DEVELOPMENT OF INSTANTANEOUS FUEL CONSUMPTION MEASURING SYSTEM USING ARDUINO

By:

TEOH CHENG LAY

(Matrix No.: 120420)

Supervisor:

Dr. Muhammad IftishahRamdan

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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STATEMENT 1

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Abstrak

“Pengukuran Penggunaan Bahan Api Serta-Merta” memainkan peranan penting dalam mengatasi masalah kenaikan harga bahan api. Dengan adanya sistem “Pengukuran Penggunaan Bahan Api Serta-Merta” , ia membolehkan pemandu untuk sentiasa berubah tingkah laku pemanduan mereka untuk mendapatkan penggunaan bahan api yang lebih rendah semasa memandu. Projek ini menunjukkan sebuah kaedah untuk mengukur “Penggunaan Bahan Api Serta-Merta” sesebuah kenderaan melalui pengukuran gelombang nadi isyarat penyuntik bahan api enjin kenderaan tersebut dengan menggunakan Arduino. Sistem “Pengukuran Penggunaan Bahan Api Serta-Merta” yang telah dicipta adalah tepat dan boleh dipercayai dengan perbezaan peratusan antara nilai diukur dan nilai sebenar adalah kurang daripada 8.2%. Sistem yang dicipta ini adalah bertujuan untuk digunakan dalam kenderaan yang tidak mempunyai system “Pengukuran Penggunaan Bahan Api Serta-Merta” yang siap sedia digabungkan dalam system kenderaan tersebut.

Abstract

Instantaneous fuel consumption measurement is playing a key role in combating fuel price hike by allowing drivers to constantly change their driving behavior to obtain lower fuel consumption while driving. This paper introduces a method of measuring instantaneous fuel consumption of a vehicle through pulse wave measurement of the injector signal by using Arduino. The instantaneous fuel consumption measuring system developed is accurate and reliable with a percentage difference between the measured value and actual value to be less than 8.2%. This measuring system is intended to be used in vehicles that do not have a built-in instantaneous fuel consumption measuring system.

1.0 Introduction

The World Bank forecast that the crude oil (petroleum) price will be doubled from $43.0 USD to & $82.6 USD by the year 2025 [1]. To make matters worse, it is predicted that the number of existing vehicles with increase to 1.7 billion units by the year of 2035 [2]. Therefore, there are currently much work and research being done to produce High Efficient Vehicle (HEV). Research and work includes technological improvements in the engine, fuel consumptions and even hybrid vehicles. These long term methods in coping the rise in fuel prices and the need of consumers in lowering vehicle usage expenditure are indeed great in the long run. However, the world is in need of a more short term method in combating the current rise fuel price. The current status quo believes that driving behaviors and patterns are one of the tools to fight against the current fuel price hike. Driving behaviors such as avoiding aggressive driving, driving steadily at the posted speed limit and avoid to idle vehicles are just some of the steps to reduce the fuel consumption of a vehicle.

Study by David L. Greene in 2005 shows that gasoline prices are often not the main concern of vehicle consumers when there are choosing or purchasing vehicles with different fuel economy ratings [3]. As future prediction in gasoline prices is not fully considered by consumers, this leads to a common believe to exist within automobile consumers that choosing a vehicle with better fuel economy leads to less expenditure on fuel in the long run. This hypothesis has been challenged in the study by Alcott which shows a phenomenon known as “Energy Paradox”. Alcott’s research shows that by not considering the rise in gasoline prices in the future, consumers might spend more on fuel consumption as they undervalue future gasoline prices when purchasing vehicle [4]. Alcott’s view is in line with Jaffe and Stavins (1994) in which consumers and firms are puzzlingly slow to make seemingly high-return investments in energy efficiency. A more general view is that by using a more fuel efficient car will cause a driver to travel more and using more fuel that leads to the driver spending more money on fuel. This is known as an “Energy Paradox”. Therefore, this shows that a more fuel efficient car may not be the absolute answer to the rise in fuel price problem.

Driving pattern has always been related to the fuel consumption of the vehicle. As researched by Ericsson, driving patterns such as extreme acceleration, late changing from gear 2 to gear 3 and much more show much effect on fuel consumption [5]. In addition, the research by Vlieger, Keukeleere and Kretzschmar states that driving behavior has a greater influence on petrol-fueled vehicles compared to diesel-fuelled cars [6]. However, these studies are made through large number of vehicle drive cycles and a large total distance in order to determine the effects of driving behavior on their fuel consumptions. Moreover, in these studies, we can see the effects on fuel consumption by specific driving behaviors individually. This does not entirely shows a real-life picture in which drivers has more complex or a combination of more than one driving behaviors. Thus, this leads to many studies made on profiling real-time driving behaviors.

In the study by Castignani, Frank and Engel, we can see an effort to record and profile real-time driving behavior with the usage of smart phones. By obtaining data from the accelerometer of the vehicle and GPS signal and orientation of the smart phones itself, there are able to generalize the drivers real-time behaviors into certain categories such as normal, moderate and aggressive styles [7]. Similar work has also been done by Javier E. Meseguer and Akhila V Khanapuri [8], [9]. This greatly improves the ability of a driver to adjust their driving pattern instantly to ensure that they do not use too much fuel.

These studies on real-time driving behaviors has lead to more studies on obtaining more useful real-time data for drivers to utilize for better vehicle performance. “Instantaneous Fuel Consumption” (IFC) is one of the data that is attracting the interest of many road users as this shows the exact value of fuel used at a particular moment. Higher IFC shows bad fuel usage where as lower IFC shows great fuel usage. By knowing the car IFC, a driver is able to keep adjusting his/her driving patterns such as throttle position or gear used to keep the IFC of the car as low as possible. This will lead to higher fuel economy in the long run. IFC is later on converted to obtain Instantaneous Fuel Economy (IFE) or sometimes is known as Instant MPG stands for Instantaneous Miles per Gallon.

However, IFC is currently only available for newly-manufacture model vehicle and also on hybrid vehicles as they are a built-in system for the vehicle and not for older model vehicle. Therefore, the current IFC technology is not easily available to most road-users having older model vehicles. As of the year 2015, there are 666,674 units of road vehicles registered in Malaysia [4]. It is estimated that 70% of the values do not have IFC measuring system built in the vehicle which include major vehicle models such as Proton Axia, Perodua Myvi, Proton Saga, Perodua Alza and Honda City which makes up the 5 most registered vehicles in Malaysia.

Generally, there are 2 methods that exist currently that are used in obtaining Instantaneous Fuel Consumption of an engine which are Direct Method and Indirect Method.

Studies have done by Alessandrini shows a clear picture of a Direct Method in obtaining Instantaneous Fuel Consumption in which sensor data is obtained from the ECU through the OBD-II port [12]. In their research, it has been shown that this method can be an accurate methodology to calculate the power and fuel consumption of vehicles during real-time usage. In addition to that On Board Diagnostics (OBD-II) standard which has been mandated since 1994, is finding use for in-vehicle applications due to the availability of OBD-II adapting connectors [11]. However, although most vehicles are equipped with the OBD-II port, not many have the sufficient sensor data or Parameter IDs from the engine to actually be used to obtain the Instantaneous Fuel Consumption. Eventually, this leads to many other studies being made to obtain the Instantaneous Fuel Consumption of the engine indirectly without connecting to the ECU itself.

Indirect Methods are mainly an accurate estimation of the Instantaneous Fuel Consumption by using other forms of external data. In the year 2002, one of the methods is done by developing microscopic fuel consumption and emission models that require instantaneous vehicle speed and acceleration levels as input variables. This research is done by Kyoungho Ahn [12]. This method is further improved by Isaac Skog which add in the usage of global positioning system receiver (GPS). By using speed and height data recorded by a GPS and vehicle parameters accessible via national vehicle registers and databases, Skog's method was shown to be quite accurate. This method is based upon a physical model describing the relationship between the dynamics of the car, engine speed, and energy consumption of the system [13].

The objective of this project is to develop a reliable system with the usage of Arduino to measure Instantaneous Fuel Consumption for a light-duty conventional car by taking Perodua Myvi as a vehicle model sample and also to develop a display interface to enable the user to easily obtain the information from the measuring system while driving.

2.0 Methodology

2.1 Conceptual of the Fuel Consumption Measuring System

The general concept of the method used to measure the fuel consumption of the vehicle is by using a microcontroller which is an “Arduino UNO” to measure the pulse width of the injector signal using the “Timer” and “Interrupt” function exist in the Arduino. Once the, injector pulse width is obtained, the instantaneous fuel consumption can be obtained through manipulation of data to a set of mathematical formulas.

2.1.1 Timer and Interrupt

Timer is a part of the Arduino which responsible for precise time counting independently of currently executed program. There are 3 timers available but we can divide them into 2 types which are 8-bit and 16-bit timers. Timers work based on counter which incremented from 0 to a specified value and resets once it reaches a maximum value. This is important as we can set an interrupt to occur at the point which the counter resets. As this measuring system requires really precise time counting, interrupt can ensure that the code will be executed exactly in the moment when it is needed.

Interrupt is a function of the Arduino that are able to stop the program execution and force the processor to execute the code from the interrupt handler, when a specified event has happened. This specific event is based on the state of the interrupt pin. In this measuring system, the interrupt is set to occur if there is any change in the state of the interrupt pin which means from “high” to “low” and vice versa. In this system, pin 2 of the Arduino is used as the interrupt pin. The interrupt function is similar to the function calling but it happens automatically. The interrupt function is the most critical function of the fuel consumption measuring system.

2.1.2 Pulse Width Measurement

To measure fuel consumption of a vehicle, the injector signal is needed. Injector signal is the signal that manages the work of the engine’s fuel injectors based on some calculation coming from the Engine Control Unit (ECU). This signal is built by the ECU on HIGH and LOW state periods in which one of the states is to inject fuel into the engine. The injector is basically either open or closed only which no intermediate states. The injector closes at high state when the voltage is at 12V and opens at low state of 0V. Fig 1 shows a general signal that flows into the fuel injector of the engine.

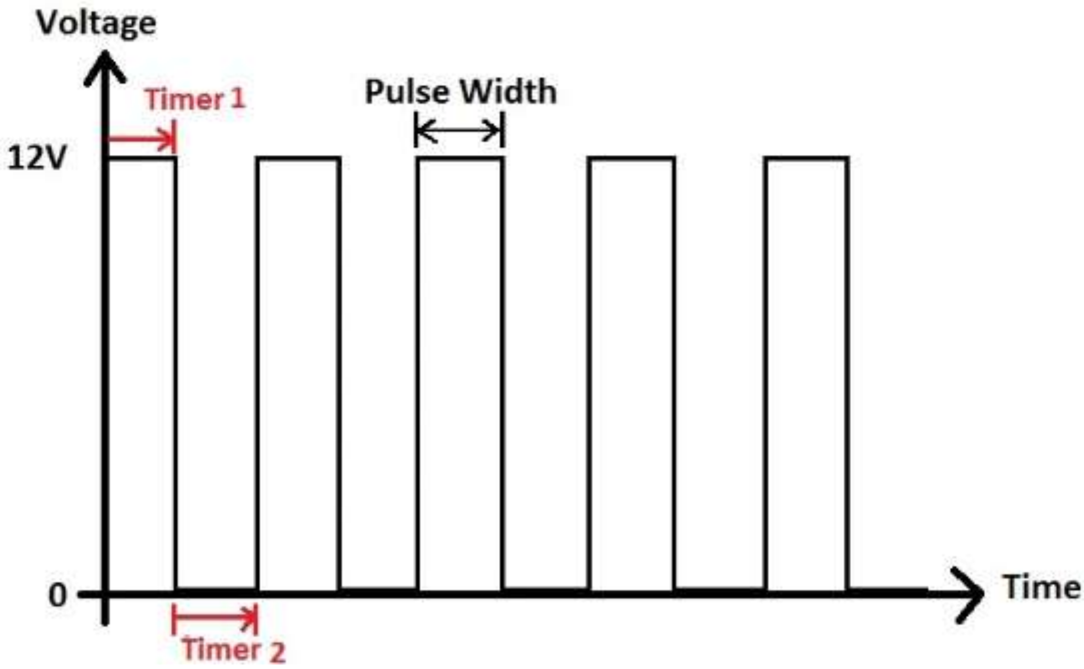

Figure 1: Injector Signal of the Fuel Injector

Pulse width is the duration in which the injector in open for a particular cycle. The length of the pulse width may vary between cycles depending on the fuel needed by the engine. The length of the pulse width is generally controlled by the ECU. Therefore, by measuring the pulse width, the fuel consumption can be identified.

To measure the length of the pulse width, the timer and interrupt function explained in the previous section are used. As stated, an interrupt function will occur if there is a change in the interrupt pin state. To explain further, we take into consideration of the signal in Fig. 1. In this case, initially the pin state is at “HIGH” thus will start the timer named “Timer 1”. Once the pin state changes to “LOW”, an interrupt will occur and causes the time to stop for “Timer 1” and to continue on another timer called “Timer 2”. “Timer 2” will continue to run until the pin state changes again to “HIGH” state in which causing another interrupt to occur which runs a program to subtract “Timer 2” with “Timer 1” to obtain the pulse width for one cycle. This process repeats itself for every cycle of the signal.

Instantaneous Fuel Consumption (IFC) can be obtained by obtaining the total pulse width produce in one second. The total pulse width must multiply with a value known as the injector rate of the fuel injector which is the rate at which the injector is able to inject the fuel into the engine. The unit for the injector rate is normally in cc/min or litre/s which will be calculated using the developed measuring system. Once the IFC is obtained, total fuel consumption per trip can also be obtained by summing up the IFC at every one second.

Below are the relationships and mathematical formula used to obtain the IFC:

$$Injector\ Pulse\ Time\ (\ per\ cycle) = Timer\ 2 - Timer\ 1$$

$$Total\ Injector\ Pulse\ Time\ (per\ second) = \ Sum\ of\ Injector\ Pulse\ Time\ in\ one\ second$$

$$Total\ Injector\ Open\ Time\ (per\ second) = \frac{Total\ Injector\ Pulse\ Time\ (microseconds)}{10^6}$$

$$IFC = [Total\ Injector\ Open\ Time\ (per\ second)\ \ x\ Injector\ Flow\ Rate\ (ml/s)\ ]\ x\ 4$$

$$Total\ Fuel\ Consumption\ (\ per\ trip) = Sum\ of\ IFC\ for\ every\ second$$

The injector pulse time is measured in microseconds by the Arduino based on the Timer setting to “micros”. The total injector pulse time per second is obtained by summing all the injector pulse time calculated in one second. The total injector pulse time is in microseconds and will need to be converted into seconds to obtain the total injector open time per second. As stated, the total injector open time is then multiplied with the injector flow rate which is in cc/s to obtain the fuel consumption of one cylinder in milliliters. To obtain the Instantaneous Fuel consumption, the fuel consumption per second needs to be multiply by 4 as there are 4 cylinders in the engine. The total fuel consumption per trip can also be calculated by summing all the IFC for every second.

The complete flowchart of the program written for the measuring system is can be seen at Fig 2 below. Moreover, the flowchart for the interrupt subsystem can also be seen at Fig 3 below. Through this flowchart, a general view of processes that occurs in the Arduino during the fuel consumption measurement can be seen clearly.

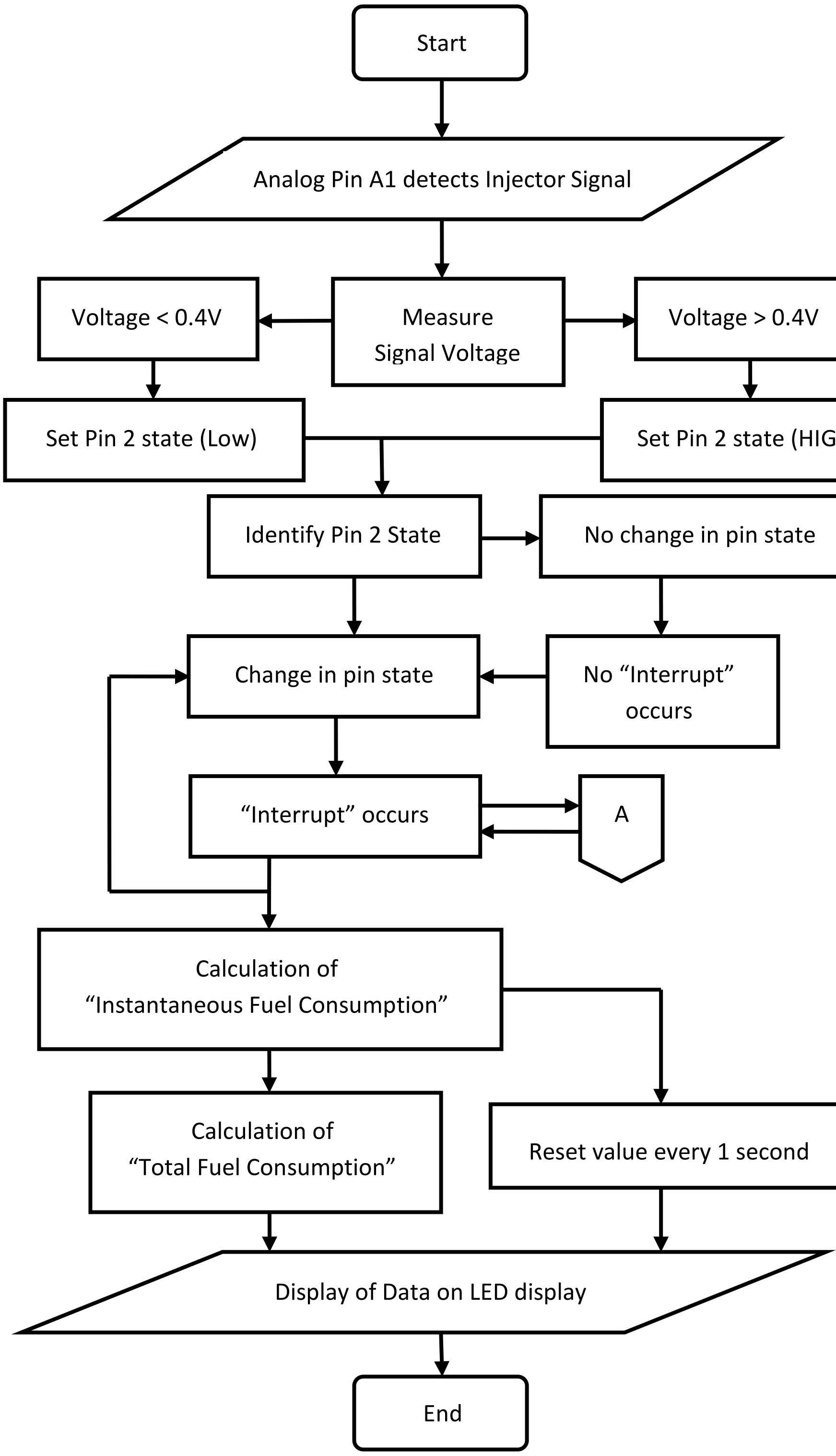

Figure 2: Flow Chart for the Fuel Consumption Measuring System

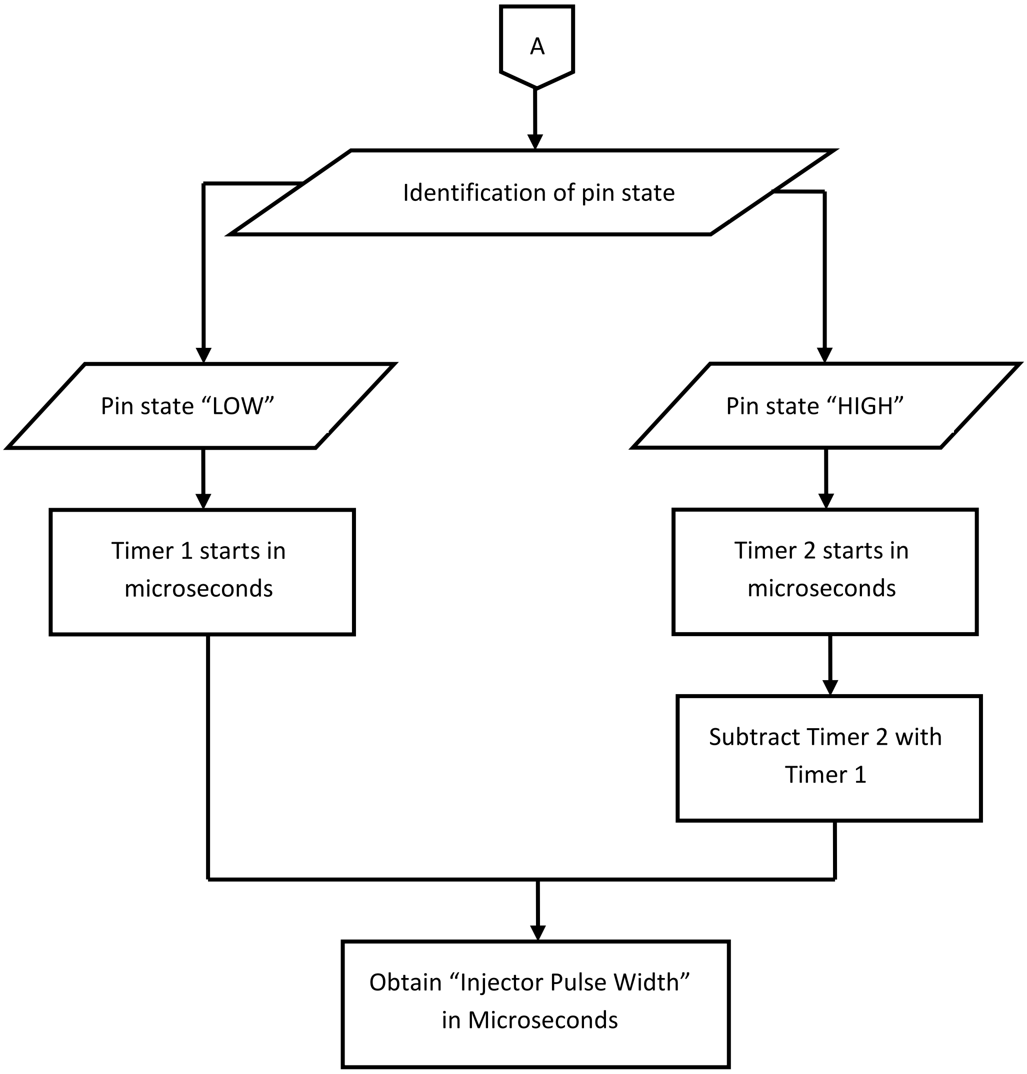

Figure 3: Flow Chart for the “Interrupt” Function subsystem

2.2 Development of Measuring System

2.2.1 Circuit Connection and Wiring

As Arduino can only supports up to a maximum of 5V of voltage, the injector signal must be directed into a voltage regulator before directing the signal into the Arduino. This is because the injector signal is a 12V signal and could short circuit the Arduino if is connected directly into it. Therefore, a 5V voltage regulator 7805 IC is used. Besides, a 16x2 LED display is also used to display the data obtained by the system. Fig. 4 below shows the complete wiring of the measuring system. Table 1 shows the Arduino’s Pinouts and wiring.

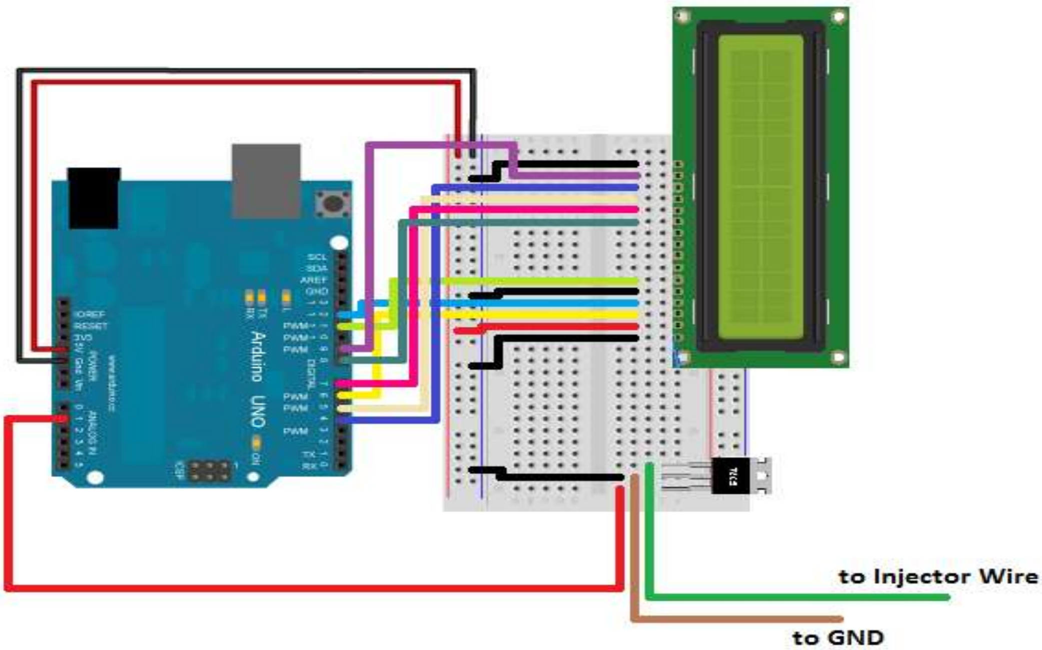

Figure 4: Schematic diagram of the Measuring System

Table 1: List of Arduino Pinouts and Wiring Connection

Pin Description	Pin Symbol	Connection to Arduino
LCD Ground	VSS	GND
LCD Supply Voltage	VDD	5V
LCD Contrast Adjustment	VO	Digital Pin 6
LCD selection of Command and Data Register	RS	Digital Pin 12
LCD Write and Read of Register	RW	GND
LCD Data Pin	E	Digital Pin 11
LCD Data Pin	D4	Digital Pin 8
LCD Data Pin	D5	Digital Pin 7
LCD Data Pin	D6	Digital Pin 5
LCD Data Pin	D7	Digital Pin 4
LCD Backlight Vcc	A	Digital Pin 9
LCD Backlight Ground	K	GND
Modified Injector Signal	From Voltage Regulator	Analog Pin A2

2.2.2 Obtaining Injector Flow Rate

Injector Flow Rate (IFR) is a crucial value that needs to be obtained experimentally to ensure that the measuring system produce an accurate measurement of the fuel consumption. At times, IFR can be found from the engine specifications, however, for a more accurate result, the actual IFR of the injector is measured.

IFR can be obtained through a simple experiment in which total fuel consumed by the engine is measured using a burette which is then divided by the total injector open time that can be obtained from the measuring system developed. Once the IFR is obtained, it is used in the measuring system. Below shows the formulation used to obtain the IFR.

$$IFR = \frac{Total\ Fuel\ Consumption\ in\ 10\ seconds}{Total\ Injector\ Open\ Time\ in\ 10\ seconds}$$

2.3 Validation of Fuel Consumption Measuring System

2.3.1 Laboratory Set up

From the engine lab of School of Mechanical Engineering, there is a K3V3 engine that has been connected to a chassis dynamometer. This engine is used for all experimentation testing which includes obtaining injector fuel rate, accuracy testing and reliability testing. The injector wire is tapped from the Engine Control Unit (ECU) in which the injector wire can be identified from the ECU wiring pinout which can be obtained from the manufacturer. Fig. 5 shows the set up for the measuring system in the engine lab.

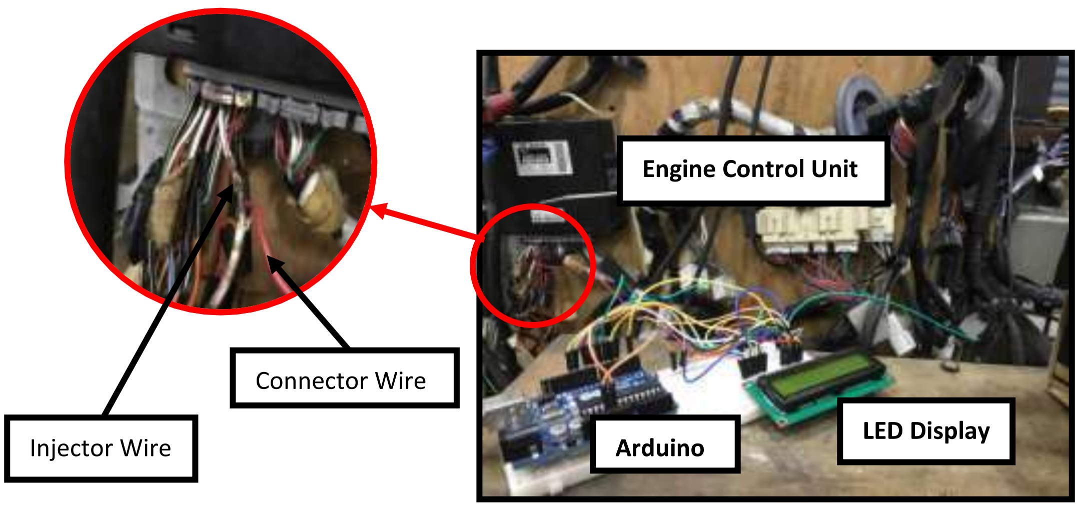

Figure 5: Laboratory Set Up of the Fuel Consumption Measuring System

2.3.2 Accuracy and Reliability Testing

The accuracy and reliability of the measuring system will be tested by comparing it with data obtained from an engine map experiment done by Lim Zhi Wey, of School of Mechanical Engineering USM. The fuel consumption of the engine is obtained at different torque and engine speed. Therefore, by using the K3V3 engine in the laboratory, the fuel consumption at specific torque and engine speed will be compared using the data from the engine map experiment and the data from the measuring system. The differences in values of the data will be plotted and discuss in the next section.

3.0 Results and Discussion

3.1 Signal Modification and Detection

Before the signal from the injector wire can be directed into the arduino, it must be modified to suit the ardunio specifications. The original signal from the injector a wire consists of a 12v to Ground pulse width which if directly inserted into the arduino will cause damage. Furthermore, the signal shows that there is a voltage spike of 40V which is caused by the back voltage of the injector. Therefore, a voltage regulator is used. The voltage regulator also removes the voltage jump after the low state and also the transient drop of the voltage back to the 12 volts. The transient drop can affect the functionality of the interrupt function used in the measuring system. Fig.6 and Fig.7 below shows the signal of the injector wire before and after modification respectively. Both of the signals are readings from an oscilloscope.

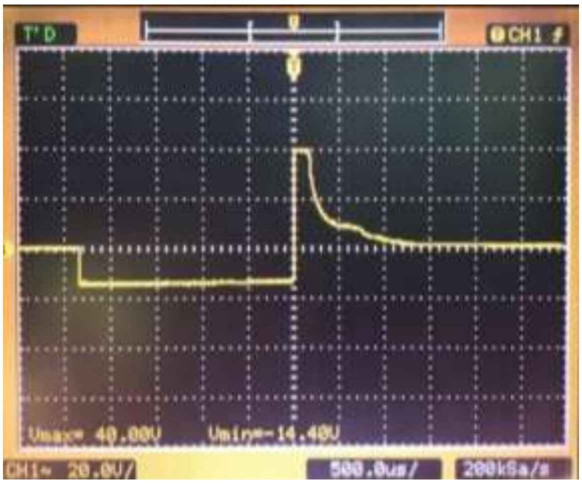

Figure 6: Original Injector Pulse Wave

Figure 7: Modified Injector Pulse Wave

Once the signal has been modified, then only it can be safely inserted into the Arduino. It can be seen that the maximum voltage of the modified pulse wave is at 0.4V which is well below the 5V limit of the Arduino. The pulse wave is then checked using the "serial plotter" function in the Arduino to see the detection of the pulse wave by the Arduino. The baud rate of the Arduino is set to 9600 baud. Baud is a unit of transmission speed equal to the number of times a signal changes state per second. For one baud is equivalent to one bit per second. Thus, the Arduino is transmitting at a frequency of 9600 bit per second. Fig.8 shows the results of the detection of the pulse wave at engine speed 800 rpm by the Arduino.

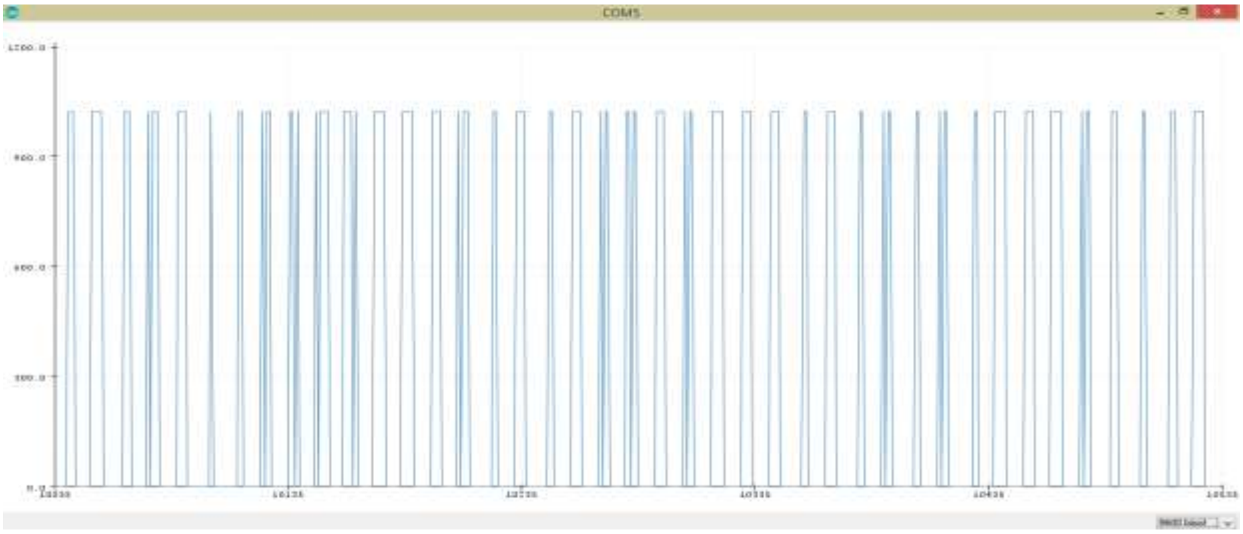

Figure 8: Pulse Wave detection of the Arduino

3.2 Injector Flow Rate

Based on the experiment carried out, the injector flow rate of the K3V3 engine fuel injectors is 188.89cc/min. The value in milliliters per second is the value used in the arduino coding. This value can also be used to calibrate the measuring system. Once the injector flow rate obtained is accurate, we can also conclude that the measuring system is correctly calibrated and ready for experimentation. Table 2 below shows the results of the injector flow rate test.

Table 2: Results and data of Injector Fuel Rate Experiment

Total Fuel Consumption for 10s	37.6ml
Fuel Consumption per Injector for 10s	9.4ml
Total Injector Open Time for 10s	2985761×10^{-6} s
Injector Fuel Rate	3.148 ml/s
Conversion to cc/min	188.89 cc/min

3.3 Accuracy and Reliability of Measuring System

The measuring system is then compared with the existing data of fuel consumption measured by using a burette. The measuring system shows great accuracy as the difference between the experimental value and the value of fuel consumption obtained by the Arduino are within 1-9% difference. The entire data and comparison can be seen in Table 3 below.

Table 3 Results and Comparison of data between Experimental Value and Measuring System Value

Torque (Nm)	1000			2000			3000			4000		
	Exp	Arduino	% Different	Exp	Arduino	% Different	Exp	Arduino	% Different	Exp	Arduino	% Different
10	0.333056	0.322	**3.319500**	0.745712	0.723	**3.045700**	0.969932	1.022	**5.368200**	1.309758	1.221	**6.776650**
20	0.470588	0.452	**3.950000**	0.866739	0.835	**3.661875**	1.139277	1.075	**5.641875**	1.669449	1.531	**8.293100**
30	0.533333	0.519	**2.687500**	1.074980	1.043	**2.974925**	1.375043	1.448	**5.305800**	2.163332	2.293	**5.993925**
40	0.666667	0.645	**3.250000**	1.292407	1.253	**3.049125**	1.621074	1.531	**5.556438**	2.256700	2.381	**5.508063**
50	0.769231	0.759	**1.330000**	1.417434	1.382	**2.499900**	1.932834	1.854	**4.078675**	2.675585	2.562	**4.245250**

There is a couple of general trend that can be seen from the data shown. Firstly, the percentage difference in value tends to drop as engine torque increases. This is because that as engine torque increases at a particular engine speed, the pulse length increases as the pulse frequency remains the same. This enables a much more precise “interrupts” to occur which lead to better pulse width measurement by the Arduino. Secondly, the percentage difference in value shows an increasing trend as the engine speed increases. Increasing the engine speed will lead to an increase in the pulse frequency detected by the Arduino. Although the interrupt function is supposed to work at an immediate action, there is a slight delay in microseconds due to the running of the codes of the program. Thus, higher frequency pulse width could lead to more interrupt to occur and may increase the error slightly. However, this error is quite minimal to bring a significant effect on the measurement system. Fig. 9 below shows the pulse width detection by the Arduino at engine speed 4000 rpm. The frequency of the pulse wave detected is about 60 Hz which can be calculate from the measuring system Fig. 10 shows the overall trend of the percentage difference of value obtained by the experiment and the measuring system with respect to engine torque and engine speed.

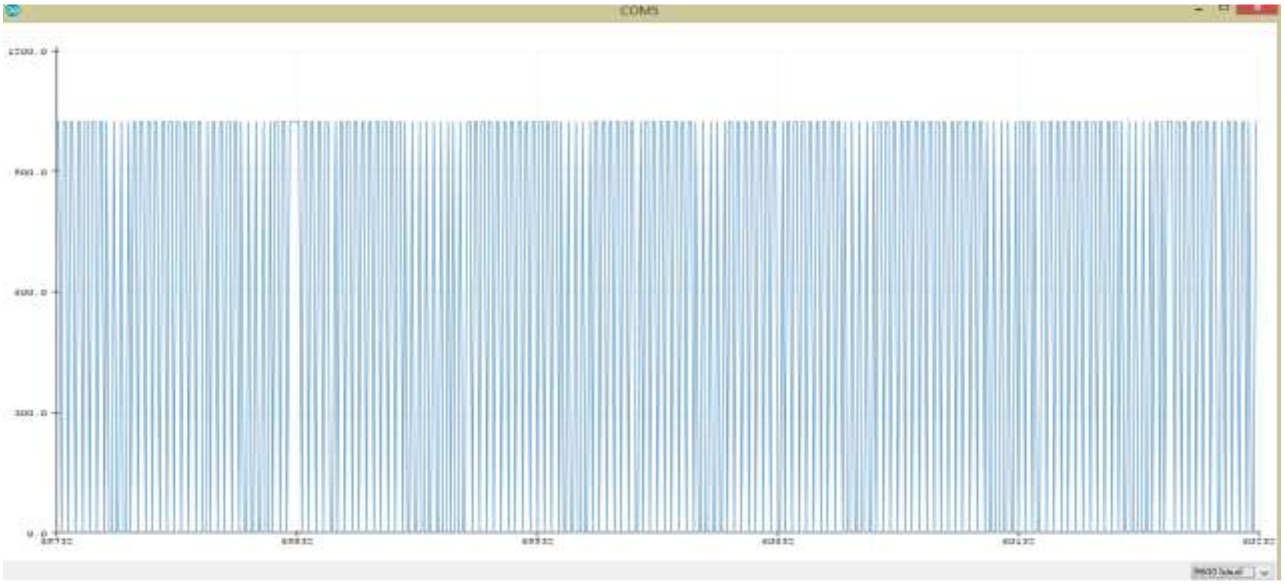

Figure 9: Pulse Wave detection of the Arduino at 4000 rpm

Therefore, it is seen that the measuring system works best at lower engine speed and higher engine torque. The percentage differences obtained at lower engine speed of 1000 rpm and 2000 rpm is within 1.3 – 4.0 %. This is excellent as daily vehicle usage is normally within this range of engine speed. Although, the percentage difference is higher for higher engine speed such as 3000 rpm and 4000 rpm which is within 4.0 – 8.2%, it is still within the acceptable tolerance limit of the measuring system.

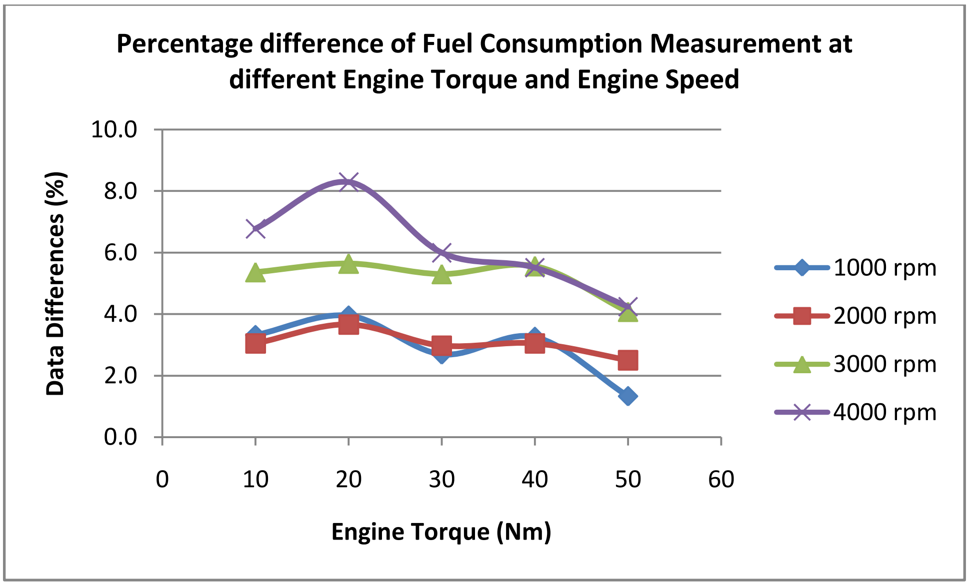

Figure 10: Graph of Percentage Difference of Fuel Consumption Measurement at different Engine Torque and Engine Speed

4.0 Conclusion

The instantaneous fuel consumption measuring system can be developed using an Arduino and the injector wire signal.

By measuring the pulse width of the injector signal, the total injector open time in 1 second can be determined. The injector flow rate of the fuel injector has been determined through experimental procedure to be 188.89cc/min. The multiplication of the injector open time and the injector flow rate value, the fuel consumption can be calculated. The instantaneous fuel consumption is obtained by determining the fuel consumption at each consecutive second. The measuring system works excellently with the percentage difference in measured value between the measuring system and the experimental system using a burette is less than 8.2%.

As for future development, this measuring system can used in vehicles that do not have a built-in Instantaneous Fuel Consumption measuring system. This could help road users in understanding the relationship between their driving habits and the vehicle's fuel consumption.

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