NUEJ
Naresuan University Engineering Journal

Lead Acid Battery Monitoring using Multiple Linear Regression Method

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(Received: 16 January 2023, Revised: 9 March 2023, Accepted: 20 March 202)

Abstract

This paper is an electric motor battery monitoring system using Multiple Linear Regression. This proposed system can display battery parameters based on internet of things that afford its values of the voltage, current, and the remaining charge capacity in a real-time scenario. Also designed electronic hardwires and data storage system are illustrated. This article concerns an electric car battery status system with Multiple Linear Regression. The prototype consists of a microcontroller, current sensor module, voltage divider circuit, and MCP3008. The data of power batteries can be displayed on a smartphone and stored in the cloud server database. Eventually, this system can also be used to study battery characteristics throughout its lifespan.

Keywords: Battery Monitoring System, Multiple Linear Regression, Internet of Things

1. Introduction

Recently, Electric-drive vehicles are relatively new to the U.S. auto market, so only a small number of them have approached the end of their useful lives. As electric-drive vehicles become increasingly common, the battery-recycling market may expand Thailand and around the world have been facing environmental problems due to the increase in population, economic and social development, and the number of cars, which is causing the use of fuel to increase while energy is limited and scarce. The current energy consumption impacts the environment since engine combustion produces noise and air pollution, which also contributes to global warming and harms human health. Due to these worries, many countries, including Thailand, have prioritized that issue. There are policies and measures relating to the use of renewable energy. Because of this, automakers are focusing on utilizing renewable energy. As a result, the car has been created and is powered by electricity. To contribute to lowering pollution that harms both the environment and consumer health. Electric cars are a new alternative becoming increasingly popular in many nations (Jung at all., 2015). To meet the present needs, it has created many electric cars. Both high and low production costs, however, there is still a drawback in that inexpensive electric cars cannot display crucial status. The Internet of Things was applied to study the electric car battery status. It displays the battery power value while in use and sends it to Google Sheets every 3 seconds. However, there is still an error in that the wrong value is caused by the storage period and some data not being recorded, causing the measured value to differ from the actual value; when used continuously, this makes estimating battery power difficult. Recently, the multiple linear regression method has been proposed to apply for approximating battery power (Feng at all., 2017) and it can further to analyze the battery health (Zhang, 2019).

In this paper, current (A) and voltage (V) were collected from research on the internet of things electric car battery status system. In addition, the Z-score was utilized to exclude the aberrant data (Abdullah at all., 2014) and (Hegde at all., 2015). Obviously, online monitoring is a key player for observing lead acid battery (Badawy at all., 2020) and (Kale at all., 2022). The method of multiple linear regression and the study of additional battery data will aid in analyzing battery power and its subsequent application in an electric car battery status system with multiple linear regression.

2. Battery Status System Process

2.1 Battery

Lead acid battery has been applied for electric vehicles, since it is low cost, safe, and reliable comparing with other batteries. Basically it can transform chemical energy into electrical energy by using a galvanic cell with an anode, a cathode, and an electrolyte solution that can be either recharged or charged (Pavlov, 2011). Batteries consist of many small battery cells, which are connected in either series or parallel connection. For example, figure 1 shows a 48V DC supply as using 12V battery within series connection that electric cars usually use the 48V supply.

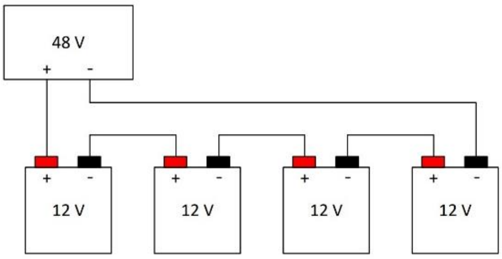


Figure 1 Battery connection

Figure 2 illustrates the utilization of the lead-acid batteries while supplying at different currents (Pavlov, 2011). For the first stage, the lead-acid batteries can basically deliver to electric load as linear characteristic. For example, when batteries are used to supply to load 0 – 10 minutes, it can supply as the linear transition period. Therefore, battery can be predicted easily. However, after 10 minutes, batteries can perform as nonlinear transition period. It is difficult to forecast battery capacity this usage time. Moreover, the battery system monitoring is required emergency a low-voltage warning system to inform to users as soon as possible.

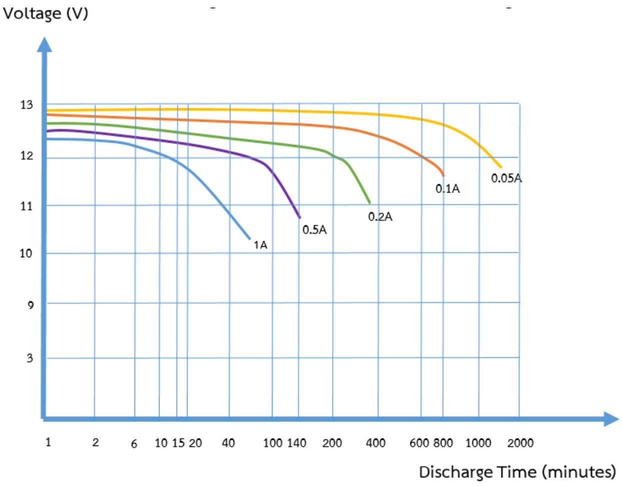


Figure 2 VRLA battery usage at different currents

2.2 The Internet of Things

The Internet of Things (IoT) electric car battery status system is a system that can display battery parameters. The battery's voltage, current, and remaining charge capacity are shown in real-time. Additionally, battery power information may be shown on a mobile device and kept in the cloud server database. The main components of the prototype system are a Wemos D1ESP8266 microcontroller board, a current measurement module to measure the battery current during operation, a voltage divider circuit to measure the battery voltage during operation, and an MCP3008 IC to convert analog signals to digital signals and amplify the status input.

Figure 3 illustrates the system and the correlation between the prototype's devices. During operation, electric cars are constantly in motion; therefore, transmitting the battery consumption data while in use is necessary. Consequently, the prototype sends real-time information to users through a portable Wi-Fi hotspot and sends the power usage status to a prepared Google Sheet.

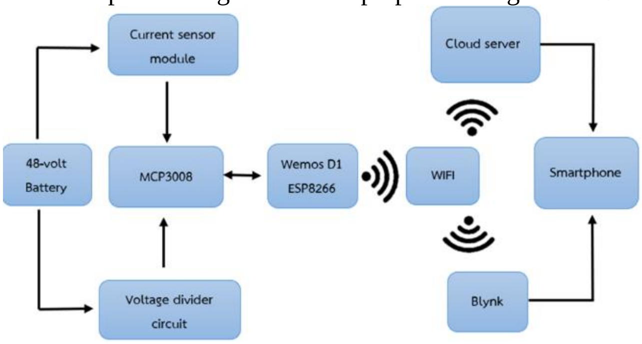


Figure 3 System components showing the battery usage of electric car

3. Case Study

The program structure and operating system can be described according to this flowchart as shown in Figure 4 and also considering figure 1 that Wemos D1ESP8266 microcontroller board mainly performs the processing of battery power by using C programming. It begins by obtaining the parameters from the electric motors current sensor module. The battery voltage divider circuit accepts a voltage of 48 volts and then it can be reduced to the desired rating.

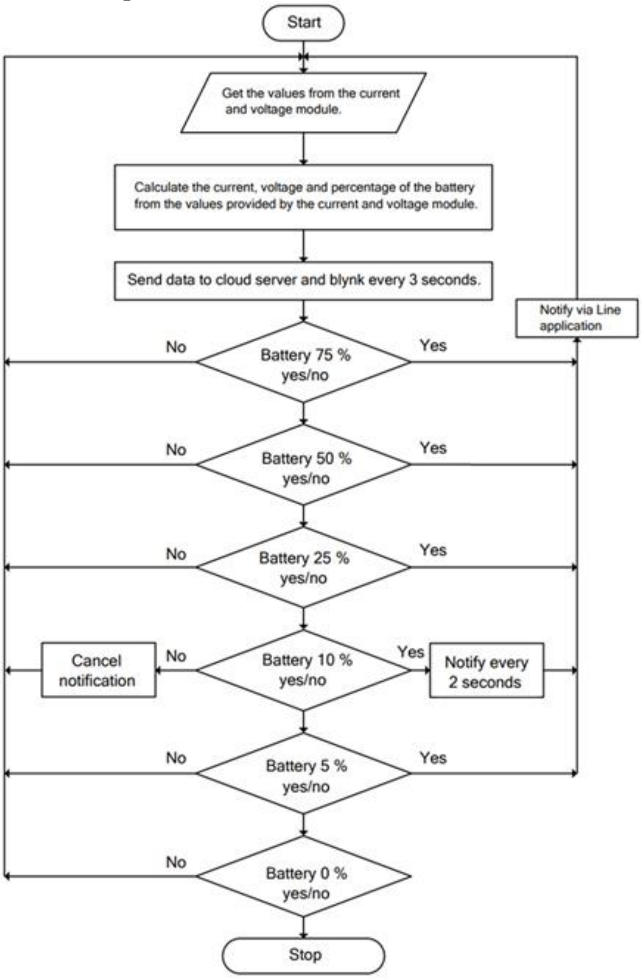


Figure 4 Prototype system program flowchart

The MCP3008 digitalizes the current and voltage. The microcontroller uses the parameters mentioned above to calculate the remaining battery power, transmitting the data to the cloud server database every 3 seconds and to the Blynk application, which calculates the remaining power percentage for example 100, 75, 50, and 25 percent, respectively. Send notices to LINE application when the specified level is reached. If the power drops below 10 percent, send a continuous (emergency) notice to the LINE application every 2 seconds to notify the user of the impending further charge. However, if there is no power left in the battery, the battery status display will stop processing, and it will resume functioning once the battery power is restored.

This study results can be summarized as follows. The WeMos D1 ESP8266 WIFI module, which is mounted in the car, captures various data. A prototype electric car with an Internet of Things battery status system has been tested. Figure 5 shows a cast study path in Naresuan University Phitsanulok, Thailand. The measured values can be transmitted to the Google Sheet. In addition, the result will send a notice to the LINE application to inform users of the remaining battery power and battery percentage in the Blynk application.

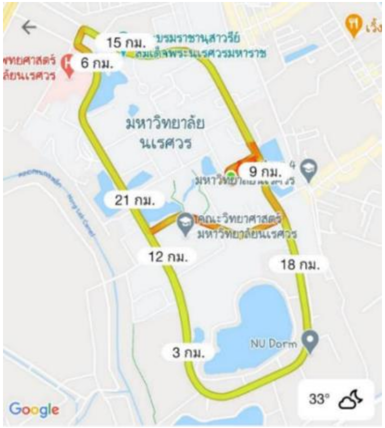
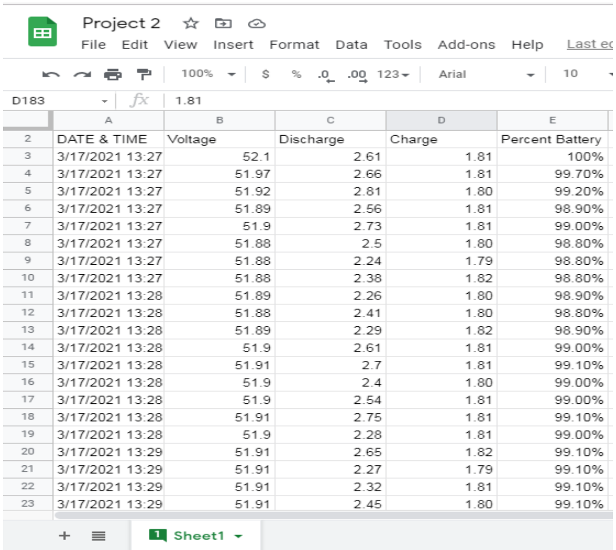


Figure 5 The path for testing the electric car's battery status system



Project 2
File Edit View Insert Format Data Tools Add-ons Help

D183 1.81

	A	B	C	D	E
2	DATE & TIME	Voltage	Discharge	Charge	Percent Battery
3	3/17/2021 13:27	52.1	2.61	1.81	100%
4	3/17/2021 13:27	51.97	2.66	1.81	99.70%
5	3/17/2021 13:27	51.92	2.81	1.80	99.20%
6	3/17/2021 13:27	51.89	2.56	1.81	98.90%
7	3/17/2021 13:27	51.9	2.73	1.81	99.00%
8	3/17/2021 13:27	51.88	2.5	1.80	98.80%
9	3/17/2021 13:27	51.88	2.24	1.79	98.80%
10	3/17/2021 13:27	51.88	2.38	1.82	98.80%
11	3/17/2021 13:28	51.89	2.26	1.80	98.90%
12	3/17/2021 13:28	51.88	2.41	1.80	98.80%
13	3/17/2021 13:28	51.89	2.29	1.82	98.90%
14	3/17/2021 13:28	51.9	2.61	1.81	99.00%
15	3/17/2021 13:28	51.91	2.7	1.81	99.10%
16	3/17/2021 13:28	51.9	2.4	1.80	99.00%
17	3/17/2021 13:28	51.9	2.54	1.81	99.00%
18	3/17/2021 13:28	51.91	2.75	1.81	99.10%
19	3/17/2021 13:28	51.9	2.28	1.81	99.00%
20	3/17/2021 13:29	51.91	2.65	1.82	99.10%
21	3/17/2021 13:29	51.91	2.27	1.79	99.10%
22	3/17/2021 13:29	51.91	2.32	1.81	99.10%
23	3/17/2021 13:29	51.91	2.45	1.80	99.10%

Sheet1

Figure 6 Battery usage status in prototypes is stored in Google Sheet

Consequently, the research findings show the battery power while using it, and the system sends the data to a Google Sheet every 3 seconds, as seen in Figure 6, and plots the remaining battery percentage. As shown in Figure 7, the test was conducted with different loads (current) with controlled values of roughly 2.35 and 6.25 A, respectively. Also the research record operation time, voltage, charge current and discharge current, so the data is of interest to academics. Therefore, the battery status system functions with a sensor.

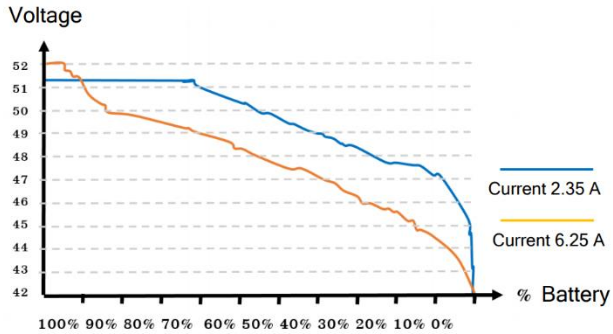


Figure 7 The graphs show the remaining percentage of batteries

4. Multiple Linear Regression Model

This paper is for predicting battery power of the electric car with different transition periods. The Multiple Linear Regression model is planned to apply for the prediction. The standard Multiple Linear Regression equation can be expressed as follows:

$$\psi = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + \varepsilon \quad (1)$$

Main parameters of battery, for example, voltage, charge current and discharge current affect the battery power prediction. Consequently, the battery status system for electric car has the following equation:

$$\psi = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon \quad (2)$$

β_0 to β_3 is an unknown parameter known as the regression coefficient. ε is the random error and the predicted variable for the battery power of electric car. The independent variables X_1 to X_3 are the voltage, charge current, and discharge current, which influence battery power. The regression mentioned above model has been defined.

$$Battery = -409.257 + 9.844 X_1 - 0.513 X_2 + 0.322 X_3 \quad (3)$$

Data for battery power predictions include the following: voltage, charge current, and discharge current. The regression model described above (3) has been established.

Table 1 Descriptive statistical results of continuous variables

	% Battery	Voltage	Discharge	Charge
Count	24857	24857	24857	24857
Mean	79.58	49.62	2.69	1.08
Std	27.07	2.74	2.981	0.61
Min	0.00	-0.24	0.00	0.00
max	100.00	53.97	12.65	2.29

The following section will introduce the data required for model testing with JupyterLab (Ochkov at all., 2022). As shown in Figures 7, 8, and 9, JupyterLab is typically used for continuous variables with a linear correlation between data.

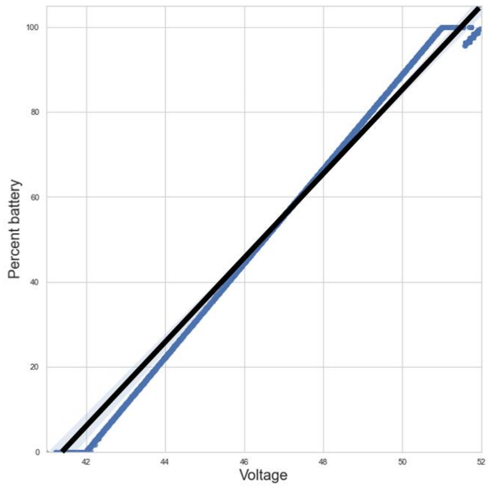


Figure 7 Correlation between voltage and battery power

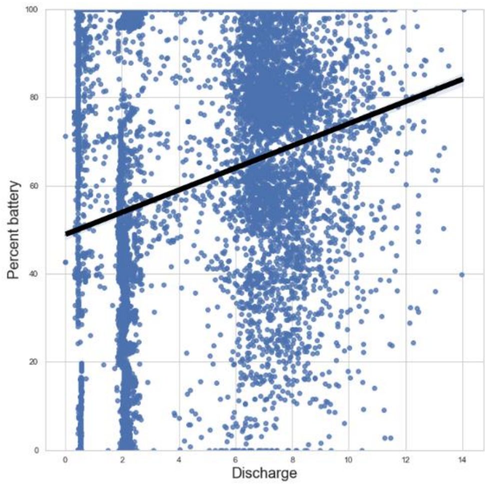


Figure 8 Correlation between discharge current and battery power

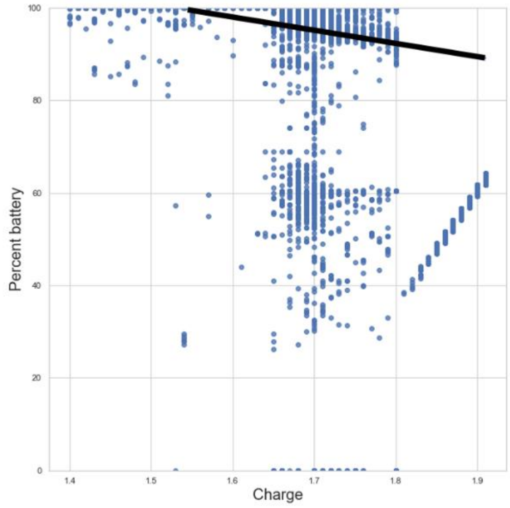


Figure 9 Correlation between charge current and battery power

Figure 7 illustrates the correlation between voltage and battery power, which can be determined by comparing battery power with three factors influencing forecasts. Figure 8 demonstrates the correlation between discharge current and battery power, while Figure 9 explains the correlation between charge current and battery power. According to the analysis above, JupyterLab is applied to multiple variables. Analysis of linear regression can be expressed as the following multivariate linear regression equation.

Table 2 Summary of model assessment

R Square	Mean Absolute Error	Mean Square Error
0.966	2.471	25.071

According to the multivariate linear regression equation, we estimate that the accuracy of test data and predictions is approximately 96.60 %. The inaccurate value may be caused by the storage period. Some data, such as the first, second, and third seconds, are not recorded. The load is always not constant; the measured data may be incorrect compared to the value that should be measured.

4. CONCLUSION

This paper is positively a battery monitoring system using the Multiple Linear Regression technique for predicting battery status. Also internet of things (IoT) is applied for either recording or displaying battery capacity of an electric car. The prototype consists of a microcontroller, current sensor module, voltage divider circuit, and MCP3008. The data of power batteries can be displayed on a smartphone and stored in the cloud server database. However, some errors have been found in MAE and MSE values, for example, the values have not yet approached 0, which is considered an error. The evidence is from the MSE values that have significantly high tolerances. Since MSE are less tolerant of outliers, which are an anomaly, the model must be able to detect them. As a result, there was an error in processing, which was used as a solution for further improvements.

5. ACKNOWLEDGMENT

The authors are grateful to the Faculty of Engineering, Naresuan University for supporting this research financially and also providing research facilities. Especially, Thiraphong Banchong and Sumet Sittisrijan are awarded as student scholarships in the Faculty of Engineering, Naresuan University.

6. REFERENCES

Abdullah, N. F., Rashid, N. E. A., Othman, K. A., & Musirin, I. (2014). Vehicles classification using Z-score and modelling neural network for forward scattering radar. *15th International Radar Symposium (IRS)* (pp. 1-4).

Badawy, A., El-Habrouk, M., Ragi Ali Rifaat Hamdy, R.A.R., Karim Hassan Youssef, K. H. (2020). Online monitoring and fault diagnosis and isolation of Valve Regulated Lead Acid batteries in Uninterruptible Power Supplies using decision trees. *11th International Renewable Energy Congress (IREC)*.

Feng, Y., & Wang, S. (2017). A forecast for bicycle rental demand based on random forests and multiple linear regression. *IEEE/ACIS 16th International Conference on Computer and Information Science (ICIS)* (pp. 101–105).

Hegde, V, & Pallavi, S. (2015). Descriptive analytical approach to analyze the student performance by comparative study using Z score factor through R language. *IEEE International Conference on Computational Intelligence and Computing Research (ICCIC)* (pp. 1-4).

Jung, J., Zhang, L., & Zhang, J. (Eds.). (2015). Lead-Acid Battery Technologies: Fundamentals, Materials, and Applications CRC Press.

Kale, S., Chaudhari, B.N. (2022), IoT Based Battery Monitoring System. *International Conference on Advances in Computing, Communication and Materials (ICACCM)*.

Ochkov, V. F., & Tikhonov, A. I. (2022) Jupyter Notebook, JupyterLab – Integrated Environment for STEM Education. *International Conference on Information Technologies in Engineering Education (Inforino)* (pp. 1-5).

Pavlov, D. (2011). Processes After Formation of the Plates and During Battery Storage. Lead-Acid Batteries: Science and Technology, Elsevier, 2011, pp. 535-566.

Zhang, Z., Li, Y., Li, L., Zhu, L., & Liu, S. (2019). Multiple linear regression for high efficiency video intra coding. *ICASSP 2019–2019 IEEE International Conference on Acoustics Speech and Signal Processing (ICASSP)* (pp. 1832-1836).

7. BIOGRAPHIES

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