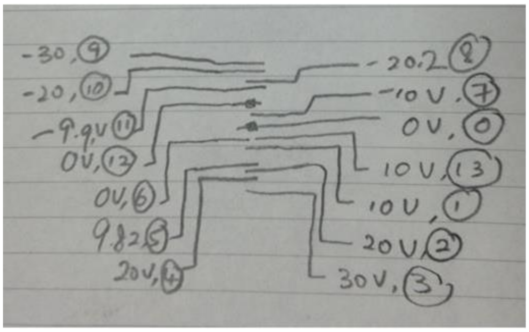
However, this is only for ideal case. First, we cannot prove the screen is totally parallel with normal. If the screen is not parallel, distance X that we measured will be different.

Second error, piezoelectric buzzer is not lift up horizontally, it lift up and become a round shape, thus, we cannot expect mirror can lift up horizontally. When mirror is lift up, it will band to another side and make the angle of reflection become different.

Other than that, the laser target 45 degree away the normal, but when I had fixed the angle, there is no perfectly and ideally to be 45 degree.

In conclusion, cause of surrounding, and the piezoelectric buzzer problem, I cannot get a perfect result.

Table 4. 1(a) & (b) Laser that had targeted had been drawn and recorded



(a)

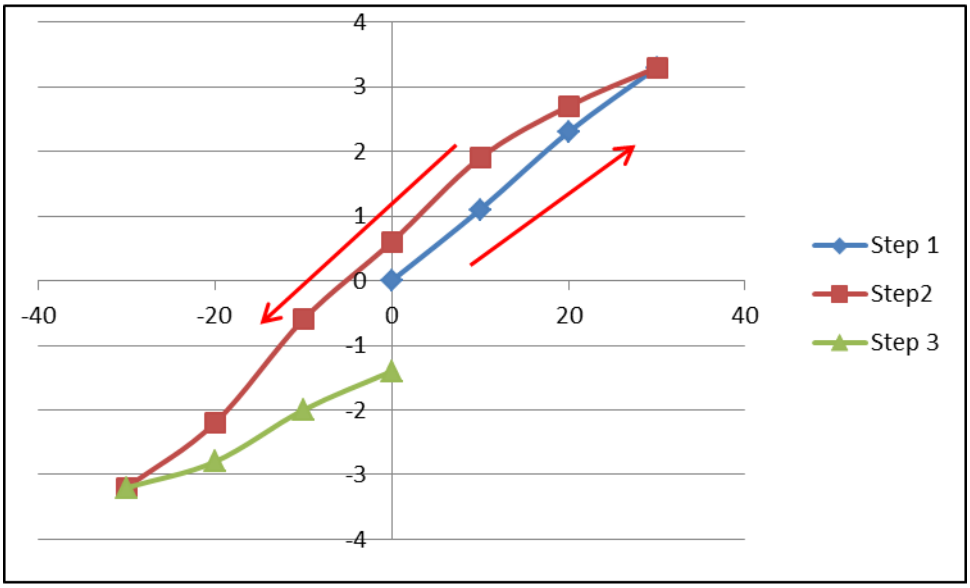
Voltage apply	Step 1 (increasing)	Step 2 (Decreasing)	Step 3 (Increasing)
-30		-3.2	-3.2
-20		-2.2	-2.8
-10		-0.6	-2
0	0	0.6	-1.4
10	1.1	1.9	
20	2.3	2.7	
30	3.3	3.3	

(b)

From table above, I observed the piezoelectric buzzer perform better when it goes higher than 10V. Hysteresis occur in this piezoelectric buzzer, hysteresis defined as an object initially level is different after increase and return back to the same point. For example, just like this piezoelectric buzzer starting with 0V and increase up to 30V and decrease back to 0V, it cannot goes back to the starting point.

When it inversed decrease until -30V and come back but did not return to eventually point. In the other hand, I can said that it not consider hysteresis, because it not yet saturation. It might saturation at 60V but I cannot make it is because our power supply only goes up to 30V and thus It limit me to do it better.

Graph 4.1 Graph of movement of piezoelectric buzzer



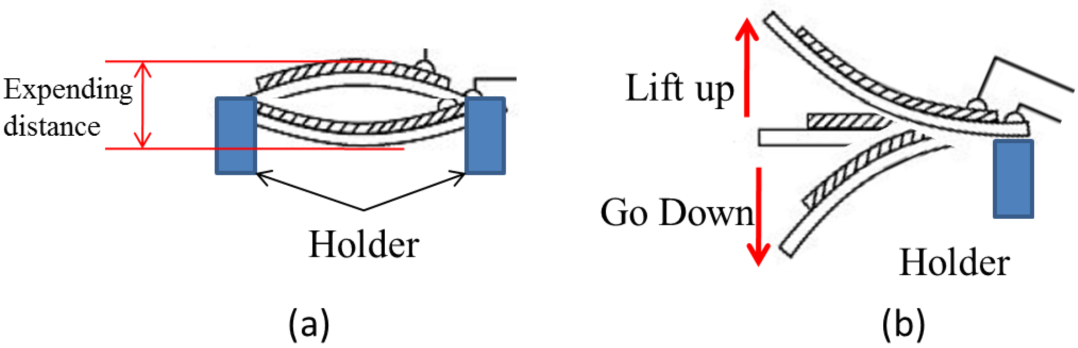


Figure 4-6 a) Distance expending with 2 holder (b) Distance expending with 1 holder

Other than that, we found that to hold both side and move the piezoelectric buzzer will expend lesser than holding only one side. We found that if we only folding one side, the opposite will expending double higher compare to two holders.

Table 4.1 Table of distance of piezoelectric buzzer supply by voltage

Voltage Applying	step 1 Incresing	step 2 Decreasing	Step 3 Increasing
-20		-5.5	-5.5
-16		-4.5	-4.5
-12		-3.5	-3.5
-8		-2.3	-2.3
-4		-1	-1
0	-1.3	0.5	-1.3
4	0.8	1.8	
8	1.8	2.5	
12	2.5	3.5	
16	3.8	4.3	
20	5	5	

Graph 4.2 Graph of piezoelectric buzzer with only one holder

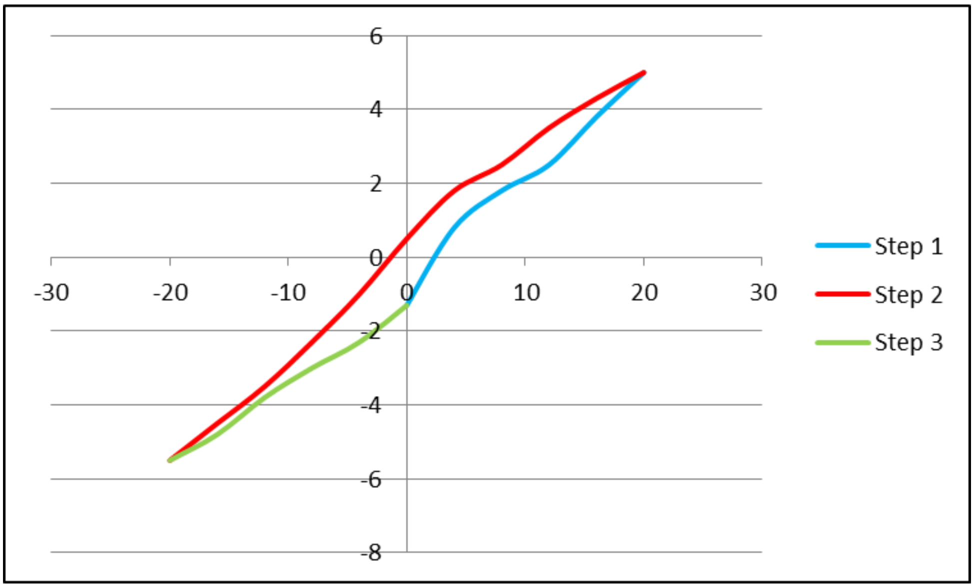


Figure above show how the piezoelectric buzzer that glue up with only one holder. Compare one holder and two holder, one holder can expend more efficiency.

4.3 Design

4.3.1 Version 1.0

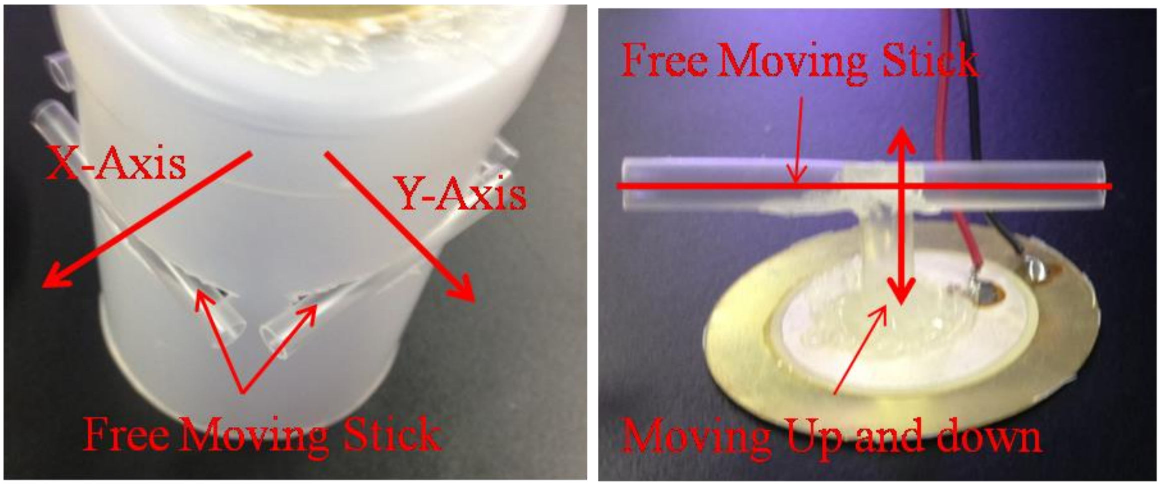


Figure 4-7 Design of version 1.0

Figure above shows the first version. According to chapter 3 methodology, piezoelectric buzzer initially is to put inside the inner part. However, the inner part (skim milk bottle) cannot contain 4 piezoelectric buzzers and thus, I decide to swap the position. Piezoelectric buzzer will stick with external part; free moving stick will stick with inner part.

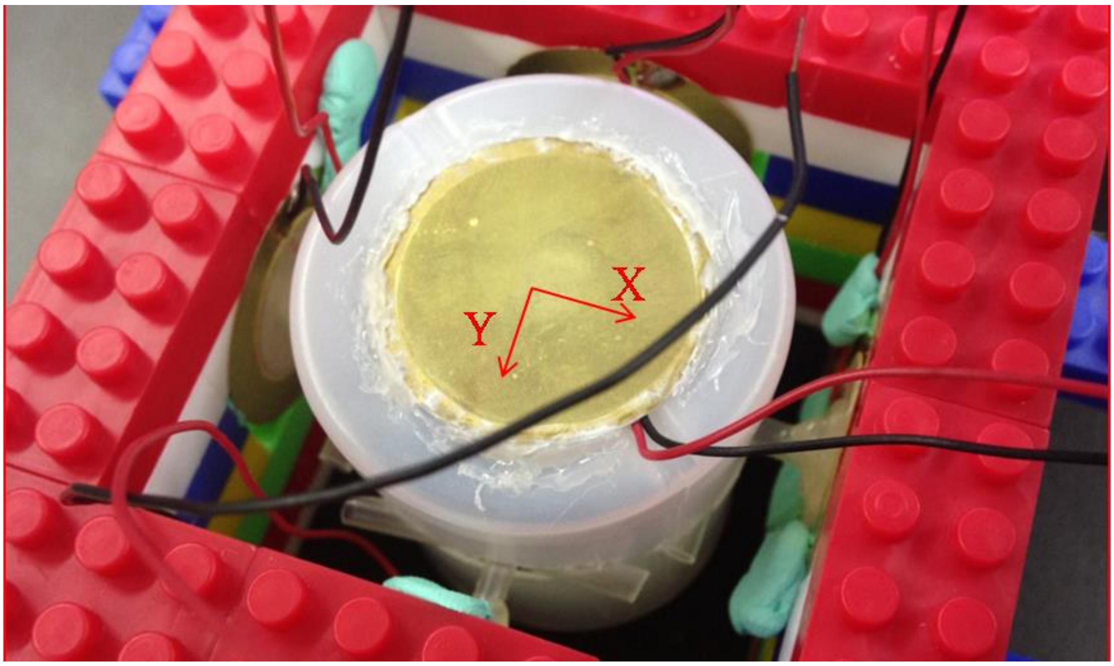


Figure 4-8 Version 1.0 had put inside bricks

This version is fail because it sticks too tight. Skim milk bottle cannot easily move because of many issue regarding mechanical problems. From my observation, the main issue that makes this bottle cannot move is too tight. When it is too tight, piezoelectric buzzer from x-axis pushing, y-axis is too tight until cannot move the bottle.

Straws too soft and can easily bend it. When it is easily bend that mean it easily change direction or angle. Direction had changed, in the middle process of push pull, it will cause of different angle and move it wrongly or cannot move it efficiency. Other than that, it will also force to lift up or down, figure below explain more about the force.

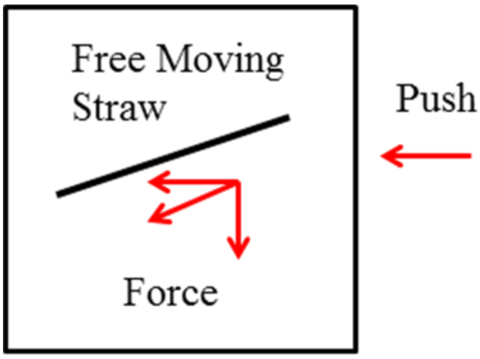


Figure 4-9 Practical problems in version 1.0

In conclusion, to make it not that tight, I need to adjust the length of the straw and fixed the free moving stick.

4.3.2 Version 1.2

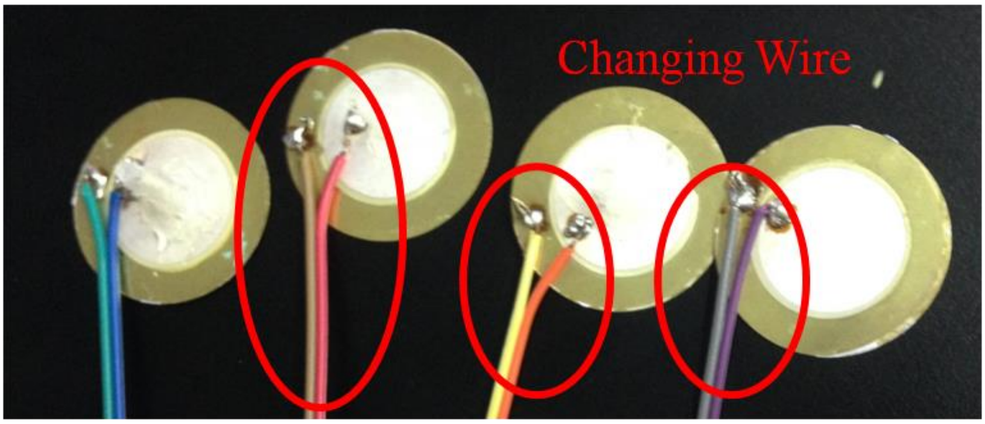


Figure 4-10 Version 1.2 had change the wire

This Version, I had changed the soft wires to strong wires. The reason why I want to change the wire, first, is to make wire stronger so that, it would not easily rotate left or right easily. Second is the end of the wire has a socket for user easily plug in and out.

However, there are many pro and cons in this case. The wires look strong, it also flexible. However, because of too strong, it makes a big disadvantage to me. When I was building it to the circuit, it can rotate cause of its flexible, but if you do not hold carefully the soldering part between wire and piezoelectric buzzer, and rotate a little angle, it will damage the piezoelectric buzzer.

In this part, I had learned that, it is not easy to choose a suitable wire for piezoelectric buzzer and it is easily damage a buzzer.

4.3.3 Version 2.0

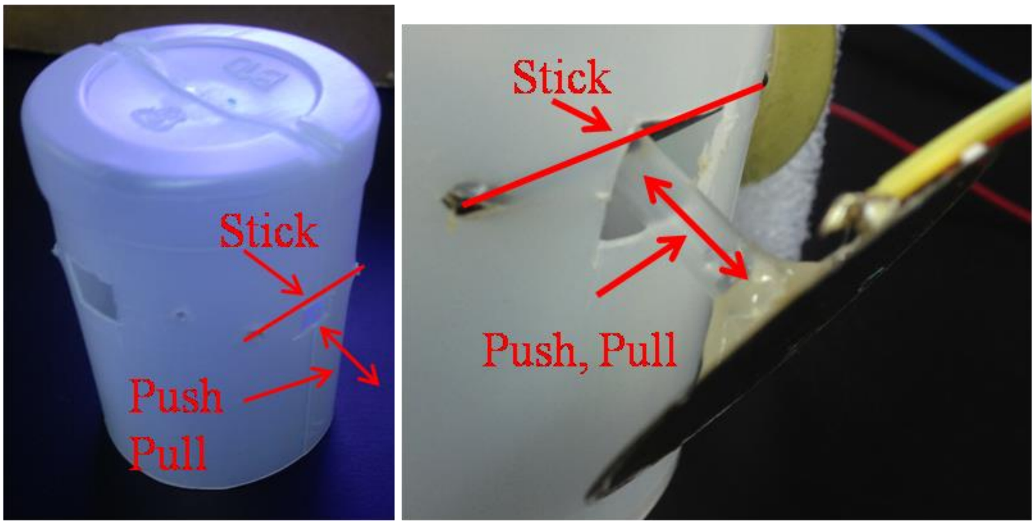


Figure 4-11 Version 2.0 had changed straw stick to a steel stick

From experience of first version, I decide to change straw to iron stick. In addition, I heat up two holes at straw to let the straw pass through iron stick. The advantage of using iron stick is because, it strong enough and not flexible to move. Thus it solves the first version that cause of flexible enough and make a different angle.

Advantages always carry with disadvantages. Disadvantage of this design is the iron would not be too strong, iron would not be straight it still has a little bit of bend. When it bend, it will keep moving up and down and make this design fail.

Other than that, there is still a problem when I make the holes. It is because when the hole is too big, and iron stick move from left to right, it will need to move a short distance and just start pulling or pushing the metal.

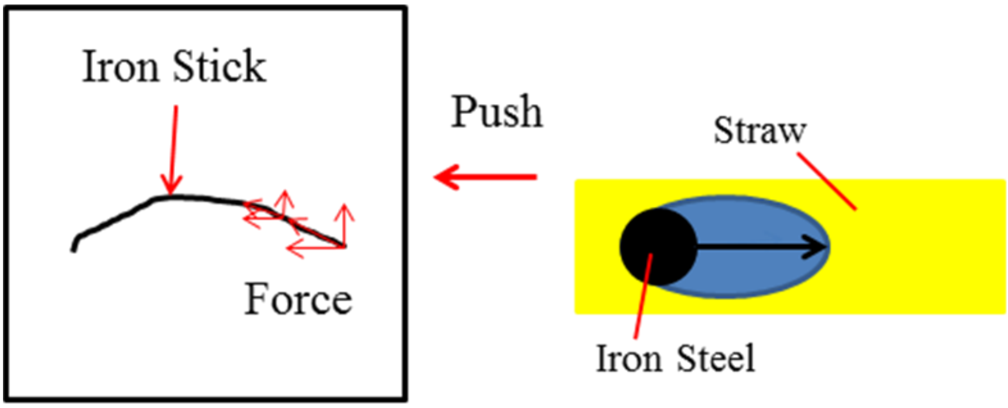


Figure 4-12 Problems facing in Version 2.0

In this version, it cannot consider fail, but I cannot prove that it is successfully works. To prove it works, I had to prove it move. To prove the machine move horizontal move from left to right is easy, just observe whether it moves or not. However, when we talk about moving in micrometer scale, it is not easy to make it.

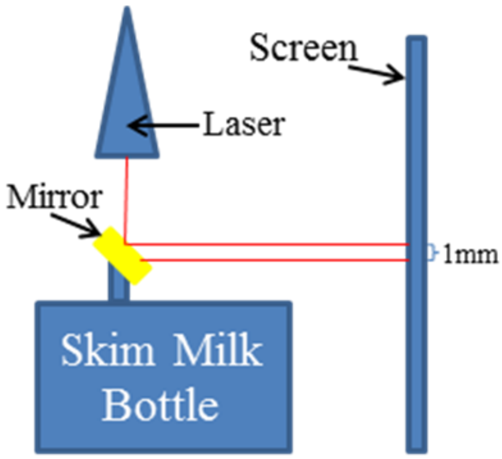


Figure 4-13 Challenging cases

For instance, figure below shown how I had tried to prove. Piezoelectric buzzer move from left to right maximum is 1-2mm. To prove it had moved 1mm, I need to use some device to detect, but badly said that I do not have that device. In addition, I cannot test 2-D in one time. The reason is because when testing x-axis, the mirror must facing x-axis, and thus it is parallel with y-axis.

4.3.4 Version 3.0

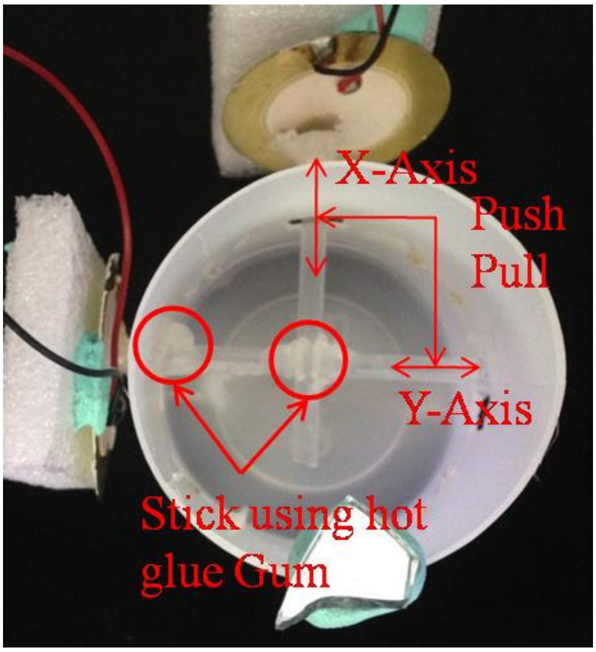


Figure 4-14 Design of Version 3.0

In this version, I had changed by using stick from the side. Ideally it works like this, when X-axis pull, straw rod will pull from the middle point that sticks with y-axis straw rod and then, the whole object will then move. In other hand, when y-axis pushes, the glue that sticks straw rod of y-axis and skim milk bottle will immediately pushes away.

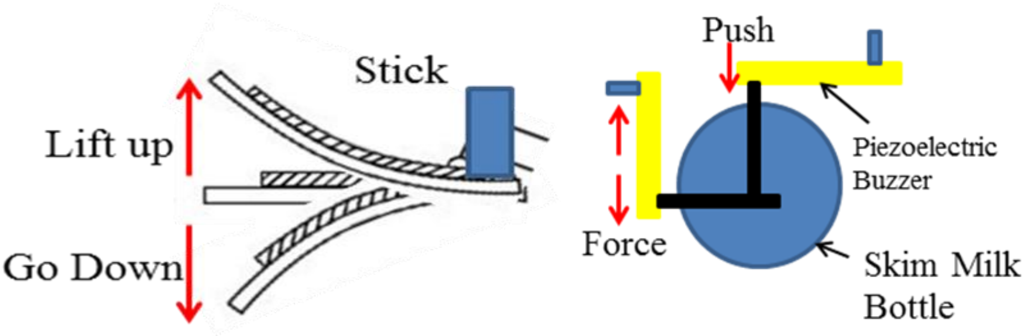


Figure 4-15 Problems that facing

However, this version is fail because of no support from outside. There is no anything to hold the opposite part of the piezoelectric buzzer and thus, it cannot move. In the other hand, I also cannot stick the piezoelectric buzzer with rod to support it. When I stick the rod, it means it had to stick with other in station mode.

In this part, I had learn that, to push a piezoelectric buzzer, first you need to have a support.

4.3.5 Version 4.0

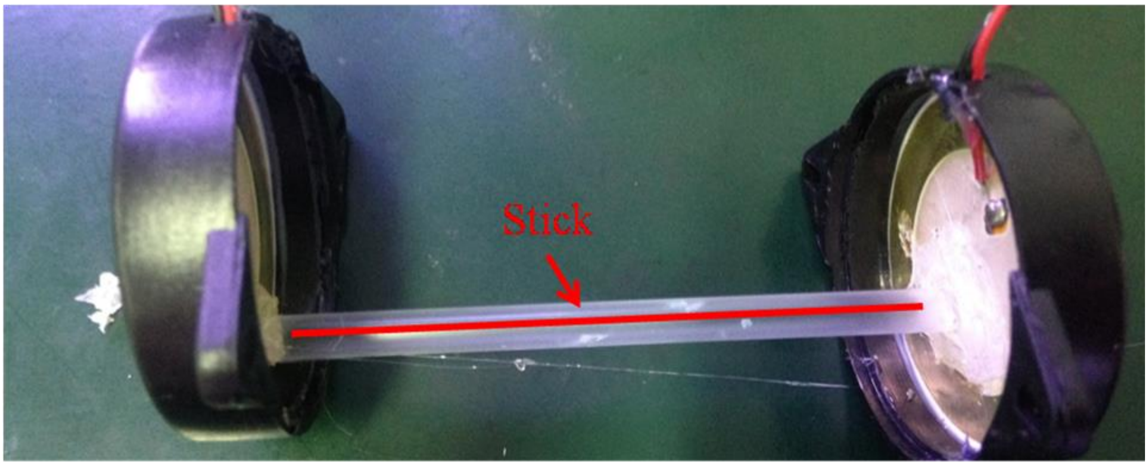


Figure 4-16 Version 5.0 had stick the straw with two piezoelectric buzzer

In this version, to solve version 4 problem, I decide to stick the straw both side with piezoelectric buzzer. While piezoelectric buzzer pushes in, the other buzzer's side will pull in to move the skim milk bottle. Piezoelectric buzzer **must** put inside its own container so that it has a support from the back to push it forward. The Idea that I am imagine shown in figure below.

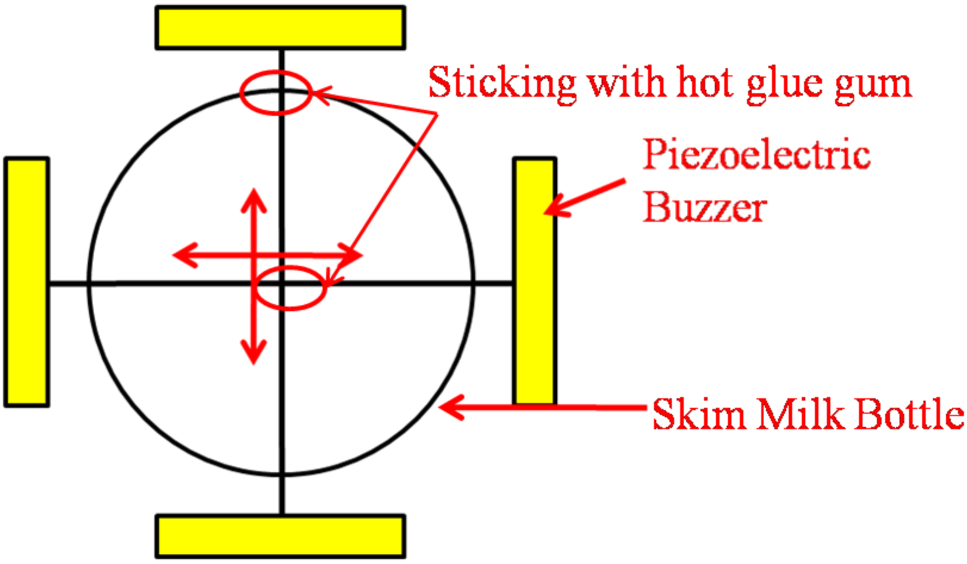


Figure 4-17 Concept and Ideal of this version

I had failed to make it cause of many reason, but one of the main reason is I had no remove it from the packing. Piezoelectric buzzer was glued with packaging that shown in figure below. When voltage was applied, piezoelectric buzzer will try to lift up. However, the gum will try to pull it back and thus, it will just only move in a very small scale. If the packaging was removed, it did not have any support to push or pull.

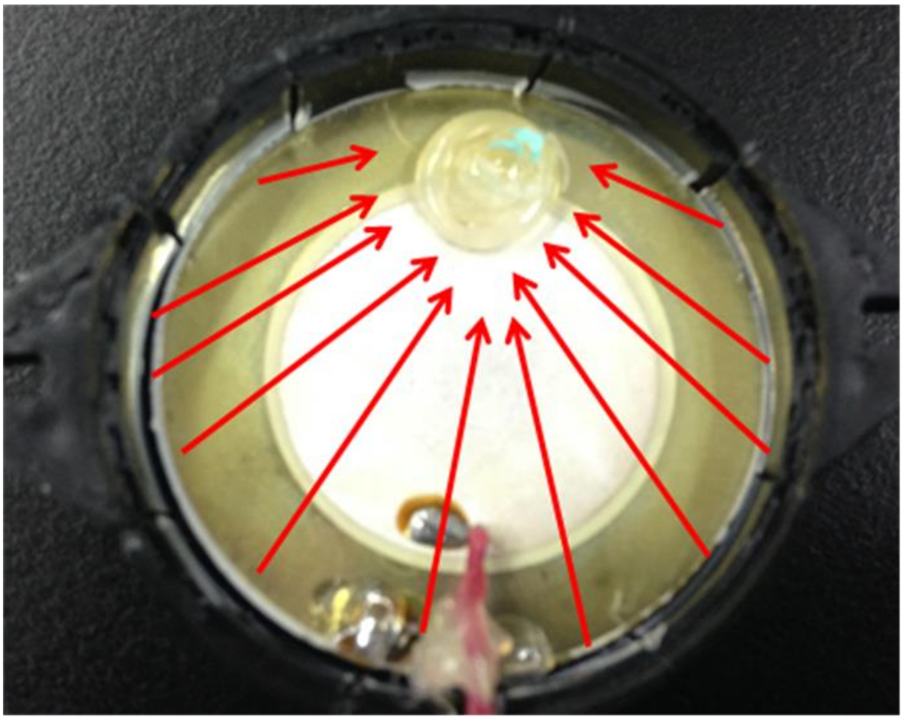


Figure 4-18 When piezoelectric buzzer expend, the glue pull to stay equivalence

Thus, in this version, I learned that, piezoelectric buzzer cannot put inside the packaging, it cannot move efficiency in the package.

4.3.6 Version 5.0

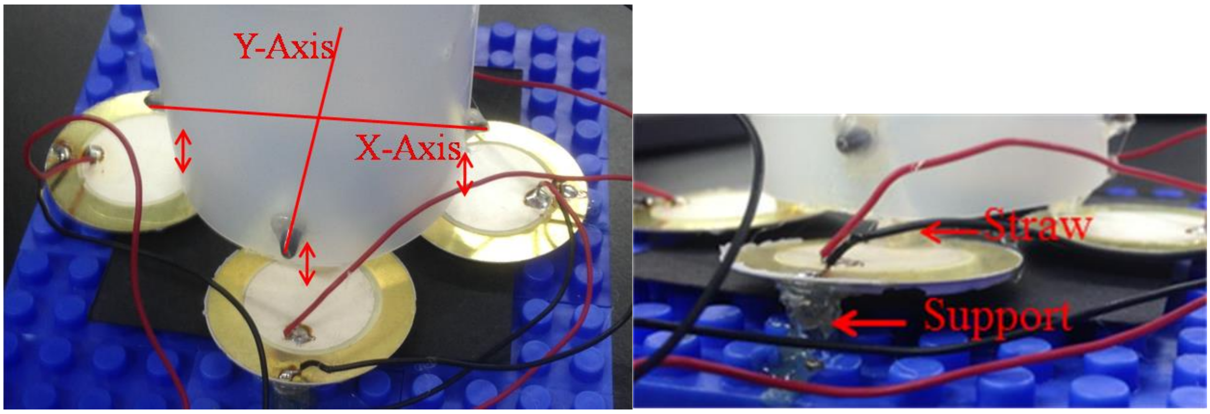


Figure 4-19 Design of Version 6.0

This is the first version that I had proved that it is works. First step, I make two holes at straw and put inside the iron stick. Then, I glued the iron stick with x-axis and y-axis to make sure the skim milk bottle fixed in the shape. After that, I glued another end of the straw with piezoelectric buzzer to let it stay on the buzzer. Then I also use the experiences gained from version 4.0 that piezoelectric buzzer need a support to push and apply on it.

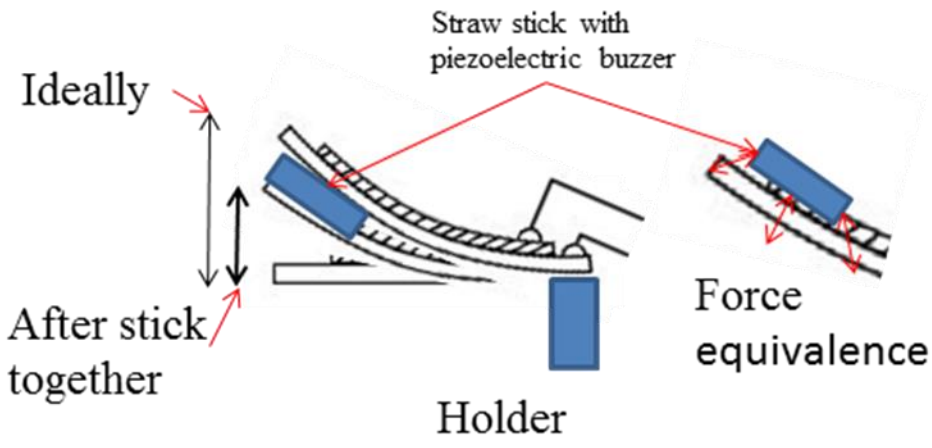


Figure 4-20 Piezoelectric Buzzer had sticked by glue and makes the same problems with last version

After study this version, I found that, there is still can modified. In this version, the change from left to right is very small. It is because the straw sticks with piezoelectric buzzer. Combine version 5.0 and this version, I observe there is something weakness when piezoelectric buzzer stick with straw. The area expend of the piezoelectric buzzer plate will getting smaller. The glue stick them together make the force equivalence and become station. When it is station, it mean move in small distance. Figure below explain thousand words.

4.3.7 Final Version

Figure 4-21 Design of Final version

This is the final version and the most successful version that I had designed. In this version, by using the same concept from version 6.0 and cut down the volume of skim milk bottle to decrease the weight that apply pressure to piezoelectric buzzer.

Other than that, to upgrade or develop the imperfect version 6.0, I decide not to glue up the stand of the straw and piezoelectric buzzer. This makes this version getting more perfect is because first, skim milk bottle can move freely efficiency; second piezoelectric buzzer would not because of glue with the straw and introduces force equivalence to affect the efficiency of lifting distance; third, piezoelectric buzzer would not cause of glue sticking and damage itself anymore.

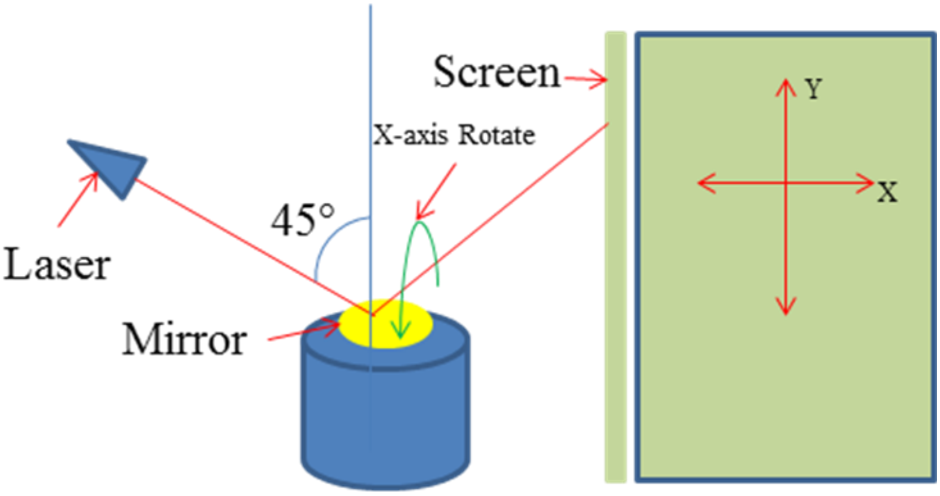


Figure 4-22 Ideal design of how to prove

To make sure the skim milk bottle that stick with straw and put on the top of piezoelectric buzzer will not fluctuation, I need to add some glue on the straw to lift it up. However, at the same time I need to glue piezoelectric buzzer at the LEGO. Thus, I decide to start from the base, which means first step will start from LEGO and piezoelectric buzzer.

To confirm four of the piezoelectric buzzer at the same level, initially I decide to glue with straw. But after I saw version 6.0, I observed every piezoelectric buzzer will bend down cause of small area that holding to support the buzzer. Then, I saw the bump up of the LEGO have the same high, and bigger area. It makes benefits to my design, so that, I start cut down all bumps that might prevent my piezoelectric buzzer to bend. After that, start the glue process.

Next step, balance the skim milk bottle at the 4 buzzers. The reason why I glue a straw is to make a point rather than just put a plate on the buzzer. Make a point so that it can lift it more efficiency.

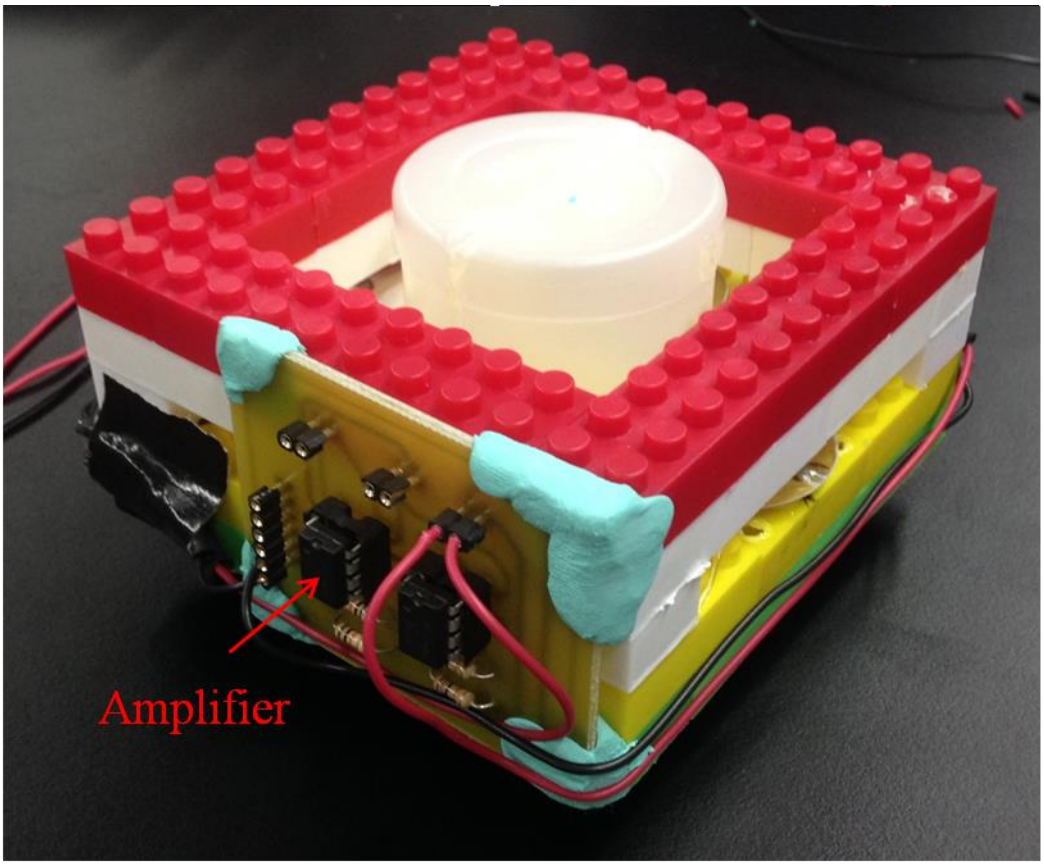


Figure 4-23 Combine of finalize Version

Figure above is overall of my finalize design. The circuit shown in the figure is an amplifier to amplify up to 30V. To prove my design can turn from left to right, I put the mirror horizontally on the top of the design and use laser with 45 degree to normal target the mirror. Figure below explain how I test my circuit.

4.4 Circuit Design

4.4.1 Circuit Diagram

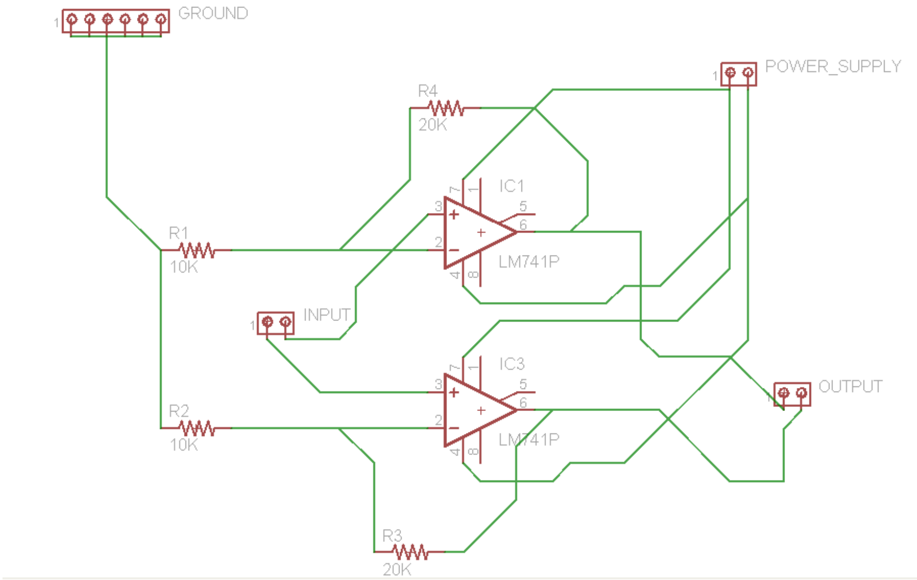


Figure 4-24 Schematic Diagram

Figure above is how I design my circuit in EAGLE software. I decide to extend more port for ground in case more than one pin is needed.

4.4.2 EAGLE Diagram

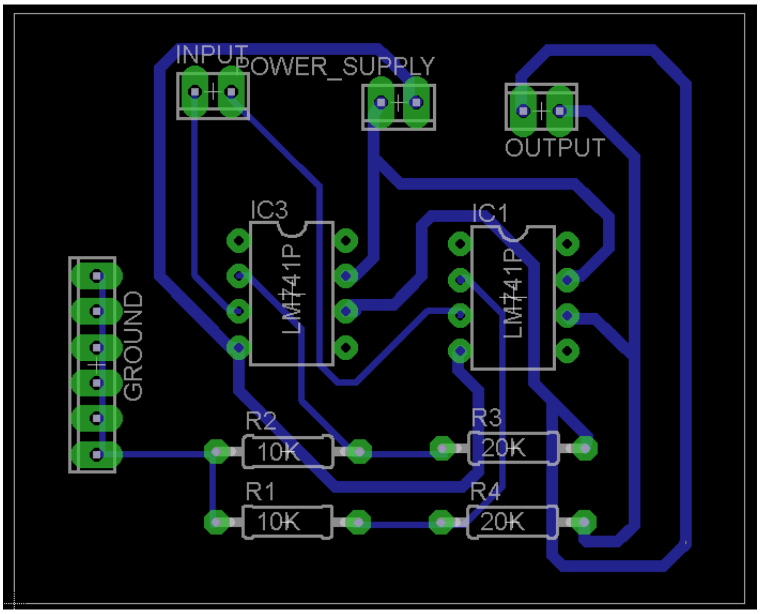


Figure 4-25 Board diagram designed in EAGLE

Figure above show layout that before print it out and apply to printed circuit board, PCB. In this circuit layout, you can see there is two size of wire. Bigger wire is to support up to 30V while, smaller wire is to support only up to 10V.

4.4.3 Apply in PCB

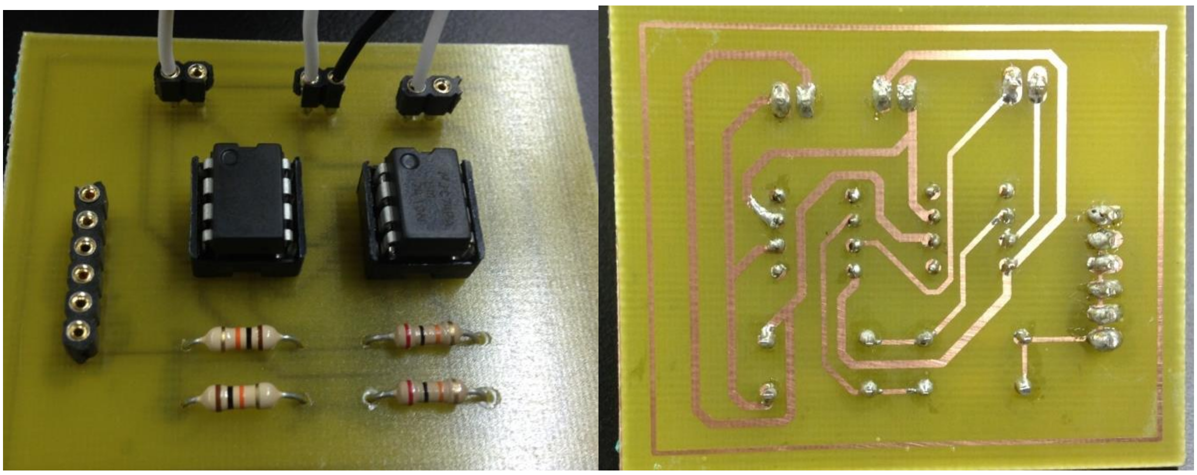


Figure 4-26 An Operation amplifier was designed

After printed circuit board had done, I decided to solder chip socket rather that soldering chip. First of all, I was going to use 30V to supply on the amplifier. According to the LM741 datasheet written by Texas Instrument Company said that the maximum voltage supplying is ±22V. In my case, I must use 30V because according to my observation, piezoelectric buzzer banding more efficiency is starting from 20V, so that, to make my piezoelectric buzzer getting more efficiency, I had to supply 30V and tested the amplifier that it still can make it efficiency. However, to supply until 30V, there is still a probability of breaking down and that why I soldering with chip socket rather than soldering the chips.

Other than that, I also need to think about when amplifier is breaking down will it burn my NI ELVIS II^{++} board? **The answer is no!** It is because LM741 when break down, it will automatically open circuit to protect input and output port so that the power will not goes to NI ELVIS II^{++} to burn it. In addition, NI ELVIS II^{++} also has a protection until 60V and 2A. So in conclusion, it still safe to use it.

4.5 Programming

4.5.1 Block Diagram

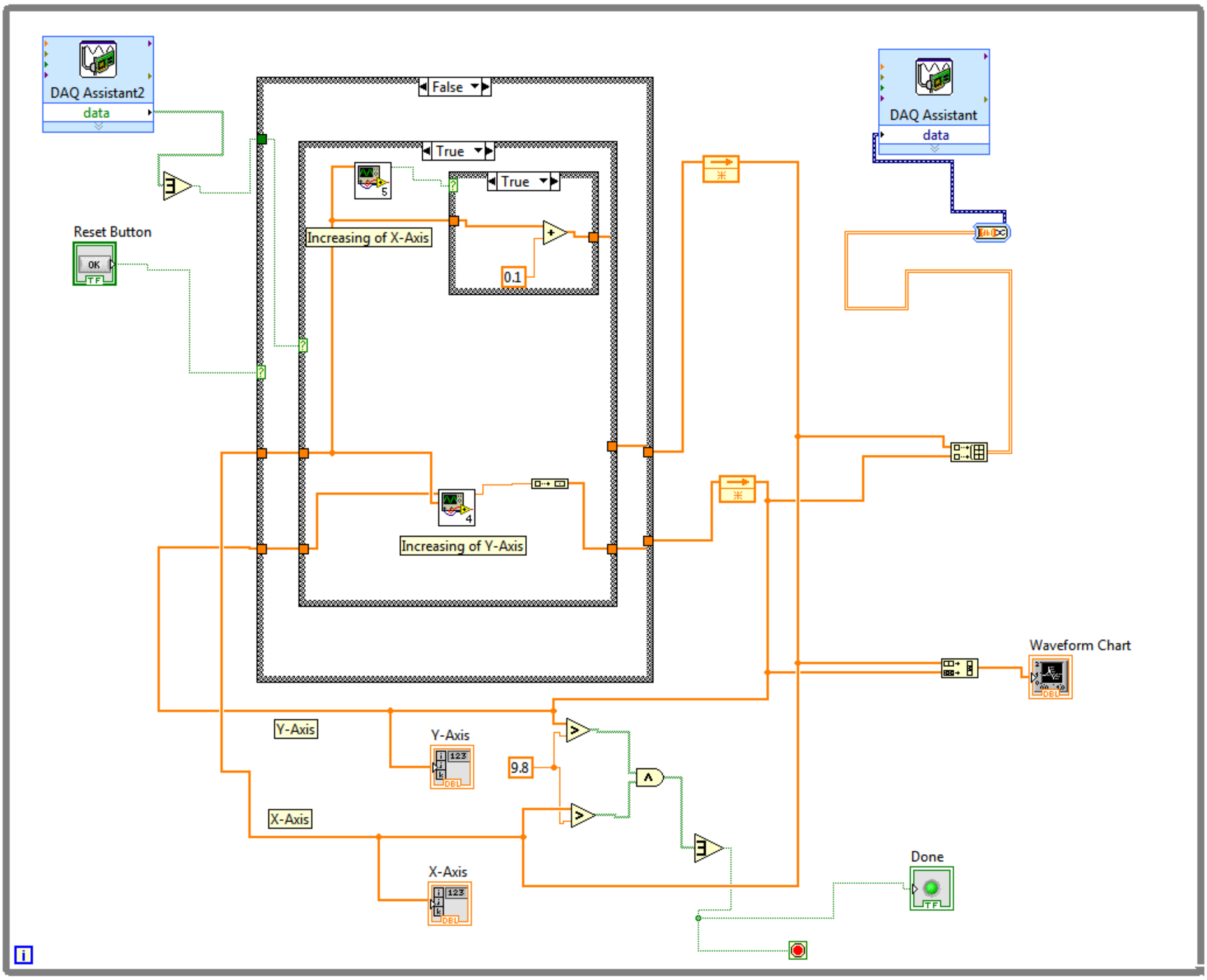


Figure 4-27 Block diagram shown in LabView

This figure showed the block diagram of my programming. This is my finalize version of programming. In this program, it contain of two subroutines, one while-loop, three if-else and many mathematical calculation. It also contains DAQ input and output. DAQ stand for Data Acquisition, It used to read and write data from and to NI ELVIS II^{++}.

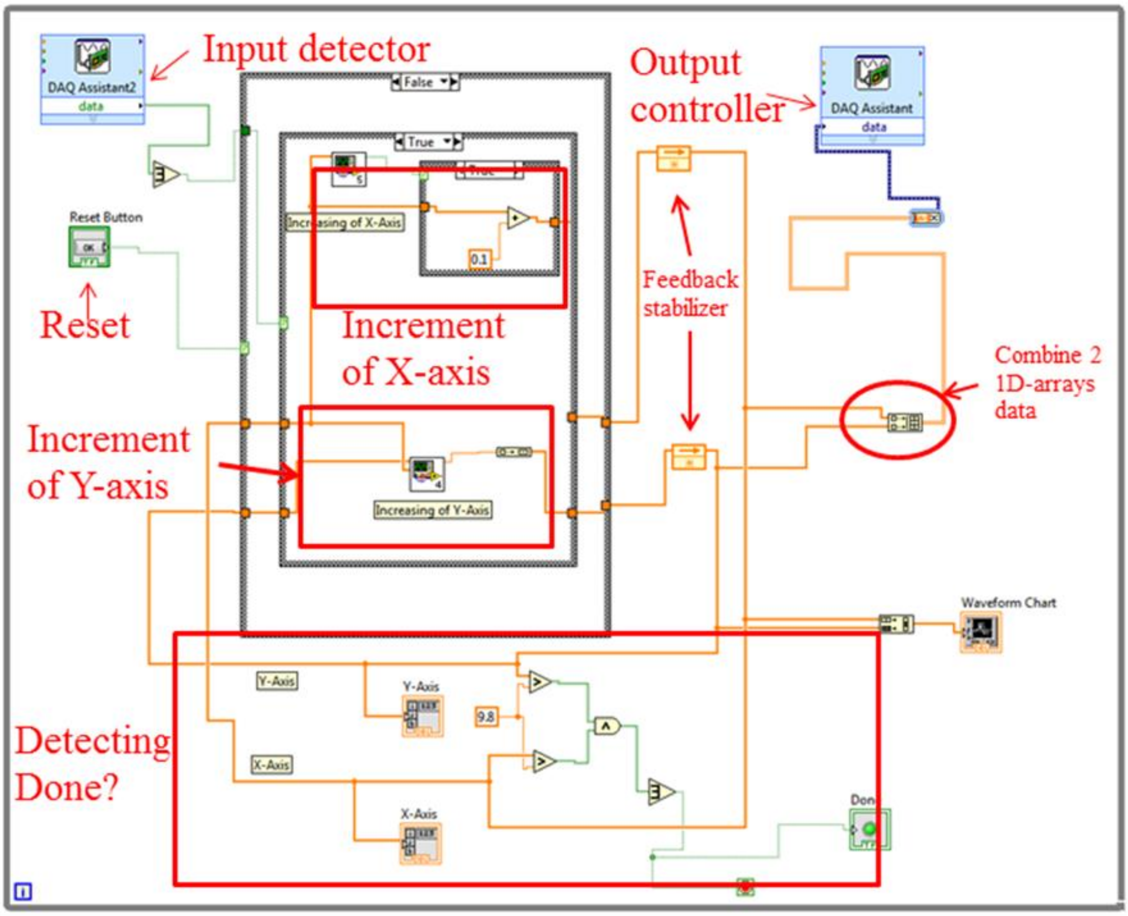


Figure 4-28 Programming that had seperated to list out the function

Figure above shown basically all function of this program. Input detector is to receive Boolean signal from NI ELVIS II^{++}. Boolean signal is the signal that only carries high or low. This DAQ input detector is to allow X-axis continue move from previous state to next state. When input is low, consider false, amplitude of X-axis and Y-axis will remain the same; when it is high, it will keep on moving.

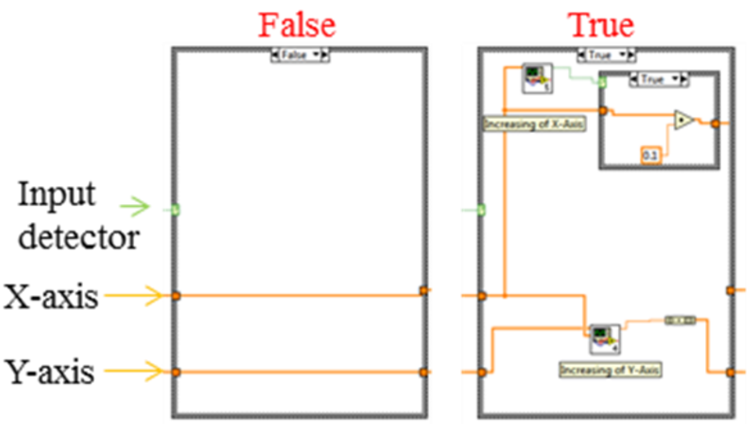


Figure 4-29 Function of input detector.

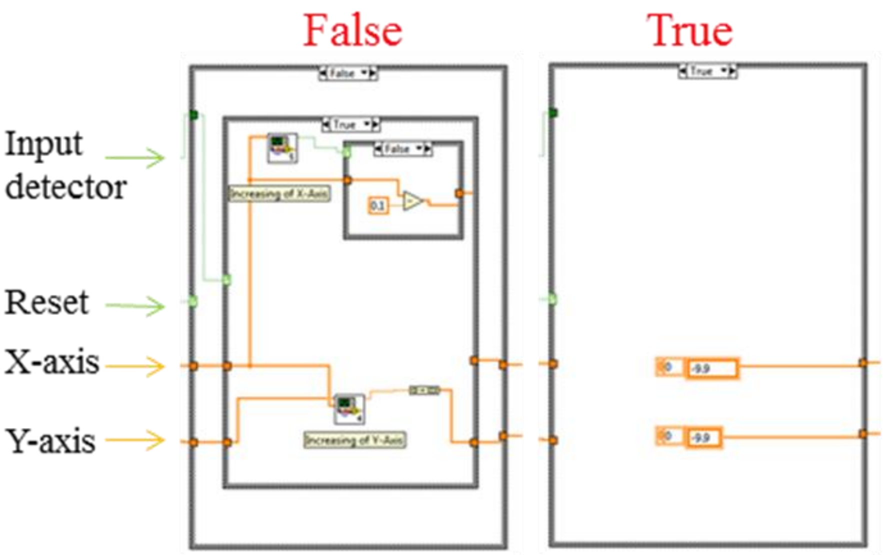


Figure 4-30 Function of reset button

Reset button is to allow user choose to recount again. It will start counting until the middle of time, a reset button is clicked, amplitude of X-axis and Y-axis will reset to -9.9V. Initially I set it as 10V, but there is a error on 10V. The reason will have error is when the reset button is clicked, amplitude of X-axis and Y-axis will fall in10.02V and it had break NI ELVIS II^{++} rules. In this board, it only allow output maximum of ±10V, thus, I had to set to -9.9V.

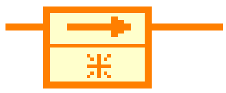


Figure 4-31 Feedback system

Feedback stabilizer is actually use for starting. If a feedback circuit without this stabilizer, computer will not understand what is the starting amplitude of this signal and makes overall the circuit keep on crash. Although feedback stabilizer looks not important but it might let your circuit clash and do not understand where is the error.

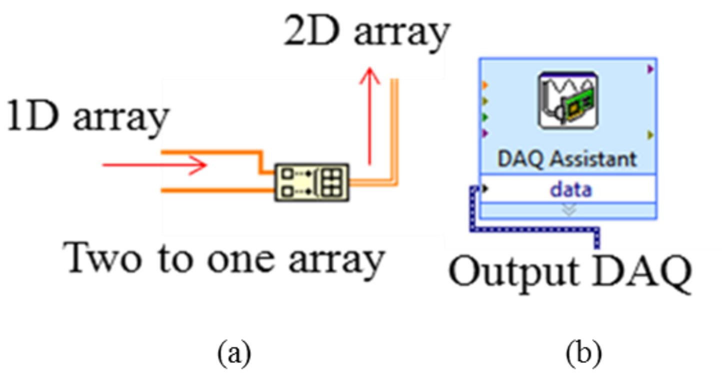


Figure 4-32 (a) two 1D arrays to one 2D array.

In my project, I am going to control X-axis and Y-axis. In order to control two outputs, two ports are required in this process to ensure whole project worked completely and perfectly. However, DAQ assistant only allow one signal to pass through and thus, I had to combine this 2 signal into one by using two to one array convertor.

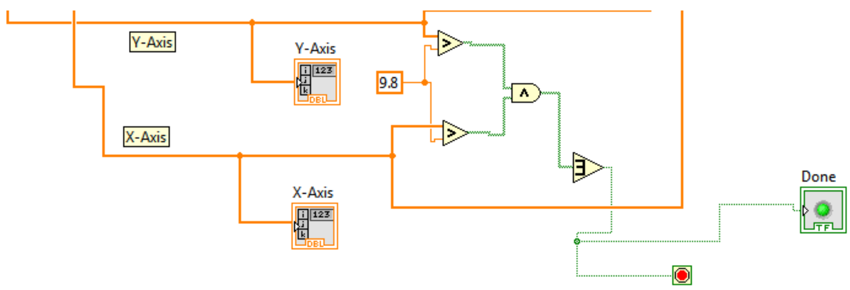


Figure 4-33 Done detector

Programming above use to track the coordinate of X-axis and Y-axis to ensure the whole process had completely done. The function is going to detect amplitude of X-axis and Y-axis is more than 9.8V or not. If yes, the whole process show done, else it keep looping until it detect value that required.

4.5.2 Front Panel

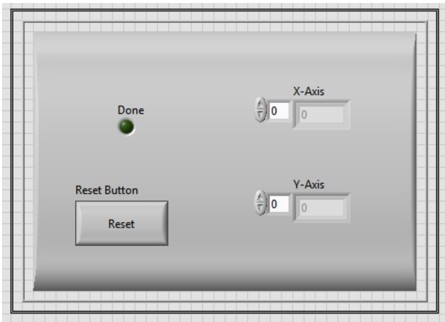
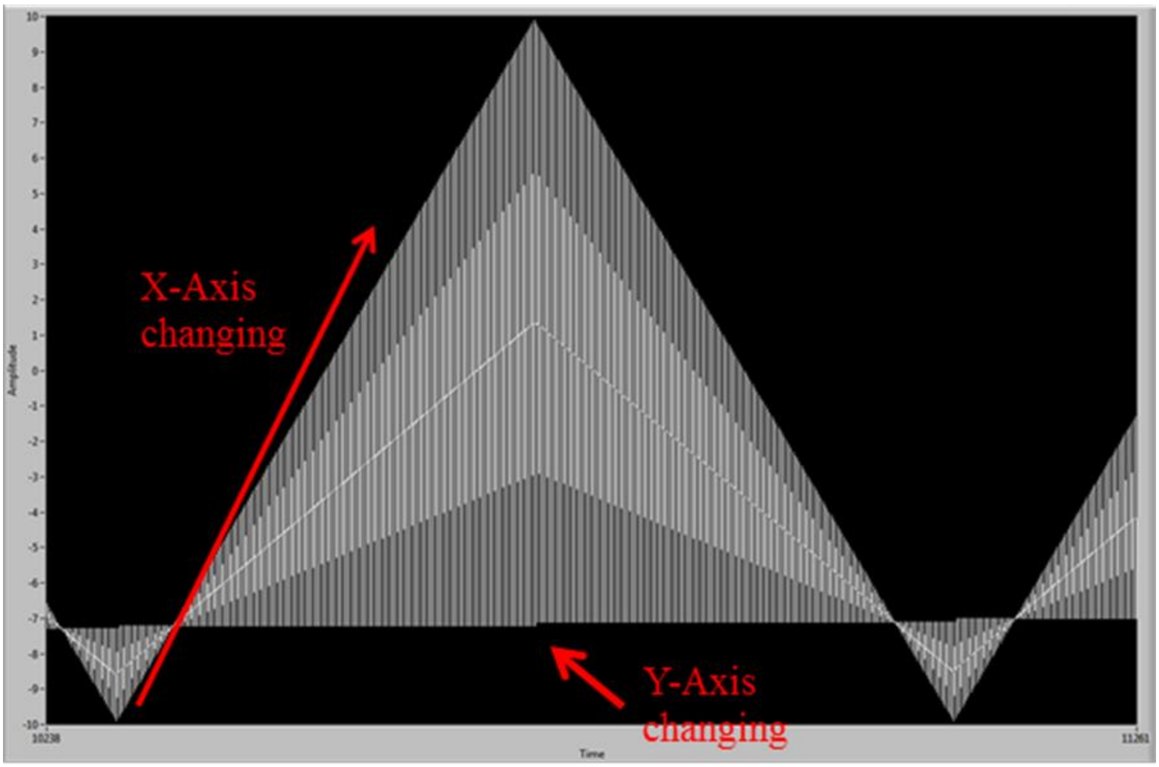


Figure 4-34 Displays in front panel

This is the front panel for user to use and test. In this front panel, there are two display bars to let user observe the amplitude of X-axis and Y-axis. There is also a reset button for user to reset the coordinate of X-axis and Y-axis. A LED there to show user the overall process is done.

Graph 4.3 Graph of proving my program is works



Other than that, there is also show a graph to user how X-axis and Y-axis eventually moved. When X-axis move from -10 to +10, you can see that, y axis had changed that pointed in graph above.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Material Used

ELVIS II++ had used in my project. I had learned how to test, operate, supplying voltage and other by using computer to control ELVIS II++ board.

Other than that, I also learn how to use LabView software. I had learned many structures, mathematical calculation, logic gates and others. By using LabView to give ELVIS II++ board.

In addition, my hardware part, I am using piezoelectric buzzer to lift up my object. To lift up an object, I am going to power up piezoelectric buzzer by using ELVIS II++ board. However, piezoelectric buzzer need up to 30V, but ELVIS II++ only can goes up to 10V. Thus I need to use amplifier and external power supply to boost up.

5.2 Proved 2 Dimension automation devices

In this project, by using graph 4.3, I had proved my programming is works smoothly. Other than that, to prove how hardware works, I had recording it in video and proved it works and smooth.

Other than that, overall I had used in our project is not overRM300.00 including the starting research fees. Furthermore, we had successfully build it in low cost.

CHAPTER 6

References

AFM, A.F.M. (n.d.) *Atomic Force Microscope AFM* [Online]. Available from: HYPERLINK "http://web1.knvs.tp.edu.tw/AFM/ch4.htm" http://web1.knvs.tp.edu.tw/AFM/ch4.htm [Accessed 28 March 2015].

AndyGadget. (2003) *Make your hot glue gun cooler* [Online]. (1.0) Available from: HYPERLINK "http://www.instructables.com/id/Make-your-hot-glue-gun-cooler/" http://www.instructables.com/id/Make-your-hot-glue-gun-cooler/ [Accessed 11 June 2015].

Axotron. (2011) *Desgn of an H Bridge* [Online]. Available from: HYPERLINK "http://axotron.se/index_en.php?page=34" http://axotron.se/index_en.php?page=34 [Accessed 28 March 2015].

EAGLE, P. (2011) *EAGLE PCB Design Software* [Online]. (1.0) Available from: HYPERLINK "http://www.cadsoftusa.com/eagle-pcb-design-software/about-eagle/" http://www.cadsoftusa.com/eagle-pcb-design-software/about-eagle/ [Accessed 28 May 2015].

ELVIS, N. (n.d.) *National Instruments* [Online]. (1.0) Available from: HYPERLINK "http://sine.ni.com/nips/cds/view/p/lang/en/nid/205425" http://sine.ni.com/nips/cds/view/p/lang/en/nid/205425 [Accessed 28 April 2015].

LabView. (n.d.) *National Instuments* [Online]. (1.0) Available from: HYPERLINK "http://www.ni.com/labview/why/" http://www.ni.com/labview/why/ [Accessed 28 April 2015].

LM741. (2013) *LM741 Opperational Amplifier* [Online]. (2.0) Available from: HYPERLINK "http://www.ti.com/lit/ds/symlink/lm741.pdf" http://www.ti.com/lit/ds/symlink/lm741.pdf [Accessed 15 May 2015].

Murata. (2012) *Piezoelectric Sound Components* [Online]. Available from: HYPERLINK "http://www.murata.com/~/media/webrenewal/support/library/catalog/products/sound/p15e.ashx" http://www.murata.com/~/media/webrenewal/support/library/catalog/products/sound/p15e.ashx [Accessed 21 March 2015].

PCB, P.C.B. (n.d.) *PCB Types* [Online]. (1.0) Available from: HYPERLINK "http://www.pwcircuits.co.uk/singledoublesided.html" http://www.pwcircuits.co.uk/singledoublesided.html [Accessed 22 May 2015].

TV, L.C. (2010) *The LEGO story* [Online]. (1.0) Available from: HYPERLINK "https://www.youtube.com/watch?v=NdDU_BBJW9Y" https://www.youtube.com/watch?v=NdDU_BBJW9Y [Accessed 15 May 2015].

Workshop, A. (n.d.) *TT-AFM* [Online]. Available from: HYPERLINK "http://www.afmworkshop.com/images/datasheets/TT-AFM_Datasheet_FINAL_1_lowres.pdf" http://www.afmworkshop.com/images/datasheets/TT-AFM_Datasheet_FINAL_1_lowres.pdf [Accessed 30 March 2015].

Zang, P. (2013) *Basics of AtomicForce Microscope (AFM)* [Online]. Available from: HYPERLINK "http://www.eng.utah.edu/~lzang/images/Lecture_10_AFM.pdf" http://www.eng.utah.edu/~lzang/images/Lecture_10_AFM.pdf [Accessed 22 March 2015].

CHAPTER 7

APPENDICES

Appendix A: LM741 Data Sheet

Connection Diagrams

LM741H is available per JM38510/10101

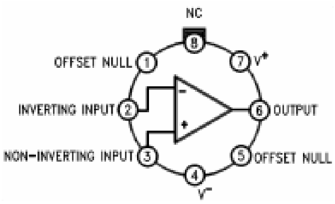


Figure 1. TO-99 Package
See Package Number LMC0008C

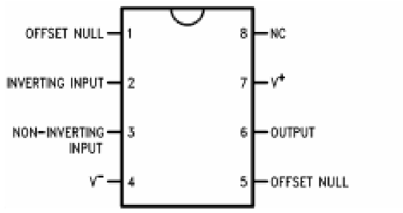


Figure 2. CDIP or PDIP Package
See Package Number NAB0008A, P0008E

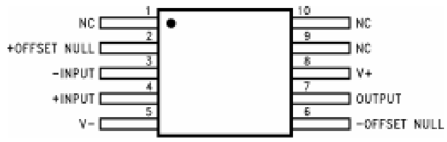


Figure 3. CLGA Package
See Package Number NAD0010A

DESCRIPTION

The LM741 series are general purpose operational amplifiers which feature improved performance over industry standards like the LM709. They are direct, plug-in replacements for the 709C, LM201, MC1439 and 748 in most applications.

The amplifiers offer many features which make their application nearly foolproof: overload protection on the input and output, no latch-up when the common mode range is exceeded, as well as freedom from oscillations.

The LM741C is identical to the LM741/LM741A except that the LM741C has their performance ensured over a 0°C to +70°C temperature range, instead of −55°C to +125°C.

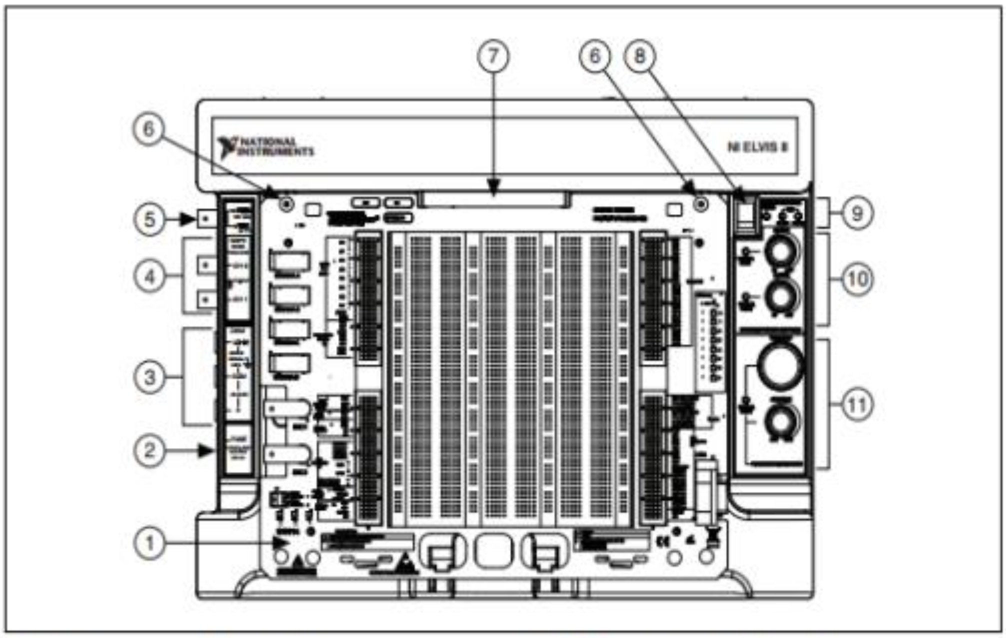
Absolute Maximum Ratings [1][2][3]

	LM741A	LM741	LM741C
Supply Voltage	±22V	±22V	±18V
Power Dissipation [4]	500 mW	500 mW	500 mW
Differential Input Voltage	±30V	±30V	±30V
Input Voltage [5]	±15V	±15V	±15V
Output Short Circuit Duration	Continuous	Continuous	Continuous
Operating Temperature Range	−55°C to +125°C	−55°C to +125°C	0°C to +70°C
Storage Temperature Range	−65°C to +150°C	−65°C to +150°C	−65°C to +150°C
Junction Temperature	150°C	150°C	100°C
Soldering Information			
P0008E-Package (10 seconds)	260°C	260°C	260°C
NAB0008A- or LMC0008C-Package (10 seconds)	300°C	300°C	300°C
M-Package			
Vapor Phase (60 seconds)	215°C	215°C	215°C
Infrared (15 seconds)	215°C	215°C	215°C
ESD Tolerance [6]	400V	400V	400V

(1) "Absolute Maximum Ratings" indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not ensure specific performance limits.
(2) For military specifications see RETS741X for LM741 and RETS741AX for LM741A.
(3) If Military/Aerospace specified devices are required, please contact the TI Sales Office/Distributors for availability and specifications.
(4) For operation at elevated temperatures, these devices must be derated based on thermal resistance, and T_j max. (listed under "Absolute Maximum Ratings"). $T_j = T_A + (\theta_{jA} P_D)$.
(5) For supply voltages less than ±15V, the absolute maximum input voltage is equal to the supply voltage.
(6) Human body model, 1.5 kΩ in series with 100 pF.

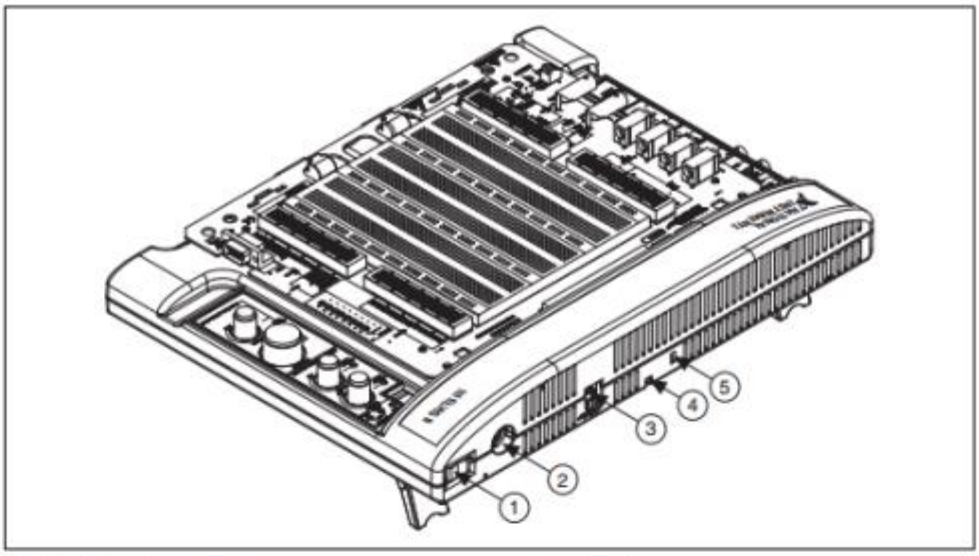
Appendix B: ELVIS II++ Data Sheet

Figure 2-2 shows the workstation parts locator diagram.



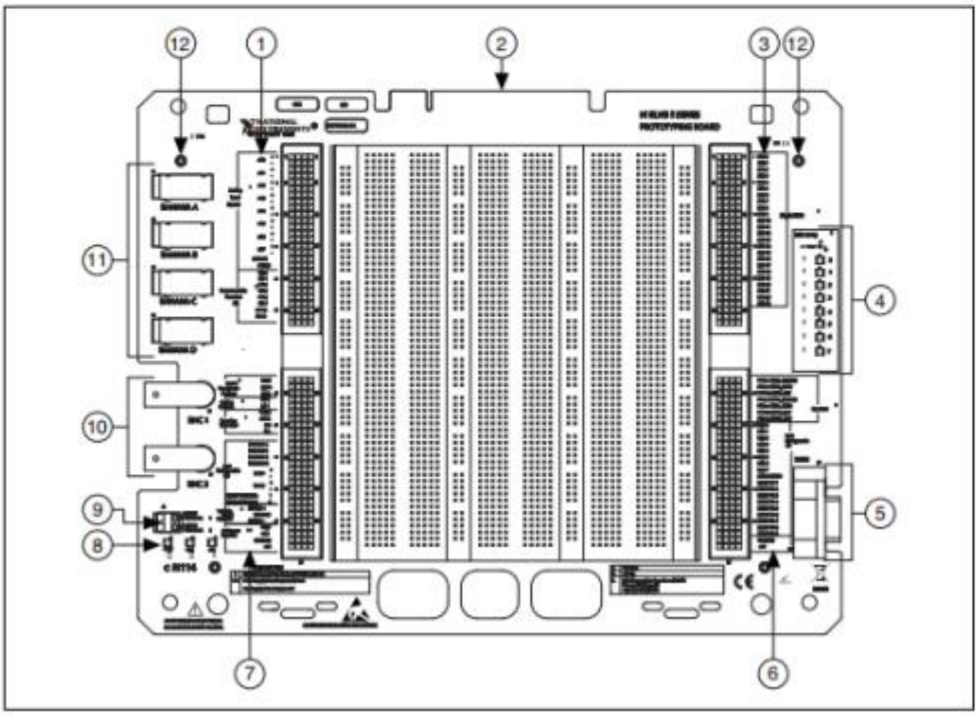
1	NI ELVIS II Series Prototyping Board	6	Prototyping Board Mounting Screw Holes
2	DMM Fuse	7	Prototyping Board Connector
3	DMM Connectors	8	Prototyping Board Power Switch
4	Oscilloscope Connectors	9	Status LEDs
5	Function Generator Output/Digital Trigger Input Connector	10	Variable Power Supplies Manual 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
2 AC/DC Power Supply Connector
3 USB Port
4 Cable Tie Slot
5 Kensington Security Slot

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.