Real-Time Capacity Monitoring for Lithium Polymer Batteries

by

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16397

Dissertation submitted in partial fulfilment of the requirements for the Degree of
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

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January 2016

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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EAN CHIN TECK

ABSTRACT

Lithium Polymer (Li-Po) batteries are commonly used for applications that need medium current consumption in the range of about 0.5-3 A such as RC planes and RC cars. However, inefficient use and charging/discharging operation of Li-Po batteries can severely reduce their lifetime making the batteries unusable. Besides that, there is a need survey cost-effective methods to monitor the Li-Po battery in current application. An estimation of state-of-charge (SOC) is a practical indication of battery capacity which can be obtained from the linear range of the Li-Po battery discharge curves. In addition to the project, the chosen Li-Po battery have been tested on a 4WD Hercules Mobile Robotic Platform. As the mobile robot moves through its pre-programmed movement which is controlled using Bluetooth, voltage of the Li-Po battery is measured using analog input and the measurement is converted through analog-to-digital converter inside an Arduino Mega. Meanwhile, current drawn is measured by a current sensor module that connected in series with positive terminal of the battery and motor controller. The real-time battery voltage and current data is transmitted wirelessly through a 433 MHz radio frequency module to a laptop for monitoring and recording purposes. The SOC is currently estimated by comparing real-time voltage reading to associated points in the battery discharge graph. The Arduino board voltage measurement system have been tested and it is able to measure real-time voltage of a Li-Po battery used on the mobile robot. The mobile robot was tested on a track with bump to observe the voltage drop of the Li-Po battery and the measurement is also compared to a local battery tester.

ACKNOWLEDGEMENTS

Along the period of my final year project, there are a few mentors who I would like to express my deepest gratitude. First, I would like to thanks my supervisor Ms. Suhaila binti Badarol Hisham, lecturer of Universiti Teknologi PETRONAS. She is a great mentor and supervisor as she always takes good care of her students. She always gives me the best guidance and very willing to help me whenever I have any doubts or confusions in my project. She is my role model and my motivation to do better in this project.

Besides that, I want to take this opportunity thanks my friends and colleagues who directly or indirectly helped and supported me throughout this period. They gave me advices and recommendations towards improvement.

My project will not be completed without the presence of these individuals above as intense guidance and support was needed to make this project a fruitful one. I would like to express my earnest gratitude to them and also to my family members for supporting me all the time.

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LIST OF ABBREVIATIONS

Li-Po	Lithium Polymer
SOC	State-of-charge
RC	RC Radio Controlled
EODV	End-of-discharge voltage
SPE	Solid Polymer Electrolyte
DC	Direct current
ADC	Analog-to-digital converter
LCD	Liquid Crystal Display
RF	Radio Frequency
DVM	Digital voltmeter
DVA	Digital Voltmeter Ammeter

CHAPTER 1

INTRODUCTION

1.1 Background

Lithium-polymer (Li-Po) batteries are commonly used to power up mobile systems and remote-control applications such as radio-controlled (RC) cars and RC planes. These rechargeable batteries are made of lithium-ion technology in a pouch format. They are portable, lightweight due to its flexible shell and provide a significant amount of current suitable for small to medium-size motors. However, inefficient use and charging/discharging operation of Li-Po batteries can severely reduce their lifetime.

Li-Po batteries operate within a given voltage range that cannot be exceeded. This usable discharge range is called as state-of-charge (SOC) of the battery. The SOC is measured in percentage points from 0% to 100% [1]. During discharge, Li-Po battery provides a steady voltage under load until reaching the knee point where the voltage begins to drop rapidly and the discharge must be terminated. This point is called as end-of-discharge voltage (EODV). Over-discharge may affect a Li-Po in many ways and can cause permanent damage and loss of performance to the battery.

Therefore, it is very important to know the SOC of the Li-Po battery from time to time when using it to prevent over-discharge of the battery. Besides that, it will be very useful if the capacity of the battery is monitored and the data is either stored in a memory and available offline or transmitted directly using wireless methods. The information can be used to manage the power consumption of the mobile robot and enhance the efficiency of the battery usage.

1.2 Problem Statements

i. The Li-Po battery capacity is not measured and monitored in current applications, such as mobile robot projects, RC car, and RC planes.

   This will cause the applications that using Li-Po batteries are not using its capacity efficiently. Changes of the battery capacity will cause systems/units powered by these portable batteries to lose its accuracy and degrade system performance. Precautions should also be taken so that a Li-Po battery is not discharged below its end-of-discharge voltage (EODV) which will cause the battery not able to charge again.

ii. A need to explore a variety cost-effective ways to monitor the Li-Po battery.

   Local indication for capacity of Li-Po battery is needed without relying on the battery charger. Besides that, remote monitoring of voltage and current of Li-Po battery by being able to monitor at a distance will be very helpful to use the battery capacity efficiently.

1.3 Objectives and Scope of Study

The objectives of the project are:

- To develop a cost-effective real time capacity monitoring system for Li-Po battery.
- To test a battery monitoring system on a mobile robot platform.

The scope of study for this project is to construct a cost-effective Li-Po battery monitoring system that:

i. Record voltage and current
ii. Indicate state-of-charge (SOC) in term of percentage
iii. Indicate end-of-discharge voltage (EODV) for a Li-Po battery
iv. Able to transmit measurements over wireless communication

This system was tested in a mobile robot platform that undergoes a programmed movement on an indoor track with bump.

CHAPTER 2

LITERATURE REVIEW

2.1 Li-Po Battery Characteristics

The term “polymer” in lithium-polymer battery identified as being a type of “plastic” and as denomination to lithium-ion cells in pouch format. However, from a technological point of view, Li-Po batteries are the same as the ones marketed simply as "Li-ion" batteries, as the underlying electrochemistry is the same [2].

What makes Li-Po battery special than other battery systems is the type of electrolyte that Li-Po battery used. Initially, a plastic anode material and Solid Polymer Electrolyte (SPE) is used as the electrolyte for Li-Po battery. After the new technology rapidly evolved and improved, a gelled electrolyte and separator are used in modern Li-Po batteries [3]. Figure 1 below shows construction of a Li-Po battery cell.

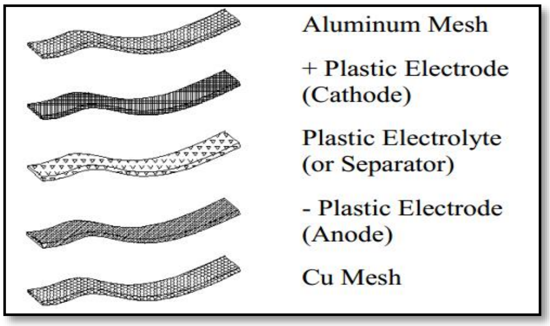


Figure 1: Lithium Polymer Cell Construction

One of the reaction example for Lithium battery is as following.
The cathode (marked +) half-reaction is: [3]

$$Li_{1-x}CoO_2 + xLi^+ + xe^- \leftrightarrows LiCoO_2$$

The anode (marked -) half reaction is:

$$xLiC_6 \leftrightarrows xLi^+ + xe^- + xC_6$$

The overall reaction is:

$$Li^{+} + e^{-} + LiCoO_2 \rightarrow Li_2O + CoO$$

Nowadays, the name of "Li-Po" is more popular as power source for RC models applications. It may come in a single cell or a battery pack with cells connected in series or parallel. Meanwhile, the name of "Li-ion" is used on other electronics devices such as notebook computers, mobile phones, and battery electric vehicles.

There are many type of Li-Po battery with different C-rate. C-rate is a measure that governs at what current a battery is charged and discharged [4]. If a 2200mAh rechargeable battery rated at 1C, it means that the battery can provide a continuous current of 2200mA for one hour. If the same battery rated at 0.5C, then it would provide 1100mA for two hours. While if it is rated at 2C, it would deliver 4400mA for 30 minutes.

2.2 SOC Estimation Methods

Meanwhile, SOC is the percentage of the maximum possible charge that is present inside a rechargeable battery [5]. Li-Po battery should not be discharged below the manufacturer specified level or also known as the EDOV of the battery. Some batteries come with a protection circuit. The battery's protection circuit may put the battery into a sleep mode if it is over-discharge. This renders the battery unserviceable and a recharge is not possible. The relationship of the C-rate and SOC can be observed in the graph or Figure 2 below.

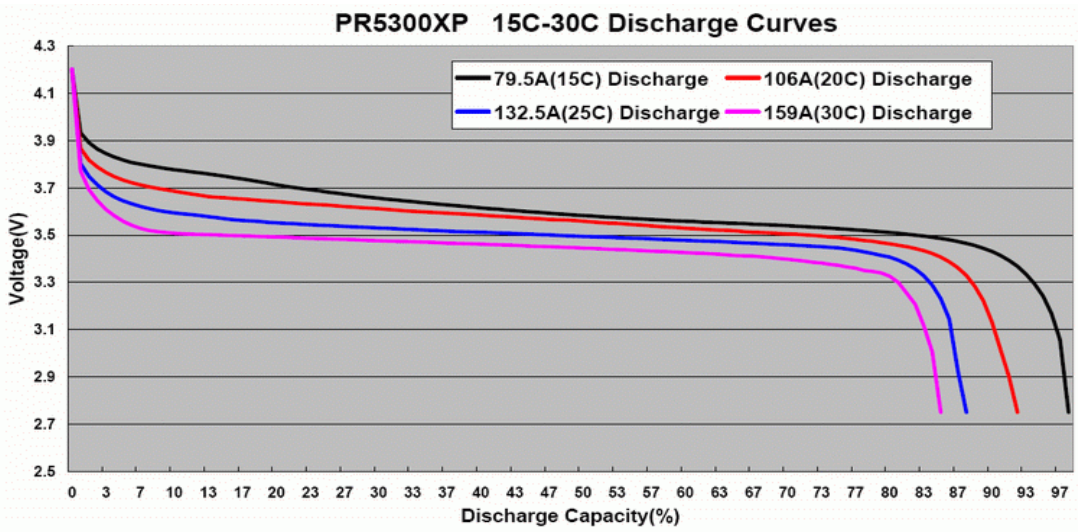


Figure 2: 15C-30C Discharge Curves

Hence, it is very important to have a real-time capacity monitoring system for Li-Po battery to prevent it from being discharge below EODV or before it is rendered defective. There are many ways to measure the SOC of a Li-Po battery. Table 1 below shows five methods to determine SOC indirectly with their advantages and disadvantages.

Table 1: Methods to Determine SOC Indirectly

Method	Advantages	Disadvantages
i) Chemical method	Can be used to indicate SOC of the battery by using specific gravity or pH of the electrolyte [6].	Only can be used on batteries that offer access to their liquid electrolytes, such as non-sealed lead acid batteries [6].
ii) Voltage method	Using known discharge curve (voltage vs. SOC) of the battery to converts a measurement of the battery voltage to SOC [6].	Result is affected by the battery current and temperature. This happens because of the battery's electrochemical kinetics [6].
iii) Current integration method	Known as "coulomb counting", calculates the SOC by measuring the battery current and integrating it in time [1].	Suffers from long-term drift and lack of a reference point [1].
iv) Kalman Filtering	Can overcome the weakness of the Voltage method and the Current integration method by predicting the over-voltage and make combination with coulomb counting method [7].	An electrical model of the SOC has to be obtained before using this filter [7].

Method	Advantages	Disadvantages
v) Pressure method	Can indicate SOC of the battery by using the internal pressure of the battery [6].	Only can be used with battery that its internal pressure increases rapidly during charging, such as nickel–metal hydride (NiMH) battery [6].

There is no direct way of measuring the SOC of a Li-Po battery. Each method suffers from limitations. However, by combining two techniques of Voltage method and Current Integration method can result in a reasonable estimate of SOC [8]. For example, based on the reference capacity, 50 Ah, the current integrated to determine the value of the SOC is using the formula below.

$$\text{SOC [\%]} = \frac{50 - \int_{t_0}^{t_0 - T} i(t)dt}{50} \times 100$$

Thus, a direct current (DC) voltmeter and ammeter are required to indicate the SOC of the Li-Po battery.

2.3 DC Voltage & Ammeter

There are two main types of DC voltmeter and ammeter: (1) analog and (2) digital meter. The sensing mechanism used in DC voltmeter and ammeter is a current-sensing device called D' Arsonval meter movement. When current passes through the coil, a needle is deflected due to electromagnetic deflection [9]. Figure 3 shows the construction of D'Arsonval meter movement.

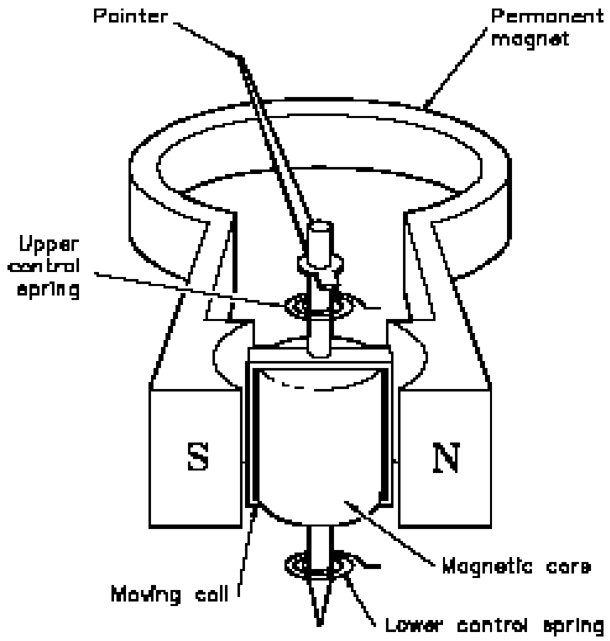


Figure 3: Construction of D'Arsonval Meter Movement

On the other hand, the main component of a digital voltmeter circuit is an integrated circuits such as IC 7107 which is a low power, high performance, 3.5 digit analog-to-digital converter (ADC) [10]. The principal operation of digital voltmeter can be explained in two stages. On the first operation, the input measured voltage specified is integrated over a preset period. At the end of this preset period, voltage at the output of integrator and input voltage are directly proportional to each other. While on the second operation, internal reference voltage is fed to integrator at the end of the preset period. The output of the circuit is steadily decreased using the internal reference voltage until it reaches zero. Hence, the input voltage can be then compared to the internal reference voltage and the multiple will give the amount of measured voltage [11]. Figure 4 below is the circuit diagram of digital voltmeter with IC7107. Range of the voltmeter can be controlled by the R4 resistor [10].

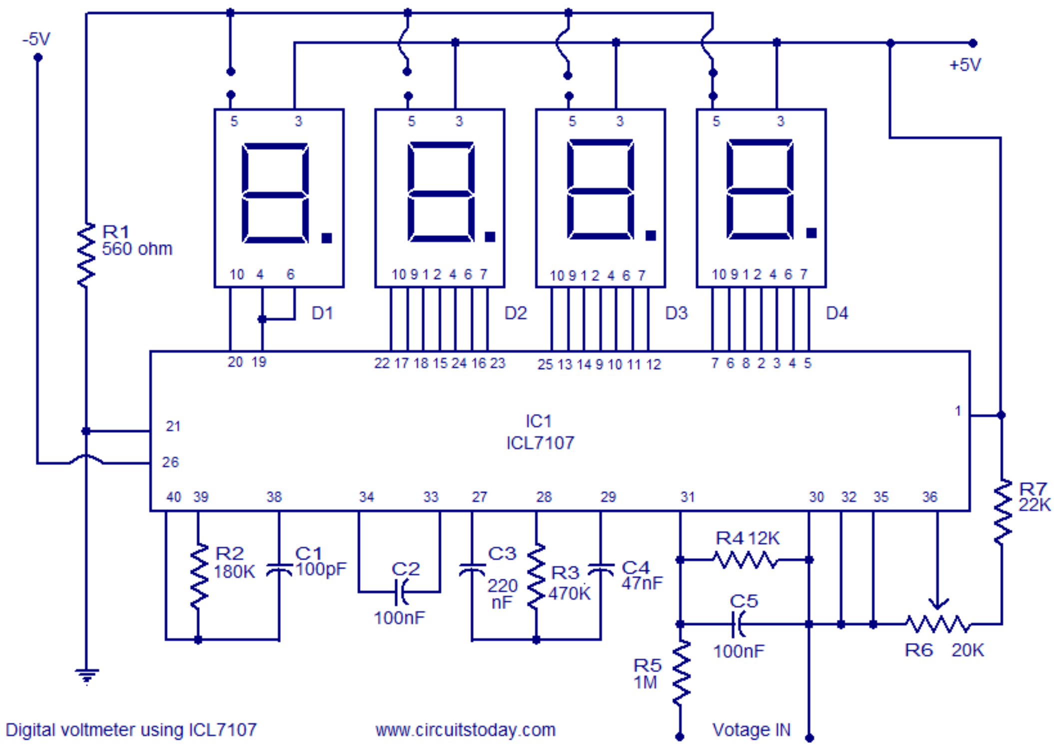


Figure 4: LED Digital Voltmeter Circuit Diagram with IC 7107 [10]

The above voltmeter can also be achieved by using an Arduino processor board. The voltage is measured through one of its analog inputs and converted to digits display using analog-to-digital converter (ADC) within the Arduino. Details of this method are further explained in next section.

2.4 Testing Platform

A suitable application has to be chosen as the testing platform for the Li-Po battery monitoring system. Open-source mobile robot and a LEGO Mindstorms EV3 robot are being considered as the testing platform for this project. The comparison of the two robots is shown below in Table 2.

Table 2: Comparison of Robots to Be Used as Testing Platform

Robot	Advantages	Disadvantages
Open-source Mobile Robot (Arduino)	○ Low cost (under budget) ○ Complexity suitable for degree student project.	○ Need to create own interface to monitor the capacity. ○ Less stable or robust and integration issues between different components may arise.
LEGO Mindstorms EV3 robot	○ Easy to build the robot ○ Come with data logging software for experimental purpose.	○ Cost RM2300 (over budget) ○ Designed for primary school student.

CHAPTER 3

METHODOLOGY/PROJECT WORK

3.1 Overall Diagram

Version 1

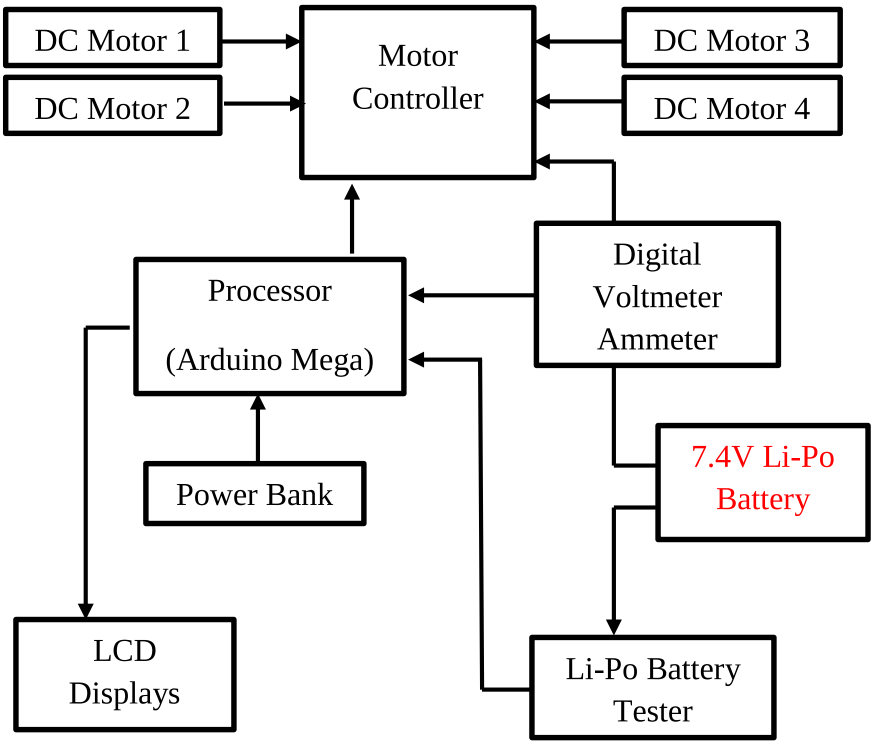


Figure 5: Block Diagram of Li-Po Battery with The Mobile Robot

Figure 5 above shows the earlier version of overall block diagram of the mobile robot used as testing platform for the Li-Po battery. The motor controller will be powered by the 7.4 V Li-Po battery, while the Arduino Mega will be powered by a 5 V, 1 A, and 2800mAh power bank. Then, Arduino Mega provides power for the Digital Voltmeter Ammeter, Li-Po Battery Tester, and the Liquid Crystal Display (LCD) displays. This mobile robot has a total of 4 DC motors, each of them connected to the motor controller.

A Digital Voltmeter Ammeter will be used to measure the current drawn, while the Li-Po Battery Tester be used to measure the voltage of the Li-Po battery. Arduino Mega will then collect voltage and current data to be used to estimate the SOC of the Li-Po battery and indicates on the LCD display. By this way, the current SOC of the Li-Po battery can be known and this can prevent the battery from over-discharging. In addition, all the data of voltage and current from the Digital Voltmeter Ammeter will be stored in Arduino memory and can be used to analyse on how the 4 DC motors drain the current and voltage from the Li-Po battery.

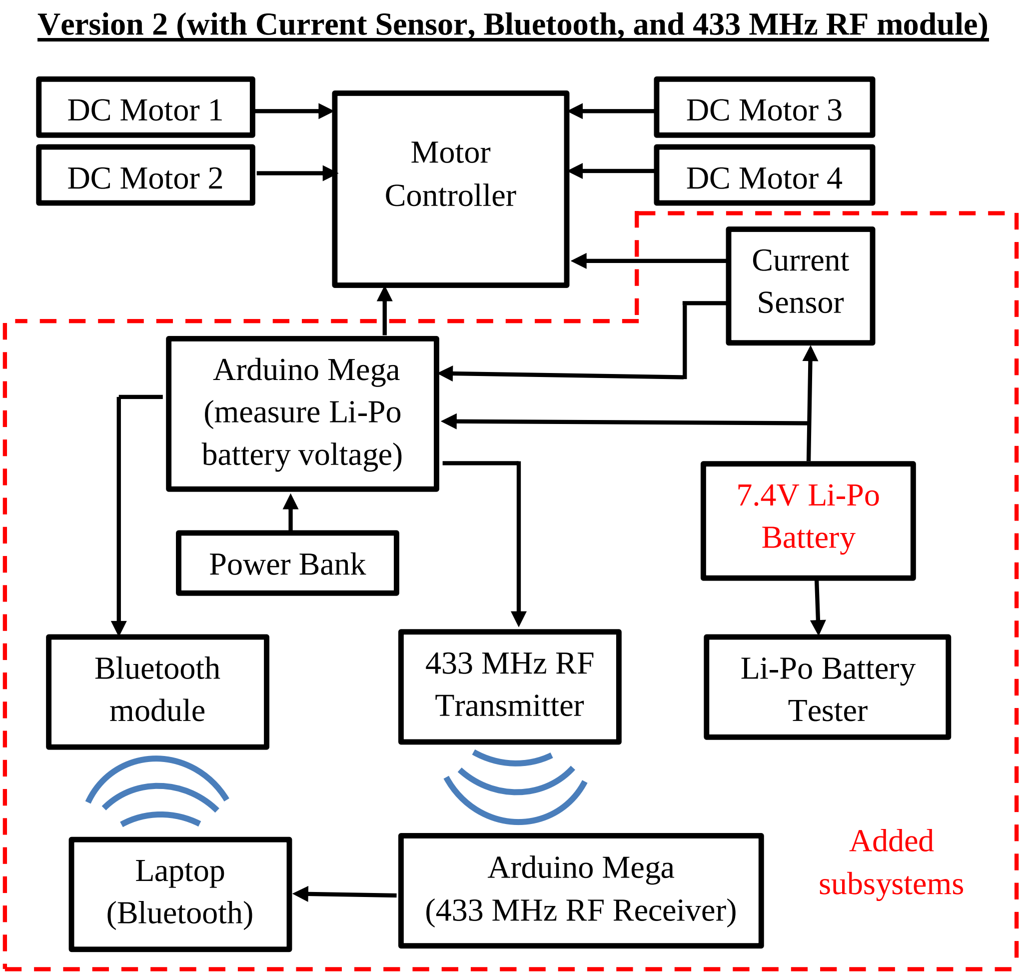


Figure 6: New Block Diagram of Li-Po Battery with The Mobile Robot with Current Sensor, Bluetooth and 433 MHz RF Module

The new block diagram in Figure 6 has the previous commercial digital voltmeter ammeter replaced by an Arduino Mega board to measure the voltage of the Li-Po battery directly and a current sensor module to measure the current. This prove to be economical since Arduino Mega board is already being used to as the mobile robot microprocessor and also to transmit the real-time data of the Li-Po battery wirelessly via 433 MHz Radio Frequency (RF) module.

Besides that, the movement of mobile robot is controlled via Bluetooth connected to a laptop. The movement direction is controlled using 4 arrows (up, down, left, and right) on the laptop's keyboard. In addition, 433 MHz RF receiver will also be connected to the laptop to collect and store data of the measured voltage. However, the capability of the Arduino also has to be considered when all the 3 functions are combined.

3.2 Battery Specifications

A Li-Po rechargeable battery with the following specifications will be used in this project:

- Number of cells: 2
- Nominal Voltage: 7.4 V
- Fully-charged Voltage: 8.4 V
- Capacity: 2200 mAh
- Discharge rate: 15C

3.3 Voltage and Current Measurement

Since an Arduino Mega is used as the microprocessor of the mobile robot, hence the analog-to-digital converter (ADC) inside analog input pins of the Arduino can be used to measure voltage of the Li-Po battery. The Arduino ADC is a 10-bit converter, meaning that the output value having total 1024 values ranging from 0 to 1023. This value can be obtained by using the analogRead() function. The reference voltage of Arduino analog pins is 5V. Hence, voltage present at the analog input can be easily calculated by using the formula:

$$V_m = \frac{5\,V_i}{1024}$$

where V_m is the discrete measured voltage, and V_i is the analog input voltage.

In order to measure voltages greater than 5 V, a voltage divider is needed to divide the input voltage so that the actual voltage across analog input and ground on Arduino is 5 V or less. In this project, a 100 kΩ and a 10 kΩ resistors are used to create a 10:1 voltage divider. Therefore, a voltage up to 50V can be measured using this method with the formula:

$$V_m = \frac{5\,V_i}{1024} \times \frac{100\,k\; +\; 10\,k}{10\,k}$$

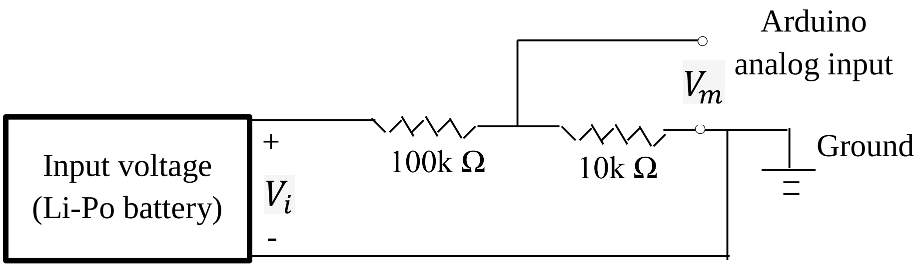


Figure 7: Circuit Diagram of the Voltage Divider

In addition, a current sensor module is used to measure the current drawn from the Li-Po battery. The current sensor is connected in series from the positive terminal of Li-Po battery and the positive terminal of motor controller. This sensor comes with three pins, there are VCC, GND and OUT. When current flow is detected by the sensor, it gives out an analog output signal (voltage) that decrease linearly with sensed current. This current sensor has a sensitivity of 100mV/A and it can measure current range up to ±20A.

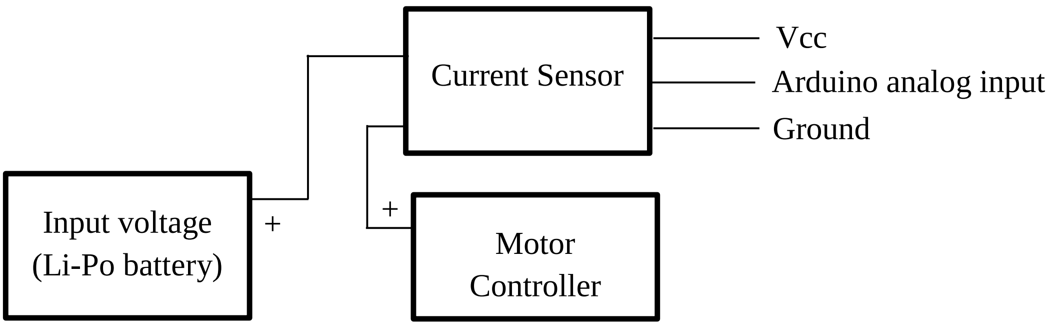


Figure 8: Circuit Diagram of the Current Sensor Module

3.4 SOC Estimation

According to the Figure 9, each cell of a 15C Li-Po battery can be fully charged to 4.2V, while the EODV is about 3.5 V for each cell. This means that a 2-cell Li-Po battery can be fully charged up to 8.4 V and has an EODV around 7 V. Thus, by using the Voltage method, a possible SOC indication is shown in Table 3 where each 10 % increase in SOC is obtained from the linear range of the discharge curve. Therefore, 100 % SOC is related to 8.2 V to make sure the Li-Po battery is not over-charged, while 7V is estimated as 0% due to the EDOV.

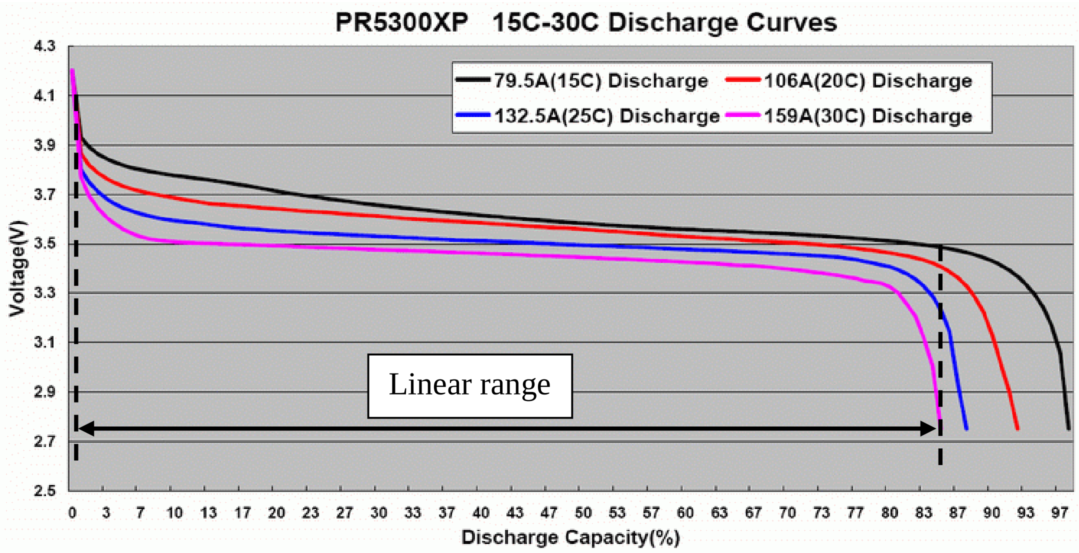


Figure 9: 15C-30C Discharge Curves with Linear Range

Table 3: SOC Estimation of Li-Po Battery

Voltage of Li-Po Battery, V (for 2-cell)	State-of-Charge (SOC), %
8.20	100
8.08	90
7.96	80
7.84	70
7.72	60
7.60	50
7.48	40
7.36	30
7.24	20

Voltage of Li-Po Battery, V (for 2-cell)	State-of-Charge (SOC), %
7.12	10
7.00	0

Therefore, real-time capacity of the Li-Po battery will be able to monitor through the voltage and current drawn from the Li-Po battery. A SOC estimation for the Li-Po battery will be make based on the result of the experiment. Then, Arduino Mega will process the information and indicate the SOC of the Li-Po battery on a laptop display. Graph of the remote monitoring, local monitoring, and 15C Li-Po battery discharge curves also will be compared together to see the discharge rates of Li-Po battery along the usage duration.

3.5 Components and Tools

There are few important tools or software that we required to complete this project. All of those are listed as below including the components and devices needed:

Prototype:

- Li-Po rechargeable battery
- 4WD Hercules Mobile Robotic Platform with motor controller
- 2 Arduino Mega boards
- Current sensor module
- Li-Po battery tester
- 433 MHz Radio Frequency (RF) module
- Bluetooth module
- Power bank

Experiment Tools:

- Multi-Function Li-Po Balance Charger (Model no: iMax B6AC)
- Testing track with bumps [from Integrated System Design Project lab]

Software:

- Arduino IDE software
- Processing software
- Bridge Control Panel software

3.6 Project Schedule and Implementation Stages.

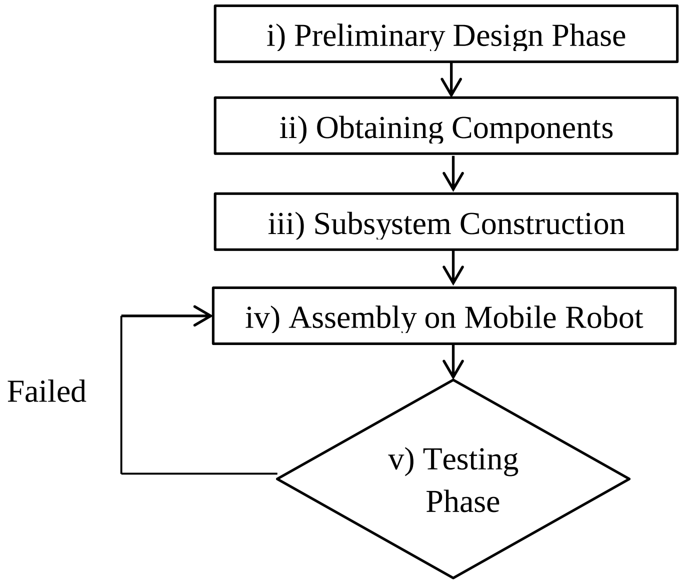


Figure 10: Flow Chart of Project Schedule and Implementation Stages

ii) Preliminary Design Phase

A literature review about the project is conducted to look for the most suitable way to indicate SOC estimation for Li-Po battery. Combination of Voltage method and Current integration method will be used in this project. A testing platform needs to be chosen to test the real-time capacity monitoring for a Li-Po battery. Thus, a 4WD Hercules Mobile Robotic Platform mobile robot is chosen because this mobile car has four 6V DC motors that suitable to be powered up by Li-Po battery. Besides that, it is available to be borrowed from the UTP EE lab. Furthermore, parameters of the components to build the prototype of digital voltmeter (DVM) and all others components needed are also finalised.

iii) Obtaining Components

All components to build the DVM prototype and components for capacity monitoring system are obtained in this stage. Example of the components for DVM needed are ICL7107, resistors, capacitors, seven segment display, and more. Meanwhile, 7.4V Li-Po battery, Multi-Function Li-Po Balance Charger, 4WD Hercules Mobile Robotic Platform mobile robot with motor controller are borrowed from the UTP EE lab. Other components such as Arduino Mega, current sensor module, Li-Po battery tester, 433 MHz RF module, and Bluetooth module will be purchased online.

iv) Subsystem Construction

This stage consists several parts. One of them is the building and testing of DVM prototype. In addition, each of the subsystems such as the controlling of the car via Bluetooth, measuring the voltage of Li-Po battery using Arduino board, measuring current of Li-Po battery via current sensor module, and transferring data wirelessly through 433 MHz transmitter and receiver will be done and tested separately before all the subsystems are integrated together.

v) Assembly on Mobile Robot

All the subsystems are integrated using a single Arduino Mega and are assembled on the mobile robot. The mobile robot is also equipped with a remote controller using a laptop keyboard via Bluetooth to run on the track. Then, the mobile robot is tested to make sure the integrated systems is operating well.

vi) Testing Phase

The cost-effective Li-Po battery monitoring system is to be tested on a mobile robot with following specification:

- Dual channel 10A DC motor driver
- Four reducing-motors with 310rpm DC6V and stalling torque: 7.0 Kg.cm
- Four plastic + rubber wheels

Figure 11: 4WD Hercules Mobile Robotic

The testing track consists of 1.5m acupuncture mats and a 3-inch bump to provide more friction on the track to speed up the draining process. Meanwhile, the bump is also added to observe how much current is drawn when the mobile robot travel across the bump.

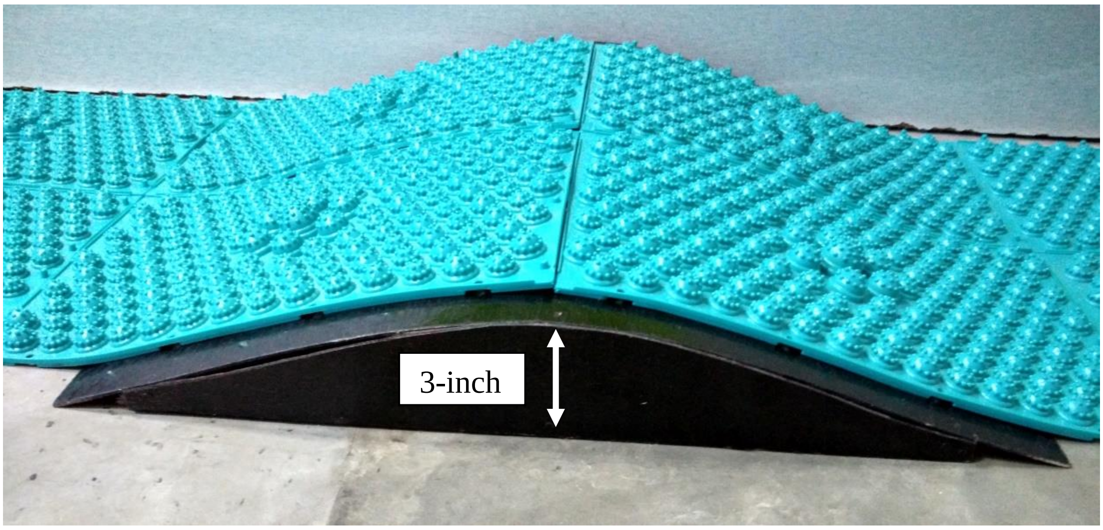


Figure 12: 3-inch Bump on Track (Side View)

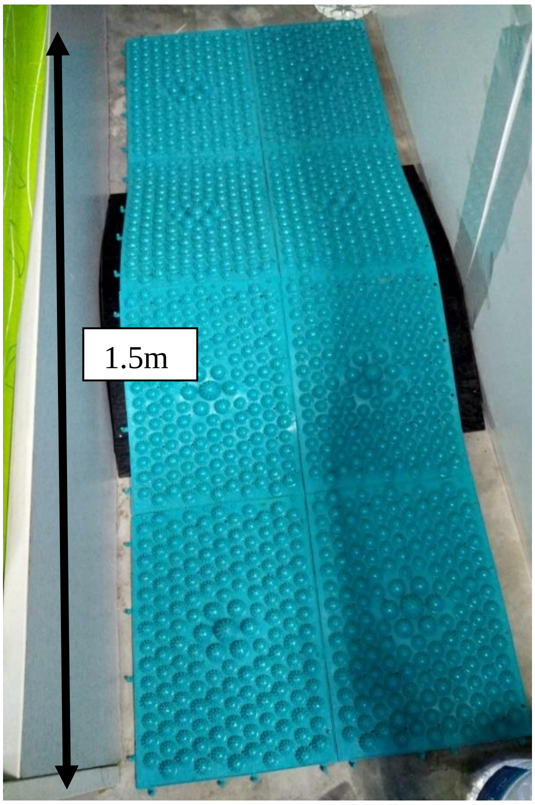


Figure 13: 1.5m Track with Acupuncture Mats (Top View)

The mobile robot is pre-programmed to move back and forth along the track for 5 minutes non-stop with a break in between for 30 seconds to avoid the DC motors from overheating. Voltage and current data are sent every 1 second via the 433 MHz RF module to a laptop where a real-time graph of each variable versus time is generated and stored for data collection. For every 30-second break, total voltage value indicated by the Li-Po battery tester will also be recorded. The mobile robot is instructed to move via input from the laptop keyboard via Bluetooth. Besides that, the Li-Po battery tester is pre-set with an EODV alarm at 3.5V. The whole experiment is repeated until one of the Li-Po battery cells reached 3.5V when the buzzer of the battery tester is triggered and the experiment is completed.

3.7 Gantt Chart

Activities / Week	1	2	3	4	5	6	7	8	9	10	11	12	13
Survey of method to measure the voltage of the Li-Po battery	■	■	■	■	■	■							
Selection on voltage measurement method						◆							
Purchase components required						■	■						
Components ready for assembly							◆						
Building the DVM prototype								■	■				
Testing and troubleshooting commercial Digital Voltmeter Ammeter for a Li-Po battery and a mobile robot										■	■	■	■
Ensure the commercial Digital Voltmeter Ammeter can measure voltage, current and SOC of the battery													◆

Figure 14: Gantt Chart FYP 1

■ Timeline ◆ Key milestone

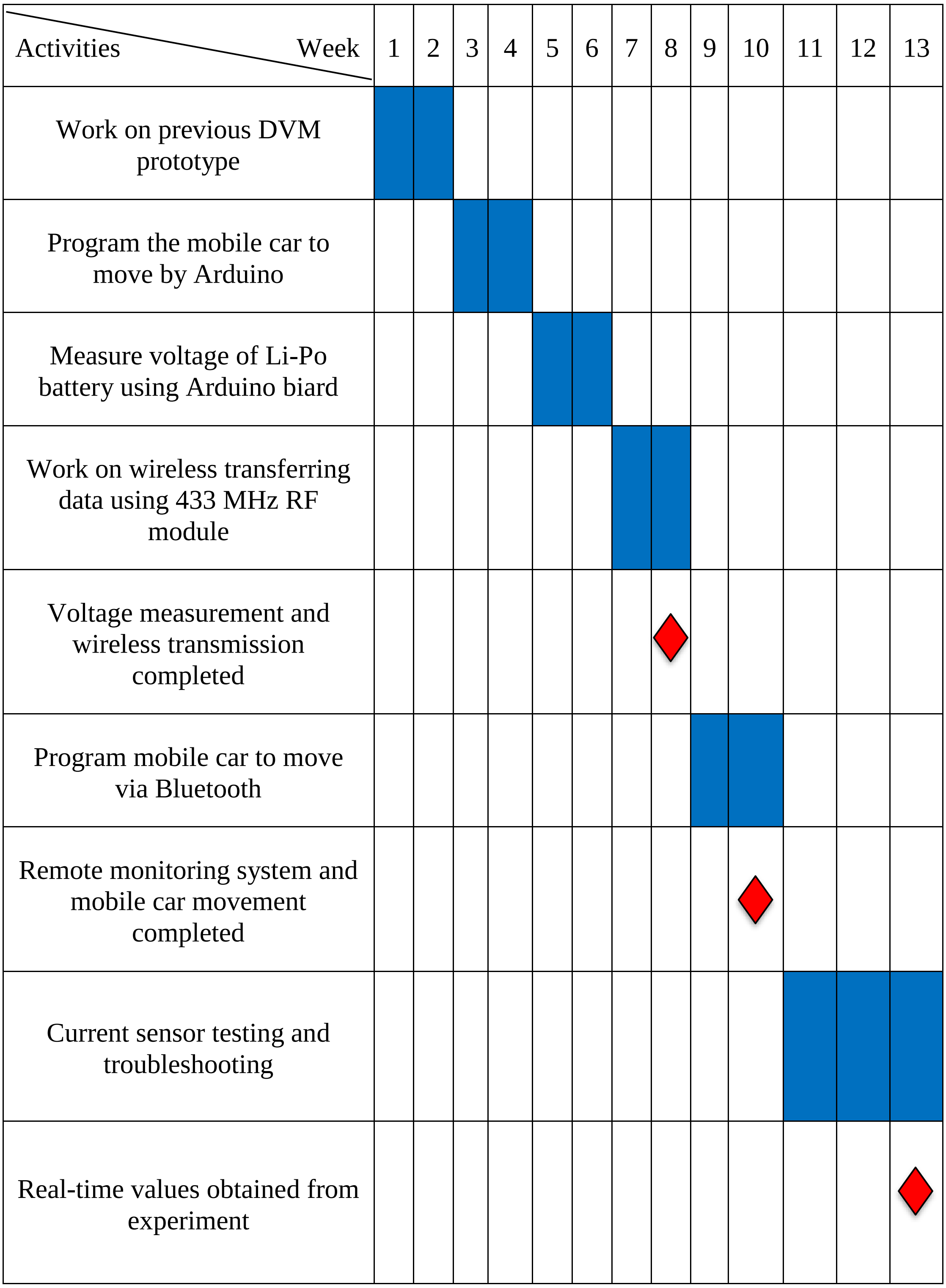
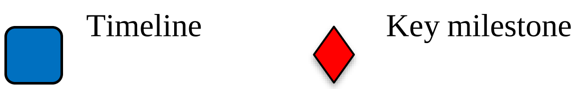


Figure 15: Gantt Chart FYP 2



CHAPTER 4

RESULT AND DISCUSSION

4.1 DVM Prototype

A DVM prototype is built based on the schematic diagram in Figure 4 [section: Literature Review] using the IC 7107. The objective of building this DVM prototype is to study and understand how a digital voltmeter works. The prototype is shows in Figure 16 below.

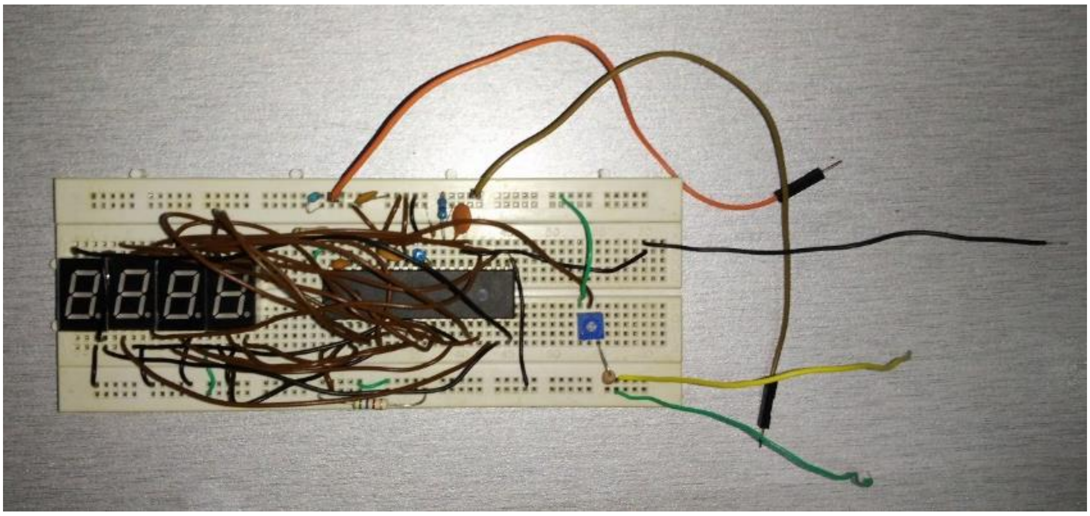


Figure 16: DVM Prototype

The DVM prototype is tested in the lab to make sure it is working. However, when DC power is supplied, no voltage is indicated on any of the 7 segment displays. All the connection of the components had been double checked according to the schematic diagram in Figure 4. On top of that, the connections for the 5V and -5V terminals are corrected and the DVM managed to show some value. Unfortunately, the reading kept changing and unable to provide measurement of the input voltage.

Therefore, a better method to measure the voltage is suggested by using the Arduino analog input. A Li-Po battery tester will be used as a comparison to the results from the Arduino board is further discussed in Section 4.4.

4.2 Testing On Commercial Digital Voltmeter Ammeter

A commercial Digital Voltmeter Ammeter (DVA) was planned for use to measure the voltage and current drawn from the Li-Po battery. The DVA is tested in the lab with DC power supply to verify its accuracy. Two DC power sources are used in this experiment; one source to power up the DVA, while another power source is used as the target measurement. The connection for Digital Voltmeter Ammeter is shown in Figure 17 below.

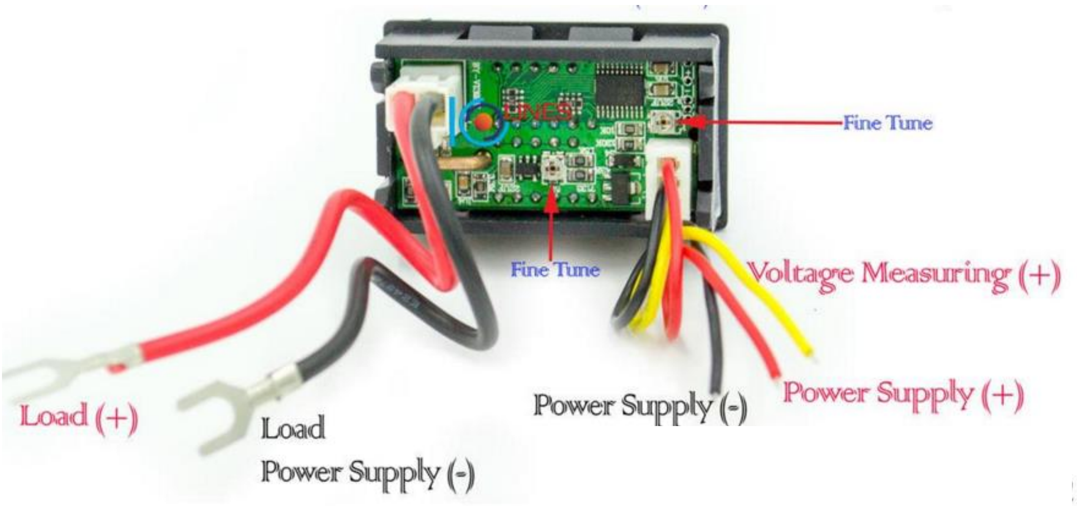


Figure 17: Commercial Digital Voltmeter Ammeter

Results of the experiment is shown on Figure 18 and tabulated in Table 4 below, where the accuracy of the DVA is found to be around ±0.01 V and ±0.01 A. However, it will be difficult to store the data and send it wirelessly to a laptop using this method. Hence, this method is replaced by combination of measuring voltage via Arduino board and measuring current drawn via current sensor method.

Table 4: Supplied VS Measured Values for Both Current and Voltage

Supplied Voltage (DC Power Supply)	**Measured Voltage (Digital Voltmeter Ammeter)**
3.0 V	2.99 V
4.0 V	4.01 V
5.0 V	5.00 V
Supplied Current	**Measured Current**
0.30 A	0.31 A
0.40 A	0.40 A
0.50 A	0.50 A

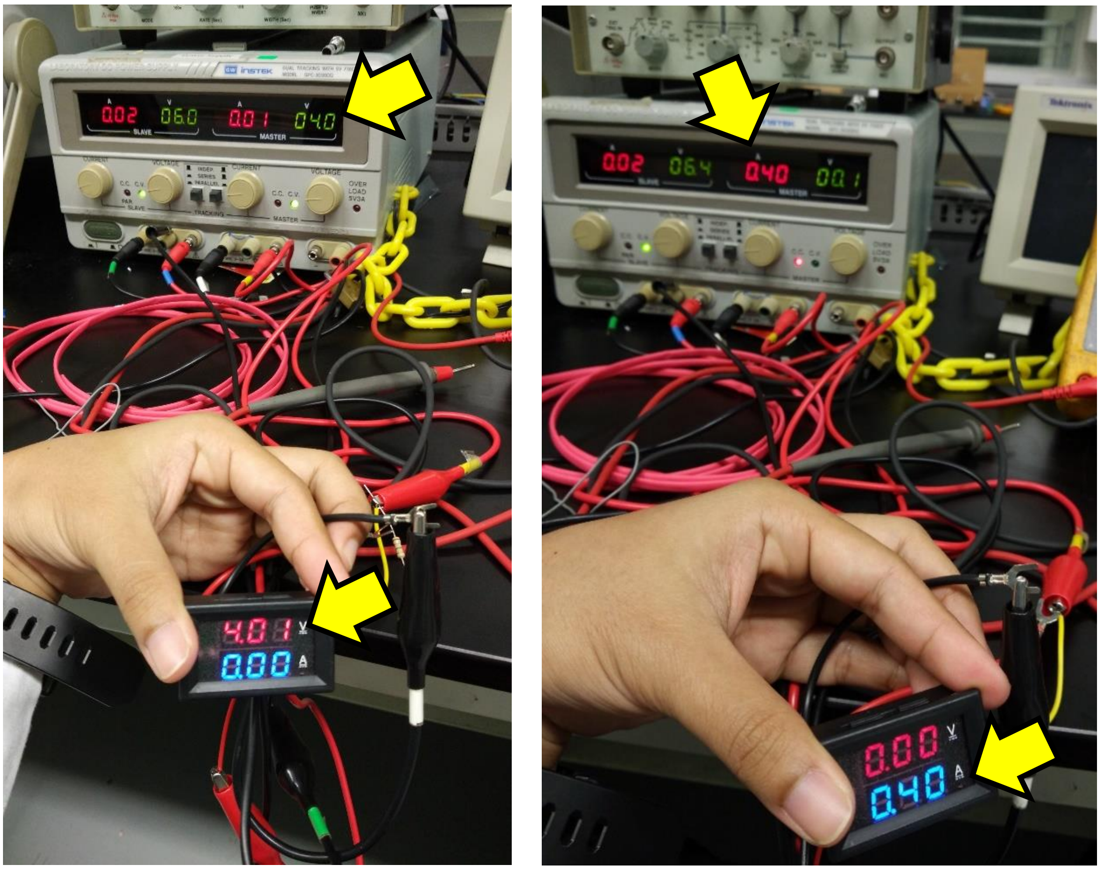


Figure 18: Supplied VS Measured Values for Both Current and Voltage

4.3 Testing On Li-Po Battery Voltage Tester

A Li-Po Battery Voltage Tester can also be used to measure the capacity of Li-Po battery for local monitoring. It is capable of monitoring each cell in the Li-Po battery and provided an alarm when the battery capacity is reduced to a pre-set threshold. The Battery Voltage Tester is first tested on a 11.1 V, 2200 mAh Li-Po battery. The test gave a total value of 11.6V for all 3 cells. After that, the Li-Po battery is then plugged to the Li-Po Balance Charger through T-Connector and it shows total voltage value of 11.79V. Thus, the Battery Voltage Tester is shown to be quite accurate and reliable. Comparison of both results are shown in the Figure 19.

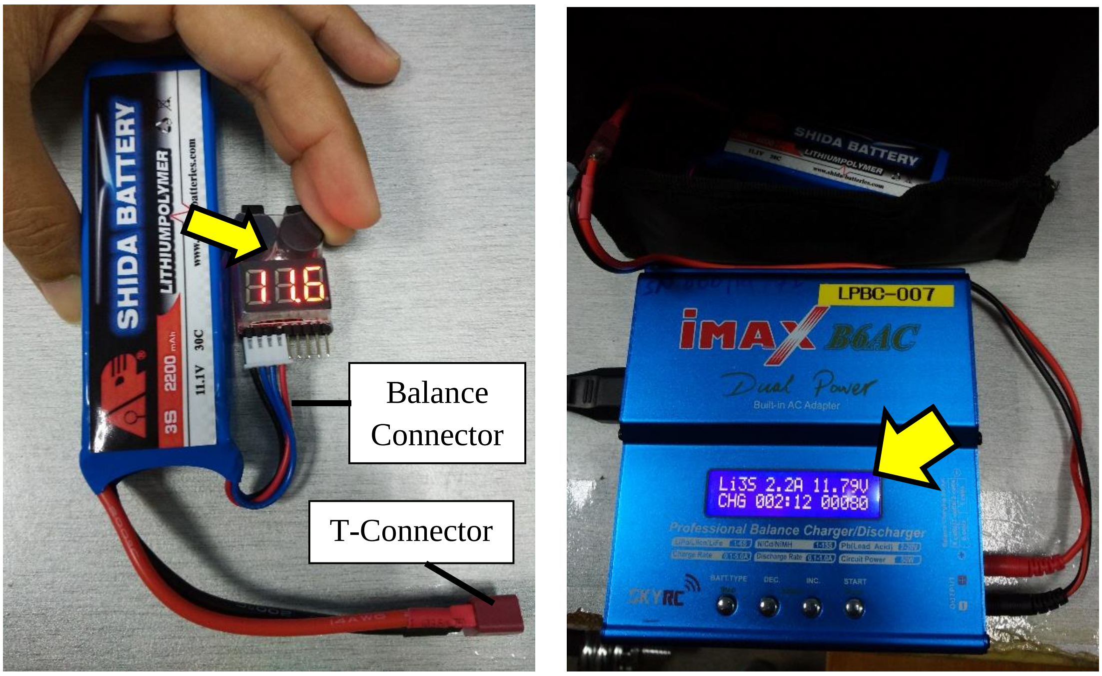


Figure 19: Comparison of Battery Voltage Tester with Multi-Function Li-Po Balance Charger

4.4 Measuring Voltage Using Arduino Board

Figures 20 and 21 show the voltage measurement of the Li-Po battery obtained from Li-Po battery tester compared to the one from Arduino board. The two measurements gave a difference of only 0.05V. Hence, it is concluded that the Arduino board voltage measurement is sufficiently accurate and the measurement system is operating well.

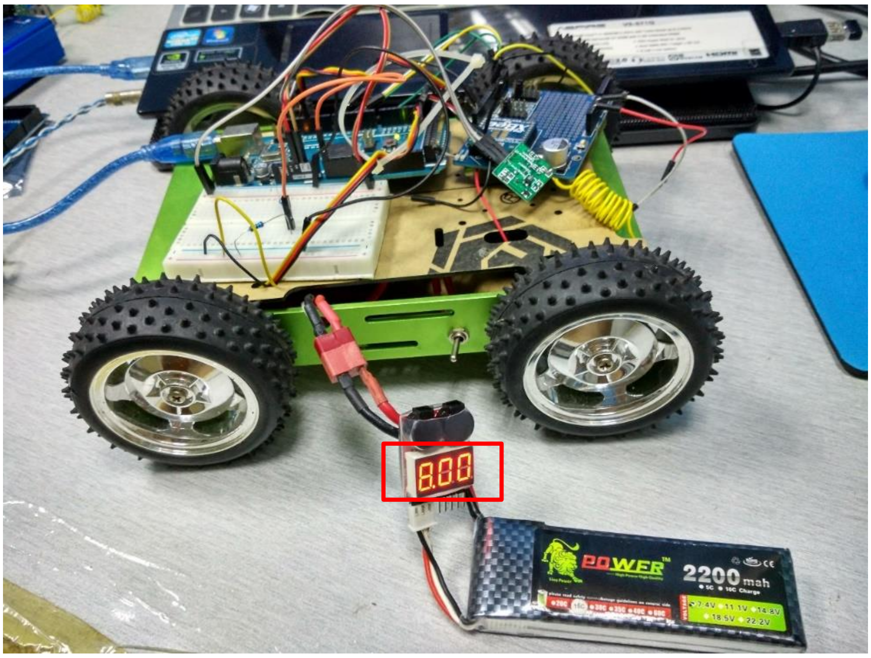


Figure 20: Voltage Measurement Using Li-Po Battery Tester

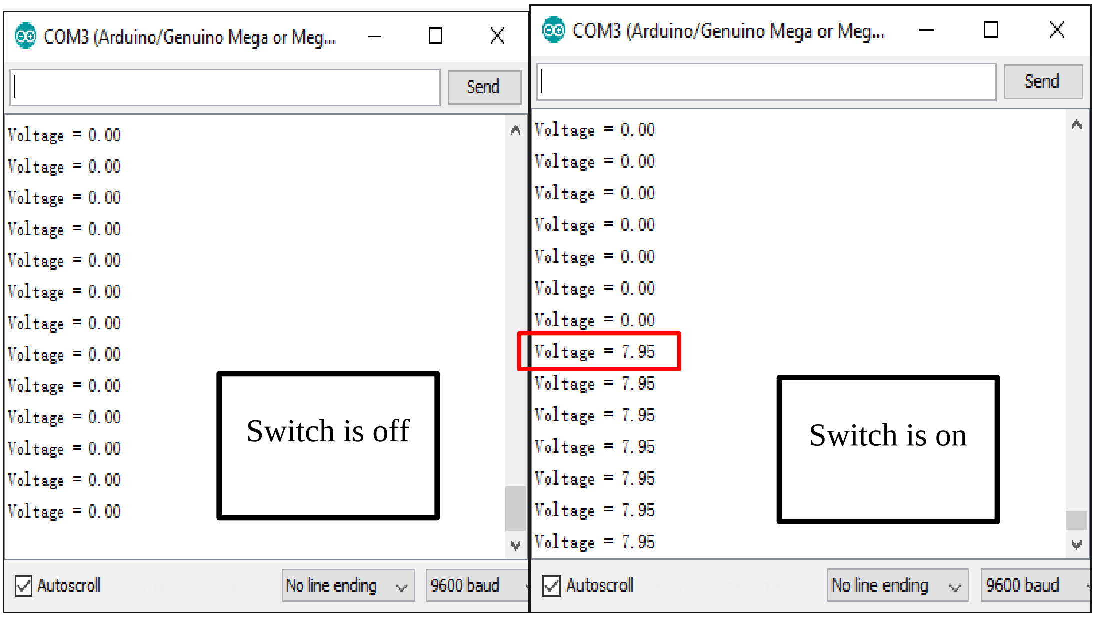


Figure 21: Result of the Voltage Measurement Using Arduino Board

4.5 Data Transmission Using 433 MHz RF Module

Figure 22 shows the setup of how the battery voltage is measured using Arduino Mega and transmitted wirelessly via 433 MHz RF module. Result of the data transmission is shown in Figure 23. Therefore, the wireless data transmission is successful. However, wireless data transmission is only available for a short range of about 1.6 m and it need to be further improved.

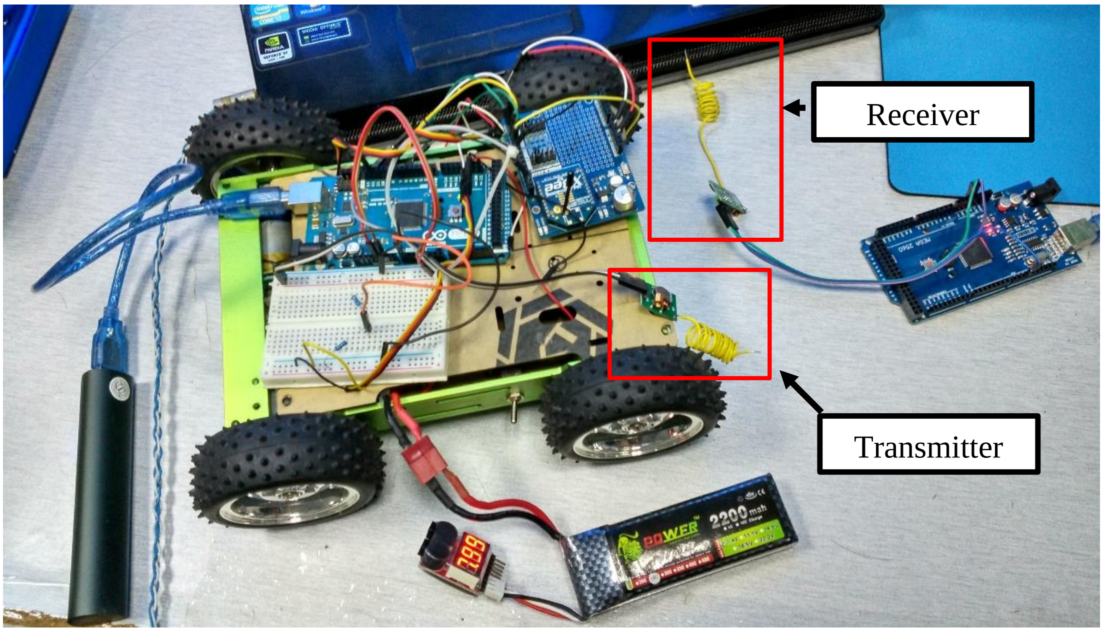


Figure 22: Wireless Data Transmission Via 433 MHz RF Module

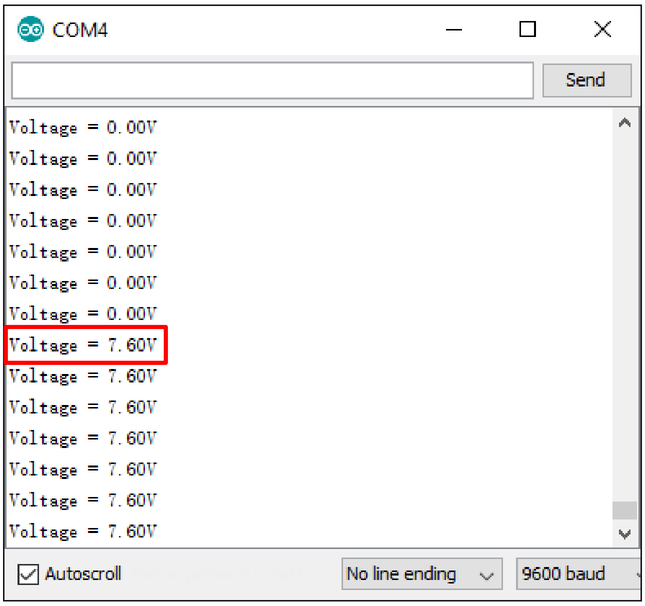


Figure 23: Data Received From Wireless Data Transmission

4.6 Battery Discharge Result Using Mobile Robot (Remote and Local)

Experiment 1 (Voltage Measurement)

Li-Po battery is mounted as power source of mobile robot. Mobile robot is ready to be tested on track. However, current sensor is not yet integrated with the whole system at that particular time. Thus, only voltage drop of Li-Po battery is recorded during this experiment. The whole process took about 2 hours to drain the Li-Po battery from 7.6 V to its EODV at 7 V. In this experiment, mobile robot is moving back and forth repeatedly for 5 mins and break for 2 mins. Real-time voltage of Li-Po battery is transmitted via 433 MHz RF module on average every 1 second. Voltage indicated by the Li-Po battery tester is recorded every 7 mins during the break time of 2 mins. Once the buzzer of battery tester is triggered, the experiment is finished. The result of remote and local monitoring are displayed in Figure 24 and 25.

At the beginning of the experiment, the remote monitoring indicates a voltage value of 7.5 V. After the Bluetooth module is connected, the voltage dropped to 7.4 V. Besides that, the result that observed from the remote monitoring is always spiking and not constant. This might be caused by noise due to wireless data transmission or due to quantization error of the received data. The spikes grew larger when the mobile robot is moving. Overall, voltage is discharged steadily until it reached close to the EODV as highlighted in Figure 24 where the rate of discharge increased rapidly. The rate of discharge continued to increase even further after the EODV. Therefore, any usage of Li-Po battery should be stopped before it reaches the EODV to protect the Li-Po battery and prolong its lifetime. The result from remote monitoring also supported by the discrete voltage measured for every 7 mins as shown in Figure 25.

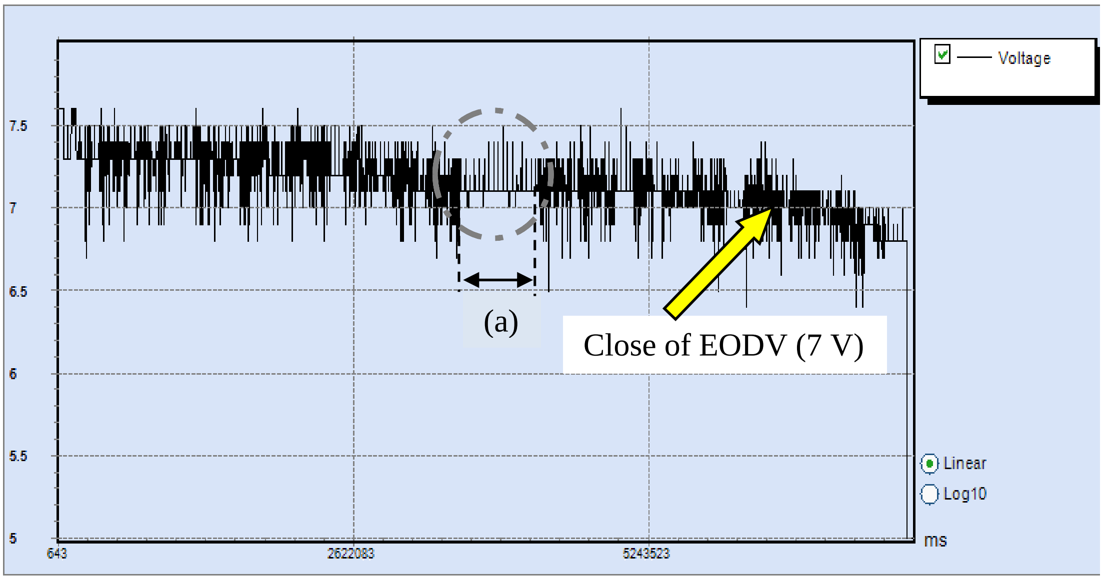


Figure 24: Result of the Remote Monitoring by Wireless Data Transmission

Note (a): Car is not moving due to a longer break in experiment

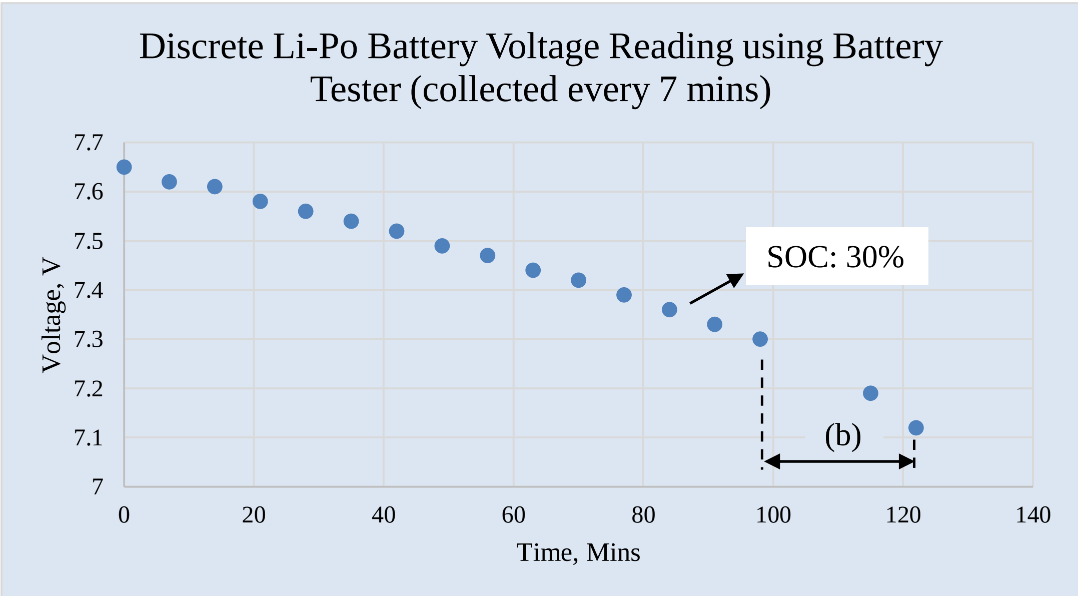


Figure 25: Result of the Local Monitoring by Li-Po Battery Tester

Note (b): Voltage started to drop rapidly

Experiment 2 (Voltage and Current Measurement)

After the current sensor is added to the system, another experiment is conducted to observe the current drawn when the mobile robot ran across the bump. The whole process took 2 hours and 12 minutes to drain the Li-Po battery from 8 V to its EODV at 7 V. In this experiment, 1 kg weight is added to the mobile robot to speed up the draining process. Then, the mobile robot is pre-programmed to move back and forth along the track for 5 minutes non-stop with a break in between for 1 minute. Real-time voltage of Li-Po battery is received on laptop via 433 MHz RF module on average every 1 second. However, the quality of the graph setting is set to high compared to the previous Experiment 1 which used normal quality setting. Besides that, voltage indicated by the Li-Po battery tester is recorded every 6 mins during the break time of 1 minute. The experiment is finished once the buzzer of battery tester is triggered. The result of remote and local monitoring are displayed in Figure 27 and 28.

The voltage measurement result that observed from the remote monitoring is almost similar with Experiment 1 result where it is always spiking and not constant. Both the discharge rate is increased rapidly once the voltage drop close to EODV. Meanwhile, the result of current measurement is also not constant. As the mobile robot moved along the track, the current drawn is increased rapidly and even further increased when the mobile robot ran across the bump. When the mobile robot is placed manually at the slope of the bump, a very large current is drawn from the DC motors to start moving the mobile robot. The highest current drawn recorded is 7.9 A.

When the battery tester buzzer is triggered, the voltage value indicated at battery tester is 7.09 V. The switch of the mobile car is immediately turned off and battery tester is unplugged from the Li-Po battery balance connector to turn off the buzzer. After 5 minutes, battery tester is plugged again to the Li-Po battery and it indicate a voltage value of 7.17 V. The battery voltage had increased 0.08 V. This is because all the sensors and motors are using about 0.1 V before the mobile car is turned off.

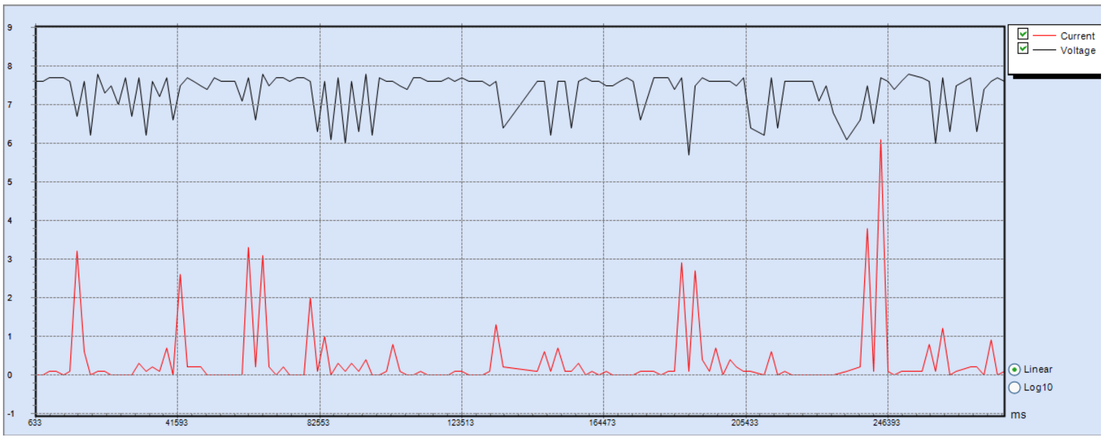


Figure 26: Result for Remote Monitoring for Duration of 5 Minutes

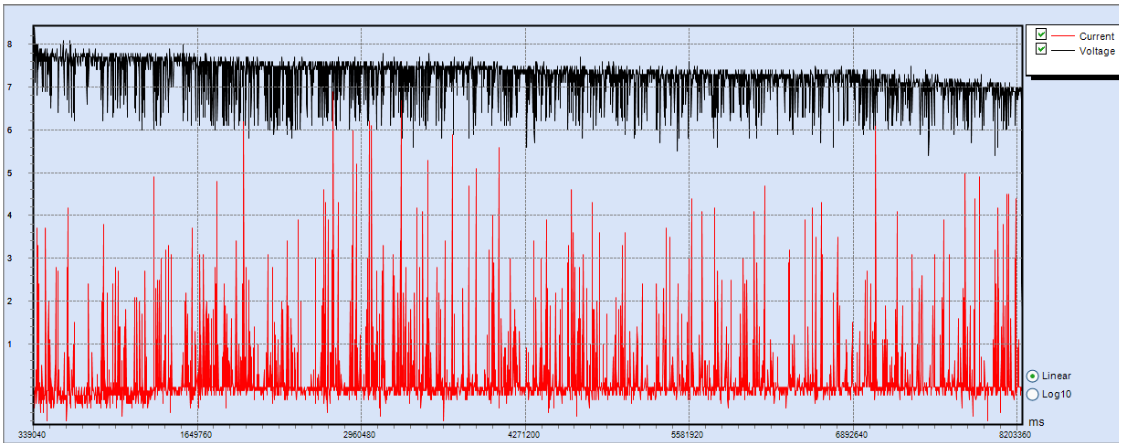


Figure 27: Result for Remote Monitoring for Duration of 2 Hours 12 Minutes

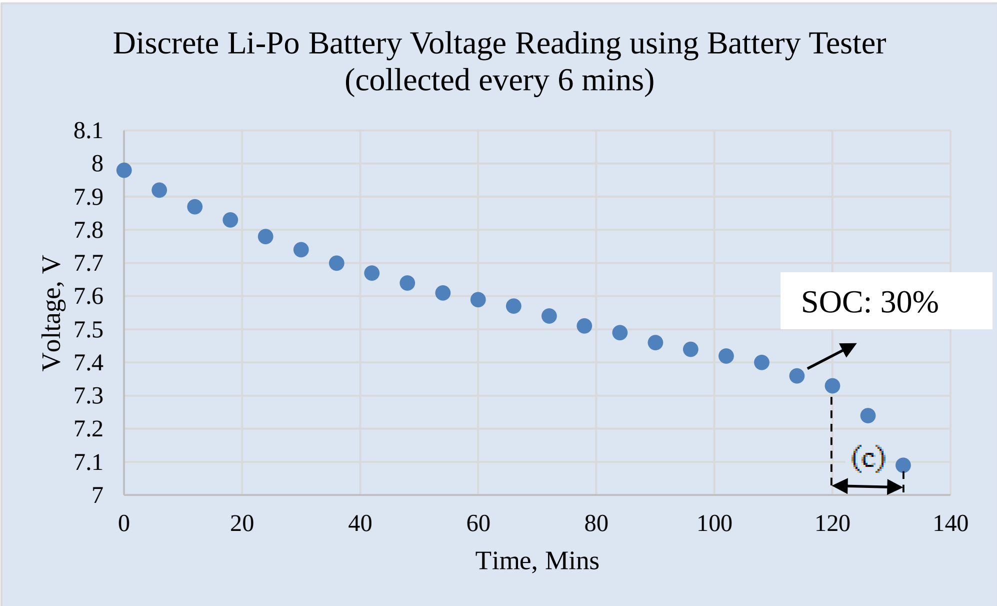


Figure 28: Result for Local Monitoring

Note (c): Voltage started to drop rapidly

4.7 Troubleshooting for Battery Discharge Result of Remote Monitoring

The previous result of voltage data recorded in remote monitoring have many spike and measurements are not consistent. A few short experiments are carried out to solve this problem. The mobile robot is turned on and put in stationary position to observe the voltage recorded for 5 minutes with different conditions. First, the robot is placed in two locations, 0.02 m and 1.5 m away from the receiver. The data transmission results are shown in Figures 29 and 30 respectively. These figures show that although the robot is not moving, the range of wireless data transmission is not the factor causing inconsistent voltage measurement.

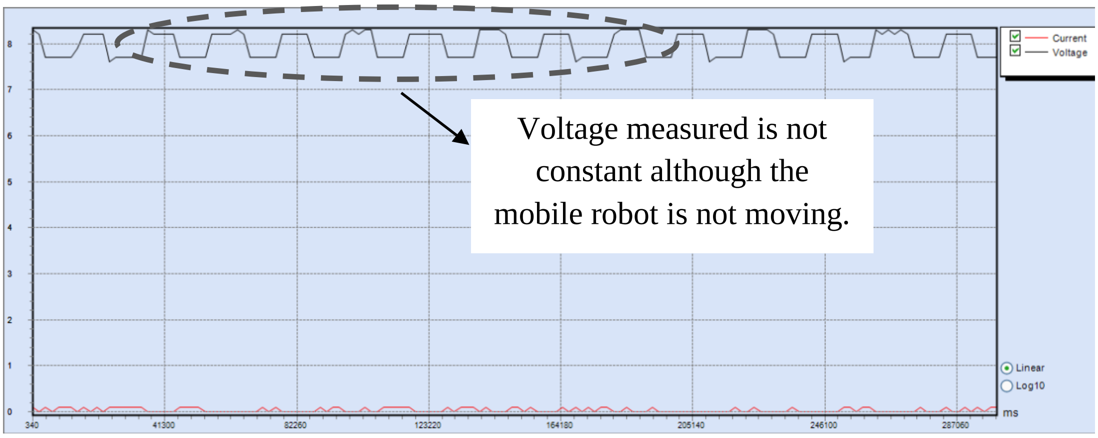


Figure 29: Result of Mobile Robot at 0.02m Away from Receiver and in Stationary Position

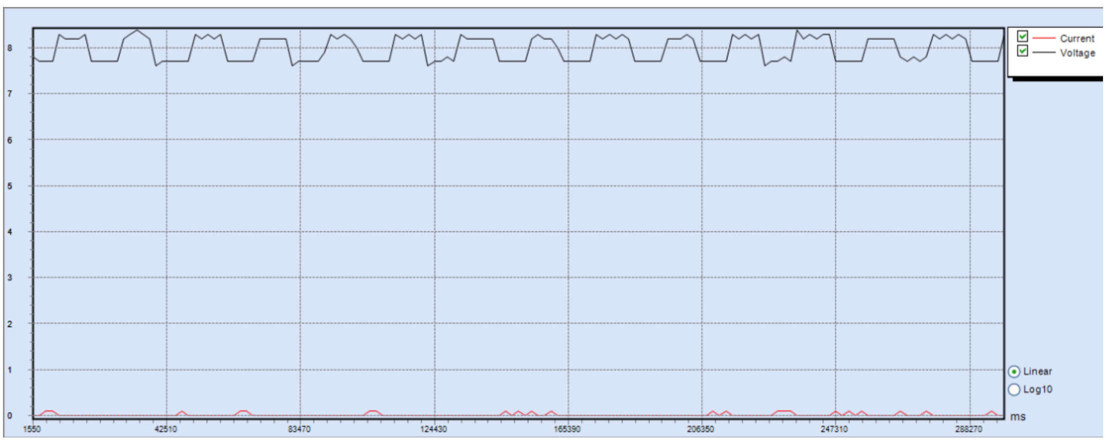


Figure 30: Result of Mobile Robot at 1.5m Away from Receiver and in Stationary Position

Then, the Processing software is turned on to connect the Bluetooth module of mobile robot to control its movement by the input from laptop keyboard. However, the voltage measured had become spikier as shown in Figure 31 (compared to Figures 29 and 30). This shows that the Bluetooth module is the reason behind the spikes and inconsistent reading.

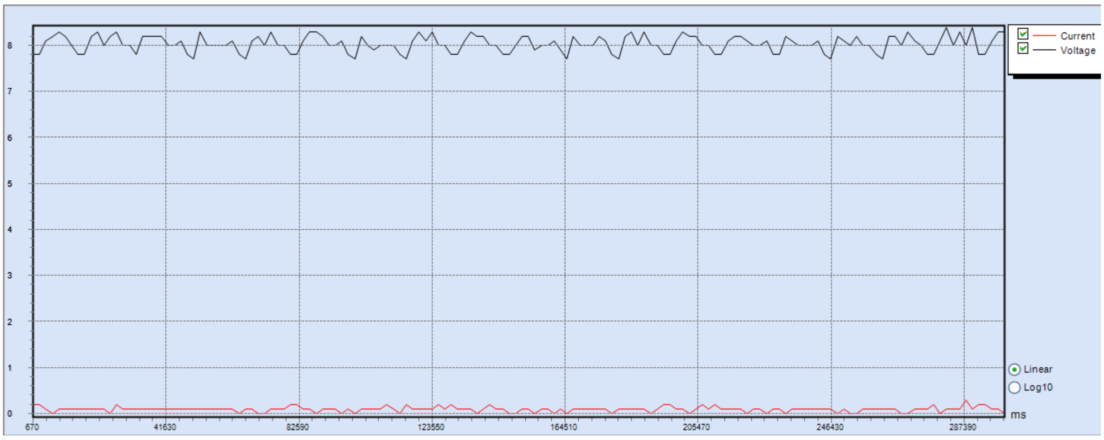


Figure 31: Result of Mobile Robot in Stationary Position and with Bluetooth Module Connected to Laptop

Hence, the Bluetooth module is separated from the main system by unplugging it from Arduino Mega and reinstalled on another Arduino board. Thus, the system is now using two Arduino boards where one is used to measure voltage and current of Li-Po battery and transmit the data through 433 MHz RF module. Meanwhile, another Arduino board is used only for to control the movement of mobile robot via Bluetooth module. Figure 32 shows the result after the modification and the voltage measured is now constant.

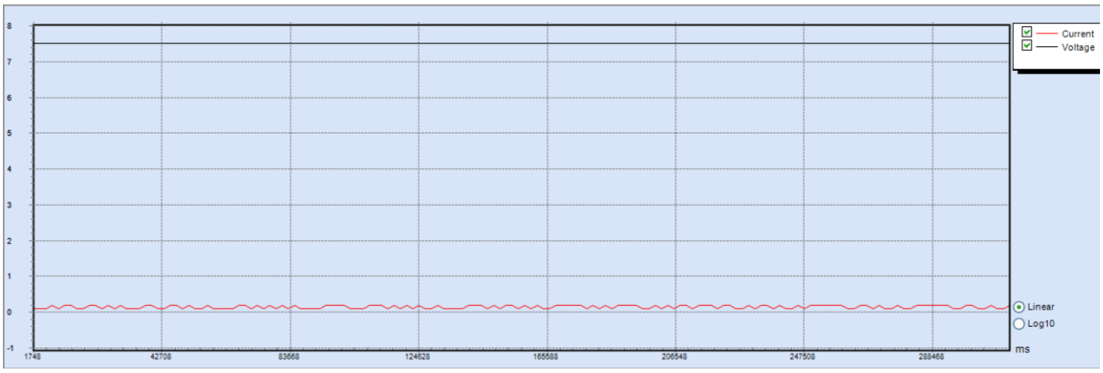


Figure 32: Result of Mobile Robot in Stationary Position with Bluetooth Module is Separated and Installed on Another Arduino Board.

Figure 33 shows the result of mobile robot moving for 5 minutes and 1-minute break after the modification where Bluetooth module is installed on another Arduino board. The voltage measured became more accurate and has less spikes compared to the previous result.

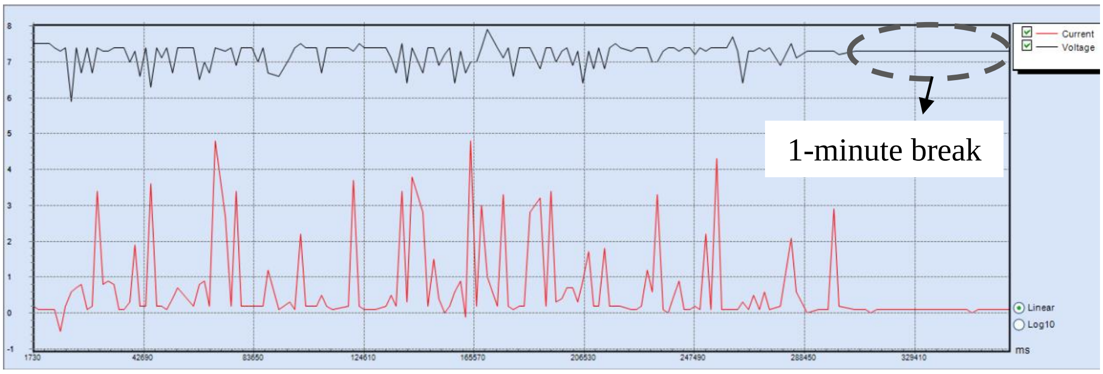


Figure 33: Result of Mobile Robot Moving for 5 Minutes and 1-Minute Break with Bluetooth Module is Separated and Installed on Another Arduino Board.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Li-Po batteries are widely used and famous for application that need medium current consumption such as RC cars and RC planes. Li-Po battery need essential care and if the battery capacity falls below EODV, the battery will become permanently damaged and unusable. However, there is a need to explore a variety cost-effective ways to monitor the Li-Po battery. Hence, the important of this project is to design a system to monitor Li-Po battery capacity and at the same time to use the information provided by the system to ensure efficient utilization of the battery capacity.

Voltage method by using the linear range of voltage discharge curves is used to indicate of SOC estimation of the Li-Po battery. A 7.4 V Li-Po battery is used to power up 4 DC motors on a mobile robot in this project. The voltage reading of this Li-Po battery is measured using an Arduino board, and a current sensor module is used to measure the current drawn. A 433 MHz RF module is then used to transmit the data wirelessly to a laptop display. SOC is estimated with 8.2 V for 100% and 7 V for 0 %. The SOC of Li-Po battery is indicated on a LCD and the information of voltage and current drained from Li-Po battery can now be monitored by both remote and local indications.

In a nutshell, this project had achieved all its objectives where a cost-effective real time capacity monitoring system for Li-Po battery is developed and tested on a mobile robot platform.

5.2 Recommendations

For now, all the subsystems have been integrated and the mobile robot was tested on the track with bump. The system is operating well and real-time capacity is monitored wirelessly and displayed in a graph to a laptop. However, only Voltage method is used in this project to estimate the SOC of Li-Po battery due to time limitation. Following recommendations is suggested for future improvement of the project:

i) A Kalman Filtering method can be added to the program to make combination of Voltage Method and Current Integrating Method to improve the SOC estimation.

ii) Range of wireless data transmission also can be improved by using Arduino XBee or via Bluetooth.

iii) Send the data to internet cloud account so that user can access and check capacity of Li-Po battery through smartphone or PC anywhere and anytime.

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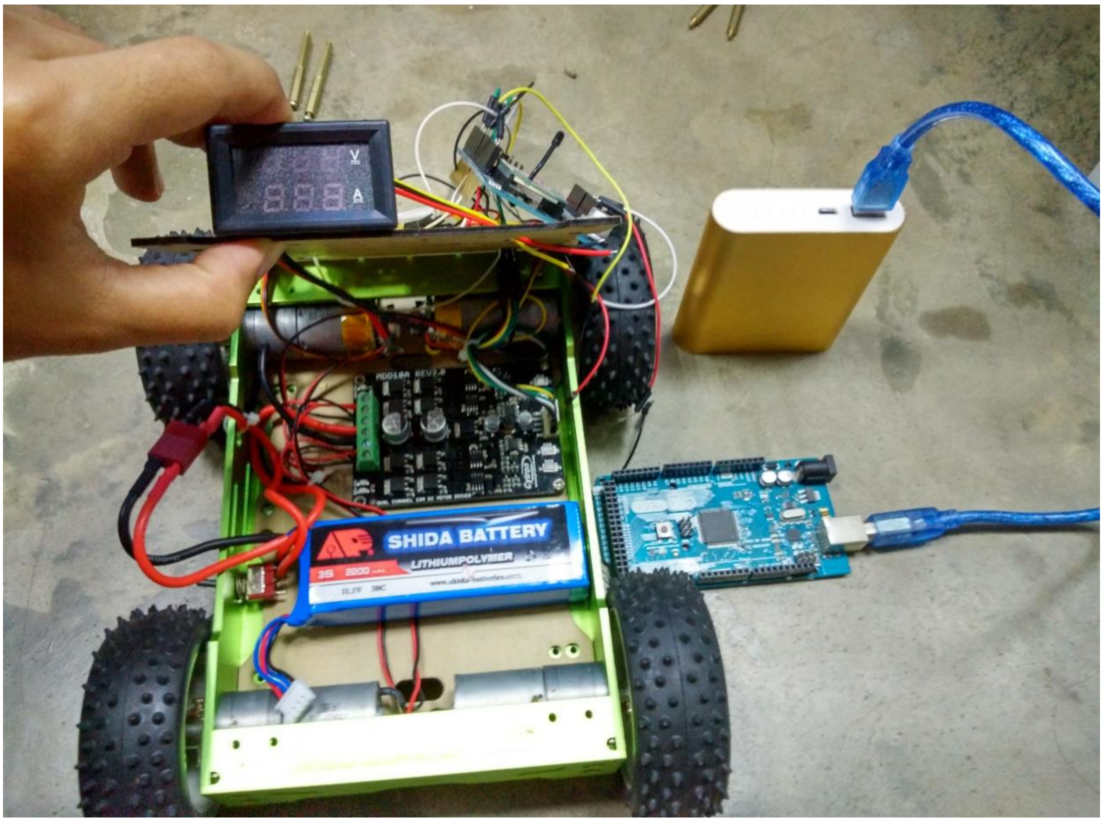
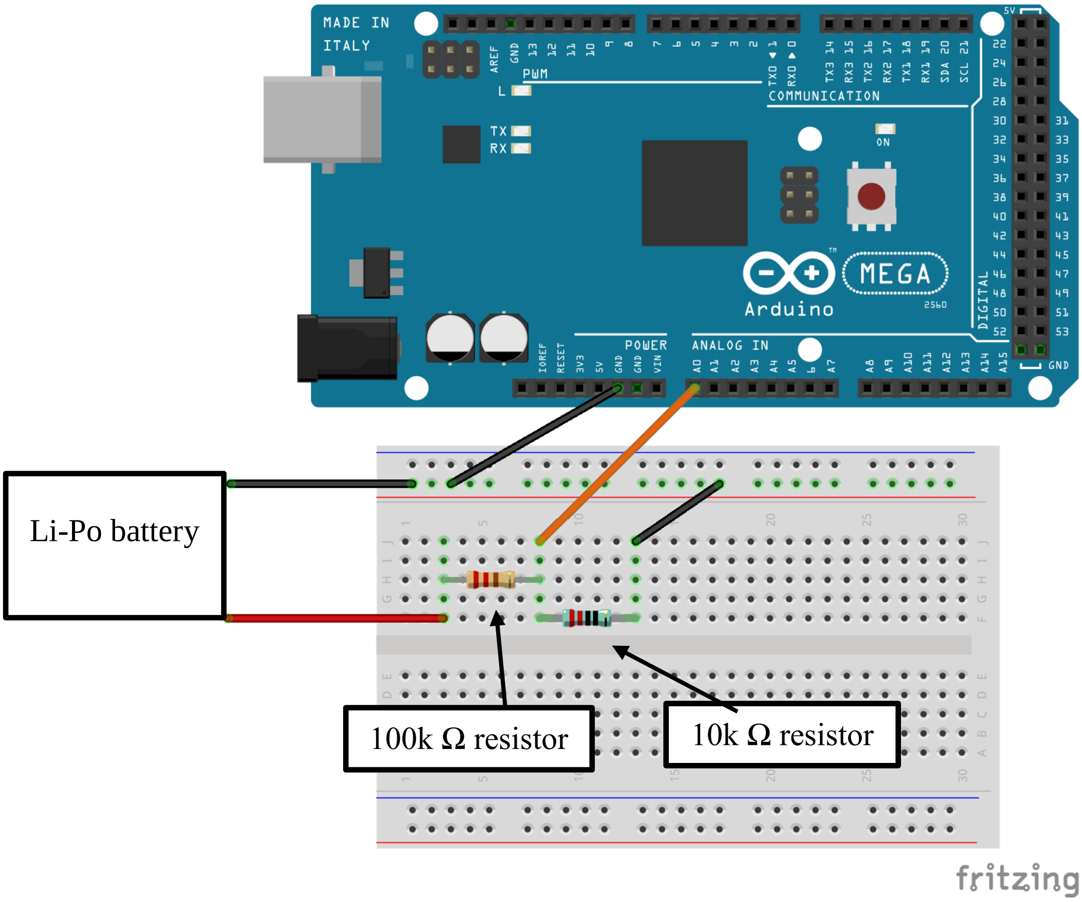
APPENDICES

Appendix 1 – Mobile Robot Connected with Li-Po Battery



Appendix II – Wiring Diagram of Voltage Measurement using Arduino Analog Input



Appendix II1 – Coding for Voltage Measurement using Arduino Analog Input

```
float input_voltage = 0.0;
float temp=0.0;
float r1=100000.0;
float r2=10000.0;

void setup()
{
   Serial.begin(9600);     //  opens serial port, sets data rate to 9600 bps
}
void loop()
{
   int analog_value = analogRead(A0);
    temp = (analog_value * 5.0) / 1024.0; //Conversion formula
   input_voltage = temp / (r2/(r1+r2));

   if (input_voltage < 0.1)
   {
     input_voltage=0.0;
   }
    Serial.print("Voltage = ");
    Serial.println(input_voltage);

    delay(300);
}
```