Fuzzy logic method for making push notifications on monitoring system of IoT-based electric truck charging

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ABSTRACT

To minimize the negligence when charging electric vehicles, it is deemed important to have an internet of things (IoT) based monitoring system using a notification feature. The monitoring system of electric vehicle battery charging used a voltage divider and temperature sensor (DS18B20) installed on the Arduino Mega 2560 microcontroller with the addition of an ESP8266 Wi-Fi module for sending microcontroller data into the Blynk platform. A notification feature was added as the reminder that the battery has been overcharging or overheating. This study applied the Mamdani fuzzy logic method to determine the conditions when notifications must appear. The results of the application of the Mamdani fuzzy logic method were able to determine the conditions for push notifications to appear using the parameters as desired; by so doing, it is possible to create a battery monitoring system with accurate push notification feature to prevent the battery from being overcharged and overheated.

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1. INTRODUCTION

Technology in Indonesia, particularly in transportation has been very rapidly improving as seen, for instance, in the development of the electric vehicle that has entered and is still being researched at Institut Teknologi Telkom Surabaya. The electric vehicle uses 2 batteries of LifePo4 48 V, 48 Ah as electrical energy in which these batteries have limited capacity that must be recharged when reaching a certain mileage. However, many people are found still negligent when recharging electric vehicles, then leading to overcharging and overheating, later on causing damage and reducing the battery life [1], [2].

To reduce negligence and monitor the temperature and capacity conditions of the battery during electric truck charging, it is essential to design an advanced charging system. This system should allow users to monitor the battery status online and in real-time via the internet. The system will use an Arduino Mega 2560 as the main controller [3], a temperature sensor (DS18B20) [4] to measure the battery temperature, a voltage sensor to monitor the battery voltage, and a Node MCU ESP8266 Wi-Fi module for internet connectivity [5]. All these components will be connected to an internet of things (IoT) platform that serves as the monitoring and notification interface. As a result, users will receive notifications when the battery approaches overcharge or overheating conditions, thus preventing damage and extending the battery's lifespan [6]-[8].

Developed an automatic battery charging in electric car using IoT for controlling system via smartphone in which it enabled the users to know the complete status of the battery [9], [10]. However, this system still had a weakness for having no push notification appearing when the battery has been fully charged [11]. This system only provided a monitoring display only for the battery status but there was no reminder for the user. In another study, developed an IoT-based electric car battery monitoring system that was previously Bluetooth-based only to monitor the battery condition but not monitoring the process of battery charging [12], [13]. The application of a battery management system (BMS) using the state of charge (SOC) with the modified coulomb counting (MCC) method where there was a re-measurement of the SOC using the MCC method to result in a properly displayed SOC to avoid overcharging [14].

In another study, implemented the fuzzy logic method as a SOC measurement on electric car [15]-[17]. The method used was through a simulation of SOC measurement with Kalman filter method containing fuzzy logic implementation resulting in the more accurate SOC value measurement. Another previous study about notification of indoor air quality with the IoT platform using Blynk apps connected to Wemos and MQ135 in which the notifications appearing on Blynk apps was about the level of air quality as detected in the room [18], [19].

Based on the literature studies above, it can be seen that various monitoring system designs have succeeded in reducing an overcharge that can reduce the battery life. However, the monitoring system design had a push notification to minimize the negligence during charging, which as a matter of fact also becomes a factor of overcharging [20], [21]. Hence, to overcome these problems, the researcher developed an IoT-based monitoring system by applying the Mamdani fuzzy logic method [22] in making push notifications on the IoT platform to reduce negligence when charging electric trucks using voltage and temperature parameters to prevent the battery from being overcharged and overheated [23]-[26]. The main contribution of this research is the development of a monitoring system that not only displays the battery status in real-time but also provides immediate notifications to users when the battery approaches overcharge or overheating conditions. Thus, this system is expected to enhance charging safety and efficiency, as well as extend the battery lifespan in electric vehicles. This research also offers an innovative solution that can be adapted to various other types of electric vehicles and can contribute to further developments in the field of battery technology and energy management systems.

2. METHOD

This method was carried out using the Mamdani fuzzy logic method to determine the firm value of several conditions when charging an electric truck battery. The study focused on using two critical parameters: voltage (V) and temperature (C), to accurately assess the overcharging and overheating conditions of a battery during the charging process.

2.1. Battery monitoring system design

The monitoring system design in displaying notifications and battery capacity status when charging started from the EVB battery in which a voltage sensor made of a voltage divider circuit has been installed on the battery and a temperature sensor (DS18B20) was attached to the body of the battery so that the battery temperature when being charged could be detected. Subsequently, universal serial bus (USB) Type-A on power bank was connected to the USB Type-B on the Arduino Mega 2560 as power to turn on the microcontroller [27], [28]. When the microcontroller turned on, the Wi-Fi module was installed on the microcontroller using the Node MCU ESP8266 serial software as an IoT supporting device by connecting power (3.3 V & ground pins) as well as serial D1 & D2 with serial (RX & TX) on the microcontroller to allow the module to receive and read programs from Arduino used for the input data values for the IoT platform [6], [29].

Having successfully paired the module, the device was paired with the IoT platform, i.e., Blynk apps in which all output results would be displayed on the app to be displayed as monitoring results when charging [30]. It was then followed with the last scheme to add fuzzy algorithm into the microcontroller program [31] for making push notifications on Blynk purposely to give notification if the battery has an overheating temperature and has been being overcharged when charging was in the range between 99% and 100% capacity [32]-[34]. By so doing, it could prevent overheating and overcharging. Figure 1 illustrates the schematic circuit arrangement of this battery monitoring system. The output generated from the schematic design should be compared with before and after the fuzzy logic implementation in the IoT-based monitoring system design. Therefore, in this study a comparison was made between when using push notifications and when not using push notifications as the data analysis to answer the problem formulation in the study.

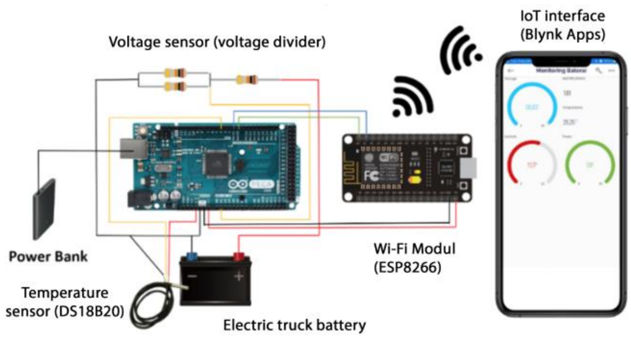


Figure 1. Schematic design of IoT-based battery charging monitoring system

2.1.1. Voltage divider

Voltage divider is a simple electronic circuit consisting of 2 resistors in series, which, as its name implies, has a function as a voltage divider. In this study, it was used to divide the voltage from the DC/DC buck converter output of 10 VDC into a maximum voltage of 5 VDC according to the maximum input voltage on the Arduino ADC pin [21]. The series of voltage divider shown in Figure 2(a). The amount of $Vout$ can be (1):

$$Vout = Vin \frac{R2}{R1+R2} \tag{1}$$

In this context, $Vout$ represents the output voltage, while Vin denotes the input voltage. The parameters $R1$ and $R2$ refer to resistor 1 and resistor 2, respectively. Making the voltage divider into a voltage sensor was conducted by finding the suitable resistor capacity dependent upon the input voltage to be used to allow Arduino, which had a maximum capacity of Vin 5 V, to read the sensor. For example, in making a voltage sensor with a voltage divider, if the input Vin voltage is 50 V, $R1$ will be 100 kΩ and R2 will be 5 kΩ as shown in Figure 2(b).

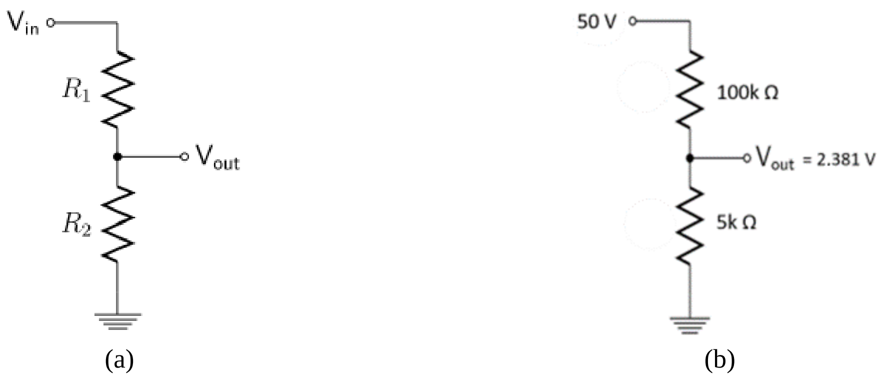


Figure 2. Voltage divider; (a) series of voltage divider and (b) sample in calculating the voltage divider as the voltage sensor

As seen in Figure 2(b), the Vout generated is shown in (2):

$$Vout = 50\,V \frac{5k\Omega}{100k\Omega+5k\Omega} = 2.381\,V \tag{2}$$

Thus, the resulting output voltage $Vout$ to be received by the microcontroller is 2.381 V. This voltage is a crucial piece of data, as it will be processed by the microcontroller to perform necessary operations. To ensure the accuracy and relevance of this voltage in the context of the overall system, the $Vout$ value will be converted back into the input voltage Vin using the inverse of the voltage divider formula. This conversion is carried out by incorporating the original formula into the programming within the Arduino software. By doing so, the microcontroller can interpret the $Vout$ as it correlates to the initial Vin, allowing for precise monitoring and control based on the original input conditions.

2.1.2. DS18B20 sensor

The DS18B20 temperature sensor is an electronic component that is able to capture any changes in environmental temperature and then convert them into electrical quantities [35]. This sensor is a digital sensor using 1 wire to communicate with the microcontroller [36]. Uniquely, each sensor has a serial code allowing for the use of more than one DS18B20 in one 1 wire communication. DS18B20 is a digital temperature sensor released by Dallas Semiconductor [37], [38]. For temperature reading, the sensor uses a 1 wire communication protocol. Figure 3 portrays the DS18B20 sensor.

Figure 3. DS18B20 sensor

DS18B20 has 3 pins consisting of Vs, ground and data input/output. The Vs leg is the source voltage. The source voltage for the DS18B20 temperature sensor is about 3 V to 5.5 V. In general, Vs is given with a +5 V voltage based on the working voltage of the microcontroller. Then, the ground leg is connected to the circuit ground. While the detailed specifications of the DS18B20 sensor are presented as:

a. 1-wire interface uniquely requires only one pin port for 1-Wire communication
b. Each device has a 64-bit serial code stored in an onboard ROM
c. It does not require any additional components
d. It works in the range of 3 to 5.5 V
e. It can measure temperature in the range of -55 to 125 °C
f. ±0.5 °C accuracy from -10 to 85 °C
g. The user is able to select resolution between 9 and 12 bits
h. It has the maximum temperature converting speed of 750 ms

2.2. Process and making monitoring system

The process and making of monitoring system of electric truck battery charging consisted of several stages such as literature study, design, making schematic design, sensor data retrieval, method implementation, feature addition, and analysis. The process began by reading literature studies in the form of previous journals that had the similar topic and by doing literature review related to the research title. Having gained information from previous journals, it was continued with the redesign of the scheme of previous research by adding supporting hardware and software components to be used in the study [39]. After redesigning, a programming was added to show the notification bar as a push notification. Then, the tools and programs that have been made were tested. When an error in the program was found and made the push notification not to appear or errorous, then the improvement of the programmed algorithm was made to make the notification able to appear and function properly [40], [41]. When all was able to run, an analysis of the test results was conducted using the method that has been determined as a comparison of the research output.

2.3. Design and testing

Testing the monitoring system needs a design explaining the test flow to allow all components in the monitoring system to run well. Figure 4 presents a design that has been made and displayed in the form of a block diagram of an IoT-based monitoring system.

The flow of the monitoring system started from the battery used as the input or the material to be studied. Subsequently, it entered the sensor where this sensor would be used to detect what would be monitored. Then, the sensor would send a signal to the microcontroller as the brain to manage programming data from the sensor. Finally, the data managed on the microcontroller would be displayed using the data viewer module, i.e., the LCD [42]. From the literature study, there is a relationship between the material described in this research, such as a monitoring system to be developed as a test tool to obtain data to be displayed on the IoT platform to be later on forwarded as the input data for making push notification [43]. In addition, the battery monitoring and estimating system are able to monitor and control based on previous variables and generate new variables as the output, such as: i) battery charge when being fully charged, ii) battery power at saturation state, iii) total energy delivered since it is firstly operated, iv) total length of battery operation since first operation, and v) average current when traveling at a constant speed.

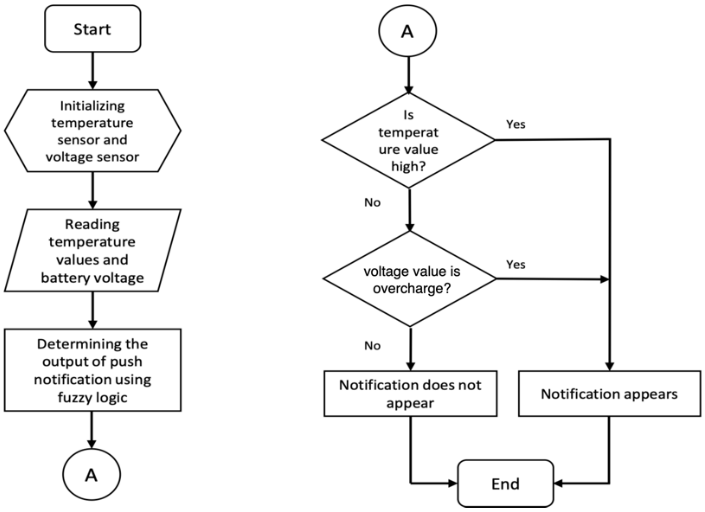


Figure 4. Block diagram of IoT-based battery charging monitoring system

The battery monitoring system is designed to interface the battery capacity with a graph of V, A parameter indicators, and to measure the efficiency of battery consumption both at the end of use and in charging. The battery management system is designed to estimate the health, life, remaining power of the battery, and to report available battery power to find out the remaining mileage of electric vehicle.

3. FUZZY LOGIC METHOD

The application of the fuzzy logic method was by selecting the Mamdani method to determine the condition of the push notification output (appears or not appear) using the voltage (V) and temperature (ºC) parameters. Figure 5 depicts the flowchart of fuzzy algorithm implementation for push notification.

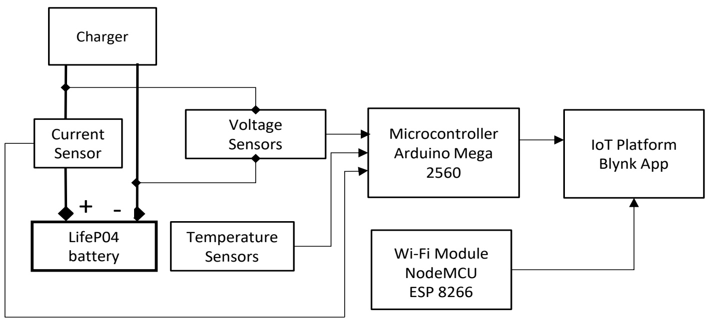


Figure 5. Flowchart of fuzzy algorithm implementation for push notification

The first step was to arrange the flow of using the Mamdani fuzzy logic method started from the initialization of the temperature sensor and voltage sensor into the process of reading the temperature and voltage values. It was then continued by determining the output of push notification until the push notification output appeared or not on the IoT-based battery charging monitoring system out as targeted in this study. The fuzzy algorithm design consisted of 3 parts: i) fuzzyfication, ii) fuzzy system inference, and iii) defuzzification [44]. The results of fuzzy algorithm output were in the form of push notification condition. The results of this test were used to compare the output in the form of C language source code with the output in the results of MATLAB software simulation. The results of this test were also used to determine the % error of each variable determined.

3.1. Fuzzy logic analysis technique

In this final project, analytical technique used was by applying the fuzzy logic method by choosing the Mamdani method to determine the condition of the push notification output (appearing or not appearing) using the parameters of V and ^{o}C. Figure 6 depicts the flowchart of using the analysis technique of push notification controlling system using a fuzzy algorithm.

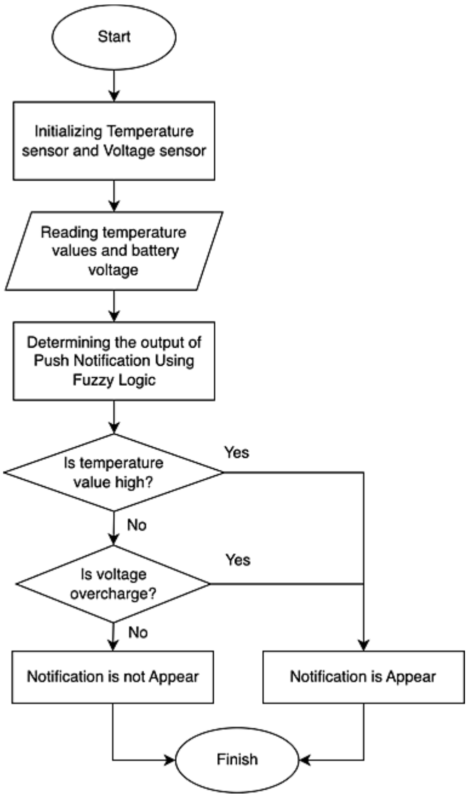


Figure 6. Flowchart of fuzzy algorithm implementation for push notification

The first step was to arrange the flow of using the Mamdani fuzzy logic method started from the initialization of the temperature sensor and voltage sensor into the process of reading the temperature and voltage values. It was then continued by determining the push notification output until the push notification output appeared or not on the IoT-based battery charging monitoring system as targeted in this study. The fuzzy algorithm design consisted of 3 parts: i) fuzzification, ii) fuzzy system inference, and iii) defuzzification [45]. The output of the fuzzy algorithm was in the form of the push notification condition. The results of this test were used to compare the output in the form of the C language source code with the output in the MATLAB software simulation results. The results of this test were also to determine the % error of each variable determined.

3.2. Fuzzification

In this part, the variable of membership function was determined from two input parameters, i.e., based on the value of the temperature sensor and voltage sensor. In this case, the temperature sensor variable had two membership functions: low and high. For voltage sensor variable, it had three membership functions: undercharge, full charge, and overcharge. Once the fuzzification process was done, fuzzy input would be obtained and entered in the inference part of the fuzzy system to determine the rule-base [46]. The fuzzy membership function used as input in the fuzzification process is presented in Figure 7.

3.2.1. Temperature sensor input variable (ºC)

As shown in Figure 7(a), the variable membership function of temperature sensor input consisted of two sets: low and high. The low temperature set was in the range of 0–39 ºC and the high temperature set was in the range of 39–40 ºC. Commonly, the temperature level of the battery is in the range of 0-40 ºC.

3.2.2. Voltage sensor input variable

Based on Figure 7(b), the variable of membership function of voltage sensor input consisted of three sets: undercharge, full charge, and overcharge. The undercharge voltage set had a range of 45 to 57.5 V, the full charge voltage set was in the range of 57.5 to 58 V range, and the overcharge voltage set was in the range of 58 to 59 V. The battery voltage value used was in the range of the 45 to 59 V.

3.3. Fuzzy system inference (rule-base)

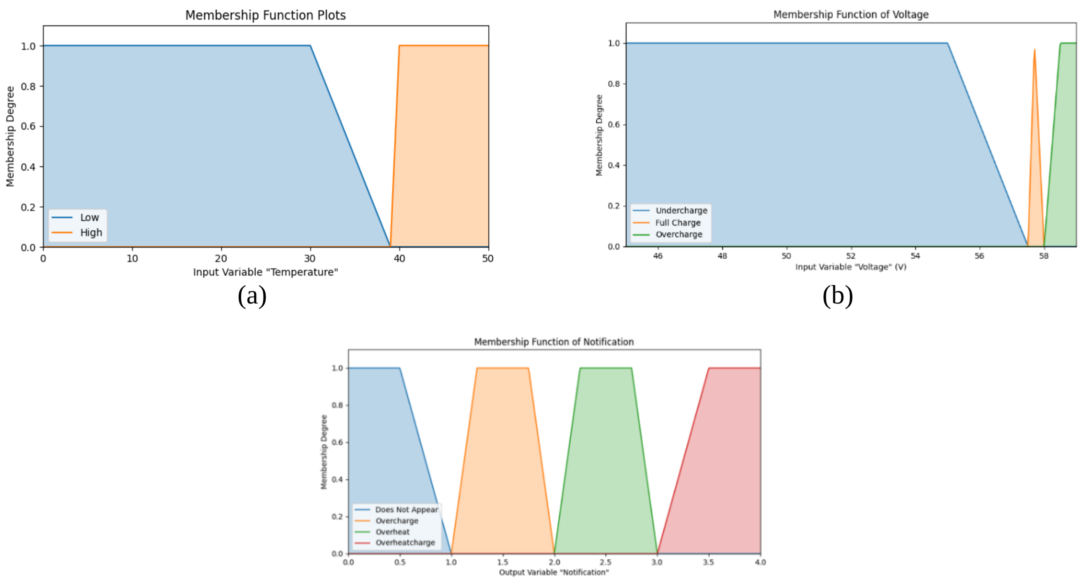
This part refers to the condition of the value of the fuzzy input variable used. This rule refers to the push notification displayed on the IoT platform if it fulfills the membership function of the two input parameters during the fuzzification process. In this case, a notification must be displayed when the battery is overcharging and overheating where overcharge is a condition when the battery is almost full, i.e., 58–59 V (90%-100%) and overheating is a condition when the battery temperature is high or hot (39–40 ºC). Thus, the rules (rule-base) for testing the push notification prototype on the IoT-based monitoring system are made as follows:

- [R1] if the battery temperature is low, and the voltage is low, then the notification does not appear.
- [R2] if the battery temperature is low, and the voltage is full, the push notification does not appear.
- [R3] if the battery temperature is low, and the voltage is over, then the notification is overcharging.
- [R4] if the battery temperature is high, and the voltage is low, then the notification is overheating.
- [R5] if the battery temperature is high, and the voltage is full, then the notification is overheating.
- [R6] if the battery temperature is high, and the voltage is over, then the notification is overheating and overcharging.

Based on the results of processing the rules above, if the battery temperature reaches a high point, above 38 ºC and if the voltage reaches the overcharging point, hitting 58 V–59 V, a notification will appear with the indicators of overcharge, overheat, and overheat and overcharge. After processing the fuzzy inference system (rule-base), the next process is defuzzification to see the output of the fuzzy algorithm.

3.4. Defuzzification

In this part, the processing results from the fuzzy algorithm would be read by the microcontroller, later on to be used as a reference for the appearance of push notifications on the IoT platform to be used. Figure 7(c) displays the membership function of the fuzzy algorithm output. Based on the results of the defuzzification, the output value to be obtained was in the form of the appearance of push notification. The three-dimensional rule evaluation surface of a fuzzy logic control is presented in Figure 8.



(a) (b) (c)

Figure 7. Membership function; (a) temperature (ºC), (b) voltage, and (c) output of push notification

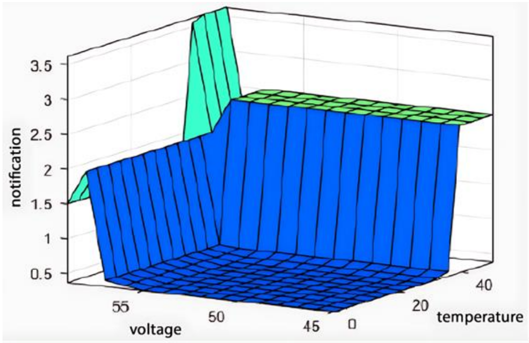


Figure 8. Rule evaluation surface notification

Figure 8 shows a graph of the effects of input on the resulted output based on the rule-base that has been made on fuzzy Mamdani. Based on the surface results, the surface graph would change along with the changes in the value of the fuzzy data input variable from the temperature sensor and voltage sensor. It can be seen from the green and turquoise patterns showing the condition of the push notification output of overheat, overcharge, and overheat and overcharge or the membership function temperature and voltage in the desired range (for temperatures above 38 ^{o}C and for voltages above 58 V). Meanwhile, the blue pattern indicates the push notification output condition that does not appear or a minimal condition where the notification will not come out because it has not touched the desired range value, indicating the safe value of the membership.

4. RESULTS AND DISCUSSION

This study developed and tested an IoT-based electric truck battery charging monitoring system with a push notification feature. The testing was divided into three main categories: sensor testing, fuzzy logic implementation, and notification testing. Sensor testing involved evaluating temperature sensors' response to air-conditioned room temperature changes and voltage sensor's performance under varying load values using a DC power supply. Fuzzy logic implementation tested the integration and effectiveness of algorithms in managing battery charging. Notification testing ensured that the system accurately sent real-time updates to users.

4.1. Sensor testing

The process of testing the two sensors on objects with certain parameters was based on their specific characteristics. Temperature sensors were evaluated based on their response to changes in air-conditioned room temperature. Similarly, voltage sensors were tested by varying load values using a DC power supply. The tests aimed to assess the accuracy and stability of the sensors under different conditions to ensure they perform reliably in their intended applications.

4.1.1. Testing 1

The data from the temperature sensor test results were taken by measuring the temperature of the object in an air-conditioned room with temperature parameter that have been set using an AC remote. As seen in Table 1, the temperature that has been read on the temperature sensor followed from the temperature of the air-conditioned room, set using the AC remote although there was still a slight difference because the AC remote used integers and the temperature sensor readings used decimal numbers or used comma (,). Figure 9(a) illustrates a graph of the results of the temperature sensor test.

Table 1. Data of the temperature values in air-conditioned room

Room AC	Temperature sensor
29	29.20
30	29.55
29	28.95
28	28.30
29	29.15
29	28.70
27	27.50
28	28.15
28	27.68
28	27.92

4.1.2. Results of voltage sensor test

Data from the test results of the voltage sensor were taken by changing the voltage value measured using a DC power supply. As seen in Table 2, the value of the appearing voltage sensor followed the voltage value as set and changed using a DC power supply. However, the value of the appearing power supply was the result of rounded value coming out from the voltage sensor because the voltage sensor was able to read decimal values up to 0.00. It was different from the power supply which was only able to read decimal values up to 0.0. Figure 9(b) shows the graph of the results of the voltage value test.

Table 2. Data of voltage value in DC power supply

DC power supply	Voltage sensor
10.2	10.24
15.5	15.54
16.3	16.33
16.8	16.82
17.1	17.11
19.5	19.51
20.6	20.63
22.8	22.82

4.2. Fuzzy logic output calibration results

The results of fuzzy logic calibration were obtained from the comparison of the 2 outputs before and after being given with the fuzzy algorithm as seen on the Arduino serial monitor. Then, the calibration between the results of fuzzy logic output from the Arduino software and the output generated from the MATLAB software simulation was done.

4.2.1. Testing 2

The results of fuzzy logic implementation data on Arduino microcontrollers were obtained from a comparison of 2 serial monitor outputs on Arduino software, i.e., the output before and after the implementation of fuzzy logic. Fuzzy logic had output variable only presenting LABEL values, time, $V, A,$ power (W), temperature (C) indicating that it was still only the output data value from the sensor and has not been added with the results of the implementation of fuzzy logic in the form of fuzzy output value. Furthermore, there were the results of output data after fuzzy logic was entered into programming. After the fuzzy implementation has been successfully done, the output that previously only presented LABEL values, time, V, A, W, C changed into LABEL, time, V, A, W, C, where notification referred to the output value generated from the fuzzy logic implementation.

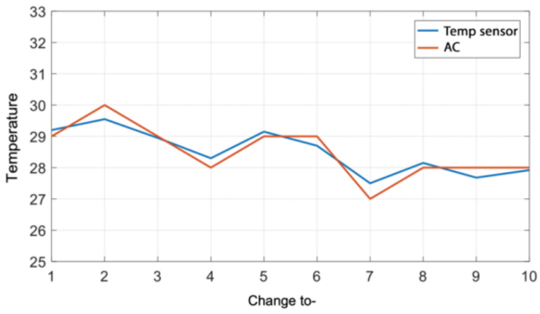
4.2.2. Results of implementation output with the MATLAB simulation

The results of the output calibration data of Arduino software with MATLAB software were divided into several conditions based upon the Mamdani fuzzy rule-base. There were 6 rule-bases created. Then, from the rule-base a calibration test was carried out on each rule-base by matching the defuzzification data on the Arduino software and MATLAB software. Table 3 presents the results of the 6 rule-base tests.

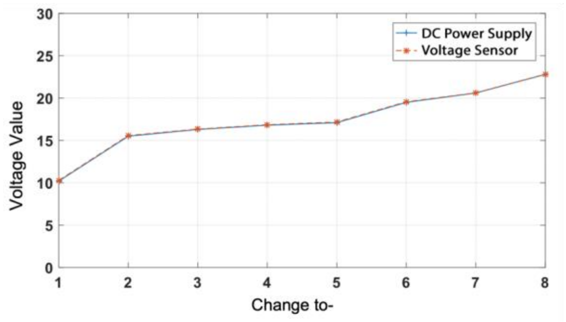
Table 3. Results of the defuzzification value calibration test data implemented with simulation

Rule-base	Results of defuzzification		Error
	Implementation	Simulation	(%)
1	0.39	0.378	3.17
2	0.42	0.415	1.20
3	1.50	1.500	0.00
4	2.50	2.500	0.00
5	2.50	2.500	0.00
6	3.52	3.540	0.56
	Mean error		0.82

As seen in Table 3, the error percentage from the calibration results from the first to the sixth rule-base had the highest error during the first rule-base calibration, i.e., 3.17%. While, the lowest one was during the fourth and fifth rule-base calibration, i.e., 0% (no error). Thus, the average error obtained from the overall rule-base calibration was 0.82%, indicating that the value was relatively low and the fuzzy implementation output calibration was successful. Figure 9(c) presents the graphs of the results of the calibration data of the two software. As seen from the graph in Figure 9(c), the calibration values of the two software were very closely the same, meaning that the calibration has been successfully to be carried out.



(a)



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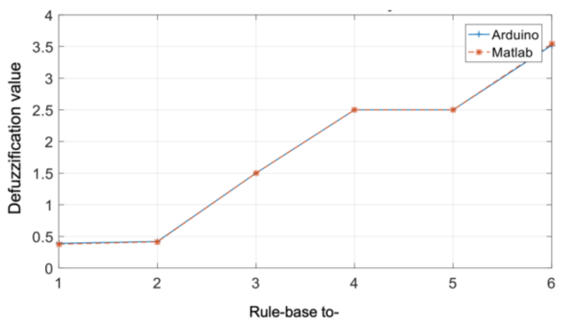
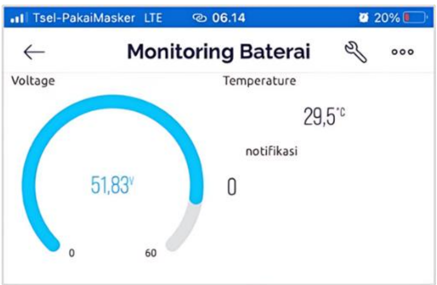


(c)

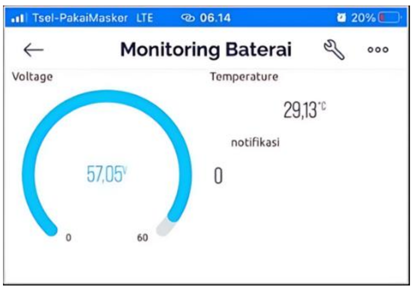
Figure 9. The graph of; (a) temperature sensor test in air-conditioned room, (b) voltage sensor test using DC power supply, and (c) Arduino defuzzification value calibration data with MATLAB simulation

4.2.3. Testing monitoring and sending notifications to the Blynk app

After the fuzzy implementation was carried out, there were IoT display results using the Blynk application as monitoring when charging the electric truck battery under undercharge and low temperature condition as shown in Figure 10(a). Figure 10(a) illustrates that when the battery was undercharged and the temperature was low, there was no push notification appearing and the notification indicator had a value of 0 indicating that push notifications would not appear in these conditions. Figure 10(b) shows the Blynk display of the battery condition in a full charge and low temperature. As seen in Figure 10(b), the push notification still did not appear when the battery was fully charged and the temperature was low because the condition was 0 as shown in the notification indicator. Figure 11(a) presents the Blynk display when the battery was overcharged with low temperature.



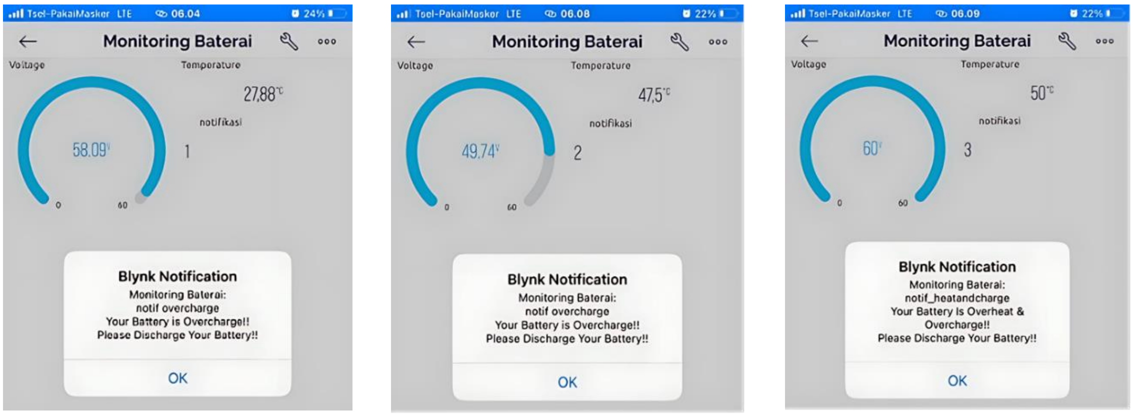
(a)



(b)

Figure 10. The display of Blynk; (a) battery was undercharged with low temperature and (b) battery is fully charged with low temperature

As seen from Figure 11(a), the overcharge notification appeared when the battery was overcharged with low temperature where this condition had a value of 1 on the notification indicator indicating an overcharge notification would appear on Blynk. There was also a Blynk display when the battery temperature was high but the battery voltage was undercharged as shown in Figure 11(b). As seen in Figure 11(b), the push notification of overheating appeared when the battery temperature was high and the voltage was undercharged where the notification indicator was worth 2 meaning that the overheating notification would appear during these conditions. The final Blynk display was when the battery was overcharging and the battery temperature was high, as shown in Figure 11(c). Figure 11(c) shows the appearance of overcharge and overheat notifications when the battery was overcharging and the temperature was high where the notification indicator was 3 requiring the appearance of notification of overheating and overcharging on the Blynk application.



(a) (b) (c)

Figure 11. The display of Blynk; (a) battery was overcharged in low temperature, (b) battery was undercharged with high temperature, and (c) battery was overcharged with high temperature

5. CONCLUSION

The membership function on the fuzzy Mamdani output was made as if it were a condition of 0 to 4 because it had 4 conditions based on the notification that would appear whether it was overcharged/overheating/overheating and overcharging. The new version of the Blynk application (Blynk 2.0) is different from the old version of the Blynk IoT application because the new version of Blynk has no notification widget where push notifications in the new version of the application use the event or reminder feature as push notifications in the new version of the application. The implementation of fuzzy logic until the interface on the IoT platform was running correctly, but push notifications was only able to appear 1 to 4 times for using the Blynk application which is not paid making it to have a database limit every day; as a consequence, push notifications were not able to appear continuously.

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