THROTTLE-BY-WIRE (TBW) FOR RETROFIT CONVERSION OF HYBRID ELECTRIC VEHICLE (HEV) USING NI COMPACT RIO & LABVIEW

By

ABDUL AZEEM BIN MOHAMED MOHIDEEN

FINAL PROJECT REPORT

Submitted to the Department of Electrical & Electronic Engineering
in Partial Fulfillment of the Requirements
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CERTIFICATION OF APPROVAL

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Approved:

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Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

June 2013

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.

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Abdul Azeem bin Mohamed Mohideen

ABSTRACT

Conventional throttle body in a vehicle is controlled mechanically via cable and this project propose a method for replacing the conventional throttle body with an electronic throttle body (ETB) and fine-tune the system in order to implement electronic throttle-by-wire (TBW) for retrofit conversion of hybrid electric vehicle (HEV) to enable diligent control of throttle valve by using National Instrument's compact Reconfigurable Input Output (cRIO) hardware and Laboratory Instrumentation Engineering Workbench (LabVIEW) graphical user interface (GUI).

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LIST OF ABBREVIATIONS

APP – Accelerator Pedal Position

CRIO – Compact Reconfigurable-Input-Output

ETB – Electronic Throttle Body

ETC – Electronic Throttle Control

GUI – Graphical User Interface

LabVIEW – Laboratory Virtual Instrumentation Engineering Workbench

MV – Manipulated Variable

NI – National Instrument

PID – Proportional-Integral-Derivative

PV – Process Variable

PWM – Pulse Width Modulation

SP - Setpoint

TPS – Throttle Position Sensor

Z-N – Ziegler Nichols

CHAPTER 1
INTRODUCTION

1.1 Background

Lately, the demand for renewable energy increases due to depletion of fossil fuel in earth. This phenomenon has raged the scientist and engineers to find a sustainable energy source in order to preserve the remaining fossil fuel for the future generation. Previously most of the transportation sectors rely solely on petrol and diesel as the source of energy. Recently, development of hybrid technology has changed the face of automotive industry. Nowadays car manufacturers are looking into implementing hybrid technology in their vehicles to capture the automotive market with fuel saving features [2].

In conjunction to that approach, most of the car manufacturer's keen to invest in hybrid technology research lately. UTP's CAREM has utilized this opportunity to take the challenge in developing a Retrofit Conversion kit for Hybrid Electric Vehicle (HEV) since 2007 [3].

The main purpose of this project is to design and implement the Throttle-by-Wire (TBW) into retrofit converted Hybrid Electric Vehicle (HEV). Conventional throttle body control system uses accelerator pedal to pull the cable that is attached to the pulling mechanism on throttle body in order to open the butterfly valve to allow air flow in and mix with fuel inside the engine to initiate combustion.

The idea behind, implementing TBW is to reduce the weight and complexity of mechanical assembly used to control the conventional throttle body with an electronic throttle body and equip the existing accelerator pedal with pedal position sensors to enable diligent throttle valve opening for rich, lean or stoichiometric combustion.

1.2 Problem Statement

Basically, the challenges involved in this project are such as listed below:

i. Understand the concept of modern electronic control of throttle.
ii. Determine the characteristic of electronic throttle body (ETB) response in order to fine-tuning the close-loop throttle position control system.
iii. Integration of hardware and software for TBW using NI Compact RIO & LabVIEW 2012.

1.2.1 Project Feasibility

This project considerably feasible since UTP's CAREM has sufficient resources in order to complete this project successfully within the given time frame as specified in proposed Gantt chart.

1.2.2 Project Relevancy

The project is relevant since the demand for hybrid cars increases substantially due to its capability of fuel and money saving. Now days, almost everyone prefers to own a hybrid car unfortunately not everyone affords to change their cars due to their financial status. Thus, this project has been initiated to help those who wanted to convert their existing conventional car into HEV for improved fuel efficiency with minimal cost.

1.3 **Objective**

Following is the objectives of the project:

i. Replacement of mechanical cable-driven throttle body with an electronic throttle body (ETB).
ii. Configuration of interface & power circuitry for ETB.
iii. NI Compact RIO controller programming & configuration for electronic control of throttle.
iv. Dynamic simulation & tuning of close-loop throttle position control system via LabVIEW 2012.

CHAPTER 2
LITERATURE REVIEW

2.1 Hybrid Electric Vehicle (HEV)

Hybrid Electric Vehicle (HEV) is an integration of electric motor with Internal Combustion Engine (ICE) in order to create a propulsion system. HEVs also can be classified into several architectures based on the different manners in which the hybridization can occur such as series hybrid, parallel hybrid, series-parallel hybrid, and etc. [4] as shown in Figure 1 below.

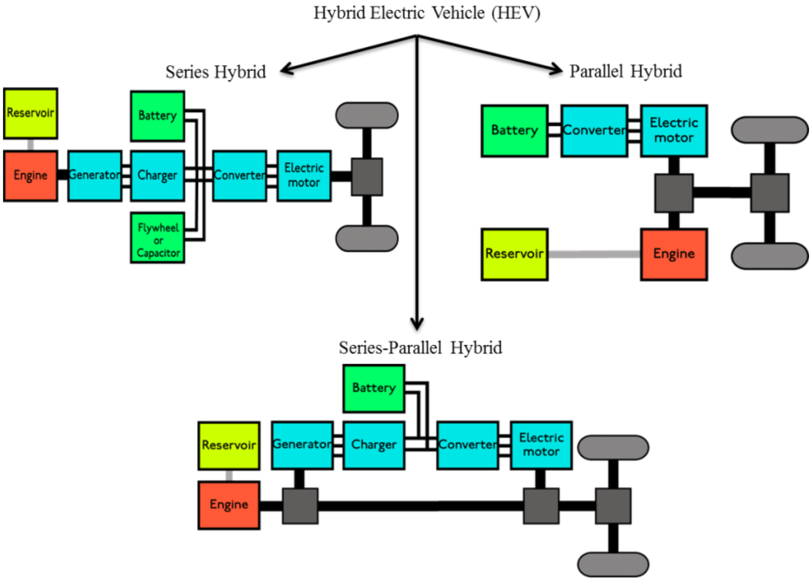

Figure 1: Different types of HEV Architectures

In this project, a team of lecturers and FYP students work together in developing a Retrofit Conversion kit for Hybrid Electric Vehicle (HEV) and initially will be implemented on Perodua MyVI. This project is an initiative of UTPs CAREM. The author involved in designing and implementing the Throttle-by-Wire (TBW).

2.2 Electronic Throttle Body (ETB)

Electronic Throttle Body (ETB) which consists of butterfly valve and Throttle Position Sensor (TPS) as shown in Figure 2, plays an important role in allowing air intake to the combustion chamber for enabling efficient & low-emission fuel burning in gasoline engines [5].

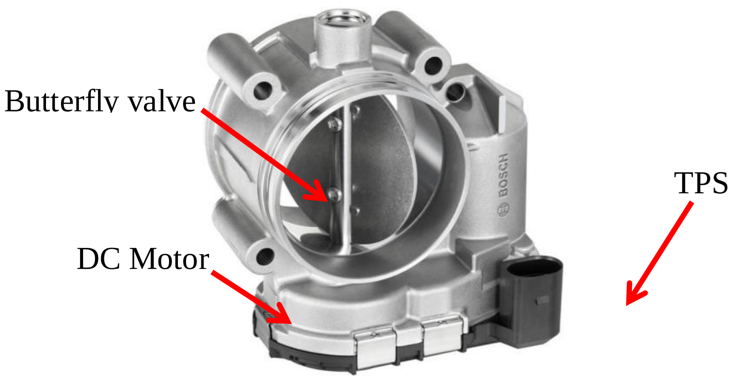

Figure 2: BOSCH DV-E5 Electronic Throttle Body [5]

Motion of the piston inside cylinder creates an acceleration force for the car. Where else, the throttle valve openings have significant impact in improving fuel efficiency. Research shows that if a car accelerates in Wide Open Throttle (WOT), it able to reach desired speed with less fuel with some additional conditions [6].

Literally, there are 3 types of combustion occurring in any Internal Combustion Engine (ICE) and they are rich, stoichiometric and lean combustion [7]. Throttle valve is the one actually controls the air flow to achieve different types of engine response such as high performance with rich combustion, moderate performance with stoichiometric combustion and high fuel efficient with lean combustion. Basically, more and smooth air flow to the engine will reduce the amount of fuel consumption.

2.3 Electronic Throttle Control (ETC)

Electronic Throttle Control is an important subsystem in engine air control. Basically, the ETC system controls the opening of ETB's butterfly valve significant to the position of accelerator pedal via close-loop control algorithm in Engine Control Unit (ECU). ETC system is an armature-controlled linear system which does not require field circuit, in some cases ETB with separately excited DC motor requires field circuit for non-linear modeling as shown in Figure 3 below.

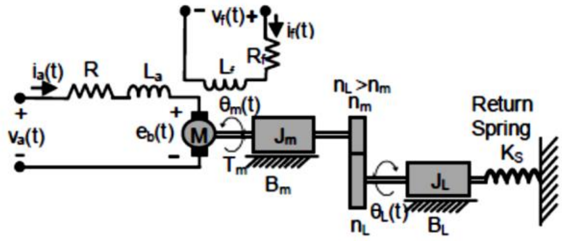

Figure 3 Electronic Throttle Control (ETC) System [8]

The entire ETC is a sealed module and can be treated as a single shaft mechanical system as shown above in Figure 3. The armature-controlled mathematical model of the ETC system is shown in the equation below [8]:

$$J_{eq}\dot{\omega}_L(t) + B_{eq}\omega_L(t) + K_s\theta_L(t) + T_{PL} + T_f\,\mathrm{sgn}(\omega_L) = \bar{K}_m i_a(t),$$

$$L_a\frac{di_a(t)}{dt} + R_a i_a(t) + \bar{K}_b\omega_L(t) = v_a(t),$$

The Simulink Design for ETC system simulation constructed as shown on page 33 to analyze the 2nd order response of the close-loop PID controller implementations.

2.4 PID Controller

Proportional-Integral-Derivative (PID) Controller is close-loop control system that corrects the error between a desired set point and a measured process variable. Literally, PID controller calculates and fixes any discrepancies in the process [9] [10]. Figure 4 below show the block diagram of PID Controller.

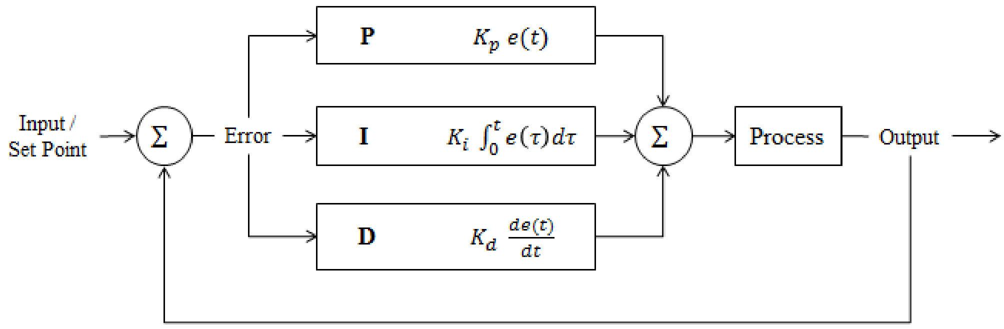

Figure 4: PID Controller Block Diagram [11]

The PID controller algorithm contains three separate parameters as follows:

i. Proportional value determines the reactions to the current error [11]

ii. Integral value determines the reaction based on the sum of recent errors [11]

iii. Derivative value determines the reaction to the changing rate of errors [11]

The equation below explains the relationship PID controller parameters explained above:

$$MV(t) = K_p \left[E(t) + \frac{1}{Ti}\int_0^{\infty} E(t')dt' - T_d \frac{dCV(t)}{dt}\right] + I$$

Where;

MV	: Manipulated variable
K_p	: Proportional gain
Ti	: Integral gain
T_d	: Derivative gain
I	: Bias

2.5 Throttle Position Sensor (TPS)

Throttle Position Sensor (TPS) are also known as angle sensor used in throttle body to determine the percentage of butterfly valve opening. Wide Open Throttle (WOT) or also called as full throttle significantly means the valves opening is almost 100% where maximum air flow allowed into the engine's combustion chamber for fuel burning.

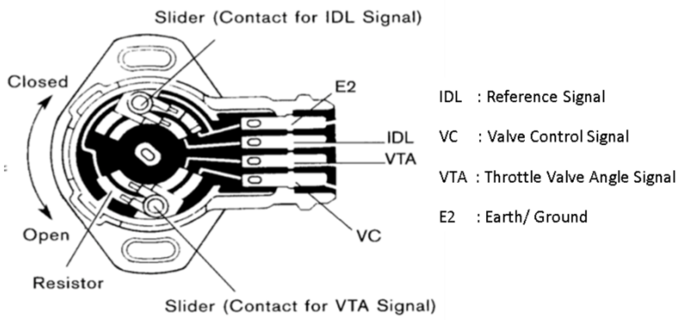

Figure 5: Cross Sectional View of TPS [12]

The TPS implies the basic concept of potentiometer to determine the angle of throttle valve by referring to voltage produced as shown in Figure 5 above. Basically when the valve is fully closed the Electronic Control Unit (ECU) will receives zero voltage (0 Volts) where else when the valve fully opened the TPS will send a signal reaching almost 5 Volts as shown in Figure 6 below. From the voltage signal received from TPS, ECU will send appropriate Pulse Width Modulation (PWM) signal required by servo motor to adjust the throttle body valve opening for desired engine response as discussed earlier.

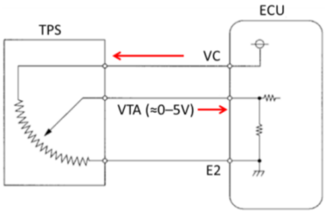

Figure 6: TPS Signal Response to ECU [10]

2.6 Accelerator Pedal Position (APP) Sensor

Accelerator Pedal Position (APP) Sensor is a pair of potentiometer or non-contact Hall Effect sensor that mounted onto the throttle pedal as shown in Figure 7 below. The APP sensor sends voltage signal to ECU in order to control the butterfly valve's opening angle on motorized throttle body. Basically, APP sensor operates in the same manner as TPS and both sensors used for controlling the electronic throttle body valve opening with compliment to each other [13].

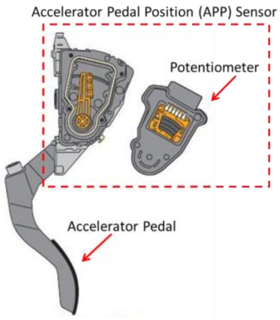

Figure 7: Accelerator Pedal Position (APP) Sensor [13]

2.7 NI CompactRIO

National Instruments (NI) CompactRIO module is a hi-tech embedded control and data acquisition system designed for specifically for high performance and reliability industrial applications [14]. NI CompactRIO is configured as Engine Management System (EMS) for this retrofit converted HEV project. Literally, NI CompactRIO controls all the subsystem of HEV. Usually, the NI CompactRIO hardware programmed using NI LabVIEW software. Figure 8 shows the picture of NI CompactRIO Module that will be used incorporate to TBW and for the complete retrofit conversion of HEV project generally.

Figure 8: CompactRIO Module [14]

Some of the attractive features of this device are the unsophisticated architecture of NI CompactRIO hardware, affordable price, and user friendly programming platform. Figure 9 below shows the basic Architecture of CompactRIO that consist of embedded real-time processor, a high-performance FPGA, and interchangeable I/O modules for controlling more devices or subsystems diligently.

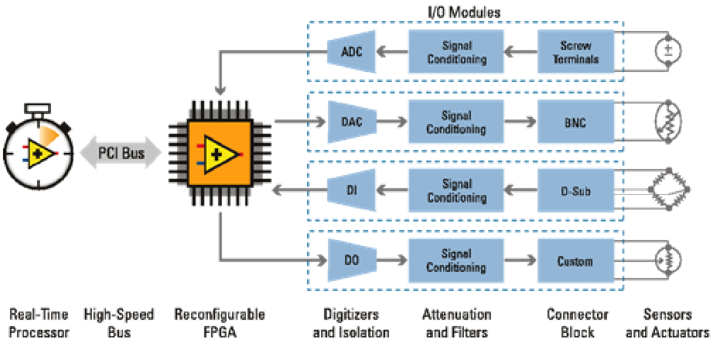

Figure 9: Architecture of CompactRIO [14]

2.8 NI LabVIEW

LabVIEW contains built-in data transfer mechanisms to pass data from the I/O modules to the FPGA and also from the FPGA to the embedded processor for real-time analysis, post processing, data logging, or communication to a networked host computer [14]. There is two kind of software available for programming NI CompactRIO Module which is the NI LabVIEW Real-Time, generally used for data acquisition purpose and where else NI LabVIEW FPGA used commonly for data logging purposes. Figure 10 below highlights the features of NI LabVIEW.

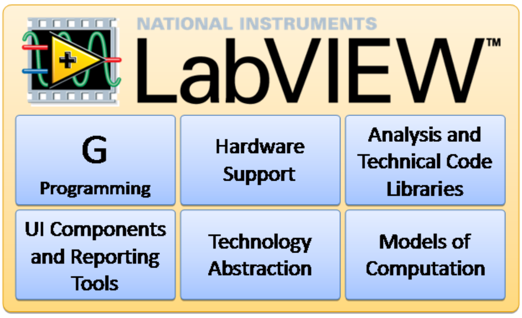

Figure 10: NI LabVIEW Software Features [14]

Some of the NI CompactRIO and NI LabVIEW applications that are widely implemented around the globe such as listed below:

i. Mobile/portable noise, vibration, and harshness (NVH) analysis

ii. Electrical power monitoring and power electronics control

iii. In-vehicle data acquisition, data logging, and control

iv. Servo-hydraulic and heavy machinery control

v. Machine condition monitoring and protection

vi. Remote and distributed monitoring

vii. Custom multi-axis motion control

viii. Embedded system prototyping

ix. Batch and discrete control

x. Embedded data logging

CHAPTER 3
METHODOLOGY

3.1 Research Methodology

Besides having strong literature review of the project, it is also necessary to have a strategic and feasible project planning to complete the project successfully within the given time frame. This section will discuss more on the proposed research methodology, project process flow, Gantt chart, tools and equipment that is required for this project. However this project will be completed in two phases where some of the procedures will be prepared during the first semester and the overall project will be completed on the second semester.

3.2 Key Milestone

Several key milestones are highlighted using simple flow chart in the following Figure 11 below:

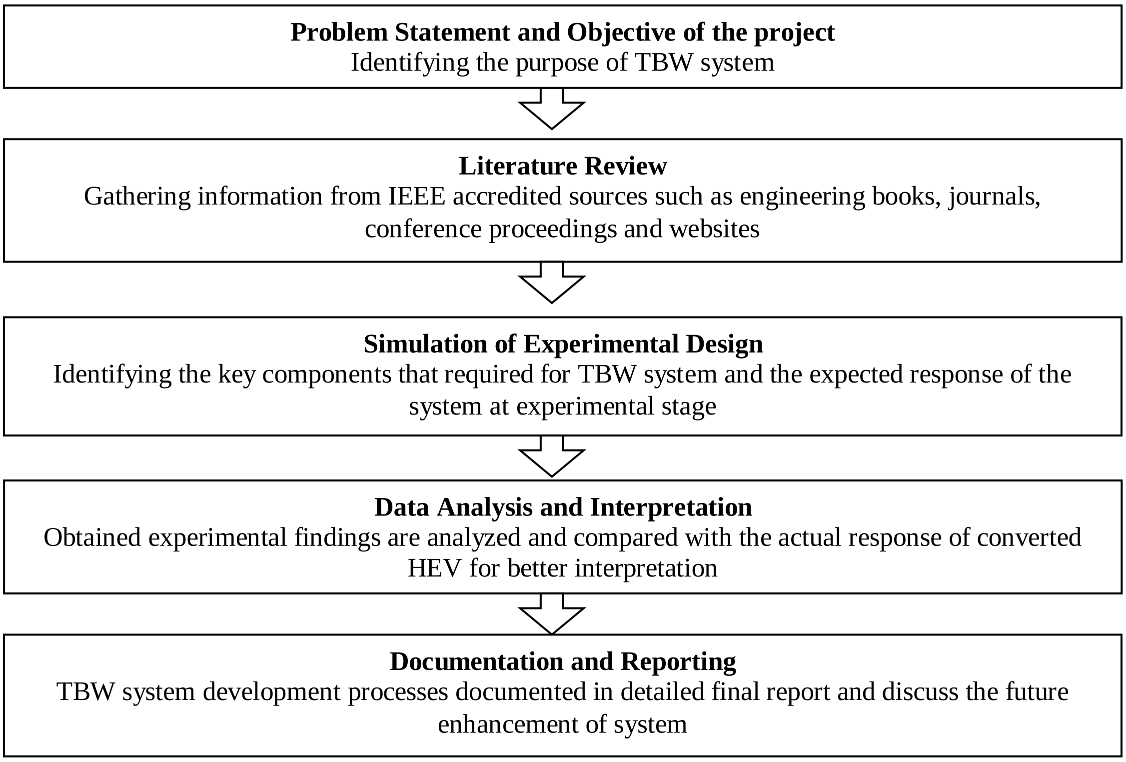

Figure 11: Key Milestone Flow Chart

3.3 Project Process Flow

Project process flow represented using flow charts for easy understanding of the overall process involved in completing the project as shown in Figure 12 below:

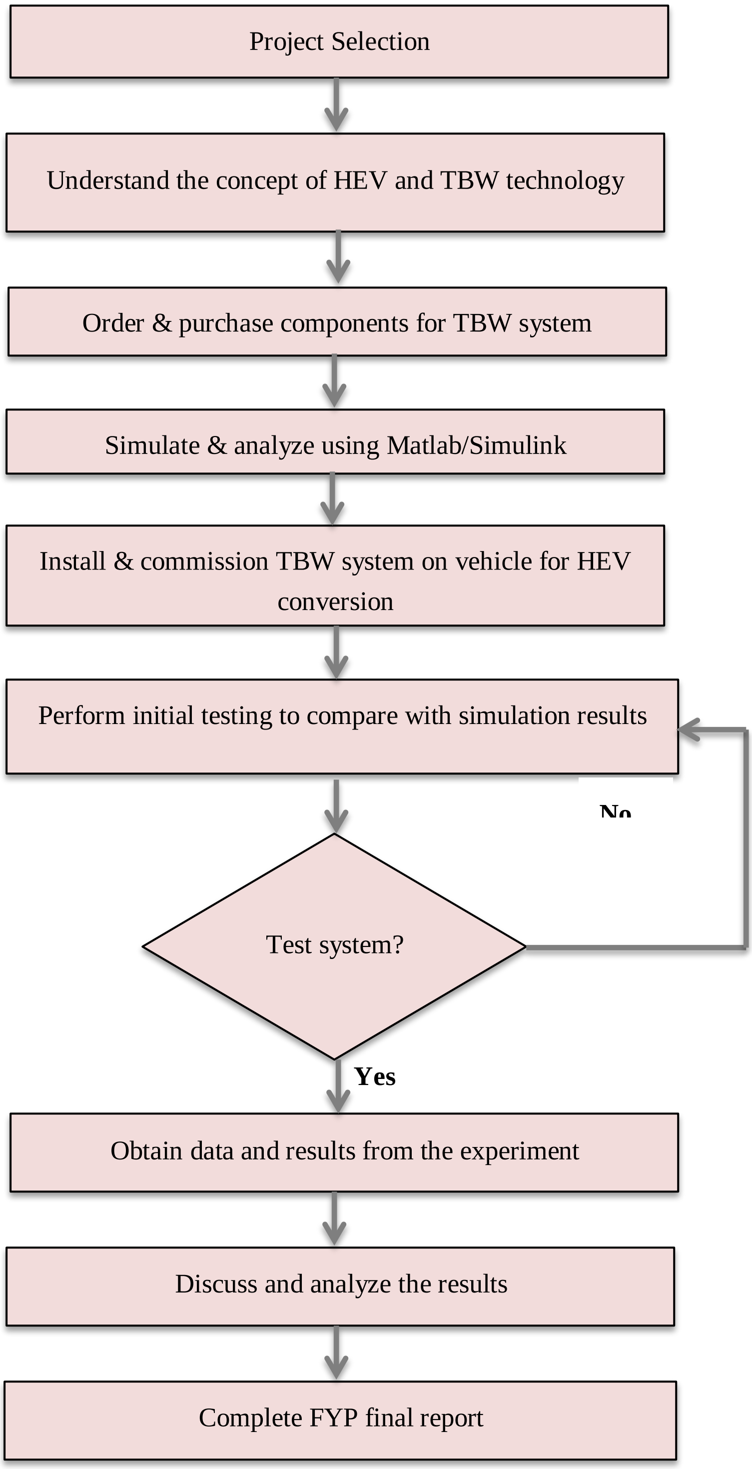

Figure 12: Project Process Flow Chart

3.4 Tools and Equipment

Hardware requirement:

i. Accelerator Pedal Position (APP) Sensor

Description:

A pair of potentiometer that sends pedal position to EMS in order to allow throttle valve opened electronically using motorized throttle body

Part Number: O 280 752 023

ii. BOSCH DV-E5

Description:

Motorized electronic throttle body with flange diameter, 50mm & bore diameter, 40mm equipped with angle sensor known TPS.

Part Number: O 280 750 149

iii. DRIVVEN Throttle Driver Module Kit

Description:

H-Bridge servo motor driver kit for controlling butterfly valve openings of electronic throttle body.

Part Number: 782081-01

iv. National Instruments CompactRIO (Model cRIO-9076)

Description:

Reconfigurable embedded control & acquisition system which act as EMS to integrate all subsystem of retrofit converted HEV.

Part Number: 781716-01

Software requirement:

i. Matlab Simulink 2009

ii. National Instruments LabVIEW 2012 Real-Time

iii. National Instruments LabVIEW 2012 FPGA

iv. Microsoft Visio 2010

CHAPTER 4
RESULT & DISCUSSION

4.1 Hardware Development

4.1.1 TBW Bench test & Tuning Setup

Components required to perform a functional test on TBW is listed in the Table 1 below. In addition for the test, a calibrated oscilloscope and Function Generator is required to measure PWM Output generated by the NI 9401 CompactRIO Digital I/O Module.

Table 1: TBW components for bench test & tuning setup

No	Component	Description
1	BOSCH DV-E5	Electronic Throttle Body equipped with TPS
2	Cytron MD 30C	H-Bridge Motor Driver that capable of handling 30A of peak current.
3	NI cRIO-9076	National Instrument's reconfigurable input /output embedded real time controller. Requires LabVIEW interface to operate.
4	NI 9401	National Instrument Digital Input / Output Module to generate PWM signal for the Motor Driver.
5	Throttle Pedal	Kelly throttle pedal for controlling the throttle valve opening.
6	NI 9201	National Instrument Analogue Input Module to process input signal 0V to +5V from APP & TPS.
7	Oscilloscope	Measure the Duty Cycle and Amplitude of generated PWM signal

Figure 13 below shows the TBW Bench test & Tuning Setup and it explains the physical connection of the TBW tuning system on bench. The pedal equipped with APP sensor and TPS will be connected to analogue input module NI 9201 on NI cRIO-9076 via an interface board. Where else the PWM generated by NI 9401 is connected to the MD 30C Motor Driver Board to control the BOSCH DV-E5 via the same interface board. The NI cRIO-9076 is supplied with regulated 24 VDC supply and the BOSCH DV-E5 is provided with a separate 12V battery supply. All sensor such APP and TPS which require +5V supply is provided with 5V via 5V regulator circuit on the interface board using the same 12V battery supply for the BOSCH DV-E5.

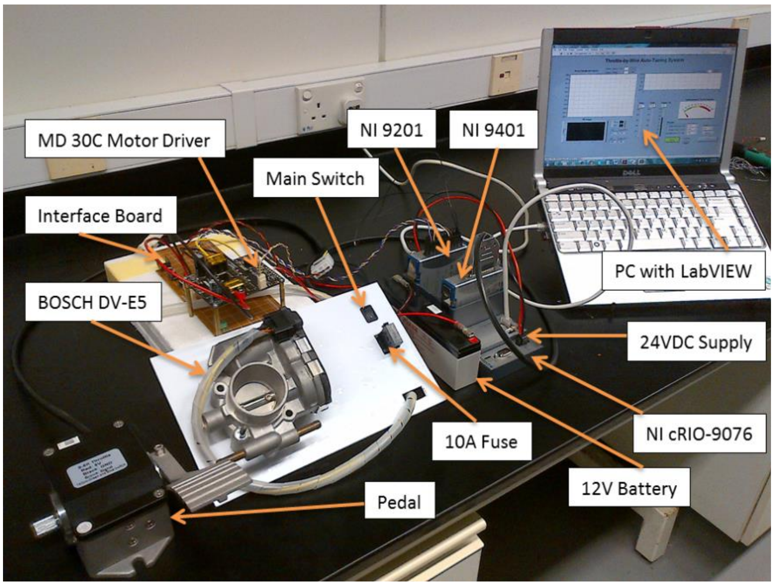

Figure 13: TBW Bench Test & Tuning Setup

Where else, Figure 14 shows the Motor Driver & Interface circuitry to provide common supply for all subsystem of TBW and grounding for all the input/output signals. MD 30C Motor Driver is integrated with an interface circuit in order to reduce the complexity of the TBW power & signal circuitry and also to increase the efficiency of space usage for installing the TBW on retrofit converted HEV.

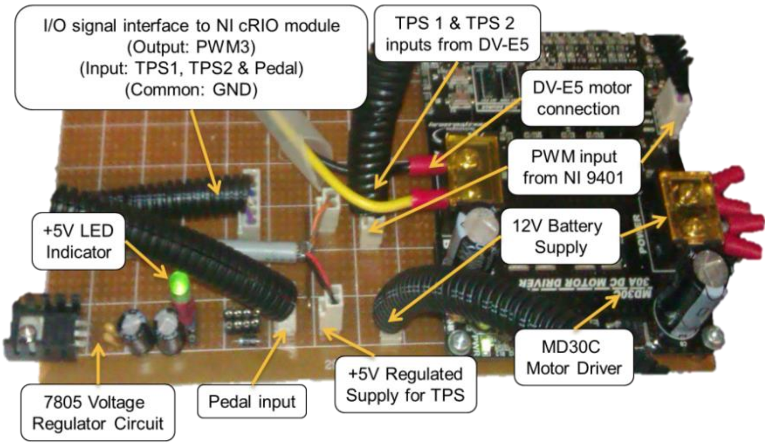

Figure 14: Motor Driver & Interface Circuitry

The subsystem is connected using specific wires for power (red color) and signal sending and receiving (blue color) as shown in the Figure **15** below and explained the connections and the type of cables used in the table beside it:

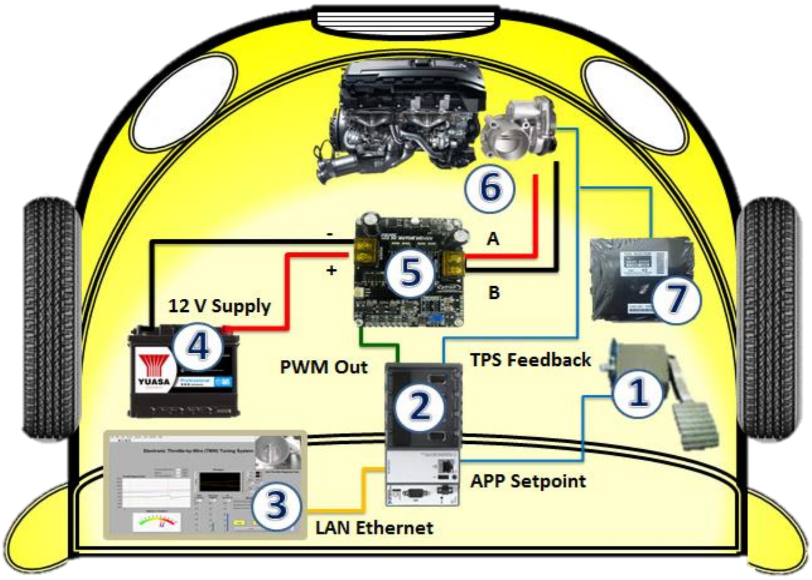

Figure 15: TBW On-Vehicle Block Diagram

No	Component	Description
1	Kelly throttle pedal	Throttle pedal with 0-5V APP
	0-5V APP	Setpoint signal to NI cRIO
2	NI cRIO 9076	CompactRIO controller
	NI 9401	DIO: PWM Out Module for MD30C
	NI 9201	AI: Analogue Input Module for APP & TPS
3	Acer Aconia Tablet	Monitor the throttle response via LabVIEW GUI
4	12V Battery	Power supply for MD30C & ETB
5	MD30C	H-bridge circuit for driving ETB
6	BOSCH DV-E5	Electronic Throttle Body
	0-5V TPS	Feedback signal to NI cRIO & ECU
7	ECU	Engine Control Unit

Table 2: Description of TBW Components on HEV Block Diagram

The detail wiring of TBW for on the vehicle implementation represented in the Figure 16 including all the signal lines and power lines involved for retrofit conversion HEV.

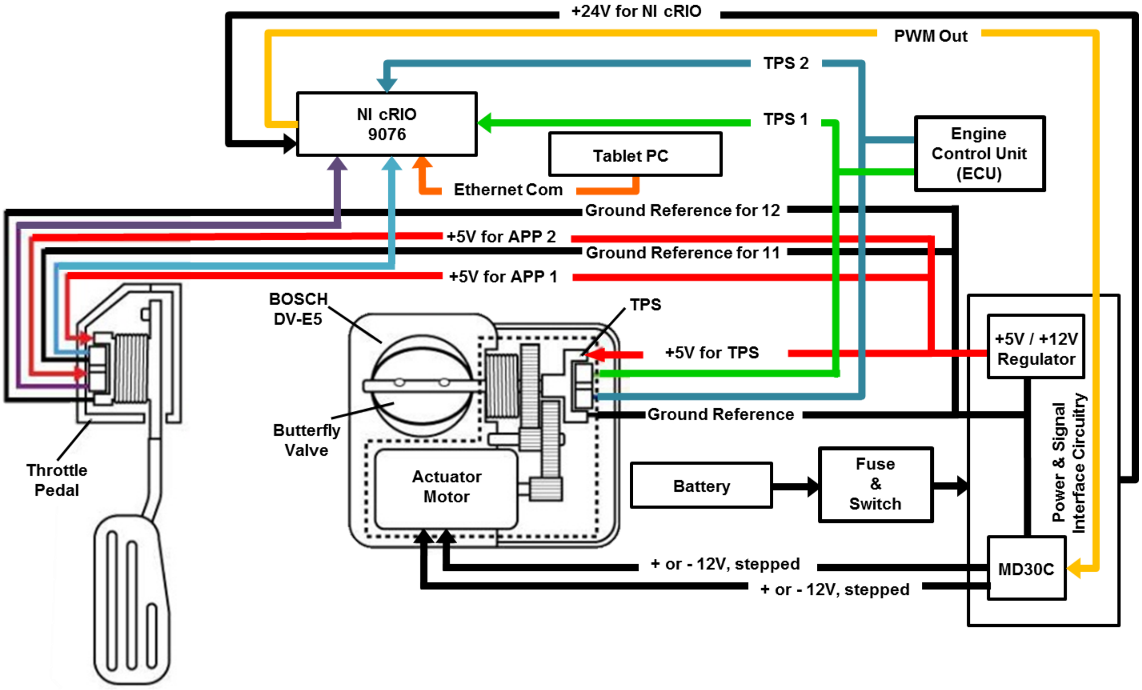

Figure 16: Detail wiring diagram of TBW on vehicle implementation

4.1.2 Wiring Schematic of TBW

Wiring diagram for TBW developed together with the connections of throttle pedal for controlling both ETB and the In-Wheel BLDC Motor via NI Compact RIO which will act as the Energy Management System (EMS) for the Retrofit Converted HEV as shown in Figure 17 and Figure 18 below. Thick red and black lines represent power lines and thin green lines represent signal lines on the TBW System wiring diagram.

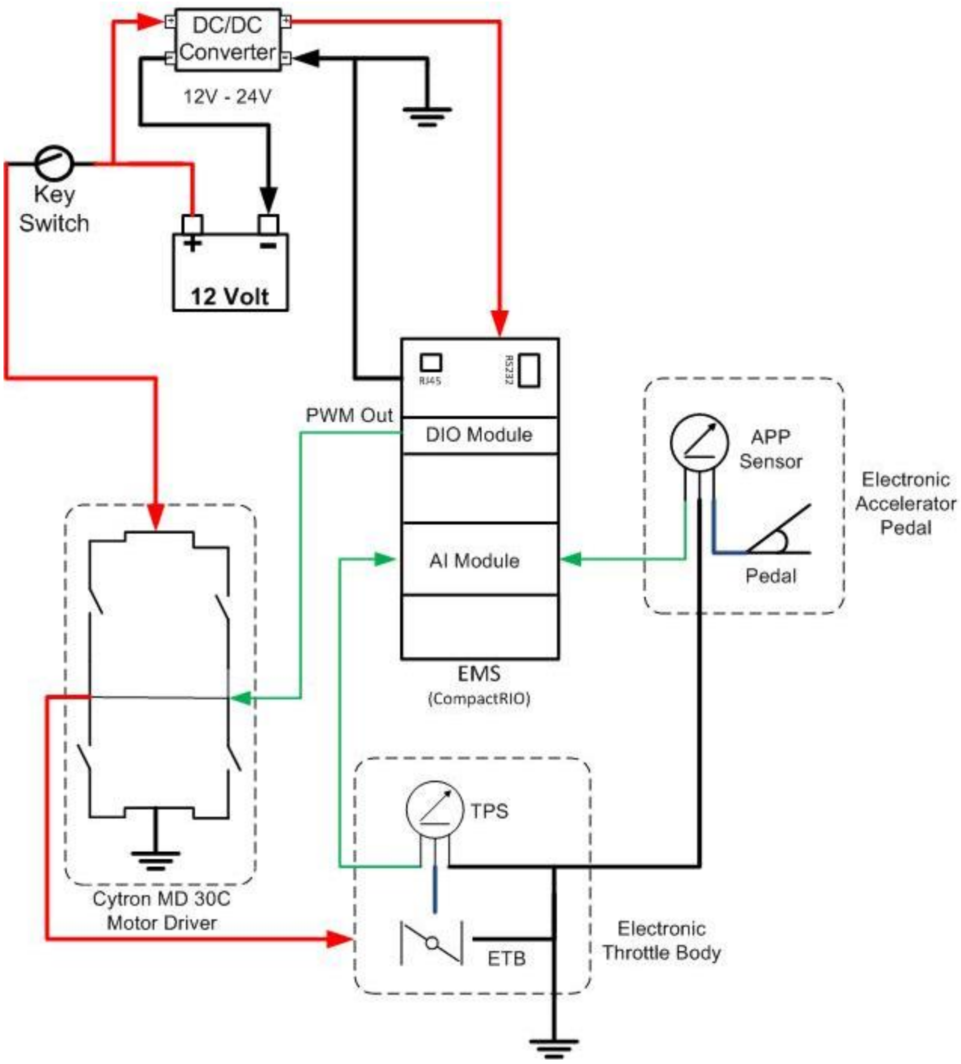

Figure 17: TBW Wiring Diagram for Bench Test & PID Tuning

The wiring diagram in Figure 17 earlier explains about the wiring connections only for bench test and tuning setup for the TBW system, where else in Figure 18 the diagram explains the actual wiring that will be implemented on the retrofit converted HEV using DRIVVEN Throttle Control Module which consist of built in Motor Driver & Analogue Input processing circuits.

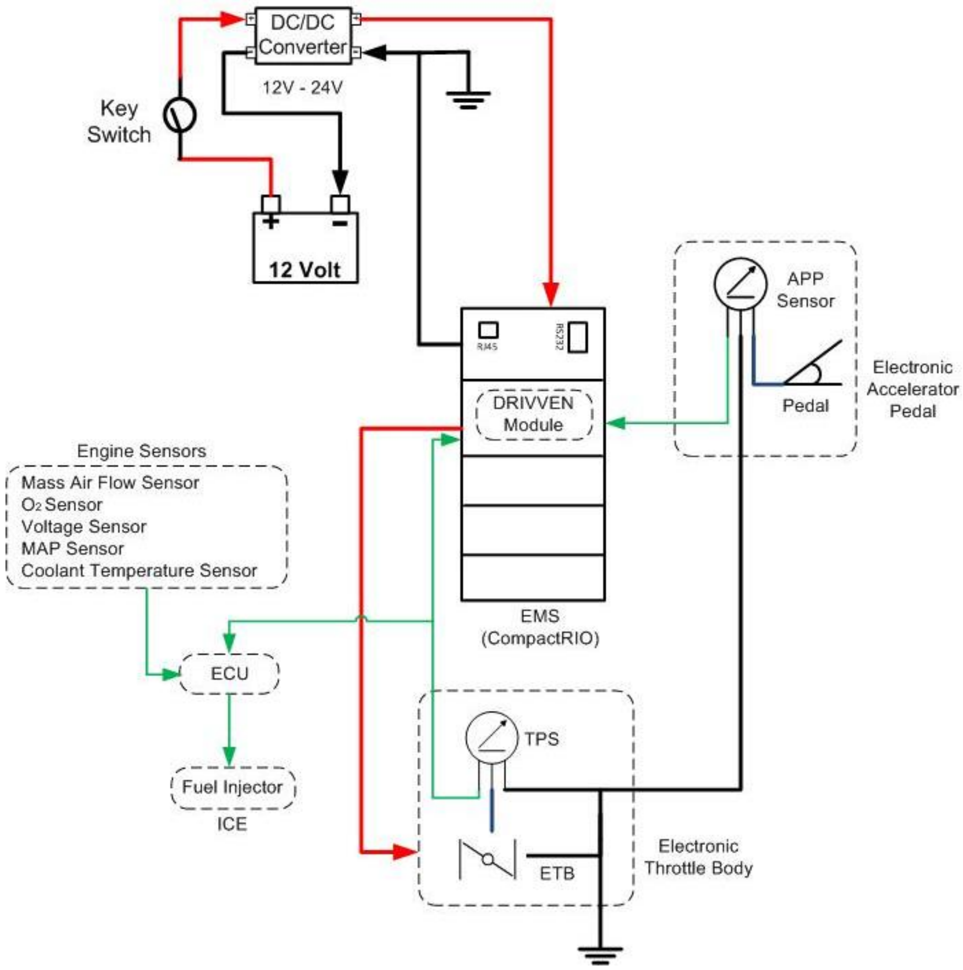

Figure 18: TBW Wiring Diagram using DRIVVEN Module

4.1.3 NI Compact RIO Configuration

National Instrument’s Compact RIO configured similarly for TBW bench test & tuning and also for on vehicle installation using NI cRIO 9076 chassis together with digital I/O module and analogue Input module . Figure 19 below shows the NI cRIO configuration for TBW. NI 9201 module used for processing the analogue input (0-5V) from Pedal (AI 0), TPS 1 (AI 1) and TPS 2(AI 2). Where else, NI 9401 is used for generating PWM signal for MD30C, H-bridge motor driver circuit. Channel 3 is occupied for TBW and rest of the channel of digital I/O will be used for different subsystem of retrofit converted HEV.

The I/O signals will only be stable without noise when all the ground is configured to be common including the ground for compact RIO's power supply from wall plug when performing tuning on bench. On the other hand, this problem will not occur while on vehicle implementation since all the ground terminal of car's electrical subsystem will be grounded to the common negative terminal of battery.

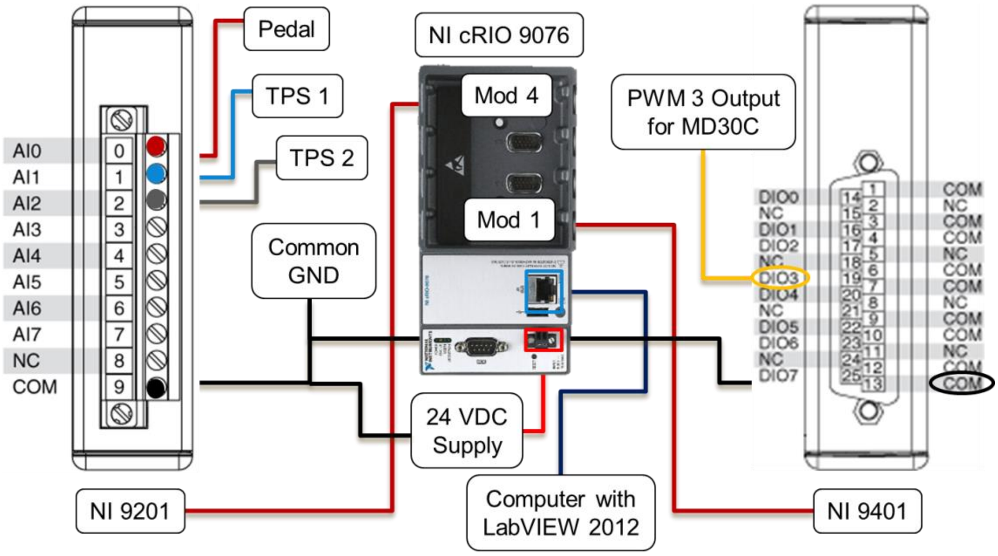

Figure 19: NI cRIO Configuration

4.2 LabVIEW Program Development

4.2.1 LabVIEW Programming (Front Panel)

LabVIEW 2012's front panel equipped with easy to access graphical user interface (GUI) panels, logic buttons, control knobs, and various types of graph display for the ease of programmer. Figure 20 below, shows the front panel developed for TBW tuning system and the operation of TBW tuning system will be explained further in LabVIEW Programming (Block Diagram).

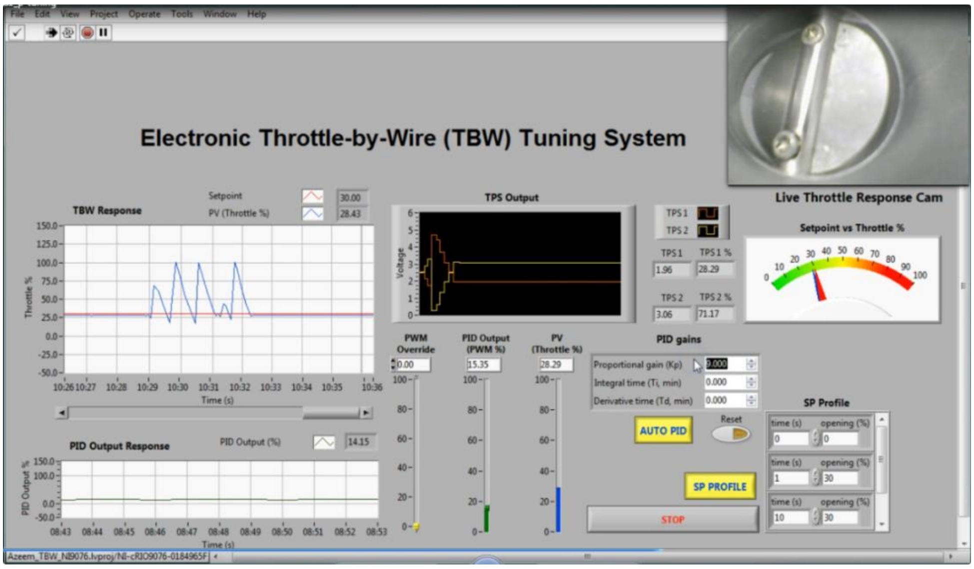

Figure 20 : LabVIEW Program (Front Panel)

The AUTO PID/ MANUAL button above shows the option to control the % of throttle valve opening manually by using PWM Override slider or Kelly throttle pedal without the presence of PID controller. Where else, with AUTO PID option the Setpoint Profile (SP) or Kelly throttle pedal enabled for controlling the throttle valve opening diligently using PID controller as shown in Figure 21.

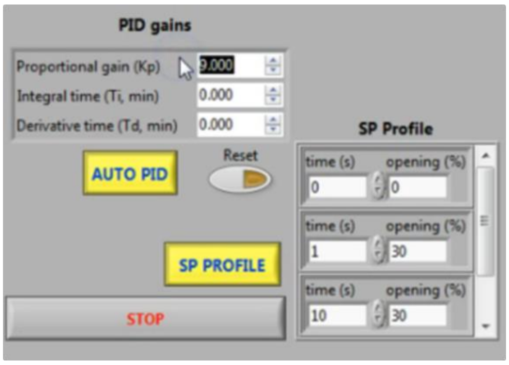

Figure 21: AUTO PID/ MANUAL Selection Button

In AUTO PID option, Setpoint Profile (SP) programmed for controlling the setpoint automatically using preprogramed value and fixes the % of throttle valve opening in order to maintain the speed of vehicle similar to auto-cruise feature but the actual purpose of developing SP Profile is to perform necessary tuning referring to a step response of certain % of throttle valve opening.

TPS output voltage (0-5V) is monitored to make sure the TPS is operating correctly by providing the actual % of throttle valve opening diligently in Figure 22.

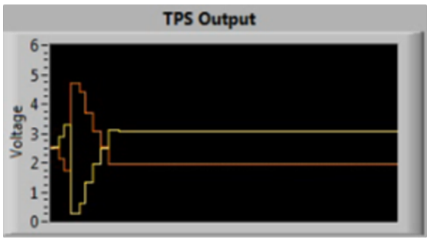

Figure 22: TPS Voltage Monitor

Live throttle response cam feature used for monitoring the DV-E5 response in real-time on the same control panel as shown in Figure 23.

Figure 23: Live Throttle Response Cam

TBW Response chart is used for analyzing the throttle valve response graphically to perform PID tuning using any available method, for this project Ziegler-Nichols method used for tuning the TBW as shown in Figure 24.

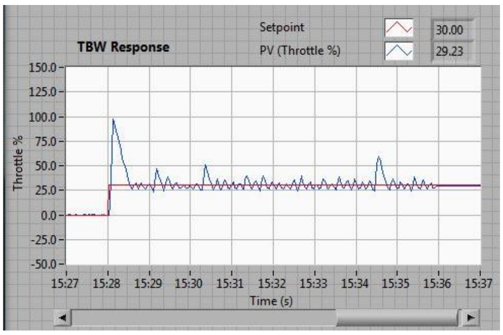

Figure 24: TBW Response Chart

Setpoint versus Throttle % needle indicator is used for indicating the requested setpoint (red needle) and the actual response of the throttle valve (blue needle) to monitor the steady-state error (SSR) range visually.

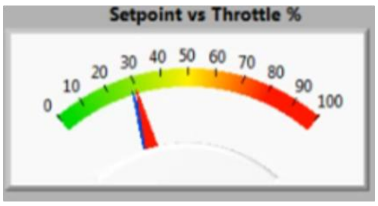

Figure 25: Setpoint vs Throttle % Needle Indicator

4.2.2 LabVIEW Programming (Block Diagram)

LabVIEW 2012's block diagram as shown in Figure 26, equipped with a lot of graphical programming toolkits such as PID & Fuzzy Logic Toolkits and Express Toolkits which help the programmer to develop a complex program with less time for debugging the syntax error and coding that normally occur in most of the programming language such Visual Basic, C, C++, Verilog, VHDL and etc.

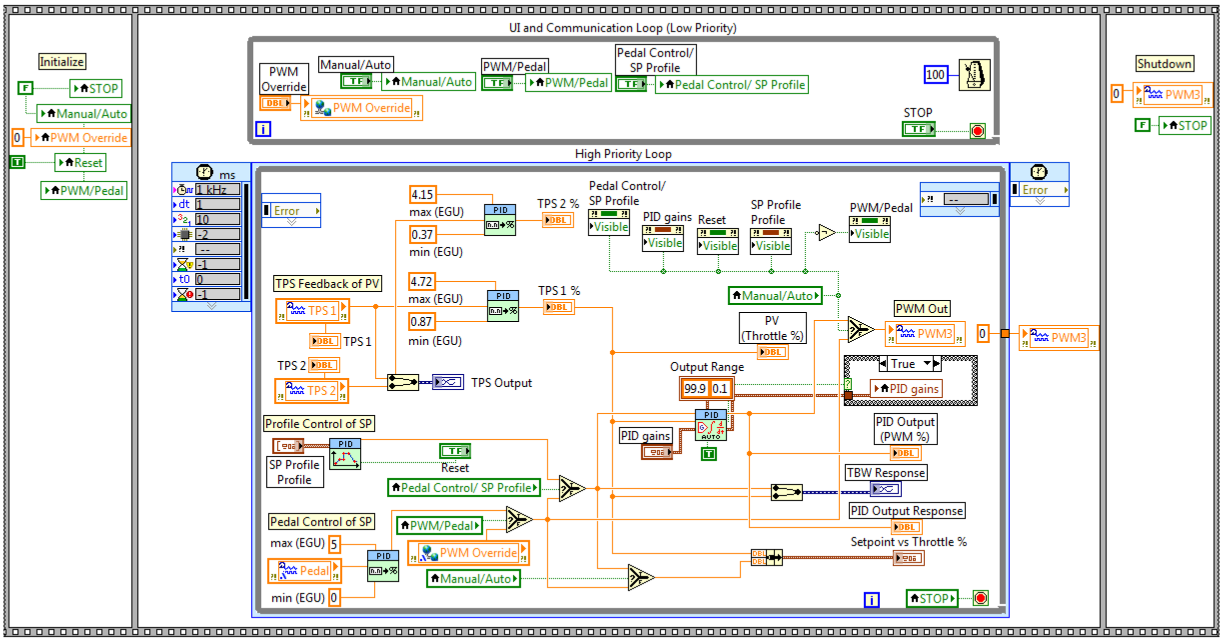

Figure 26: LabVIEW 2012 Block Diagram

The program shown above developed using stack sequence structure loop. Where the loop is divided into 3 phases and every phase will be executed in sequence. The program will start by initializing all values in the program to default or zero in order to make sure the program will run consistently and diligently without any error in phase 1, the 2nd phase will be the main program structure, where all the main body of the program will be executed accordingly and the last phase of execution is the shutdown, where all the values or function will be turned off or stopped completely when the STOP button pressed.

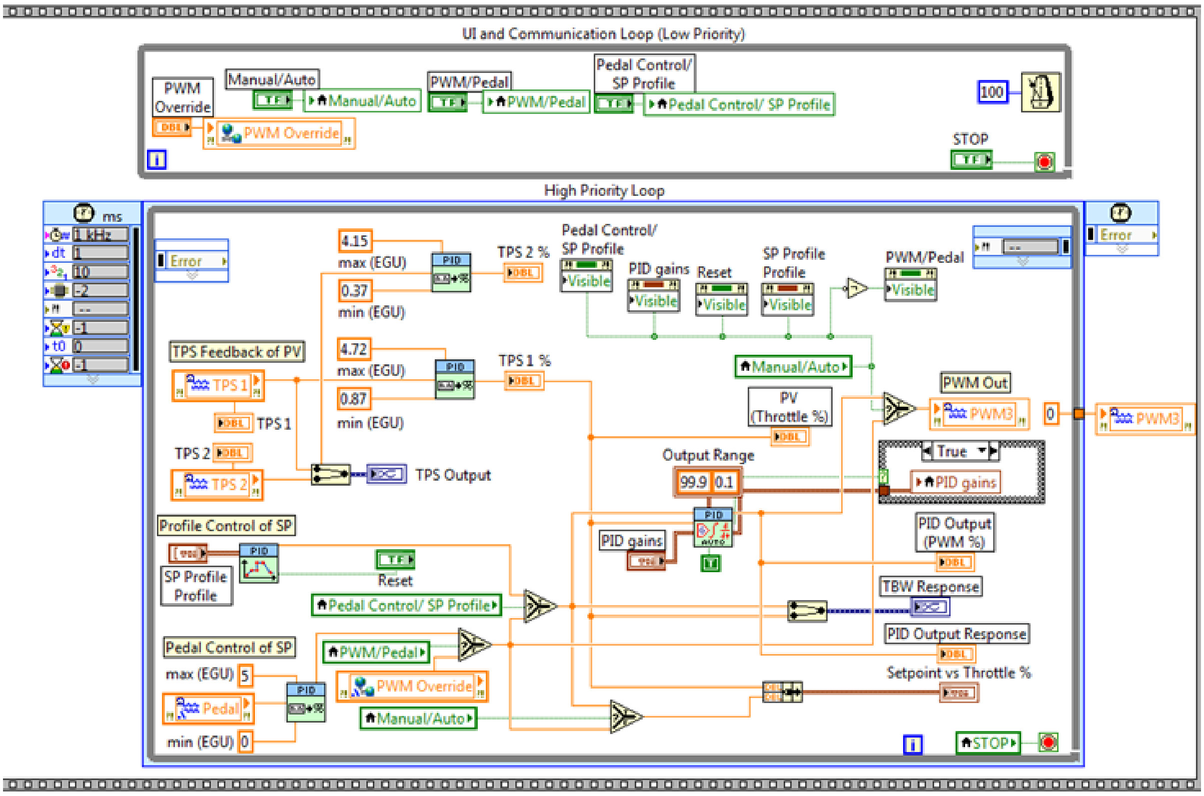

Figure 27: 2nd Phase of the Stack Sequence Loop

The 2nd phase of the program contains two different loops as shown above in Figure 27, which are the High Priority Loop and Low Priority Loop. The high priority loop contains the program that requires more attention or service compare to the low priority loop. Most of the buttons and switches that is not critical will be placed inside the low priority loop and all the time critical operations will be placed in the high priority loop and set the priority level accordingly. The program identifies the priority according to largest value of number assigned for the loop, means the value 100 is given more priority compare to value 10.

In the high priority loop the time critical operation such as input, output PID controller is designed for accuracy and improves the reliability of the system. 3 analogue inputs were assigned from NI 9201 Analogue Input module, Channel AI 0, AI 1, AI 2 assigned respectively to Pedal, TPS 1 and TPS 2 as shown in Figure 28.

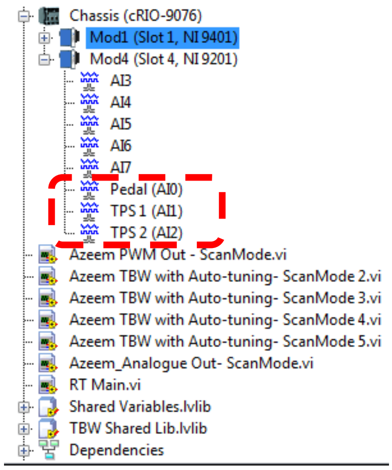

Figure 28: Configuring NI 9201 Analogue Inputs

The output of this program is % duty cycle of PWM. The PWM output is produced by configuring the digital input/output module NI 9401 to PWM3 Out Channel with 10 kHz of frequency as shown in Figure 29.

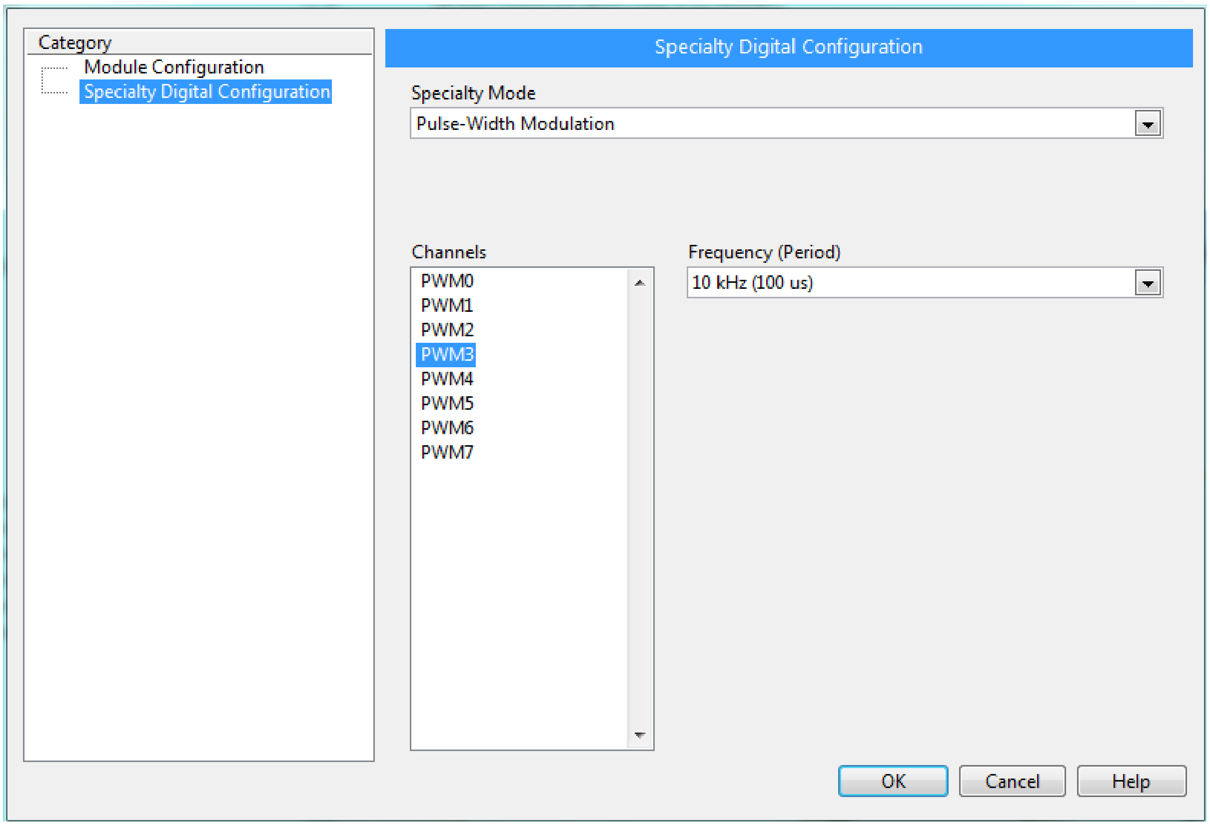

Figure 29: Configuring NI 9401 to PWM Output Mode

4.3 **PID Tuning Methods**

4.3.1 Manual Tuning Method

Manual Tuning used for adjusting the parameters of a controller manually using trial and error approach to fine tune the system for desired output response. It is best to utilize manual tuning method in the initial stage of developing a new system without any knowledge of the system's response. Besides that, the method also helpful in understanding and characterize the response of an each component in the system. Table 3 below exhibits the general parameters for Electronic Throttle Control (ETC) with relationship to some effecting factors.

	Rise Time	Overshoot	Settling Time	Steady-State Error
K_P	↓	↑	Small Change	↓
K_i	↓	↑	↑	Eliminated
K_d	Small Change	↓	↓	Small Change

Table 3: Relationship of PID parameter with Rise Time, Overshoot, and Settling Time & Steady-State Error [10]

Initially TBW System has been tuned manually using a specific program developed through LabVIEW software with the aid of PID & Fuzzy Logic Toolkits. Figure 18 below shows the snapshots of simple PID manual tuning program designed for tuning TBW System. Eventually, the manual tuning requires longer time to tune the system and not an effective tuning method. Hence, we decided to yield for other PID tuning methods such as Ziegler-Nichols Tuning method will be described on the next section of this chapter.

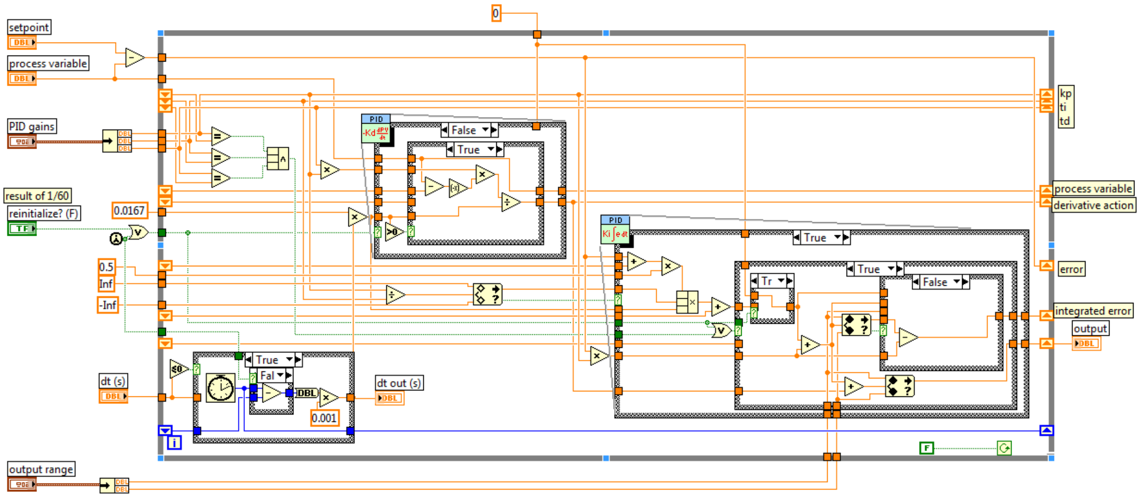

Figure 30: PID Manual Tuning VI for TBW System

4.3.2 *Ziegler-Nichols Tuning Method*

Ziegler- Nichols method is another method that is proven to work with both step response and frequency response diligently. Ziegler-Nichols step response method is based on a step response logged for analysis from step input. Where else, the Ziegler-Nichols frequency response method is based on using the controller connected as a proportional controller. It is performed by setting the parameter I & D gains to zero. The P gain then increased (from zero) until it reaches the critical gain $\boldsymbol{k_u}$, at which the output of the control loop begins to oscillates. $\boldsymbol{k_u}$, and the oscillation period $\boldsymbol{P_u}$ are used to set the P, I, and D gains depending on the type of controller used. Table 4 below shows the Ziegler-Nichols Tuning Chart on P, PI, and PID.

	K_P	T_i	T_d
P	$\frac{K_u}{2}$	-	-
PI	$\frac{K_u}{2.2}$	$\frac{P_u}{1.2}$	-
PID	$\frac{K_u}{1.7}$	$\frac{P_u}{2}$	$\frac{P_u}{8}$

Table 4: Ziegler-Nichols Tuning Chart [10]

4.4 Comparison of Result

The result of different PID gains is compared to identify the best PID tuning according to Ziegler-Nichols tuning method by measuring the % of overshoot (%OS), settling time and steady-state-error (SSR). According to TBW tuning result of DV-E5 the best PID gains is suggested as Kp = 0.98, Ki= 51.58, Kd= 0.00196 as shown in Table 5. Which is shown in relationship of $Ti = \frac{Kp}{Ki}$ and $Td = \frac{Kd}{Kp}$ .The graph below compares the result of TBW developed using NI cRIO and LabVIEW.

$$Ti = \frac{0.98}{51.58} = 0.019$$

$$Td = \frac{0.00196}{0.98} = 0.002$$

Table **5** shown below compares the throttle opening response for different setpoint requested using the PID gain depicted from the TBW tuning analysis.

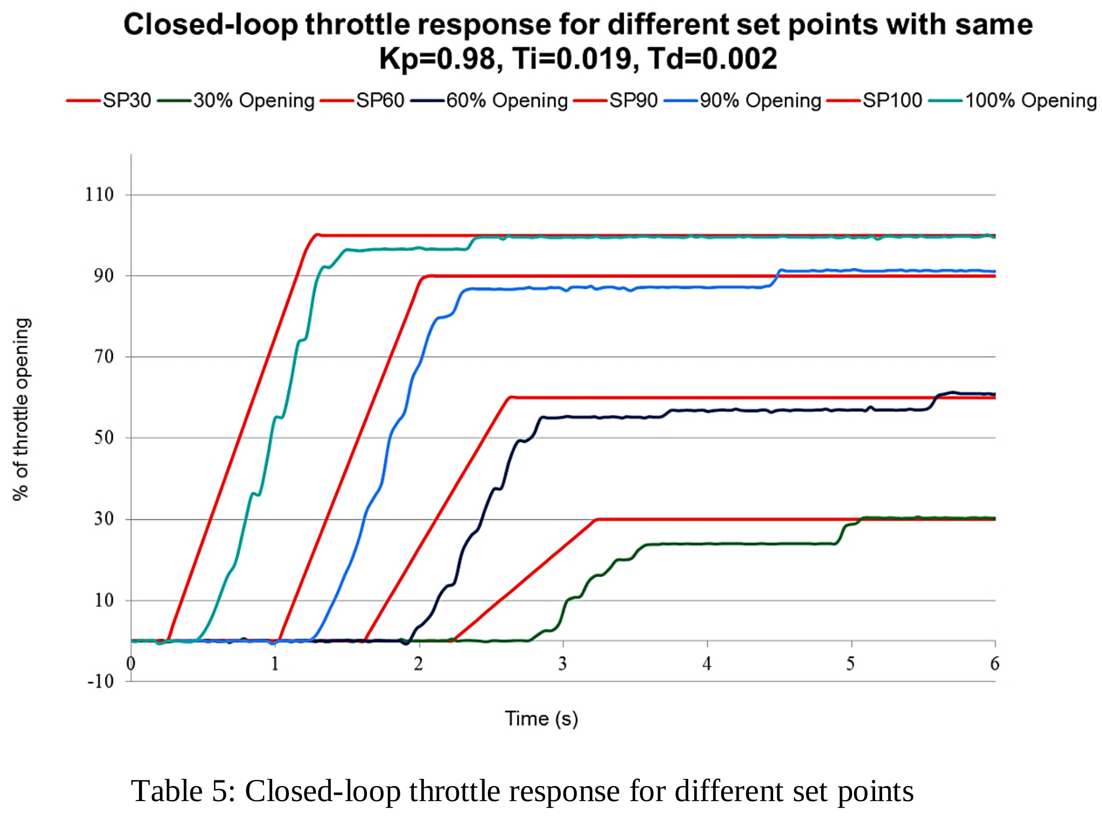

Table 5: Closed-loop throttle response for different set points

CHAPTER 5
CONCLUSION & RECOMMENDATION

5.1 Conclusion

As a conclusion, the TBW System is established system in the market but yet requires a lot of fine tuning and improvement when we deal with different Electronic Throttle Body such DV-E5 and different controller used such as NI Compact RIO. Besides that, it is a great challenge to integrate, fine tune the devices from different manufacturer with their own specifications in order to develop a reliable and effective Electronic Throttle Control (ETC) system for retrofit conversion of Hybrid Electric Vehicle (HEV).

5.2 Recommendation

The next step will be to complete the wiring, implementation of programming, testing and troubleshooting the TBW System on the actual car. Therefore a lot of experimentation and PID tuning required to be completed prior to finalize this project. Further investigation on the profiles of current, voltage, and throttle position sensor (TPS) feedback for various control inputs is also recommended for future improvements. Further research on the effectiveness of current system using PID & Fuzzy Logic Toolkits in LabVIEW highly encouraged for better control of Electronic Throttle Body (ETB). Implement the Electronic Throttle Body Controller using NI CompactRIO and NI LabVIEW. The in addition, study and familiarize with modern throttle control, specifically with the PID algorithm. In the future, it is advisable to investigate the system response using other control algorithm such as modified Ziegler-Nichols PID control method, and fuzzy logic control method, and compare the performance of both control approaches. Data and results obtained during testing can be kept for improvement of the project in the future.

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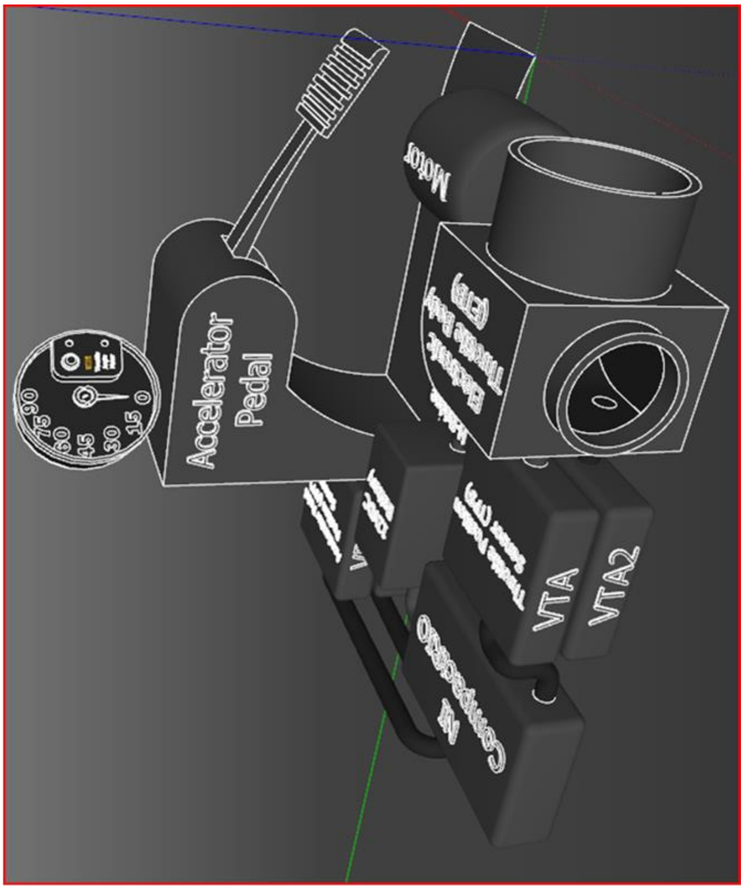
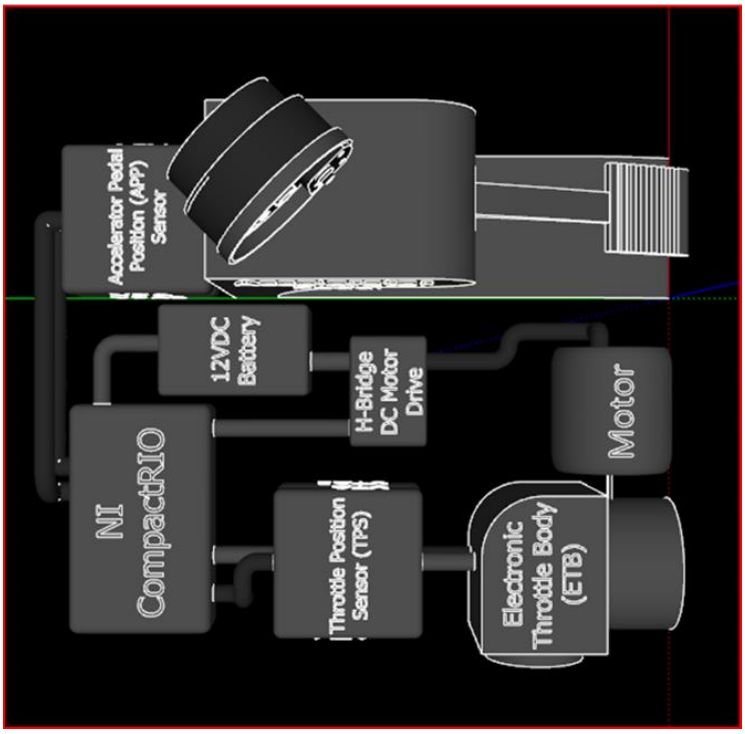
APPENDICES

APPENDIX A

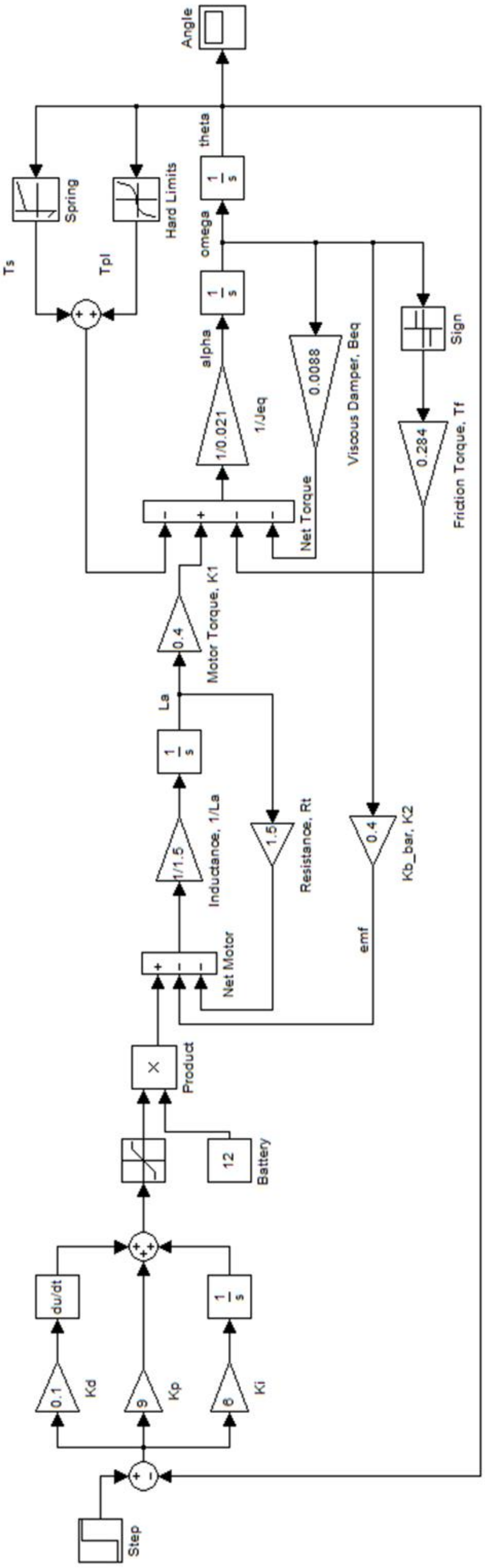
3D MODEL OF TBW





APPENDIX B

NON- LINEAR ETC SYSTEM SIMULINK DIAGRAM



APPENDIX C

PROJECT GANTT CHARTS

PROJECT GANTT CHART JAN 2013

Title	No	Description	Weeks													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
FYP 1	1	Literature review on Hybrid Electric Vehicle (HEV) & Throttle-by-Wire (TBW) technology														
	2	Order & purchase required components for TBW														
	3	Learn configuration of NI Compact RIO controller & programming with NI LabVIEW software														
	4	Prepare & submit Interim Extended Proposal														
	5	Perform simulation & control analysis of the TBW using Matlab/Simulink														
	6	Assemble TBW on test bench & perform initial testing to compare with simulation results														

PROJECT GANTT CHART MAY 2013

Title	No	Description	Weeks													
			15	16	17	18	19	20	21	22	23	24	25	26	27	28
FYP 2	7	Continue TBW system bench test & comparison with simulation														
	8	Install & commission TBW on vehicle for HEV conversion														
	9	Conduct experiment & analyze in-vehicle performance of TBW														
	10	Prepare & submit hardcopy final report														