DEVELOPMENT OF POWER MONITORING SYSTEM USING RASPBERRY PI

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in fulfillment of the requirements for the degree of
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DECLARATION

I declare that this thesis entitled " Development of Power Monitoring System using Raspberry Pi" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

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Date : 12/01/2024

APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Mechanical Engineering Technology (Automotive Technology) with Honours.

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DEDICATION

I am dedicating this thesis to my beloved parents, Mr. Nazri Bin Saad and Mrs. Noriha Binti Derin @ Derawi who has always be a huge role model in my life and for their constant moral, spiritual, emotional, and financial support. Thank you for being my source of inspiration and gives me strength when I am on my weakness point.

I also want to dedicate this research paper to my friends that been with me since orientation and provide me with the strength to power through these research process while also believing in me that I can complete it.

Also, I would like to dedicate this thesis to my supervisor and groupmate that been with me through the highs and lows throughout the entire of the project duration.

ABSTRACT

Electric vehicles (EV) rely on the battery voltage and current to ensure sufficient power is delivered according to the electric motor. The research focuses on the main aspect that makes up a monitoring system in a vehicle in general which is the integration of sensors, data acquisition and processing, and also the real-time sensor monitoring capabilities. The implementation of these aspect was crucial in order to paint a clear picture on the flow of information from the raw data from the vehicle to the interface that the user can easily interpret. Through the study of data acquisition method, different types of sensor technologies that are related to the EV were analysed such as for the voltage, current, battery temperature, state of charge of battery, and also the power consumption. Continuing on, the paper moves on to the data processing process through the usage of Vehicle Control Unit (VCU) such as Arduino board and Raspberry Pi. These VCU are the brain of the power monitoring system that receives the raw data and interpret them in order for the user to easily read and observed the data. Other than that, the system has been tested in order to confirm its connectivity and accuracy of data measured. From the test that were done, the accuracy percentage of the data received by the sensor, Arduino, and Raspberry Pi were accuracy to the extent of 90%.Overall, this paper provides a holistic overview into the power monitoring system of an EV where from its process of retrieving data until its data displayed were analysed and explored so that the system may be studied and be improved on throughout the advancement of EV technology globally.

ABSTRAK

Kenderaan Elektrik bergantung kepada voltan dan arus elektrik to memastikan kuasa yang mencukupi disalurkan kepada motor elektriknya. Kajian ini fokuskan kepada aspek penting yang memainkan peranan penting dalam mewujudkan sesebuah sistem pemerhatian kuasa dalam kenderaan elektrik secara umum iaitu penggunaan penderia, pemerolehan dan pemprosesan data, dan juga kemampuan untuk memerhatikan penderia secara langsung. Penggunaan aspek penting ini adalah penting dalam proses untuk menggambarkan perjalanan data yang diperolehi dari penderia kepada papan pemuka supaya memudahkan pengguna untuk mentafsir data tersebut. Selain daripada itu, dengan mempelajari kaedah untuk memperolehi data, pelbagai jenis teknologi penderia yang berkaitan dengan kenderaan elektrik telah dianalisis seperti untuk voltan, arus elektrik, suhu bateri, paras kuasa bateri, dan juga penggunaan kuasa. Di samping itu, kertas kajian ini beralih kepada data pemprosesan di mana ianya menggunakan papan Arduino dan juga papan Raspberry Pi. Unit kawalan kenderaan ini adalah minda di sebalik sistem yang di mana ianya memperoleh data mentah daripada penderia yang seterusnya ditafsir supaya mudah dibaca oleh pengguna untuk membaca dan melakukan pemerhatian terhadap data tersebut. Selain itu, sistem telah diuji untuk mengesahkan ketersambungan dan ketepatan data yang diukur. Daripada ujian yang dilakukan, peratusan ketepatan data yang diterima oleh penderia, Arduino, dan Raspberry Pi adalah ketepatan sehingga 90%.Secara keseluruhannya, kertas kerja ini memberikan gambaran menyeluruh ke dalam sistem pemantauan kuasa EV di mana dari proses mendapatkan semula data sehingga datanya dipaparkan dianalisis dan diterokai supaya sistem boleh dikaji dan diperbaiki sepanjang kemajuan teknologi EV di peringkat global.

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In the Name of Allah, the Most Gracious, the Most Merciful, I would like to express my greatest gratitude to Allah S.W.T that provide me with nothing with blessings and also the opportunity to write this paper while helping me grow as a person.

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LIST OF SYMBOLS AND ABBREVIATIONS

EV	-	Electric Vehicle
ICE		Internal Combustion Engine
LIB	-	Li-Ion Battery
LFP	-	Lithium Iron Phosphate

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CHAPTER 1

INTRODUCTION

1.1 Background

Vehicle has been an integral part of society since the early version of it during the 1800s. Due to its ability to travel at a huge distance with short time, vehicle has been a reliable alternative for everyone and it is more visible in today society where everyone has to do their task with their limited time and not spending it to reach the destination. Due to that, vehicle needed to be moving parallel to the constant current of modernization in its system, handling, and also environmentally friendly.

In the 1890s, the first fully- electric vehicle were produced by a French inventor with a human carrying capabilities and rechargeable battery. These variants of vehicle considered popular until the late 19th and early 20th centuries due to its non-vibrate, less odor, and less noise produced when compared to the internal combustion engine (ICE) vehicle. The were mainly famous as a taxi in the residential area and even gain the moniker Hummingbirds and “city cars”. But because of its short distance range and the mass production of gasoline-powered vehicles that reduced its price, the EV were having difficulties to keep up with the ICE vehicle. As the development of ICE vehicles keep increasing such as the invention of electric starter, development of muffler for noise reduction, and also the early production of turbocharger, the production EV were to be decreased and soon after lose its early gained traction the world of automotive dominance (Schiffer et al., 1994).

Figure 1.1 The First Electric Taxi in London

In the recent years, a new breed of vehicle that uses battery-powered system were released to the public where it is said to be needing less maintenance process, safer for the environment, and also less cost required for fuel. This new type of electric vehicle has the same concept of the internal combustion engine car with an exception of a few systems that were changed to better suit the electric vehicle requirement. Such system mentioned before can be seen in its power monitoring system where currently the the parameters that usually monitored are the battery level, battery usage rate, and lastly the battery consumed in different load and condition (Selvabharathi & Muruganantham, 2021).

In this project, the development of the power monitoring system of an electric buggy that was previously build by a group of Universiti Teknikal Malaysia Melaka (UTeM) student was focused on. During this stage, it has the ability to move but its capability and power needed to be optimally operatable were still unknown. With the development of a power monitoring system, the better understanding of an electric vehicle in the aspect of the electric vehicle (EV)'s range along with the factors affecting it. This revelation will provide the driver with the information in order for them to plan their drive and when to make a stop. Thus, indirectly improving the EV driving experience.

The end product of the power monitoring system can be tested by running the EV through a selected route and comparing its result with the different runs of the EV. This way, the optimal energy consumption and also its power usage through the different section of the route can be observed and made any improvement. The end product should also be a cheaper alternative for the power monitoring system. In the current times, an electric vehicle power monitoring system is the company trade secrets and patented or copyrighted and it costs a lot in order to obtained the technology. So, an alternative that is cheaper and also easy to maintain may be needed in order to makes the total money spent on an electric vehicle become less. The know-how of developing the battery and power monitoring system is crucial to the country's advancement on electric vehicles technology. This way, an environmentally friendly, energy efficient electric vehicle can be affordable to the Malaysian and to the world.

1.2 Problem Statement

The power monitoring system is a crucial part of a vehicle where it can monitor the power level and usage of a vehicle in order to determine its efficiency and also increase the driving experience for the user. This project focuses on the development of an electric-powered vehicle monitoring system. The system should be able to monitor the battery level of the vehicle, power usage, and also the vehicle speed. Other than that, they should be able to be used to determine the system efficiency to ensure that the electric-powered vehicle runs smoothly without any hiccups. When presented with different situation, the vehicle will be experiencing different loads that in which will affecting the battery usage. So, with this system, the data from the vehicle's battery usage should be able to visualize the situation or problem that may affecting the user's driving experience.

1.3 Research Objective

1. To develop a power monitoring system intended for an EV.
2. To collect the voltage and current data from sensor.
3. To achieve more than 90% accuracy of value measured from sensor.

1.4 Scope of Research

This study focuses on the development of a power monitoring system intended for an EV using a Raspberry Pi. The power monitoring system development will mainly focus on its main function to monitor the power usage and battery level. On that note, the system end product should be tested in order to evaluate its performance and to measure its ability to deliver the information for the user precisely.

The limitations of this project are shown below ;

1. The development of a power monitoring system come with its own complexity that may requires specialized hardware that is more precise and accurate while being costly.
2. The monitoring system must be integrated into the existing electronics and battery management system that may have different communicating hardware or protocols.
3. To stabilize the data received in order to improve the accuracy of data when compared to the standard value.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, by referring various resources such as articles, journals, research papers, and also reviews, research was done in order to clarify and gain a deeper understanding regarding the research topic. This chapter will focus on the fundamental component of an electric vehicle and also the mechanism that grants it the ability to operate. An example for the topic that will be discussed are the computer processing unit, sensor, and also the power unit of the electric vehicle. Furthermore, the results of the research were targeted to be able to smoothen the process of learning and the development of the power monitoring system.

2.2 EV Power Source

In terms of power supply for generic EV, the energy supplied from battery to the vehicle motor in order to give it ability to moves. The battery that was used have their own different sets of parameters that resulted from the different chemicals used for the working mechanism of the battery. The different parameters that can be highlights are its specific energy, life cycle, and nominal cell voltage. The parameters were selected to be discussed are because of its ability to determine the battery's overall performance qualities (Koniak & Czerepicki, 2017).

The specific energy of a battery can be defined as its energy that can be stored compared to its weight and it can be expressed in the unit (Wh/kg). The specific energy can help to determine the battery's total energy while be conscience of its weight and indirectly helps with the weight management process. Other than that, life cycle can be defined by the process of charge-discharge cycles of the battery without significant degradation in their performance. Every battery has a chemical electrolyte that will degrade after a set period of usage. The life cycle can help to determine the battery usability period during its constant cycle of charge/discharge before experiencing any degradation in its efficiency. Last but not least, the last parameters that will be discussed is the battery's nominal cell voltage. In each steel case that makes up a battery has a number of cells that provide a low amount of voltage which typically around 1 to 3V. The total of cells combined are what made the total voltage of an EV battery. The nominal cell voltage can be interpreted as the average voltage value of cells produces when its discharge cycle. It can help to determine the battery's compatibility with the peripherals and device in the EV system. Based on the paper by (Sepasi, 2014) and (Anseán et al., 2013), the different chemical properties of each different battery cells are highlighted as follows.

Table 2.1 Comparison of Different Chemistry of Battery Cells.

	Lead Acid	NiMH	Li-Ion	LiFePO4
Nominal cell voltage	2V	1.2V	2.5V/3.3V/3.6-3.7V	3.2V
Specific Energy	30-45 Wh/kg	30-80 Wh/kg	90-220 Wh/kg	80-100Wh/kg
Energy Density	60-75 Wh/L	140-300 Wh/L	280-400 Wh/L	220Wh/L
Specific power	180 W/kg	250-1000W/kg	600-3400 W/kg	400 W/kg
Cycle life	500-800	500-1000	1000-8000	5000
Self-discharge	2-45% /month	20-30% /month	2-5% /month	5% /month
Optimum working temperature range	-40-55°C	-20-45°C	15-35°C	-20-60°C

2.2.1 Nickel Metal Hydride Battery (NiMH)

One of the sought after energy storage system in the industries due to its high energy densities, long lasting performance, less environmentally harmful materials, and also its compact build. The Nickel Metal Hydride (NiMH) battery is using the combination of nickel oxyhydroxide positive electrodes and metal hydride negative electrodes to produce the charge/discharge electrochemical reaction through an alkaline electrolyte. The NiMH battery was considered to be a relatively matured technology where its current state has gone through various trial and error era and even has a significant increase of energy per unit mass from 54 Wh/kg during it early days to 100 Wh/kg (Fetcenko et al., 2007).

NiMH battery are able to provide a higher energy density with the cost of a reduced life cycle at only 516 cycles compared to the NiCad battery at 688 cycles when both of them were compared in a controlled experiment. But due to its negative electrode use a metal hydride element, it is more easily disposed and will cause less significant amount of impact to the environment. On the other hand, the cadmium electrode used in NiCad battery is carcinogenic and can cause pollution if it is not disposed correctly (Chanoine et al., 2011).

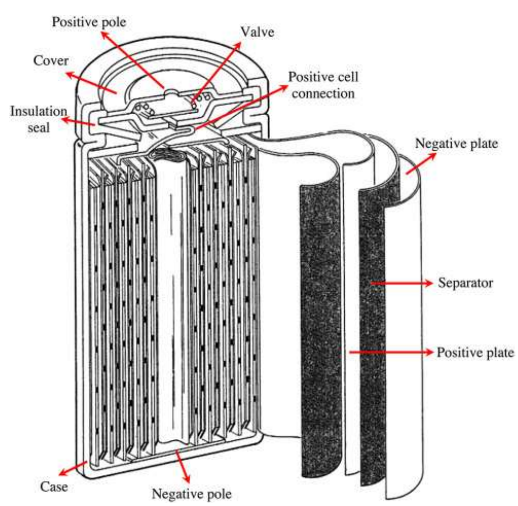

Figure 2.1 NiMH Battery Cell Structure.

2.2.2 Lithium Ion Battery (LiB)

Another option for an EV battery is the Lithium Ion Battery (LiB). It has a different working principle compared to the NiMH battery where its typically use Lithium Cobalt Oxide (LiCoO2) for its positive electrode and graphite or any other elements with the ability to receive lithium ions during its charge/discharge process. It also has an organic solvent as the electrolyte in order to solute the lithium salts such as a Lithium Hexafluorophosphate (LiPF6) solution (Silva, 2016).

These types of battery are initially developed for the electronic devices uses such as in laptops, smartphone, and even power tools. Furthermore, the LiB that are used in EVs are the latest variation where they have a better fire resistance property, longer lifespan, fast charging capabilities, and even a high energy per unit mass where it can reach 200-250 W.h/kg (Fatima et al., 2018). As for its voltage output, the nominal voltage of a LiB cell has a different variation where it depends on its application requirement which is 2.5V, 3.3V, and 3.6-3.7V (Sepasi, 2014). Despite that, there are some underlying issues in LiB in which it may experience low performance power in low temperature, performance degradation with age, and may ignite when pierced or charged improperly. In addition, the increase in temperature in the battery cell may degrade its cycling performance and leads to thermal runaway where the battery cell enters an uncontrollable and self-heating state. This issue also can lead to non-uniformed heat to be transfered within the battery pasck and also leads to fire or even explosion (Abu et al., 2023).

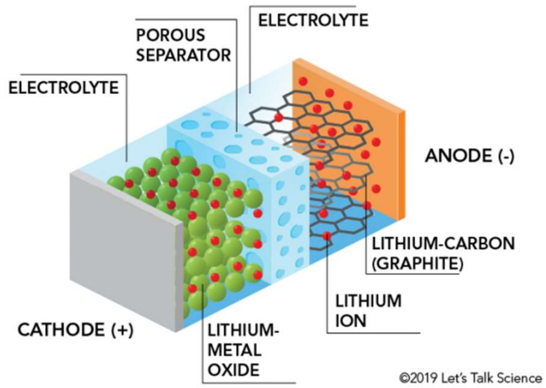

Figure 2.2 Li-Ion Battery Cell Structure.

2.2.3 Lithium Iron Phosphate (LiFePO4) Battery

Lithium Iron Phosphate (LFP) battery are another option for an EV power storage system. It is considered to be an important component for making a more energy efficient and less dependent on petroleum through its usage in various electric based vehicle such as hybrid, plug-in hybrid, and even full electric vehicle (Liu et al., 2012). In a single cell of the battery, it has a nominal voltage of 3.2V, specific energy at 80-100Wh/kg, and also a life cycle at around 5000 cycles (Anseán et al., 2013). Based on these numbers obtained, it is can be said that the LFP battery were another suitable choice in order to be implemented as an EV power storage as it is able to rival the other battery and not be too inferior in its specifications thanks to the advantages of wide temperature range, fast charge/discharge rate, and relatively long-life cycle. On the downside, the LFP battery has a low energy density value when compared to the already existing EV battery which is the LIB. The low energy density of the LFP battery can hinder the vehicle ability in its weight management aspect of the car as it requires a much higher number of battery cells in order to provide the same amount of power as the LiB (Egashira et al., 2011).

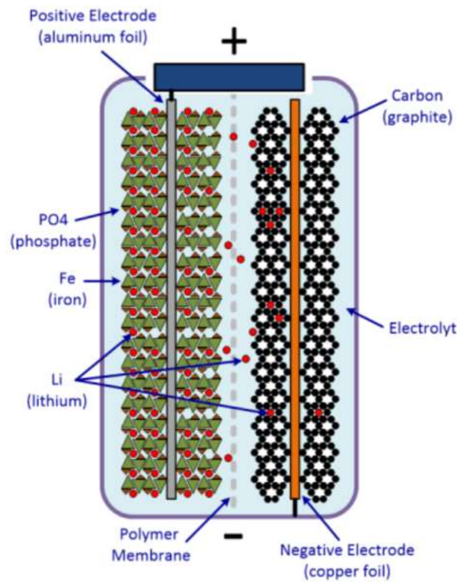

Figure 2.3 LiFePo4 Battery Cell Structure.

2.3 Signal Processing Unit

Traditionally, in order to produce a reliable and efficient EV control system, two major components are required which is the battery management system (BMS) and the vehicle control unit (VCU). The VCU of an EV is responsible to communicate with the sensors and actuators of an EV in order to make it function as per command and also coordinating the operation of the entire vehicle (Li et al., 2020). In this case, the task of sending signal to the actuators were done by a separate controller that is directly connected to the motor. The flaw of this system is that there is currently no way to determine the input, output, and also the battery level of the EV. This situation leads to the decision to find a suitable signal processing unit in order to monitor and do improvement to the power used by the EV as a whole. Currently, there are two candidates that is under consideration for the role of the signal processing unit of the EV.

2.3.1 Arduino

An open-source electronic platform that is versatile, user-friendly features, and flexibility, Arduino has become favorite choice in every group of people that looking for more accessible electronics to learn. It is equipped with a microcontroller that is responsible for executing program codes and controlling the actuators connected to it, and input/output (I/O) pins to connect to various components, and also a USB port to ease the communication connection between the Arduino board with a computer. The input and output voltage of an Arduino is only around 5V which makes it a very suitable for only small-scale project and not to mention it is only a simple microcontroller which only makes it possible to process a simple coding task (Badamasi, 2014). As for the application aspect of Arduino, despite it is able to serve its purpose in providing a low-cost and energy efficient platform, in some cases where a project requires a higher processing capability along with more hardware compatibility, the Arduino fall short in some aspect when compared to a full-fledged microcomputer (Kondaveeti et al., 2021).

Figure 2.4 An Example of an Arduino Uno Board.

2.3.2 Single Board Computer

A single board computer (SBC) can be seen as a microcomputer that is built on a single circuit board that has all the essential components of a computer such as a processor, storage unit, I/O interfaces, and also memory unit. The example of an SBC is Raspberry Pi 4, BeagleBoard, and Asus Tinker Board 2S. The SBCs are considered to be a famous choice in the industrial application due to it has a great computing ability, low power consumption, low cost while producing less heat compared to a full computer. Other than that, the low voltage required from external power source at 5V or 12V makes it a good choice in order to make an EV power monitoring system where its only required a lead acid battery that can produce 12V power or uses a regulator to reduce its voltage for the SBCs that uses 5V power input. Based on the data provided by the manufacturer, below are the comparison in the hardware of the aforementioned SBCs:

Table 2.2 Hardware Comparison Between SBCs.

Technical Specifications	Raspberry Pi 4B	BeagleBone Black	ASUS Tinker Board 2S
Processor unit	Quad Core 1.8GHz Cortex-A72	AM335x 1GHz ARM Cortex A8	Quad-Core 1.5GHz Cortex A53
Memory unit	1/2/4/8GB LPDDR4	512MB DDR3 RAM	2/4GB LPDDR4
Graphic processing unit	Broadcom VideoCore VI @ 500MHz	PowerVR SGX530 @ 200MHz	Arm Mali-T860 MP4 GPU @ 800MHz
Display	-2 micro-HDMI ports -MIPI DSI (2 lane)	-1 micro-HDMI ports	-1 HDMI with CEC hardware ready port -MIPI DSI (4 lane)
Power	-5V DC via USB-C connector and GPIO header -Power over Ethernet enabled (requires separate PoE HAT)	-5V DC Barrel Plug 5.5mm/2.1mm -5V mini-USB port -3.7V nominal voltage cell through the battery pins	-12~19V DC Power Input Jack (5.5/2.5 mm)
GPIO	40-pin GPIO pins	69-pin digital pins and 7 analog inputs	40-pin GPIO pins
Connectivity	-Gigabit Ethernet -802.11b/g/n/ac wireless -Bluetooth 5.0	-802.11b/g/n wireless - Bluetooth 4.1	-Gigabit Ethernet -M.2 802.11a/b/g/n/ac wireless -Bluetooth 5.0
USB port	-2 USB 3.0 Type-A ports -2 USB 2.0 ports	-1 USB 3.0 Type-A port	-3 USB 3.2 Gen1 Type-A ports -1 USB 3.2 Gen 1 Type-C OTG port
Storage	-Micro-SD card slot	-4GB eMMc flash storage	-16GB eMMC flash storage -Micro-SD card slot
Price	$35.00-$75.00	$107.99	$119.00-$159.00

Based on the hardware specifications and its price range, the Raspberry Pi 4 Model B and ASUS Tinker Board 2S were tie in certain aspect as both of it has a great hardware implemented but the Raspberry Pi 4 Model B were deemed suitable for this research application as it has a great combination of integrated hardware along with a reasonable price.

Figure 2.5 An Example of A Raspberry Pi 4 Board.

2.4 Sensor

For the purpose of collecting the data produced by the EV, a sensor is needed in order to produce a data in a numerical form in order to analyse, process, and improve on the already established system. In a standard vehicle, there are currently a lot of sensors that was being utilised in order to receive an accurate and credible data. In this chapter, the various variation of EV sensor that can be used for the purpose of monitoring the vehicle will be discussed.

2.4.1 Voltage Sensor

In an EV system, the voltage output of the battery has a major role in determining the vehicle capabilities and performance. In order to build a system that is reliable and efficient, the voltage output of a system should be proportional to its energy reserve. If a system were to supply too much voltage, it can reduce the torque and the overall power of the EV. Based on the voltage sensor that will be used, the voltage input should be able to withstand a high voltage as it is will be connected to the battery in series position. As for the output of the sensor, it should be around 5V as it will be connected to the signal processing unit i.e., Raspberry Pi 4.

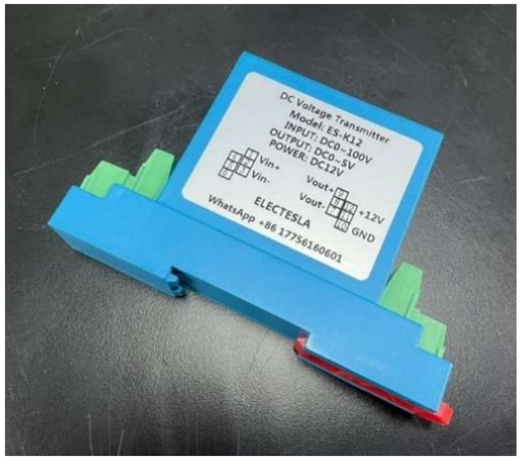

Figure 2.6 An Example of Voltage Sensor.

2.4.2 Current Sensor

The current sensor on the other hand, it is use to determine the current flowing from the battery into the motor that drive the EV. The current of an EV can be defined as the rate in which the electrical charges pass through a point in a circuit. The purpose of identifying the current of an EV during its operation is to calculate the power use by the EV during its operation period. The current and voltage of the vehicle are used in the formula of finding the power which is

$$Power\ (W) = Voltage\ (V)\ X\ Current\ (I) \tag{2.1}$$

If a system were to supply too much current, the battery will probably run out faster and thus, making it inefficient for longer driving period. Thus, proper calculations energy required per distance (Wh /km) is required to design a proper energy storage system of the vehicle.

Figure 2.7 An Example of Current Sensor.

2.4.3 Battery Temperature Sensor

During the charging and discharging process of a battery, it will undergo a chemical reaction in its electrolyte and can generate heat within the battery cells. If battery cells were to be in too high temperature, it may cause the chemical of the battery especially in the LiB to deteriorate. If the battery were ever to exceed its acceptable temperature range, which is between 15-35°C (Agwu et al., 2018). The instance where the battery was to reach hot temperature may happen anytime during its operation process and when it is used in a hot climate country, it may contribute to the overheating condition of the battery. In order to maintain a good battery health and prolong its life cycle, the temperature of the battery should be monitored. As for the others EV battery that are usable, it has different sets of chemistry involve for its charge/discharge process. Below are included the optimal battery temperature for each different types of battery used (Sepasi, 2014; Anseán et al., 2013). Thus, it is crucial that the battery temperature of an EV should be monitored in real time in order to negate any possibilities that the battery can malfunction and causing any unnecessary hazard for the user.

Table 2.3 EV Battery Optimum Working Temperature

	Lead Acid	NiMH	Li-Ion	LiFePO4
Optimum working temperature range	-40 to 55°C	-20 to 45°C	15 to 35°C	-20 to 60°C

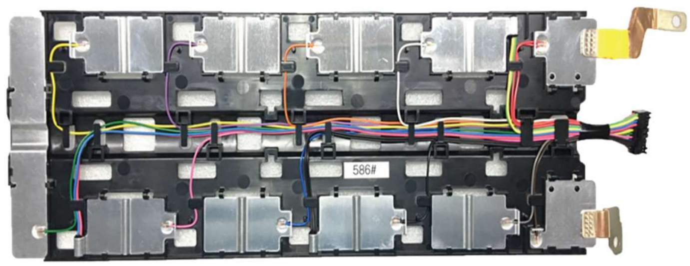

Figure 2.8 A Battery Sensing Film With a NTC Thermistors.

2.4.4 Battery State of Charge (SOC)

In a battery powered vehicle, the battery is a crucial component that powered the vehicle. The state of charge (SOC) of a battery can be explain as the battery's current energy value compared to when its fully charged capacity. As a crucial parameter in the BMS of an EV, the SOC plays a major part in various system of the vehicle where it can determine the vehicle driving range, preventing the battery overcharge, and over discharge. Continuing that, the aging characteristic of the battery electrochemical can cause the battery to experience drop in performance level over its lifespan (Rivera-Barrera et al., 2017). In order to prevent the further deterioration and improve the lifespan of the battery, an SOC estimating method should be develop and implemented based on the requirements of the battery.

In general, there are three ways to estimate the SOC level of a battery which is direct measurement method that measure the amount of charge stored in a battery, estimation based on black box model that replicate the battery internal details and open-circuit voltage as a black box, and state space-based estimation method that presented as a mathematical representation based on the battery (Zhou et al., 2021).

CHAPTER 3

METHODOLOGY

3.1 Introduction

The planning, resource gathering, and execution processes were essential in a research project as they made the flow of work smoother and less unpredictable. In this methodology part of the research paper, the proper procedures, techniques, tools, and troubleshooting problems were presented and discussed in order to outline the framework of the execution aspect of the project. The methodology for the power monitoring system in an e-buggy exposes the research and procedures for the installation and implementation of the hardware used in the project. The testing and troubleshooting processes were also discussed in this chapter of the research paper in order to find any weaknesses or errors in the methods that were used for the project and maybe provide any improvement upon the problems.

3.2 Flowchart

The project flowchart highlights the steps taken from the early phase of the project with its problem identification process until the testing of the hardware. This flowchart helps to guide the phase that should be redone if any difficulties were to happen during any stage of the project duration.

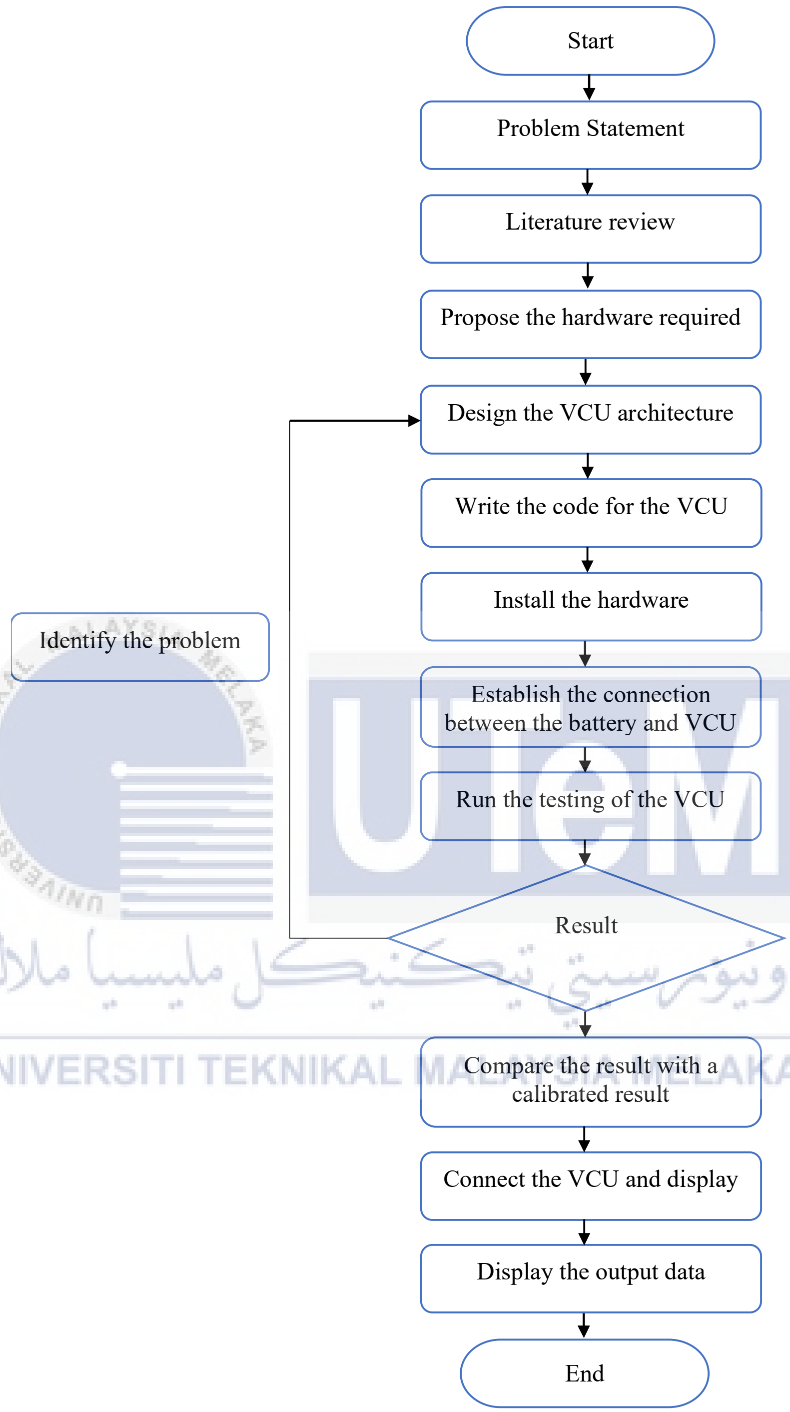

Figure 3.1 Project Flowchart.

3.3 Vehicle control unit (VCU) architecture.

The architecture of the VCU were included in order to exposes the structure of a system and how this different hardware communicate with each other and work without any problem. If any problem were to arise during the testing process that resulted from the hardware connection, the VCU architecture are a crucial indicator and clue that can helps to identify which hardware that having a connection issue. In the figure below, the proposed VCU architecture were included.

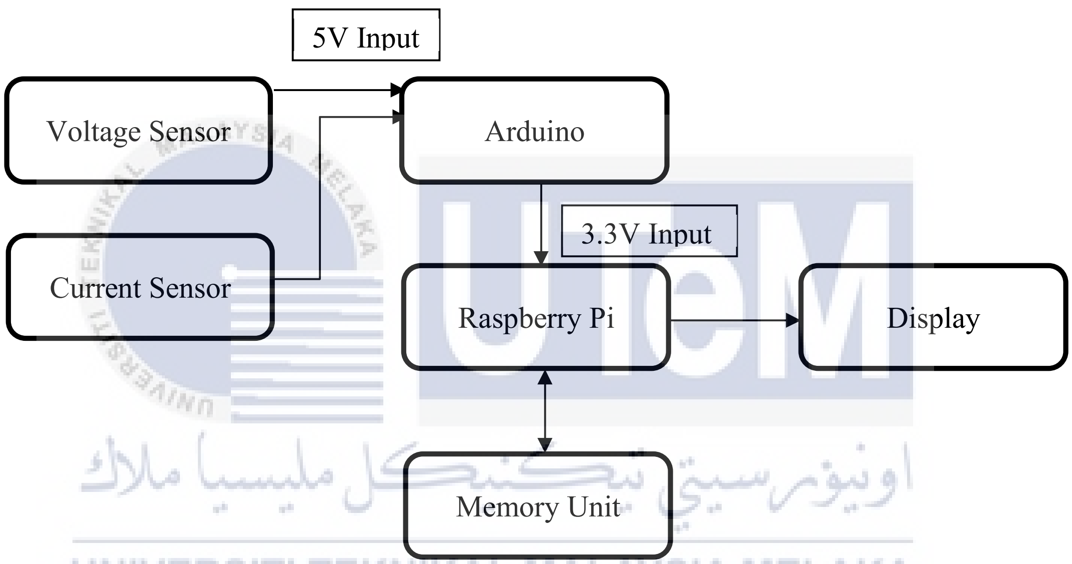

Figure 3.2 The VCU Architecture.

The combination of Arduino and Raspberry Pi was used due to the Raspberry Pi's inability to read an input signal that is higher than a 3.3V signal from both the voltage and current sensors. As the analogue signal from both of the sensors has a maximum output of 5V, the Arduino was used as a signal receiver unit to receive and reduce the signal to 5V for the Raspberry Pi to interpret and display on the dashboard.

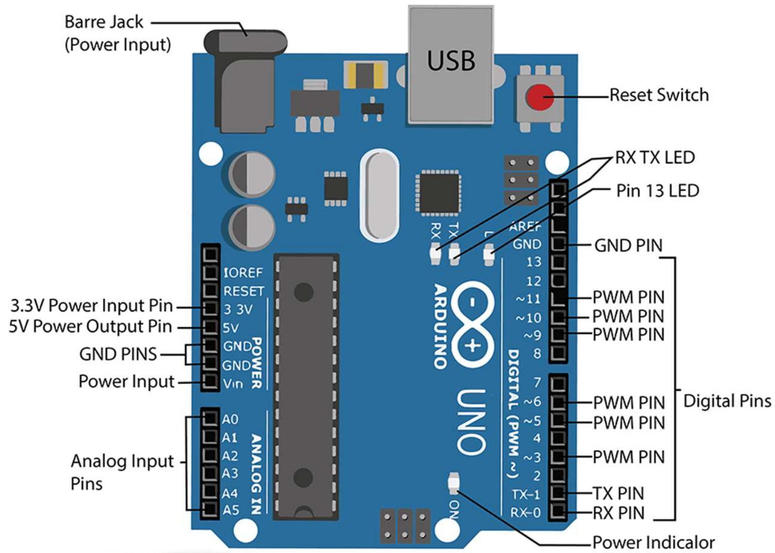

Figure 3.3 The I/O Pins for The Arduino Uno Board

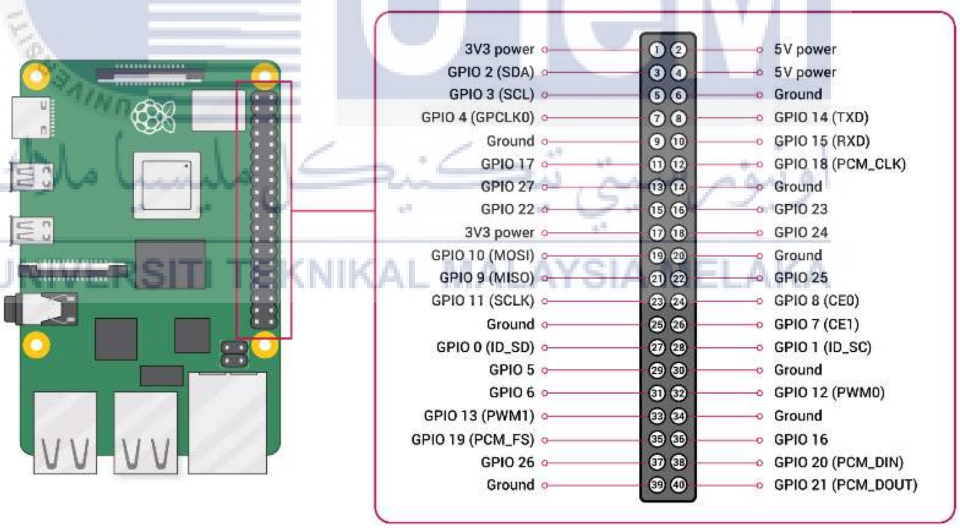

Figure 3.4 The I/O Pins for The Raspberry Pi Board.

While the input signal will be connected to the Arduino through the Analogue Input Pins, the proposed connection between the boards will using the Serial Connection where the Raspberry Pi will receive the data and the Arduino will supply the data received from sensor, in order for the Raspberry Pi to read the signal if it were to reach more than 3.3V signal.

3.4 Coding Language for the Raspberry Pi and Arduino.

For the method of giving the VCU the required instructions to receive the data, analyses it, and also display the data, Phyton was chosen as a suitable language as it has a beginner-friendly learning curve and is also versatile for the implementation of this research project. With the extensive library and huge community-backed language, it should be easy to divulge and find any problem or error with the coding during the troubleshooting process. For Arduino, basic C++ programming has been used. Below. The coding that was done to read the sensor input signal using the Arduino were included.


```
int CurrPin=A2;
int VoltPin=A3;
float CurrentSensor;
float VoltageSensor;
int delayTime=1000;

void setup(){
  pinMode(CurrPin,INPUT);
  pinMode(VoltPin,INPUT);
  Serial.begin(9600);
}

void loop(){

  CurrentSensor=analogRead(CurrPin)*(5.0/1023.0);
  VoltageSensor=analogRead(VoltPin)*(5.0/1023.0);

 Serial.print(" Current Value: ");
   Serial.print(CurrentSensor);
   Serial.print(" A");
 Serial.print(" | Voltage PMW Value:");
  Serial.print(VoltageSensor);
  Serial.print(" V");
 Serial.print(" | Power Value:");
  Serial.print((VoltageSensor*CurrentSensor));
  Serial.println("W");

  delay(delayTime);
}
```

Figure 3.5 The C++ Language Coding for the Arduino.

```
import serial

if __name__ = '__main__':
    ser = serial.Serial('/dev/ttyUSB0', 9600, timeout=1)
    ser.flush()

    while True:
        if ser.in waiting > 0:
            Line = ser.readline().decode('utf-8').rstrip()
            print(line)
```

Figure 3.6 The Coding for the Raspberry Pi 4

3.5 Installation Process

The hardware for the power monitoring system was installed into the already-existing buggy. The installation process included the battery, voltage sensor, current sensor, and wiring for the sensor signal. The LIB was chosen to be installed under the seat of the driver, with 20 battery cells separated into two sets of 10 battery cells installed in a parallel configuration. Other than that, both of these battery cells were included with two different switches in order to control each battery separately. As for the both of the sensor, it was installed at the back of the buggy near the controller. The voltage sensor and current sensor were installed in a series configuration where their supplies originated from the lead-acid battery.

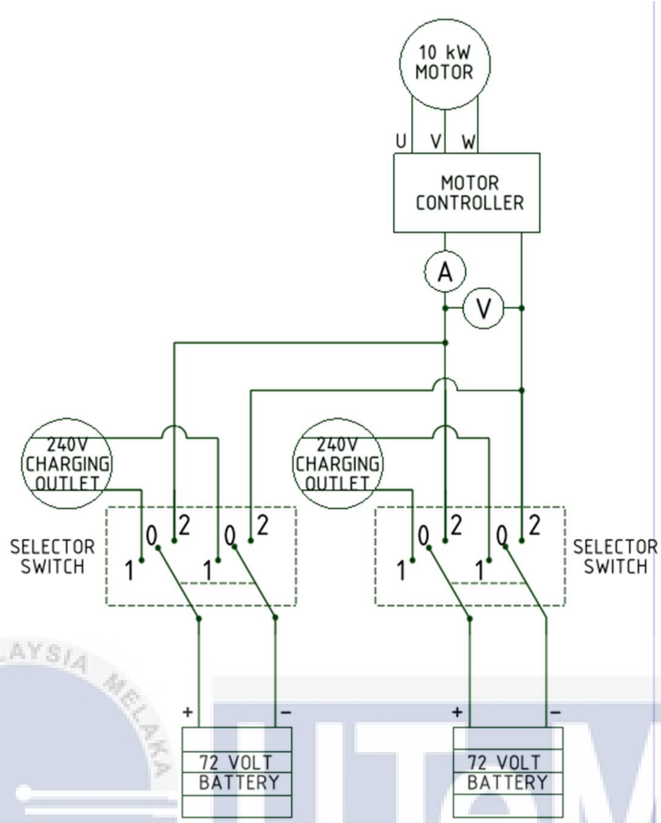

Figure 3.7 Circuit Diagram for The Li-Ion Battery.

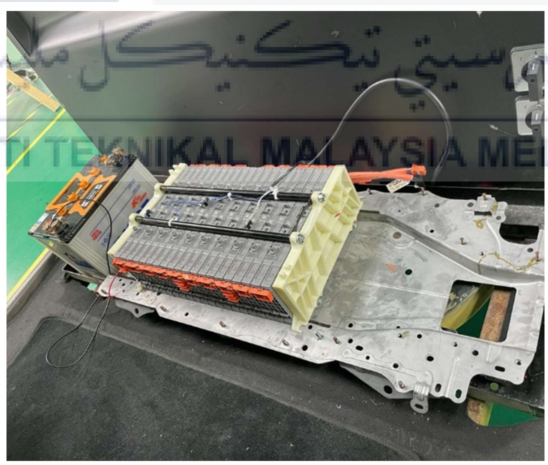

Figure 3.8 The NiMH Battery Used for The Research

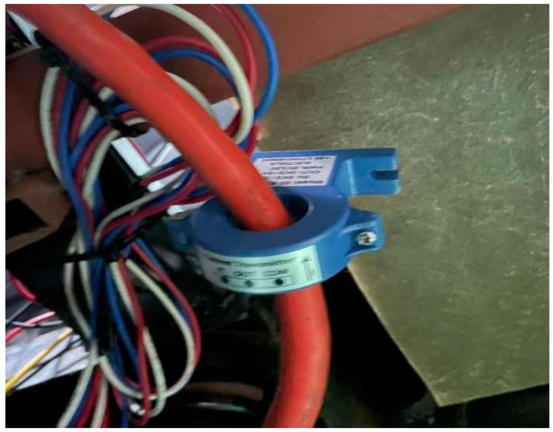

Figure 3.9 The Current Sensor Installed For The Research

Figure 3.10 The Voltage Sensor Installed For The Research

3.6 VCU testing

In the testing phase of the research, the testing that was done for the VCU was to establish the connection between the sensor and the VCU. When the coding of the Arduino was run during the testing, the Arduino was aimed to receive the output from the sensor, and then transfer the data received to Raspberry Pi. The reading of the Arduino was set up to update the data received in every second to simulate any fluctuation in output produce by the battery. This indicates that when the motor was supplied with power by battery, there were readings of voltage and current. The next step was to connect the already-connected Arduino with the Raspberry Pi in order to display the obtained results.

Figure 3.11The Sensor Reading Observed From Arduino

As for the transferring the data from Arduino to Raspberry Pi, the Serial Connection were used as it is eliminates a separate wire to power up the Arduino and to transfer data received. In this case only single UART wire was used for both of the purposes. This configuration also removes the risk of data wire to be disturb and shaking during test that may increases the difference in data collected when compared to the standard data (data measured by multimeter).

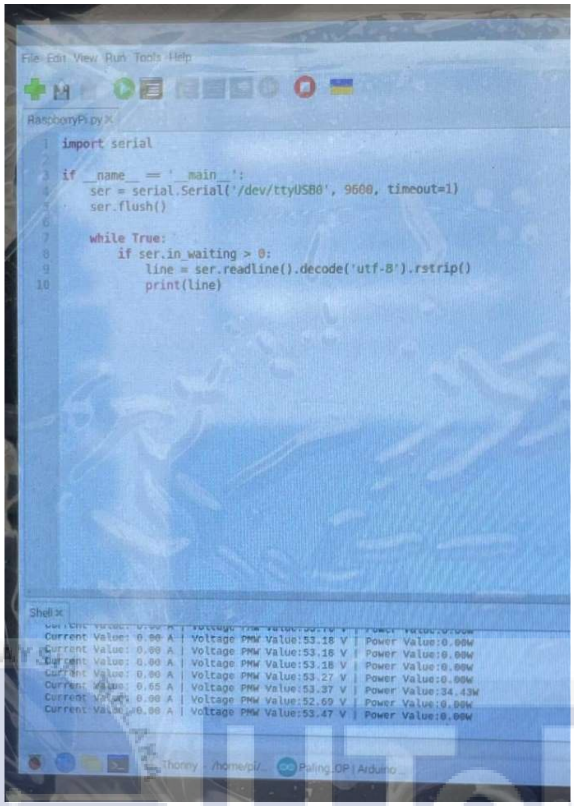

Figure 3.12 Data Displayed from Raspberry Pi 4

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter will present the data and fundings obtained from the research that were done and also the implementation of the project of the monitoring system of the E-Buggy. The test was to done to verify the connection and data feedback when the parameters were changed.

4.2 Result and Discussion

4.2.1 Connectivity Test between Arduino Uno Board and Raspberry Pi

There is various method that can be used in order to established the connection between the Arduino and the Raspberry Pi such as the I2C protocol and Serial Connection that utilize the UART cable. In the end the Serial connection was used due to its simplicity and removes the need to use multiple wire to connect the Arduino and also power it up. Other than that, for the connectivity test between the Arduino and Raspberry Pi, the Arduino was first confirmed to be able to receive the data send by the sensor and then the same data window was then confirmed to be seen from the Raspberry Pi. As for the voltage and current input for the sensor, a DC power supply was used in order to safely monitor and set a preferred data.

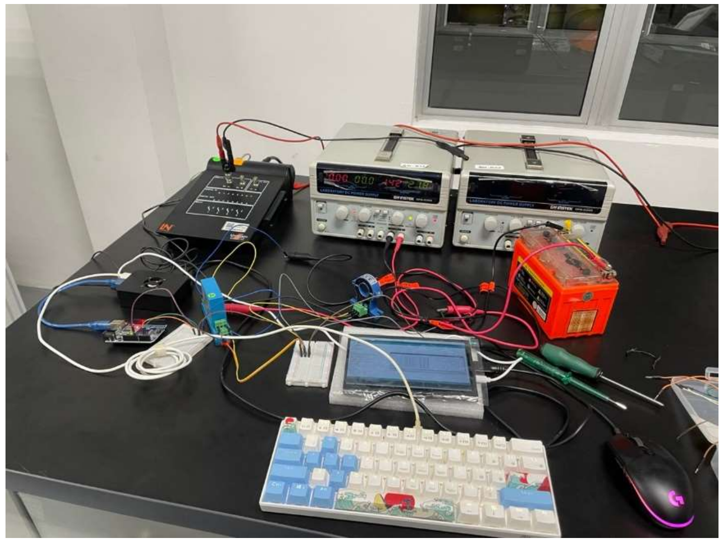

Figure 4.1 The Setup Used For The Test.

4.2.2 Output Accuracy by The Sensor

After the data connectivity were established between the Raspberry Pi and Arduino, The test to measure the accuracy of the data output by the sensor were done to measure the difference between the value supplied to the sensor and the value put out by the sensor. The same setup for the connectivity test was used for the accuracy test.

For the test, the supply voltage and current were then adjusted to a specific value on the DC power supply and the value output by the sensor were observed on the LCD screen connected to the Raspberry Pi. The test was done thrice in order to find the average difference between the data. The value chosen was at 5V, 10V, 20V. The data were then observed and recorded. The value recorded by the multimeter were then compared to the value measure by the sensor and presented the difference in percentage. For the difference in the standard and measured value, the equation used is as below.

$$\frac{Standard\ Value - Measured\ Value}{Standard\ Value}\ x\ 100 = \%Difference \tag{4.2}$$

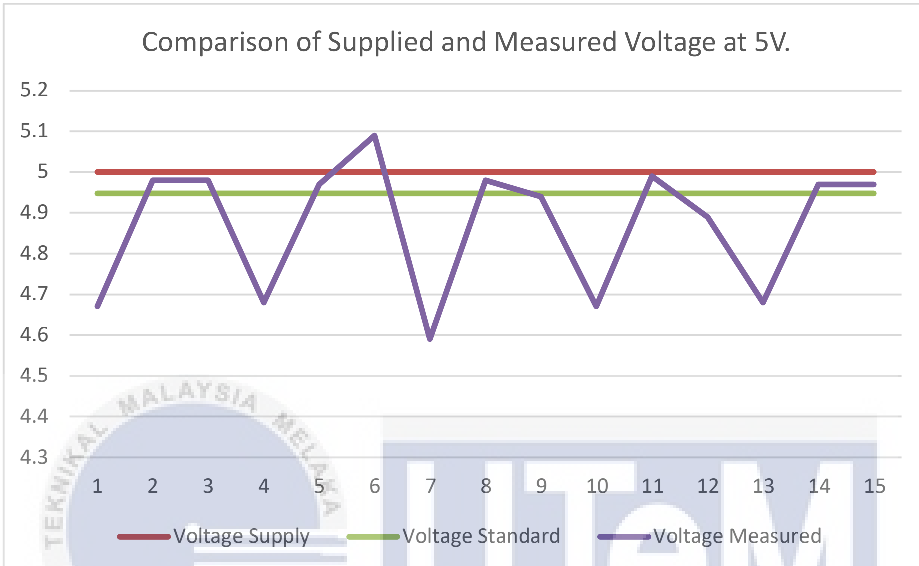

Figure 4.2 Comparison Between Supplied and Measured Voltage at 5V.

From the test that were done at 5V value, the difference between the standard voltage that were measured by a multimeter and the voltage measured by the sensor were recorded. In the data recorded, the highest error recorded were during the 7-second mark at which the value recorded were at 4.6V compared to the recorded value by multimeter. The value came out at 6.12% difference.

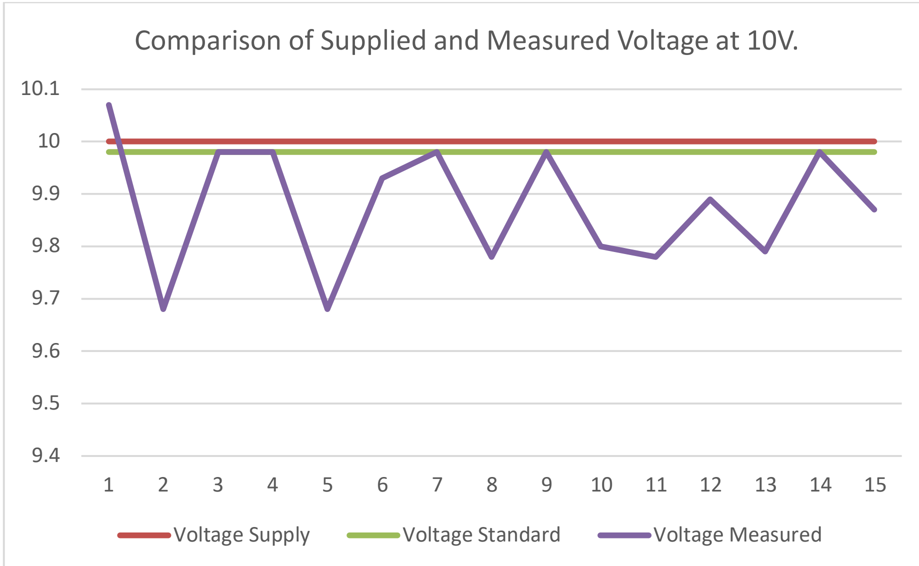

Figure 4.3 Comparison Between Supplied and Measured Voltage at 10V.

From the test that were done at 10V value, the difference between the standard voltage that were measured by a multimeter and the voltage measured by the sensor were recorded and the highest error recorded were during the 2-second and 5-second mark at which the value recorded were at 19.32V compared to the recorded value by multimeter. The value came out at 2.00% difference.

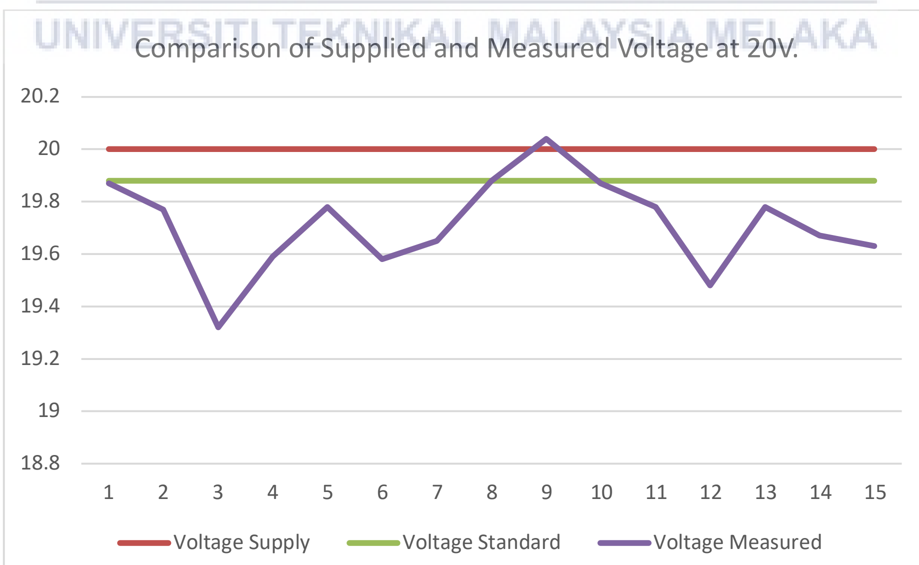

Figure 4.4 Comparison Between Supplied and Measured Voltage at 20V.

From the test that were done at 20V value, the difference between the standard voltage that were measured by a multimeter and the voltage measured by the sensor were recorded and the highest error recorded were during the 3-second mark at which the value recorded were at 19.32V compared to the recorded value by multimeter. The value came out at 2.82% difference.

Table 4.1 Comparison of Accuracy For Voltage Measured From Sensor.

No	Voltage Supplied	Voltage Standard	Average Voltage Measured	Percentage of Average Voltage Difference
1	5V	4.95	$\frac{73.05}{15} = 4.87$	$\frac{4.95-4.87}{4.95}$ x $100 = 1.62\%$
2	10V	9.98	$\frac{148.17}{15} = 9.88$	$\frac{9.98-9.88}{9.98}$ x $100 = 1.00\%$
3	20V	19.88	$\frac{295.69}{15} = 19.71$	$\frac{19.88-19.71}{19.88}$ x $100 = 0.86\%$

The percentage of voltage difference were seen at highest at lower voltage of 5V which is at 6.12% and the highest average voltage percentage difference were also at a 5V where it is at 1.62%. The system was developed to be used at a high voltage EV where it is usually used at 50+V. For the error in the reading to be occurred at 5V can be seen as a minor issue that will not become a major flaw in the system when it is been integrated into the system in the future.

As for the current sensor output, the same test was done with the configuration on the DC Supply as in the Arduino and Raspberry connectivity setting. The output received were then recorded and analyze. Due to the setting of the DC Supply that has lower current output, the test was only done at low current but the test was done thrice at the same current value which is at 2A and 10V.

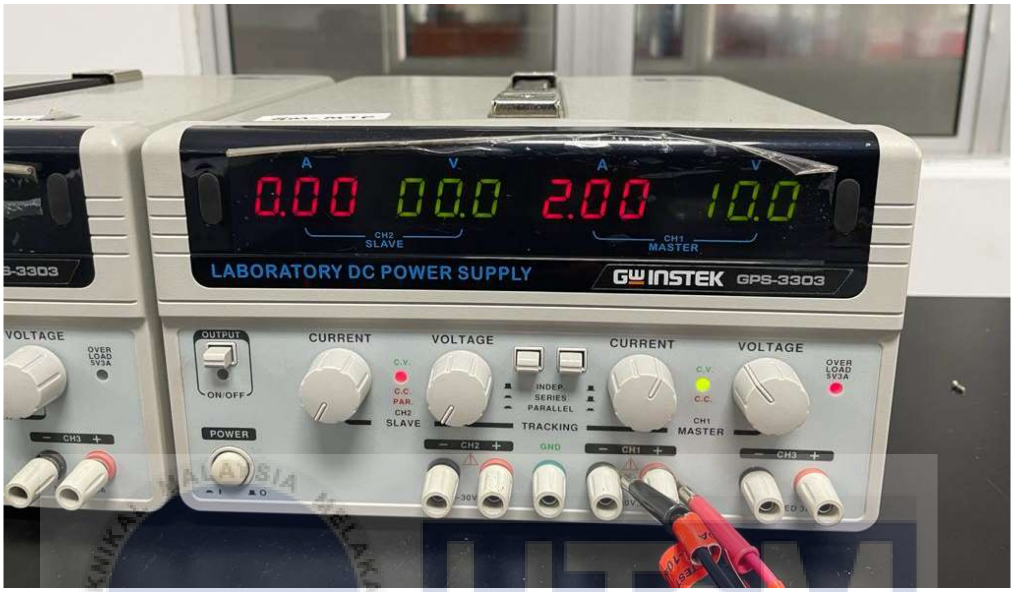

Figure 4.5 Setting On The DC Power Supply.

```
Current Value: 1.98 A | Voltage PMW Value:9.94 V | Power Value:19.68W
Current Value: 1.93 A | Voltage PMW Value:9.97 V | Power Value:19.24W
Current Value: 1.95 A | Voltage PMW Value:9.95 V | Power Value:19.40W
Current Value: 1.92 A | Voltage PMW Value:9.90 V | Power Value:19.01W
Current Value: 1.90 A | Voltage PMW Value:9.94 V | Power Value:18.89W
Current Value: 1.95 A | Voltage PMW Value:9.96 V | Power Value:19.42W
Current Value: 1.99 A | Voltage PMW Value:9.95 V | Power Value:19.80W
Current Value: 1.90 A | Voltage PMW Value:9.97 V | Power Value:18.94W
Current Value: 1.97 A | Voltage PMW Value:9.92 V | Power Value:19.54W
Current Value: 1.95 A | Voltage PMW Value:9.92 V | Power Value:19.34W
```

Figure 4.6 Result Example Obtained From The Test.

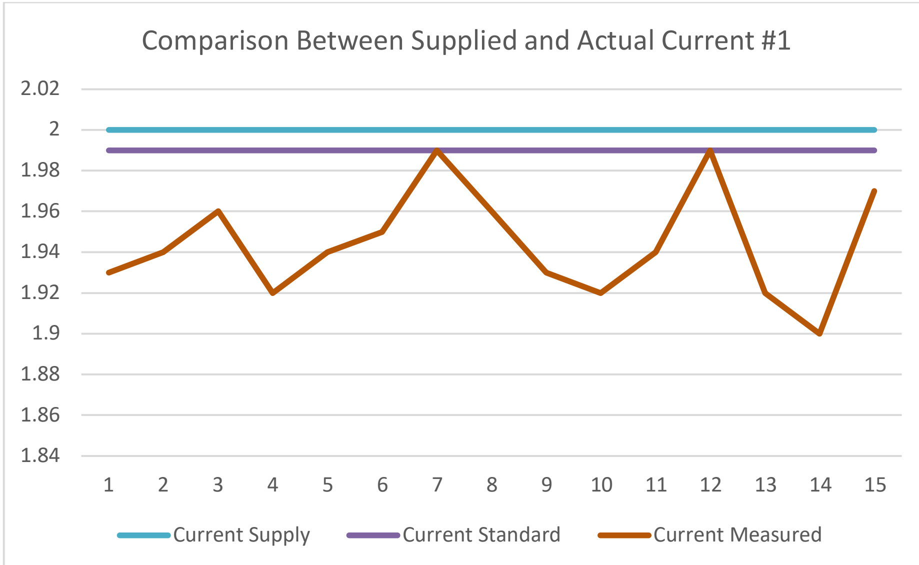

Figure 4.7 Comparison Between Supplied and Actual Current Run #1

For the first test run, the difference between the standard current that were measured by a multimeter and the current measured by the sensor were recorded. In the data recorded, the highest error recorded were during the 14-second mark at which the value recorded were at 1.90A compared to the recorded value by multimeter. The value came out at 4.52% difference.

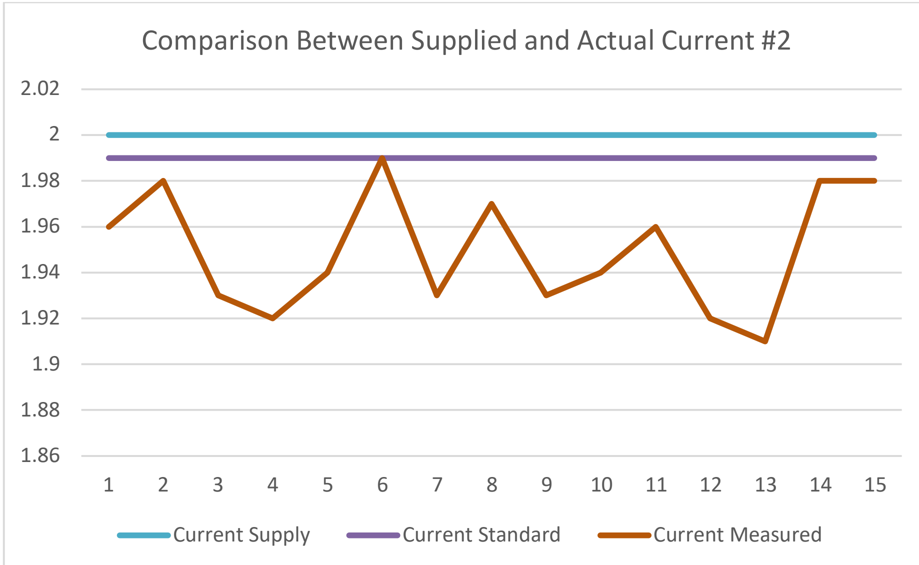

Figure 4.8 Comparison Between Supplied and Actual Current Run#2

For the second test run, the difference between the standard current that were measured by a multimeter and the current measured by the sensor were recorded. In the data recorded, the highest error recorded were during the 13-second mark at which the value recorded were at 1.91A compared to the recorded value by multimeter. The value came out at 4.02% difference.

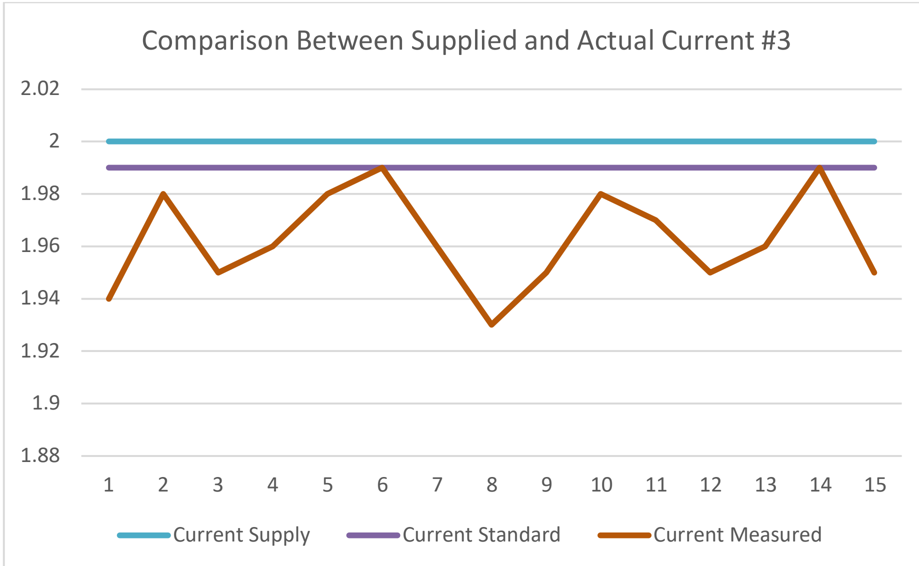

Figure 4.9 Comparison Between Supplied and Actual Current Run #3

For the third and last test run, the difference between the standard current that were measured by a multimeter and the current measured by the sensor were recorded. In the data recorded, the highest error recorded were during the 8-second mark at which the value recorded were at 1.93A compared to the recorded value by multimeter. The value came out at 3.02% difference.

Table 4.2 Comparison of Accuracy For Current Measured From Sensor.

Test Run	Current Supplied	Current Standard	Average Current Measured	Percentage of Average Current Difference
1	2A	1.99A	$\frac{29.16}{15} = 1.94$	$\frac{1.99 - 1.94}{1.99}$ x 100 = 2.50%
2			$\frac{29.24}{15} = 1.95$	$\frac{1.99-1.95}{1.99}$ x 100 = 2.01%
3			$\frac{29.44}{15} = 1.96$	$\frac{1.99-1.96}{1.99}$ x 100 = 1.51%

The percentage of current difference were seen at highest at the first run which is at 2.50%. The current fluctuation percentage that occurred were only around 2% and it is still obliged to the objective of the research project. Even though the project was intended to measure the current at higher value which is over 50A, the low value was proved to be readable by the system and it is then can be used for higher current value.

Based on the result analyze, the reasoning behind the fluctuations of the sensor reading may due to the step voltages, where the value may differ at regular or irregular timing. The step voltage can be defined as two points of contact with the ground and each of those point is at different potential. Other than that, a cyclic or random voltage changes caused by variation in load impedances may also be cause of the difference between the standard and measured value (MASOUM & FUCHS, 2001). In order to counter this issue a voltage regulator should be installed in order to reduce the percentage difference between the value measured and standard value.

As for the current sensor fluctuation, the issue may be due to the sudden change in load of the component connected to the circuit that may increase or decrease the current flow in the circuit. Other than that, the temperature of the current sensor may increase the resistance and directly causes the inaccurate sensor output. Lastly, the electrical noise that occurs may also be the reason of fluctuations in both voltage and current sensor(Moench et al., 2023).

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

This chapter will conclude the overall process and findings in terms of finding the effectiveness of the system developed and the difference in the results obtained from the sensor and standard. Recommendations for future study to improved and progress the further development of the system were also mention in this chapter.

5.2 Conclusion

As a conclusion for the research done, the study has successfully achieved the main objective of this study which is to develop a power monitoring system to be implemented into an EV-Buggy vehicle. For the current system developed, it is usable to be implemented into the current system of the EV-Buggy as it is does not need any external power supply as the Raspberry Pi can be supplied with 5V-12V DC which can be supply by the 12V battery used for other instruments in the vehicle. Other than that, the sensor also uses 12V as a power supply which also can be use from the 12V battery.

Other than that, based on the result obtained from chapter 4, the sensor was able to provide an output that is able to be read by the Raspberry Pi that were originated from the Arduino. The test was able to prove the stable connection between both of the Arduino and Raspberry Pi and it is also proven that it is capable to put out the high voltage from the battery. Continuing that, the sensor was also able to put out an accurate reading of the reading in which the highest difference the voltage that the sensor was able to read was at 6.12% at

5V. As the system were intended to be used at high current and voltage value, the difference that happened only become apparent in lower power system.

5.3 Recommendation for Future Work

In the future, this study can be used for the further development of the system by adding new sensor for the EV-Buggy. Other than that, the system can also be implemented to monitor the battery monitoring system (BMS). The battery monitoring system is crucial in order to monitor the SOC of the battery. The parameter used in estimation the battery SOC were usually consists of terminal voltage, current output, and temperature. With the integration of the monitoring system, the value needed for the estimation calculation can easily be retrieved.

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APPENDICES

Appendix A Arduino UNO Spec Sheets.

Technical Specifications	Arduino UNO
Microcontroller	Atmega328
Operating Voltage	5V
Recommended Input Voltage	6 to 20V
Input Voltage	14 (6 provide PWM output)
Digital I/O Pins	6
DC Current per I/O Pin	40mA
DC Current per for 3.3V Pin	50mA
Flash Memory	32 KB (Atmega328) (0.5KB reserved for bootloader)
SRAM	2 KB (Atmega328)
EEPROM	1 KB (Atmega328)
Clock Speed	16MHz

Appendix B Rapberry Pi 4 Specification Sheet

Technical Specifications	Raspberry Pi 4B
Processor unit	Quad Core 1.8GHz Cortex-A72
Memory unit	1/2/4/8GB LPDDR4
Graphic processing unit	Broadcom VideoCore VI @ 500MHz
Display	-2 micro-HDMI ports -MIPI DSI (2 lane)
Power	-5V DC via USB-C connector and GPIO header -Power over Ethernet enabled (requires separate PoE HAT)
GPIO	40-pin GPIO pins
Connectivity	-Gigabit Ethernet -802.11b/g/n/ac wireless -Bluetooth 5.0
USB port	-2 USB 3.0 Type-A ports -2 USB 2.0 ports
Storage	-Micro-SD card slot
Price	$35.00-$75.00

Appendix C Motor Specifications Sheet

Technical Specifications	3KW BLDC Motor
Voltages	48 V
Rated Power	2 to 3 KW
Peak Power	6 KW
Speed	3000 to 5000 rpm
Rated Torque	10 Nm
Peak Torque	25 Nm
Efficiency	>90%
Dimensions	18 cm Diameter, 12.5 cm Height
Weight	7.3 kg
Cooling System	Fan Cooling

Appendix D Current Sensor Specification Sheet

Technical Specifications	ES – K7 Current Sensor
Input Current Range	DC 0 to 220A
Output Current Range	DC 0 to 5 V
Power Supply Range	DC 12 V
Hole Diameter	25 mm

Appendix E Voltage Sensor Specification Sheet

Technical Specifications	ES – K12 Voltage Sensor
Input Current Range	DC 0 to 100 V
Output Current Range	DC 0 to 5 V
Power Supply Range	DC 12 V