FUEL CONSUMPTION AND FUEL ECONOMY OF HYDRAULIC HYBRID VEHICLE

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FUEL CONSUMPTION AND FUEL ECONOMY OF HYDRAULIC HYBRID VEHICLE

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DECLARATION

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LIST OF ABBREVIATIONS

ACOF : Air Conditioner Off

ACON : Air Conditioner On

EUDC : Extra Urban Driving Cycle

HEV : Hybrid Electric Vehicle

HHV : Hydraulic Hybrid Vehicle

ICE : Internal Combustion Engine

NEDC : New European Driving Cycle

PHEV : Parallel Hybrid Electric Vehicle

PHHV : Parallel Hydraulic Hybrid Vehicle

SOC : State of Charge

SHHV : Series Hydraulic Hybrid Vehicle

TTR : Through-The-Road

UDC : Urban Driving Cycle

VSS : Vehicle Speed Sensor

ABSTRAK

Kajian ini memfokuskan pada prestasi ekonomi bahan bakar "Through-The-Road (TTR)" Kenderaan Hibrid Hidraulik (HHV). TTR adalah sejenis seni bina selari yang menghubungkan kereta pemacu konvensional dan kereta pemacu hibrid melalui jalan raya. Kereta pemacu hibrid hidraulik yang ada di dalam kenderaan digunakan untuk diuji dalam eksperimen. Sistem program Arduino untuk hibrid hidraulik melalui jalan dikembangkan untuk menentukan penggunaan bahan bakar kenderaan. Penggunaan bahan bakar diukur dengan menimbang tangki bahan bakar sebelum dan selepas setiap larian kitaran pemacu bandar yang mempunyai jarak dan laluan yang sama. Ujian penggunaan bahan bakar hibrid hidraulik melalui jalan raya dipisahkan menjadi dua yang dengan penghawa dingin dihidupkan dan dengan penghawa dingin dimatikan. Dengan menggunakan data dari ujian penggunaan bahan bakar, ekonomi bahan bakar diperoleh jika dibandingkan antara mod Perodua Myvi yang asli, mod konvensional hybrid hidraulik Myvi dan mod hibrid hidraulik hibrid Myvi. Oleh itu, ujian menunjukkan bahawa untuk mod ACON, mod hibrid hidraulik memberikan peningkatan ekonomi bahan bakar sekitar 8% berbanding mod konvensional. Namun mod asal ACON mempunyai ekonomi bahan bakar 41% lebih baik daripada mod hibrid ACON. Sebagai tambahan, untuk mod ACOF, mod asal ACOF mempunyai ekonomi bahan bakar 78% lebih tinggi daripada mod hibrid ACON. Akhirnya, data juga dibandingkan antara mod ACON dan mod ACOF di mana ekonomi bahan bakar mod asal ACON adalah 24% lebih baik daripada mod hibrid ACOF. Hal ini kerana, berat komponen hidraulik yang terdapat di Myvi hibrid yang menggunakan lebih banyak bahan bakar untuk mendorong kenderaan.

ABSTRACT

This study focuses on the fuel economy performance of the Through-The-Road (TTR) Hydraulic Hybrid Vehicle (HHV). TTR is a type of parallel architecture that connects the conventional drive train and the hybrid drive train through the road. The hydraulic hybrid drive train that was in the vehicle was used to be tested in the experiment. An Arduino programme system for through-the-road hydraulic hybrid was developed to determine the fuel consumption and fuel economy of the vehicle. The fuel consumption is measured by weighing the fuel tank before and after each run of similar urban drive cycle that has same driver and circuit for testing. The through-the-road hydraulic hybrid fuel consumption test was separated into two which is with the air conditioner on (ACON) and with the air conditioner off (ACOF). By using the data from the fuel consumption test, the fuel economy is obtained where it is compared between the original Perodua Myvi mode, conventional hybrid myvi mode and the hybrid myvi hybrid mode. Thus, the test shows that for ACON mode, the hydraulic hybrid mode provides about 8% fuel economy improvement compared to the conventional hybrid mode. While ACON original Myvi mode has 41% better fuel economy than ACON hybrid Myvi hybrid mode. In addition, for the ACOF mode, ACOF original Myvi mode has 78% higher fuel economy than ACOF hybrid mode. Finally, the data was also compared between the ACON mode and ACOF mode where the fuel economy of ACON original Myvi mode was 24% better than ACOF hybrid Myvi hybrid mode. This is because of the heavy weight of the hydraulic components that are in the Hybrid Myvi which consumes more fuel to propel the vehicle.

CHAPTER 1

INTRODUCTION

1.1 Research Background

As per the (International Energy Agency. & Organisation for Economic Co-operation and Development., 2011), by the year 2035 the number of passenger cars in the world are expected to increase from 1 billion to 1.7 billion cars. This predicted number of cars are rising the concern on the excessive fossil fuel consumption and carbon emissions, as transport vehicles are said to be the major source of carbon dioxide emissions to the environment. (Al-Samari, 2017)(Wu & Liu, 2012). As a result of carbon dioxide emissions and other greenhouse gas emissions, the climate is becoming warmer. (Papagiannaki & Diakoulaki, 2009) As a result of these concerns, there is a strong demand for automobiles that have a low impact on the environment and fuel efficient, while still maintaining the vehicle's performance and the level of safety they provide. (Karden et al., 2007) The enormous demand can be satisfied by hybrid vehicles, which have already been shown to solve the environmental issue on a worldwide scale. Hybrid vehicles consume less gasoline and emit fewer exhaust emissions than conventional automobiles do. (Katrašnik, 2007)

A hybrid system is designed by alternating the power train of a conventional vehicle with the help of the power source, which can be from a hydraulic or electrical energy source. This categorises hybrid into two prominent types, which are the Hydraulic Hybrid Vehicle (HHV), and the Hybrid Electric Vehicle (HEV). One of the hybrid vehicles on the market is the Toyota Prius, which, when compared to standard automobiles under real-world driving conditions, achieves a fuel efficiency that is about fifty percent better while consuming just about a third of the amount of gasoline. (Adithya Jayakumar et al., 2014.) Increasing the fuel efficiency of automobiles has emerged as a possible strategy for tackling environmental power shortages. Medium-duty trucks and passenger cars are increasingly being powered by electric and hybrid electric motor systems. (Pugi et al., 2017) For the HEV, electric motor and battery must be huge to meet the vehicle's power requirements, which significantly increases the vehicle's weight and cost. While with the high-power density and low cost, hydraulic hybrid drive system has gained a lot of interest in recent years. (Pugi et al., 2017)

The poor attainability rate of an efficient hybrid vehicle may be overcome with the hydraulic hybrid parallel architecture. To reduce construction costs and for an ease system setup, a parallel hydraulic hybrid driving system would be a suitable solution as it can be retrofitted to traditional engine-driven vehicles. This design also incorporates a regenerative braking system onto automobiles that are already on the road. (Azzam et al., 2022) Due to its simplicity, the hydraulic system is extremely reliable and can be simply maintained by any specialised mechanic. (Azzam et al., 2022) High fuel economy and energy savings are possible with this technology, making it a viable alternative to more traditional drivetrain configurations.

Efficient use of fuel is one of the primary factors that has attracted the interest of numerous researchers in hybrid technology. The contrast between the conventional driving mode and the hybrid driving mode is one of the most significant aspects in determining the HHV's overall efficiency in terms of fuel consumption. As to collect the data, real world driving cycle and standard driving cycle can be used in testing a passenger car (Azzam et al., 2022) In this project only urban driving cycle is used to obtain the fuel economy of the hydraulic hybrid vehicle. Therefore, even if the fuel economy test shows that it is just as effective as the conventional mode, there are still other advantages associated with using HHV. One of the reasons is that it has a low cost, which makes it easier for customers with lower incomes to purchase it.

1.2 Problem Statement

Recent research in the field of hydraulic hybrid vehicles has produced a significant amount of published material (HHV). The current goal of hybrid car technology is to lower overall fuel usage as well as the negative effects of carbon emissions on the surrounding environment. On the other hand, the introduction of hybrid technology in hybrid electric vehicles (HEVs) in Malaysia has not been met with a particularly encouraging reception. This is because of the relatively high price of HEVs on the market at the moment. Therefore, the primary purpose of this research is to evaluate the effectiveness of HHVs in terms of fuel economy in relation to conventional cars. Once the desired degree of effectiveness is achieved, practical usage of HHV in developing countries will be achievable.

1.3 Objective

The main objectives of this research are:

1. To obtain the base fuel consumption for through-the-road hydraulic hybrid system on the prototype vehicle.
2. To compare the fuel economy between the ACON mode and ACOF mode.
3. To compare the fuel economy between the original driving mode in original Myvi, conventional driving mode and hybrid driving mode in HHV.

1.4 Scope of Work

The parallel hydraulic hybrid Perodua Myvi that is now in the lab will be utilised for the purposes of this project in order to determine its fuel consumption as well as its fuel economy. The dataset needs to be obtained by connecting an Arduino microcontroller with the speedometer, and then it needs to be compared between the original mode, conventional mode and the hybrid mode. In addition, the fuel consumption dataset must be gathered both when the air conditioning system is turned on (ACON) and when it is turned off (ACOF), and it is compared between the two types of modes. In order to successfully complete this project, the most important steps are to do research, experiments, Arduino programming and compare data.

CHAPTER 2

LITERATURE REVIEW

2.1 Hydraulic Hybrid System

The primary idea behind the hydraulic hybrid vehicle (HHV) is that it combines a conventional internal combustion engine (ICE) with a pressurised fluid power source in order to achieve greater fuel efficiency and less harmful emissions. The hydraulic hybrid architecture is comprised of hydraulic pumps and motors, and the reclaimed energy from the braking event is stored in an accumulator as pressurised fluid. (Barbosa et al., 2022)The idea was to convert the kinetic engine from the vehicle into hydraulic potential energy using a hydraulic pump which is then transferred through a series of control valves in hydraulic hoses. The hydraulic potential energy is then converted into mechanical energy by the hydraulic motor. (Huang et al., 2015) This energy is then used by driving the hydraulic motors, which gives the vehicle its forward momentum. (Barbosa et al., 2022) Hydraulic transmissions have a number of advantages which includes smooth transmission, light weight, and high-power density. (Chen, 2015) These hydraulic hybrid technologies are best suited for applications with duty cycles that require high power and make frequent stops in urban areas, such as those found in heavy vehicles like refuse trucks and transportation sector vehicles like buses and delivery vehicles. However, for through-the-road vehicles, only a few research studies have proposed hybrid hydraulic architectures. Through-the-road hydraulic hybrid parallel architecture, which allows regenerative braking components to be retrofitted into an existing conventional vehicle, could be the solution to the low attainability rate of efficient hybrid automobiles. Due to its simplicity, the hydraulic system is incredibly reliable and easy to maintain. (Ramdan et al., 2020)

2.2 Comparison of hybrid systems

Each type of hybrid car, whether it be a hybrid electric vehicle (HEV) or a hydraulic hybrid vehicle (HHV), has its own set of benefits and drawbacks. In contrast to a hydraulic hybrid powertrain, which employs hydraulic accumulators and pump/motors to convert energy, a hybrid electric power-train uses an electric battery to store energy and an electric motor to convert energy. (Chen, 2015) The main drawback of HHV is its lower energy density than HEV. Because the electric battery has a relatively high energy density, HEV do not experience this issue. In order to conserve energy and use it again in HHV, a relatively large accumulator is required. (Tvrdić et al., 2018) However, it can be demonstrated that the capacity of energy storage for hydraulic hybrids does not necessarily need to be extremely great with the help of appropriate control strategies. (IEEE Staff & IEEE Staff, n.d.) HEV parts have a lower power density than HHVs pumps, motors, and accumulators. Or to put it another way, HHV has the ability to rapidly transport large amounts of energy. Compared to their electrical counterparts, hydraulic components are more cost-effective. (Stelson et al., 2008) The regenerative braking efficiency is significantly better in HHV than in HEV. (Tvrdić et al., 2018) Furthermore, the hydraulic hybrid vehicle can save about 50% more of the kinetic energy and re-turn it into useful work, than the hybrid electric. (Tvrdić et al., 2018) Finally, HHV can be fully charged and discharged many times and switched back and forth between charging and discharging states repeatedly without losing capacity or functionality. Because of all these advantages, hydraulic systems are great for stop-and-go driving, especially in cities. (Huang et al., 2015)

Table 2.1: Table of comparison between HHV and HEV (Tvrdić et al., 2018)

Parameters	HHV	HEV
Energy density	Low	High
Power density	High	Low
Braking regeneration efficiency	80%	30%
Regeneration charging	Quick	Slow
Power to weight ratio	High	Low
Initial cost and maintenance cost	Low	High

Based on (Chen, 2015) who compared the fuel economy of HHV with HEV by manipulating the drivetrain architecture for both the hybrid system. To build all seven complete models for backward simulations, this research employs MATLAB Simulink. Furthermore, to reduce the impacts of different component masses, this study purposefully ignored vehicle mass differences in order to compare the real functional contribution of alternative powertrain architectures. The fuel economy is then assessed by thoroughly comparing all the powertrain architecture based on New European Driving Cycle (NEDC). With just focusing on the parallel hybrid architecture, the parallel hydraulic hybrid vehicle (PHHV) demonstrated 6.32 percent better fuel efficiency than the parallel hybrid electric vehicle (PHEV) for Urban Driving Cycle (UDC). While in the Extra Urban Driving Cycle (EUDC), the PHHV resulted in a 9.26 percent lower fuel economy compared to the PHEV. (Chen, 2015)

2.3 Type of drivetrain architectures for HHV

There are a few hybrid architectures, which includes parallel, series, and power split. In the power split architecture, which is a combination of series and parallel architectures, the conventional mechanical drive system of the parallel design is utilised in the power split architecture. (Pakdelbonab et al., 2021) The benefits of both parallel and series arrangements are combined in a power-split. While a series hybrid vehicle eliminates a mechanical propulsion train and is entirely hydraulically propelled. A hydraulic pump that is directly coupled to the engine shaft is attached to an accumulator for energy storage. Each wheel has a hydraulic motor to give power and move the vehicle forward. In addition, the parallel architecture's highly effective power transfer from engine to wheels is made possible by the mechanical drive train, which also maintains the series architecture's ideal engine management. (Stelson et al., 2008) With the mechanical drive train removed in this configuration, a series hydraulic pump and motors are attached to drive wheel shafts where the vehicle is entirely hydraulically powered. (Pakdelbonab et al., 2021)

In a parallel architecture, a traditional mechanical transmission is directly coupled to the output shaft by a differential gearbox and the transmission is driven by hydraulic fluid to provide power to each wheel. (Azzam et al., 2022)The hydraulic pump/motors are attached to the driving shaft that runs between the engine and the gearbox. This allows them to either deliver power or to absorb power from the accumulator, depending on the situation. (Chen, 2015) A clutch is installed in between the engine and the hydraulic pump or motors so that the engine can be disconnected from the load being carried by the road and the vehicle can be operated entirely by hydraulics. Because of this, the engine can be shut off when it is not required and then restarted when the accumulator must be charged again. (Stelson et al., 2008) The parallel architecture as shown in figure 2.2 is the simplest of the three because it is almost impossible to tell it apart from a conventional drive train. The only difference is that it contains a few additional hydraulic hybrid components that make it possible to implement regenerative braking, which is the only reason it is considered the simplest. Heavy vehicles employ hydraulic systems such as in garbage trucks, transportation sector vehicles, buses and delivery vehicles. However, for through-the-road vehicles, only a few research studies have shown hybrid hydraulic architectures. (Ramdan et al., 2020)

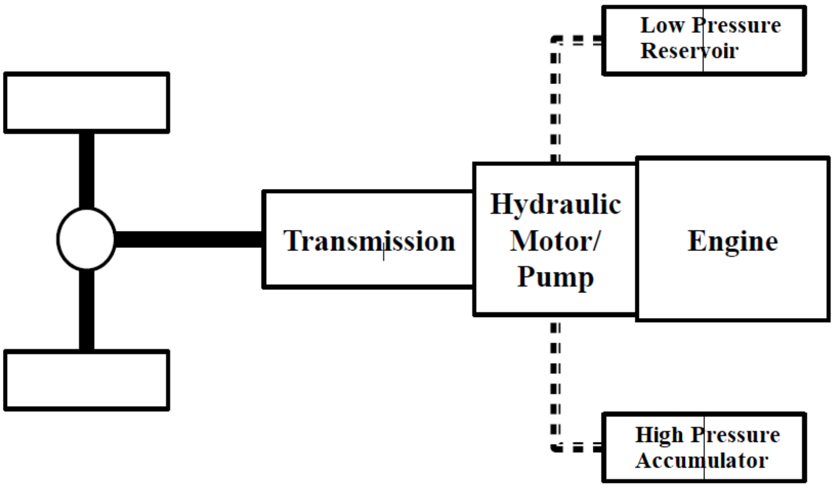

Figure 2.1 : Parallel Architecture of Hydraulic Hybrid Vehicle (Chen, 2015)

For a through-the-road (TTR) parallel hybrid, an internal combustion engine is positioned on the front axle of a TTR HHV, and the rear axle is powered by a hydraulic motor. Both axles will move at the same pace due to the parallel configuration created by the contact of the road and tyre. While the hydraulic motors drive the rear wheels or regenerates power from them during regenerative braking, the engine works to propel the front wheels. The energy flow of a TTR parallel hybrid vehicle is shown in Figure

2.2. The parallel architecture allows for the installing of regenerative braking components into an existing conventional car, a through-the-road hydraulic hybrid parallel design could be the answer to the low attainability rate of efficient hybrid vehicles. (Pisanti et al., 2018.)

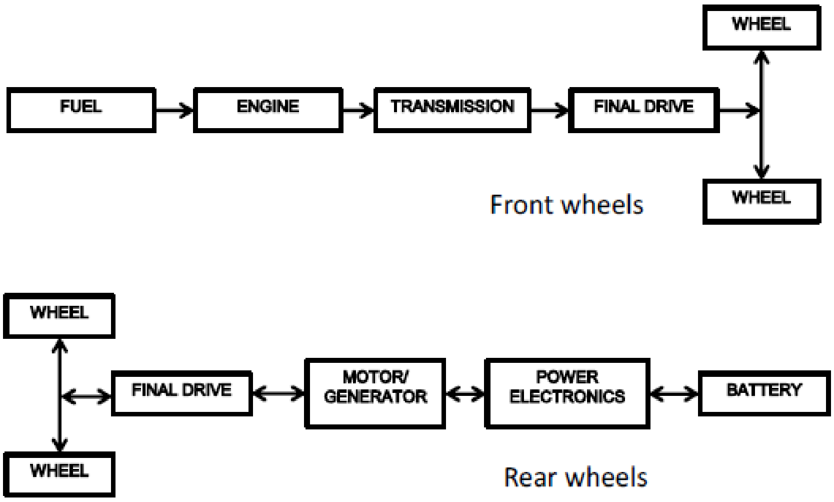

Figure 2.2: Energy flow in a TTR parallel hybrid vehicle (Pisanti et al., 2018)

2.4 Regenerative braking system in HHV

The regenerative braking system of the hybrid car is the fundamental idea behind the hybrid vehicle. This system recovers kinetic energy when the vehicle decelerates, which may subsequently be used to propel the vehicle forward. It is necessary to have a good control strategy for the regenerative braking system in order to optimise the efficiency of the braking, boost the comfort while driving, and improve the efficiency of the regeneration while preserving resources. (Liu et al., 2013) The hydraulic pump or motor unit, the high-pressure accumulator, and the low-pressure reservoir are the components that make up the regenerative braking system in the HHV. This system uses the kinetic energy that is transferred from the wheel as the vehicle is being braked to compress the hydraulic fluid, which is then stored as high-pressure fluid in the accumulator. After being stored under pressure, the fluid is drawn upon by the hydraulic pump or motor in order to produce torque for the subsequent stages of the vehicle's launch and acceleration. By fixing the regenerative braking force on the real wheel axle of the vehicle, the rear wheels should be locked after the front wheels to ensure that the vehicle maintains its stability while it is being braked. The position of this system plays an important role in determining the safety and efficiency of the vehicle**.** (Liu et al., 2013) Based on the needs of braking energy recovery and safety constraints, the braking force distribution between the front and rear wheels must be carefully constructed. Braking safety is considered as the most important factor when designing the braking control strategy. (Zhou et al., 2019) Fitting the system to the rear axle would be the most efficient and high safety method. The design of the hydraulic accumulator plays an important role as the preservation and conservation of the energy, which is very critical for the HHV system. (Tvrdić et al., 2018) The safety of the hydraulic regenerative braking system is linked to its performance. The hydraulic regenerative braking system's braking force should be consistent and effective. The exchange of high and low pressures occurs in hydraulic regenerative braking mode. The hydraulic motor's speed and the hydraulic system efficiency are inextricably linked. (Wu et al., 2019)

Because of its high-power density, the hydraulic hybrid propulsion system is an attractive option for regenerative braking in a vehicle that comes to a stop quite regularly. (Wu et al., 2016) Hydraulic energy storage systems have a number of benefits, some of which include a high-power density, a long cycle life, and the capability to charge and discharge fluids often. A component of a hydraulic hybrid vehicle that is responsible for storing hydraulic energy. Recuperating the kinetic energy lost during braking is another function that can be performed by an effective control strategy. (Wang et al., 2018) In a hybrid car, how soon the system can conserve energy is critical, at HHV the regenerative charging is much faster. Depending on the pressure differences, the hydraulic regenerative might have a very wide working range but not enough for the necessary brake torque. (Wang et al., 2015) Therefore, regenerative braking is one of the best systems of HHV which saves fuel.

2.5 Fuel consumption and fuel economy of HHV

Nearly half of the 4.8 billion barrels of crude oil are used annually by passenger vehicles. The drive to create a car with considerably better fuel economy stems from the huge amount of oil used by passenger automobiles. (Stelson et al., 2008) Therefore much research was made on the strategy to improve the fuel economy of HHV so that it can compete with HEVs in the market.

Firstly, (Barbosa et al., 2022) researched on fuel saving possibilities in HHV. To get an exact outcome that closely resembles real driving, a computational mode was developed in MATLAB Simulink for the simulation of a backward-facing approach with estimated driving resistance forces as in figure 2.2. As a result, when compared to the mean fuel consumption of actual vehicles, the simulation fuel consumption output had an error of less than 2%, allowing the simulation model to be utilised as a reference for the fuel savings potential analysis of the HHV architecture. The comparison of fuel consumption is between normal series hydraulic hybrid architecture (SHHV), optimized SHHV and the simulated conventional vehicle. The hydraulic components' sizing and operational parameters, such as the minimum working pressure, accumulator preload pressure, and motor/pump volumetric displacement, are optimised. Finally, the results showed that the normal SHHV and the optimized SHHV has about 18% and 38% fuel consumption reduction compared to the conventional simulated vehicle. Thus, it can be concluded that the hydraulic components sizing plays an important role in improving the fuel economy of HHV.

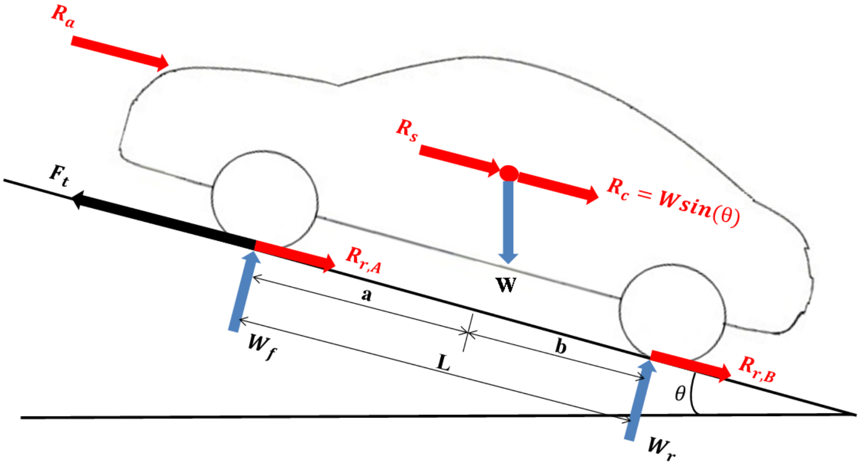

Figure 2.3: Resistance forces in a moving vehicle (Chen, 2015)

The next study, by (IEEE Staff & IEEE Staff, 2013.) evaluates the fuel economy and performance of the three hydraulic hybrid architectures: series, parallel, and power split. Fuel economy are analysed for the best design for each architecture, which takes into account the study on effect of pump/motor sizes, extra gears and different engine efficiency maps using an engine and chassis similar to the Toyota Prius as common components. To further increase fuel economy, new operating modes that includes de-clutching and engine shut-off are incorporated in addition to the hybrid architectures' normal operating modes while using the same engine, drive cycle, vehicle weight, wind, and road drag. According to the results, the power-split architecture has better fuel economy and works the pump/motor more effectively compared to series and parallel architectures. Additionally, enabling a second gear improves the fuel efficiency of all three architectures, with the parallel architecture's fuel economy becoming close to that of the power-split configuration at this point. Additionally, it has been found that increasing accumulator size does not considerably improve fuel economy after a certain value. Therefore, it can be concluded that increasing the number of gear shifts and minimising the diameters of the pump and motor, particularly for the parallel and power-split architecture, enhances the fuel economy.

Finally, the research by (Fontaras et al., 2008) conducted a fuel economy evaluation on two hybrid cars which is the Full Hybrid Prius II and Mild Hybrid Civic IMA using the European legislated driving cycle and the real-world driving cycle. The drive cycle method, which consists of one cold New European Driving Cycle (NEDC), one hot Urban Driving Cycle (UDC), and then fluidly the Artemis driving cycles, was done according to the ARTEMIS protocol. Based on the results for the four seasons of spring, autumn, summer, and winter, the spring has the lowest fuel consumption due to moderate air conditioning use when the temperature is high, while the summer has the highest due to more severe air conditioning use. Due to the lower ambient temperatures and the usual use of air conditioning, both the winter and autumn seasons experienced increased fuel use. Finally, the fuel consumption was shown to be 40–60% lower in urban driving situations than the typical equivalent traditional gasoline car in which the findings demonstrated that greater fuel economy was attained for vehicles with higher levels of hybridization. However, the fuel consumption of the two HEVs was the same over 60 km/h and over 95 km/h their fuel consumption was roughly the same as that of a regular automobile. Therefore, it can be concluded that the level of hybridization, ambient temperature and the use of air conditioner have a big impact on how much fuel a hybrid automobile uses.

2.5.1 Drive Cycle

The driving cycle that the vehicle is put through has a significant effect on the amount of fuel consumed produced by the vehicle. (Barbosa et al., 2022) Therefore, a driving cycle as shown in table 2.2 is a predetermined schedule of several operations that enables the repeatability of a fuel economy and emission test. Typically, driving cycles are described in terms of timing-dependent changes in vehicle speed and gear. The driving cycle must be closely followed as possible by a trained driver while conducting the test. (Barlow et al., n.d.) A higher level of driving volatility results in greater changes in acceleration which cause the driver to demand a higher level of power from the powertrain of the vehicle in order to meet their demand. Thus, it is possible for different driving styles to have dramatically varied fuel consumption, even when the driving conditions are the same. This indicates that the choice of driving cycle influences the fuel consumption. (Rios-Torres et al., 2019) Urban Driving Cycle (UDC) and real-world driving cycle are two instances of the driving cycles which are very advantageous in frequent stop-start (urban) driving regimes. (Zeljko et al., n.d.-a) This is because both driving cycles include a lot of deceleration and start-stop process, which makes good use of the regenerative braking system and subsequently reduces the fuel usage. The UDC is the optimum driving cycle to illustrate the experiment in this research paper as it was carried out in the university. It is so because the UDC cycle accurately simulates the driving conditions utilised in the experiment, which includes low engine load, low exhaust gas temperature, and a maximum speed of 50 km/h. (Zeljko et al., n.d.-a)

Firstly, (Zeljko et al., n.d.-b) researched the fuel consumption comparison between a hybrid hydraulic vehicle (HHV) and conventional vehicle in an Urban Driving Cycle (UDC) and New European Driving Cycle (NEDC) which consists of four UDC and Extra Urban Driving Cycles (EUDC). To perform vehicle simulation and the powertrain analysis AVL CRUISE software was used on hybrid vehicle built on the Yugo Florida platform. As for the result from the analysis, the fuel consumption of the vehicle is determined during engine idling, acceleration, constant drive, and deceleration. Therefore, the result showed that the overall reduction in fuel consumption for dual UDC cycle was about 30% while for NEDC it was only 7.1%. It can be concluded that hybrid vehicles are useful in stop-start driving situations like in urban driving cycle

The research by (Rios-Torres et al., 2019) estimated the fuel consumption between conventional and hybrid electric car (HEV) in various driving styles on personalized driving cycles. In order to provide more exact information about people's fuel usage depending on their social features, the personalized driving cycle prediction is carried out utilising a large-scale database of actual driving data combined with information on drivers, vehicles, and environments. While, in an urban and highway driving scenario, a designed driver-vehicle simulation is used to obtain the fuel consumption by classifying the driver into one of the three driving styles: normal, calm and volatile. The results showed that depending on the driving style, the fuel consumption of HEV and conventional vehicles is lowered about 12% to 13% in calm urban driving while for volatile highway driving it showed significantly higher fuel consumption for both the vehicles. It has been concluded that given the wide range of speeds in urban driving cycles, regeneration braking has a greater potential for energy recovery, which leads to larger fuel-saving improvements than the highway driving.

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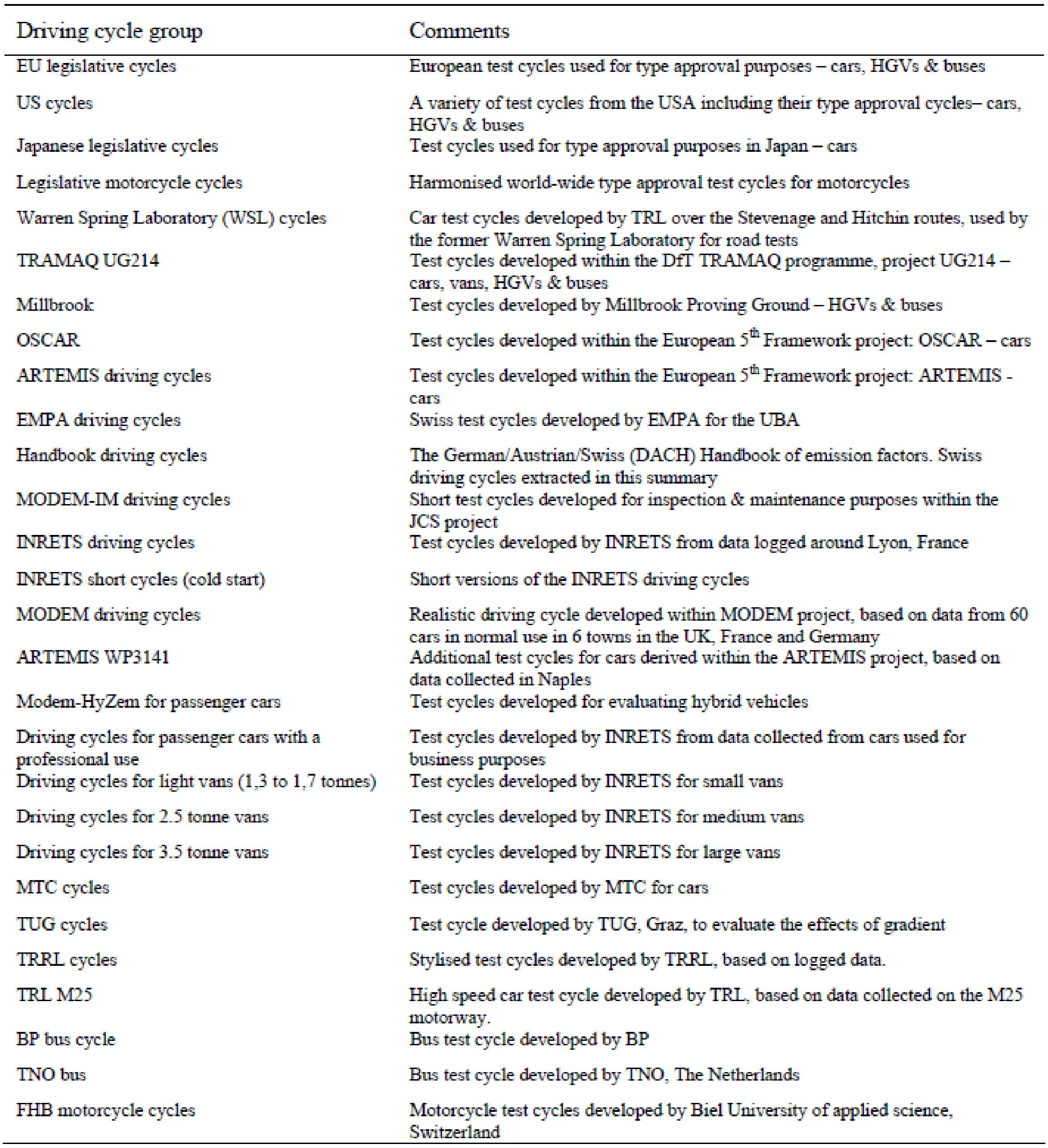
Table 2.2: List of driving cycles (Barlow et al., n.d.)



Driving cycle group	Comments
EU legislative cycles	European test cycles used for type approval purposes – cars, HGVs & buses
US cycles	A variety of test cycles from the USA including their type approval cycles– cars, HGVs & buses
Japanese legislative cycles	Test cycles used for type approval purposes in Japan – cars
Legislative motorcycle cycles	Harmonised world-wide type approval test cycles for motorcycles
Warren Spring Laboratory (WSL) cycles	Car test cycles developed by TRL over the Stevenage and Hitchin routes, used by the former Warren Spring Laboratory for road tests
TRAMAQ UG214	Test cycles developed within the DfT TRAMAQ programme, project UG214 – cars, vans, HGVs & buses
Millbrook	Test cycles developed by Millbrook Proving Ground – HGVs & buses
OSCAR	Test cycles developed within the European 5th Framework project: OSCAR – cars
ARTEMIS driving cycles	Test cycles developed within the European 5th Framework project: ARTEMIS - cars
EMPA driving cycles	Swiss test cycles developed by EMPA for the UBA
Handbook driving cycles	The German/Austrian/Swiss (DACH) Handbook of emission factors. Swiss driving cycles extracted in this summary
MODEM-IM driving cycles	Short test cycles developed for inspection & maintenance purposes within the JCS project
INRETS driving cycles	Test cycles developed by INRETS from data logged around Lyon, France
INRETS short cycles (cold start)	Short versions of the INRETS driving cycles
MODEM driving cycles	Realistic driving cycle developed within MODEM project, based on data from 60 cars in normal use in 6 towns in the UK, France and Germany
ARTEMIS WP3141	Additional test cycles for cars derived within the ARTEMIS project, based on data collected in Naples
Modem-HyZem for passenger cars	Test cycles developed for evaluating hybrid vehicles
Driving cycles for passenger cars with a professional use	Test cycles developed by INRETS from data collected from cars used for business purposes
Driving cycles for light vans (1,3 to 1,7 tonnes)	Test cycles developed by INRETS for small vans
Driving cycles for 2.5 tonne vans	Test cycles developed by INRETS for medium vans
Driving cycles for 3.5 tonne vans	Test cycles developed by INRETS for large vans
MTC cycles	Test cycles developed by MTC for cars
TUG cycles	Test cycle developed by TUG, Graz, to evaluate the effects of gradient
TRRL cycles	Stylised test cycles developed by TRRL, based on logged data.
TRL M25	High speed car test cycle developed by TRL, based on data collected on the M25 motorway.
BP bus cycle	Bus test cycle developed by BP
TNO bus	Bus test cycle developed by TNO, The Netherlands
FHB motorcycle cycles	Motorcycle test cycles developed by Biel University of applied science, Switzerland

Finally, the research by (Al-Samari, 2017) compares conventional vehicle models to different real-world driving cycles in Iraq to determine any potential benefits of employing parallel HEVs. The real-world driving cycle that was used in this study primarily corresponds to urban activities. Using Autonomie, a simulation tool that can simulate any real-world scenario, fuel economy and fuel emissions are calculated in the simulation. The study's standard driving cycles were for highway and city driving. Additionally, the real-world driving cycle reflected the volume of traffic in Iraqi cities.

As for the outcomes, in a real-world driving cycle, the parallel HEV's fuel economy significantly improved by 68 percent when compared to a conventional car. While standard driving, which mainly involved highway activity, only slightly improved fuel economy. Therefore, it can be stated that fuel economy depends on how often the brake system is utilised or the vehicle is decelerated, which results in the collection of free energy and subsequent re-use of that energy to drive the vehicle, which primarily happens in city driving cycles.

In conclusion, a hybrid vehicle's fuel consumption might vary greatly for a variety of reasons, according to research on fuel efficiency. First of all, it was found by (Barbosa et al., 2022) that the sizing of hydraulic components is crucial for enhancing fuel efficiency. Next, (IEEE Staff & IEEE Staff, 2013) concluded that improving fuel economy through more gear shifts and reducing motor and pump diameters. Finally, it was concluded that the level of hybridization, the outside temperature, and the operation of the air conditioner all affect the fuel use. In addition, (Rios-Torres et al., 2019), (Zeljko et al., n.d.-a) and (Al-Samari, 2017) came to the conclusion that a significant amount of regenerative braking is used from the Urban Driving Cycle (UDC) and real-world driving cycles, which results in an improvement in fuel economy.

CHAPTER 3

METHODOLOGY

3.1 Introduction

After years of prior students working on projects involving this hydraulic hybrid vehicle, my project's major objective is to measure the fuel consumption of the car in conventional and hybrid modes while also with the air conditioner on and off and contrasting the fuel economy between them. The hydraulic hybrid system is installed on a Perodua Myvi.

Figure 3.1: Prototype vehicle (Perodua Myvi)

3.2 Prototype

3.2.1 Hardware

The parallel hydraulic hybrid vehicle's setup system for this experiment is initially comprehended in which the system consists of a low-pressure reservoir, high pressure accumulator, a pump which transfers the kinetic energy from braking into hydraulic potential energy, a motor converts the hydraulic potential energy to mechanical energy, a variable throttle valve, a 3/2-way throttle valve, a pressure relief valve, and a pressure gauge. Table 3.1 below shows the functions of the components

Figure 3.2: Setup of hydraulic system

Table 3.1: List and function of components in the Hydraulic Hybrid Car

List of Components	Function
Low-Pressure Reservoir	Store and provide hydraulic fluid to the system via the pump.
High-Pressure Accumulator	To store and supply high-pressure hydraulic fluid to the motor from the pump.
Motor	Converts the hydraulic energy from the high-pressure accumulator into mechanical energy which is used to accelerate the wheel.
Pump	Converts the kinetic energy (braking) into hydraulic potential energy where the fluid is pumped from the low-pressure tank when the brake is pressed.
3/2 Way Throttle Valve	To direct the flow of fluid from the pump, either forward to the pressure sensor or back to the low-pressure tank.
Pressure Relief Valve	To observe and monitor the pressure going into the high-pressure accumulator
Pressure Gauge	To provide the reading of the fluid flowing from the low-pressure reservoir to high pressure accumulator

The system above is used to obtain the base fuel consumption and fuel economy of the Hydraulic Hybrid Perodua Myvi. The process flow for this project was to apply the Arduino microcontroller code, which obtains the fuel consumption of the parallel hydraulic hybrid Perodua Myvi and the result is then used to compare the fuel economy between the conventional mode and hybrid mode of driving based on the same driving map.

3.2.2 Software

The microcontroller used in this experiment is Arduino microcontroller system which is used to calculate the base fuel consumption during the conventional and hybrid mode driving of the Hydraulic hybrid vehicle. The input of the code to determine the fuel consumption is, the signal from the vehicle speed sensor (VSS) in the speedometer. Whenever the acceleration pedal is pressed, the VSS sends the signal to the Arduino and the data is extracted by the code itself into an excel file.

3.3 Experiment

3.3.1 Project setup

The setup consists of a hydraulic hybrid vehicle which is a Perodua Myvi 1.3 litre engine capacity with a manual transmission. The hybrid system consists of components low pressure reservoir, high pressure accumulator, motor, pump, valves, and pressure gauge. The whole system is connected together with hydraulic hoses as shown in figure 3.3.

Table 3.2: List of hydraulic hoses in the Hydraulic Hybrid Myvi

Hydraulic Hose Number	Connection
1	Connected from the low-pressure reservoir to the pump
2	Connected from the pump to the 3/2-way valve
3	Connected from the 3/2-way valve to the low-pressure reservoir so that the extra hydraulic fluid will flow back to the reservoir.
4	Connected from the 3/2-way valve to the pressure relief valve
5	Connected in between the transmission of hydraulic fluid which is connected to the pressure gauge
6	Connected from the pressure relief valve to the high-pressure accumulator
7	Connected from the accumulator to the variable throttle valve
8	Connected from the variable throttle valve to the motor
9	Connected from the motor back to the low-pressure reservoir

The numbering of the hoses in table 3.2 is based on figure 3.4 which shows the schematic drawing of the whole setup.

Figure 3.3: Connection of the hydraulic hoses

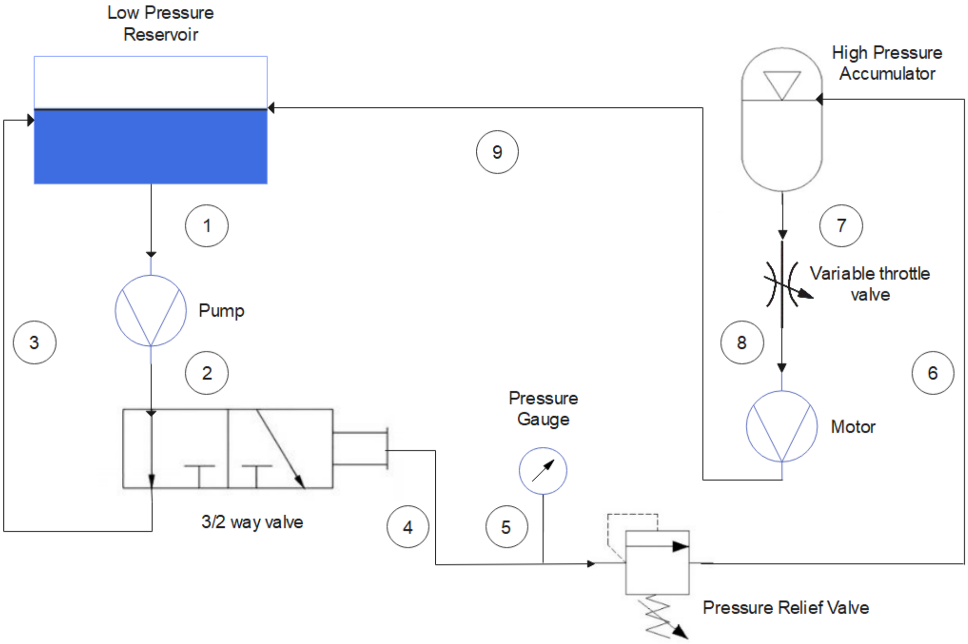


Figure 3.4: Schematic diagram of the setup

This setup of hydraulic hybrid system was fixed in the car by the previous batch for this project, so the whole system is used again to conduct the experiment. An Arduino microcontroller is also fixed to the speedometer for the data collection.

3.3.2 Compiled Code

The code starts with declaring the variable of the vehicle speed sensor wave frequency and its calibration variables. Then, the vehicle speed sensor (VSS) from the car speedometer gives out pulse wave, the pulse is high and low. From the high and low pulse, it is both summed to obtain the total sum where it is used to find the frequency and the vehicle speed. The calculation for it is:

$$frequency = \frac{1000000}{Total\ Pulse} \tag{1}$$

$$Total\ Vehiclespeed\ \left(\frac{km}{h}\right) = frequency\ \times 0.6442 \tag{2}$$

Based on equation (1) and (2), the pulse high and pulse low are summed to get the pulse total in microseconds. The frequency is then calculated by dividing the 10^{-6} s by the total pulse. The vehicle speed is then calculated from the frequency, the vehicle speed output from the Arduino is compared and calibrated with the vehicle's speedometer, and the constant 0.6442 is added to the equation to calibrate the result to match the speedometer's km/h. Thus, the same constant is used for the whole test. Next, the data of the calculated vehicle speed and the obtained time is sent to excel to be recorded. Each data is obtained at a time difference of 1000 milliseconds. The loop of this process continues from the start again till the car is turned off after reaching the destination. For both conventional mode and hybrid mode the code used are the same where only the data taken during the regenerative braking of the hybrid mode differs from both the mode. The following flowchart in figure 3.4 shows the whole flow of the programme where it starts from which is the declaration of variable, then to the input which is the pulse from the vehicle speed sensor, then the calculation of the vehicles speed, continued with the output which is set to print the time and the vehicle speed and finally sending it to excel before the loop starts again and the code ends when the vehicle stops fully.

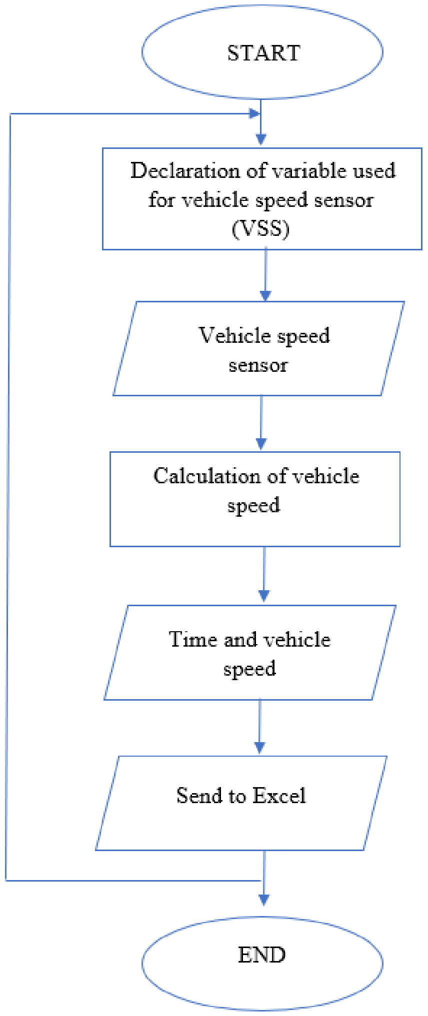


Figure 3.5: Flowchart of the Arduino code

3.3.3 Method of Fuel Consumption Test

3.3.3.1 Hall Effect Sensor

The first method to obtain the fuel consumption of the hydraulic hybrid vehicle (HHV) was conducted by using hall effect sensor. In this, the base fuel consumption of the HHV is obtained and compared. First of all, the hall effect sensor was calibrated with an Arduino microcontroller connected to it and flowing water through the sensor while measuring the water flow back in a measuring cylinder. The hall effect sensor is considered fully calibrated after getting a similar reading between the code and the measuring cylinder.

Later, a bracket was formed for the hall effect sensor to be tightly fixed into the car. The bracket was formed with a mild steel with accurate length and required thickness to withstand the weight of the sensor. After forming the bracket, it was fixed with the hall effect sensor at the engine side of the car and the fuel tank hose were connected to the hall effect sensor as shown in figure 3.4.

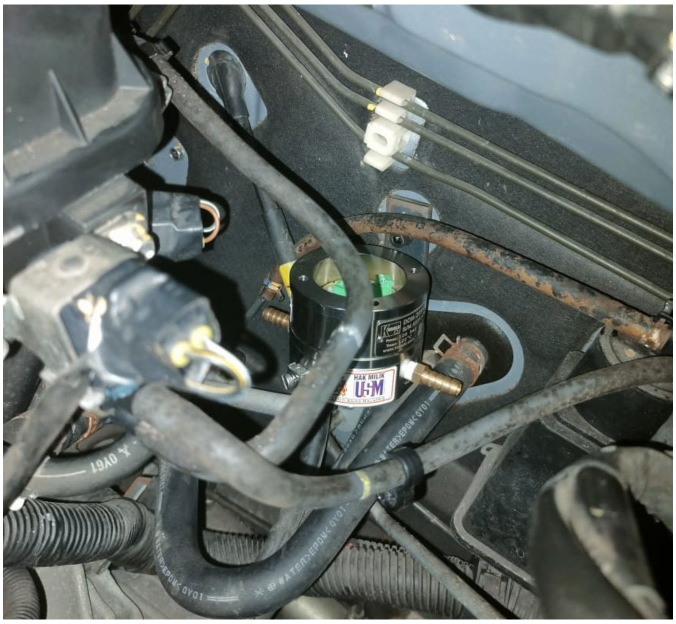


Figure 3.6: Hall Effect Sensor fixed at the engine side

Subsequently, the Arduino circuit diagram as in figure 3.7 was fixed to the sensor by connecting wires from the engine to dashboard. The Arduino code for hall effect sensor is as shown in Appendix A. The idling fuel consumption was then tested just by running the code when the engine is on. But the values did not seem logical as it was way too far from the theoretical value, in which we got a fuel consumption of 1 litre in 1 minute 20 seconds which seems illogical. Thus, to get more dataset of the fuel consumption, the parallel hybrid Perodua Myvi and was tested with a drive around the campus with conventional mode of driving. As a result, of comparing the data from the Arduino code, it was illogical again.

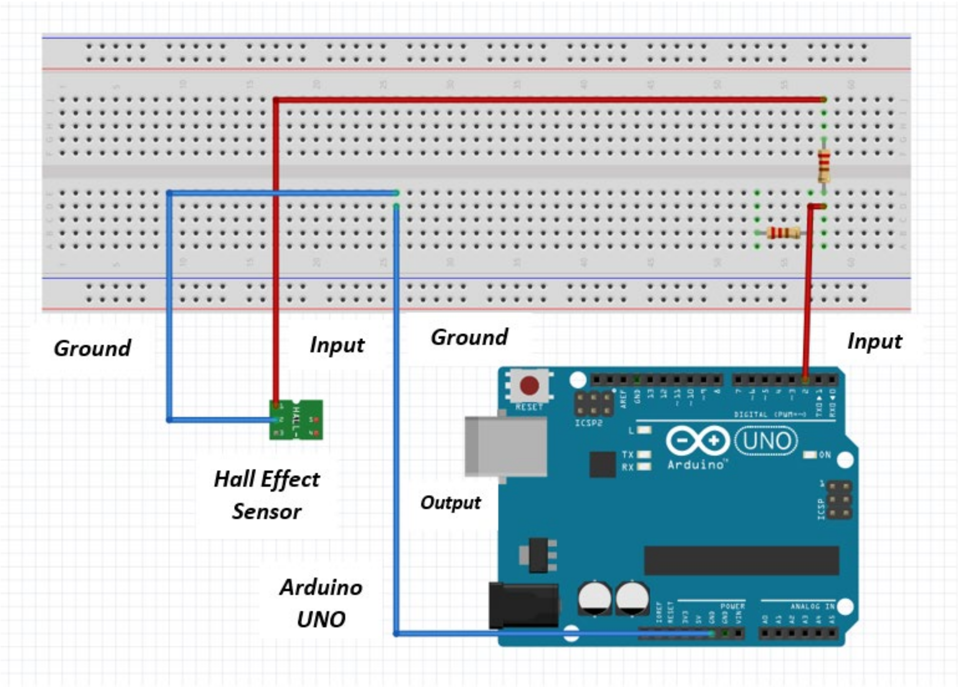


Figure 3.7: Arduino Circuit Diagram for Hall Effect Sensor

Figure 3.8: Fuel Level Checking During Test Drive

In order to determine the source of error, the data collection is done again in which the fuel hose connected to the hall effect sensor was withdrawn and a hole was poked in it to compare the theoretical and experimental value. However, the data was still irrelevant after many amendments on the code Therefore, the error was confirmed