LABVIEW BASED PID ALGORITHM DEVELOPMENT FOR Z MOTION CONTROL IN ATOMIC FORCE MICROSCOPY

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

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Universiti Tunku Abdul Rahman

May 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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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"LABVIEW BASED PID ALGORITHM DEVELOPMENT FOR Z MOTION CONTROL IN ATOMIC FORCE MICROSCOPY"** was prepared by **TEH YONG HUI** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons) Electronic Engineering at Universiti Tunku Abdul Rahman.

Approved by,

Signature : ___________________________

Supervisor : Dr. LOH SIU HONG

Date : ___________________________

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ABSTRACT

Atomic Force Microscopy is a type of scanning probe that can scan a very small object such as DNA, bacteria or virus. It provide a high resolution of 3 dimensional imaging. Thus, it is commonly used in mapping, measuring and scaling in nano sizes. The 3 dimensional imaging required a 3 dimensional motion which is XYZ to control the scanning part in the sample and map it into 3D images. Therefore, the main objective in this thesis is to develop a PID algorithm for Z motion control. As the scanning probe move in XY direction, if the tips has going up/down caused the laser does not stay at the center of photodetector. Then the Z-axis motion control which is my PID will give some output voltage to control the Z scanner so that the laser will move back to the center. The Z-axis scanner that I used in this final year project is piezoelectric buzzer, it able to convert mechanical energy to electrical energy or electrical energy to mechanical energy. However, I make use of the piezoelectric buzzer to perform electrical energy to mechanical energy by supplying voltage on it and cause it to extend or contract. In order to combine my hardware and software together, I have been written a PID algorithm in LabVIEW which can be communicate with the NI ELVIS to the piezoelectric buzzer to achieve Z motion control in atomic force microscopy.

ACKNOWLEDGEMENTS

First, I would like to express my gratitude to my research supervisor, Dr. LOH SIU HONG for his invaluable advice, guidance and his enormous patience throughout the development of the research.

Besides that, I would like to express my deepest thanks and sincere appreciation to my friend KANG QIN YEE and PHOONG WEI SIANG for their kind endless help during this project.

In addition, I would like to express my extreme sincere gratitude and appreciation to my family for their love and support.

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LIST OF SYMBOLS / ABBREVIATIONS

k	spring constant, N/m
Δl_z	vertical deformation of buzzer, m
θ_y	angular to the scanner, ^{o}
l	length of carbon fiber, m
l_m	height of sample holder, m
r	separation between two disk buzzer
kp	proportional gain
ki	integral gain
kd	derivative gain
ep	error value
ΔP	displacement changes, mm
ΔL	laser position changes, mm

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CHAPTER 1

INTRODUCTION

1.1 Background

The scanning probe microscopy have been widely used nowadays because it able to create images of a surface using a probe by moving over the specimen. Scanning probe microscopy helps researchers in reducing their time to prepare and study of those specimens, some improvements and modifications for the scanning probe instruments in order to provide more efficiency and faster performance in revealing the specimen images.

In 1931, Ernst Ruska have developed the first electron microscope which is Transmission Electron Microscopy (TEM) with assistance of Max Knolls. TEM can produces a high resolution with black and white image from the prepared specimen. The technique used is pumped out the air from vacuum chamber to create the space so that the electrons able to move. Hence, the electron is then pass through numerous electromagnetic lenses, the beam go through solenoids and electrons are converted to light while making contact with the screen then form an image. The image can be controlled by adjusting the accelerate gun voltage or changing the magnetic wavelength to decrease the speed of electrons.

In 1935, Knoll have discovered the first scanning microscope but demagnifying lenses was not used to produce a fine probe, so the resolution only limited to around 100um. In 1938, a theoretical principles underlying the scanning microscope was expressed by von Ardenne, but this is difficult to compete with TEM in resolution. Next, Zworykin was showed the secondary electron that provide topographic contrast but the resolution of 50nm still considered low as compare to TEM performance. In 1956, Smith able to improve the micrographs by using signal processing and introduced nonlinear signal amplification by enhancing the scanning system. In 1960, Everhart and Thornley have improved the secondary electron detection. Finally, Pease and Nixon combined all of the improvements to build scanning electron microscopy in year 1963. The scanning electron microscopy produce high resolution and two dimensional images of the polymer surface, it also can provide topographical, morphological and compositional information.

Another family of scanning probe microscopy is the atomic force microscopy (AFM) which invented by Gerd Binning, Quate and Gerber that earned a Nobel Price in 1986. AFM is a powerful instrument in imaging and measuring at nanoscale, it providing a high resolution and three dimensional of images. AFM consists of cantilever with a sharp tip which is used to scan or analyze the specimen surface. Thus, a forces between the tip and specimen surface caused the cantilever to bend or deflect. A detector is used to measure the cantilever deflection when it scanned over the specimen. The data will send to the computer and allow it to generate a map of surface topography based on the shape of specimen.

1.2 Problem Statements

Nowadays, the advance of technology helps human to do many impossible things, but still it is hard to develop something that can scan a very small object in nanoscaled without an error. For an example, the movement of scanner does not follow the same displacement when moving forth and back which also known as hysteresis phenomena. Secondly is the applied voltage is non-linear to the displacement of scanner. Since the scanner does not give a precise positioning/motioning, we need some sensor to solve out this problem such as strain and capacitive sensor. Besides, we also have to implement a PID system to control the input signal at the Z motion of piezoelectric scanner. This is to keep the same current and same distance in the Z motion.

1.3 Application

Piezoelectric scanner can helps in biology study such as cells, viruses, bacteria, DNA, chromatin, chromosome or any other small sizes stuffs. The motion of scanner is able to measure the height and the volume of the specimen. These can be achieved by phase imaging which known as mapping the phase difference between piezoelectric excitation and the response of cantilever tip. Without the help of piezoelectric scanner, AFM might not be able to achieve the applications in below.

- It provides nanometer resolution of the characteristic on individual cells.
- Simultaneously collecting the topological and mechanical data from the samples.
- Provide 3D topography information after completed the scan.

1.4 Aims and Objectives

The objectives of the thesis are shown as following:

i) Design a PID algorithm for Z motion control in LabVIEW.

ii) Use low cost materials to construct the Z motion hardware.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Atomic Force Microscope

The atomic force microscopy (AFM) consists of cantilever, tip, photodiode detector, laser beam and piezoelectric scanner. Each of the components have its own function and will be discussed later. The figure 2.1 shows the general AFM set-up.

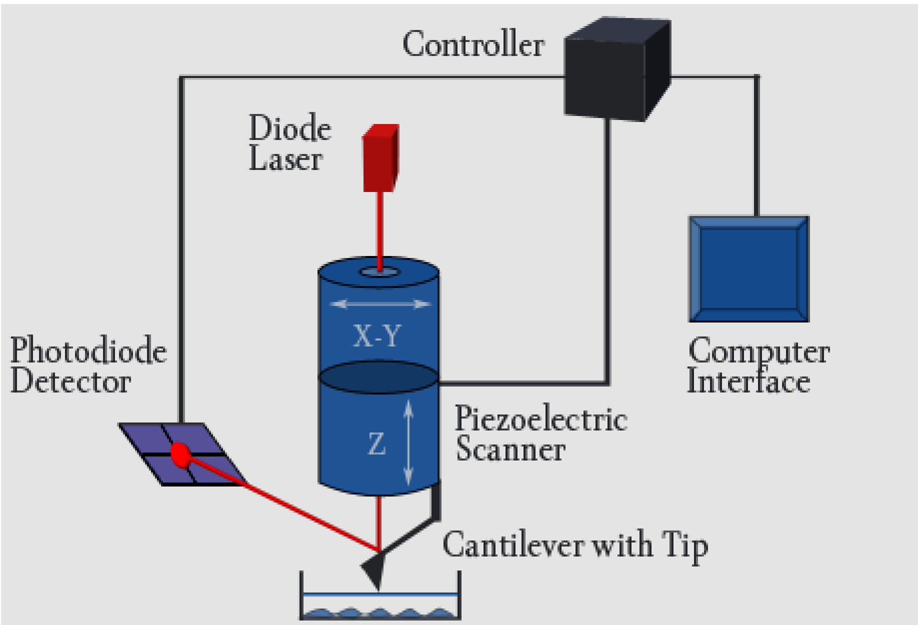


Figure 2.1: Configuration of AFM

The cantilever plays an important role in determining he force that applied to the specimen during the scan. Depends on the mode used, the spring constants, *k* of cantilever is in range of 0.01 N/m to 30 N/m. The spring constants is good to be as small as possible in order to avoid low frequency resonance, this is because smaller *k* give better sensing in deflection and also low force is required to prevent damaging the specimen.

A laser beam will be directed to the top of cantilever and get reflected to photodiode detector. The photodiode detector able to sense the position of the light and give signal to the controller. As the cantilever moving up or down, the position of light reflected to the detector will give different signal. Thus, the controller will monitoring the signal in order to minimize the error or reduction of noise, then only it will give input to the piezoelectric scanner. The scanner will extend or contract to create motion in XYZ axis by maintaining the reflected light stayed constant in the center of photodiode detector.

2.2 Piezoelectric Scanner

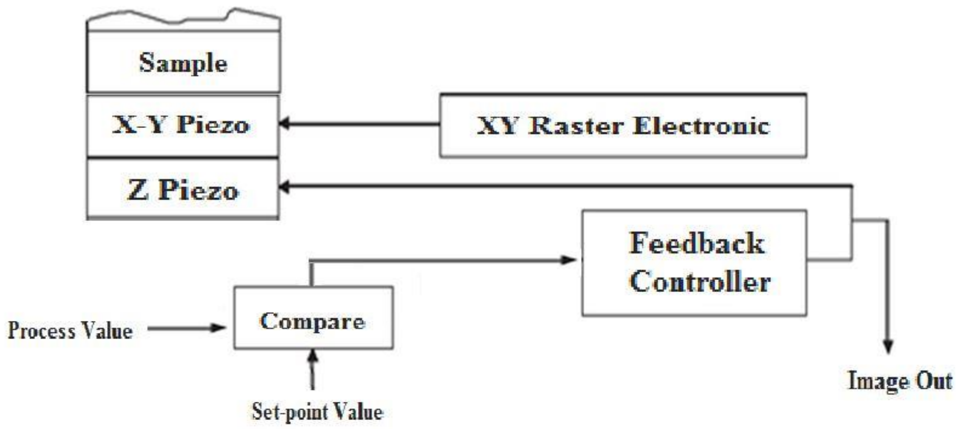


Figure 2.2: Feedback System for Z Motion

The piezoelectric scanner will receive an input signal from the feedback controller which will extend proportional with an applied voltage. The applied voltage is come from the output detection by photodiode detector. Therefore, the feedback controller will give input signal to piezoelectric scanner in Z direction by taking the laser beam back to the center of photodiode detector. The feedback controller also keeps the force constant by monitoring the expansion of Z direction precisely with good reproducibility for small distance.

There are two types of scanner which are scanned tip AFM and scanned sample AFM. The scanned tip AFM keep the tip in place and moved over the specimen surface whereas the scanned sample AFM is to keep the specimen in stationary and moved over the tip on it.

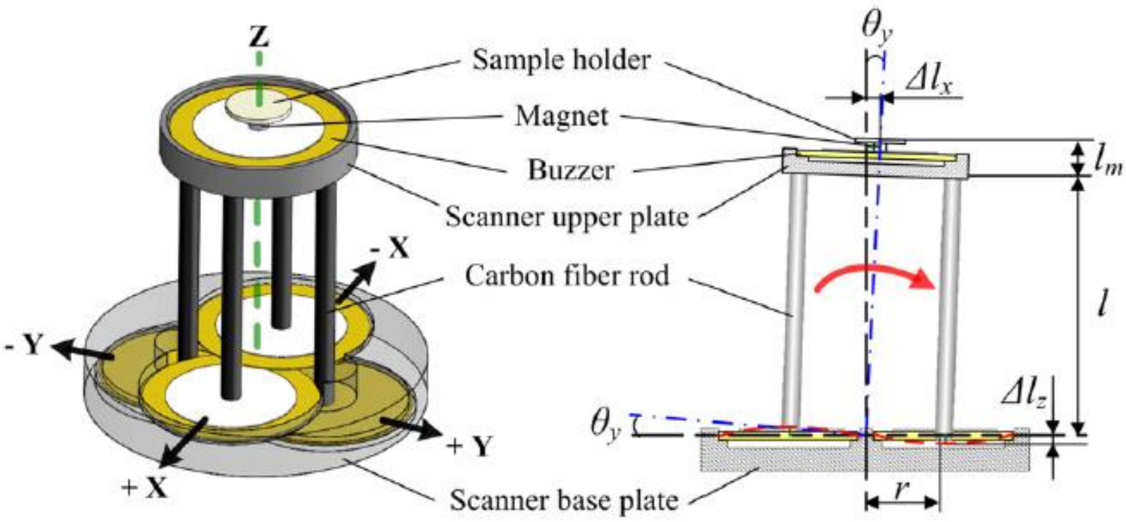


Figure 2.3: Schematic Configuration of Buzzer Scanner

As we can see from the figure 2.3, four buzzer disk fixed on the scanner base plate which used to perform XY direction. Another buzzer disk will be at top of the scanner plate for Z direction. The vertical deformation of buzzer Δl_x can form an angular θ_y to the scanner, this will provides a lateral displacement of Δl_x in the sample holder. The relationship of the parameters are:

$$\Delta l_x = (l + l_m)\sin\theta_y \cong (\frac{l + l_m}{r})\Lambda l_z \tag{2.1}$$

The l is the length of carbon fiber rod and l_m is the height of sample holder. Based on the equation above, the range can be increased either we increase the length of rod or reduce the separation between two disk buzzer, r. Larger deformation of Δl_z is due to using a larger disk buzzer, this also required to increase the separation between two disk buzzer, r. In other words, larger buzzer will provide larger motion in Z direction but the working bandwidth will be reduced.

2.3 Feedback Controller

A high gain feedback controller able to produce a high data sampling rate during the sample scan, this allow quick and accurate scanning on the specimen surface. Therefore, it is necessary to have a feedback system by adjusting the input signal of Z-axis in piezoelectric scanner. During the scanning process, the position of Z-axis is there to maintain the constant amplitude set-point to achieve a good image of the sample and prevent the touching between tip and sample. In the meantime, the feedback control should be designed in such a way that only small amount of force is applied to the sample. This can be improved by implementing a PID controller in the transient and steady state response.

2.3.1 PID Design Consideration

The PID is there to control the output of the system. It consist of 3 controller which is proportional gain, integral gain and derivative gain. A system without a PID will give slow respond in the output. Thus, the proportional gain, *Kp* helps to improve the response time to the system. In the meantime, the system will have the problem of overshoot and steady state error.

The integral gain, *Ki* can eliminate the steady state error to achieve same value of process variable and set-point. In other words, the *Ki* actually helps to minimize the error in the desired system. Lastly, the derivative gain, *Kd* used to stabilize the system by reducing the overshoot in the system. When the process variable approaching to the set-point value, the system will eventually slowdown in order to avoid overshoot occur in the system. Therefore, with this 3 controller combined together, the system will perform much faster and accurate.

2.4 Piezoelectric Buzzer

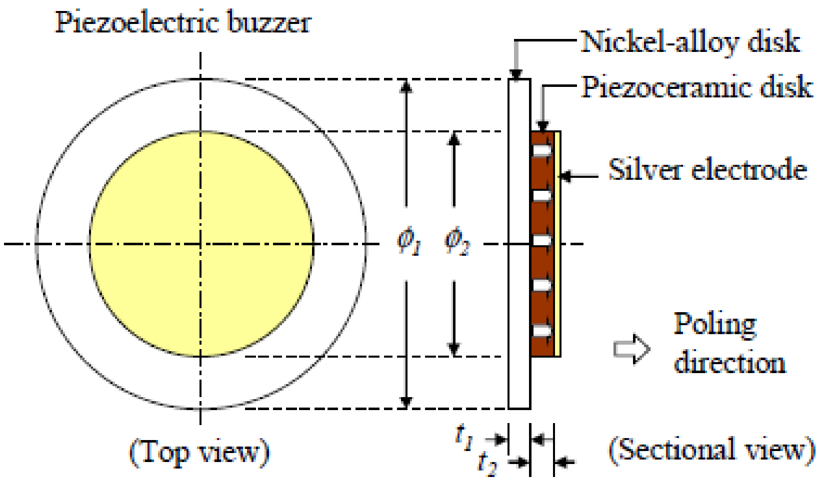


Figure 2.4: Material Contained in Piezoelectric Buzzer

The piezoelectric buzzer containing piezoceramic disk, nickel-alloy disk and silvering electrode. To drive the buzzer, the input signal is attached to the nickel-alloy disk and silvering electrode.

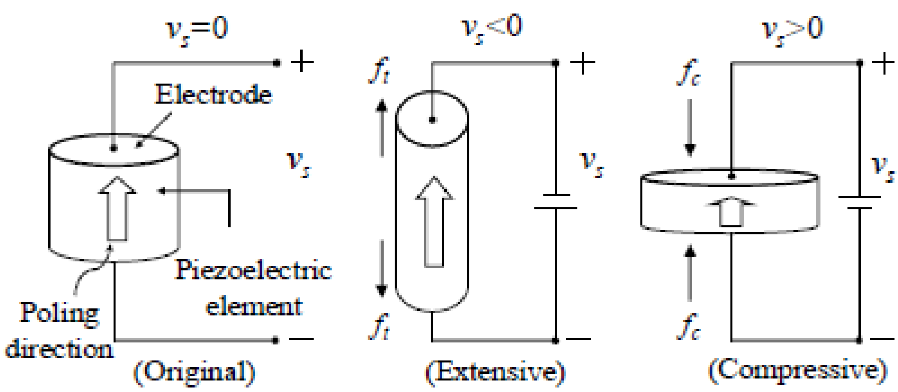


Figure 2.5: Working Principle of Piezoelectric Buzzer

The figure 2.5 shows the working principle of the piezoelectric buzzer which contained in the piezoelectric scanner. The piezoelectric buzzer will extend when driven by a positive voltage or compressed when driven by negative voltage. Thus, the extending and contracting in the piezoelectric buzzer will created the Z motion in the scanner.

2.4.1 Relationship between Photodetector, Piezoelectric Buzzer and PID

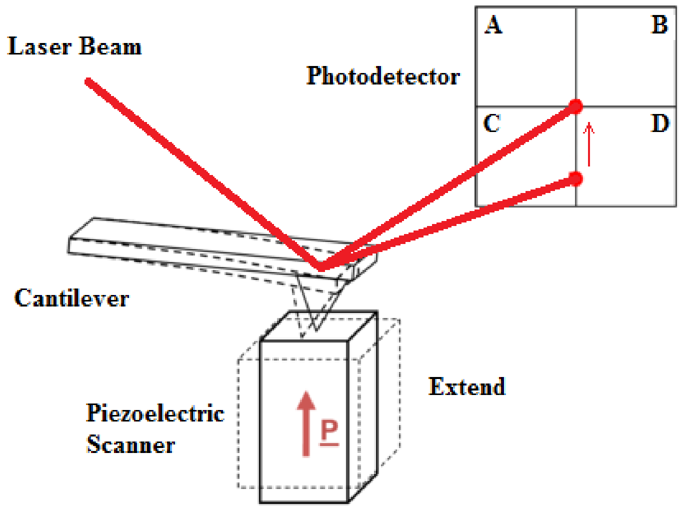


Figure 2.6: Extend Condition in Scanner

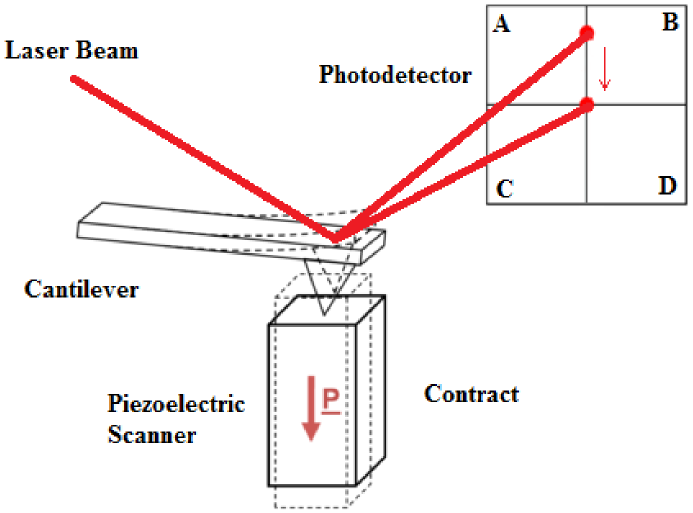


Figure 2.7: Contract Condition in Scanner

The sensed position of laser beam on photodetector will give different values of voltage level. In all the time we are required to adjust the laser beam remained in the center of photodetecter. Thus, the set-point value in the PID will be based on the voltage level sensed in the center of photodetector. As the position of laser beam go down, the piezoelectric buzzer in the scanner will then be extend until the laser go back to the center point. The response of scanner will be based on the PID design. When the laser position is at the top, the piezoelectric buzzer will then contract in order to move the laser back to the center point. Therefore, the PID helps to control the respond speed of the piezoelectric scanner by maintaining the laser in center of photodetector.

2.5 LabVIEW Interface

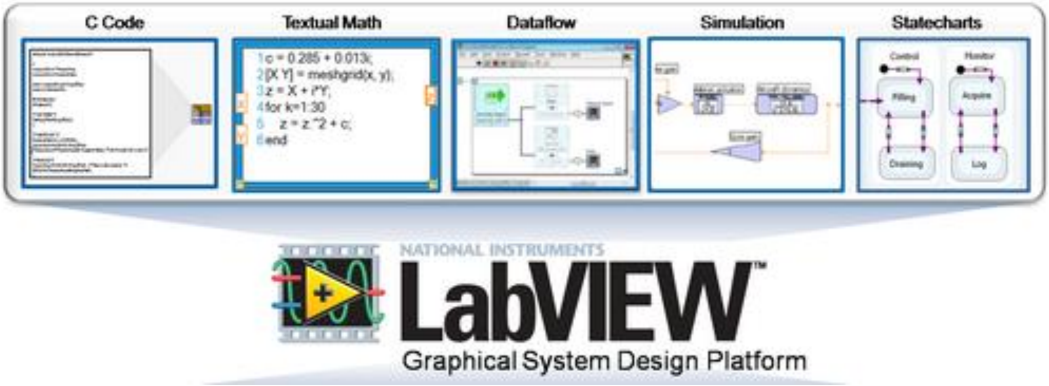


Figure 2.8: LabVIEW Graphical System Design Platform

LabVIEW which also known as Laboratory Virtual Instrument Engineering Workbench that provides a graphical programming syntax in system design platform. This graphical programming syntax give simple visualize, create and code for engineering system. The virtual instruments (VIs) is a program or subroutines from LabVIEW. Each of the VI consists of front panel and block diagram. The front panel shows the controls and indicators of the designed system, the controls are inputs that allow user to manipulate the information to the system whereas the indicators are outputs which display the results based on the input given to the system. Besides that, the block diagram consists of the graphical source code.

Any object placed on front panel will exists on the block diagram. In other words, the block diagram also contain the structures and functions to perform the operations of the designed system. This implies that each virtual instrument can be tested easily before combined into a larger program. The benefits of using LabVIEW can helps in reducing time for researching, combining the analyzed data, visualization with data acquisition, smoothen the technology of transfer process and many more.

2.6 NI ELVIS II

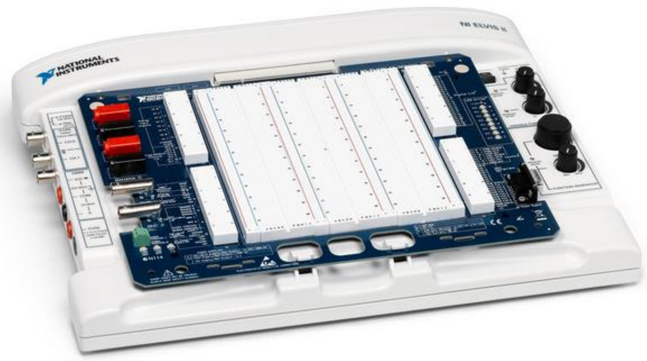


Figure 2.9: NI ELVIS II and 12 used Electronic Instrument

The NI ELVIS (National Instruments Educational Laboratory Virtual Instrumentation Suite) is a hands-on designed hardware that integrates 12 commonly used electronic instrument such as oscilloscope, digital multimeter, function generator and more. All this 12 instruments of NI ELVIS platform are accessible in the NI ELVISmx Instrument Launcher which has shown in figure 2.9.

National Instruments providing the flexibility of virtual instrumentation and customizing ability of applications. Thus, the NI ELVIS is good teaching instrument for engineering that related in electrical, electronic or mechanical field. This can be functioned as we combining the constructed system in LabVIEW and hardware on the prototyping board. With this we can see how the constructed system communicate with the hardware through the NI ELVIS.

2.7 Set-up Lego as Scanner Body

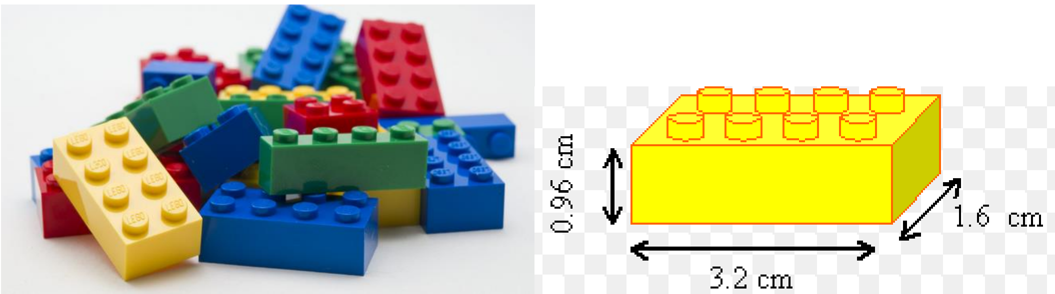


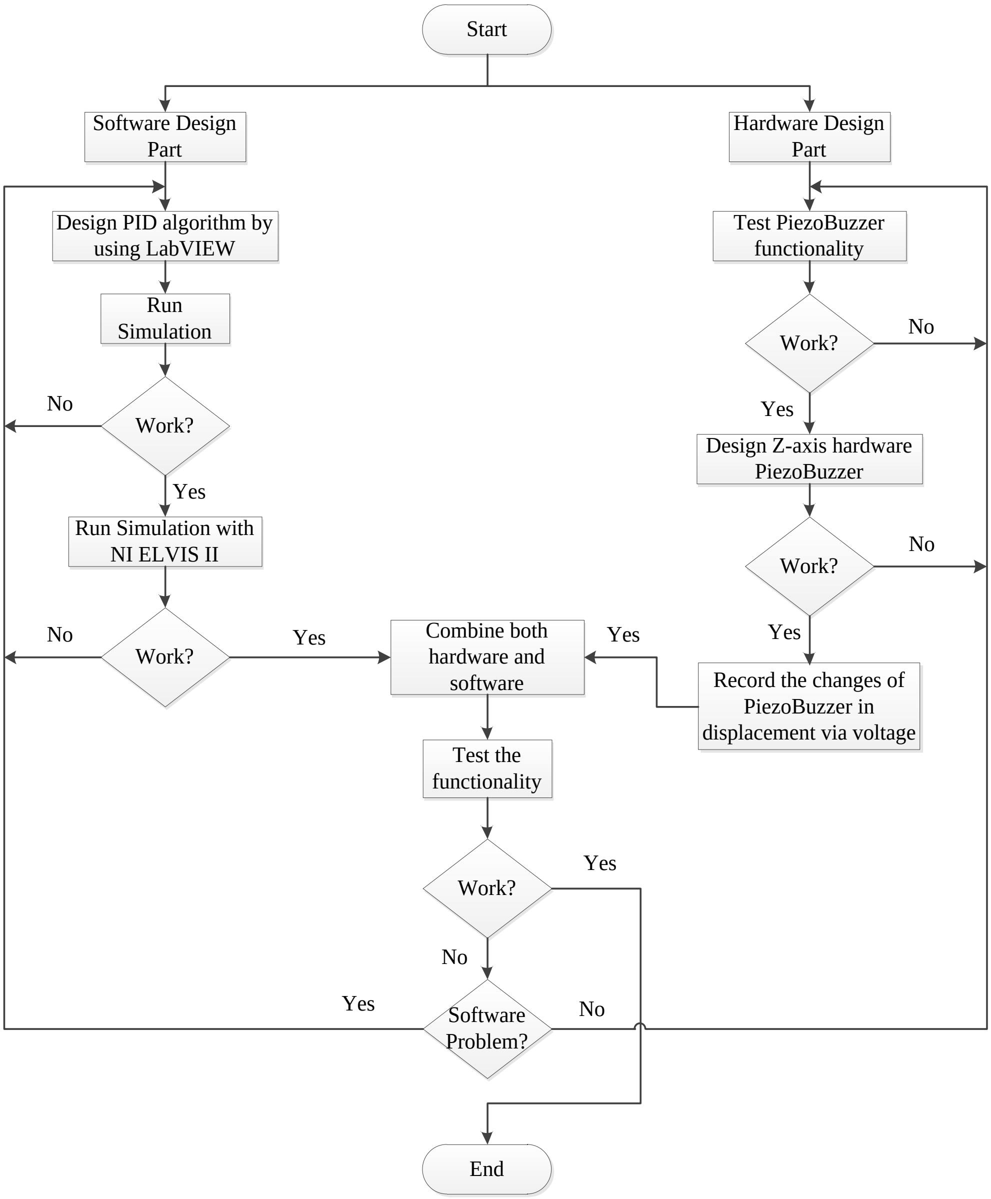
Figure 2.10: Lego Sample and Dimension

Lego is a kind of colourful interlocking plastic bricks with accompanying array of gears. The lego bricks can be linked, assembled or connected in many different ways in order to construct any objects such as building, robots or vehicles. Anything that have constructed can be removed easily and reuse the pieces to build other objects. Hence, this lego serve the purpose to cover up the piezoelectric buzzer that we used to control XYZ direction.

CHAPTER 3

METHODOLOGY

3.1 Flow Chart



3.2 FYP I & II Timetable and Schedule

The Final Year Project required two semester to complete it. The first semester was started from January of 2015 and below was the progress of FYP I.

Table 3.1: FYP I Progress

<table>
<tr><th>Week</th><th colspan="2">Progress</th></tr>
<tr><td>1</td><td colspan="2">FYP Title Selection</td></tr>
<tr><td>2</td><td colspan="2">FYP Title Confirmation with Supervisor</td></tr>
<tr><td>3</td><td rowspan="7">Literature Review</td><td rowspan="3">LabVIEW Training part I</td></tr>
<tr><td>4</td></tr>
<tr><td>5</td></tr>
<tr><td>6</td><td rowspan="3">LabVIEW Training Part II</td></tr>
<tr><td>7</td></tr>
<tr><td>8</td></tr>
<tr><td>9</td><td>LabVIEW PID Learning</td></tr>
<tr><td>10</td><td colspan="2" rowspan="3">Preparing FYP I Report</td></tr>
<tr><td>11</td></tr>
<tr><td>12</td></tr>
<tr><td>13</td><td colspan="2">Preparing FYP I Presentation Slide</td></tr>
<tr><td>14</td><td colspan="2">FYP I Presentation</td></tr>
</table>

The FYP II was started from May of 2015 and below was the progress of FYP II.

Table 3.2: FYP II Progress

<table>
<tr><th>Week</th><th colspan="4">Progress</th></tr>
<tr><td>1</td><td colspan="2">Purchase Component I</td><td rowspan="5">LabVIEW PID Design</td><td rowspan="8">Troubleshooting and reconstruction</td></tr>
<tr><td>2</td><td colspan="2">Test Piezoelectric buzzer</td></tr>
<tr><td>3</td><td colspan="2" rowspan="2">Hardware Design I</td></tr>
<tr><td>4</td></tr>
<tr><td>5</td><td rowspan="3">Hardware Design II</td><td>Purchase Component II</td></tr>
<tr><td>6</td><td colspan="2" rowspan="2">Combining both Hardware and Software (LabVIEW)</td></tr>
<tr><td>7</td></tr>
<tr><td>8</td><td colspan="3">Test combining other project and further implementation</td></tr>
<tr><td>9</td><td colspan="4" rowspan="3">Preparing FYP II Report</td></tr>
<tr><td>10</td></tr>
<tr><td>11</td></tr>
<tr><td>12</td><td colspan="4">Preparing FYP II Report and FYP II Poster</td></tr>
<tr><td>13</td><td colspan="4">FYP II Poster Presentation and Preparing FYP II Presentation</td></tr>
<tr><td>14</td><td colspan="4">FYP II Presentation and Submission of FYP II Final Report</td></tr>
</table>

3.3 Relationship between Software, Hardware and Equipment Used

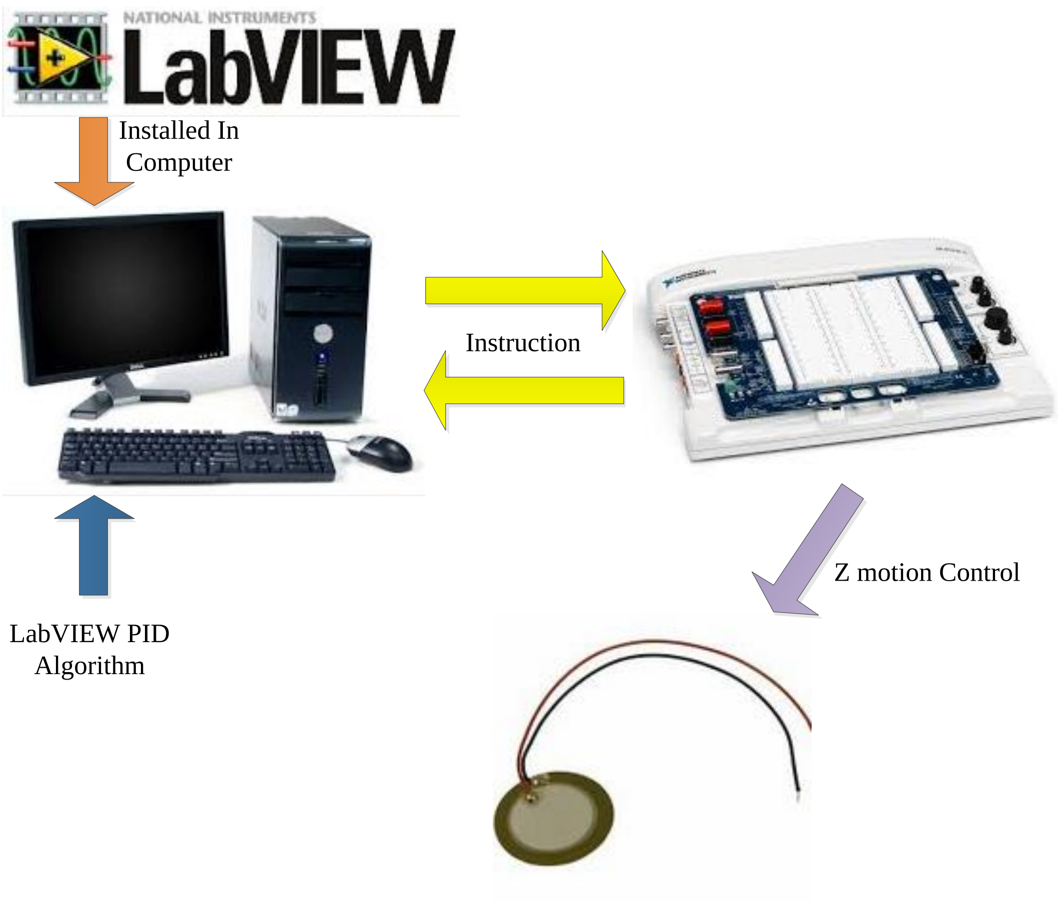


Figure 3.1: Simplified Equipment Used in Z Motion Control

A computer is required to install the LabVIEW software and design the PID algorithm in it. The NI ELVIS II will act as the port when creating an input and output in the desired software algorithm. Thus, the computer and NI ELVIS II have to be connected together in order to let the PID algorithm communicate with the NI ELVIS, the input port will be come from the output of the photodetector whereas the output port is connected to the piezoelectric buzzer for Z motion control.

3.3.1 Equipment/Item Used In This Project

Equipment/Item	Amount	Purpose
 Vitagen (half of the bottle)	1	Act as the body of piezoelectric buzzer (convenient when combine with XY motion item)
 Yakult (base part only)	1	Act as sample holder
 DC Power Supply	1	voltage supplied to piezoelectric buzzer (for testing)
 Piezoelectric Buzzer	2	For Z motion control
 Hot Glue Gun	1	Glue and fix the body of scanner
 Laser Pen	1	Used to indicate the position of piezoelectric buzzer via voltage
 Retort Stand	1	Used to hold laser pen and piezoelectric buzzer

3.4 Position in Piezoelectric Buzzer for Taking Measurement

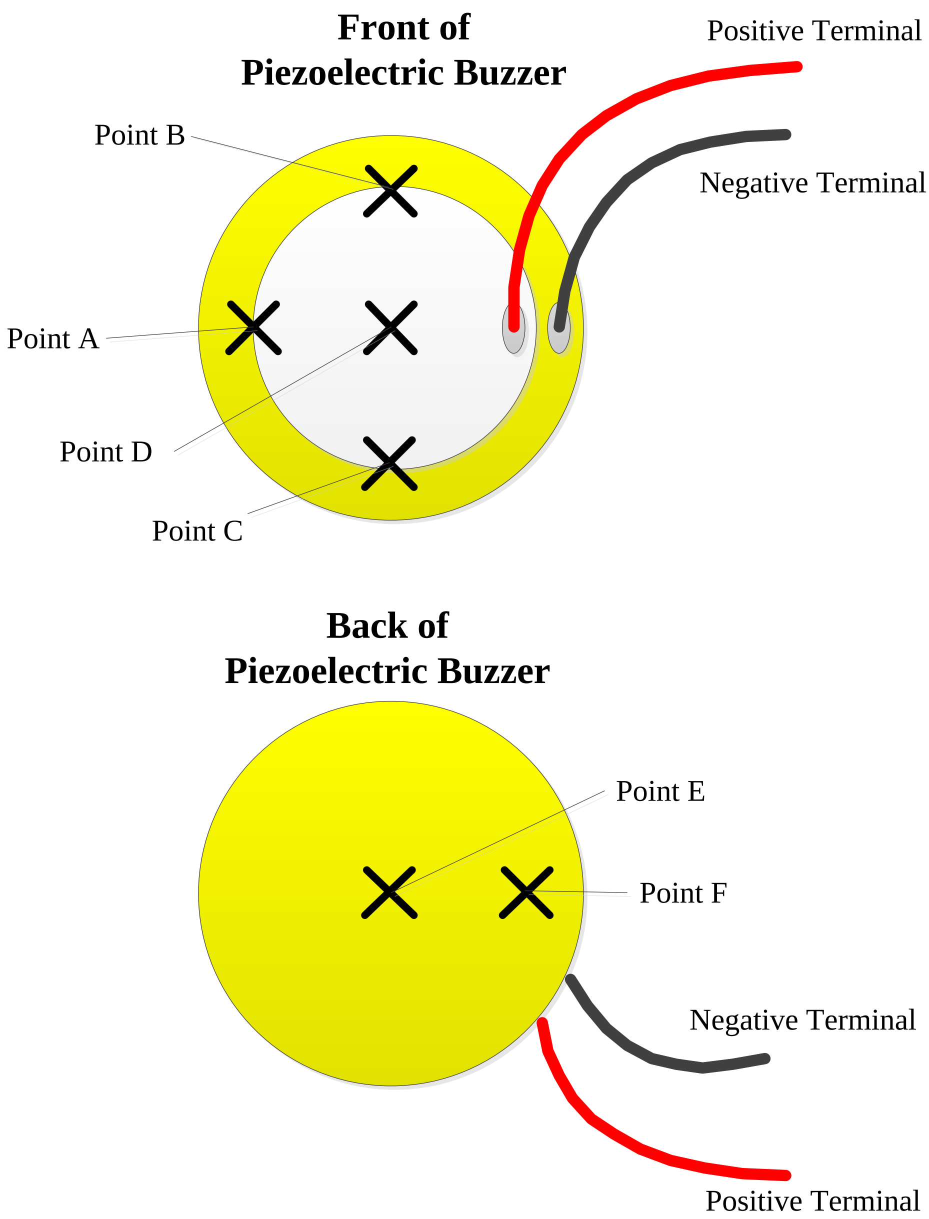


Figure 3.2: Measurement of Position in Piezoelectric Buzzer

As we know the piezoelectric buzzer will extend or contract when voltage was applied to it. How exactly it will extend is what we want to test. Therefore, the front of piezoelectric buzzer consists of four different point which were used to test the displacement changes via voltage. The back of piezoelectric buzzer consists of two point that used to hold piezoelectric buzzer or without any point to hold it. The position that give largest displacement changes will be used for Z motion in AFM.

3.5 Measurement of Displacement Changes in Piezoelectric Buzzer

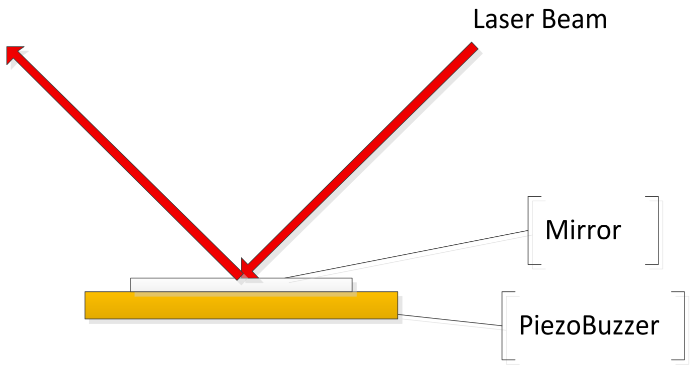


Figure 3.3: Piezoelectric Buzzer without Voltage Supplied

To measure the displacement changes in piezoelectric buzzer via the voltage supplied, we stick a small piece of mirror on top of the piezoelectric buzzer. Then the laser beam will directed to the mirror and get reflected to a piece of paper. Record down the laser position on the paper and the value of voltage supplied to the piezoelectric buzzer.

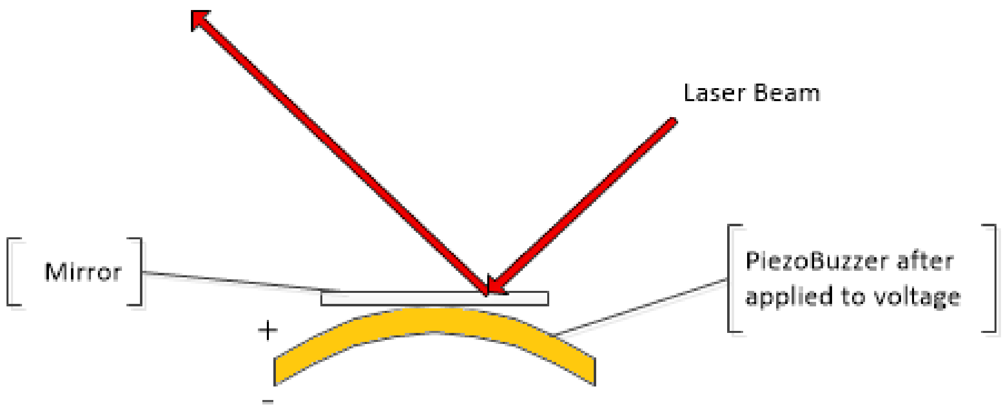


Figure 3.4: Piezoelectric Buzzer with Voltage Supplied

Figure 3.4 shows how the piezoelectric buzzer will look like when voltage was supplied to it. So we can see that the piezoelectric buzzer will change the shape (extend) as it mentioned in the section 2.4, this will also caused the change in mirror position and the position of reflected laser.

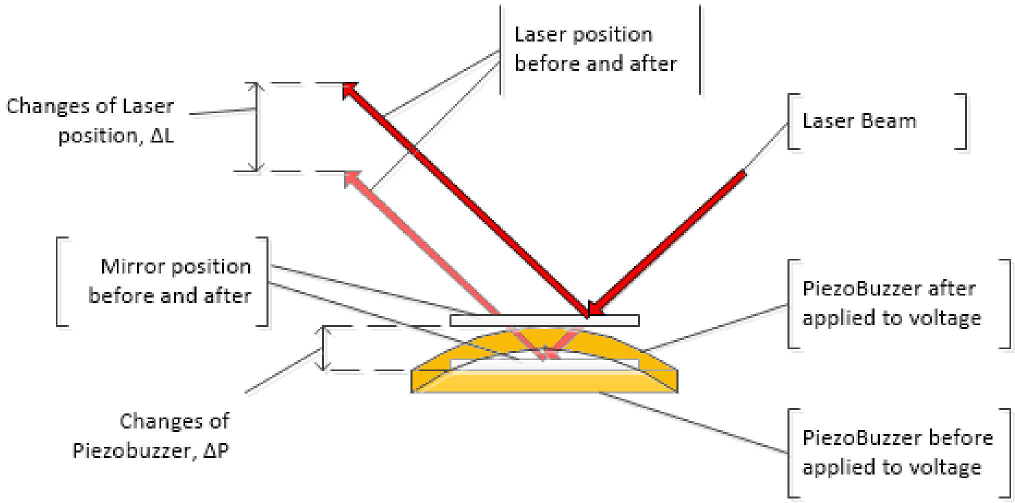


Figure 3.5: Changes of Laser Position when Voltage Supplied

Figure 3.5 shows the changes of piezoelectric buzzer before and after the voltage supplied on it. The laser diode need to be fixed in a same position so that the directed laser beam will be the same for all time. When the piezoelectric buzzer extend, the mirror will move upward which will caused the reflected laser position to move upward also. Then we are required to find the relationship between the changes of laser position, ΔL and changes of piezoelectric buzzer position, ΔP.

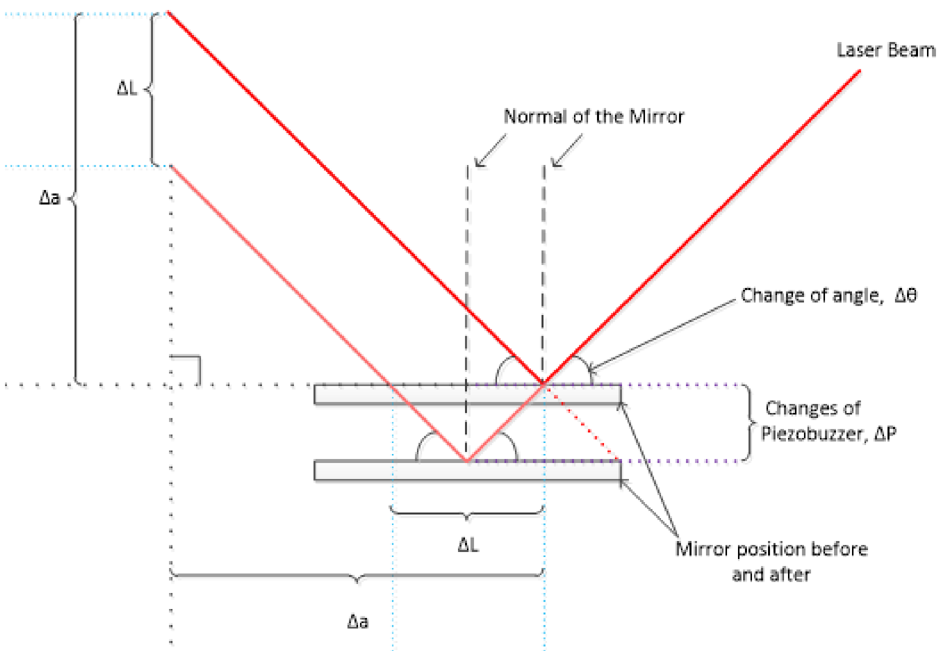


Figure 3.6: Simplified Version of Laser Position Changes

Before we measure the displacement changes in piezoelectric buzzer, we need to consider the directed laser incident angle in the mirror. Thus, we set the incident angle as 45°, then the reflected angle will also be 45°. The laser light is invisible and impossible to measure at 45 °by using protector geometry. In a triangle shape, if the adjacent and the opposite of an angle having the same length, then the angle will be 45°. With this information we can fix the distance from piezoelectric buzzer to the paper and the height of reflected laser on the paper, then we know that the incident and reflected angle are 45°. Now we can see that it can be form another small triangle shape with ΔP and ΔL.

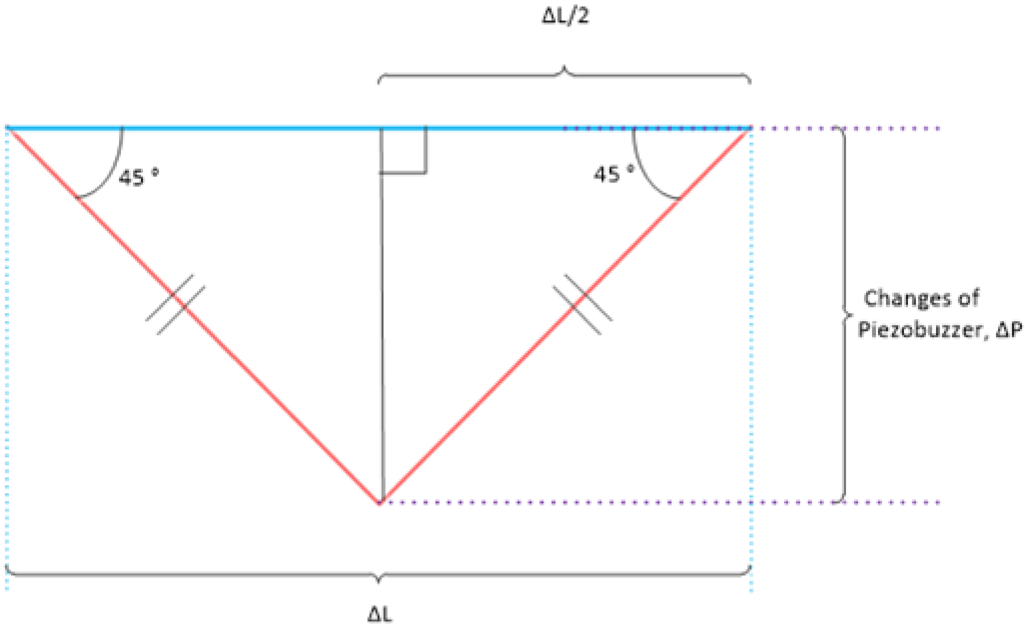


Figure 3.7: Simplified Version of Laser Position Changes and Displacement Changes of Piezoelectric Buzzer

The horizontal line indicates the change in laser position, ΔL whereas the vertical line indicates the change in piezoelectric buzzer displacement, ΔP. In order to measure the ΔP, we divide the triangle into half and we get another triangle with adjacent of ΔL/2 and opposite of ΔP. Applying the mathematical trigonometric ratios:

$$\tan \angle\theta = \frac{opposite\ \ of\ \ \angle\theta}{adjacent\ \ of\ \ \angle\theta}$$

$$\tan 45° = \frac{\Delta P}{\Delta L/2} \qquad\qquad \therefore \Delta P = \frac{\Delta L}{2} \tag{3.1}$$

Hence, the relationship between the changes of laser position and the changes of piezoelectric buzzer displacement is ΔP= ΔL/2.

3.6 Design of Z Scanner Body

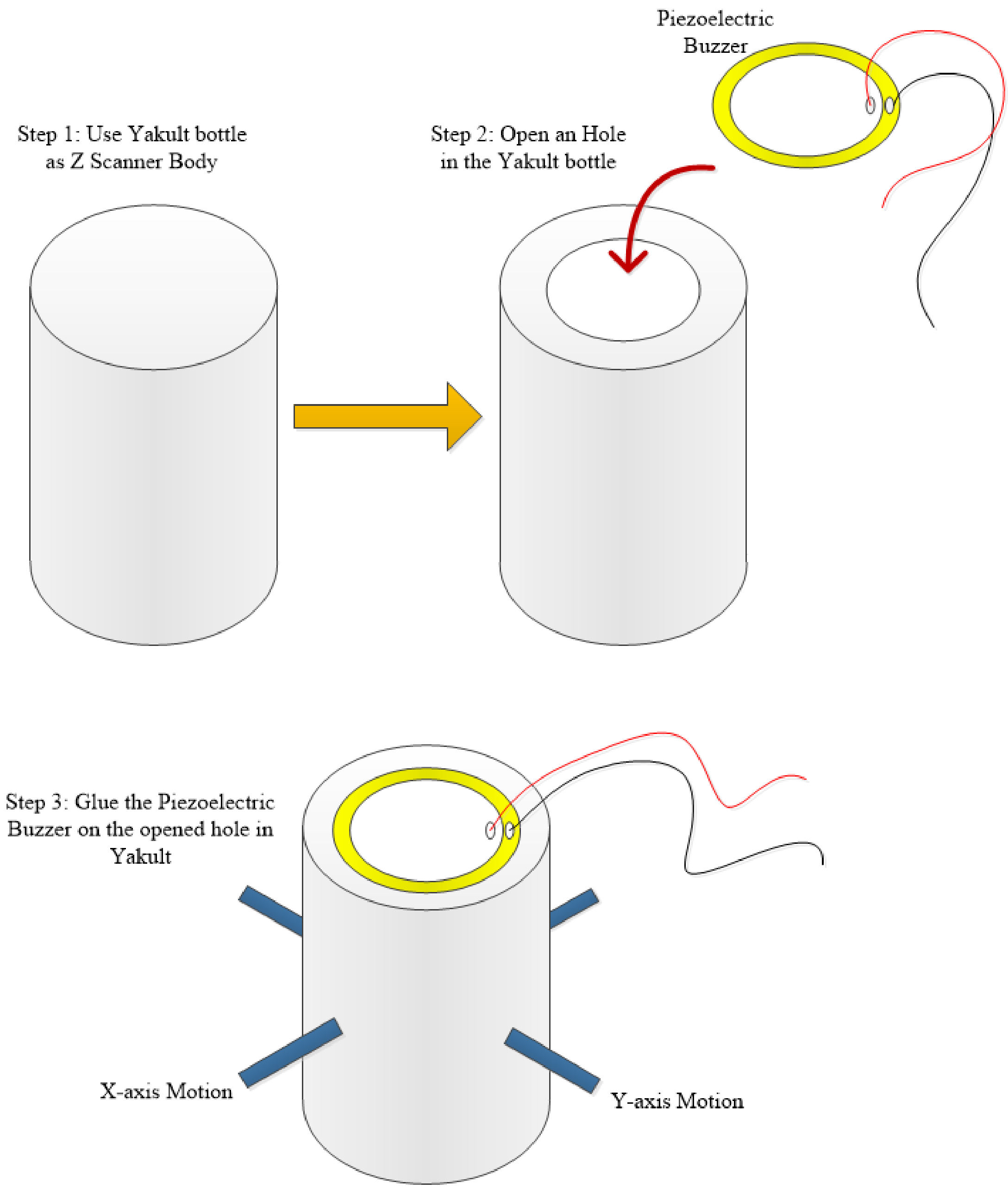


Figure 3.8: Z motion Hardware Design

I use the yakult bottle as Z scanner body. First is to open a hole on the yakult bottle to prevent any object blocking the extending or contracting in piezoelectric buzzer, the glued part only at the corner of piezoelectric buzzer, then the middle part will used to set up the sample holder. Nevertheless, this also designed for combination with XY-axis motion. The step 3 shows how the XY-axis motion to perform and the piezoelectric buzzer on top will perform Z-axis motion control.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Chosen Position in Piezoelectric Buzzer for Z motion

Based on the chapter 3 methodology section 3.4, all the experiments were tested by same distance and same height from laser position to piezoelectric buzzer. 20V of voltage was conducted through this experiment. Below was the summarized result for the position front and back combination.

Table 3.1: Tested Position Combination in Piezoelectric Buzzer

Position Combination	***Review (Laser position)***
A-E	Move in vertically
B-E	Move in diagonally
C-E	Vertically but not much changes
D-E	Move in diagonally
A-F	Vertically with largest changes
B-F	Move in diagonally
C-F	Move in vertically
D-F	Move in diagonally

Throughout this experiment, the position combination shows the biggest changes via voltage supply was A-F. This mean that the opposite of voltage supplied position in piezoelectric buzzer will give the most extend and contract. Therefore, this combination position will be used for setting up the sample holder.

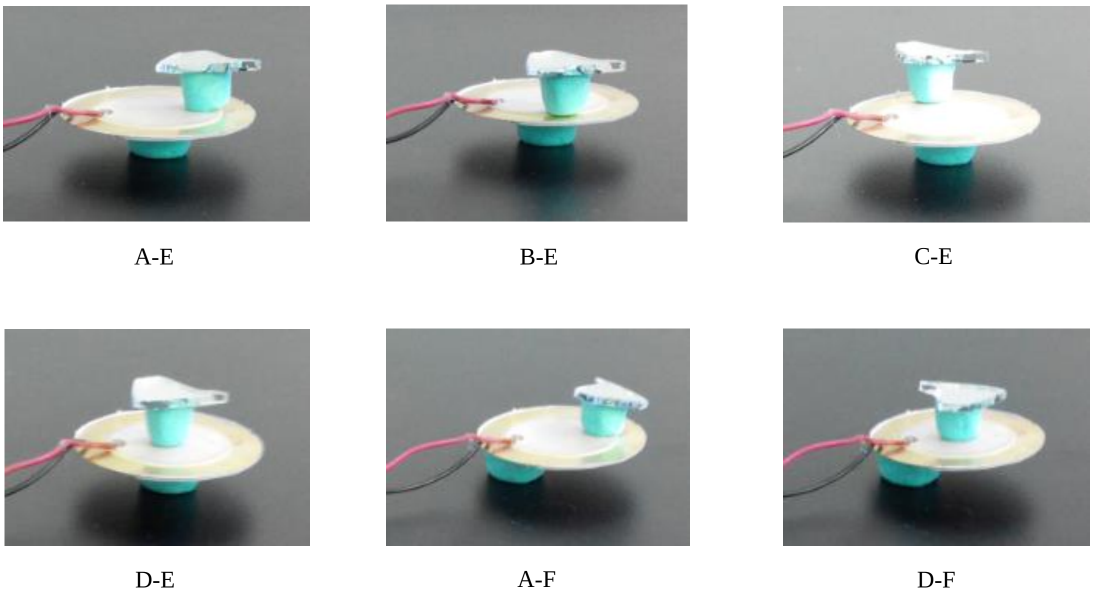


Figure 4.1: Tested Piezoelectric Buzzer Position

4.2 Improvement of Piezoelectric Buzzer Displacement Changes and Voltage Required

4.2.1 Four Stack of Piezoelectric Buzzer

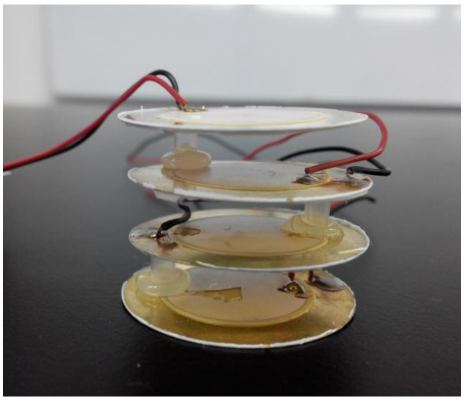


Figure 4.2: Four Stack of Piezoelectric Buzzer

Using only 1 piezoelectric buzzer was not enough to see much changes in Z motion. Hence, an idea was used to stack up more piezoelectric buzzer to test for the displacement changes. Figure 4.2 shows how I stack the four piezoelectric buzzer by using the A-F combination from table 4.1.

The obtained result from four stack piezoelectric buzzer does not improve much differences in displacement changes. When the voltage was increasing, the laser position will go up. When the laser position up to a certain level, further increase in voltage will caused the laser position fluctuate at that particular point. Even though I have tested the piezoelectric buzzer one by one, it was still able to functioning properly while supplying same voltage to all buzzer at the same time will have the fluctuation problem. Therefore, I decided to reduce the piezoelectric buzzer to two stack and test for the result again.

4.2.2 Two Stack of Piezoelectric Buzzer and Voltage Required

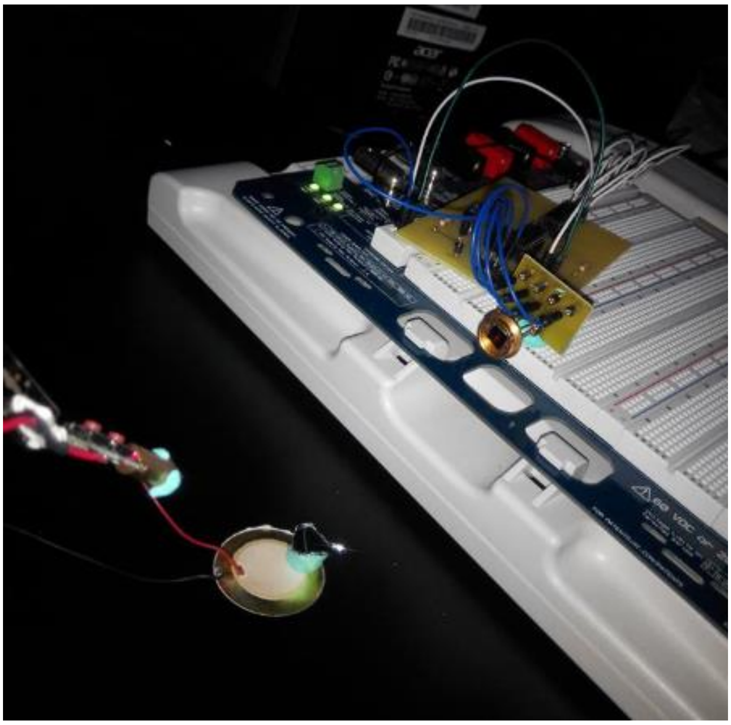


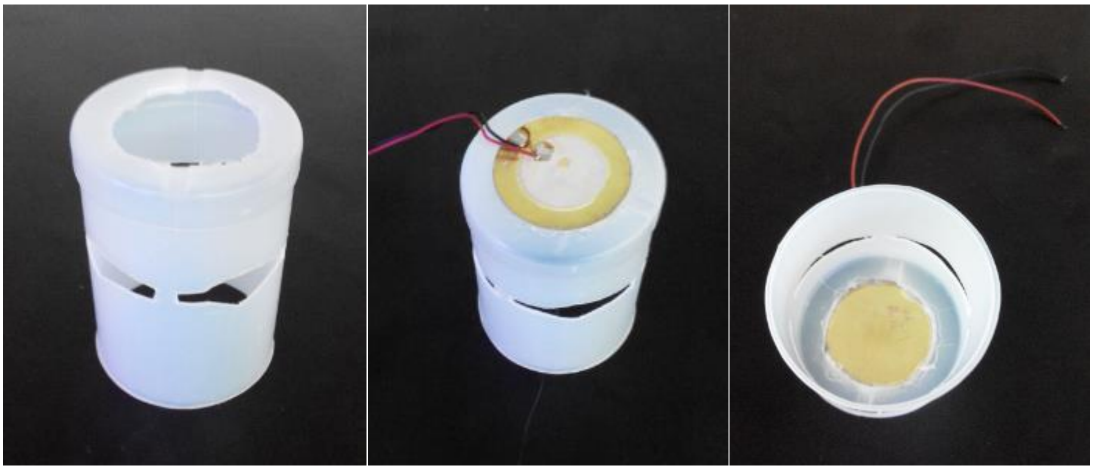
Figure 4.3: Testing Maximum Voltage Required for Z Motion

Firstly, I used only one piezoelectric buzzer to test how much voltage required that will make the laser out from photodetector sensor. Hence, the reflected laser light almost out from the photodetector sensor with only one piezoelectric buzzer. Then I used to stack two piezoelectric buzzer together and the laser light will reach the edge of sensor part within 10V.

Nevertheless, two stack of piezoelectric buzzer do not have the fluctuation problem like four stack piezoelectric buzzer. 10V of voltage required in Z motion was suitable because the NI ELVIS can only supply up to $\pm$10V. Besides that, the upper limit and lower limit in my PID algorithm will be set to $\pm$10V to cap the maximum output voltage to the piezoelectric buzzer.

4.3 Scanner Body Design for Z motion

4.3.1 Scanner Body Design using Yakult Bottle



Before Assemble | After Assemble: Top View | After Assemble: Bottom View

Figure 4.4: Designed Scanner Body

After the construction, another test was conducted to see whether the piezoelectric buzzer was still able to functioning properly or damaged after gluing it to the yakult bottle. The obtained result does not extend as much as compared to the result before the piezoelectric buzzer glued to the bottle. This might due to the edge of the piezoelectric buzzer has been stick tightly to the bottle. Thus, it limiting the extend and contract of the piezoelectric buzzer.

4.3.2 Final Version of Scanner Body Design

Before Assemble:
Half body of Vitagen bottle and 2 base part of Yakult bottle

Before Assemble:
Stacked of two piezoelectric buzzer and scanner body

Figure 4.5: Before Completion of Z Motion Hardware

As mentioned from the methodology section, I used only vitagen bottle and yakult bottle to construct my Z motion hardware. The vitagen bottle has been cut into half, then hot glue gun was used to glue the yakult base part and the two stack of piezoelectric buzzer on it.

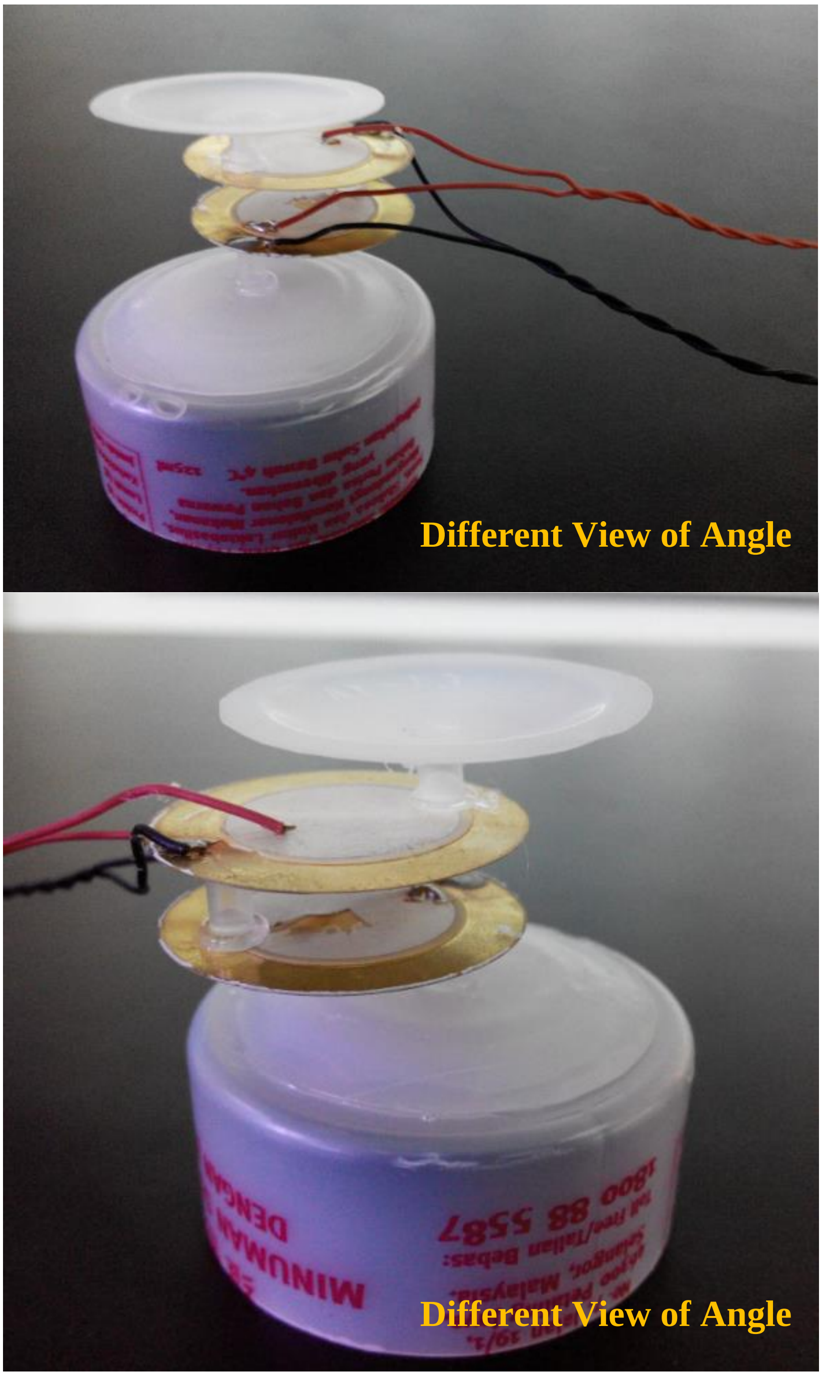


Figure 4.6: After Completion of Z Motion Hardware

The constructed Z motion hardware was based on section 4.1 (the combination of A-F) and section 4.2 (two stack of piezoelectric buzzer was enough). Therefore, the bottom of the Z motion hardware was used to combine with XY axis and also easy to dissemble from XY axis for placing the test sample.

4.4 Measured Piezoelectric Buzzer Displacement Changes via Voltage

This experiment shows how we measure the displacement changes based on the different voltage has applied to piezoelectric buzzer. Throughout so many experiment on finding the position surface of piezoelectric buzzer that will give the biggest extend, finally we discovered that the opposite of the voltage supplied side will do so. Thus, we fix the height and distance from the paper to piezoelectric buzzer as 100cm in order to achieve 45 ºof reflected angle.

Moreover, not all the piezoelectric buzzer will have the same characteristic. This is because the piezoelectric buzzer will extend or contract when positive voltage was supplied. Therefore, I always make sure which polarity of the piezoelectric buzzer will extend then only solder the two wire together.

Figure 4.7: The Progress While Measuring the Displacement Changes

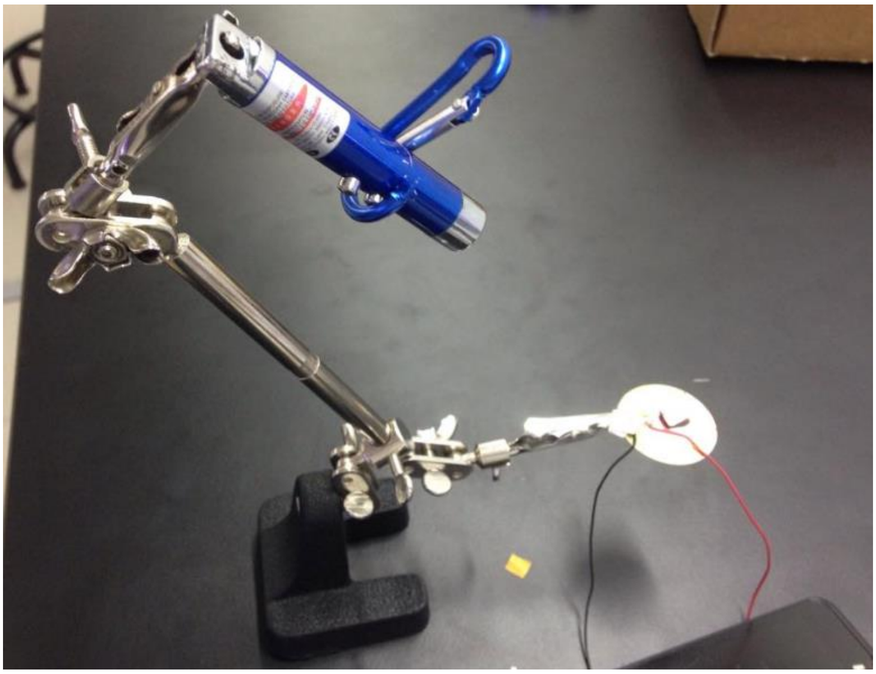


Figure 4.8: Setup of Measuring Displacement Changes of Piezoelectric Buzzer

4.4.1 Result from Piezoelectric buzzer model A

Table 4.2: Hysteresis of Piezoelectric Buzzer Model A

Voltage Applied, V	Displacement changes via increasing voltage, mm	Displacement changes via decreasing voltage, mm
-20	-4.3	-4.3
-16	-3.5	-3.3
-12	-2.8	-2.5
-8	-2	-1.8
-4	-1.3	-1.0
0	-0.5	0.5
4	0.8	1.5
8	1.5	2.3
12	2.5	3.0
16	3.5	3.8
20	4.5	4.5

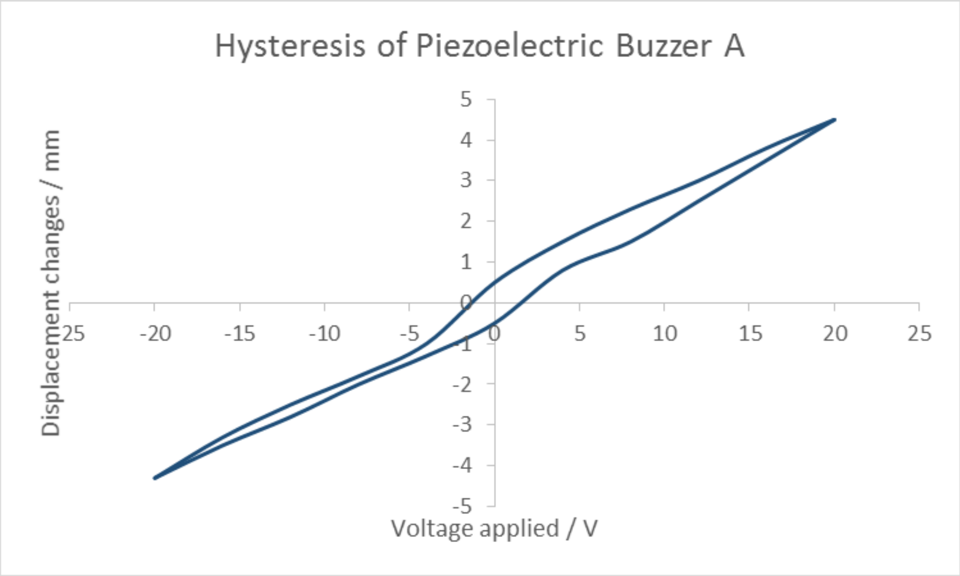


Figure 4.9: Hysteresis of Piezoelectric Buzzer Model A

4.4.2 Result from Piezoelectric buzzer model B

Table 5.3: Hysteresis of Piezoelectric Buzzer Model B

Voltage Applied, V	Displacement changes via increasing voltage, mm	Displacement changes via decreasing voltage, mm
-20	-5.5	-5.5
-16	-4.8	-4.5
-12	-3.8	-3.5
-8	-3.0	-2.3
-4	-2.3	-1.0
0	-1.3	0.5
4	0.8	1.8
8	1.8	2.5
12	2.5	3.5
16	3.8	4.3
20	5.0	5.0

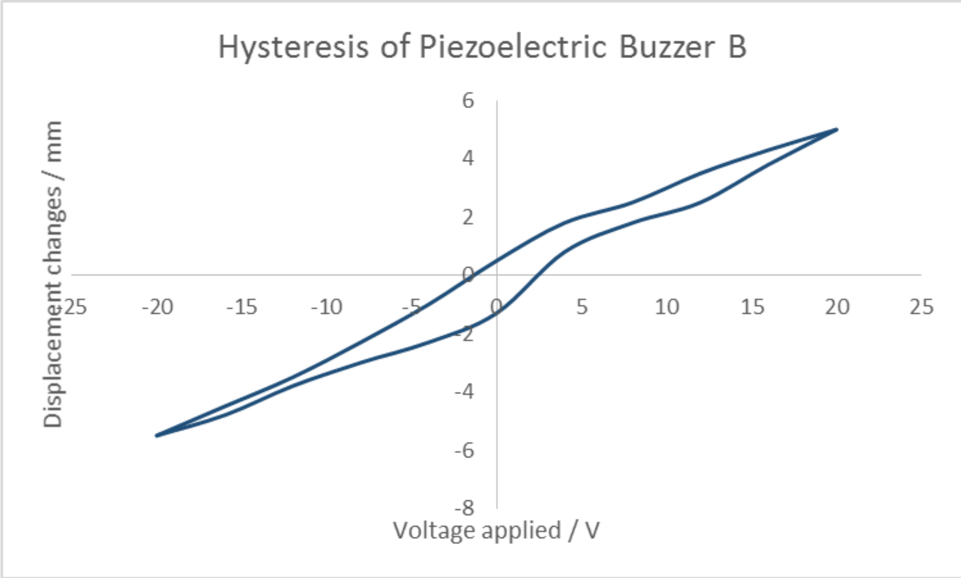


Figure 4.10: Hysteresis of Piezoelectric Buzzer Model B

Comparing both the hysteresis graph on piezoelectric buzzer A and B, the forward path and backward path of the displacement changes were different. This show that the hysteresis do occur in the piezoelectric buzzer. Besides that, the graph does not look like a normal hysteresis as shown in figure 4.11, this is because piezoelectric buzzer haven't reach the saturation point of the displacement changes and the recorded result only half way starting from the starting point. Even though the DC power supply already supplied to maximum voltage which was 30V, the piezoelectric buzzer still able to further extend at this level.

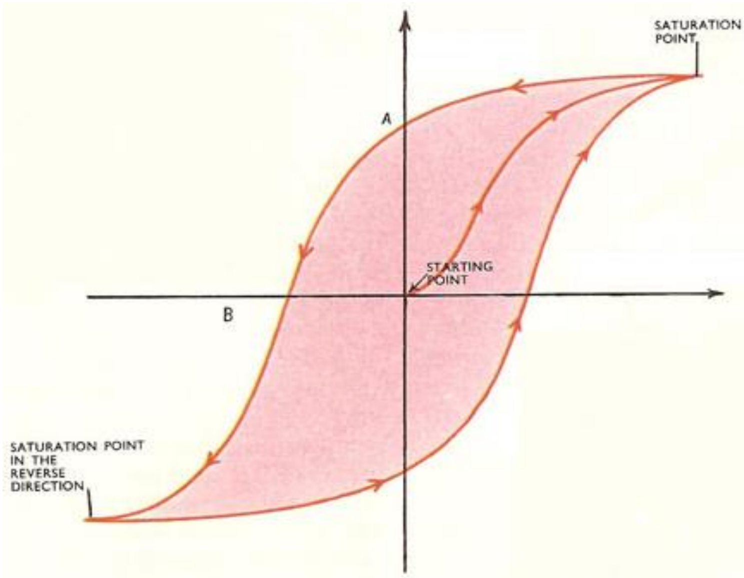


Figure 4.11: Sample Hysteresis Curve

4.4.3 Converting Voltage to Displacement Changes

The hysteresis curve can be consider as "S" shape curve, a formula was developed based on a S shape equation which was known as sigmoid equation. The sigmoid equation was a mathematical function that having an "S" Shape and the given formula was:

$$S(t) = \frac{1}{1+e^{-t}} \tag{4.1}$$

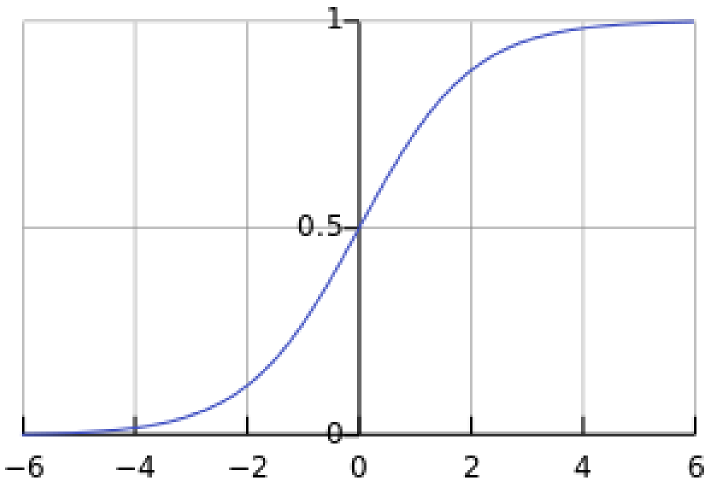


Figure 4.12: Sigmoid Shape

Based on the section 4.2, the two stack of piezoelectric buzzer was measured again with the displacement changes via $\pm$10V only. This time the measurement was taking in a very small distance which is approximately 7cm. It was too difficult to measure the laser position changes as every step of voltage changes. Thus, I recorded the displacement changes for maximum and minimum supplied voltage only. The obtained maximum and minimum displacement changes were 1mm. A plotted graph of displacement changes in piezoelectric buzzer with respect to every single step of output voltage based on the modified formula of Sigmoid equation which shown at below. The displacement changes has been converted to SI unit which was in meter, m.

$$\Delta P = \frac{0.002}{1+e^{-\frac{output}{2}}} - 0.001 \qquad (4.2)$$

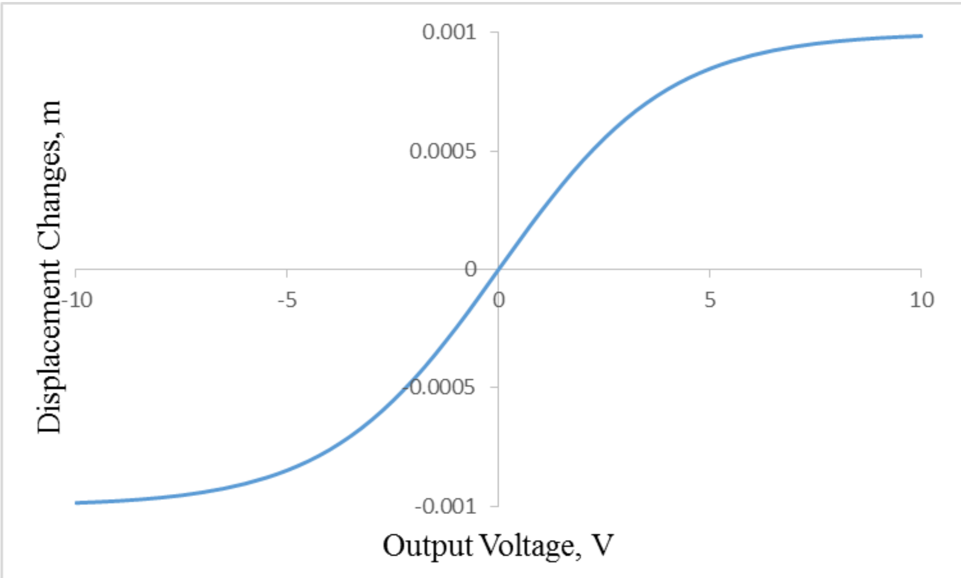


Figure 4.13: Graph of Output Voltage versus Displacement Changes

4.5 LabVIEW PID Design

4.5.1 PID Design for Classical Notation

In order to start to design the PID algorithm, we make use of the control system equation with the ratio of output to input.

$$u(t) = k_p e_p + k_i \int e_p dt + k_d \frac{de_p}{dt}$$

$$u(t) = e_p (k_p + k_i \int dt + k_d \frac{d}{dt}) \tag{4.3}$$

$u(t)$ = output $\quad\quad$ e_p = set-point – process variable

k_p, k_i, k_d = PID gain constant

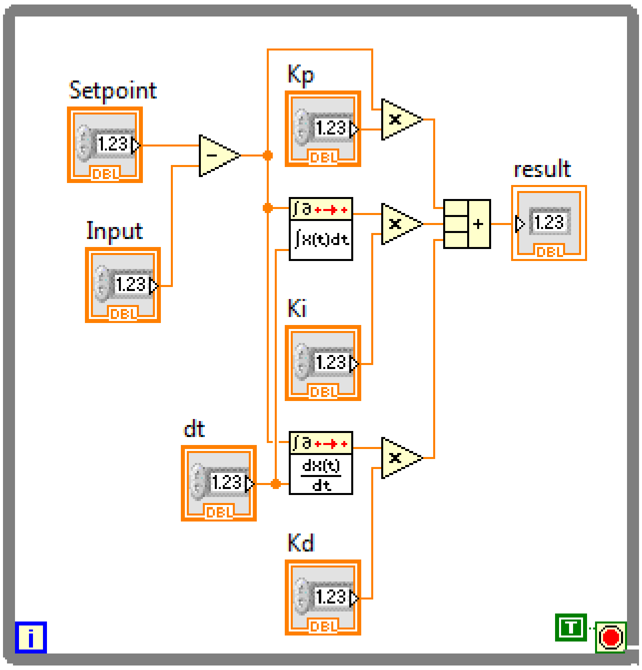


Figure 4.14: PID Classical Notation

The PID algorithm only required some numeric, controller, indicator and integral & differential PtByPt VIs. The PtByPt performs discrete differentiation and integration on the e_p at regular intervals of dt.

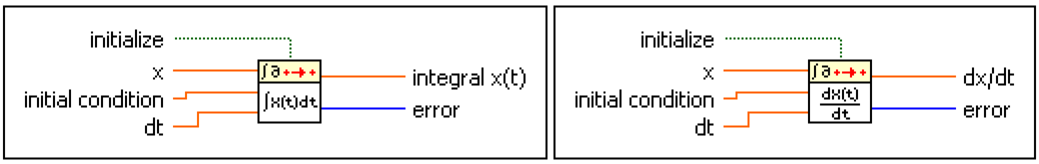


Figure 4.15: Integral & Derivative PtByPt Vis

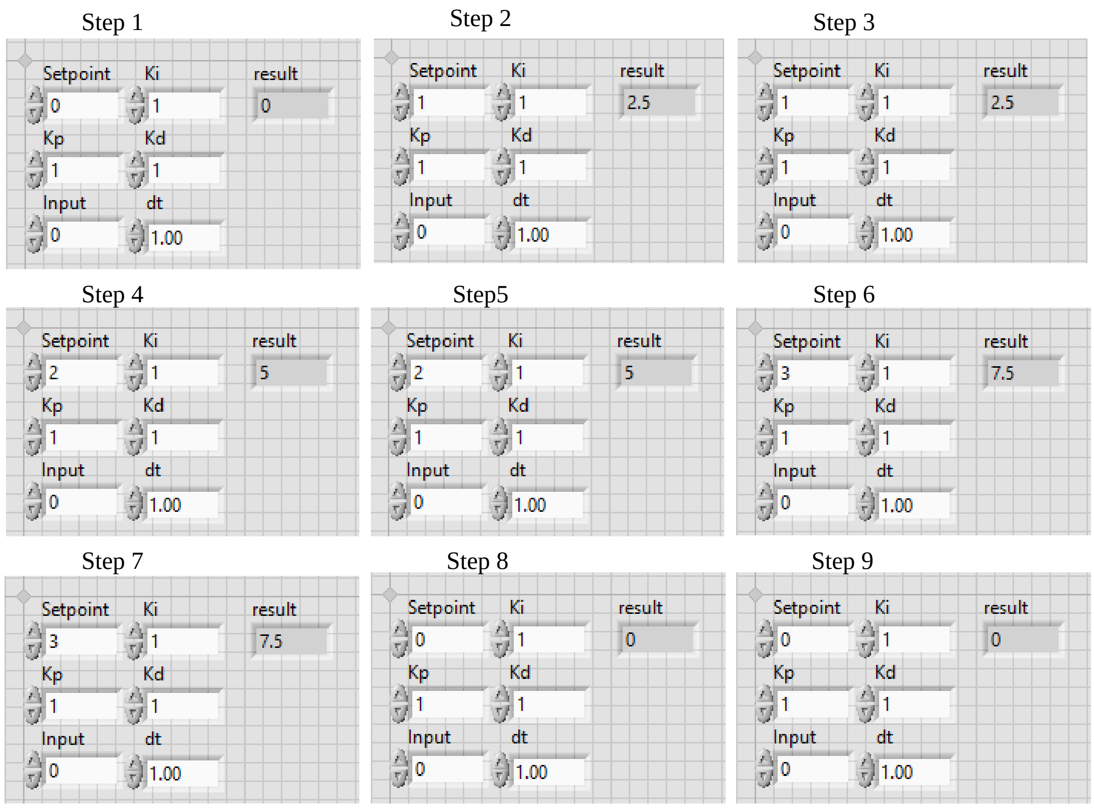


Figure 4.16: Result from PID Classical Notation

When the input and set-point were different, the PID will keep on increasing or decreasing the output based on the differences sign. But the result that I get from PID algorithm was just giving a constant output, bigger range between input and set-point will produces higher output result. In other words, the algorithm that I have implemented just like a linear equation. This is because the output increased linearly with 2.5 as the set-point increased by 1.

4.5.2 PID Design for Laplace Notation

The control equation can be transformed into laplacian equation.

$$u(t) = e_p(k_p + k_i \int dt + k_d \frac{d}{dt})$$

In laplacian conversation: $\int dt = \frac{1}{S}$ $\qquad \frac{d}{dt} = S$

$$U(s) = e_p(K_p + K_i(\frac{1}{S}) + K_d(S)) \tag{4.4}$$

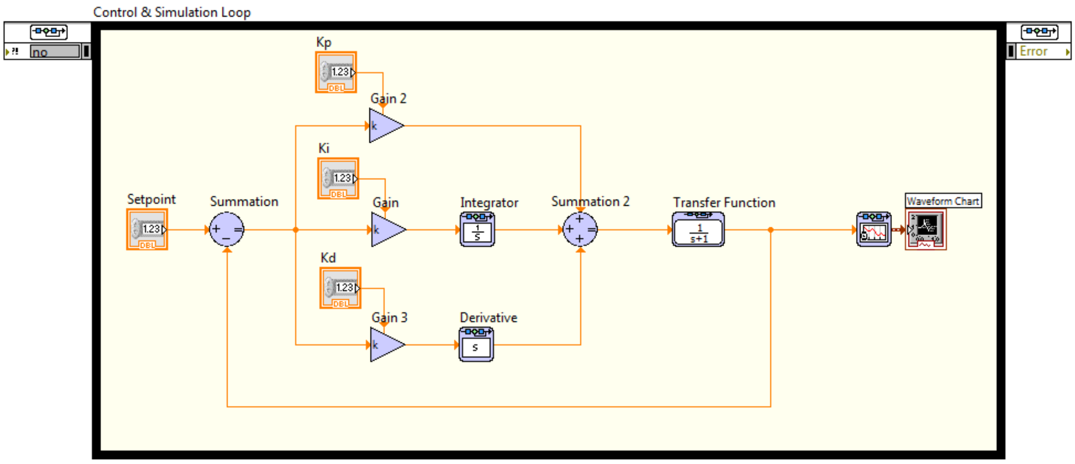


Figure 4.17: PID Laplace Notation

By comparing to the previous designed PID algorithm, this PID does not required 'while loop' whereas it used the 'control & simulation loop'. The component of summation, integrator, derivative, transfer function and waveform chart were used from the Control Design & Simulation palette. All of this component can only place inside the control & simulation loop otherwise it cannot be used. I have used a first order of transfer function to act as a plant in the overall system and the output has been feedback to the process variable. Then I can run the simulation to test for the functionality of PID.

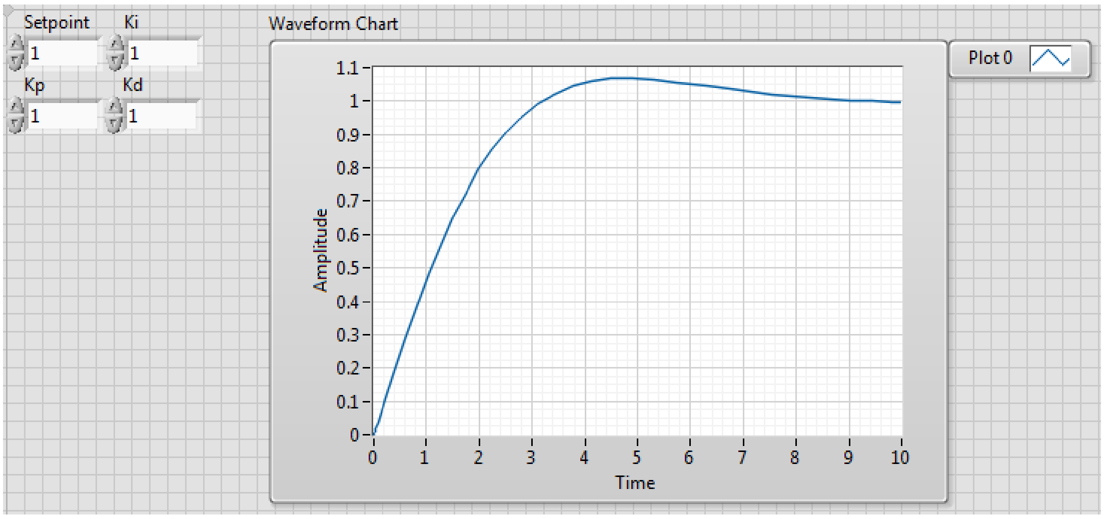


Figure 4.18: Result from PID Laplace Notation

Setting all the gain constant to 1 and set-point to 1, the output will slowly rise from 0 to 1. The rise time of this system take a bit longer time and some overshoot occur in this system. We can tune the gain constant to get a better output waveform.

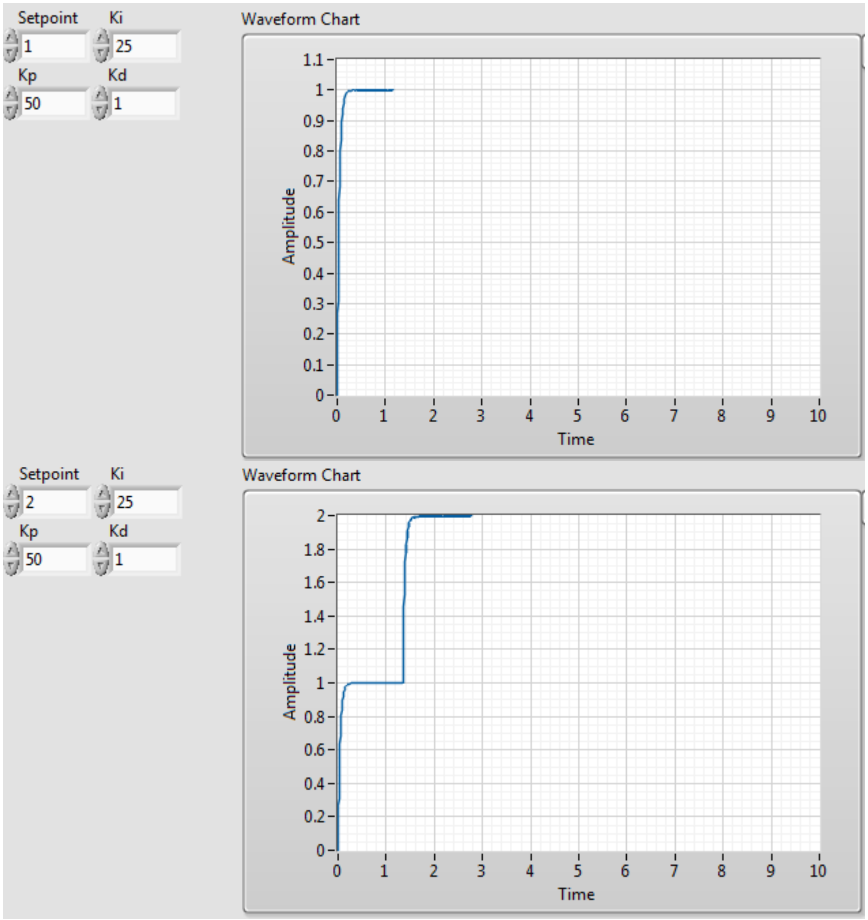


Figure 4.19: Result from PID Laplace Notation Part I

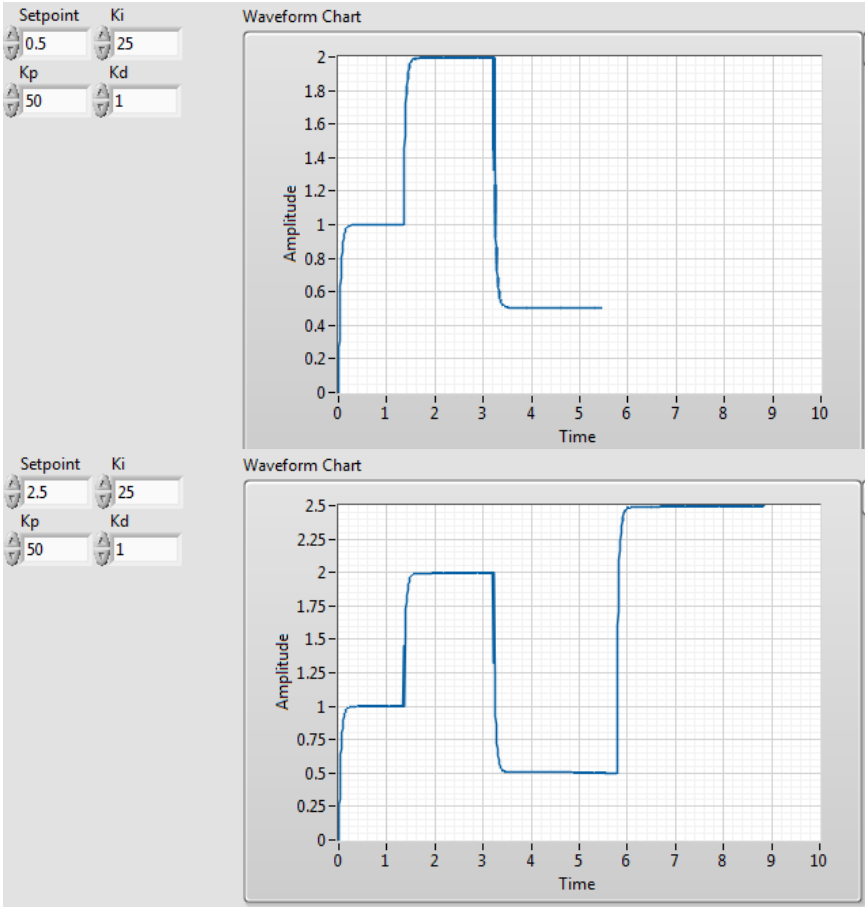


Figure 4.20: Result from PID Laplace Notation Part II

The gain constants of proportional, integrator, derivative have been set to 50, 25 and 1 according to achieve a better output. Based on the figure 4.19, the set-point was set to 1 and the output will rise steadily and remain at 1, then the set-point changed to 2 and the output will increase from 1 to 2 also. Next, the set-point also set to 0.5 and 2.5 to test for the PID algorithm and it prove that by running LabVIEW simulation it can be done perfectly.

The used value of gain constants only suitable for this transfer function, different transfer function will required different value of gain constant to achieve better result. Thus, the gain constant need to reset when using the piezoelectric buzzer. Since the LabVIEW simulation have no problem, then I create an input and output port to perform a real time simulation in NI ELVIS II.

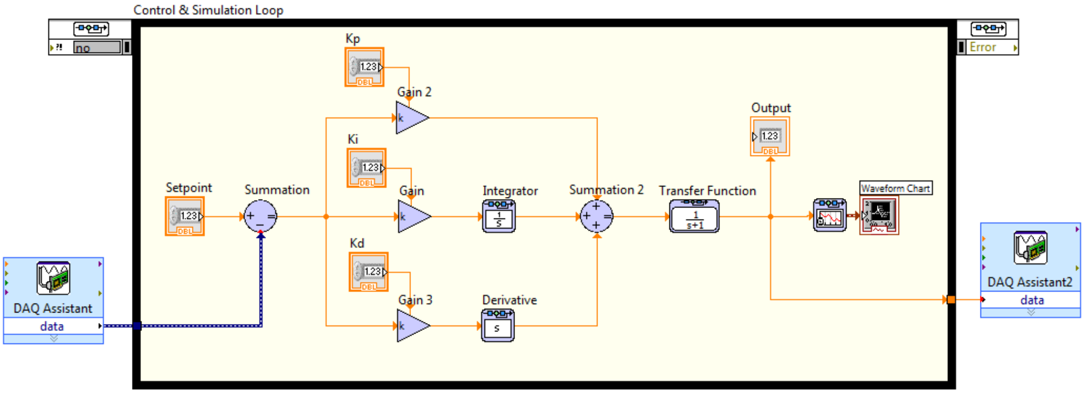


Figure 4.21: PID Laplace Notation with DAQ Input / Output

The process variable controller has been replaced by the DAQ Assistant, the NI ELVIS II need to be switched on so that the DAQ Assistant can set to act as input and output port. There were many analogue input port and two analogue output port only, so I just make use of analogue input 0, AI0 and analogue output 0, AO0 in this PID. For the NI ELVIS II, I connect the output and input in series in order to obtain a closed loop controller just like the previous simulation. Unfortunately the result does not goes well due to the output from transfer function was not able to reach the input AI0. The waveform chart shown in below was correct because when the process variable remained in 0, the PID will keep on increasing the output until the process variable matched to the set-point.

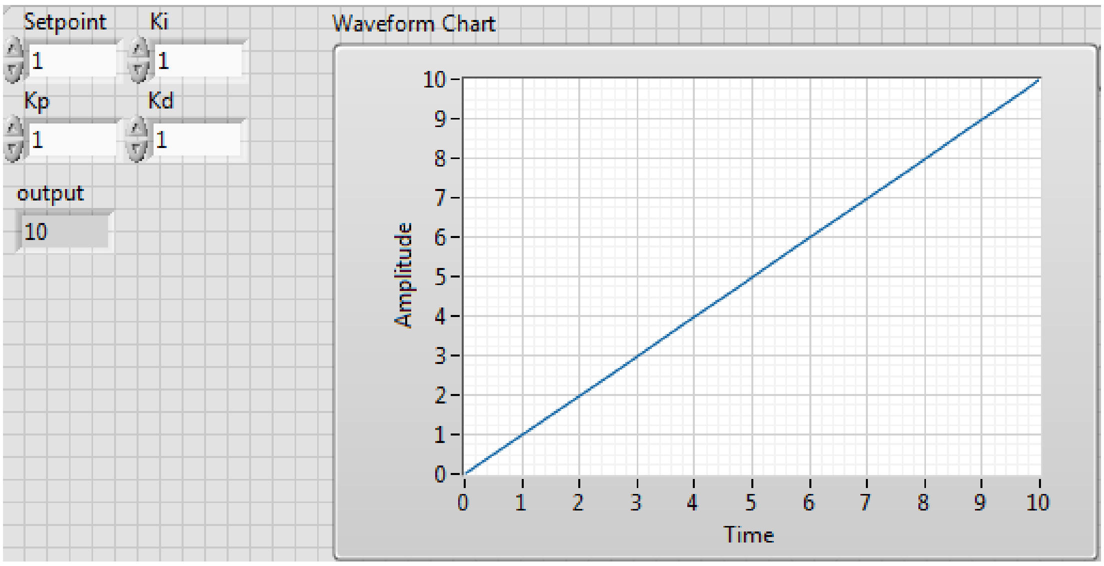


Figure 4.22: Result from PID Laplace Notation with NI

4.5.3 PID Design Using Simple Numeric

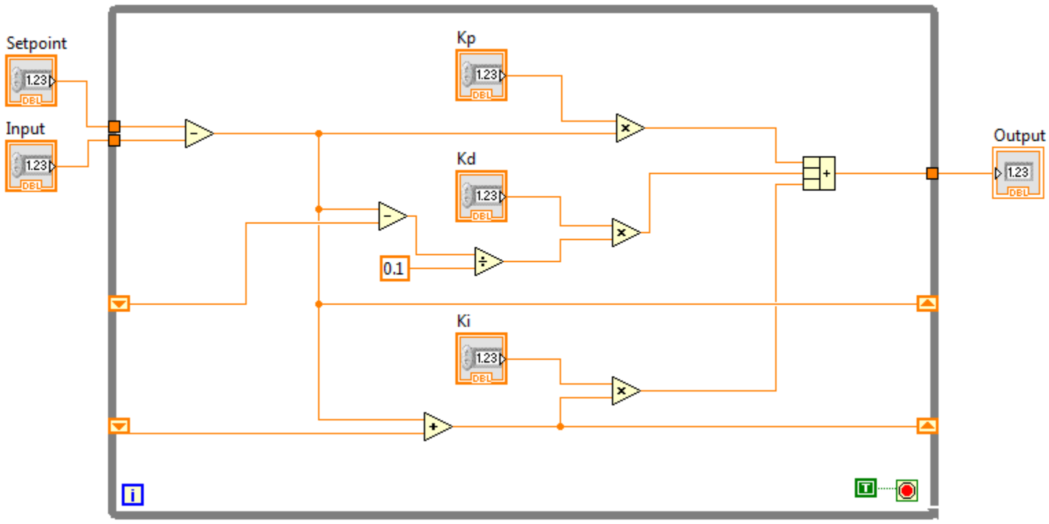


Figure 4.23: PID with Simple Numeric

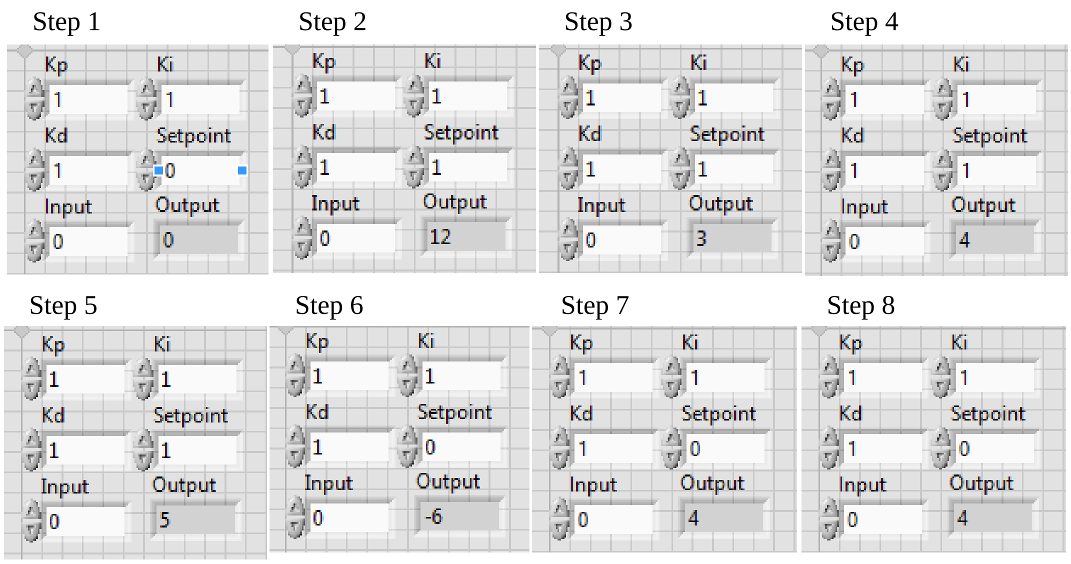


Figure 4.24: Result from PID with Simple Numeric

Initially I set all the gain constant to 1, when the set-point was different to input value, the output will start increasing. In step 1, the set-point and input were set to 0, when the set-point was change to 1, an error was detected and PID will give some output. But this PID does not increase steadily whereas it increased to 12 and then drop back to 3, after that it only increase steadily. When the set-point was changed back to 0, the output will drop to -6 and remained at 4 after that. This designed PID not so stable because it might fluctuate when input value keep on changing.

4.5.4 Designed PID Algorithm in digitally

This was the final version for my designed PID algorithm that shows how the internal working principle of PID in digitally.

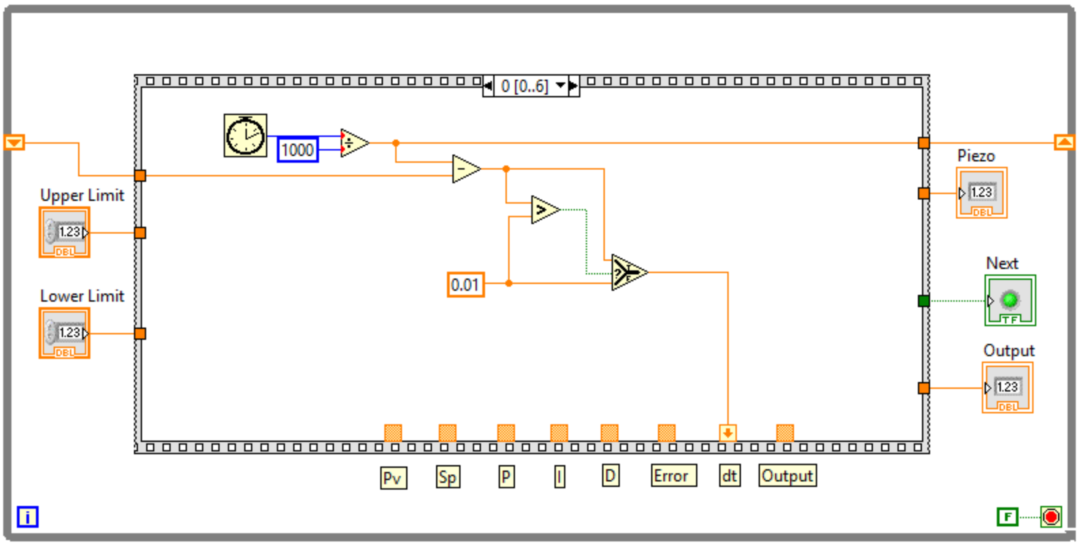


Figure 4.25: PID of dt

The dt was the time difference between the n-1 instance and the nth instance. The tick count was used to calculate the elapsed time. By using the tick count only, it will increase the output slowly as the system run. Therefore, the result from the tick count has go through a shift register to obtain the n-1 instance, then using a numeric of subtract to take the differences of current tick count value and the previous tick count value to get the time difference, dt. In order not to let the dt too small, a comparison of select was used if the dt was smaller than 0.01, it will choose to use 0.01 of dt in this PID system.

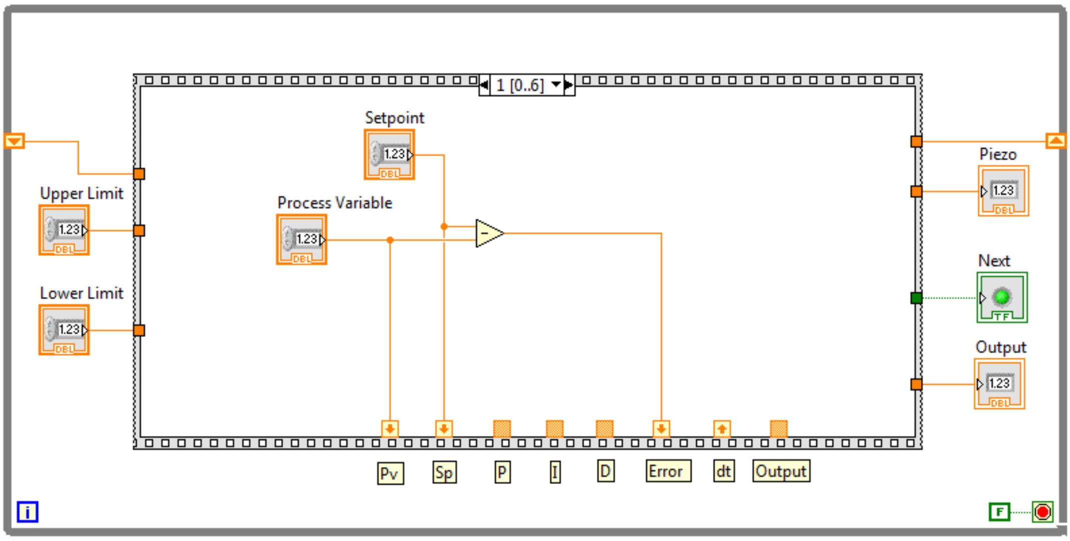


Figure 4.26: PID of Error Value

The error value was the differences between the set-point and process variable at that particular time. The laser position in the center of photodetector will provide a voltage signal and this signal was set to the set-point controller.

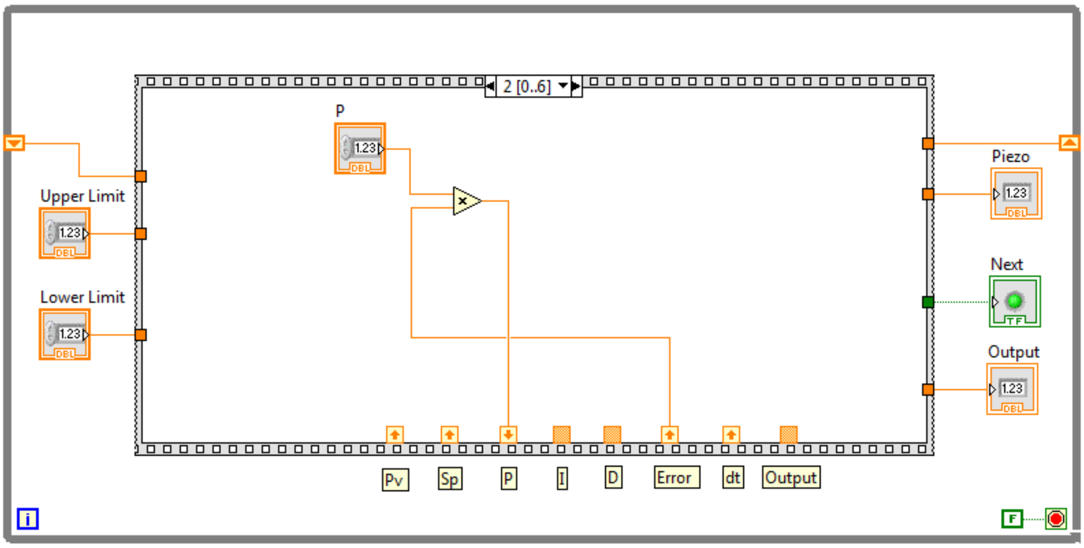


Figure 4.27: PID of Proportional Gain

The purpose of proportional in PID was to increase the rise time of the result. Bigger range of error value that multiplied with a constant proportional gain value will give higher output of P.

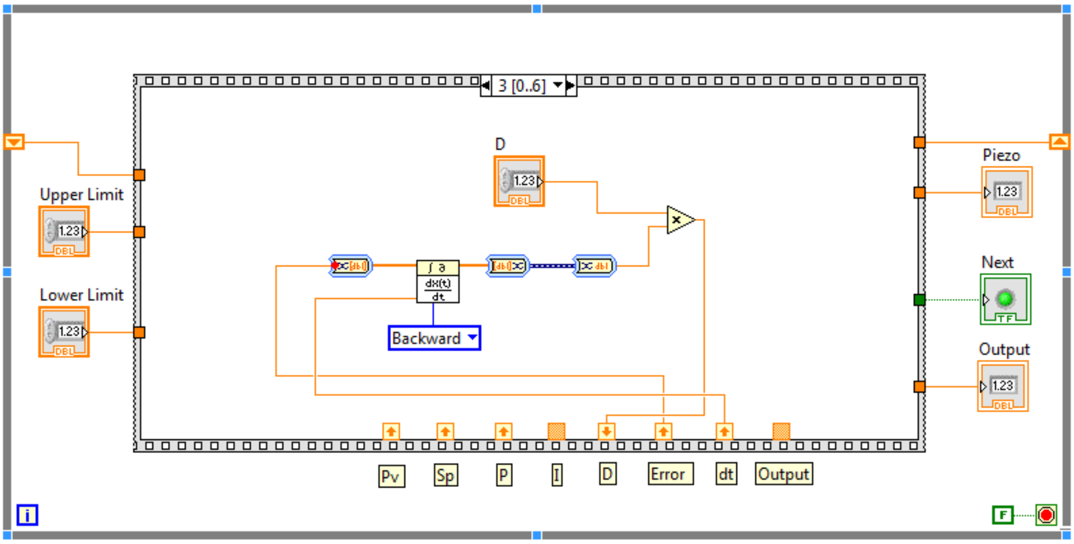


Figure 4.28: PID of Derivative Gain

The derivative serves the purpose of reducing the overshoot of the system. In other words, it will slow down the output when the output approaches to the setpoint value. I used the derivative x(t) VI to calculate the derivative system. The input and output of the derivative x(t) VI was 1D array wire, then a conversation from dynamic data and conversation to dynamic data were required to convert the wire data type to the desired type of input in the derivative x(t) VI.

The derivative x(t) VI consists of 4 different method which were 2nd order central, 4th order central, Forward and Backward. The following equation illustrate the method used.

$$2^{nd} \text{ order central: } y_i = \frac{1}{2dt}(x_{i+1} - x_{i-1})$$

$$4^{th} \text{ order central: } y_i = \frac{1}{12dt}(-x_{i+2} + 8x_{i+1} - 8x_{i-1} + x_{i-2})$$

$$\text{Forward: } y_i = \frac{1}{dt}(x_{i+1} - x_i) \quad \text{Backward: } y_i = \frac{1}{dt}(x_i - x_{i-1})$$

In this case, Backward method was used due to the nth and n-1 instances of error value. Then the output from the derivative was multiplied by a derivative gain constant.

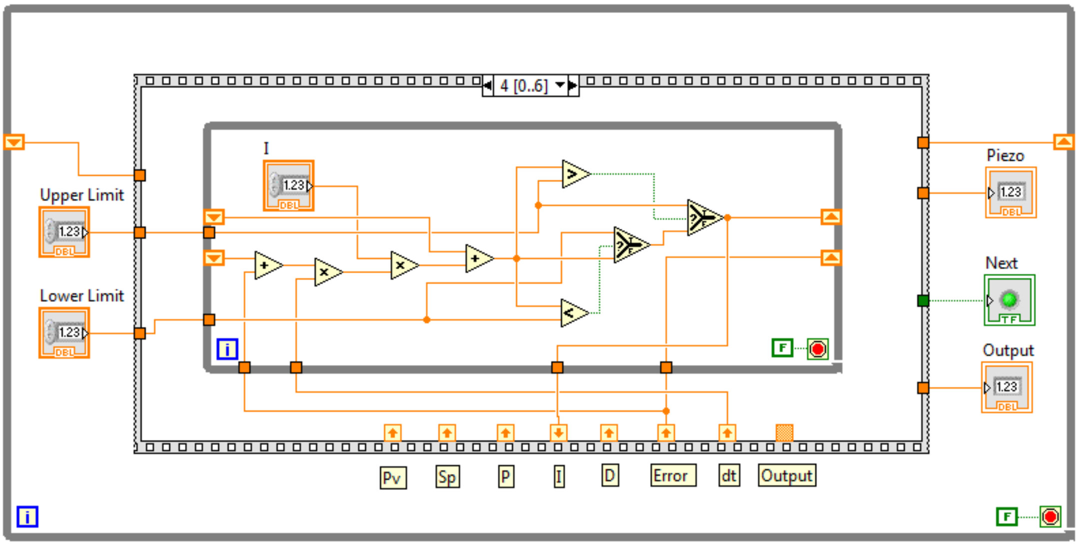


Figure 4.29: PID of Integral Gain

The integral was there to eliminate the steady state error. In this integral algorithm, I only used numeric and comparison to perform the output of integral. Thus, a numeric of add was used to add the error value and previous error value, then multiply to the dt and constant integral gain. The comparison of greater than, smaller than and select act as a comparator in order to make sure the output integral to stay within the upper limit and lower limit.

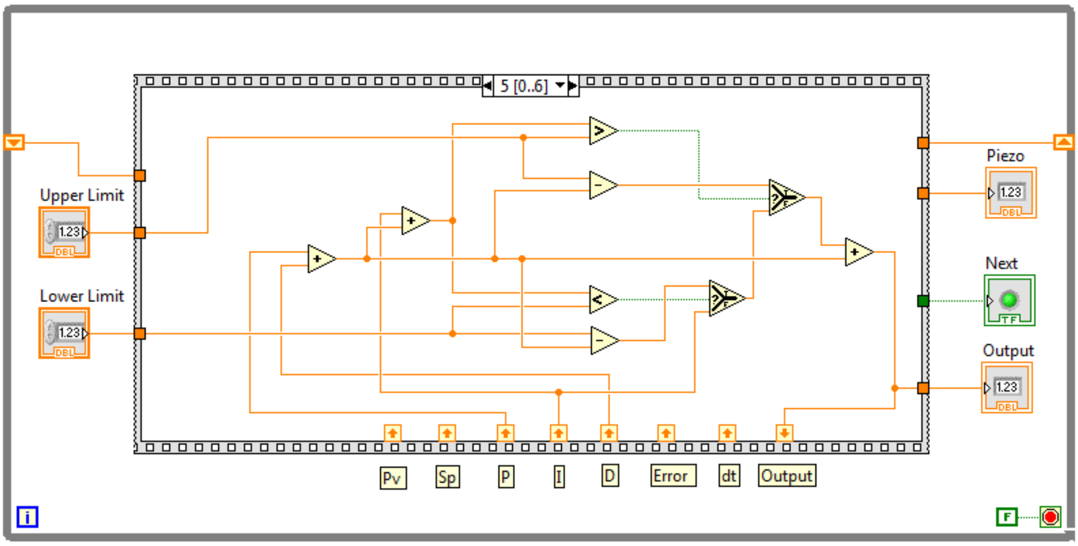


Figure 4.30: Output of PID

Here come to the final output of the PID, basically it just add up three of the output P, I, D respectively. Another comparator was used to make sure the output value falls within the upper limit and lower limit.

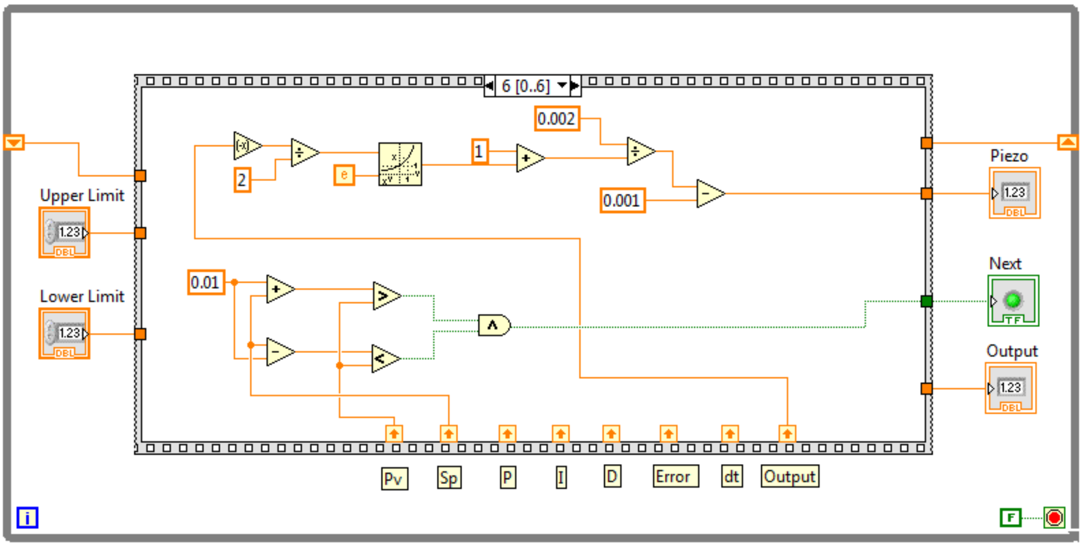


Figure 4.31: Conversation of Displacement Changes in Piezoelectric Buzzer

This was the last algorithm that I have wrote in my LabVIEW. The upper part algorithm was based on the equation in below, this has been proven in the section 4.4.3. The lower part algorithm shows a comparator between set-point and process variable. When the Process variable falls within ± 0.01 of set-point, this mean that the output of PID already stabled. Therefore, a Boolean logical 1 will send to the XY motion system to inform them to execute next instruction.

$$\Delta P = \frac{0.002}{1 + e^{-\frac{output}{2}}} - 0.001 \tag{4.5}$$

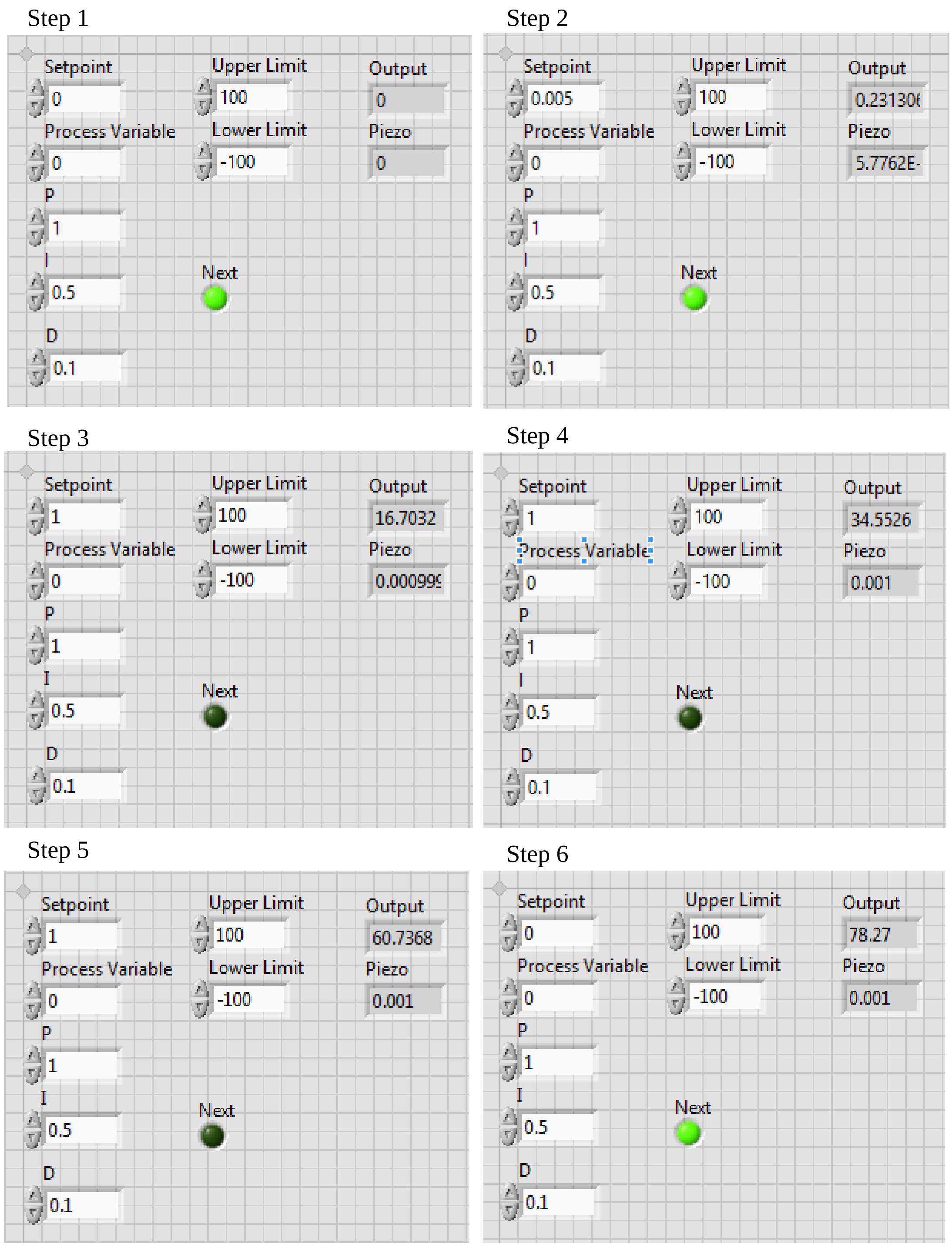


Figure 4.32: Result from PID

When the process variable was within $\pm$0.01 of set-point, the 'next' Boolean indicator will lighten up. If the differences between set-point and process variable was larger, the PID will give more output to the system. When the set-point was equal to the process variable, the output will remain in constant, but the output have some overshoot due to instant change of value in set-point from 1 to 0.

Table 6.4: Summarized of All PID Result

Designed PID Output	Set-point > Process Variable		Set-point = Process Variable
	Starting	After	
PID Classical	Increase	No increase	Zero
PID Laplace	Increase	Continue Increase	Remained at previous output
PID Simple Numeric	Increase then will decrease	Increase steadily	Decrease then increase and remain at that value
PID final version	increase	Increase steadily	Remained at previous output

4.6 Combined Software & Hardware

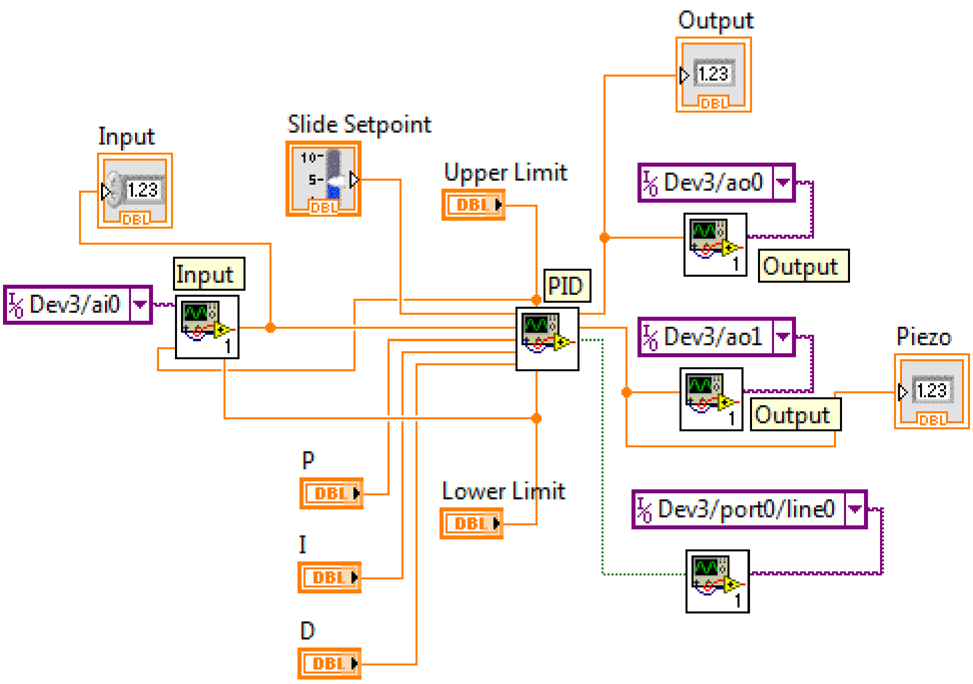


Figure 4.33: PID LabVIEW Z Motion Control

This PID LabVIEW sub VI was used from the PID algorithm in section 4.5.4. Then the input was come from the photodetector which is to the process variable part. There will be three output coming out from the PID which were output voltage to control the plant (piezoelectric buzzer), output voltage that converted into displacement changes of piezoelectric buzzer and boolean output that send logical 1 to tell XY motion to execute next step. Furthermore, the input and output port can be set manually by which port in the NI ELVIS II wanted to use. The rest of the controller such as P, I, D, Upper limit and Lower limit were set by myself in LabVIEW to achieve a better response time in PID.

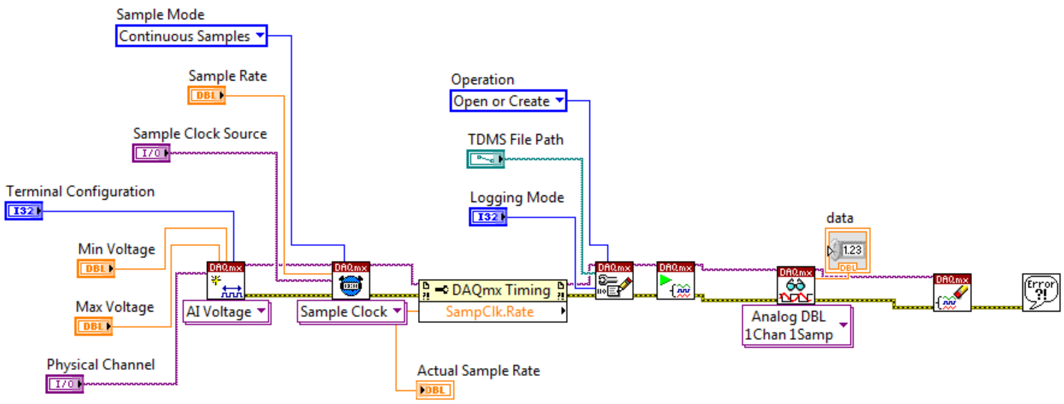


Figure 4.34: PID Analogue Input Port Algorithm

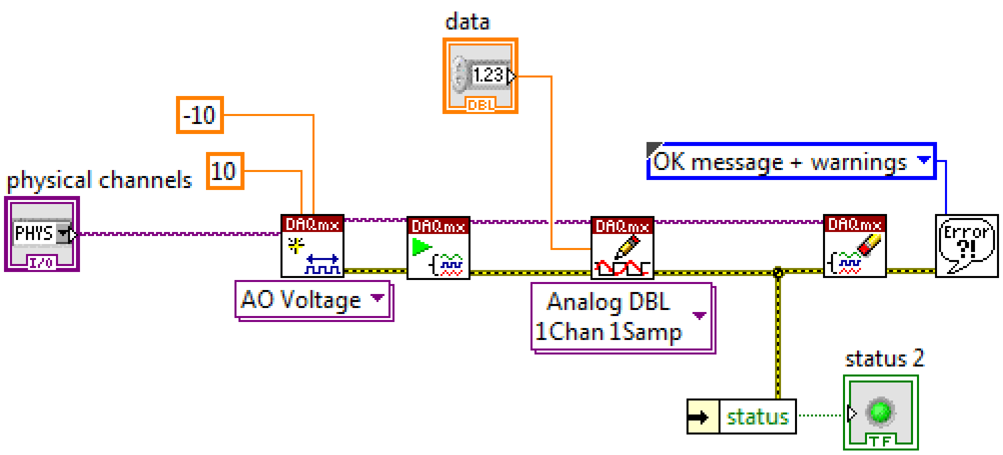


Figure 4.35: PID Analogue Output Port Algorithm

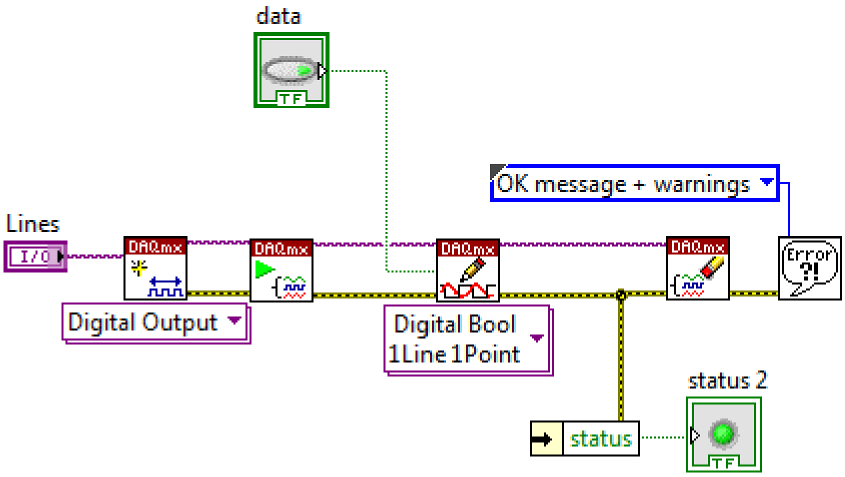


Figure 4.36: PID Digital Output Port Algorithm

From figure 4.34 to figure 4.36, this is another LabVIEW algorithm for converting the voltage signal either in 1D array, 2D array or some other. For my PID algorithm, all of the wire connection was used 1D array. Hence, this input/output port were convenient for my PID to receive input signal from photodetector and send signal to XY motion.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This final year project is to develop a PID algorithm for Z motion control in atomic force microscopy. The overall progress has been differentiated into two part which are hardware-based design and software-based design. Once both of the design has been completed and it will then be combined to run for a test. Although it has encountered a lot of problem, using trial error approach may solved the problem or new idea for another way to do it.

Throughout this final year project, I have a better understanding on PID application. PID is very useful to control the stabilization and the speed of a system (piezoelectric buzzer). There are many way to design a PID either using laplacian equation or basic equation. For my PID algorithm, I using only numeric terms to represent how the PID works in digitally. The result has been proven that the PID can be functional correctly.

Furthermore, the item that I used to control Z motion is piezoelectric buzzer. The challenging part is how we calculate the displacement changes in piezoelectric buzzer via voltage. This is because the extend and contract of piezoelectric only move in few mille meter, this is also true for the application of atomic force microscopy which is used to measure the scale in nano or micro meter only. Finally, applying trigonometry equation and I manage to obtain the relationship between displacement changes and laser position changes which is about $\Delta P = \Delta L/2$.

Lastly, LabVIEW is the most important in my final year project. My PID algorithm was designed in the LabVIEW and all of the user interfaces was ease to use and understandable. Thus, LabVIEW is a very good programming for user to do system designing. Moreover, LabVIEW also have another feature which is able to communicate with the NI ELVIS. We can make use of this features to communicate with our hardware (piezoelectric buzzer), and also sending and receiving data from one and another to perform PID control.

5.2 Recommendations

The type of piezoelectric buzzer that I used in this final year project is not so preferable because it is too small and easily being damaged although it is low cost material. Therefore, using a bigger size of piezoelectric buzzer is more suitable and the displacement changes is more sensitive to voltage.

Instead of using piezoelectric buzzer, there have other type of item that can move in XYZ direction very precisely such as piezoelectric linear motor 6 N. This kind of motor able to move within scale of nano meter because the motor used a very small gear in it. Besides that, I also recommend to try out using balloon to control XYZ direction, when air is slowly flow into the balloon, it will then be slowly to expand and pushed the direction in the scanner.

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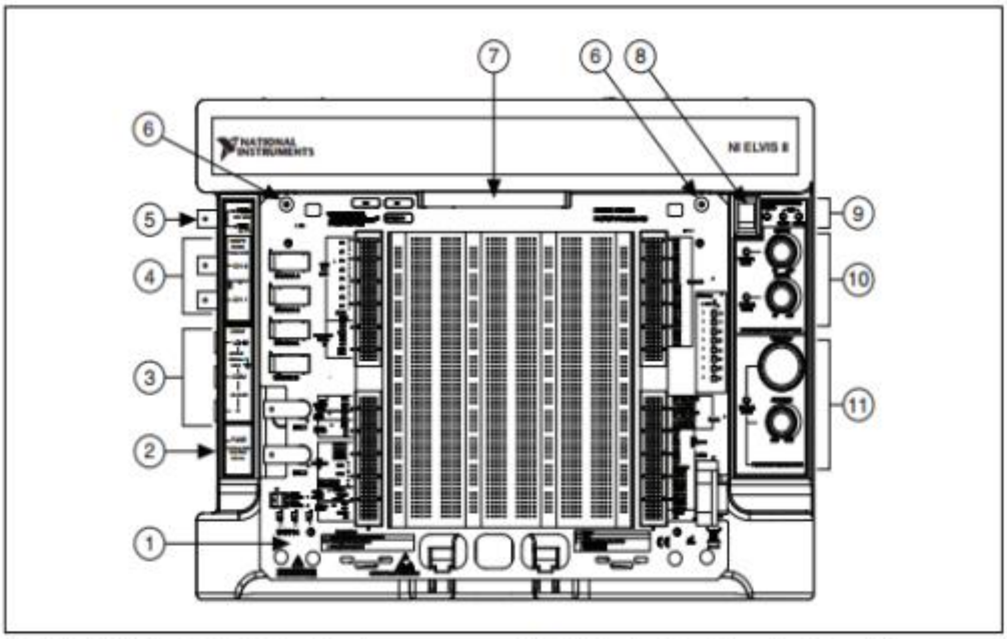
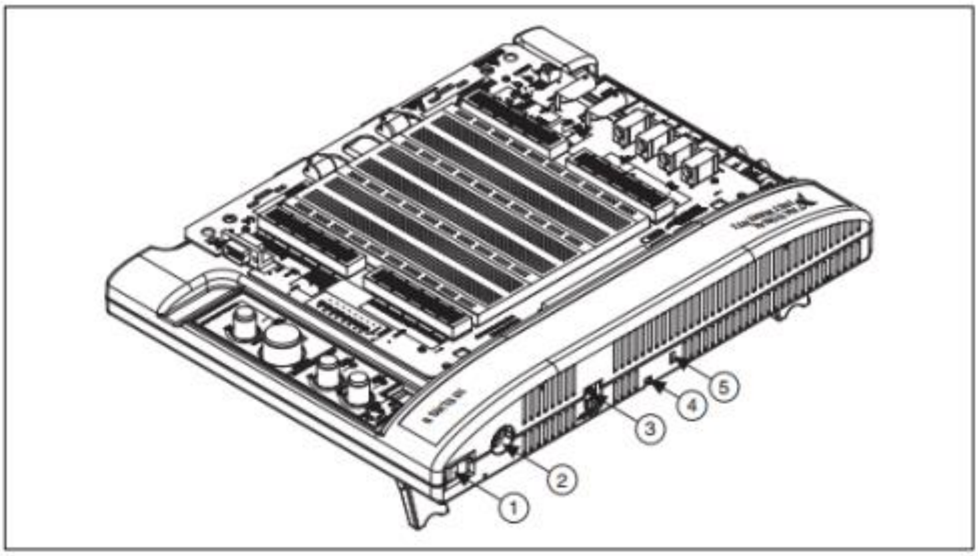
APPENDICES

APPENDIX A: NI -ELVIS II data sheet



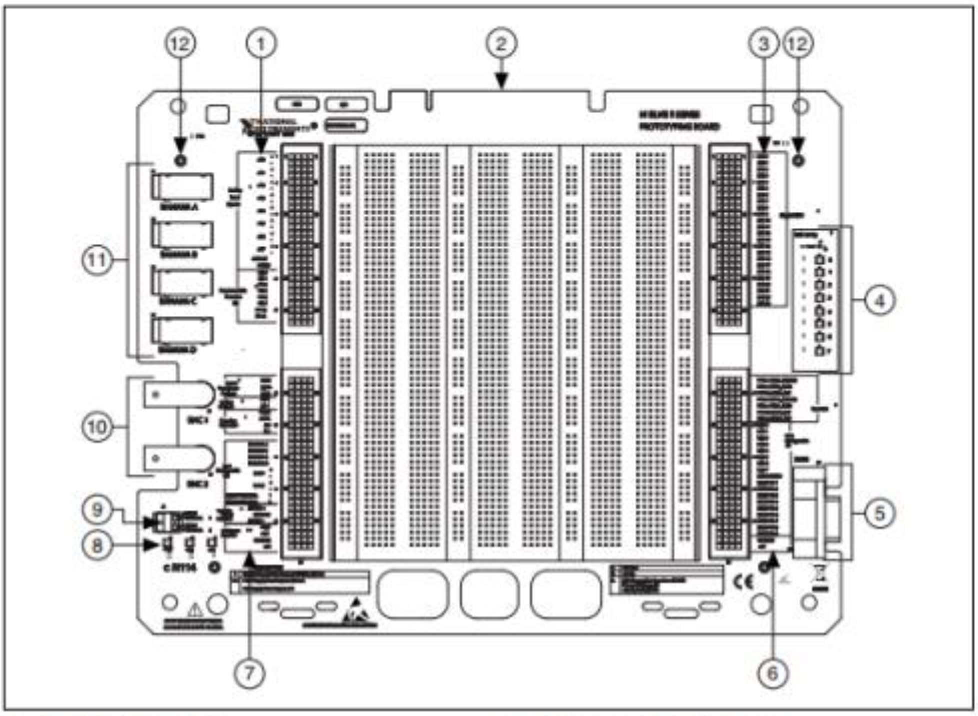
1	NI ELVIS II Series Prototyping Board	6	Prototyping Board Mounting Screw Holes
2	DMM Fuse	7	Prototyping Board Connector
3	DMM Connectors	8	Prototyping Board Power Switch
4	Oscilloscope Connectors	9	Status LEDs
5	Function Generator Output/Digital Trigger Input Connector	10	Variable Power Supplies Manual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

Top View of NI ELVIS II Workstation with Prototyping Board



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

Rear View of NI ELVIS II Series System



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

NI ELVIS II Series Prototyping Board

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.

Signal Description