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Motorcycle Battery Health Monitoring System IoT-Based Electricity Using the Sugeno Fuzzy Method

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Abstract : *Electric motorcycles require battery condition monitoring to maintain performance and support sustainable battery use. This study aims to develop an Internet of Things (IoT)-based battery health monitoring system for electric motorcycles using the Fuzzy Sugeno method. The study employed a prototype-based system development method. The research object was a 12-volt battery used in an electric motorcycle, while data were obtained through observation and experiments under several battery conditions. The instruments included an ESP32, INA226 sensor, 16×2 I2C LCD, temperature sensor, adapter, and web dashboard. Voltage and current data were analyzed using Fuzzy Sugeno with a weighted score of 70% for voltage and 30% for current to determine the battery State of Health (SoH). The results showed SoH values of 93% and 79%, categorized as good, 41% as fairly good, and 26% as poor. The system also successfully displayed the results on the LCD and transmitted monitoring data to the web dashboard in real time. In conclusion, the developed system was able to monitor and classify battery health based on the measured parameters and support remote battery condition monitoring.*

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Introduction

Electric motorcycles are vehicles that utilize electrical energy as a power source and convert it into mechanical energy through a dynamo. Their use in Indonesia is increasing because electric motorcycles are seen as an environmentally friendly and emission-free means of transportation. To support the use of battery-based electric motorcycles, attention is needed to the energy source used, especially the battery, because the battery plays a key role in supplying energy to the electric motor (Ilham M et al., 2022). Lithium-ion (Li-ion) batteries are widely used due to their high energy density, light weight, and

long cycle life compared to lead-acid batteries. However, battery safety is also a concern because several incidents of electric vehicle battery fires have occurred (Khrisna & Soewono, 2025). This condition indicates that the use of electric motorcycles is not only related to energy availability, but also requires monitoring the condition and performance of the battery to ensure its safe use.

Electric vehicle batteries come in various types and specifications, depending on the energy requirements of electric motors. Therefore, a monitoring system is needed to measure and manage the energy used during vehicle operation (Zain et al., 2023). Battery monitoring is also related to battery health checks, or State of Health (SoH), which are used to determine the level of battery performance degradation due to charge and discharge cycles, material aging, and operating conditions such as temperature and load. SoH information can be used to determine the condition of battery use, maintain vehicle performance, and prevent battery damage or failure that could endanger users. An integrated monitoring system can also help manage electric vehicle energy, resulting in more efficient energy use, stable vehicle performance, and reduced risk of battery damage (Titho Bafrendy Wibowo, 2024).

One of the problems with electric vehicle batteries is overcharging, overdischarge, and overheating. These conditions indicate the need for battery management and monitoring through a Battery Management System (BMS). A BMS is needed to monitor battery condition and help prevent conditions that can cause damage, thereby maintaining a longer battery life cycle (Rahmad et al., 2024). When using electric motorcycles, monitoring battery condition becomes increasingly important because vehicle performance is highly dependent on the condition of the battery used. This problem is also related to users' limited understanding of how to maintain batteries to ensure longevity and efficiency. Users generally only pay attention to the battery percentage on the vehicle dashboard, while this information does not accurately reflect the battery's health (Mufid & Samsul, 2025).

These monitoring limitations prevent users from directly monitoring critical battery parameters such as voltage, current, and temperature in real time. Changes in these parameters can be early indicators of battery health decline, which can impact driving safety and comfort. Therefore, a BMS is needed to help prevent overcharging, overdischarging, overcurrent, short circuits, and extreme temperatures in the battery. The BMS also functions in battery modeling, battery status estimation, charging, and power usage. With this system, unsafe conditions in the battery can be detected, damage due to failure can be minimized, and battery life can be extended (Wahyu et al., 2023). Furthermore, the use of Internet of Things (IoT) technology allows users to monitor battery condition directly through devices in real time. However, the raw data obtained from sensors is still difficult for users to directly understand, requiring a processing method that can transform this data into information about battery health.

This problem is also evident from the results of previous studies that still have limitations in the aspect of battery health monitoring. Furqon et al. (2025) developed a battery estimator for electric vehicles using the Fuzzy Logic method that focuses on parameters of voltage, current, speed, location, and remaining battery usage time, but the study did not discuss battery health monitoring (State of Health) and did not incorporate an IoT-based system. Siregar et al. (2025) applied IoT and the Fuzzy Sugeno method to monitor and secure three-phase electrical loads in real-time, but its application is still limited to general electrical systems and has not been applied to electric vehicles. Meanwhile, Qalbi et al. (2023) studied the effect of coolant on the battery temperature of a Viar electric motorcycle, but did not incorporate temperature parameters in an intelligent monitoring system or battery health analysis. Based on these conditions, a system is needed that is able to monitor battery conditions in real-time, analyze battery health, and provide information that is easy for users to understand. The Sugeno Fuzzy Method can be used to process voltage, current, and temperature data into SOH values so that battery conditions can be categorized into good, sufficient, or bad conditions and provide information regarding the possibility of damage (Siregar et al., 2025).

Based on these problems, this study aims to develop an IoT-based electric motorcycle battery health monitoring system that is able to monitor voltage, current, and temperature parameters in real-time, and utilize the Fuzzy Sugeno method to process these parameters in determining the State of Health (SOH) value of the battery. This research is important because the developed system is expected to help users obtain battery condition information more precisely, practically, and can be monitored remotely, thereby supporting battery maintenance and extending its lifespan. The novelty of this research lies in the development of an IoT-based electric motorcycle battery health monitoring system that combines

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voltage, current, and temperature parameters with the Fuzzy Sugeno method to produce SOH indicators and present monitoring results to users in real-time. Thus, this research develops aspects that have not been found in an integrated manner in previous research, namely monitoring the health of electric vehicle batteries, implementing IoT, and processing several battery parameters using Fuzzy Sugeno in one system.

Method

This research uses a prototype-based system development method to produce an Internet of Things (IoT)-based electric motorcycle battery health monitoring system using Fuzzy Sugeno. Development was carried out through the gradual creation, testing, and refinement of the prototype. The system integrates ESP32, INA226 sensors, a web dashboard, and an LCD to monitor battery condition in real time and process battery parameters into State of Health (SoH) values (Mahardika et al., 2024; Suprasetyo et al., 2023).

The research instruments include an ESP32, an INA226 sensor, a temperature sensor, a 16x2 I2C LCD, a 12 to 14.4 V adapter or charger, and connecting cables. Data were collected through observation and experimentation at full, medium, and low battery levels, as well as when the electric motorcycle was in use and stopped. Voltage and current data were analyzed using Fuzzy Sugeno with a voltage score of 70% and a current score of 30%. The battery health value was calculated using the equation Health (%) = (Voltage Score × 0.7) + (Current Score × 0.3), then categorized as good, medium, or bad and displayed on the LCD and web dashboard (Rahmad Doni1, 2020; Suprasetyo et al., 2023).

The research object was a 12-volt battery in an electric motorcycle, so the population and sample were not human respondents. Data was obtained from battery parameter readings using sensors at full, medium, and low levels, as well as when the motorcycle was in use and stopped. This data was used as input in the process of determining the SoH value using Fuzzy Sugeno.

The research was conducted through the stages of problem identification, literature study, formulation of objectives and limitations, design, implementation, and system testing. The design includes the integration of ESP32, INA226 sensor, temperature sensor, LCD, Fuzzy Sugeno, and IoT communication. The system was then implemented in prototype form to read battery parameters, process data using Fuzzy Sugeno, and display the results on the LCD and web dashboard in real-time. Testing was carried out on parameter reading, Fuzzy Sugeno processing, and presentation of monitoring results.

Results and Discussion

System Implementation Results

The results of the system implementation show that the 12volt battery health monitoring system based on the Internet of Things (IoT) has been realized in accordance with the planned design. This system utilizes ESP32 as the main microcontroller, INA226 sensor to measure battery current and voltage, and the Fuzzy Sugeno method to process measurement data into information regarding the State of Health (SoH). The processed data is displayed on a 16x2 I2C LCD and sent to a web dashboard via the internet directly, allowing users to more easily monitor battery health. Based on the implementation results, all hardware and software elements can operate synergistically well, starting from data reading, processing using the Fuzzy Sugeno method, to automatic information presentation, so that this system is able to support the battery health monitoring process practically, efficiently, and effectively.

Tool Assembly Results and System Analysis

1. Tool Assembly Results

At this stage, the tool assembly process is carried out which aims to produce an Internet of Things (IoT) based electric motorcycle battery health monitoring system using the Fuzzy Sugeno method. The design of this tool is carried out to integrate various hardware and software components, such as ESP32, INA226 sensor, 16x2 I2C LCD, relay, and web dashboard, so that it can work in a coordinated manner in monitoring battery conditions in real-time. The designed system is able to measure battery voltage and current parameters, then process the data using the Fuzzy Sugeno method to determine the battery health level (State of Health/SoH). The monitoring results are then displayed on the LCD and web dashboard so that users can find out the battery condition easily and accurately.

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Figure 1. Tool Assembly Results

The results of the tool's estimation show that all elements in the system have been connected according to the design that has been made. The 12 V adapter serves as a power source for the ESP32 and the monitoring circuit. The INA226 sensor is placed on the 12 V battery line to measure voltage and current directly, then the measurement results are sent to the ESP32 which acts as the main microcontroller. The ESP32 processes the received data using the Fuzzy Sugeno method to determine the State of Health (SOH) value of the battery. After completing the calculation, the ESP32 sends monitoring data via a Wi-Fi network to the Arduino IoT Cloud, so that information about voltage, current, SOH values, and the eligibility status of the battery can be observed directly through the dashboard on a cellphone or computer. Based on the estimation results, all components can function synergistically, data communication runs smoothly, and the system is able to monitor battery health according to the stated research objectives.

2. Battery Test Results on LCD

Based on the test results that have been carried out, the 16x2 LCD can display battery monitoring results clearly, including voltage, current, and battery health levels (State of Health/SoH). The information displayed is the result of processing INA226 sensor data using the Fuzzy Sugeno method which classifies battery conditions into good, fairly good, or poor categories. The LCD display makes it easy for users to know the condition of the battery directly and in real-time after the measurement process is complete, so users can monitor battery health more easily without the need for additional measuring tools.



Figure 2. Battery Test Results on LCD in Good Condition

The image shows the results of the implementation of a battery health monitoring tool that has been successfully assembled and functions well. Based on the 16x2 LCD display, the system is able to display a battery voltage value of 13.68 V, a current of 15,924 mA, and the results of the Fuzzy Sugeno method calculation which shows a State of Health (SOH) value of 93% with a status of "Good". This shows that all components, from the sensor, ESP32, to the monitoring system, have worked according to the design and are able to provide information on battery conditions in real-time.

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Figure 3. Battery Test Results on LCD in Good Condition

The image shows the results of the battery health monitoring tool test that has worked well. The 16x2 LCD displays the battery voltage value of 12.27 V, the current of 14,964 mA, and the results of the Fuzzy Sugeno method calculation which produces a State of Health (SOH) value of 79% with a status of "Good". These results indicate that the system is able to read battery parameters, process data using the Fuzzy Sugeno method, and display the battery health condition in real-time according to the research design.



Figure 4. Battery Test Results on LCD: Fairly Good Condition

The image shows the results of the battery health monitoring tool test that has worked well. On the 16x2 LCD, the battery voltage value is displayed at 10.45 V, the current is 13194 mA, and the results of the Fuzzy Sugeno method calculation which produces a State of Health (SOH) value of 41% with a status of "Good Enough". These results indicate that the system is able to read battery parameters, process data using the Fuzzy Sugeno method, and display the battery health condition in real-time according to the research design.



Figure 5. Battery Test Results on LCD in Bad Condition

The image shows the results of the battery health monitoring tool testing that has worked well. The 16x2 LCD displays a battery voltage value of 0.01 V, a current of 54 mA, and the results of the Fuzzy Sugeno method calculation which produces a State of Health (SOH) value of 26% with a status of "Poor". These results indicate that the system is able to read battery parameters, process data using the Fuzzy Sugeno method, and display the battery health condition in real-time according to the research design.

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Figure 6. Battery Test Results Over 12 Volts

The image shows the results of the battery health monitoring tool test that has worked well. The 16x2 LCD displays the battery voltage value of 13.51 V, the current of 15816 mA, and the results of the Fuzzy Sugeno method calculation which produces a State of Health (SOH) value of 93% with a status of "Good". These results indicate that the system is able to read battery parameters, process data using the Fuzzy Sugeno method, and display the battery health condition in real-time according to the research design.

3. Website Monitoring View

The battery health monitoring website is designed to display real-time sensor readings, allowing users to monitor battery health more easily and efficiently. The website displays information such as battery voltage, battery current, and State of Health (SoH), obtained from the INA226 sensor reading process and data processing using the Fuzzy Sugeno method. Users can monitor battery health remotely via the internet.

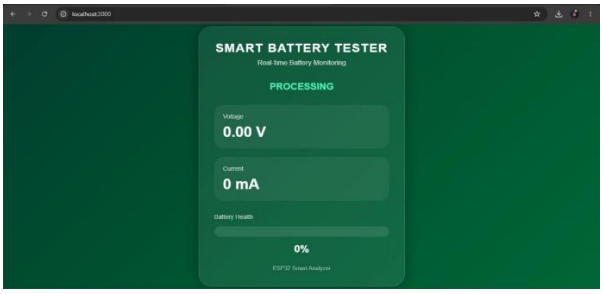


Figure 7. Battery Processing Monitoring Website Display

The image shows the web dashboard of a battery health monitoring system that has been successfully created using Node.js and can be accessed through a browser. The dashboard displays real-time monitoring information, including voltage, current, and battery health percentage (State of Health/SOH). In this display, the system is still in the Processing status, so the voltage, current, and SOH values still show 0. This indicates that the dashboard is active and ready to receive data sent by the ESP32 over the internet network to be automatically displayed to the user.



Figure 8. Good Condition Battery Monitoring Test Results

The image shows the web dashboard of the battery health monitoring system that successfully displays real-time monitoring results. Based on the data received from the ESP32, the dashboard displays a battery voltage value of 13.43 V, a current of 15,719 mA, and the results of the Fuzzy Sugeno method calculation which produces a State of Health (SOH) value of 93% with a status of "GOOD". This indicates that the process of reading the sensor, processing data by the ESP32, and sending data to

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the web dashboard has run well, so that users can monitor the condition of the battery health directly through the browser.



Figure 9. Battery Monitoring Test Results: Fairly Good Condition

The image shows the web dashboard of the battery health monitoring system that successfully displays real-time monitoring results. Based on the data received from the ESP32, the dashboard displays a battery voltage value of 12.08 V, a current of 14826 mA, and the results of the Fuzzy Sugeno method calculation which produces a State of Health (SOH) value of 62% with a status of "Good Enough". This indicates that the process of reading the sensor, processing data by the ESP32, and sending data to the web dashboard has run well, so that users can monitor the condition of the battery health directly through the browser.



Figure 10. Battery Monitoring Test Results: Fairly Good Condition

The image shows the web dashboard of the battery health monitoring system that successfully displays real-time monitoring results. Based on the data received from the ESP32, the dashboard displays a battery voltage value of 9.76 V, a current of 11973 mA, and the results of the Fuzzy Sugeno method calculation which produces a State of Health (SOH) value of 41% with a status of "Good Enough". This indicates that the process of reading the sensor, processing data by the ESP32, and sending data to the web dashboard has run well, so that users can monitor the condition of the battery health directly through the browser.

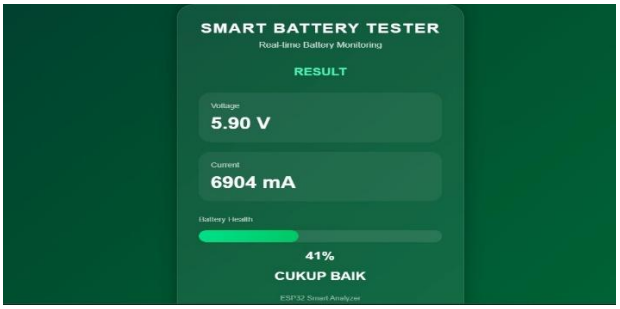


Figure 11. Battery Monitoring Test Results: Fairly Good Condition

The image shows the web dashboard of the battery health monitoring system that successfully displays real-time monitoring results. Based on the data received from the ESP32, the dashboard displays a battery voltage value of 5.90 V, a current of 6904 mA, and the results of the Fuzzy Sugeno method calculation which produces a State of Health (SOH) value of 41% with a status of "Good Enough". This indicates that the process of reading the sensor, processing data by the ESP32, and sending data to the web dashboard has run well, so that users can monitor the condition of the battery health directly through the browser.

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Figure 12. Results of the Bad Condition Battery Monitoring Test

The image shows the web dashboard of the battery health monitoring system that successfully displays real-time monitoring results. Based on the data received from the ESP32, the dashboard displays a battery voltage value of 0.00 V, a current of -4 mA, and the results of the Fuzzy Sugeno method calculation which produces a State of Health (SOH) value of 26% with a status of "Bad". This indicates that the process of reading the sensor, processing data by the ESP32, and sending data to the web dashboard has run well, so that users can monitor the condition of the battery health directly through the browser.

4. Results of Arduino IDE Coding Implementation

The results of the program implementation on the system show that all the designed codes can run according to the expected function. The program embedded in the ESP32 microcontroller is able to integrate the INA226 sensor, 16x2 I2C LCD, relay, and WiFi connection to carry out the battery health monitoring process automatically and in real-time. The data obtained from the INA226 sensor in the form of battery voltage and current values are then processed using the Fuzzy Sugeno method to determine the battery health level (State of Health/SoH) based on predetermined parameters.

```
336   // ======================
337   // VOLTAGE SCORE
338   // ======================
339   float voltageScore = 0;
340
341   if (v >= 12.6)
342   {
343     voltageScore = 95;
344   }
345   else if (v >= 12.2)
346   {
347     voltageScore = 75;
348   }
349   else if (v >= 11.8)
350   {
351     voltageScore = 50;
352   }
353   else
354   {
355     voltageScore = 20;
356   }
```

Figure 13. Battery Voltage Range Display

This program fragment is designed to calculate a voltage score based on battery voltage measurements. The system compares the voltage reading obtained with a predetermined threshold. If the voltage is equal to or greater than 12.6 V, then the score given is 95 (very good), for a voltage equal to or greater than 12.2 V gets a score of 75 (good), for a voltage equal to or greater than 11.8 V is given a score of 50 (sufficient), and if the voltage is less than 11.8 V then the score given is 20 (poor). This voltage score value is then used as one of the input elements in the calculation process using the Fuzzy Sugeno method to assess the condition of the battery health.

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```
// ======================
// CURRENT SCORE
// ======================
float currentScore = 0;

if (c >= 800)
{
  currentScore = 90;
}
else if (c >= 500)
{
  currentScore = 75;
}
else if (c >= 200)
{
  currentScore = 60;
}
else
{
  currentScore = 40;
}
```

Figure 14. Battery Current Range Display

This code snippet is used to determine the Current Score based on the current value (c) read by the INA226 sensor. The system will compare the current value with a predetermined range. If the current is ≥ 800 mA, then the Current Score = 90; if 500–799 mA, then the Current Score = 75; if 200–499 mA, then the Current Score = 60; and if < 200 mA, then the Current Score = 40. This Current Score value is then used as one of the inputs in the Fuzzy Sugeno method calculation to determine the battery health percentage (Health (%)).

```
// ======================
// SUGENO AVERAGE
// ======================
int result =
(
  (voltageScore * 0.7)
  +
  (currentScore * 0.3)
);
```

Figure 15. Display of Sugeno Fuzzy Calculation

CodeThis is the defuzzification process in the Sugeno Fuzzy method. The final value (result) is calculated using a weighted average, which is 70% of the voltage value (voltageScore) and 30% of the current value (currentScore). The results of this calculation are used to determine the health level of the electric motorcycle battery.

The system also successfully displays monitoring results on the LCD and sends data to the website via the internet network so that battery condition information can be monitored remotely in real-time. The displayed data includes battery voltage, battery current, and battery health level (State of Health/SoH) obtained from processing results using the Fuzzy Sugeno method. In addition, the system is able to provide battery condition information based on predetermined categories, so that users can know whether the battery is in good, good enough, or poor condition. Based on the results of the implementation test, the developed program can work stably, integrated, and is able to support the process of monitoring the health of electric motorcycle batteries based on the Internet of Things (IoT) effectively and sustainably.

Test Results of the Sugeno Fuzzy Method

Table 1. Sugeno Fuzzy Analysis

No	Voltage (V)	Current (Ma)	Percentage	Sugeno Fuzzy Results	Battery Condition
1	13.68	15,924	93%	Tall	Good
2	12.27	14,964	79%	Medium - High	Good
3	10.45	13,194	41%	Currently	Pretty good
4	9.81	54	26%	Low	Bad

The test results show that the Fuzzy Sugeno method is able to classify battery health based on voltage and current values. When the voltage is at 13.68 V, the system produces 93% with a Good status.

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At 12.27 V, the system displays 79% and is still categorized as Good. When the voltage drops to 10.45 V, the battery health value becomes 41% with a Fair status. Meanwhile, at a voltage of 9.81 V, the system produces 26% with a Poor status, which indicates the battery is in an unsuitable condition and requires charging or replacement.

These results show that the IoT-based monitoring system with the Fuzzy Sugeno method is able to provide a gradual assessment of battery condition and according to changes in voltage and current values, so that it can be used to monitor battery health effectively.

Table 2. Script Description

Script	Information
#include <WiFi.h> #include <HTTPClient.h> #include <ArduinoJson.h> #include <Wire.h> #include <LiquidCrystal_I2C.h> #include <INA226.h>	Functions to call various libraries required by the system. The WiFi and HTTPClient libraries are used for network communication and sending data to the server, ArduinoJson is used to form data in JSON format, Wire is used for I2C communication, LiquidCrystal_I2C is used to control the LCD display, while INA226 is used to read the battery voltage and current values via the INA226 sensor.
const char* ssid = "Treasure 4G"; const char* password = "Yeloow_2003";	Used to store the network name (SSID) and WiFi password information that the ESP32 will use to connect to the network. This connection is necessary so that battery measurement results can be sent to the server in real time.
string serverURL = "http://192.168.18.108:3000/update";	This variable specifies the destination server address that will receive battery test data. All data sent by the ESP32 using the HTTP POST method will be directed to the address stored in this variable.
LiquidCrystal_I2C lcd(0x27, 16, 2);	Used to create an I2C LCD object with a device address of 0x27 and a screen size of 16 columns × 2 rows. The LCD functions as a medium for displaying information about the testing process and battery measurement results to the user.
INA226 ina(0x40);	Used to create an INA226 sensor object that measures battery voltage and current. This sensor is the primary source of data used in calculating battery health.
#define RELAY_PIN 25	This section defines GPIO 25 as the relay control pin. The relay is used to connect or disconnect the test circuit as needed by the system during the measurement process.

float voltage = 0.0;
float current = 0.0;
float avgVoltage = 0.0;
float avgCurrent = 0.0;
int health = 0;
	Used to store voltage, current, average voltage, average current, and battery health percentage values. These variables are used during data collection and test result calculations.

bool testing = false;	Used to indicate whether a test is in progress. This variable prevents the system from performing duplicate tests while the battery is still connected.
float detectVoltage = 0.20;	Used as a threshold to detect the presence of a battery. If the voltage reading exceeds a predetermined value, the system will assume that the battery is installed and ready to be tested.

lcd.setCursor(0, 0);
lcd.print("BATTERY TESTER");
lcd.setCursor(0, 1);
lcd.print("Initializing");
delay(2000);
	Displays initial information such as device identity and system initialization status. This display informs the user that the device is undergoing preparation before it is ready for use.

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lcd.clear();
lcd.setCursor(0, 0);
lcd.print("Connecting WiFi");
WiFi.begin(ssid, password);
while (WiFi.status() != WL_CONNECTED)
{
delay(500);
Serial.print(".");
}
Serial.println("");
Serial.println("WIFI CONNECTED");
	This function connects the ESP32 to a pre-configured Wi-Fi network. The system will continue to attempt a connection until it successfully connects to the network and is ready to communicate with the server.

if (!ina.begin())
{
lcd.clear();
lcd.setCursor(0, 0);
lcd.print("INA226 ERROR");
while (1);
}
ina.setMaxCurrentShunt(10, 0.002);
	This section checks for the presence of the INA226 sensor. If the sensor is not detected, the system displays an error message and terminates the program. Furthermore, the sensor is calibrated by determining the maximum current and shunt resistance values used.

voltage = ina.getBusVoltage();	In this section, the system continuously reads the voltage value from the INA226 sensor. The voltage data is used to monitor the battery's presence and determine when to begin the testing process. What is the voltage?

if (voltage > detectVoltage && !testing)
{
testing = true;
processBattery();
}
delay(200);
}
	This function detects whether the battery is connected to the device. When the voltage reading exceeds the threshold and the system is not performing a test, the battery test function will automatically run.

sendData("PROCESSING", 0, 0, 0);	The system sends information to the server that the testing process is in progress. This information can be used by the monitoring application to display the device's status in real time.
float totalVoltage = 0; float totalCurrent = 0;	The total voltage and total current variables are used to sum all sensor readings during the sampling process. These values are then used to calculate the average measurement results.
int sampleCount = 0;	This variable is used to calculate the number of data samples successfully obtained during the measurement process.
unsigned long startTime = millis();	This variable is used to calculate the number of data samples successfully obtained during the measurement process.
unsigned long startTime = millis();	This code is used to record the start time of the measurement so that the system can control the length of the sampling process.
while (millis() - startTime < 5000) { voltage = ina.getBusVoltage(); current = ina.getCurrent_mA(); totalVoltage += voltage; totalCurrent += current; sampleCount++; delay(200); }	This code performs a five-second voltage and current sampling process. Each data point is summed and used to calculate the average value.
digitalWrite(RELAY_PIN, HIGH);	Used to activate the relay according to the needs of the testing process designed on the system hardware.
avgVoltage = totalVoltage / sampleCount; avgCurrent = totalCurrent / sampleCount;	Used to calculate the average voltage and current values based on all samples collected during the measurement process.

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health = calculateFuzzy(avgVoltage, avgCurrent);	Used to calculate the battery health level based on the average voltage and current obtained from the measurement results.
sendData("RESULT", avgVoltage, avgCurrent, health);	Used to send the final results of electric motorcycle battery testing in the form of voltage, current, and battery health sent to the server.
while (millis() - resultStart < 10000) { lcd.clear(); lcd.setCursor(0,0); lcd.print(avgVoltage,2); lcd.print("V"); lcd.setCursor(0,1); lcd.print("Health:"); lcd.print(health); }	Used to display test results on the LCD for ten seconds so that users can see the measurement results directly.
testing = false; showStandby();	Used to return the system to standby mode after the test process is complete so that it is ready to receive the next test.
int calculateFuzzy(float v, float c)	used to calculate the battery health level based on a combination of voltage and current values using a weighted scoring method.
float voltageScore = 0; if (v >= 12.6) voltageScore = 95; else if (v >= 12.2) voltageScore = 75; else if (v >= 11.8) voltageScore = 50; else voltageScore = 20;	Used to score battery condition based on measured voltage. The higher the voltage, the higher the score.
float currentScore = 0; if (c >= 800) currentScore = 90; else if (c >= 500) currentScore = 75; else if (c >= 200) currentScore = 60; else currentScore = 40;	Used to provide a score based on the measured current value so that it can be used in the battery health calculation process.
int result = ((voltageScore * 0.7) + (currentScore * 0.3));	Used to calculate battery health score by combining voltage score and current score using 70% and 30% weighting.
if (result > 100) result = 100; if (result < 0) result = 0; return result;	Used to ensure the battery health value remains in the range of 0% to 100%, then returns the calculation results to the main program.
void sendData(String status, float volt, float curr, int healthValue)	Used to send battery measurement data to the server via a WiFi network using the HTTP POST method.
if (WiFi.status() == WL_CONNECTED)	Used to ensure that the WiFi connection is still active before the data transmission process is carried out.
HTTPClient http; http.begin(serverURL); http.addHeader("Content-Type","application/json");	Used to create an HTTP connection to the server and specify that the data sent uses JSON format.
StaticJsonDocument<200> doc; doc["status"] = status; doc["voltage"] = volts; doc["current"] = curr; doc["health"] = healthValue;	Used to create a JSON data structure containing battery status, voltage, current, and health information before sending it to the server so that it is easy to understand and explain in detail.
String jsonData; serializeJson(doc, jsonData);	Used to convert JSON objects into strings so they can be sent via the HTTP protocol.
nt httpResponseCode = http.POST(jsonData); Serial.println(httpResponseCode);	Used to send data to the server using the POST method and displays the server response code as an indicator of successful delivery.
http.end();	Used to close an HTTP connection and free up memory resources that have been used during the communication process with the server.

Table 3. Strengths and Weaknesses of Research

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NO	Excess	Lack
1.	The system is capable of monitoring the health of 12-volt batteries in real-time using Internet of Things (IoT) technology.	The system only uses voltage and current parameters, so it does not consider other parameters such as battery temperature, State of Charge (SoC), battery capacity, and charge cycles which also affect battery health.
2.	The INA226 sensor can measure battery voltage and current well as parameters to determine the battery health condition.	The method used is only Fuzzy Sugeno so that comparisons have not been carried out with other methods to determine the optimal level of accuracy.
3.	The Sugeno Fuzzy Method is able to process voltage and current data into State of Health (SoH) information so that the battery condition is easier for users to understand.	The monitoring dashboard still has limited features because it is not equipped with historical graphs, data storage, and automatic notifications when the battery condition is in the bad category.
4.	The system developed has relatively affordable implementation costs because it uses components that are easy to obtain and easy to implement.	System testing is still limited to 12-volt batteries and has not been tested under various load conditions, usage durations, or other battery types.

Conclusion

This research produces an Internet of Things (IoT) based electric motorcycle battery health monitoring system using the Fuzzy Sugeno method that is able to read voltage and current parameters through the INA226 sensor, process data on the ESP32, and display the results on the LCD and web dashboard in real-time. The test results show that the system is able to classify battery conditions based on the State of Health (SoH) value. In the test, the SoH value of 93% is categorized as good, 79% is categorized as good, 41% is categorized as quite good, and 26% is categorized as bad. The system is also able to send data via the internet network so that battery conditions can be monitored remotely. These results show that the integration of the ESP32, INA226 sensor, IoT, and Fuzzy Sugeno can be used to support the battery health monitoring process directly and help users obtain battery condition information more easily.

This research has limitations because the system still uses voltage and current parameters and testing is still focused on 12-volt batteries. The system does not consider temperature parameters, State of Charge (SoC), battery capacity, and charging cycles, and there has been no comparison of the Fuzzy Sugeno method with other methods. The dashboard is also still limited because it is not equipped with historical graphs, data storage, and automatic notifications. Future research can add these parameters, compare the Fuzzy Sugeno method with other methods, develop dashboard features, and conduct tests on various load conditions, usage durations, and battery types. Practically, the developed system can be used as a real-time battery condition monitoring medium and help users know the condition of the battery to support maintenance and extend its lifespan.

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