PID CONTROL OF ELECTRONIC THROTTLE FOR DRIVE BY WIRE APPLICATION

By

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CERTIFICATION OF APPROVAL

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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.

Abdullah Saeed Mahfoudh Mohiri

ABSTRACT

The importance of electronic throttle in modern automotive engines is obvious. The opening of the throttle blade has to be controlled. This final year project is an attempt to control the opening of the throttle blade to a certain position by tuning the parameters of PID controller. This is to eliminate the disturbances and make the electronic throttle perform more accurately. The purpose of this report is to give an overview on the method chosen to perform the control system analysis of electronic throttle for drive by wire applications. In addition, the report discusses the results obtained and the tuning procedures used to control the opening of the throttle blade. It also shows the initial steps taken in order to develop an electronic throttle control system for the project as well as representing the tools needed to develop the system based on the chosen method. A general review on PID controller and its parameters as well as the H-bridge driver and the procedure analysis is also given in this report.

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LIST OF ABBREVIATIONS

ETC	Electronic throttle Control
PWM	Pulse Width Modulation
GUI	Graphical User Interface
DbW	Drive by Wire
SISO	Single-Input Single-Output
PID	Proportional Integral Derivative
PV	Process Variable

CHAPTER 1
INTRODUCTION

1.1 Background of Study

This project investigates the performance of an electronic throttle by using PID control for drive by wire application. Electronic throttle Control (ETC) is an automobile technology that replaces the mechanical link between the accelerator pedal and the throttle. In addition, the electronic throttle is a DC motor that has many applications. This DC motor can be used in modern automotive engines to improve vehicle drivability as well as fuel economy.

In this project, the design and study of PID control will be done for an existing electronic throttle at UTP's Automotive Research Centre. First, the system will be characterized on individual components. Then a complete hardware system will be built in order to study the electronic throttle performance. The control will be implemented on a controller along on H-bridge driver and electronic throttle.

1.2 Problem Statement

1.2.1 Problem Identification

As a DC motor, the electronic throttle receives a command from the controller in order to open the throttle blade to a certain position, resisting a spring force and other disturbances such as friction and stiction that can affect the electronic throttle performance.

The response of the DC motor is very fast. Current supplied to the motor needs to be controlled to enable control of the torque while turns the throttle blade to a required position.

The current to the throttle motor is controlled by an H-bridge driver using a technique called Pulse Width Modulation (PWM). Thus, the H-bridge and PWM operation needs to be investigated.

This project is an attempt to develop a control system for controlling the throttle blade by:

- Characterizing the system for Single-Input Single-Output (SISO) PID control.
- Determining a proper transfer function, block diagram and step response for the throttle operating process.
- Studying the relationship between measured voltage and % opening.
- Implementation and testing on hardware.
- Studying the effects of varying the PID parameters to obtain a stable and accurate control system.

1.2.2 Significance of Project

This project would help in controlling the electronic throttle for Drive by Wire applications (DbW) by using PID control so that a mechanical throttle-pedal system can be replaced by an electronic throttle system.

1.3 Objective and Scope of Study

1.3.1 Objectives

The objectives of the project are:

- To study, design, and implement PID controller to operate an electronic throttle.
- To characterize the system.
- To study variations of PID parameters for controllability and stability of the system.

1.3.2 Scope of Study

The study begins with understanding a PID control system and characterizing a PID-controlled electronic throttle system to come up with a control block diagram. Basic input-output relationships between system components are studied and established, especially the throttle position feedback.

On the second part of the project, hardware implementation of the electronic control system will be performed. We will implement the PID control on the electronic throttle followed by testing with an H-bridge driver that is connected to the electronic throttle. Finally, controllability and stability of the system will be studied by varying and tuning the PID parameters.

CHAPTER 2
LITERATURE REVIEW

2.1 PID Controller

Proportional-Integral-Derivative controller (PID controller) is a control loop feedback system that corrects the error between a measured process variable and a desired set point by calculating and then outputting a corrective action that can adjust the process. [1], [4]

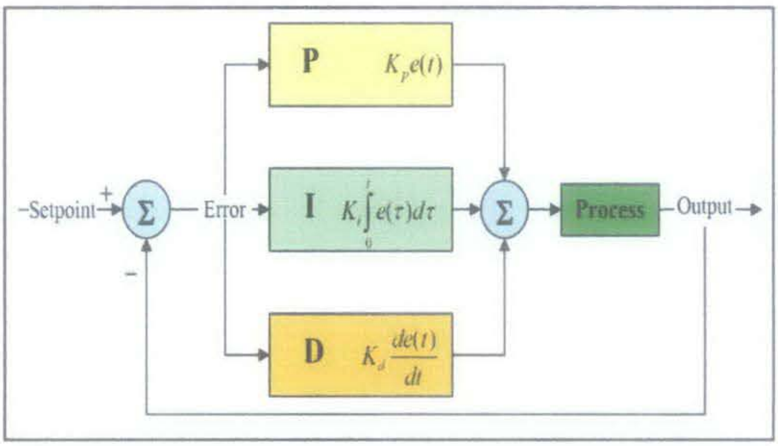

Figure 1: Block Diagram of PID Controller [12]

The PID controller algorithm contains three separate parameters as follows:

1) The Proportional value determines the reaction to the current error [12].
2) The Integral value determines the reaction based on the sum of recent errors [12].
3) The Derivative value determines the reaction to the rate at which the error has been changing [12].

The equation that relates the PID parameters with each other is given as bellow:

$$MV(t) = K_C \left[E(t) + \frac{1}{T_I}\int_0^{\infty} E(t')\,dt' - T_D \frac{dCV(t)}{dt}\right] + I$$

Where;

MV: is the manipulated variable

K_C : is the proportional gain.

T_I : is the integral gain.

T_D: is the derivative gain.

I: is a bias.

2.2 H-bridge Driver

Sometimes it is called a "full bridge". It is an electronic circuit that enables a voltage to be applied across a load in either polarity. H-bridges are used in many applications to allow DC motors to run forwards and backwards. In addition, H-bridges are available as integrated circuits. According to [2], an H-bridge consists of four switching elements at the "corners" of the H and the motor. These four switching elements are called high side left, high side right, low side right, and low side left (when traversing in clockwise order)[5].

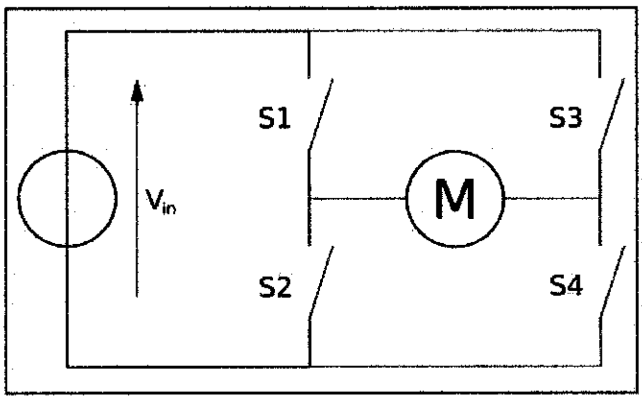

Figure 2: H-bridge Structure [6]

The switches are turned on in pairs; either high left (S1) and low right (S4), or low left (S2) and high right (S3), but never both switches on the same "side" of the bridge which will create a short circuit between the battery plus and minus terminals if both switches on one side of a bridge are turned on. Thus, the switches (S1) and (S2) should never be closed at the same time, as this would cause a short circuit on the input voltage source. The same applies to the switches (S3) and (S4). This condition is known as shoot-through. If the bridge is sufficiently powerful it will absorb the load by causing a quick drain of the battery energy.

By turning on two switches that are diagonally opposed, the motor will be powered. As shown in Figure 3 below, if the switches S1 (high left) and S4 (low right) are closed and S2 (low left) and S3 (high right) are opened, a positive voltage will be applied across the motor and the motor turns in a certain direction. By opening (S1) and (S4) switches and closing (S2) and (S3) switches, this voltage is reversed, so that the motor turns in the opposite direction [6].

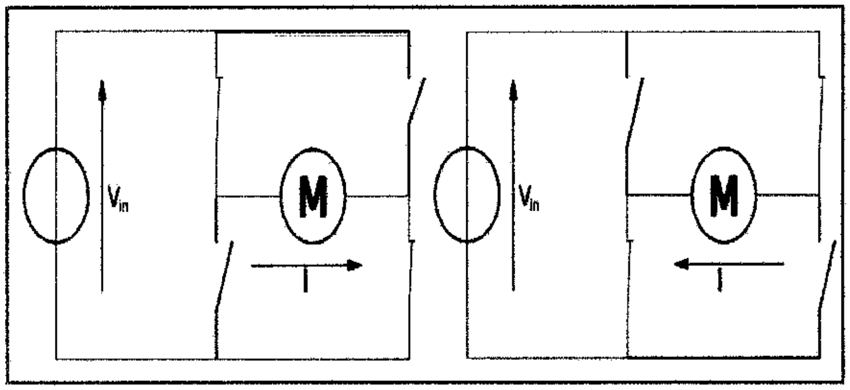

Figure 3: H-bridge Operation Theory [6]

In addition, the turning motor generates a voltage which tries to force the motor to turn the opposite direction. This causes the motor to rapidly stop spinning and is called "braking" on a lot of H-bridge designs. However, for the electronic throttle motor, it does not turn full circle but only a certain degree of opening.

The arrangement of the H-Bridge is used to reverse the polarity of the motor. The operation of the H- Bridge can be summarized in the following table:

Table 1: H-bridge Operation Theory [6]

S1	S2	S3	S4	Results
1	0	0	1	Motor moves right
0	1	1	0	Motor moves left
0	0	0	0	Motor free runs
0	1	0	1	Short circuit
1	0	1	0	Short circuit

2.2.1 *VNH3SP30 Fully Integrated H-bridge Driver*

It is a full bridge motor driver used for many automotive applications. It has a dual monolithic HSD (high side switches) and two low side switches.
In this project, the VNH3SP30 Fully Integrated H-Bridge Driver is used to power the electronic throttle in order to control the opening of the electronic throttle blade.

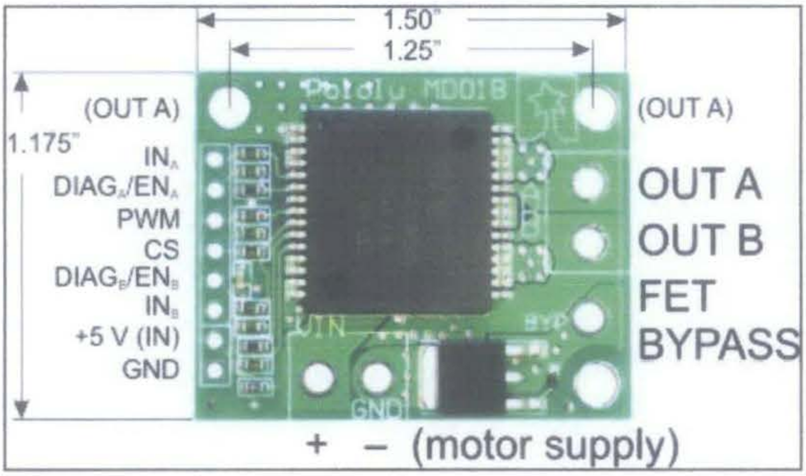

Figure 4 : VNH3SP30 H-bridge Connections and Dimensions [11]

As shown in Figure 9, IN_A and IN_B, are the voltage controlled input pins with hysteresis, CMOS compatible. They are used to control the direction of the motor. OUT_A, and OUT_B are used for the connection to the motor. The PWM pin is used to turn the motor either ON or OFF. This H-Bridge has a Reverse Battery Protection done by the N-channel MOSFET which keeps the driver from damaging itself if a backwards connections accidentally happened. This MOSFET can also bypassed by connecting the negative terminal of the battery to the bypass pin [11].

In the normal operating conditions, both $DIAG_A/EN_A$, and $DIAG_B/EN_B$ are pulled high. Besides, in a fault conditions, one of them will turn low in order to give fault information.

The operations of this smart H-bridge driver can be concluded in the following truth table:

Table 2: Truth Table for VNH3SP30 H-bridge Driver [11]

IN_A	IN_B	$DIAG_A/EN_A$	$DIAG_B/EN_B$	OUT_A	OUT_B	Comment
1	1	1	1	H	H	Brake to V_{CC}
1	0	1	1	H	L	Clockwise
0	1	1	1	L	H	Counter CW
0	0	1	1	L	L	Brake to GND

By following Figure 10, we can understand how the pins connect internally and how the movement of the motor occurs.

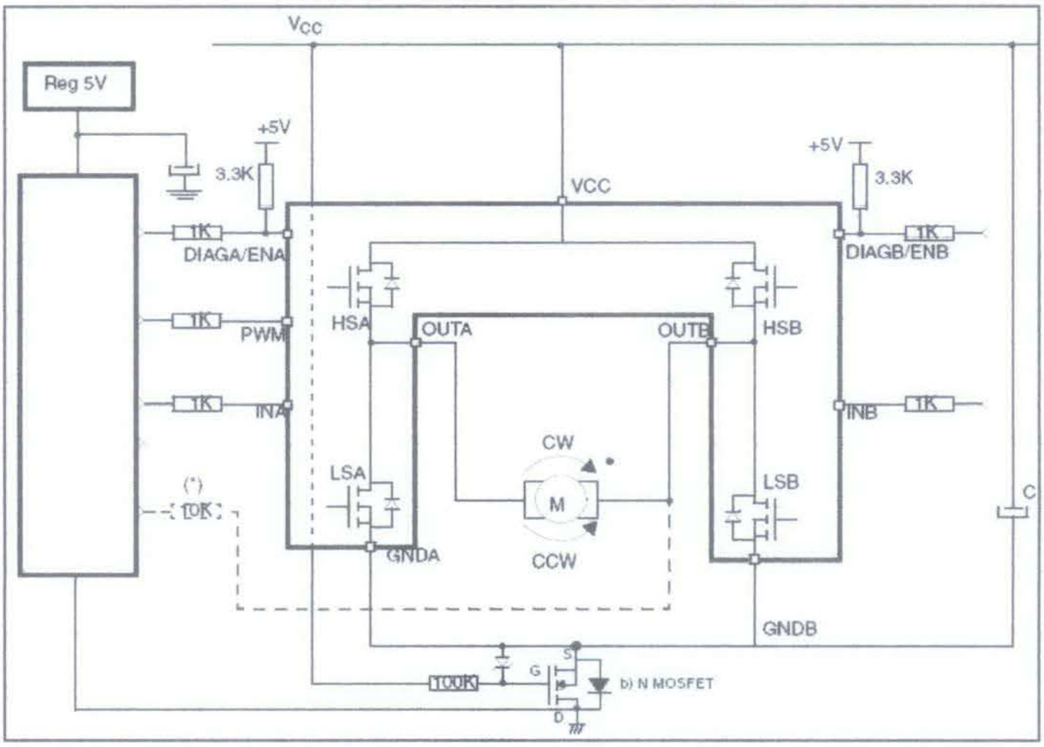

Figure 5: Typical VNH3SP30 H-bridge Driver [11]

In order to operate the motor in a clockwise direction, we supply the H-bridge with a PWM signal and the LSA side will turn on while LSB remains off (low). But in order to move the motor in counter clockwise direction, the LSB side will turn on while LSA will be off.

CHAPTER 3
METHODOLOGY

3.1 Research Methodology

The overall flow of the project can be divided into the following:

3.1.1 Literature Review and Research:

At the beginning, a review on the PID controller, the H-bridge driver, the electronic throttle and the DC motor should be done in order to be familiar with the project requirements.

3.1.2 Study on Bosch Electronic Throttle

As shown in Figure 6, the main purpose here is to find the relation between the torque (τ) and the angle (θ) of the throttle blade, as well as converting of the resistance and measured voltage from the voltage divider. Here, the angle (θ) represents the opening position of the throttle blade.

We have to familiarize the Pulse Width Modulation (PWM) concept in designing and functioning of the electronic throttle. PWM is based on duty cycle which is defined as the amount of time that a signal is high compared to the amount of time that the signal is low.

By observing the throttle control loop, the throttle PID controller sends a Duty Cycle signal (% PWM) to Instrumentation Driver Board (consists of H-bridge driver and voltage divider). The main purpose of the H-bridge driver is to power the throttle motor. The output of the H-bridge is current that enters the throttle motor.

Due to the injected current, there is a torque introduced in the throttle motor (actually the throttle blade) where:

$$\tau_{net} = \tau_{motor} - \tau_{spring}$$

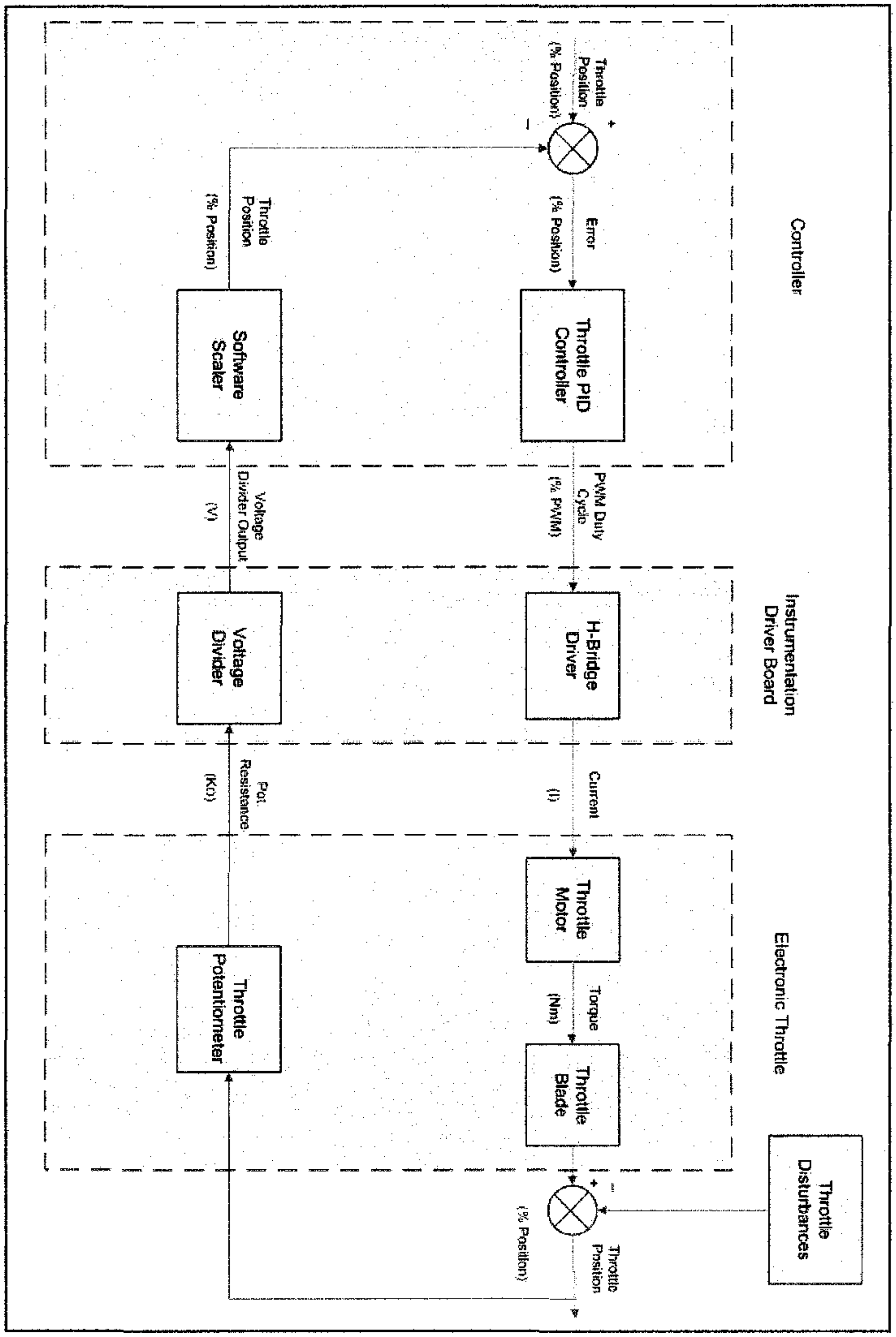

Figure 6: Electronic Throttle Control System

According to [10], the complete electronic throttle plant can be given by the following:

$$\theta' = \omega$$

$$\omega' = -\frac{K_s}{J}\theta - \frac{C_S}{J} - \frac{K_d'}{J}\omega - \frac{K_f}{J}sgn(\omega) + \frac{K_T}{J}\frac{V_{Bar}}{R_a + R_{Bar}}u$$

Where:

θ : is the throttle angle.

ω: is the throttle angular velocity.

J : is lumped inertia plate, "reduction gears of the motor".

K_s: is spring constant.

C_S : is torque constant.

K_d' : is equivalent viscous friction constant.

K_f: is Coulomb friction constant.

K_T: is motor torque constant.

V_{Bar}: is no-load voltage.

$sgn(.)$: is the signum function.

R_a : is armature resistance.

R_{Bar} : is internal resistance of the source and *(u)* is the control signal.

By following the control loop as in Figure 6, we will observe that the throttle position (angle (θ)) will be the input of the throttle potentiometer where the angle (θ) has a relation with the resistor R (θ vs. R). Thus, the output of the potentiometer is a resistance. This potentiometer resistance enters a voltage divider as an input. In the voltage divider, a relation between the voltage and the resistance (V *vs.* R) can be achieved by voltage divider equation as follows:

$$V_{pot} = \left(\frac{R_{pot}}{R_{pot} + R_1}\right)V_{in}$$

From the above equation, the output voltage *(V_{pot})* can be calculated in order to sketch a relation between the output voltage and the potentiometer resistance *(R_{pot})*.

Thus, in order to findV_{in}:

$$V_{in} = V_{pot}\left(\frac{R_{pot} + R_1}{R_{pot}}\right)$$

, in order to findR_1:

$$R_1 = R_{pot}\left(\frac{V_{in}}{V_{pot}} - 1\right)$$

, in order to find R_{pot} :

$$R_{pot} = \frac{\frac{V_{pot}}{V_{in}} R_1}{1 - \frac{V_{pot}}{V_{in}}}$$

Hence, the output of the voltage divider is a voltage that enters a software scaler in order to obtain a relation between a voltage and the angle (V *vs.* θ). The output of the software scaler is a throttle position (angle (θ)) that is feedback to the control system. Therefore, the importance of the angle (θ) occurs clearly in the electronic throttle in order to control the opening position of the throttle.

3.1.3 Characterizing the System

This involves identifying the proper PID parameters, determining the system block diagram, the transfer-function, the step response as well as the relationship of the measured voltage and the % opening of the throttle blade.

In this project, a closed-loop control system is required instead of an open-loop system. This feedback loop system will be less sensitive to disturbances compared with an open loop system [7].

According to [7], the closed loop system is very accurate in tuning procedure. The steady-state oscillation should be under process, and the PV (process variable) on a strip sharp chart should be observed as well.

Based on [1], tuning is the procedure of adjusting the feedback controller parameters to obtain a specified closed /open-loop response.

Based on [7], the following steps should be completed in order to do the closed-loop tuning procedure.

1. The derivative time and the integral time (on PID) should be set to zero.
2. In the automatic mode of the controller, the proportional gain (K_c) should be increased in little increments. The set-point (SP) has to have a small change in order to disturb the loop after each increment. Making these changes should be done till the oscillation is neither growing nor decaying over time.
3. The proportional band (PB) should be recorded as a percent ($PB = 100/K_c$).
4. The oscillation period should be recorded as well (in minutes).
5. The measured values should be multiplied by the factors shown in Appendix B-Table-6, after this, the new tuning parameters should be entered into the PID controller. (Less overshoot requires an increase of K_c).

In the open-loop (Step Test) tuning procedures, [7] suggested that modeling any process as a first order lag and dead time as well. In this process, the PV should be noticed carefully on a strip chart as well as the output.

Tuning the open loop requires following the procedures below:

1. The PID controller should be turn into a manual mode. Besides, the output should be set to a nominal value of operating. The PV should be settled completely and recorded.
2. A step change should be done to the output, and its new value should be recorded as well.
3. After waiting for the PV to be settled, the values derived from the chart should be determined from the output and process variable strip chart obtained.
4. The measured values should be then multiplied by the factors shown in Appendix-B Table-7, and the new parameters that being tuned has to be entered to the controller.

The summarized process of tuning PID parameters using the Ziegler-Nichols Method can be noticed by following Figure below:

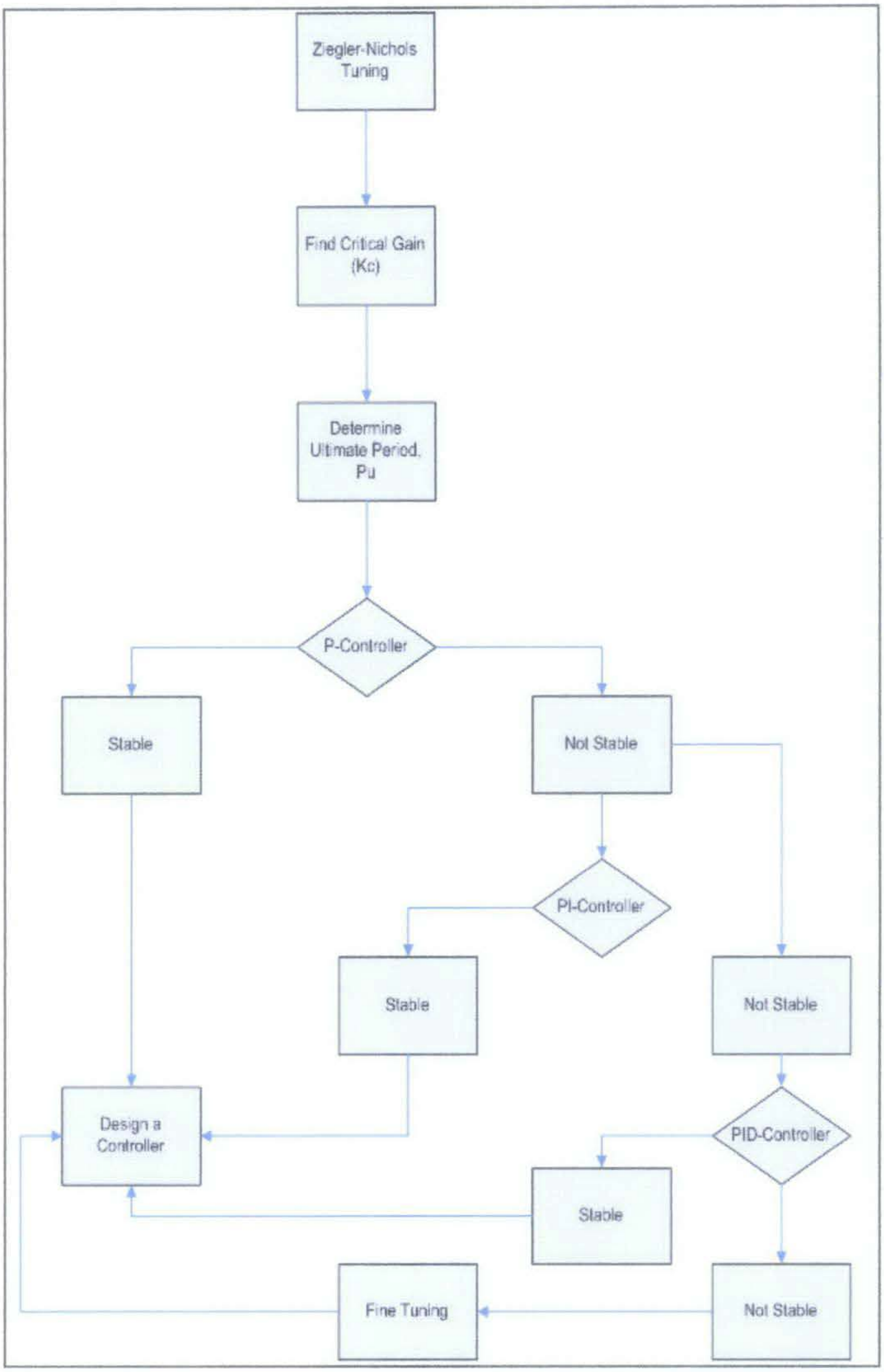

Figure 7: Flowchart of Controller Design

3.1.4 Implementation and Testing

At this stage, the control system will be implemented on hardware in order to achieve the experimental results. This can be conducted by implementing the control on a controller and then tested by H-bridge driver and electronic throttle.

A summary of the project procedure can be noticed by the following flowchart:

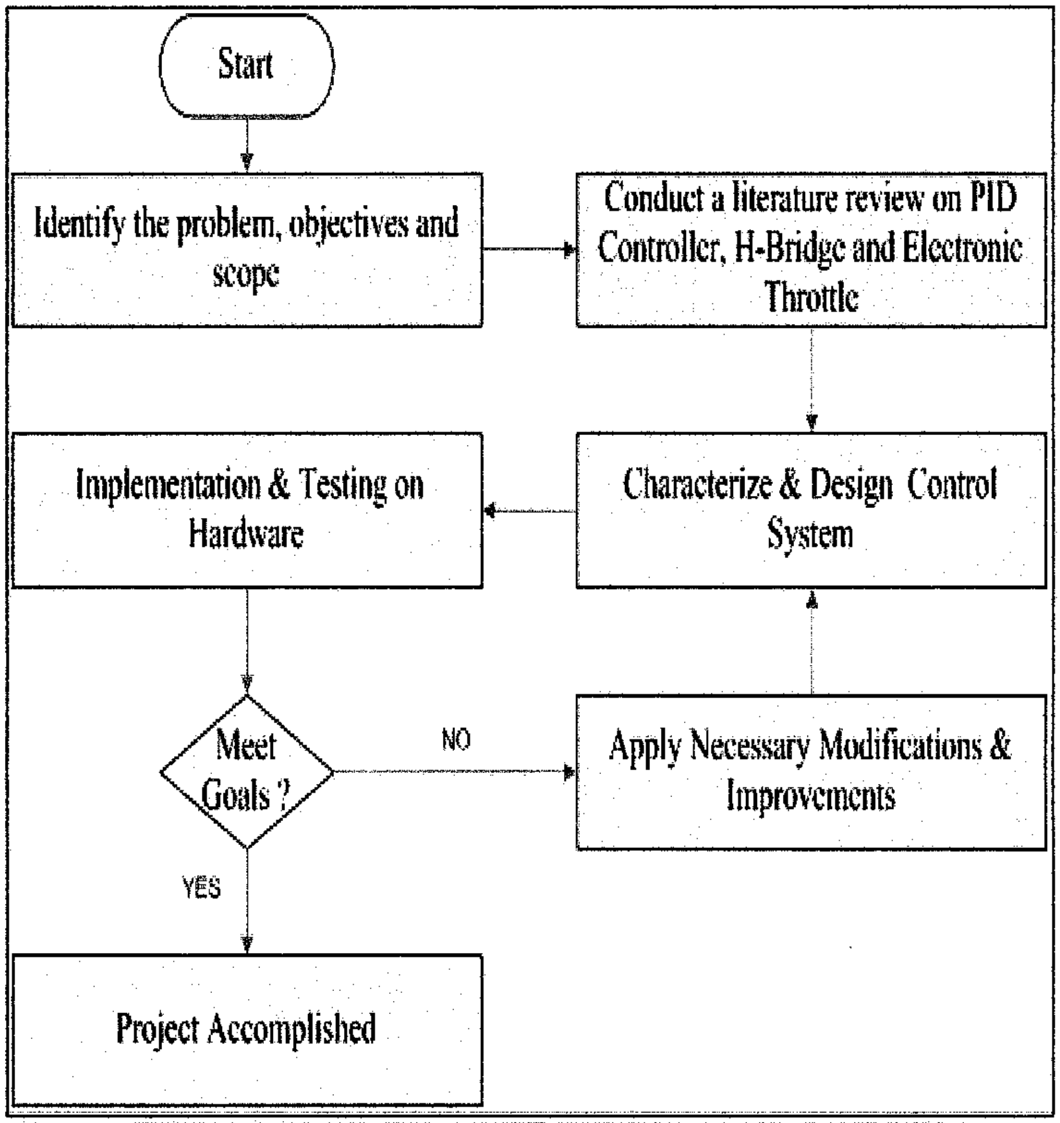

Figure 8: Overall Project Procedures

3.2 Tools and Software

The required equipments, software and tools for the projects are as follows:

3.2.1 Electronically Controlled Throttle (ECT) Body

The electronic throttle used in this project is Bosch (Part# 0280750133) with 40 mm diameter blade. It is a hardware that controls the airflow into the engine.

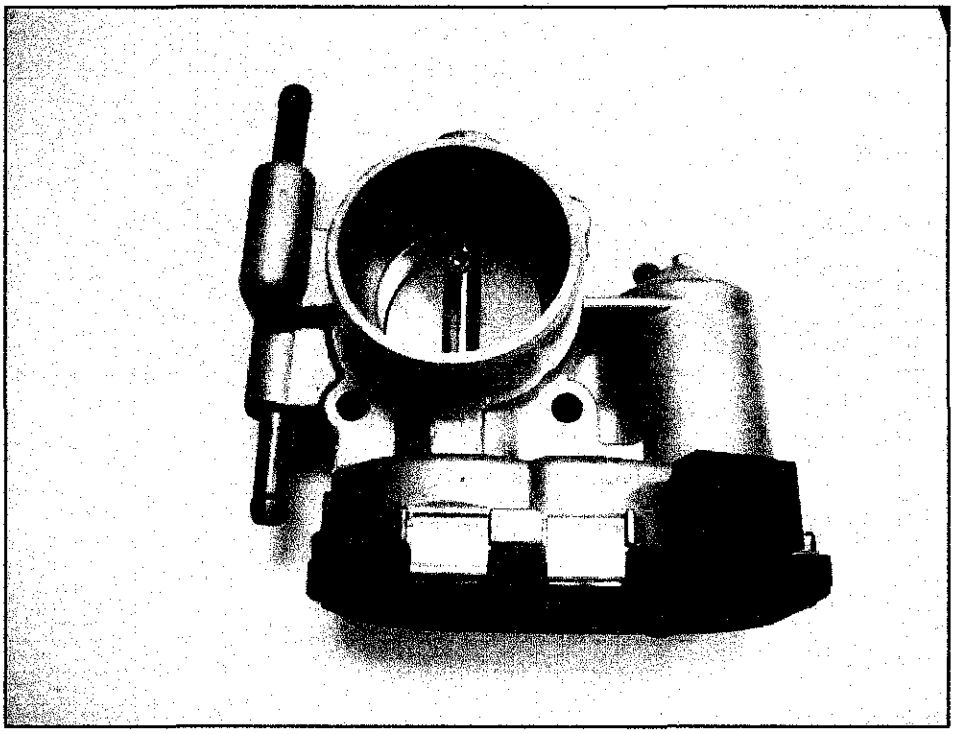

Figure 9: Bosch Electronic Throttle

This DC motor with a 6-pin connection is known as the DV-E5 model. The description of DV-E5 connections is illustrated as in the table below:

Table 3: Pin Connections of 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

3.2.2 H-Bridge Driver

H-Bridge driver is an electronic circuit that receives a signal from the controller and then amplifies it in order to allow DC motors to run forwards and backwards. This H-bridge can vary the received duty cycle of the applied voltage therefore, varying the average current that flows through the load as well as the direction of current flow.

3.2.3 Lab VIEW

Based on [7], Lab VIEW (Laboratory Instrumentation Engineering Workbench) is dataflow programming software that structures of graphical block diagrams with different functions built by a programmer. By using this software, we can connect between the hardware, drivers and different instruments as well.

3.2.4 PID controller

The PID controller is used to correct the error between a measured process variable and a desired set-point. In this project, a proper tuning of the PID parameters has to be done for accurate response of the electronic throttle blade.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Results

After conducting extensive research on electronic throttles, H bridge, and PID controller as well as LabVIEW that had been chosen to be implemented in this project, in this second semester of the final year project I have done some experimental testing and implementation on H-bridge driver to check the functionality and performance of H-bridge driver in order to operate the Electronic Throttle. Then, the implementation part by using PID controller is conducted to achieve the objectives of this project.

4.1.1 Testing MD03 - 50Volt 20Amp H Bridge Motor Driver

Since this H-bridge driver is available in the UTP automotive research centre and LG lab, I have done some testing on this H-bridge driver to check its functionality, so there will be no need to order and buy a new H-bridge driver.

This MD03 H-bridge driver is a medium-power motor driver that is designed to power a motor. It has a smart chip and many features in order to ease supplying power to any motor and to be more flexible.

This H-bridge requires only two supply voltages; one is a standard 5V DC supply for the control logic (only 50 mA maximum is required), and the other is motor voltage (anything from 5V DC to 50V DC to suit the motors). The control of this H-Bridge driver can be any of:

- I2C bus, up to 8 MD03 modules, switches selectable addresses.
- 0V-2.5-5V analog input. 0V full reverse, 2.5V center stop, 5V full forward.
- 0V-5V analog input with separate direction control.
- RC mode. Controlled directly from the RC receiver output.

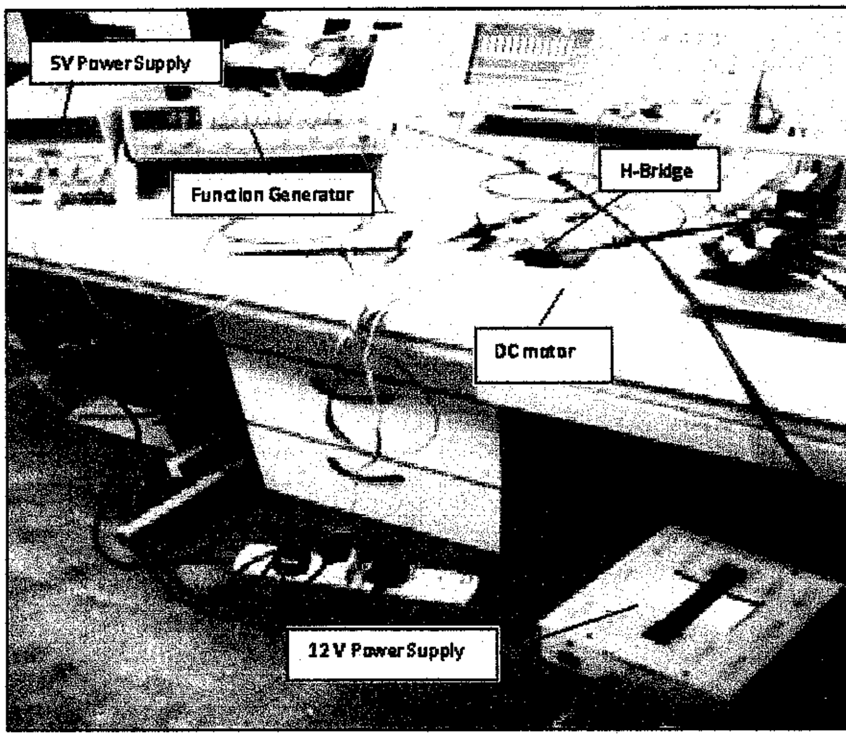

Figure 12: VNH3SP30 H-bridge Connections

After that, the duty cycle of the PWM is varied, and the monitored mean voltage is recorded. The testing is repeated with varies PWM values of Hz such as 1 kHz, 2 kHz and 3 KHz.

The obtained results, when (IN_A = 0, and IN_B = 1), and when (IN_A = 1, and IN_B = 0) with CH1=2V, CH2=10V, DT=400μs, are recorded as below:

Table 4: Recorded Data for $IN_A = 0$, $IN_B = 1$

IN_A = 0, IN_B =1,	***Duty Cycle***	**20%**	**40%**	**60%**	**80%**
PWM = 1kHz	***Mean(V)***	2.32	3.34	6.54	7.04
	RMS(V)	4.87	5.86	8.1	8.52
IN_A = 0, IN_B =1,	***Duty Cycle***	20%	40%	60%	80%
PWM = 2kHz	***Mean(V)***	2.09	2.57	4.3	3.94
	RMS(V)	4.35	5.04	6.66	6.44
IN_A = 0, IN_B =1,	***Duty Cycle***	20%	40%	60%	80%
PWM = 3kHz	***Mean(V)***	1.9	2.74	2.9	2.84

Table 5: Recorded Data for IN_A= 1, IN_B= 0

$IN_A = 1, IN_B = 0,$ $PWM = 1kHz$	***Duty Cycle***	20%	40%	60%	80%
	Mean(V)	-12.2	-12.2	-12.2	-12.2
	RMS(V)	12.2	12.2	12.2	12.2
$IN_A = 1, IN_B = 0,$ $PWM = 2kHz$	***Duty Cycle***	20%	40%	60%	80%
	Mean(V)	-12.2	-12.2	-12.2	-12.2
	RMS(V)	12.2	12.2	12.2	12.2
$IN_A = 1, IN_B = 0,$ $PWM = 3kHz$	***Duty Cycle***	20%	40%	60%	80%
	Mean(V)	-12.2	-12.2	-12.2	-12.2

And the obtained graphs for $IN_A = 0$, $IN_B = 1$are as below:

Figure 13: PWM = 20% and f = 1 kHz

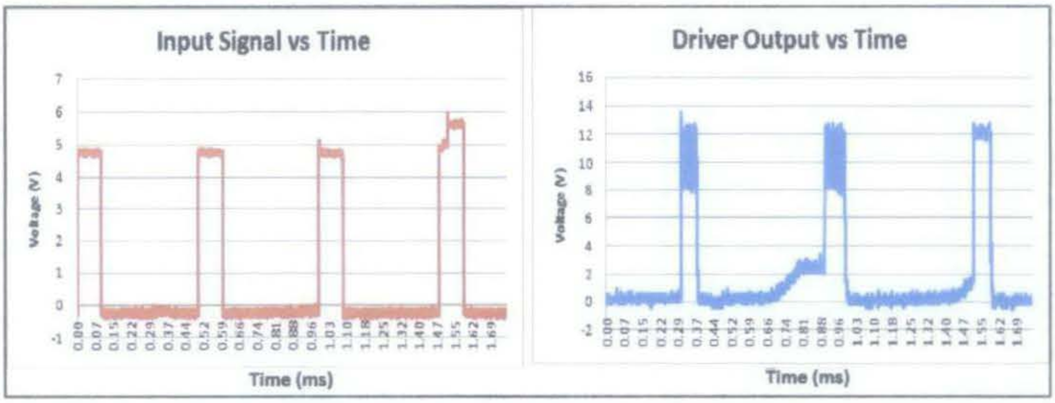

Figure 14: PWM = 20% and f = 2 kHz

For the rest of the obtained graphs of PWM variations (40%, 60%, 80%), please refer to appendix C

4.1.3 Implementation and Testing of the Control System without PID controller

In this part of implementation, the control system has been tested without using the PID controller to ensure that the electronic throttle is working properly. In this testing, PWM duty cycles of 25%. 50% and 75% are sent as input to the control system in order to check the response of the electronic throttle blade's opening. The obtained result is as shown in Figure below:

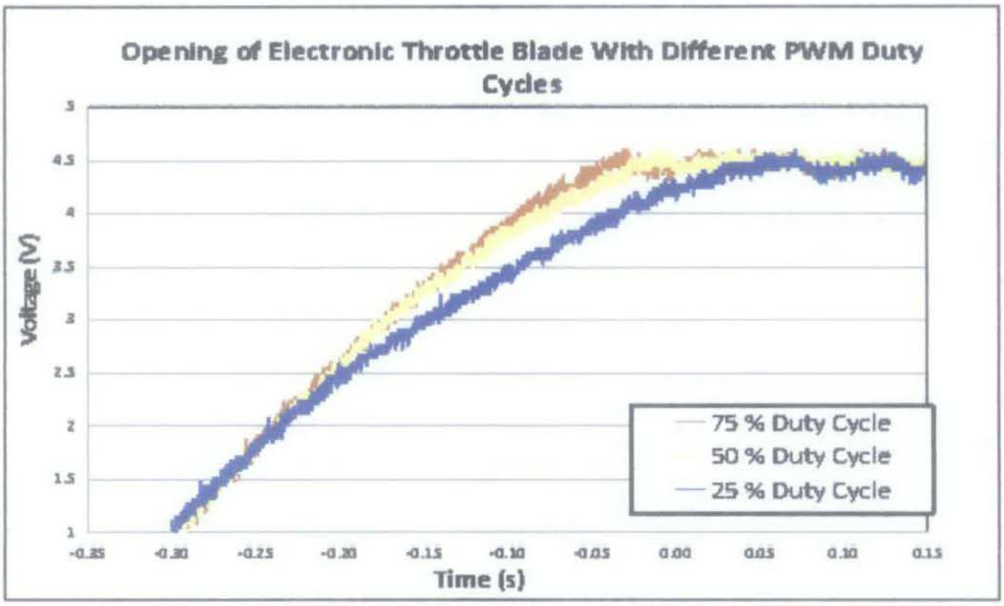

Figure 15: Opening of Electronic Throttle Blade with Different PWM Duty Cycles

4.1.4 Implementation and Testing Using PID controller

In this part of implementation on hardware, the PID controller is used as a main part of the control loop system. This implementation is conducted by tuning the PID parameters using Ziegler-Nichols tuning method. The software used for this implementation is Lab VIEW software as it is already installed in the computer used at UTP'S automotive research center and LG lab.

In the Lab VIEW software installed in the control system, the proportional gain, K_c is set to 0.35, the Integral time is set to 0.0152715 minutes, and the derivative time is set to 0.0038179 minutes. This is to check the response of the opening of the electronic throttle blade. After setting these values, the set-point has to change from 18 to 35 and the tuning has to quickly change from manual tuning to PID tuning. The data has to be recorded as the response of the throttle blade's opening occurs.

We have chosen various values of the proportional gain(K_c), as we increase it in little increments in order to get oscillation so we can calculate the oscillation period and get accurate PID parameters for tuning process.

The obtained result when proportional gain, $K_c = 0.35$ is as below:

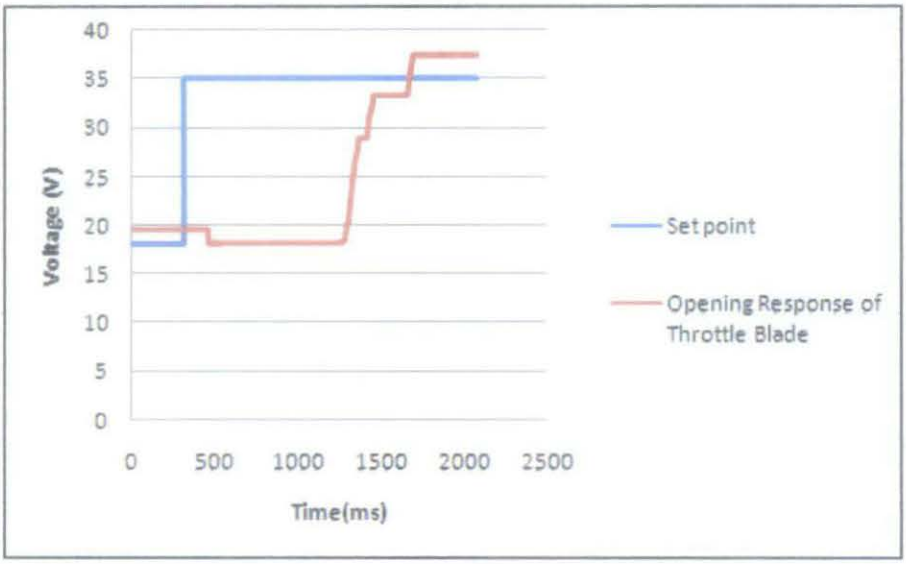

Figure 16: Opening Response of Throttle Blade when Kc = 0.35

The obtained result when proportional gain(K_c) equals 0.55, is shown as below:

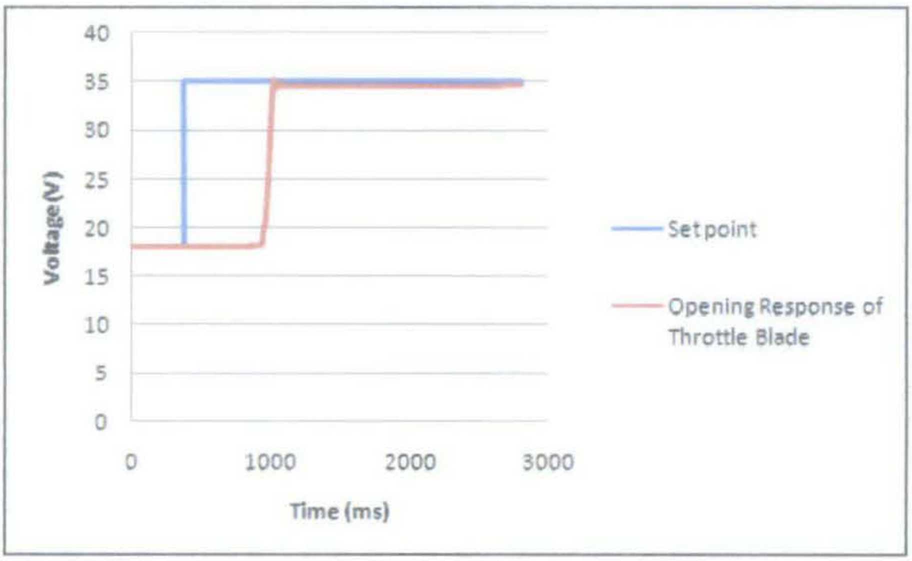

Figure 17: Opening Response of Throttle Blade when Kc = 0.55

Besides, the result obtained when proportional gain(K_c) equals 0.65, is shown as below:

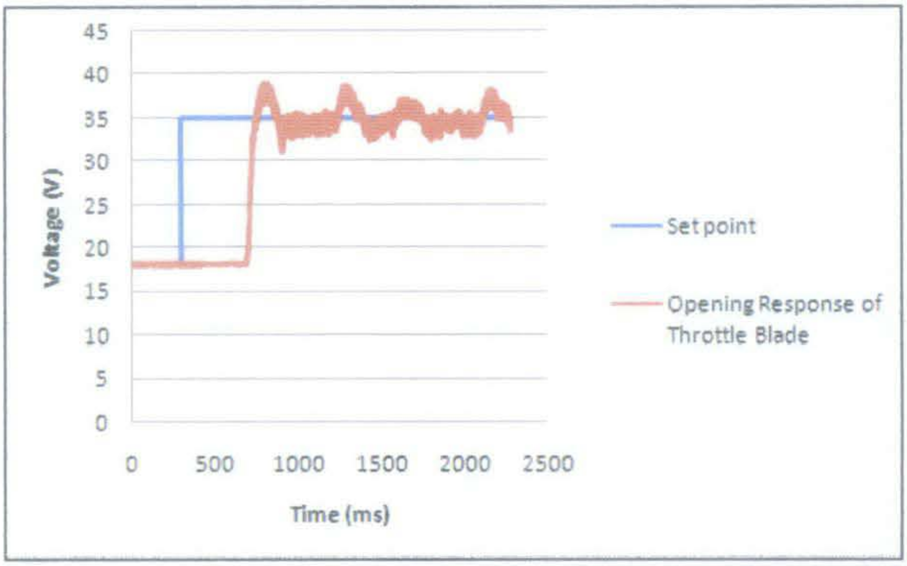

Figure 18: Opening Response of Throttle Blade when Kc = 0.65

Also, the result obtained when proportional gain(K_c) equals 0.75, is shown as below:

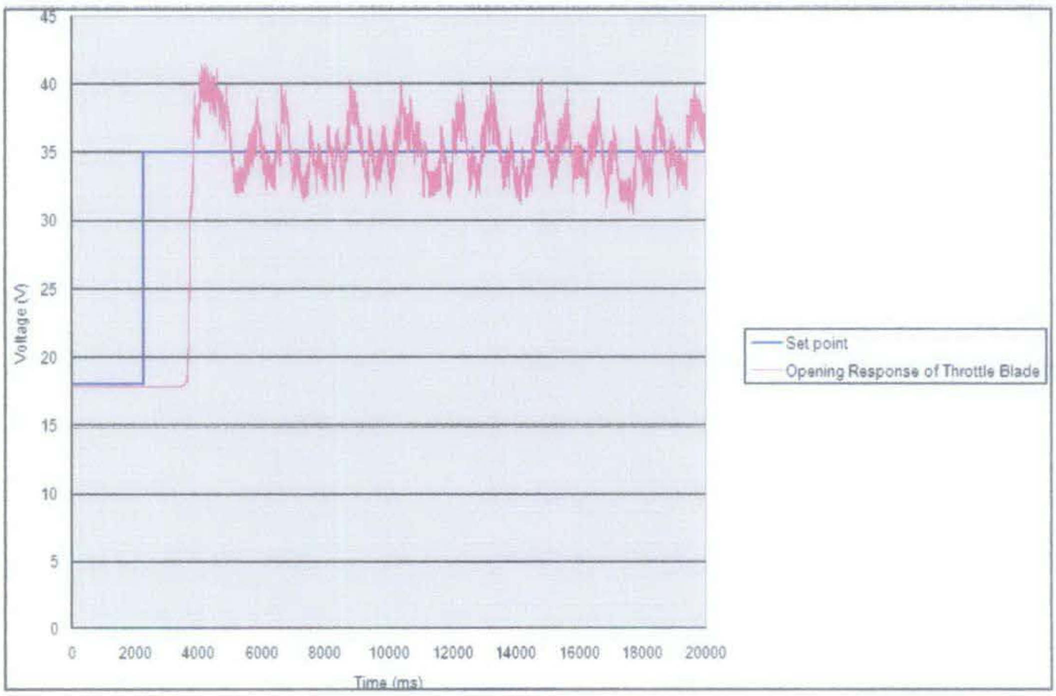

Figure 19: Opening Response of Throttle Blade when Kc = 0.75

The oscillation period (from peak to peak) equals 7000 – 5250 = 1750 ms

4.2 Discussion

4.2.1 Analysis of Testing MD03 - 50Volt 20Amp H Bridge Motor Driver

After varying the duty cycle of the PWM signal, there is no output signal monitored on the screen. This means that this H-bridge driver does not function properly and is probably damaged. Thus, we ordered a new H-Bridge driver in order to complete this project. The ordered H-Bridge is VNH3SP30 from Pololu Robotics and Electronics Company. This ordered H-bridge has taken three weeks for shipping from Singapore to UTP. After receiving this H-Bridge driver, we did some testing on it to check its function as well as performance before connecting it to the Electronic Throttle and Controller.

4.2.2 Analysis of Testing VNH3SP30 Fully Integrated H-Bridge Driver

All outputs have the same square-waveform voltage corresponding to the square-waveform input signals. Besides, the as the time period gets shorter, the frequency gets higher as shown in the graphs obtained.

The duty cycle of the input signal carries over to the output waveform (same duty cycle input and output). However, each PWM duty cycle will result in different levels of average effective voltage going to the load (in this case the DC motor coil). Besides, the mean voltage (effective voltage) shown in Figure 13, with a PWM at 1 kHz will be better in use as it is close to the ideal values of the PWM and Effective Voltage.

When IN_A= 1, and IN_B= 0, the mean voltage remains at -12.2. This because the Dc motor used is one directional DC motor not bidirectional motor. Thus, the reading of the mean voltage does not change even with different PWM values applied.

4.2.3 Analysis of Testing the Control System without PID controller

As shown in Figure 15, The PWM (%) has a linear relationship with the effective voltage and the effective current as well. For instance, if the PWM has a duty cycle of 25%, the effective voltage will be 3V. If the PWM has a duty cycle of

50%, the effective voltage will be 6V and if the PWM has a duty cycle of 100%, the effective voltage will be 12V.

From the obtained results, as Duty Cycle increases, the Effective voltage increases as well. More effective voltage means more current flow means more torque applied, thus, as the torque increases, the speed response of the Electronic Throttle Blade increases.

4.2.4 Analysis of Implementation and Testing Using PID controller

As shown in Figure 21 below, the PID controller receives an error that equals to set point minus the process variable (e = SP - PV). The PID controller controls the opening of throttle blade by a closed loop system. This PID controller defines the voltage signal supplied to the motor of the electronic throttle. The output of the PID controller is a PID % that enters the EGU unit as input to give a torque as output signal.

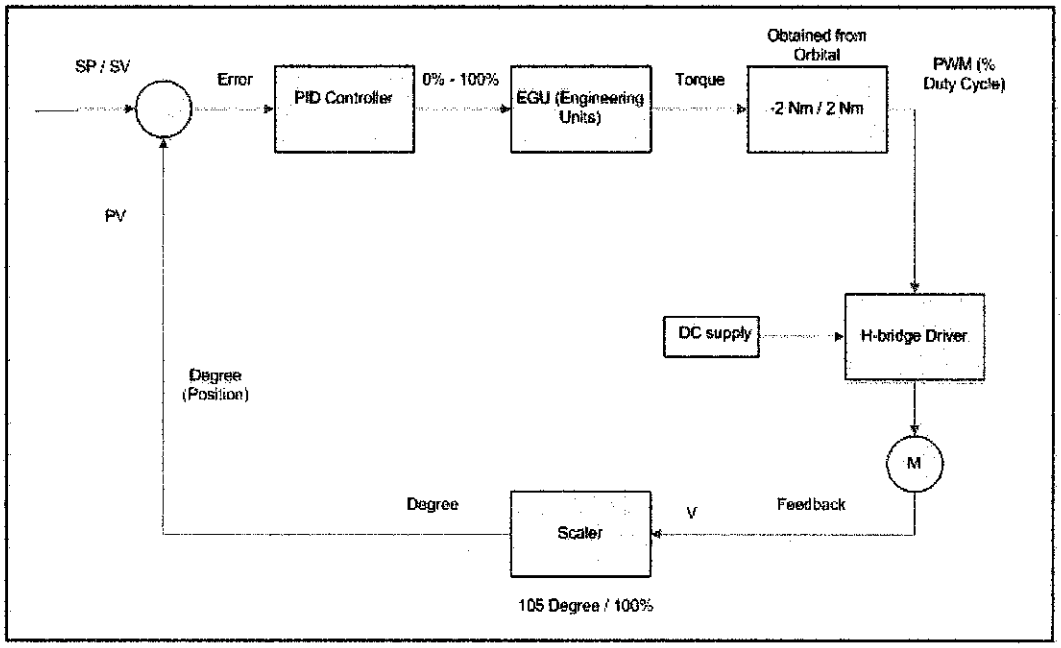

Figure 20: analysis of Control System PID controller

A potential meter is used for the throttle to get more accurate output. The torque has values of 2Nm and -2 Nm as stated in Orbital datasheet because the graph available from Orbital goes from-2Nm to 2Nm. The output of this map is PWM duty cycle that enters the H-bridge driver as input. In fact, H-bridge driver is one way used to push the electronic throttle blade and power the motor of the throttle. The output of the throttle motor is voltage that enters a scaler and converts to a degree opening of the throttle blade position. Thus, the degree (Position %) is feedback to the PID controller that compares the error and does appropriate actions and calculations to accurate the control system performance.

As shown in Figure 16, when proportional gain, $K_c = 0.35$, the response time taken for the throttle blade to be opened is 10.25 s. this means that the performance of the opening of the throttle blade is not acceptable. When the proportional gain, $K_c = 0.55$, the time taken is 7.98s and the obtained graph (Figure 17) shows that the performance is more stable as compared to Figure 16.

Besides, as shown in Figure 18, the opening response of throttle blade when Kc = 0.65, is started to oscillate (unstable). For the graph obtained in Figure 19, the value of the proportional gain, $K_c = 0.75$ is chosen for Ziegler-Nichols method in order to calculate the values of P, PI and PID.

From Figure 19, the oscillation time = 1750 ms. This time is used to fill the Ziegler-Nichols closed loop tuning correlations. In addition, the sampling rate equals: 1 second / 200 samples as used =0.005s = 0.005 * 1000 = 5 ms. Thus, every 2 samples, the PID controller makes one decision.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

As a conclusion, the use of electronic throttle can be clearly noticed in modern automotive engines. Therefore, electronic throttle for drive by wire applications needs a very good control strategy. Obviously, beside the voltage and the potentiometer resistance, the angle (θ) and torque (τ) play a very important role in controlling the opening of the throttle blade into a certain position.

This project investigates the performance of the electronic throttle blade by using PID controller, H-bridge driver and Lab-VIEW software. The PID controller is used to correct the error between a measured process variable and a desired set point in order to make an accurate decisions and actions to control the system. The H-bridge driver is used to power the throttle motor and ease the opening process of the throttle blade. The well functioned H-bridge driver, the more accurate values can be obtained in this project.

The relation between the pulse with modulation (PWM) and the effective voltage and current is linear. Thus, more duty cycle means more effective voltage. More effective voltage means more current flow means more torque applied, thus, as the torque increases, the speed response of the electronic throttle blade increases.

As objectives of this project, the implementation and testing on hardware has performed, and the control system has been characterized. The report shows a good and reliable strategy (PID control strategy) that can help achieving as well as developing good safety system. In addition, the report introduced the basic theory and the overall methodology to successfully run the project and gain accurate results in term of controlling the opening of the throttle blade.

5.2 Recommendation

As a recommendation, a heat sink has to be installed on the H-bridge driver to sink the temperature produced in side H-bridge driver so the H-bridge can be protected from damage. As known, all components including inductors, capacitors and circuits have maximum operating temperature as specified by manufacturer. More temperature means less reliability of H-bridge driver, thus it needs a heat sink to reduce its temperature.

It is recommended to have a gain-scheduled PID tuning in order to ease the tuning process and obtain more accurate and specified results and data. Besides, by using the gain-scheduled PID, the control system performance could be improved by using this method.

It is also recommended to check every single connection before doing the implementation and testing part on hardware. Since misconnections of the components may lead to a huge damage of the components and also will give inaccurate readings and data.

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APPENDICES

Appendix A: Project Gantt chart

Appendix B: Closed and Open Loop-Quarter-Decay Ratio Values

Appendix C: Obtained Graphs for Testing VNH3SP30 Fully Integrated H-Bridge Driver

APPENDIX A

PROJECT GANTT CHART

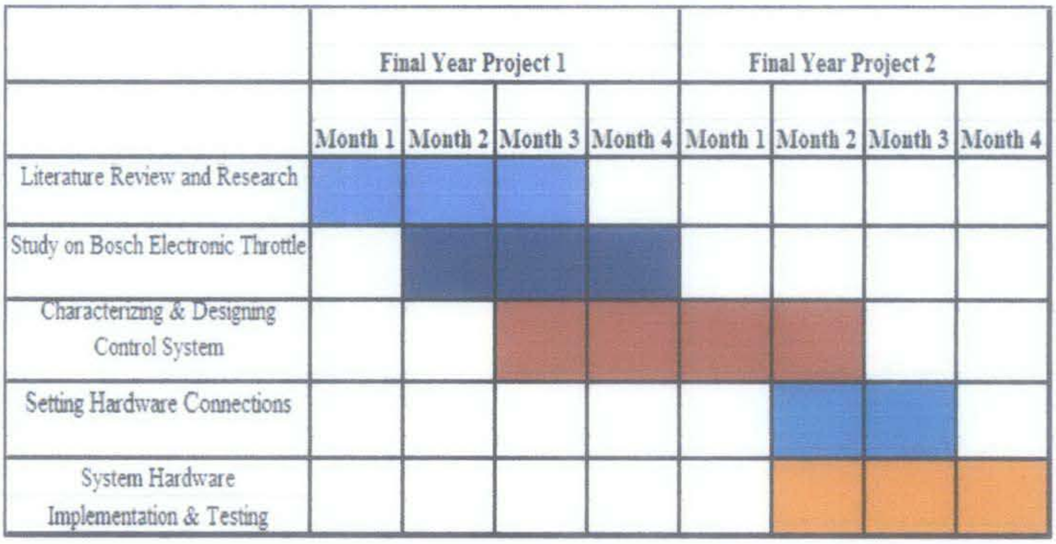

Figure 21: Project Gantt chart

APPENDIX B:

CLOSED AND OPEN LOOP-QUARTER-DECAY RATIO VALUES

Table 6: Closed Loop-Quarter-Decay Ratio Values

Controller	PB (percent)	Reset (minutes)	Rate(minutes)
P	2.00 *PBu*	-	-
PI	2.22 *PBu*	0.83 *Tu*	-
PID	1.67 *PBu*	0.50 *T Tu*	0.125 *Tu*

K_c *(Proportional gain) = 100/PB*

Table 7: Open- Loop-Quarter-Decay Ratio Values

Controller	PB (percent)	Reset (minutes)	Rate(minutes)
P	100 $K T_d/T$	-	-
PI	110 $K T_d/T$	$3.33T_d$	-
PID	80 $K T_d/T$	2.00 $T T_d$	0.50 T_d

APPENDIX C:

OBTAINED GRAPHS FOR TESTING VNH3SP30 FULLY INTEGRATED H-BRIDGE DRIVER

Figure 22: PWM=20% & f=3kHz

Figure 23: PWM=40% & f=1 kHz

Figure 24: PWM=40% & f=2 kHz

Figure 25: PWM=40% & f=3 kHz

Figure 26: PWM=60% & f=1 kHz

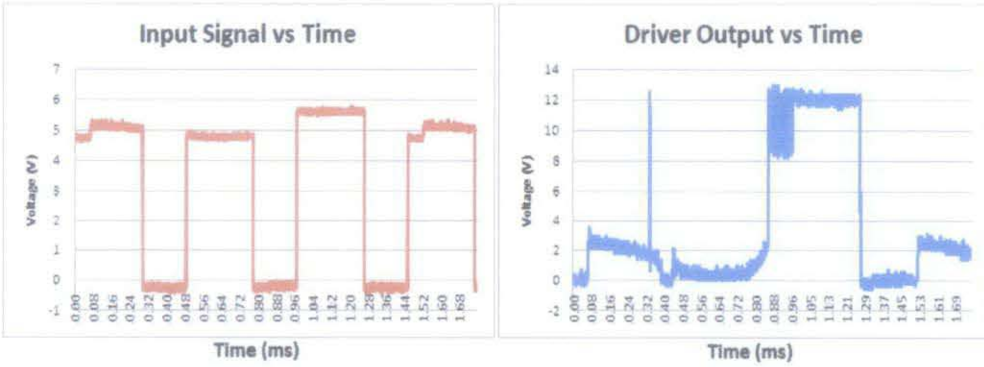

Figure 27: PWM=60% & f=2 kHz

Figure 28: PWM=60% & f=3 kHz

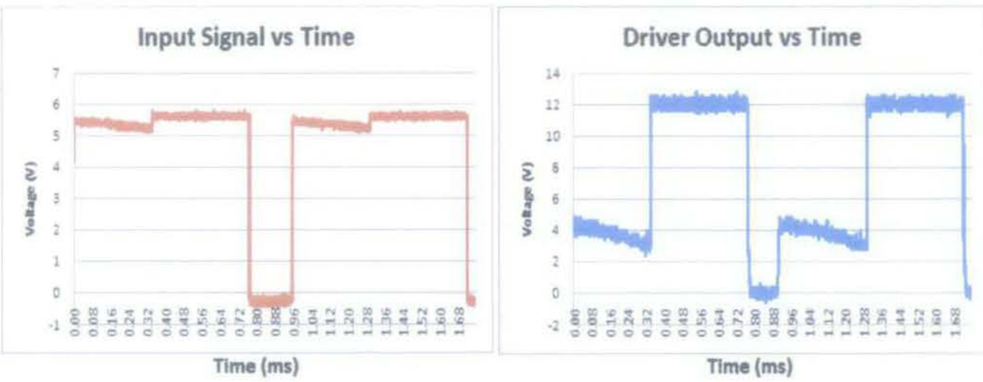

Figure 29: PWM=20% & f=1 kHz

Figure 30: PWM=80% & f=2 kHz

Figure 31: PWM=80% & f=3 kHz