PID CONTROL OF ELECTRONIC THROTTLE
FOR DRIVE-BY-WIRE APPLICATION

By

NADIA BINTI ROSLI

DISSERTATION

Submitted to the Electrical & Electronics Engineering Programme

in Partial Fulfillment of the Requirements

for the Degree

Bachelor of Engineering (Hons)

(Electrical & Electronics Engineering)

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

PID CONTROL OF ELECTRONIC THROTTLE
FOR DRIVE-BY-WIRE APPLICATION

by

Nadia Binti Rosli

A project dissertation submitted to the
Electrical & Electronics Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Approved:

____
Mr. Saiful Azrin Bin Mohd Zulkifli
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

December 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

____

Nadia Binti Rosli

ABSTRACT

The main purpose of this project is to research and design PID controls for an electronic throttle at UTP's Automotive Research Centre. Electronic throttle for Drive-By-Wire applications is an advanced technology that replaces mechanical function of an engine by sophisticated fast responding electronic. The PID control on electronic throttle will improve the efficiency of the air intake into the engine by controlling the blade opening of the electronic throttle. With Ziegler-Nichols tuning method, this controller will modulate the opening of throttle blade to the desired opening. This project will require knowledge in every aspect of PID control from software applied and hardware needed to realize the objective of this project.

ACKNOWLEDGEMENT

First and foremost, thanks to Allah S.W.T for giving me the strength and blessing to finish the dissertation report and some of the project work.

I would like to take this opportunity to thank my Final Year Project Supervisor; Mr. Saiful Azrin Bin Mohd Zulkifli for the inspiration and moral support. The practical learning has been the best lesson I've ever learnt during the period of learning in Universiti Teknologi PETRONAS.

Thanks a lot to my beloved friend Siti Sarah Marjunit for providing the best transport, WKW 2482.

This acknowledgement also goes to my family whose loving support, able me gone through those hard times.

Last but not least, thanks to others who directly or indirectly involved.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATION

PID	-	Proportional-Integral-Derivative
DC	-	Direct Current
PWM	-	Pulse-Width-Modulation
GUI	-	Graphical User Interface
TPS	-	Throttle Position Sensor

CHAPTER 1
INTRODUCTION

1.1 Background of Study

The main purpose of this project is to research and design PID controls for an electronic throttle at UTP's Automotive Research Centre. Electronic throttle for Drive-By-Wire application is one of the major parts in engines that is widely used in the industry which eliminates the mechanical elements and substituting it with fast responding electronics. Basically, an electronic throttle is a DC motor that receives specific instruction from a controller to adjust the throttle blade opening to a certain position, resisting a spring force on the blade, friction, stiction and other disturbances. In this case, the throttle blade opening allows air flow into the main engine to combine with the fuel during combustion process. PID control with suitable Ziegler-Nichols tuning method correlated with manual tuning on the controller will improve the blade opening efficiency and optimize air intake into the engine.

1.2 Problem Statement

1.2.1 Problem Identification

The completion of this project will involve different stages of problem to be solved during the period of time provided. The following list will summarize the different stage of problems:

i. Understand and study the throttle system.
ii. Understand and study the H-bridge driver.
iii. Determination of system characteristic and deriving transfer function of the system.
iv. Implement PID control on hardware
v. Tuning the controller with Zeigler-Nichols tuning method.
vi. Enhancement of the system by varying the PID parameters.

1.2.2 Significance of the Project

The PID control on electronic throttle will improve the efficiency of the fuel injection. With suitable tuning of the PID parameters, this controller will modulate the opening of the throttle blade to the desired opening. In the future, the output from this project will be useful for engine drivability and fuel saving.

1.3 Objectives

The main objective of this project is to research and design PID controls for an electronic throttle at UTP's Automotive Research Centre. This project involves characterizing the system and determining its control block diagram, investigating the effectiveness of PID control for electronic throttle, studying controllability and stability issues of the system and finally implementing it on the hardware (H-bridge driver and controller) and performing experiments on an electronic throttle at UTP's Automotive Research Centre

1.4 Scope of study

The scope of study will be focused on PID control reliability to control the blade opening of electronic throttle. PID control behaviour will be explained and discussed further in the next chapter. The throttle system and how it functions will be studied in the early period of data gathering and information research. After that, the system characterization and transfer function determination will come in the next step. Next, the process will proceed to develop PID control on the system with LabVIEW and National Instrument PXI. On the second part of the project, PID control on the electronic throttle will be implemented through an interface card (DAQ card) to an H-bridge driver and the Bosch electronic throttle. Finally, the focus of work will concentrate on maintaining stability and the effectiveness of the PID control on the blade opening of electronic throttle.

CHAPTER 2
LITERATURE REVIEW

2.1 PID Control

2.1.1 An Overview

PID control functions to correct the error between measured process variable and desired setpoint by calculating and then outputting a corrective action that can adjust the process accordingly [6]. PID control deals with three different corrective modes which are Proportional (P), Integral (I) and Derivative (D). An investigation performed in 1989 in Japan indicated that more than 90% of the controllers used in process industries are PID controllers and advanced versions of the PID controller [9].

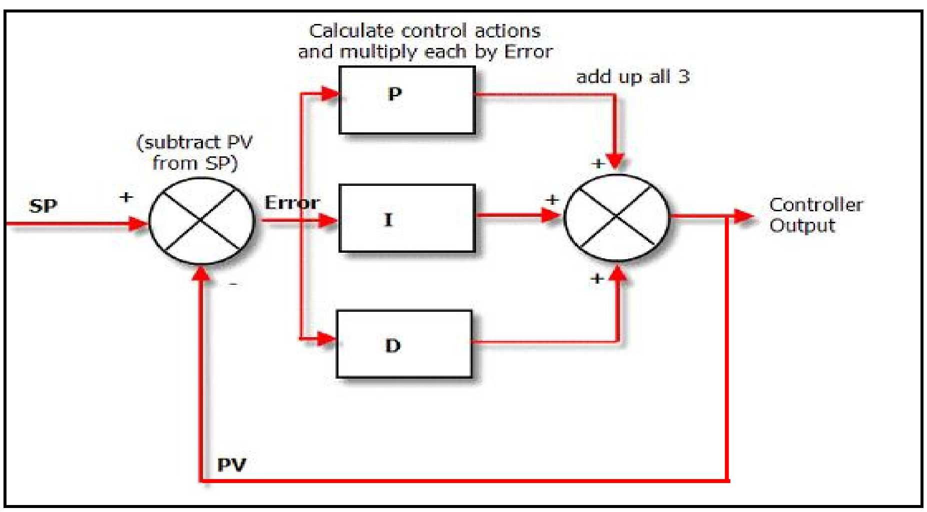

Figure 1: Basic Block Diagram of PID control.

i) Proportional Control (P)

This parameter is the immediate reaction of the current error which can be detected from the overshoot pattern. Unstable system and oscillating output might be due to a high proportional gain, K_c value while less responsive system can result from too low value of proportional gain, K_c [1]. In reality of control systems, the final value will not settle at its target value but will retain a steady-state error.

Proportional mode: $\mathbf{MV_p(t) = K_pE(t) + I_p}$

MVp(t)- manipulated variable

$\mathbf{K_p}$ - controller gain

E(t) - error

$\mathbf{I_p}$ - constant term or bias (initialization)

ii) Integral Control (I)

Integral value is proportional to magnitude and duration of error which will adjust the output to desired value or setpoint, in other words adjusting the manipulated variable until the magnitude of error is reduced to zero [4]. Integral overcomes the shortcoming of proportional control by eliminating offset without the use of large controller gain, Kc. The adjustable parameter is the integral time, $T_{I.}$ The value of T_I determines how fast the zero offset is achieved.

Integral mode: $$\mathbf{MV_I(t) = \frac{K_p}{T_I}\int_0^{\infty} E(t')dt + I_I}$$

$\mathbf{MV_I(t)}$ - manipulated variable

$\mathbf{K_p}$ - controller gain

$\mathbf{T_I}$ - integral time

E(t') - error

$\mathbf{I_I}$ - constant term or bias (initialization)

iii) Derivative Control (D)

While P and I parameters are the results of past value, derivative control is the future prediction for error correction by reducing the magnitude of overshoot by integral. D parameter is the slope overtime also known as the rate of change of controller output. The adjustable parameter is derivative time, T_d.

Derivative mode: $$\mathbf{MV_D(t) = K_p T_D \frac{dE(t)}{dt} + I_D}$$

$\mathbf{MV_d(t)}$ - manipulated variable

$\mathbf{K_p}$ - controller gain

$\mathbf{T_d}$ - integral time

$\mathbf{E(t)}$ - error

$\mathbf{I_d}$ - constant term or bias (initialization)

2.1.2 Tuning Method

i) Manual Tuning

The purpose of tuning is to adjust parameters of the controller so that the control system exhibits the desired response. This type of tuning is also known as trial and error method or fine tuning which individual parameters is tuned without the help of a systematic method. However, this type of tuning requires experienced personnel in that field or specific studies about the controller before beginning the tuning. If a systematic method may not produce the desired performance, manual tuning may become necessary to achieve the target output. Usually, manual tuning is done in the early stages of the control process to observe the behaviour of each mode and also during the tuning and testing process for the main purpose of the controller to reach the desired response.

Table 1: Relationship of PID parameters with Rise Time, Overshoot, Settling Time and Steady State Error

Parameter	Rise Time	Overshoot	Settling Time	Steady-State Error
K_p	⇩	⇧	Small Change	⇩
K_i	⇩	⇧	⇧	Eliminated
K_d	Small Change	⇩	⇩	Small Change

ii) Zeigler-Nichols Method

Ziegler-Nichols method is developed by John G. Ziegler and Nathaniel B. Nichols and a proven method that works with two types of response; step response method and frequency response method. Ziegler-Nichols step response method is based on a step response logged for analysis from step input [2]. Ziegler-Nichols frequency response method is based on using the controller connected as a proportional controller [2]. It is performed by setting the *I* and *D* gains to zero. The P gain is then increased (from zero) until it reaches the critical gain K_c, at which the output of the control loop begins to oscillate. K_c and the oscillation period P_u are used to set the P, I, and D gains depending on the type of controller used.

Table 2: Ziegler-Nichols Tuning Chart

	K_p	T_i	T_d
P	$K_c/2$	-	-
PI	$K_c/2.2$	$P_u/1.2$	-
PID	$K_c/1.7$	$P_u/2$	$P_u/8$

2.2 Electronic Throttle for Drive-By-Wire Application

A throttle controls the amount of air intake into an operating engine through the butterfly valve in the throttle for combustion purpose. Electronic throttle for Drive-By-Wire applications is an advanced technology that replaces mechanical function of a machine by sophisticated electronic control modules, sensors and actuators while the traditional throttle used to control the air intake by controlling the pedal, wired with a cable.

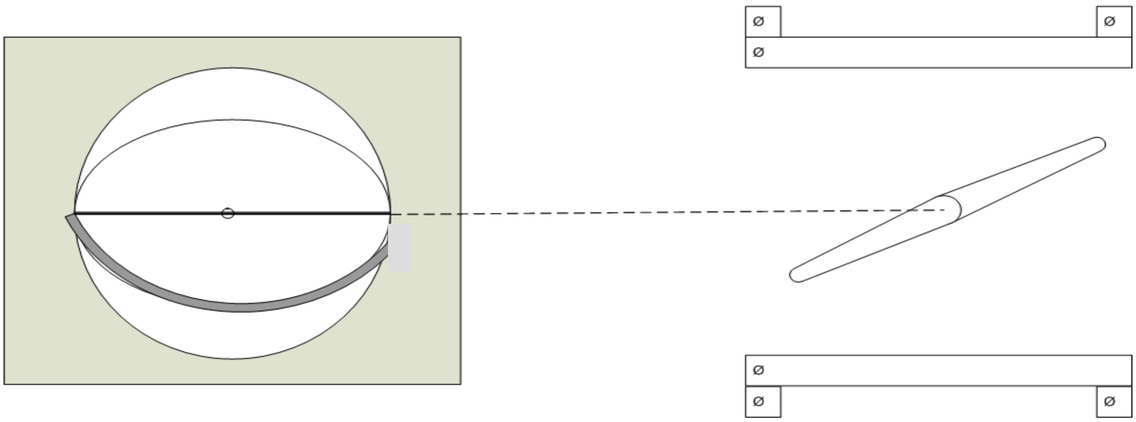

Figure 2: Front View and Side View of Throttle Butterfly Valve

For this project, we apply electronic control to adjust the throttle blade opening with some specific percentage opening since the electronic throttle has a fast response. The electronic throttle is a DC motor operated by direct current with 12V battery. The DC motor receives command from the controller to open the throttle blade to a certain position resisting a spring force, friction, stiction and other disturbances.

An H-Bridge driver allows current to flow into the motor in two different directions which will result in different movements of motor rotation; clockwise and anticlockwise. The controller signal in the form of PWM (Pulse Width Modulation) signal will be sent to the H-Bridge driver and finally produce motor power in term of voltage (V). Power from H-Bridge driver will produce current and finally produce torque to move the motor which governs the movement of the blade.

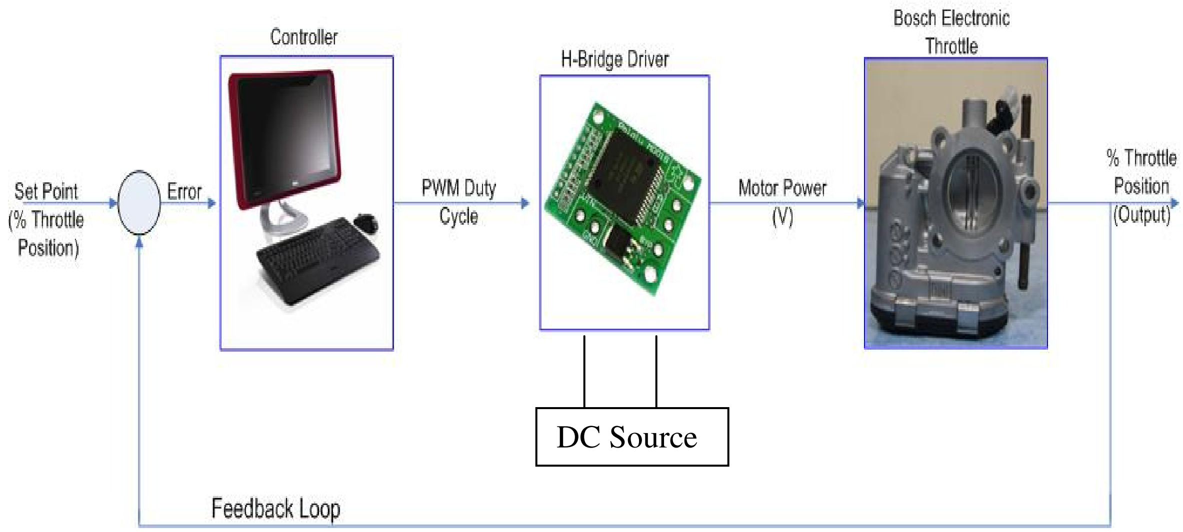

Figure 3: Simple Electronic Throttle Control System

The block diagram shows an electronic throttle control system which comprises of three main parts; controller, H-bridge driver and Bosch electronic throttle. The main components of the Bosch electronic throttle include the throttle position sensor, throttle blade and the DC motor, which is the system to be controlled. Error represents the difference between the desired blade opening input value known as set point, and actual blade opening output. This error signal will be sent to PID controller and the controller will compute both derivative and the integral of this error signal. Throttle PID controller is designed to control the overall system behaviour which provides the excitation signal for the system in terms of PWM (Pulse Width Modulation) required for electronic throttle, to the H-Bridge driver. The driver supplies the needed electrical power to the throttle DC motor. This signal will be sent to the system and the new output will be obtained. This new output will provide a new position feedback signal to the controller to find the new error signal. The controller takes this new error signal and computes its derivative and its integral again. This process will go on until the desired output achieved or the new output opening position is reached the set point given.

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

Towards the accomplishment of the project within the time frame, the steps in arriving to the final outcome are planned such as the following: *(see Appendix A: Final Year Project Gantt Chart).*

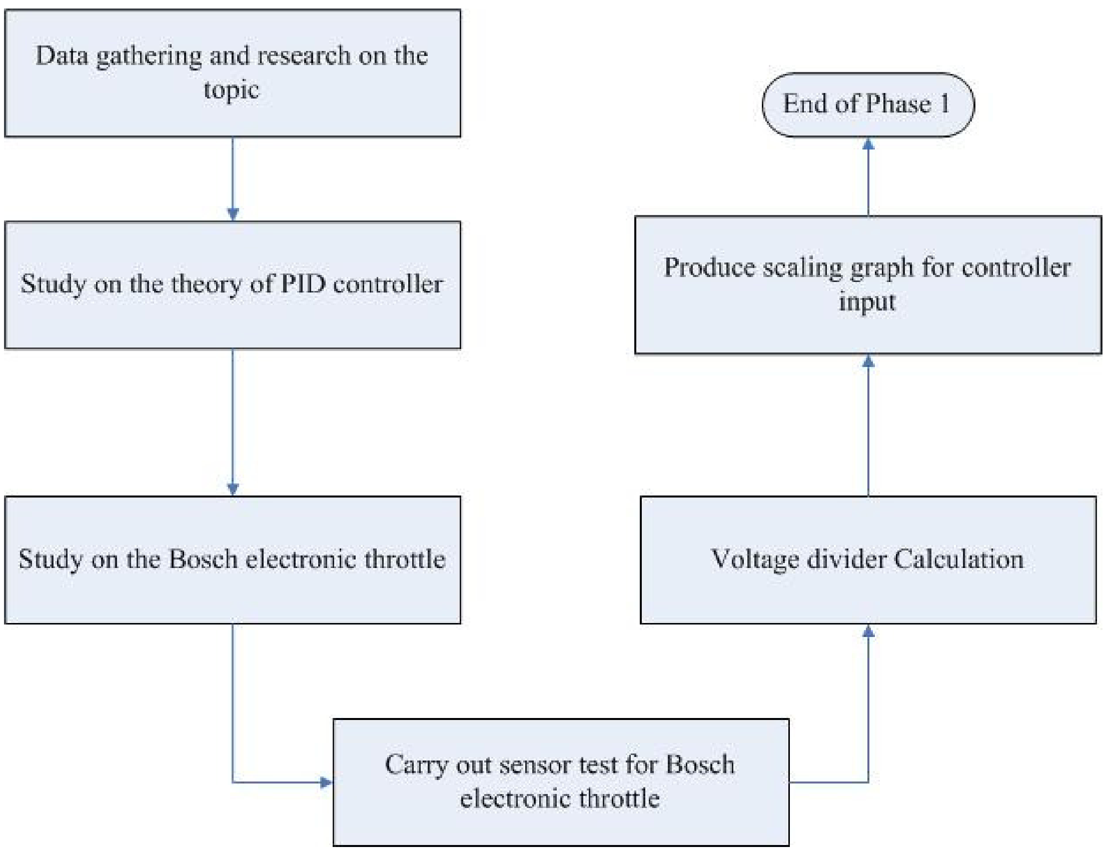

Figure 4: The Process Flow Diagram for Phase 1

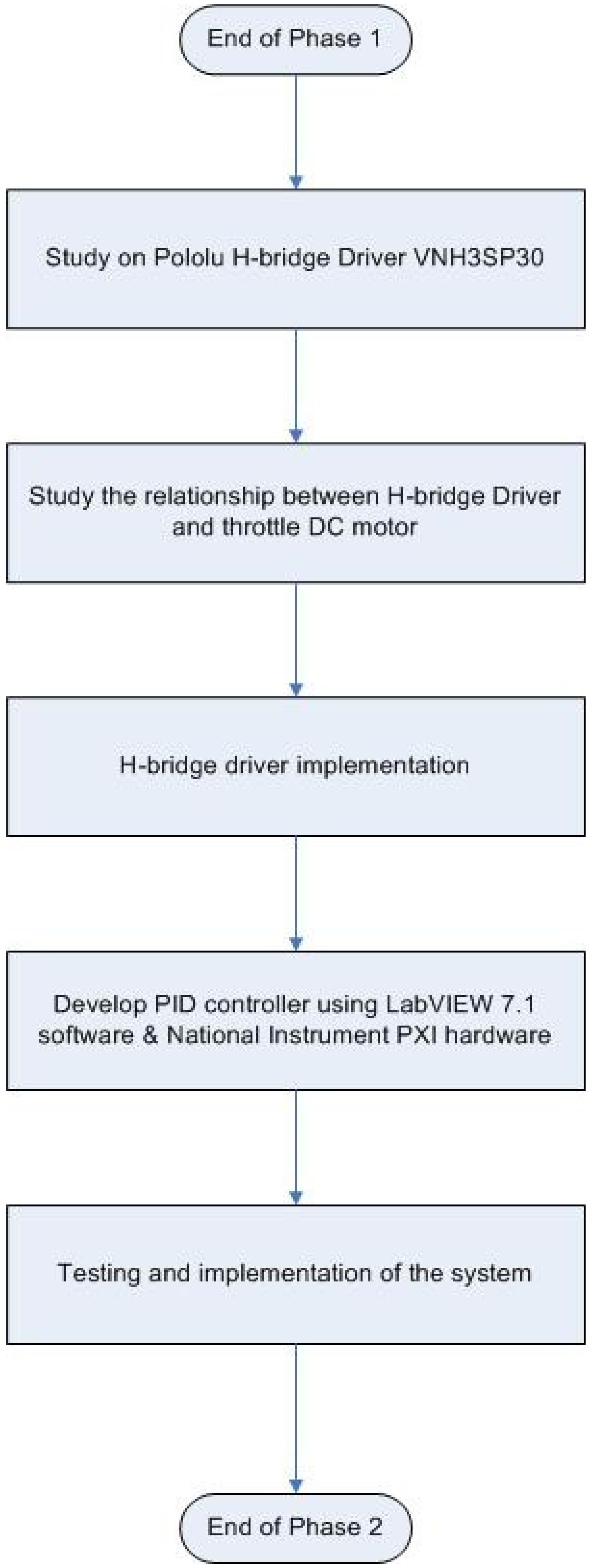

Figure 5: The Process Flow Diagram for Phase 2

3.1.1 Research and Literature Review

Initial data gathering and searching on the internet, books and journals as well as other resources were done by week four of the first semester. All the references were gathered to get a general idea in starting the project and improve the understanding about this project. Researches from those sources include findings about the previous projects involving electronic throttle and PID control. Literature review explained and visualized the theory behind the electronic throttle control system.

3.1.2 Study on the Bosch Electronic Throttle System

The project continues with studying the Bosch Electronic Throttle system by analyzing the system from the controller to instrumentation driver and finally the throttle system itself. *(Refer Figure 6: Electronic Throttle Control)* The data will then be analyzed and formulated in mathematical expression which is the transfer function.

Bosch electronic throttle body consists of a DC motor, throttle blade and potentiometer connected to the blade or also known as Throttle Position Sensor (TPS). The DC motor will receive electrical power from the H-Bridge driver and move the throttle blade resisting the spring force and other disturbances. The throttle blade works with potentiometer (TPS) that changing its resistance value due to different degree of blade opening. The initial problem is to establish precisely the characteristic of the throttle blade position. The Technical Customer Information document from Bosch stated that voltage division ratio is linearly proportional to the blade opening. *(Refer Appendix B: Voltage Division Ratio versus % Blade Opening).* An experiment is carried out to verify the relationship between the blade opening and potentiometer resistance. The data obtained will be useful for transfer function determination and initial input for LabVIEW as the position feedback of the system to develop the controller.

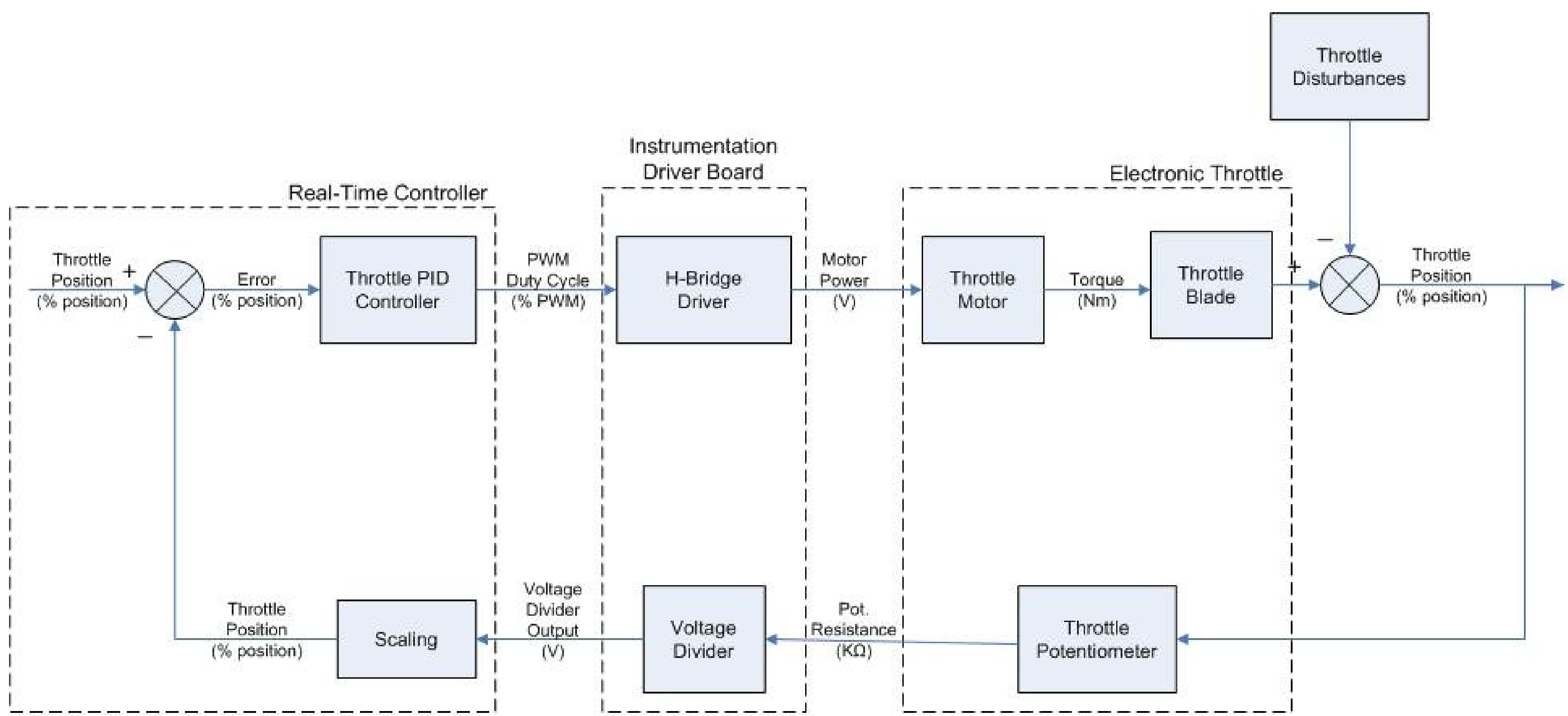

Figure 6: Electronic Throttle Control

3.1.3 Study on Pololu H-Bridge Driver

The heart of the power electronics stage is the H-Bridge, which supplies digital input to control current to the motor. Since the current supplied by the H-Bridge is proportional to the torque produced, it is necessary to control the current supplied to the motor for position control of the throttle blade. For this project, Pololu H-Bridge Driver VNH3SP30 is used. The working principal of this H-Bridge driver is switching power supply on and off, which means using the power supply at low or high power resistance to modulate the DC motor current. We will implement Pulse-Width-Modulation (PWM) and ideally, the effective voltage would be linearly proportional to the duty cycle of the PWM (Pulse Width Modulation).

An experiment is performed on the H-Bridge Driver that the PWM signal will modulate supply power to the motor. A function generator functioned as PWM signal where duty cycle from minimum duty cycle of 20% to maximum duty cycle 80% is adjusted. Applying PWM duty cycle will result in on and off of H-Bridge switching. Pololu H-Bridge Driver will only receive frequency of duty cycle maximum up to 10KHz. Analyzing from Figure 7 shows that logically the H-Bridge driver will operate when either both HS_A and LS_B or HS_B and LS_A is operated. H-Bridge will move the motor clockwise when both switch HS_A and LS_B are functioning and vice versa. The Pololu H-Bridge Driver datasheet stated that switch on the high side which are HS_A and HS_B will be controlled by controller with Boolean logic from truth table of Table 3. While the low side switch, LS_A and LS_B will be controlled by the duty cycle switching by PWM signal.

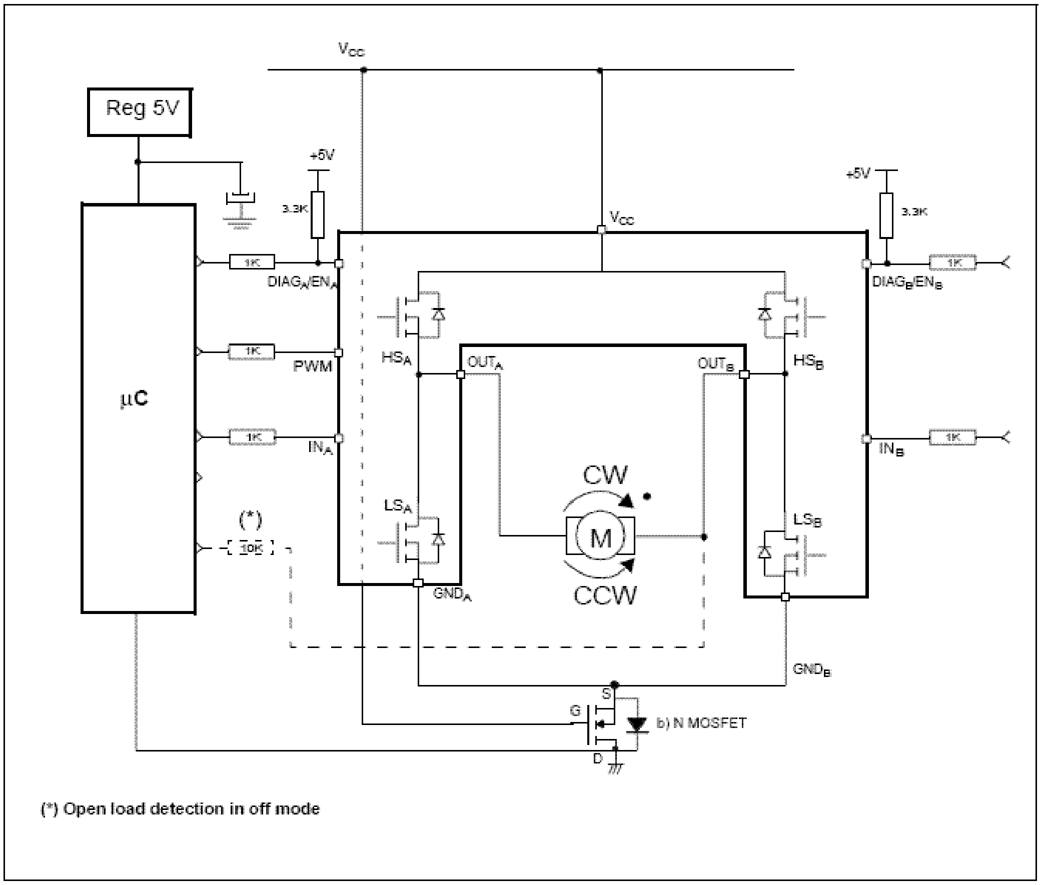

Figure 7: Typical Application Circuit for DC to 10 KHz PWM Operation

Table 3: Truth Table in Normal Operating Condition

IN_A	IN_B	$DIAG_A/EN_A$	$DIAG_B/EN_B$	OUT_A	OUT_B	REMARKS
1	1	1	1	H	H	Brake to Vcc
1	0	1	1	H	L	Clockwise
0	1	1	1	L	H	Anti-Clockwise
0	0	1	1	L	L	Brake to GND

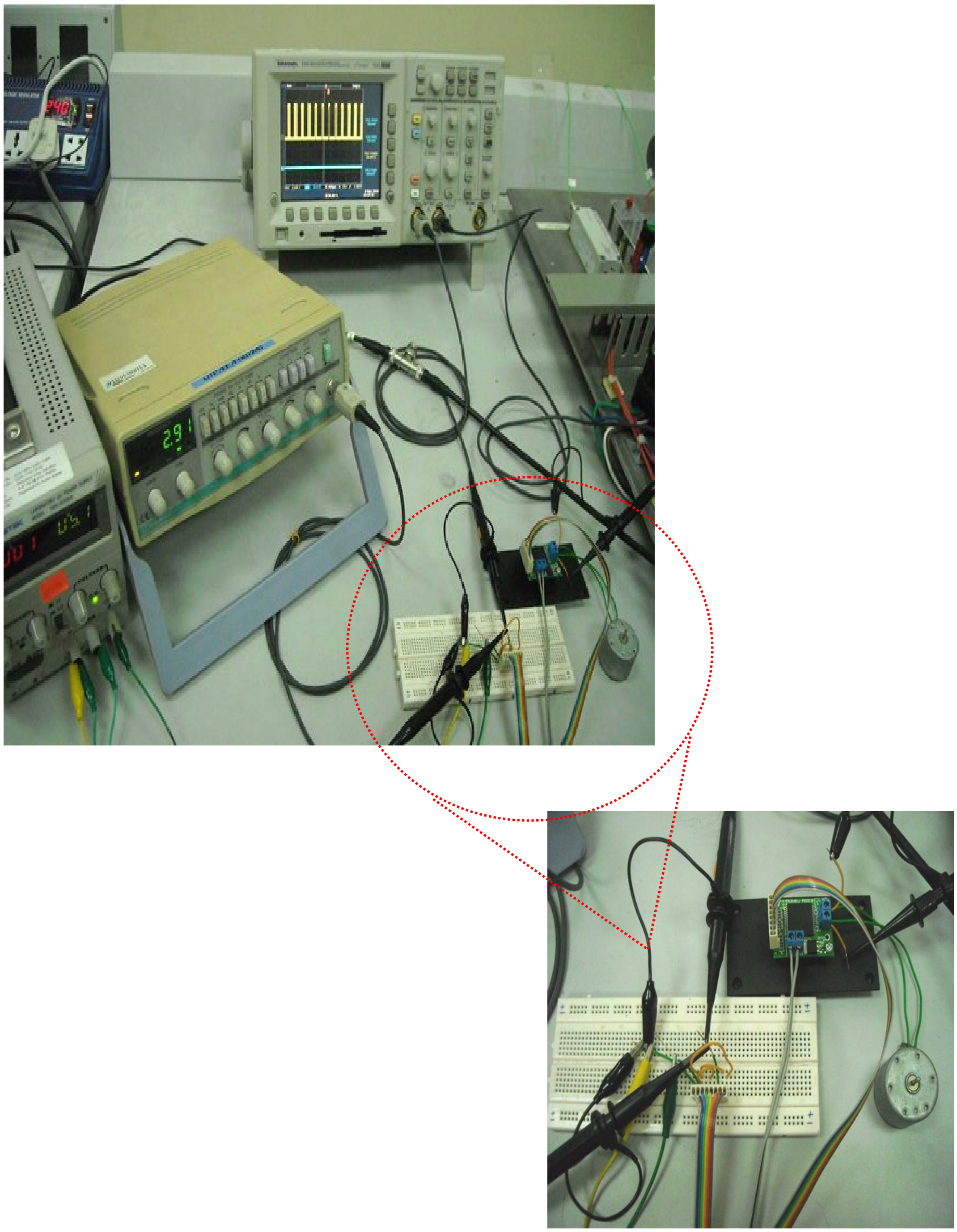

Figure 8: Pololu H-Bridge Driver Testing Circuit

3.1.4 Implement PID Control on Hardware

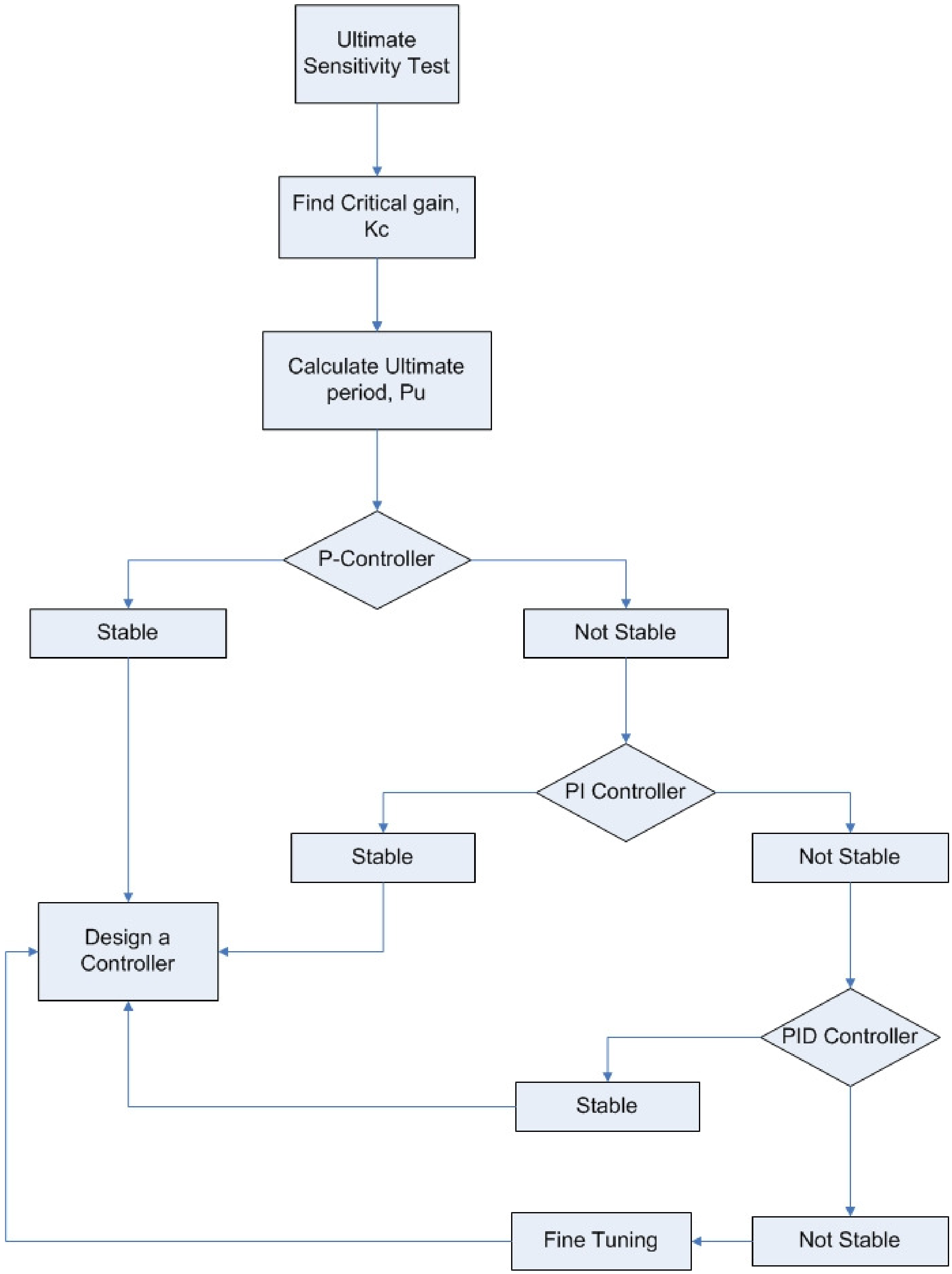

Figure 9: Flow Chart in Designing a controller

With the derivation of the transfer function, the project will resume by obtaining the value of Proportional, Integral and Derivative parameters. After that, the controller is tuned by slightly changing the values obtained and observed the output signal using Ziegler-Nichols tuning method with stability and controllability issues will be the main focus. This process will be done on a GUI in Figure 10 using LabVIEW and National Instrument PXI.

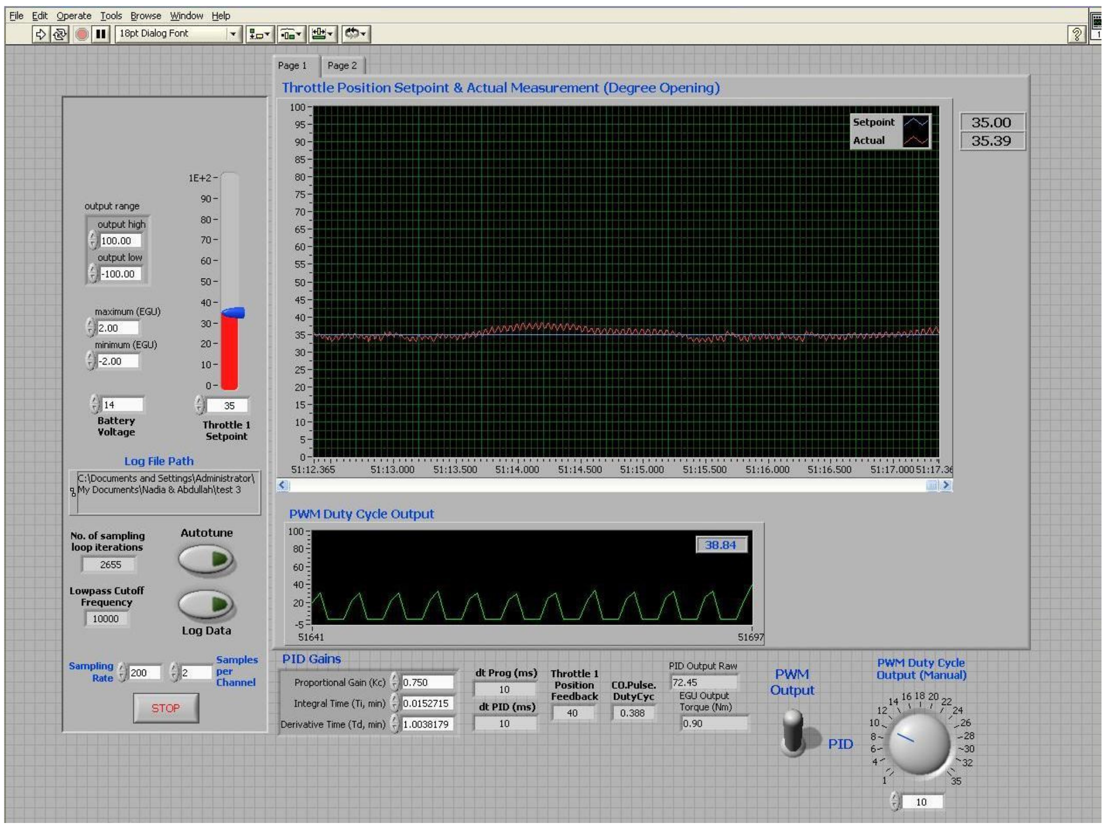

Figure 10: Graphical User Interface of Electronic Throttle in LabVIEW

The values of the PID parameters (K_p, T_i and T_d) can be determined by either an open loop or closed loop tuning method. The first step is to identify the process model for the system using the step input test. Step change will be the input and the output known as the process reaction curve. The process output obtained will be in different form and it will determine the process model. This is known as the open loop method. For the current project, the Ziegler-Nichols closed-loop tuning method, also known as ultimate sensitivity test, will be employed. The proportional gain, K_p

is increased in step change until the process oscillates continuously. This gain is called the ultimate gain,Kc and the period of the continuous oscillation is called ultimate period,P_u. The value of control parameter can be determined using this ultimate gain,K_c and ultimate period,Pu based on Table 2: Ziegler-Nichols Tuning Chart. The entire controller mode (P-only, PI and PID) is tested to yield the satisfaction performance. Finally, the relevant performance measure such as decay ratio, overshoot, settling time, rise time and dead time is determined to analyze and compare the performances between controllers.

3.1.5 Testing and Implementation

For completion of the project, the controller will be tested on hardware, testing with some suitable data and observing the output of the system. Tuning and modification process can be done by adjusting the controller parameters.

3.2 TOOLS AND EQUIPMENT REQUIRED

3.2.1 Hardware

i. Bosch Electronic Throttle (Part No: 0280750133)

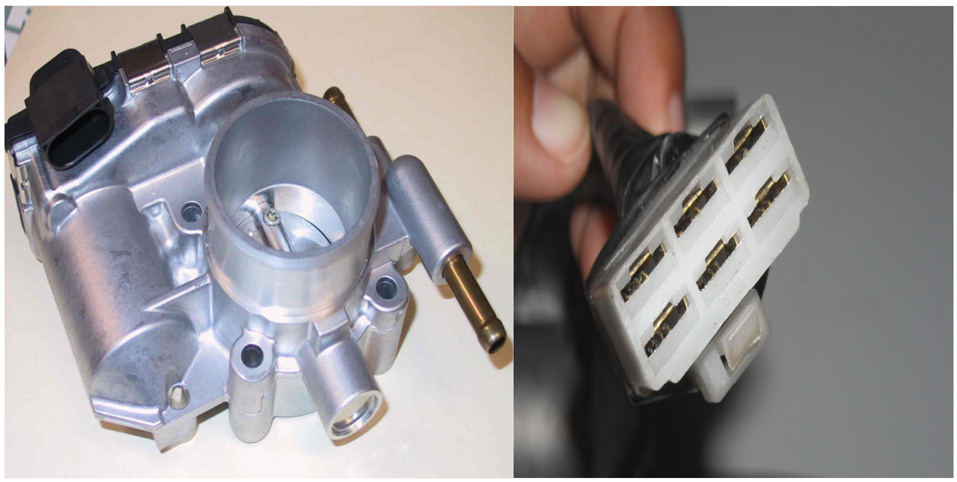

Figure 11: Bosch Electronic Throttle and 6-pin Connector

Bosch electronic throttle with 40mm blade diameter blade is hardware connected to engine to control the airflow into the engine. The electric actuator motor (DC motor) became the important part with the absence of mechanical connection to the electronic throttle. It has 6-pin electrical connections known as DV-E5 pin, which indicated its connection to the other hardware and interface. The sensor part of this electronic throttle is the potentiometer also known as Throttle Position Sensor. TPS sense the blade opening of the electronic throttle by changing its potentiometer value when the blade opening is varying.

Table 4: Connection Table for Standard Bosch DV-E5

DV-E5 PIN	DESCRIPTION
1	Motor -
2	Potentiometer Ground
3	Potentiometer Reference
4	Motor +
5	Potentiometer 1 Signal
6	Potentiometer 2 Signal

ii. Pololu H-Bridge Driver VNH3SP30

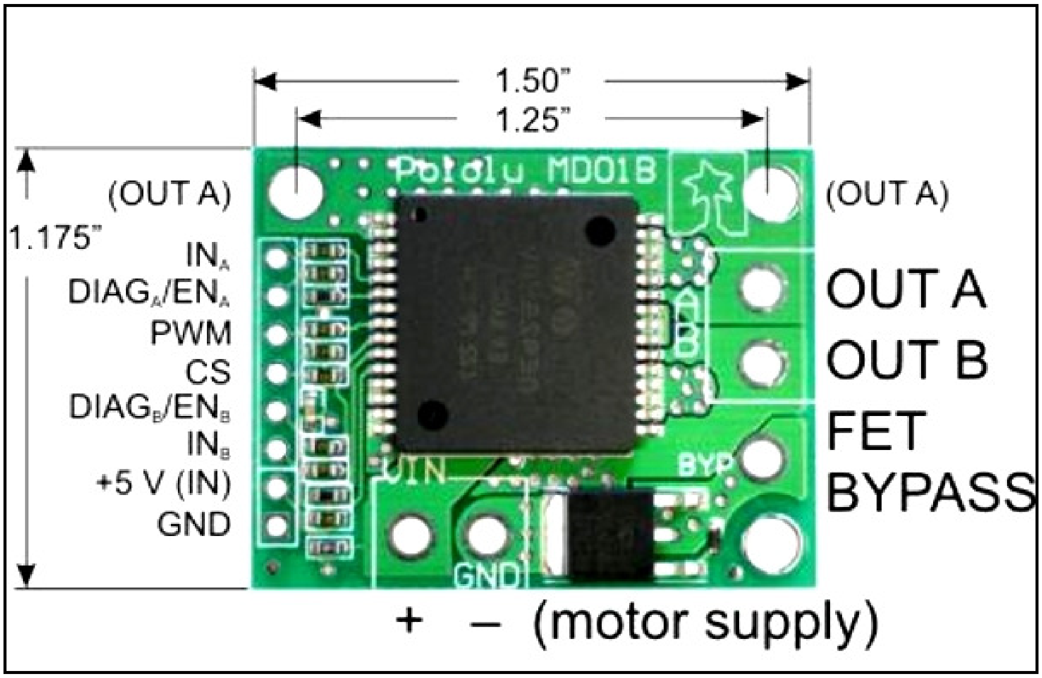

Figure 12: Pololu H-Bridge Driver VNH3SP30

H-Bridge driver is the hardware that receives signals from the controller and transfers it to the DC motor to produce torque that will move the throttle blade. H-Bridge allows current to the motor to flow in two different ways so that the DC motor will continuously receives electrical power to move the blade. For this project, Pololu H-Bridge Driver is used. This driver works with 10 KHz maximum frequency and is widely used in automotive application [10].

3.2.2 Software

i. LabVIEW 7.1 and PXI

LabVIEW (Laboratory Instrumentation Engineering Workbench) is development environment develop by National Instrument. Dataflow programming is the structures of graphical block diagram that have different functions built by a programmer. This software allows the connection between the hardware, drivers and different types of instruments. LabVIEW will be used to develop controller for the Bosch electronic throttle.

PCI eXtensions for Instrumentation (PXI) is a rugged PC-based platform that offers a high-performance, low-cost solution for measurement and automation systems. PXI also adds mechanical, electrical, and software features that define complete systems for test and measurement, data acquisition, and manufacturing applications. [12].

CHAPTER 4
RESULTS AND DISCUSSION

4.1 RESULTS

Until this period of time, the project has done successfully electronic throttle characterization, Pololu H-Bridge driver testing, open-loop control and finally the controller tuning.

4.1.1 Electronic Throttle Characterization

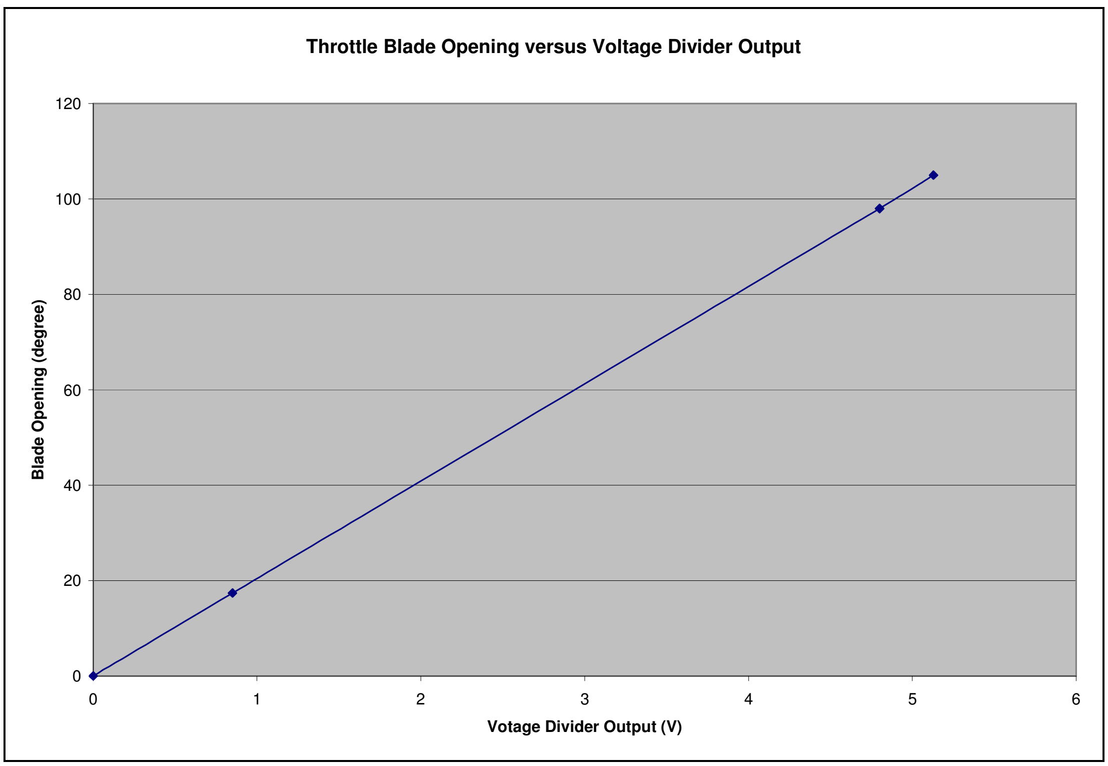

Figure 13: Throttle Blade Opening versus Voltage Divider Output

The graph shows the results for throttle blade opening versus voltage divider output. The graph is plotted based on experiment on electronic throttle to verify that it has linear relationship between throttle blade opening and voltage divider output given by the Bosch Technical Customer Information.

4.1.2 Pololu H-Bridge Driver VNH3SP30 Testing

An ideal setting of PWM = 1KHz, IN_A=0 and IN_B=1 is set to produce ideal motor output voltage. This is the basic testing to verify the duty cycle of PWM input voltage will linearly vary the motor output voltage.

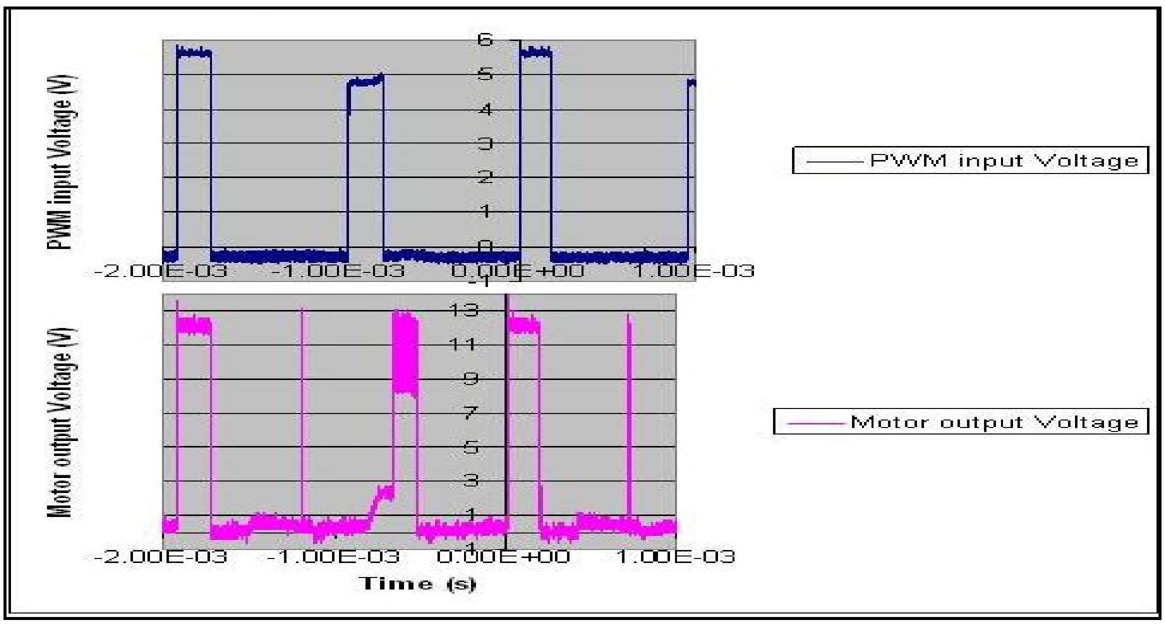

Figure 14: Voltage versus Time for 20% Duty Cycle 1KHz

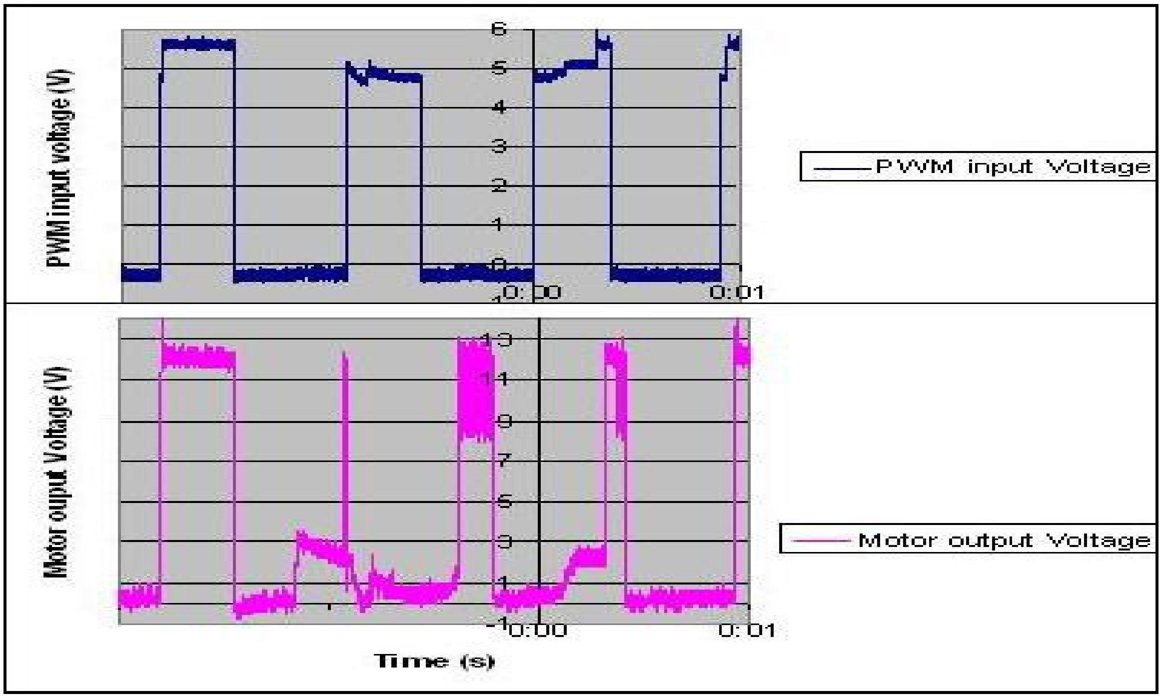

Figure 15: Voltage versus Time for 40% Duty Cycle 1KHz

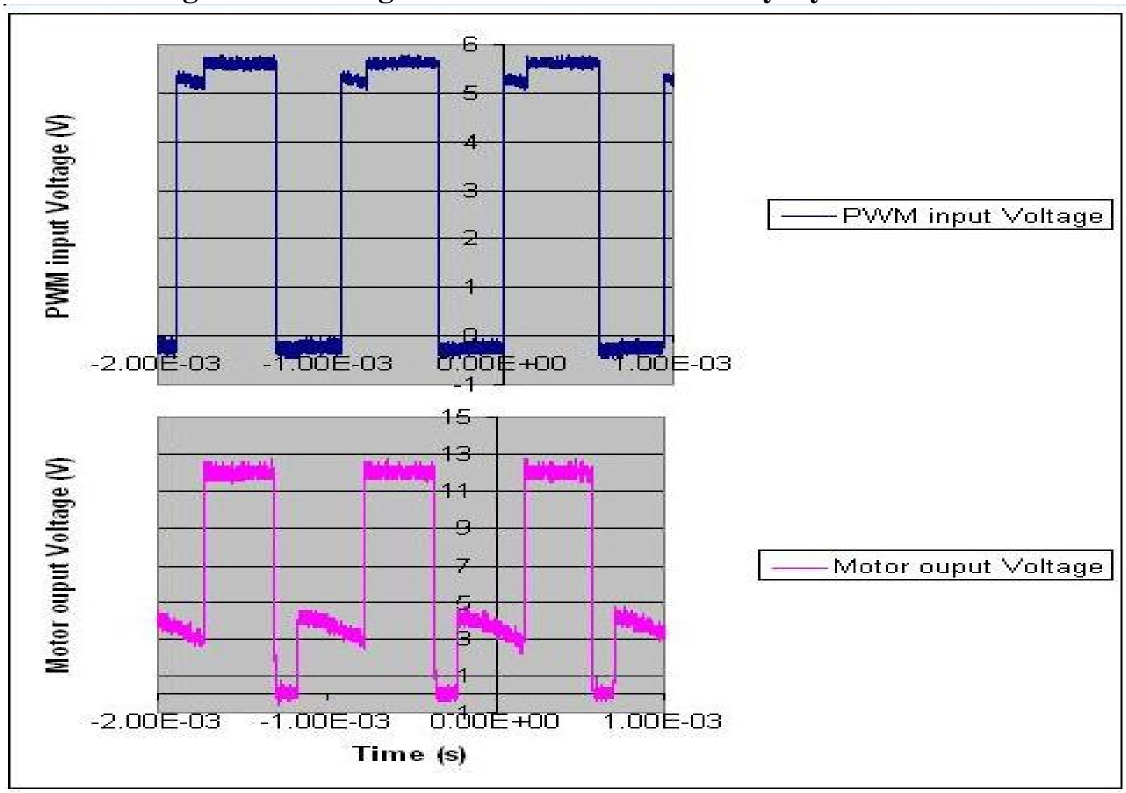

Figure 16: Voltage versus Time for 60% Duty Cycle 1KHz

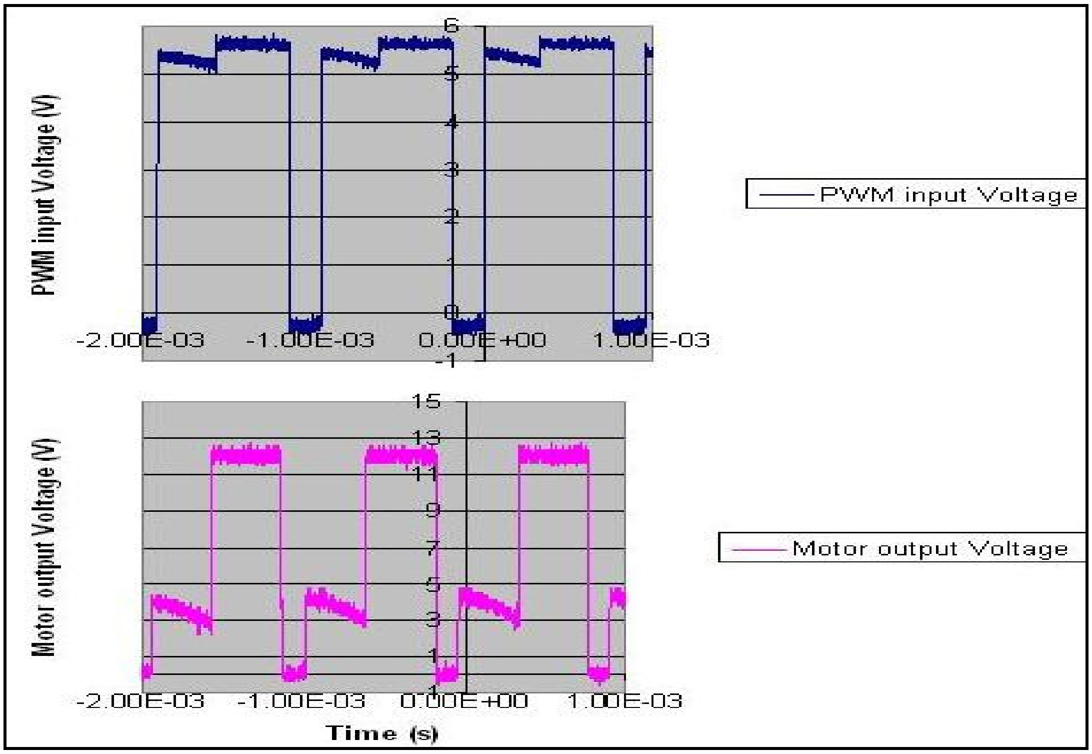

Figure 17: Voltage versus Time for 80% Duty Cycle 1KHz

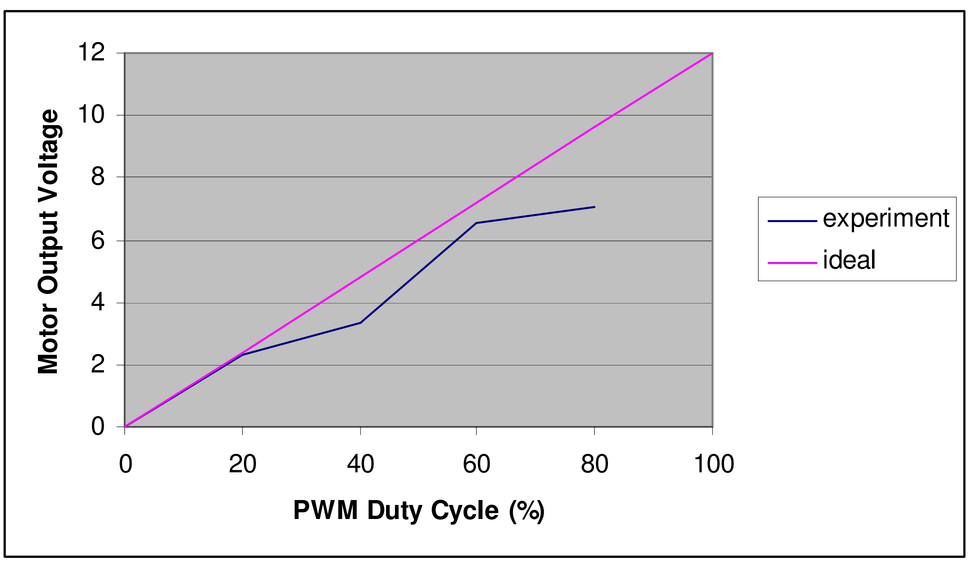

Figure 18: Motor Output Voltage versus PWM Duty Cycle

4.1.3 Open-loop Control Testing

An open-loop control is done without the presence of electronic controller. Bosch electronic throttle can be controlled by varying the duty cycle of PWM signal to the H-bridge driver.

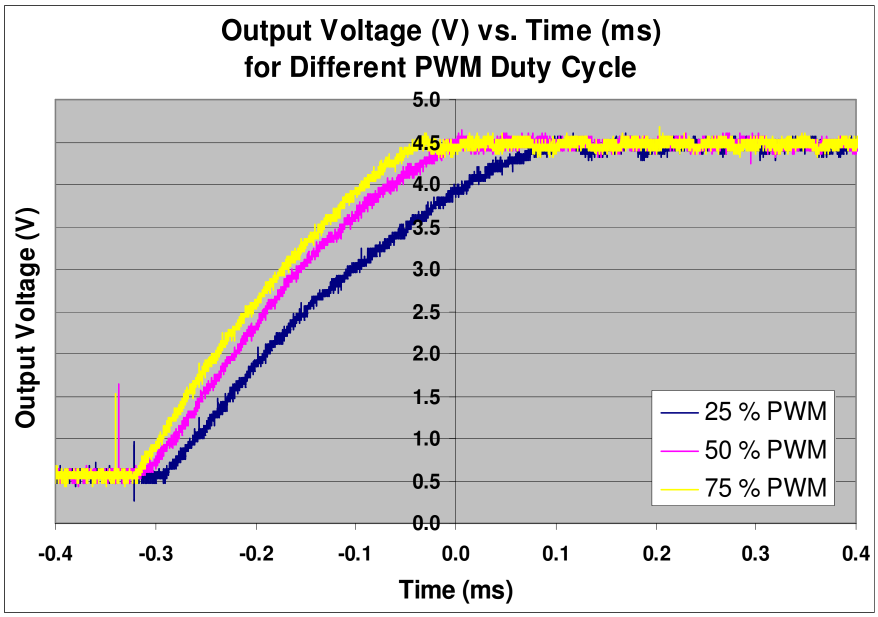

Figure 19: Motor Output Voltage versus Time for Different PWM Duty Cycle

4.1.4 Controller Manual Tuning

Controller manual tuning is done by changing the PID parameters until the desired input is gained. Two best results is taken to show the best performance measure. The best result for manual tuning is depicted in Figure 20 and Figure 21.

Table 5: PID Parameters for Electronic Throttle Manual Tuning

Parameters	**Trial 1**	**Trial 2**
K_p	0.55	0.75
T_i	0.0152715	0.0152715
T_d	0.0038279	0.0038279

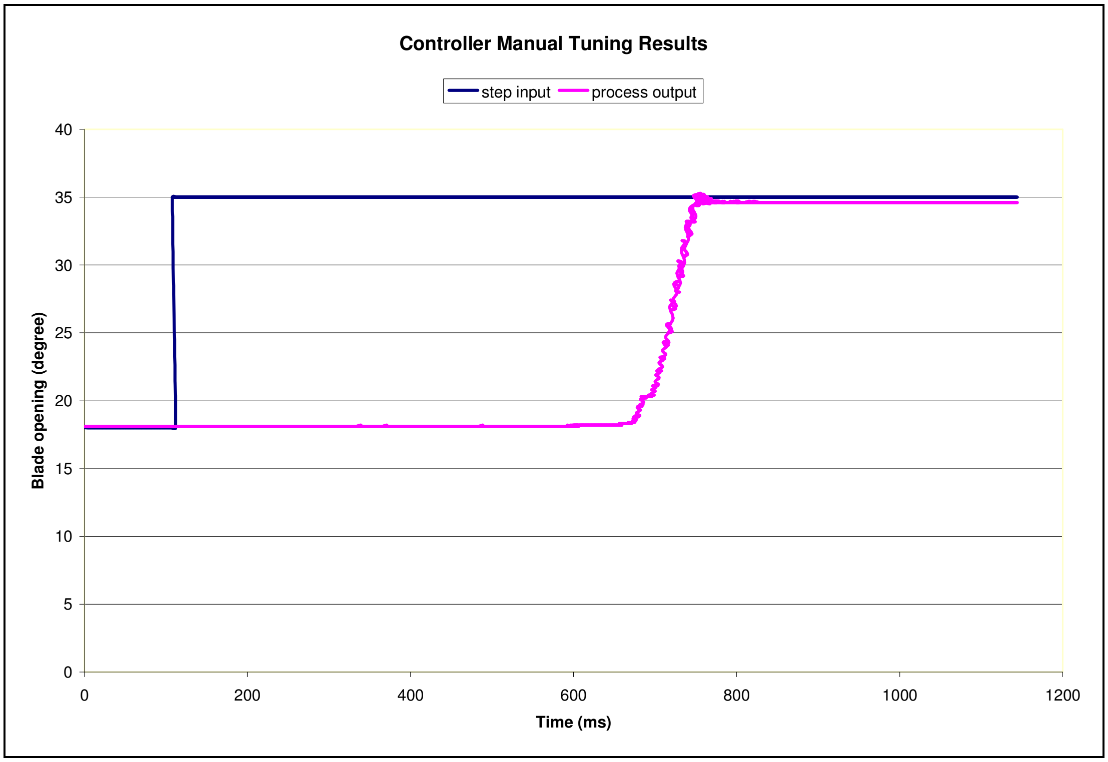

Figure 20: Trial 1 Process Output

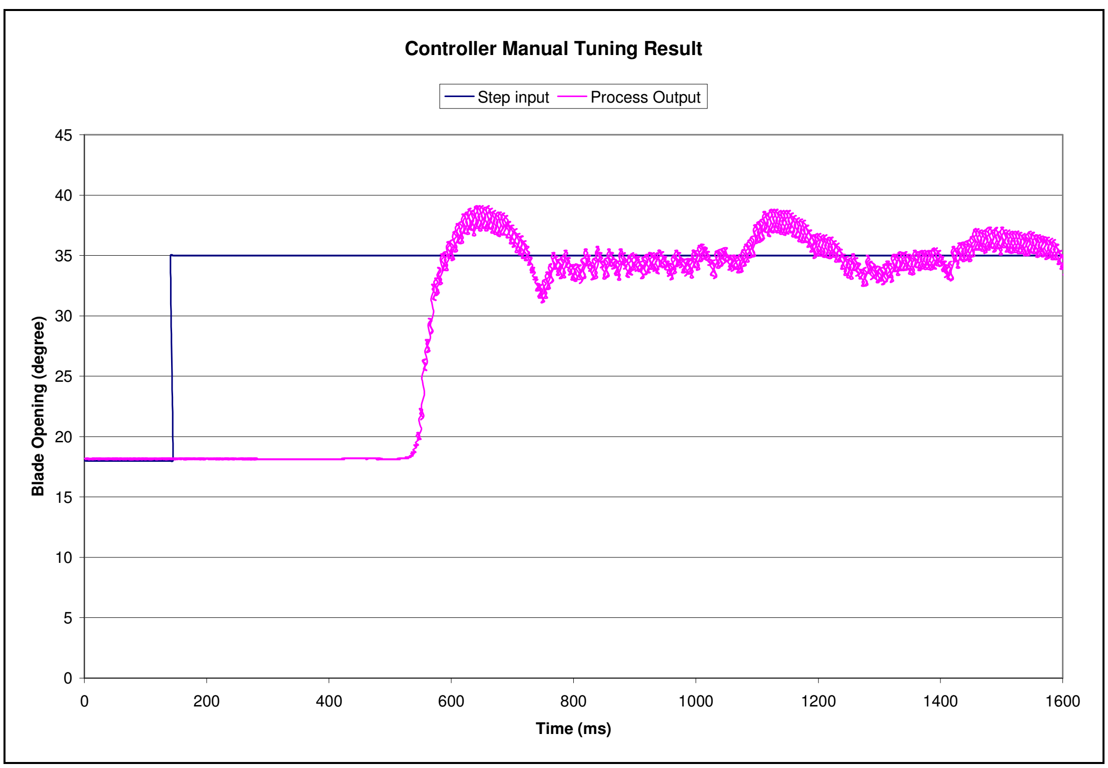

Figure 21: Trial 2 Process Output

Table 6: Performance Measure for Electronic Throttle Manual Tuning

Performance Measure	Trial 1	Trial 2
Decay ratio	1.0	0.9
Rise time	0.743 s	0.600 s
Settling time	0.760 s	1.323 s
Dead time	0.537 s	0.400 s

4.1.5 Ultimate Sensitivity Test and Ziegler-Nichols Tuning Method

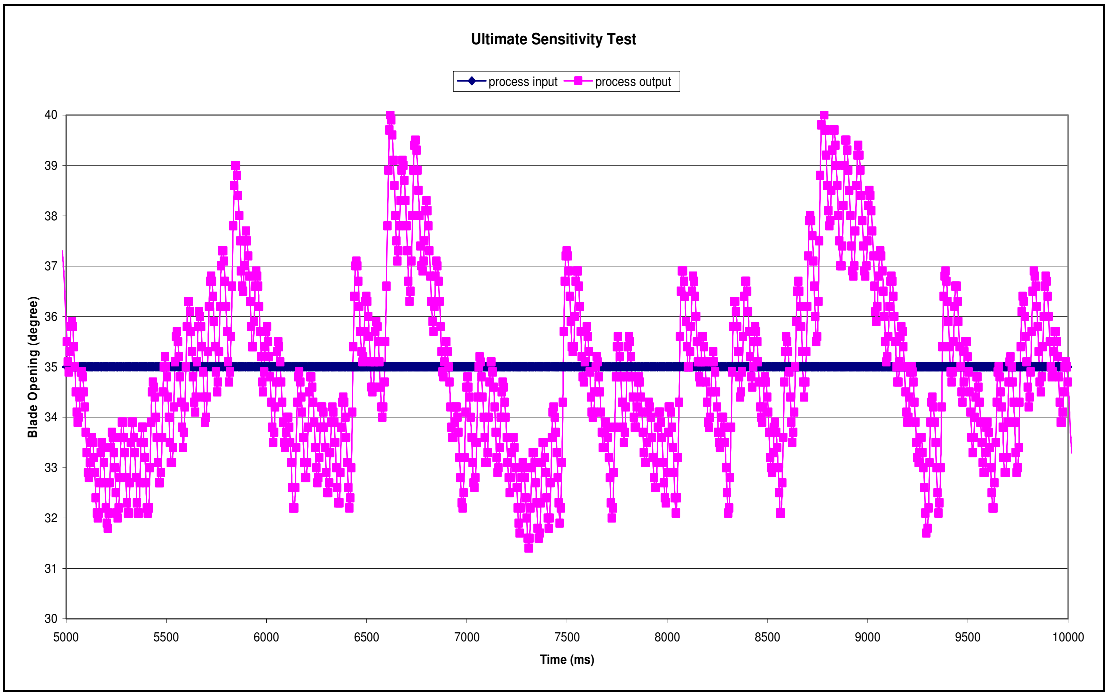

Figure 22: Ultimate Sensitivity Test Results

Ultimate gain, K_c = 0.55, calculated ultimate period, P_u = 1.75 ms. The following table shows the calculated PID parameters for Ziegler-Nichols tuning method.

Table 7: PID Parameters for Ziegler-Nichols Tuning Method

	K_p	T_i	T_d
P	0.875	-	-
PI	0.7995	1.458	-
PID	1.029	0.875	0.219

4.2 DISCUSSION

From electronic throttle position sensor experiment, we know that the blade opening and voltage divider output have linear relationship between two points from fully-closed to fully-open as it is visualized in the resulted graph in Figure 13. The Bosch Technical Customer Information document also stated that the blade opening is also linear to voltage divider output. The data obtained from this experiment is required for system feedback for controller purposes. This information will be useful for scaling input.

Pololu H-Bridge Driver VNH3SP30 testing also shows linear relationship between PWM duty cycle and output voltage to the motor. The best result for 1 KHz is both PWM duty cycle of 60% and 80%. The result is stable but with chopping signal. For 20% and 40%, the result shows noisy and unstable output.

Open-loop control testing shows that increasing PWM duty cycle of H-bridge driver increases effective voltage and current flowing through throttle motor. More current results in more torque which in turn results in faster response of throttle blade to open to its maximum.

After that, the implementation of controller on hardware using LabVIEW GUI shows that manual tuning results in better response. Trial 1 shows better performance measure than Trial 2 since its decay ratio is 1 which indicated it has less overshoot. The rise time for Trial 2 is faster than Trial 1 but the settling time for Trial

1 is faster than Trial 2. Both trial shows high dead time which indicated is response slow to its input. This is because the controller is not a stand-alone and real-time controller and depend OS which is Windows. It has to perform other instruction such as the display than just doing the controlling task. So, the controller system is not deterministic and dedicated enough to do the control.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

As a conclusion, as this project still in progress we are still working on understanding the Bosch electronic throttle system and continue develop the controller on National Instrument PXI and the software LabVIEW 7.1. The experiment performed shows Opening of electronic throttle can be controlled (open-loop) by changing duty cycle of PWM signal to H-bridge driver. Higher PWM duty cycle (%) results in faster response of electronic throttle. The manual tuning results shows the controller has the potential to control the blade opening efficiently. Next step of this project will be to test the final output with PID parameters using Ziegler-Nichols tuning method.

5.2 Recommendation

We recommend a more dedicated and deterministic controller in the future. The controller must be a stand-alone and real-time controller to reduce the dead time between the input and output. We also recommend gain-scheduling method for the different PID parameters in different stages of blade opening future controller implementation. For example, 0-30 percent of blade opening will need more on proportional gain, Kp since it needs more overshoot to move from idle mode (0% or static mode) to some degree while for 31-60 percent of blade opening will need lower overshoot and maintain at its desired position which we can assume it will use PI parameters. This PID tuning will require a lot of understanding in electronic throttle system and its control system.

REFERENCES

[1] Supplementary literature review from Mr. Saiful Azrin B. Mohd Zulkifli

[2] Tan, Wang and Hang, 1999, *Advances in PID control*, First Edition, Springer.

[3] Norman S. Nise, 2004, *Control System Engineering*, United States: Wiley International Edition.

[4] Thomas E. Marlin, 2000, *Process Control: Designing Processes and Control Systems for Dynamic Performance,* McGraw Hill.

[5] National Instrument, 2001, *LabVIEW PID Control Toolset User Manual*.

[6] The MATHWORKS, Inc., 1998, *Control System Toolbox User's Guide – for Use with MATLAB,* Version 4.

[7] http://en.wikipedia.org/wiki/PID_controller

[8] http://www.picoauto.com/applications/electronic_throttle_control.htm

[9] Araki M., 2003 *Control Systems, Robotics and Automation: PID Control* Volume II.

[10] ST, *Fully Integrated H-Bridge Motor Driver*

[11] BOSCH, 2000 *Technical Customer Information*.

[12] http://zone.ni.com/devzone/cda/tut/p/id/4811

APPENDICES

Appendix A

Final Year Project Gantt Chart

First Semester of Final Year Project

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic								SEMESTER BREAK							
2	Preliminary Research Work															
3	Submission of Preliminary Report															
4	Seminar 1 (optional)															
5	Project Work															
6	Submission of Progress Report															
7	Seminar 2 (compulsory)															
8	Project work continues															
9	Submission of Interim Report Final Draft															
10	Oral Presentation															

Suggested milestone

Process

Second Semester of Final Year Project

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Project Work Continue	■	■	■					SEMESTER BREAK							
2	Submission of Progress Report 1			●												
3	Project Work Continue				■	■	■	■								
4	Submission of Progress Report 2							●								
5	Seminar (compulsory)										■	■	■			
5	Project work continue									■	■	■	■	■		
6	Poster Exhibition													●		
7	Submission of Dissertation (soft bound)														●	
8	Oral Presentation														●	
9	Submission of Project Dissertation (Hard Bound)															●

● Suggested milestone

■ Process

APPENDIX B

VOLTAGE DIVISION RATIO VERSUS PERCENTAGE OF BLADE OPENING