LOW-COST MODULAR BATTERY MONITORING SYSTEM FOR SMALL SCALE TESTING

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ABSTRACT

Electric vehicles have become a notable topic in recent years, and they are powered by a rechargeable lithium polymer (LiPo) battery. This paper describes a battery monitoring system that uses LiPo as the test subject to monitor its stability in the event of further improvement and safety limitations. A number of battery monitoring systems have been developed, but only a few are small and comprehensive. The proposed battery monitoring system will monitor the LiPo battery's state of charge (SoC), state of health (SoH), charge, and discharge using a user-friendly and affordable method. First, the data of the LiPo battery's discharge curve of voltage is collected using a voltage sensor connected in parallel with a closed loop circuit consisting of a LiPo battery and a DC motor connected in series. Second, the SoC is calculated based on the average total time spent before the voltage drop. Several trials are conducted to examine the consistency in monitoring the charge of allocated LiPo batteries. As a result of this study, a low-cost prototype for battery monitoring was developed, which proved to be reliable and perform well with a small margin of error.

Keywords: *Battery monitoring system, state of charge, state of health*

1.0 INTRODUCTION

Nowadays, throughout the whole world, the term battery is well-known. Everyone, from the elderly to small children, grasps what a battery is and what it does. A battery, as we all know, is a device that we use to power our electrical devices. A battery contains one or more electrochemical cells which will provide voltage to our electrical devices and the function of this voltage is to power our electrical devices. In a battery, there are two terminals which are a positive terminal called cathode and a negative terminal called anode. The source of electrons is the anode, when it is connected to an external circuit it will flow and deliver energy to an electrical device. Electrolytes are able to move as ions when an external circuit has a battery connected to it. After it happened the chemical reaction is completed at the separate terminals and with this, energy is sent to the external circuit. In simpler words, the battery will provide a voltage that will give the electrical device life. Figure 1 below shows the process of the cycle of electrons.

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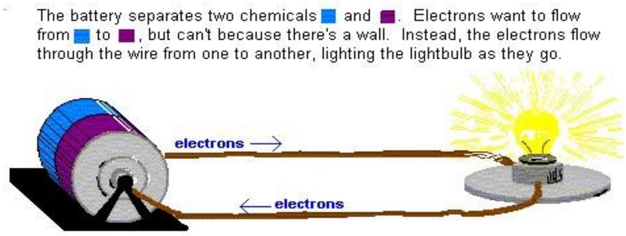

Figure 1: Process of a cycle of electrons. Retrieved from http://www.qrg.northwestern.edu/projects/ vss/docs/power /1-what-are-batteries.html

Battery can be divided into two categories which are primary and secondary battery and each of these categories have its own pros and cons. The first category is primary battery. It is known as a single-use battery because it can only be used once, meaning that it can't be recharged for reuse. It can't be recharged because of the irreversible chemical reaction and its active materials that can't return to their original forms. The advantage of primary battery is that it has a lower initial cost but a higher life-cycle cost. It does not require maintenance and charging as it is a single-use only. Primary battery has a high availability in the market which means it can be bought easily at the shops. It is also light and small in size so that's why it is used mostly in portable devices. Furthermore, it has a longer service per charge and good charge retention. The downsides of primary battery are that it is not ideal for heavy load performance, load-leveling, emergency backup, hybrid battery, and high-cost military applications.

The second battery is secondary battery. It is known as a rechargeable battery because it can be recharged for reuse. Unlike primary battery, secondary battery's chemical reaction is reversible, and its active material can return to its original forms. Both of these processes can be done because electric current can be supplied to the battery by a device called chargers. Secondary battery has a higher initial cost but a lower life-cycle cost if its charging is appropriate and cheap. Since it is a rechargeable battery, it needs regular maintenance and periodic recharging. Next, its availability is not as great as primary battery as it is produced in a small batch. Furthermore, secondary battery has small charge retention. Its advantages are it has a high discharge rate performance at heavy loads. Then, it is suited for load-leveling, emergency backup, hybrid battery, and high-cost military applications.

Recently, electric vehicle has become a hot topic for discussion. Electric vehicle is powered by lithium polymer (LiPo) battery which is a secondary battery and hence rechargeable battery. With this new power source for a vehicle, fossil fuel consumption which is a scarce power source can be reduced greatly because since the LiPo battery is a rechargeable battery, it can be used over and over again. Besides that, carbon dioxide emissions also can be reduced enormously [1]. This is because by using a LiPo battery the vehicle won't emit any gas like CO^2 and any other hazardous gas and therefore decrease air pollution to the environment. In addition, with LiPo battery as the source to power the vehicle, no sound pollution occurs since it won't emit any loud or noisy noise to the environment. It certainly is an eco-friendly power source. Although a LiPo battery is a good power source, it must be properly maintained, charged, and stored, or else a serious accident may occur. Therefore, this research revolves around lithium polymer batteries' state of health (SoH), and state of charge (SoC). By knowing this, we can increase the battery life of LiPo batteries and can prevent any explosive tragedy.

Presently, there are many battery monitoring systems but only some of them are small in size. Finding a battery monitoring system that is compact in size is not easy because a lot of hardware is needed in a battery monitoring system and the hardware needed is big hence that's why the most common battery monitoring system is big in size. A lot of hardware is needed because there are many parameters or variables that need to be considered. Furthermore, finding a battery monitoring system that suits all types of batteries is not easy because mostly the existing battery monitoring system is a specified type of battery monitoring system. This means that it can only be used for a certain type of battery, otherwise, if a different type of battery is used, the monitoring system will not give any data or will give data, but the data is gibberish and useless.

Besides that, there are many battery monitoring systems out there that are reliable but finding a reliable and affordable battery monitoring system is not easy. Thus, one of the objectives of this project is to build a reliable and affordable because usually, a battery monitoring system that has high reliability is very expensive because of its robust features, high-quality material, and many more. The main objectives of the project are:

1. To analyze the voltage characteristic of the charging and discharging of a LiPo battery.
2. To develop a simple and accurate battery monitoring system for the state of charge (SoC) and state of health (SoH) for a battery.
3. To develop an affordable and reliable battery monitoring system.

[2] defined state of charge (SoC) as the capacity gauge of the battery. It is also known as the remaining charge of the battery [3] and the percentage of current capacity compared to nominal current [4]. In simpler terms, the state of charge is accessible capacity represents as a percentage of some reference.

State of health (SoH) is usually defined or looked at as a measurement that indicates the general condition of a battery and its capability to give the curtained performance compared with a new battery. It considers factors like charge acceptance, internal acceptance, voltage, and self-discharge. As stated by [5], "it is a measure of long-term capability of the battery and gives an indication not an absolute measurement, of how much of the available lifetime energy throughput of the battery has been consumed, and how much is left". In simpler terms, SoH is referred as the present battery's ability to store energy compared to a new one.

Before methods are designed, a set of literature of previous work related to the project is reviewed to identify the best alternative that should be taken as well as increase the effectiveness of the solution. Even though the effectiveness of the earlier work is acknowledged, a low-cost prototype for a battery monitoring system with a reliable and accurate performance has not been fully taken into account. In order to develop a better battery monitoring system, other researchers may find this study useful as a starting point. The existing methods to measure SoC and SoH are summarized in Table 1.

Table 1: Summary of literature for SoC and SoH measurement methods

Ref.	Aspects	Estimating Methods	Descriptions
[6]	SoC, SoH	Existing coulomb method	Calculate cell voltage and temperature individually, fault conditions analyzer and different batteries chemistries can be used
[1]	Battery temperature, SoC	Online monitoring terminal with GPRS data transmitter and computer with a battery online monitoring system software	Can measure batteries simultaneously with small, accumulated error. Good with data transmission, user-friendly, and high reliability
[2]	SoC, SoH	Coulomb counting process	Accurate and easy-to-use solution for online indication of battery statues without the need for sophisticated calculations or intricate information
[7]	SoC, SoH	Dynamic impedance method and projection technique	Initial values are not essential, use simple operations to calculate various parameters, a complete mathematical model of the SoC and SoH is derived, and real-time Soc and SoH estimations
[8]	SoC, SoH	The first is by determining the SoC dependency of the nominal parameters of a first-order RC model. Then two Extended Kalman Filters with different time scales are used	Precise SoC and SoH estimation with the low easy calculation
[9]	SoH	An algorithm based on impedance at the low sampling rate. The algorithm includes a battery model with Warburg impedance and a recursive least	RC circuit parameters have inconsistent values compared to the estimated Warburg impedance which has a consistent value

		square method for estimating the parameters	
[3]	SoC, SoH, SoF	Extended Kalman Filter for SOC. Battery parameters are identified online by using Recursive Least Square Algorithm for SOH and SOF	The estimation accuracy is better and less calculated because of the good connection with the states
[10]	SoH	Gaussian Process Regression (GPR) and Gaussian Process Functional Regression (GPFR)	Even without the physical model, it can provide precise and accurate estimation because of its flexibility
[11]	SoC	Proportional integral observer	Simple structure, easy to implement, convenient, and accurate (2% error band for both known and unknown initial SOC cases)
[4]	SoC	Neural Networks- radial basic function (RBF), feed-forward (FF), and nonlinear autoregressive with exogenous (external) input (NARX)	NARX is the best compared to FF and RBF

2.0 METHODOLOGY

2.1 Hardware and software

2.1.1 Arduino Uno

Arduino Uno is an open-source development board that utilizes ATmega328p. It has onboard voltage regulators and a 16 MHz crystal. It contains two microcontrollers which are ATmega16u2 which handles the USB-Serial conversion and ATmega368p which is the main microcontroller. Furthermore, Arduino Uno has a reset button, a power jack, 14 digital input or output pins (of which 6 provide PWM output), 6 analog inputs, a USB connection, and an ICSP header. The function of this device is that it can be used to create interactive objects and digital devices which can control or sense objects in the physical world like a range sensor device, fire detection device, warning system, and many more. In this project, it is used as a digital device to detect the voltage of the LiPo battery. Figure 3(b) shows the Arduino Uno board.

2.1.2 Arduino 25V voltage sensor module

This device is an Arduino-compatible device. It is a voltage sensor with a built-in resistor. Inside this module, there are two resistors which are 30K and 7.5K Ohm resistors. These two resistors will act as a 5:1 voltage divider to reduce voltage since Arduino analog input only can support voltage up to 5 VDC input. This voltage sensor module has 2 inputs and outputs. The inputs are GND (this will be connected to the ground of Arduino) and VCC (this will be connected to the positive or high side of the measured voltage. The outputs are S (this will be connected to the Arduino analog input), - (this will be connected to the Arduino ground), and + (this will not be connected as it does nothing). In this project, a voltage sensor module is used to get lower the voltage and also to measure the voltage of the LiPo battery. Figure 3(c) shows the Arduino 25V voltage sensor module.

2.1.3 24V DC motor

This is a 24-volt with 350W output DC motor. This motor is usually used for the motor of electric scooters and bikes. It consists of 11-tooth and 25 chain sprockets. It also has a 4-bolt mounting bracket on the base. The speed of the motor can be controlled, and this motor can rotate both clockwise and counterclockwise, this can be done by just changing the battery polarity that is connected to the motor. This DC motor is used as a load motor to discharge the LiPo battery to get the voltage discharge curve of the LiPo battery. Figure 3(d) shows the 24V DC motor.

2.1.4 Lithium polymer (LiPo) battery

Lithium Polymer (LiPo) batteries are small, compact, reliable, rechargeable, and light. This certain battery gives an output range of 4.2V when it is completely charged to 3.7V. It has a capacity of 600mAh. It is also equipped with a protection circuit that will keep the battery from being overcharged or over-discharged and output shorts. As we all know, a LiPo battery can explode easily when it is being overcharged or over-discharged, or output shorts.

There are many infamous incidents of the explosion of LiPo batteries because the owner carelessly overcharges or overuses them. For this certain project, the LiPo battery is set as the standard battery to be tested and experimented with. Figure 3(d) shows the 3.7V 600mAh LiPo battery

2.1.5 Liquid crystal display I2C

It is an Arduino-compatible 16x2 LCD with an I2C interface. Since it has an I2C interface LCD module, it only uses 2 wires which are SDA (connect to A4 of Arduino board) and SCL (connect to A5 of Arduino board) pin to display the data, and another 2 wires which are VCC (connect to 5V of Arduino board) and GND (connect GND of Arduino board) to be connected to the Arduino board. In this project, it is used to display the time for the LiPo battery to discharge completely and also the time for certain voltage of LiPo battery level (80%, 60%, 40%, and 20%). Figure 3(f) shows LCD I2C.

2.1.6 Light emitting diode (LED)

It is a 5mm LED which will omit light. It has a variety of colors which are red, yellow, blue, and green. It is small, light, compact, user-friendly, safe, and bright LED. In this project, it is used to indicate the voltage of the LiPo battery at different levels (80%, 60%, 40%, and 20%). It will light up when reaching a certain level of voltage. Figure 3(g) shows the LED.

2.1.7 Arduino IDE

Arduino Integrated Development Environment (IDE), as shown in Figure 2(a) is open-source software for Arduino and any other board which is compatible with this program. It acts as a medium between Arduino Uno and humans. It uses C or C++ language. It also consists of two mandatory functions which are setup() and loop(). Setup() will get called once the system is reset or boots and loop() will get called repeatedly after the setup function gets executed. The user will write their codes in Arduino IDE and the program will verify and upload them to the Arduino Uno board. From this program, multiple functionalities are provided like serial monitor, serial plotter, and many more. In this project, a serial plotter is used to draw or plot the curve of voltage discharge.

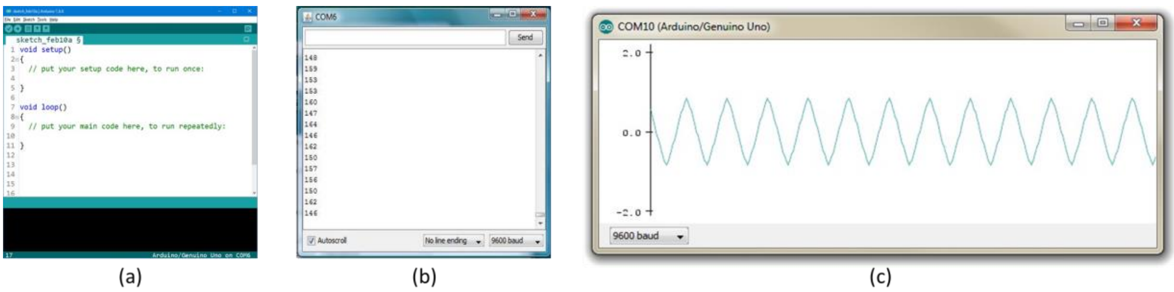

Figure 2: Arduino IDE functionality. (a) Script writing; (b) Serial monitor; (c) Serial plotter

2.2 Project design

The circuit is constructed as in Figure 3(a). The 24V dc motor is connected in series with a 3.7V LiPo battery in a closed loop circuit. The voltage sensor module is connected in parallel with the LiPo battery. The LED is a step up. The Arduino Uno board is plugged into the USB port of the laptop and the voltage sensor module is connected to the Arduino Uno board.

2.3 Working principle

2.3.1 Data collection

The coding for the data collection is uploaded to the Arduino board. The circuit for data collection of the LiPo battery's voltage is constructed. In the circuit, the LiPo battery and motor are connected in series in a closed-loop system. The voltage sensor is connected in parallel with the LiPo battery to get an accurate reading of the LiPo battery's voltage. The data that is collected is the total time taken for the LiPo battery to discharge completely. Next, the average

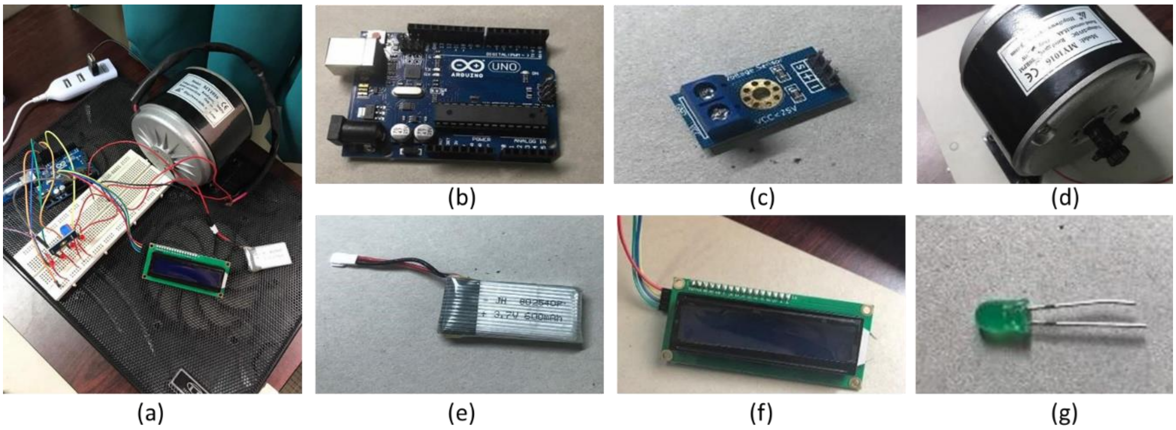

Figure 3: Components for the whole system. The project is designed as in (a) consisting of (b) Arduino Uno, (c) Arduino 25V voltage sensor module, (d) 24V DC motor, (e) 3.7V 600mAh LiPo battery, (f) LCD and (g) LED

total time taken is acquired and SoC is determined from the data. Figure 3(a) shows the circuit for data collection.

2.3.2 Project Plan

The coding for this project based on the determined SoC above is uploaded into the Arduino board. The circuit for the project is constructed. In the circuit, the motor, LiPo battery, and voltage sensor are connected like the data collecting circuit. The additional circuit is the LED and LCD I2C. The LEDs will light up once it enters the certain level of voltage (LED 1 = 80%, LED 2 = 60%, LED 3 = 40% and LED 4 = 20%) based on the coding for this project. Figure 4 shows the flowchart of the system.

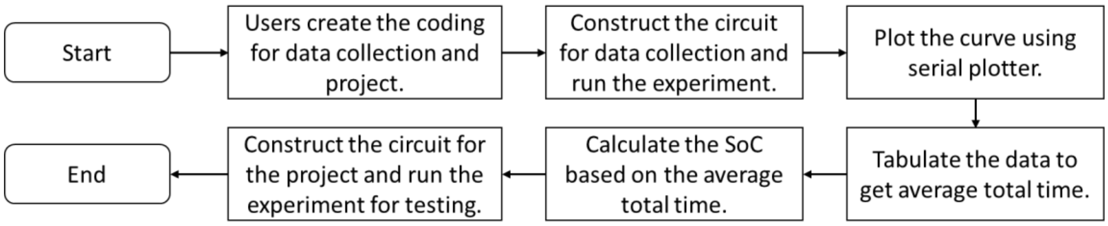

Figure 4: System flowchart

2.4 Procedures

2.4.1 Circuit development

Figure 3(a) shows the arrangement of components in a circuit. The motor and the LiPo battery are arranged in series in a closed-loop system. The voltage sensor is connected in parallel with the LiPo battery so that it can measure the voltage of the battery correctly. The VCC of the voltage sensor is connected to the positive side of the LiPo battery while the GND of the voltage sensor is connected to the negative side of the LiPo battery. The positive of LEDs are connected to pin 9, 10, 11, and 12 of Arduino and the negative of LEDs are all connected to the GND pin of Arduino. For the LCD I2C, the GND is connected to the GND pin of Arduino, VCC is connected to the 5V pin of Arduino, SDA is connected to the A4 pin of Arduino, and SCL is connected to the A5 pin of Arduino.

2.4.2 Coding development

The coding is done by using the Arduino ide software. The coding consists of two mandatory functions which are setup() and loop(). The setup() function will be called only once the system resets or boots while the loop() function will be repeatedly called after the setup() function gets executed.

This system will use wires and a liquid crystal I2C library since we are using the LCD I2C. Firstly, all the variable is initialized outside of setup() and loop() so that all the variable will be global initialization. The variables that are globally initialized are analog input, voltage in and out, and resistors. When all the variables are global initialization, the variables will be known in both functions. Secondly, the setup() function contains all the declarations of variables. The variable which is the input like analog input will be declared here. Thirdly, the loop() function contains the coding for the calculation of the voltage of the LiPo battery. The formula for calculating the voltage can be found here.

The previous steps are mainly for data collection. To complete the whole system for the project, some additional variables to be globally initialized like the LEDs, and comparators. In the setup() function, the additional coding is the LEDs are declared to be output. In the loop() function, the additional coding is the if else statement. This if else statement is used to light up the LED at a certain level of SoC based on the data collected before.

2.4.3 Graph plotting

A serial plotter, as shown in Figure 2(c) is a built-in feature of Arduino IDE software. Once the coding is done and the circuit is constructed, the serial plotter is open to see the curve of the voltage of discharge of the LiPo battery. The serial plotter will auto-scale the y-axis which is the amount of voltage but the x-axis which is the time will be fixed to a 500-point axis (each of the ticks of the axis is equal to the Serial.println() command).

2.4.4 Data tabulation and average time calculation

Once all the data are collected, it is tabulated. From the tabulated data the average total time taken before voltage drop is calculated. Then the SoC is determined using the average total time taken before voltage drop.

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2.5 Bill of materials

Table 2 shows all the materials and hardware needed to create the prototype for this project.

Table 2: Bill of materials for the developed system

No.	Components	Quantity	UMC (RM)	Total (RM)
1	24V DC Motor	1	120.00	120.00
2	Arduino Uno	1	60.00	60.00
3	Voltage Sensor	1	7.00	7.00
4	3.7V 600mAh LiPo Battery	5	25.00	125.00
5	LED	4	1.00	4.00
Total (RM)				316.00

3.0 RESULTS AND DISCUSSION

3.1 Trials on the average time of lipo battery before voltage drop

Trials on average total time before voltage drop are tabulated in Table 3 and the curve of voltage discharge for five LiPo batteries is separately shown in Figure 5.

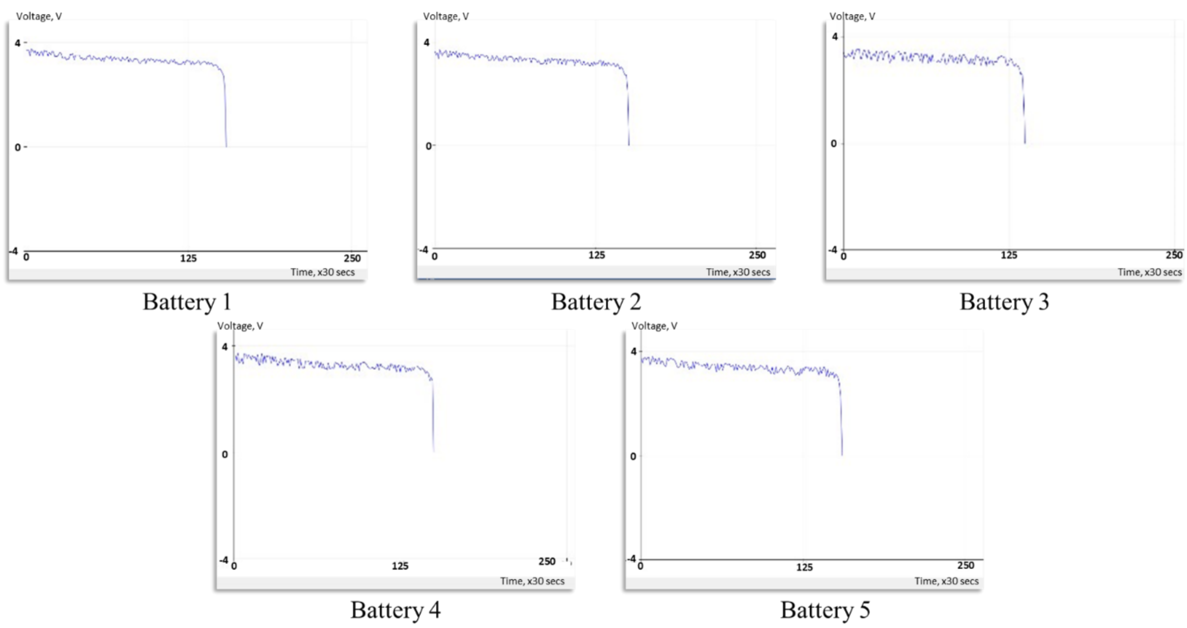

Figure 5: Curve of voltage discharge

Table 3: Summary of battery runtime tests

Battery	Test 1 time before voltage drop, secs	Test 2 time before voltage drop, secs	Average of Test 1 & 2, secs
#1	4590	4680	4635
#2	4440	4320	4380
#3	4470	4350	4410
#4	4500	4530	4515
#5	4620	4680	4650
Average Total Time Before Voltage Drop			4518 (150.6 mins)

3.2 SoC calculation

The SoC calculation is based on the average total time before voltage drop calculated in the previous subsection based on Eq. (1).

$$Total\ time\ for\ SoC = Percent\ proportion \times Average\ total\ time \quad (1)$$

Therefore, 100% SoC should have an average total time of 4518 seconds before the voltage drop. The rest of the calculations are tabulated in Table 4.

Table 4: SoC estimation

SoC	**20%**	**40%**	**60%**	**80%**	**100%**
Time, secs	903.6	1807.2	2710.8	3614.4	4518

3.3 Discussion

From all the tests of LiPo battery voltage discharge, the total time before voltage drop for different LiPo batteries does not vary much and the shape of the curve of voltage discharge is also the same for all of the tests. Aside from that, the results for test 1 and test 2 for each LiPo battery are almost identical. If the results of tests 1 and 2 are significantly different, the experimental setup may be incorrect, either with the battery, the circuit, or the coding. However, the overall experiment only has a small margin of error in which the SoC estimation is 20% SoC equals 903.6 secs, 40% SoC equals 1807.2 secs, 60% SoC equals 2710.8 secs, 80% SoC equals 3614.4 and 100% SoC equals to 4518 secs will most likely be accurate. To summarize, these experiments had a consistent performance and were successful.

4.0 CONCLUSION

In conclusion, this project can be considered a success because the developed monitoring system has a consistent result on battery charge based on test 1 and test 2. The first objective, which is to develop a simple and accurate battery monitoring system for SoC and SoH, is achieved as this method is easy to execute and user-friendly. The second objective, which is to keep track of the charge and discharge of the battery, is partly achieved because of charge of the battery is achieved but the discharge part will be worked on in future work. The last objective, which is to develop an affordable and reliable battery monitoring system, is achieved because the total cost of the components used is low.

There are some limitations to this project such as when two or more LiPo battery is connected in series, the voltage of each LiPo battery cannot be measured. The LiPo battery will heat up and eventually explode. This is because there are many loops of current in voltage sensors 1 and 2.

The coding for data collection can be improved to provide more accurate and faster results. The circuit for data collection, as well as the project, can then be improved to reduce errors and increase the accuracy of results.

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REFERENCES

[1] Luo, M., Xiao, Y., Sun, W.-M., & Wang, Z. (2013). Online battery monitoring system based on GPRS for electric vehicles. *2013 5th International Conference on Intelligent Human-Machine Systems and Cybernetics*, 122-125.

[2] Wu, T.-H., Wang, J.-K., Moo, C.-S., & Kawamura, A. (2016). State-of-charge and state-of-health estimating method for lithium-ion batteries. *2016 IEEE 17th Workshop on Control and Modeling for Power Electronics (COMPEL)*, 1–6.

[3] Shen, P., Ouyang, M., Lu, L., & Li, J. (2016). State of Charge, State of Health and State of Function Co-Estimation of Lithium-Ion Batteries for Electric Vehicles. *2016 IEEE Vehicle Power and Propulsion Conference (VPPC)*, 1-5.

[4] Enache, B.-A., & Diaconescu, E. (2014). Estimating a battery state of charge using neural networks. *International Symposium on Fundamentals of Electrical Engineering (ISFEE) 2014.*

[5] Lawson, B. (n.d.). State of Health (SOH) Determination. The Electropaedia. http://www.mpoweruk.com/soh.htm (accessed on Apr. 28, 2017).

[6] Mathew, S. A., Prakash, R., & John, P. C. (2012). A smart wireless battery monitoring system for Electric Vehicles. *2012 12th International Conference on Intelligent Systems Design and Applications (ISDA)*, 189-193.

[7] Lin, C.-H., Wang, C.-M., & Ho, C.-Y. (2016). Implementation of state-of-charge and state-of-health estimation for lithium-ion batteries. *IECON 2016 - 42nd Annual Conference of the IEEE Industrial Electronics Society*, 4790-4795.

[8] Zou, Y., Hu, X., Ma, H., & Li, S. E. (2015). Combined state of charge and state of health estimation over lithium-ion battery cell cycle lifespan for electric vehicles. *Journal of Power Sources*, 273, 793–803.

[9] Goh, T., Park, M., Koo, G., Seo, M., & Kim, S. W. (2016). State-of-health estimation algorithm of Li-ion battery using impedance at low sampling rate. *2016 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC)*, 146-150.

[10] Liu, D., Pang, J., Zhou, J., Peng, Y., & Pecht, M. (2013). Prognostics for state of health estimation of lithium-ion batteries based on combination Gaussian process functional regression. *Microelectronics Reliability*, 53(6), 832–839.

[11] Xu, J., Mi, C. C., Cao, B., Deng, J., Chen, Z., & Li, S. (2014, May). The state of charge estimation of lithium-ion batteries based on a proportional-integral observer. *IEEE Transactions on Vehicular Technology*, 63(4), 1614-1621.