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Implementation of a LoRa-Based Electric Vehicle Energy

Monitoring System in Internet-Limited Competition Areas

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Abstract – The Kontes Mobil Hemat Energi (KMHE) and the Shell Eco-marathon (SEM) are competitions that encourage students to design and develop energy-efficient and environmentally friendly electric vehicles. However, limited internet connectivity in competition track areas remains a major challenge for acquiring real-time vehicle energy consumption data, which complicates performance analysis and driving strategy optimization. This research aims to design and implement a LoRa (Long Range)-based electric vehicle energy monitoring system that operates independently of internet networks. The proposed system consists of transmitter and receiver units that monitor voltage, current, power, and electrical energy parameters using a Current Transformer (CT) sensor, a voltage divider circuit, an ADS1115 ADC module, and an ESP32 microcontroller as the main controller. A LoRa RA-02 module operating at 433 MHz is used to wirelessly send data, which are then shown in real time at the receiving device. Based on the test, the device can reliably send energy data up to a distance of about 500 meters in places without internet connectivity. The system can reliably calculate electrical power and energy during the vehicle is operating, and average errors for voltage and current results tend to be modest when compared to reference values.

Keywords: Electric Vehicle, Energy Monitoring, LoRa, ESP32

I. Introduction

The development of electric vehicle technology has become a global initiative to reduce carbon emissions and dependence on fossil fuels. One of the activities that strongly encourages innovation in this field is energy-efficient vehicle competitions, such as the Kontes Mobil Hemat Energi (KMHE) and Shell Eco-marathon, which are participated in by students from various universities. In these competitions, each team is required to design and develop a vehicle that consumes minimal energy while achieving the longest possible travel distance [1], [2]. Through these activities, students are able to contribute directly to the advancement of sustainable transportation technologies in Indonesia.

Universitas Muhammadiyah Sidoarjo is one of the higher education institutions actively involved in the development of electric vehicles through student participation in energy-efficiency competitions. The development of electric vehicles represents an important step toward promoting innovation in sustainable energy systems and demonstrates concern for realizing an environmentally friendly future. In addition, such innovations foster student awareness of global climate change issues and environmental sustainability [3], [4].

The Universitas Muhammadiyah Sidoarjo IMEI Team encountered problems in obtaining energy usage statistics throughout the building process of electric vehicles. The team has trouble getting real-time data on energy while the car runs on testing tracks or competitive circuits. Energy usage data is only accessible after the car crosses the finish line, and differences in track conditions result in differences in vehicle energy consumption. Because of this, the team found it difficult to assess vehicle performance and adjust driving strategies during competition or testing.

Previous studies have developed Internet of Things (IoT)-based electric vehicle energy monitoring systems to observe energy consumption through internet connectivity [5], [6]. However, when applied

in competition environments, such systems cannot be used due to the absence of reliable internet access.

Consequently, the goal of this research is to build an energy monitoring system that can adjust to situations of competition in which internet connectivity is either unavailable or restricted.

A monitoring system that can send data on electric vehicle energy consumption in real time without requiring internet connectivity is needed to solve this problem. The application of Long Range (LoRa) communication technology is one possible remedy. Low frequencies (433 MHz, 868 MHz, or 915 MHz) are used by LoRa, a wireless communication technology that has a long communication range, low power consumption, and the capacity to function without access to the internet [7], [8], [9]. Because this technology may attain communication ranges of several meters under line-of-sight (LOS) circumstances, it is ideal for monitoring systems in competition regions. LoRa enables the direct transmission of energy data from the electric car to the pit monitoring area without the need for further network equipment [10], [11].

This study designs and implements an electric vehicle energy monitoring system utilizing LoRa technology. The system is capable of displaying and storing energy consumption data in real time while the vehicle is operating on the track, enabling accurate and timely performance analysis. The system consists of two main components: a transmitter unit installed on the vehicle and a receiver unit located in the monitoring area. The system is equipped with a Current Transformer (CT) sensor for current measurement, a voltage divider circuit for voltage sensing, an external ADS1115 analog-to-digital converter (ADC) for accurate analog signal acquisition, and an ESP32 microcontroller as the main controller [12], [13], [14].

The IMEI Team of Universitas Muhammadiyah Sidoarjo is anticipated to helping from the suggestion LoRa-based energy monitoring system by increasing energy efficiency, optimizing driving tactics during competitions, and helping with the creation of more intelligent, effective, and ecologically friendly electric vehicle technologies.

II. Method

This study discusses the design and implementation of an electric vehicle energy monitoring system intended to operate in competition areas with limited internet connectivity. The system is developed to monitor voltage, current, power, and energy parameters in real time by utilizing LoRa (Long Range)–based wireless communication.

II.1. Electric Vehicle Energy Monitoring System

The electric vehicle energy monitoring system is designed to acquire real-time energy consumption data while the vehicle is operating on the track. The system consists of two main units: a transmitter unit installed on the electric vehicle and a receiver unit located in the monitoring area [14], [15].

The battery voltage is measured in the transmitter unit using a voltage divider circuit, and the electric current flowing from the battery to the load is measured using a Current Transformer (CT) sensor.

The measured voltage and current data are processed by an ESP32 microcontroller to calculate power and energy values [5], [16]. The processed data are then transmitted wirelessly to the receiver unit.

The receiver unit receives the transmitted data and displays the measured voltage, current, power, and energy values on an I2C LCD and serial monitor, allowing the team to monitor the vehicle's energy consumption in real time during testing and competition [12], [13], [17]. The block diagram of the proposed system is shown in Fig. 1.

Fig. 1. Block Diagram

II.2. LoRa Systems and Communications

The electric vehicle energy monitoring system utilizes LoRa-based wireless communication as the data transmission medium between the transmitter and receiver units. The RA-02 LoRa module operating at a frequency of 433 MHz is selected due to its long communication range and low power consumption, making it suitable for competition areas with limited or no internet connectivity [8], [10], [11].

On the transmitter side, the sensor measurement data processed by the ESP32 microcontroller are periodically transmitted via the LoRa module. Meanwhile, on the receiver side, the LoRa module receives the transmitted data and forwards them to the ESP32 microcontroller for further processing and real-time display. With this configuration, the system is capable of monitoring the electric vehicle's energy consumption directly without relying on an internet connection [18].

Fig. 2. Flowchart

II.3. Circuit Design and Energy Calculation

The circuitry of the electric vehicle energy monitoring system consists of a voltage measurement circuit, a current measurement circuit, and the overall circuitry of the transmitter and receiver units [6], [19]. The voltage measurement circuit employs a voltage divider method to reduce the battery voltage of the electric vehicle to a level compatible with the input limits of the ADS1115 ADC module. The output voltage from the voltage divider circuit is then read by the ADC and processed by the ESP32 microcontroller [14], [15].

The relationship between the input voltage and the output voltage in the voltage divider circuit is expressed by the following equation:

$$Vout = Vin \times \frac{R2}{R1 + R2}$$

Vout : Output Voltage (V)

Vin : Electric Vehicle Battery Voltage (V)

R1, R2 : Resistance Values (Ohm)

Where Vin represents the electric vehicle battery voltage, R1 and R2 denote the resistance values of the voltage divider, and Vout is the output voltage supplied to the ADC input. The voltage divider circuit used in this system is illustrated in Fig. 3.

Fig. 3. Voltage Divider Circuit

In addition to voltage measurement, the system is also equipped with a current sensor based on a Current Transformer (CT) to measure the electric current flowing from the battery to the vehicle load. The acquired voltage and current data are then utilized to calculate the electrical power and energy consumption [5], [16]. The power calculation is performed using the following equation:

$$P = V \times I$$

P : Power (W)

V : Voltage (V)

I : Current (A)

Meanwhile, the electrical energy is calculated as the accumulation of power over the measurement duration. The electrical energy calculation is expressed by the following equation:

$$W = P \times t$$

W : Energy (Wh)

P : Power (W)

t : Time (s)

The overall circuitry of the electric vehicle energy monitoring system, which includes the transmitter and receiver units, is designed using the ESP32 microcontroller as the main controller, the ADS1115 module as an external ADC, and the LoRa RA-02 module as the wireless communication medium [19], [20], [21]. The schematic diagram of the complete system is presented in Fig. 4.

Fig. 4. Energy Monitoring System Series

III. Result and Discussion

This section discusses the results of the design and implementation of the LoRa-based electric vehicle energy monitoring system. The system development process began with the identification of energy monitoring requirements, followed by the selection of voltage and current sensors, the design of the electronic circuitry, and the integration of hardware and software components in both the transmitter and receiver units.

The final prototype of the developed electric vehicle energy monitoring system is shown in Fig. 5, which illustrates the physical appearance of the device prior to further testing and performance evaluation.

Fig. 5. Design Results

Furthermore, performance testing was conducted to evaluate the system's capability in measuring electrical parameters, calculating power and energy, and transmitting data wirelessly using LoRa communication.

III.1. Voltage Sensor Testing

The voltage sensor testing was performed to determine the accuracy of the system in measuring the electric vehicle battery voltage through the voltage divider circuit. The voltage readings obtained from the system were compared with measurements from a digital multimeter as a reference instrument. The results of the voltage sensor testing are presented in Table 1.

TABLE I

VOLTAGE SENSOR TESTING RESULTS

No

Reference Voltage

(Digital Multimeter)

(V)

Measured Voltage

by Microcontroller

(LCD I2C) (V)

Error

(%)

1	49,66	49,63	0,06 %
2	49,59	49,57	0,04 %
3	49,51	49,47	0,08 %
4	49,44	49,41	0,06 %
5	49,40	49,39	0,02 %
6	49,33	49,32	0,02 %
7	49,29	49,27	0,04 %
8	49,21	49,18	0,06 %
9	49,19	49,15	0,08 %
10	49,14	49,13	0,02 %
11	49,11	49,09	0,04 %
12	49,05	49,02	0,06 %
13	48,88	48,85	0,06 %
14	48,81	48,79	0,04 %
15	48,74	48,70	0,08 %

Based on the results presented in Table 1, the voltage readings obtained by the system exhibit relatively small deviations compared to the reference values measured using a digital multimeter. The resulting error percentages remain within acceptable tolerance limits for electric vehicle energy monitoring applications. This indicates that the voltage divider circuit and the analog-to-digital conversion process employed in the system operate accurately and stably.

III.2. Current Sensor Testing

The current sensor testing was conducted to evaluate the performance of the Current Transformer (CT)-based sensor in measuring the electric current flowing from the battery to the vehicle load. The sensor readings were compared with current measurements obtained using a digital multimeter as the reference. The results of the current sensor testing are presented in Table 2.

TRANSMITTER

RECEIVER

TABLE 2

CURRENT SENSOR TESTING RESULTS

No	Reference Current (Digital Multimeter) (A)	easured Current by Microcontroller (LCD I2C) (A)	Error (%)
1	0	0	0 %
2	0,43	0,41	4,65 %
3	0,47	0,46	2,13 %
4	0,50	0,50	0 %
5	0,48	0,46	4,17 %
6	0,52	0,51	1,92 %
7	0,56	0,55	1,79 %
8	0,47	0,47	0 %
9	0,56	0,55	3,33 %
10	0,60	0,58	1,64 %
11	0,61	0,60	2,00 %
12	0,58	0,58	0 %
13	0,50	0,49	2,00 %
14	0,49	0,48	2,04 %
15	0,52	0,50	3,85 %

The test results indicate that the current sensor is capable of detecting current variations effectively under different load conditions. The discrepancies between the system readings and the reference measurements are influenced by the characteristics of the CT sensor as well as current fluctuations during the testing process. Overall, the current sensor demonstrates good measurement stability and is suitable for use as a basis for power and electrical energy calculations.

III.3. LoRa Communication Testing

LoRa communication testing was conducted to evaluate the effective communication range and data transmission stability between the transmitter and receiver units. The observed parameters include the data reception rate, RSSI values, and the reception conditions at various testing distances. The results of the LoRa communication testing are presented in Table 3.

TABLE 3

LORA COMMUNICATION TESTING RESULTS

No	Distance (m)	RSSI (dBm)	Data Received
1	0	-31	Yes
2	2	-35	Yes
3	5	-38	Yes
4	8	-39	Yes
5	10	-40	Yes
6	20	-51	Yes
7	30	-65	Yes
8	50	-77	Yes
9	75	-80	Yes
10	100	-89	Yes
11	200	-92	Yes
12	500	-102	Yes
13	1000	Not Connected	No
14	2000	Not Connected	No
15	5000	Not Connected	No

Based on the test results, the LoRa communication system demonstrates good performance at short to medium distances. Data transmission remains stable up to a distance of 500 meters with an RSSI value of −102 dBm. However, at distances beyond 500 meters, a significant degradation in communication quality is observed, as indicated by the failure to receive data at distances ranging from 1000 meters to 5000 meters.

The attenuation of the LoRa signal as the transmission distance grows, together with other environmental factors including physical impediments, land conditions, and antenna setup during testing, are the main causes of this reduction in communication performance. Although long-range communication is possible in principle with LoRa technology, the practical results show that the effective communication range is only about 500 meters given the system design and field circumstances used in this study. As a result, the suggested electric car energy monitoring system is still dependable enough to be used in competitive settings, but its communication range should be viewed as a constraint for larger-scale applications.

III.4. Power and Energy Calculation Testing

To confirm that the system can correctly calculate electrical power and energy values based on voltage and current data, power and energy calculation testing was carried out. After the test was run with a constant load for a predetermined amount of time, the computed outcomes were contrasted with reference data. The results of the power and energy calculation testing are presented in Table 4.

TABLE 4

POWER AND ENERGY TESTING RESULTS

No	Voltage (V)	Current (I)	Power (W)	Energy (Wh)	Time (Minutes)
1	49,63	0	0,00	0,00	0
2	49,57	0,41	20,32	0,17	0,5
3	49,47	0,46	22,76	0,37	1
4	49,41	0,50	24,71	0,57	1,5
5	49,39	0,46	22,72	0,77	2
6	49,32	0,51	25,15	0,98	2,5
7	49,27	0,55	27,10	1,21	3
8	49,18	0,47	23,11	1,41	3,5
9	49,15	0,55	27,03	1,64	4
10	49,13	0,58	28,50	1,88	4,5

11	49,09	0,60	29,45	2,13	5
12	49,02	0,58	28,43	2,37	5,5
13	48,85	0,49	23,94	2,57	6
14	48,79	0,48	23,42	2,77	6,5

15	48,70	0,50	24,35	2,98	7

The test results indicate that the system is capable of calculating electrical power and energy values consistently in accordance with variations in voltage, current, and measurement duration. The observed deviations remain within acceptable limits and are influenced by sensor accuracy and the time resolution of data acquisition. Therefore, the system is suitable for real-time monitoring of electric vehicle energy consumption.

III.5. Overall System Performance Discussion

The overall system testing was conducted to evaluate the integrated performance of the electric vehicle energy monitoring system under conditions that closely resemble actual competition track usage. In this stage, the transmitter unit was installed on the electric vehicle, while the receiver unit was positioned in the monitoring area. The overall system testing conditions are illustrated in Fig. 6.

Fig. 6. Overall System Operation Testing

Based on the experimental results, the system is able to read and display voltage, current, power, and energy parameters in real time as long as the LoRa communication remains within its effective coverage range. The measured data are clearly displayed on the LCD, and the system responds well to load variations during vehicle operation.

The system encounters difficulties sending data to the receiver unit when the communication distance is longer than the effective LoRa range. However, the voltage and current measurement processes, as well as the power and energy calculations on the transmitter unit, continue to operate correctly. The measured data are still processed and temporarily stored on the transmitter side, allowing the system to resume normal data transmission once the LoRa connection is re-established without affecting the accuracy of the energy parameters.

These findings show that the key characteristics of the electric vehicle energy monitoring system are still dependable in spite of the wireless communication range restrictions. Because of this feature, the suggested system is thought to be appropriate as a supplementary tool for monitoring energy usage in electric car efficiency contests, since the track area typically stays within the communication range.

IV. Conclusion

This study successfully designed and implemented a LoRa-based electric vehicle energy monitoring system capable of measuring voltage, current, power, and energy in real time without relying on an internet connection. The system consists of transmitter and receiver units integrated using an ESP32 microcontroller, a Current Transformer (CT) current sensor, a voltage divider circuit, an ADS1115 external ADC module, and a LoRa RA-02 communication module.

Experimental results indicate that the proposed system is able to measure voltage and current with good accuracy and to calculate power and electrical energy consistently during vehicle operation. The system can transmit measurement data wirelessly using LoRa with stable performance within an effective communication range under field conditions. Beyond this range, data transmission to the receiver becomes limited; however, the measurement and energy calculation processes on the transmitter unit continue to operate correctly.

The developed energy monitoring system can assist the team in performing more structured and accurate analysis of electric vehicle energy consumption during both testing and competition stages. Real-time energy consumption information provides a valuable basis for evaluating driving strategies and improving vehicle energy efficiency.

Further development of the system is still possible. Communication range improvement may be achieved through the use of higher-gain antennas, transmission power optimization, or the addition of signal amplification. These enhancements are expected to support broader system deployment and improve performance in larger competition areas.

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