IoT LoRa-Based Energy Management Information System with RAD Method and Laravel Frameworks

Agus Ramelan, Feri Adriyanto, Chico H. B. Apribowo, Muhammad H. Ibrahim, Meiyanto E. Sulistyo, and Kevin S. Arief

***Abstract*—This work presents a design and implementation an information system called LoRa-Building Energy Management System (Lo-BEMS). This research proposes an engaging data transmission (read and write), that combines the HTTP and MQTT protocols using third party broker that has monitor and control features for energy usages. Data retrieving uses single LoRa modulation and delivery to the Application Programming Interface (API) in Laravel Framework will then be stopped by the system and stored in the database. The development of this system uses the Rapid Application Development (RAD) method and the Laravel Frameworks. The black-box, UAT, and performance validation test results showed that the information system was running properly and following the objectives.**

***Index Terms*—Internet of Things, Information System, Web Design, LoRa, Energy Management.**

I. Introduction

Electrical energy has become a primary need for humans life [1,2]. Therefore, the demand for electrical energy also increases. Uncontrolled and continuous use of electrical energy will cause environmental damage and energy reserves depletion. A Building Energy Management System (BEMS) is a method used to monitor and control the energy requirements of a building, including accommodating electricity usage management [3-5]. The Internet of Things (IoT) approach to the energy sector is also known as the Internet of Energy (IoE) [6]. BEMS consists of sensors, actuators, embedded controllers, connectivity, and information systems. IoT has become part of human activities, both residential and industrial [7,8]. IoT promises to optimize people's daily lives with smart sensors and smart objects that connect and work together [9,10].

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At present, the application of IoT in energy management combines the application of Artificial Intelligence (AI) based on Big Data [11-14]. The sensor collects data, AI carries out the analysis process, and ends with decision making. More than that, the implementation of AI in the energy management system has entered the prediction level. Energy usage prediction models are used for precise demand projection so that energy reliability is maintained [15-17]. Research on the application of IoT to energy management is still relevant. The strengthening of smart cities supports this relevance. The smart cities place IoT as a significant role [18]. This work focuses on the application layer, namely building energy management information system. The scope of energy is more limited to electrical energy in a building.

The design of information system is to monitor and control the use of electrical energy so that it is more efficient and economical. This system uses real-time measurement by measuring energy and cost in kWh (kilowatt-hour). The database then stores these measurements, and the system can display records from a certain period. Additionally, users can export the data in *.xls* or *.csv* format. This system is designed as a controller used to manage existing devices. The controller here is done by pressing the on-off button on this system, which then the system will sent the value to the device. It uses an Application Programming Interface (API) to send data from hardware to the database. This information system uses the Laravel Framework, which is very useful in facilitating system development. Laravel is a popular PHP-framework for full-stack development and has a flatter learning curve than all frameworks [19]. Laravel is preferred for the rapid development of large-scale applications [20]. The Laravel Framework has the concept of MVC (Model, View, and Controller). The model is related to the database, the view is related to the user interface, and the controller functions as a control between the model and the view. With this concept, each component will be divided and can be arranged properly. The purpose of using the Laravel framework is that by using this framework, the creation of information systems will be faster and there are several features of the Laravel framework which are very easy to apply [21-23]. The development methodology used in this work is Rapid Application Development (RAD). The purpose of using the RAD method is that it offers speed, adaptability, and evolution [24-26].

This work is a development of previous studies. This system is an integration of LoRa-based IoT hardware and a own-built information system. The system uses a combination of Application Programming Interface (API) and Message Queuing Telemetry Transport (MQTT) as a means used to feed data from a hardware device to a server. And this system will be real time so it is very useful for users in monitoring and controlling processes, with the limitation of LoRa network as an unlicensed network.

The rest of the paper is organized as follows. Section II presents proposed methods. Section III describes result and discussion that contain detailed explanation of implementation and testing result. Finally, we conclude this research in section IV.

II. Proposed Methods

A. *Proposed Architecture System*

Figure 1 is a diagram of the proposed architecture system hardware based on LoRa and real-time monitoring and controlling system. There are four end nodes designed in this study. Each end node has four ACS712 current sensors and a ZMPT101B voltage sensor that are used to measure currents and voltages in loads. In each node, there are 4 channels relay module to control the load usages. These two sensors and relays are connected to the Arduino UNO microcontroller that is integrated with the Dragino LoRa shield to communicate with the LoRa gateway. The LoRa gateway will connect to the Thingspeak server via the internet. The current and voltage data will then be processed by Arduino UNO to obtain the results of electrical energy in Watt-Hour (Wh). Both of these data are sent to the IoT cloud server, Thingspeak. Finally, the results will be displayed in the form of a graph on the field on Thingspeak. Thingspeak is a MQTT broker that can send data to the created information system.

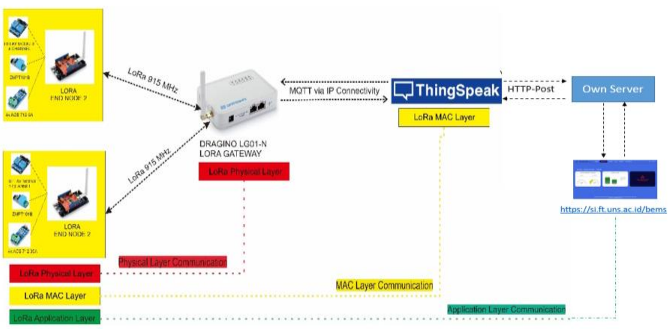

Fig. 1. Proposed system architecture hardware

This work is still in the prototype development stage, therefore it uses a single channel LoRa IoT Gateway (Private LoRa Protocol). The Dragino LGN-01 Gateway has LoRa Wireless specifications 433/868/915/920Mhz, open source openwrt, WiFi interface, ethernet port, USB host port, support 10~100 sensor nodes, and support mutiply working mode such as: MQTT mode, TCP/IP Client mode to fit different requirements for IoT connection. Private LoRa Protocol has some limitations such as doesn't have MAC control/management, the transmission is unencrypted, the gateway only works with specify LoRa end node which runs the same protocol. Therefore that future work, the system will be developed using the LoRaWAN protocol.

This paper describes an engaging data transmission, namely read and write. This work proposes a method that combines the HTTP and MQTT protocols. These two protocols are commonly used in data transmission on IoT. However, the combination of both is still quite interesting to observe and explore.

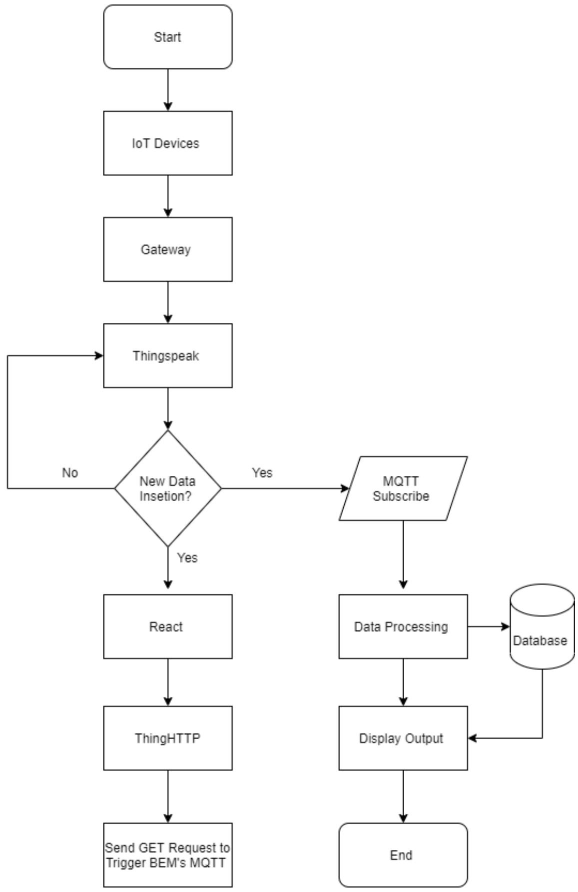

Fig. 2. Proposed flowchart of the data flow

Figure 2 is a diagram of the proposed data flow and the integration of HTTP ang MQTT protocol. The system retrieves data from the hardware that is integrated to Thingspeak. On updating new data, the react feature on Thingspeak will activate ThingHTTP. The ThingHTTP send a GET Request to trigger the MQTT protocol in BEMS Server. The BEMS server performs data processing, selects the data displayed, and stores the data in the database.

B. *Software Development*

The BEMS information system is developed by using the Rapid Application Development (RAD). The RAD method allows the user to provide the desired design and the system will be created based on the user's design. And when the user comments on discrepancies in the design, the system will be corrected according to the user's request. The user also determines the data flow that occurs in the information system, by using the API from Thingspeak.

The information system development steps are in figure 3.

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The aim of requirements planning is to identify the needs, limitations, and objective of a system to be built by collecting data from stakeholders. This process consists of developing an Entity Relationship Diagram (ERD) and a Data Flow Diagram (DFD). ERD is a diagram that shows the entities involved in a system and the relationships between these entities. Meanwhile, DFD provides a visual display of the data flow and information from a system.

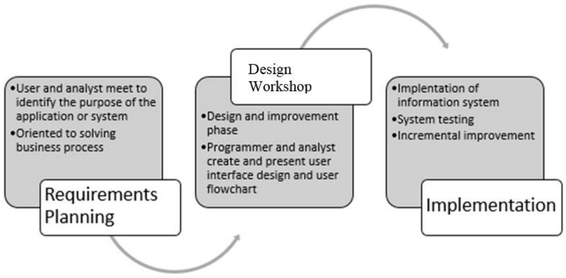

Fig. 3. Information system development step

The design workshop aims to design all activities in the overall system architecture. Besides, it improves understanding of the problem based on the analysis. This process carries out the design and improvement process if there is still a design mismatch between the user and the analyst. The user provides the desired design, and the system will be created. When the user comments on the mismatch design, the system will correct the design according to the user's request. The user also determines the occurrence of the data flow.

C. *Software Testing Method*

Software testing is an element that guarantees the quality of the software and represents the main study of specifications, design, and coding. The software testing method used in this information system is Black Box and User Acceptance Testing (UAT). Black Box is a software testing method used to examine the external work of the system, such as the input/output of the system, the expected results, and the user interfaces whether the system has made according to the design [27, 28].

TABLE I
BLACK BOX TEST MODEL

Number	Function	Testing
1.	Login process	Entering the user's email and password then checking the data user based on the entered input.
2.	Displaying Data Process	Fetching and displaying data from the database to a web page.
3.	Updating Data Process	Performing data updates.
4.	Controlling Device Process	Controlling the device on the system.
5.	Logout process	Deleting user's session and redirecting to the dashboard page.

UAT is a software testing method that involves end-users. The goal is to find out whether the system has been accepted and fulfilled the requirements requested from the end-users [29].

TABLE II
USER APPCEPTANCE FORM

Number	Question	SA	A	N	D	SD
1	This information system is attractive.					
2	This information system is understandable and feasible.					
3	This information system has a good performance.					
4	This information system fulfills a monitoring function.					
5	This information system fulfills a controlling function.					
6	This information system has many useful features.					
7	This information system monitors the use of electrical energy.					
8	The feedback for this information system.		Open answer from users.			

Annotation :
SA: strongly agree (5)
A: agree (4)
N: neutral (3)
D: disagree (2)
SD: strongly disagree (1)

III. RESULTS AND DISCUSSION

A. *Design and Implementation*

The implementation of the user interface in the information system of BEMS is user design-based. BEMS can be accessed using many types of page browsers.

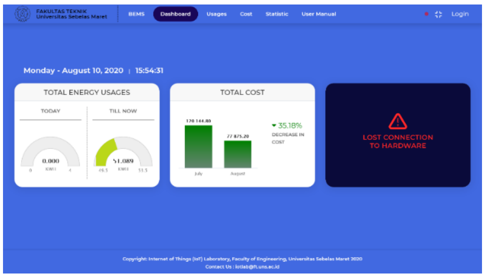

Fig. 4. Dashboard page

Fig. 5. Usage page

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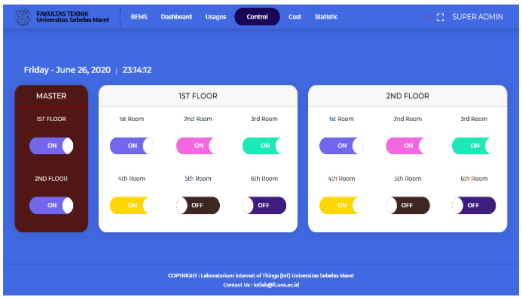

Fig. 6. Control page

The dashboard page is the first page that will be visited by the user. On the dashboard page, there is some information, namely total energy usages, total cost, and running appliances. Each of them is on the card. Meanwhile, the graph will depict the values. The usage page is a page that contains detailed energy usage information. On this page, the user can select three periods of energy use, such as today, month, and year. For each period, it has detailed information.

The control page can only be accessed by admins and super admins. It contains an on/off button for each room on each floor. Besides, it provides an on/off button for master control. The color of each button for each room is different to make it easier for users to distinguish between one and another.

The cost page contains information about costs incurred within a certain period. This information displays graphical data based on a period changed by the user so that the user can see the data for a certain period quickly. When opening the cost page, the default period is one-month. Therefore, the graph will display one-month data.

Statistics page contains information about energy use and costs during a certain period. The period is changeable so that the user can check the data quickly. When opening the statistics page, the default period is one month. Therefore, the graph displays one-month data. Besides, there is also a settings page that can be accessed by admin and super admin only. There are several important information, namely information about the cost per kWh, the controlling feature, the automatic deletion feature, the communication protocol setting, and password changing.

B. *Black Box Testing*

The use of Black Box Testing is to determine whether the system runs and functions properly. This software testing is to look for bugs, programming errors, and programming mismatches against the desired goals.

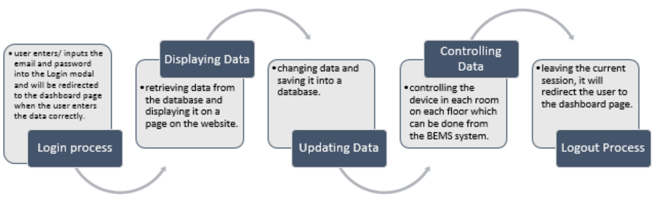

Fig. 7. Black Box Testing Process

The Black Box Testing results stated that the system was running and functioning properly. There were no bugs, programming errors, and programming mismatches.

C. *UAT Testing*

The UAT testing is to determine whether the system runs as expected and meets the objectives. The client or end-user generally carries this test. Each aspect of the questions on the UAT testing will be analyzed using proportion.

This test was conducted on 20 respondents using an online form. The respondents were the user of the information system.

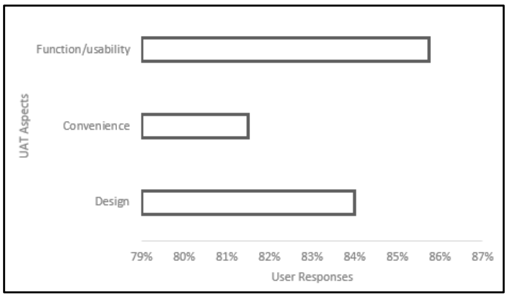

Fig. 8. UAT Result

According to table III and figure 8, the results showed the positive responses of 20 respondents towards the information system. The design aspect (question 1) got 84%. The convenience aspect (question 2-3) obtained 81.5%. The function/ usability aspect (question 4-7) gained 85.75%. The results indicated that the respondents agreed on the given questions.

D. *Data Accuracy Testing*

The data accuracy testing refers to the provisions for sending and receiving data stored in the cloud database. The test is done by comparing the logging data on the serial PC and the logging data on the cloud database. The results of the data accuracy testing are shown in tables IV-VII below.

The tables below show that the average accuracy at A node is 85.10%, B node is 89.19%, C node is 86.07%, and D node is 85.91%. This data is obtained from comparing the measurement results on the power meter, serial monitor, and database. The sensor accuracy is not good enough. However, the focus of this research is to create an energy information system, so it must be ensured that the data stored in the database is the same as the data on the serial monitor. Table IV shows that the information system successfully displays data with the same value as the serial monitor. It proved that the data on the serial monitor has the same value as the data in the database.

TABLE IV
DATA ACCURACY TESTING IN NODES A

Nodes	Load Number	Reference Power using Multimeter (Watt)	Measurement Power in Serial Monitor (Watt)	Actual Power in Cloud-Database (Watt)	Error
A	1	330.00	345.68	345.524	15.52
	2	66.00	59.67	59.63	6.37
	3	22.00	37.49	37.50	15.50
	4	374.00	408.22	409.18	35.18
	5	88.00	84.05	86.08	1.92
A Node Accuracy (%)					85.10

TABLE V
DATA ACCURACY TESTING IN NODES B

Nodes	Load Number	Reference Power using Multimeter (Watt)	Measurement Power in Serial Monitor (Watt)	Actual Power in Cloud-Database (Watt)	Error
B	1	330.00	337.05	337.05	7.05
	2	66.00	77.07	77.07	11.07
	3	22.00	25.26	25.26	3.26
	4	374.00	404.00	404.00	30.00
	5	88.00	90.70	90.70	2.70
B Node Accuracy (%)					89.19

TABLE VI
DATA ACCURACY TESTING IN NODES C

Nodes	Load Number	Reference Power using Multimeter (Watt)	Measurement Power in Serial Monitor (Watt)	Actual Power in Cloud-Database (Watt)	Error
C	1	330.00	292.39	292.39	37.61
	2	66.00	78.60	78.60	12.60
	3	22.00	23.02	23.02	1.02
	4	374.00	358.76	358.76	15.24
	5	88.00	91.18	91.18	3.18
C Node Accuracy (%)					86.07

TABLE VII
DATA ACCURACY TESTING IN NODES D

Nodes	Load Number	Reference Power using Multimeter (Watt)	Measurement Power in Serial Monitor (Watt)	Actual Power in Cloud-Database (Watt)	Error
D	1	330.00	304.75	304.75	25.25
	2	66.00	72.56	72.56	6.56
	3	22.00	39.77	39.77	17.77
	4	374.00	365.17	365.17	8.83
	5	88.00	75.98	75.98	12.02
D Node Accuracy (%)					85.91

E. Peformance Testing

The performance of the BEMS website is checked through a special website, for example Pingdom, which is used to see the performance of a website and provide suggestions on how to improve the performance of the website. On the Pingdom website, the result show that the load time for the BEMS website is fairly good, because it only takes 1.81 seconds for the page to open perfectly.

F. Coverage Gateway Testing

In this range testing is carried out with the aim of knowing how far LoRa can work. Data is taken from a distance of multiples of 50 m to 300 m. At each distance, 10 Receiver Signal Strength Indicator (RSSI) data are taken to determine whether the quality of the signal received by the receiver (end node) from the gateway (transmitter) is in the good or bad category.

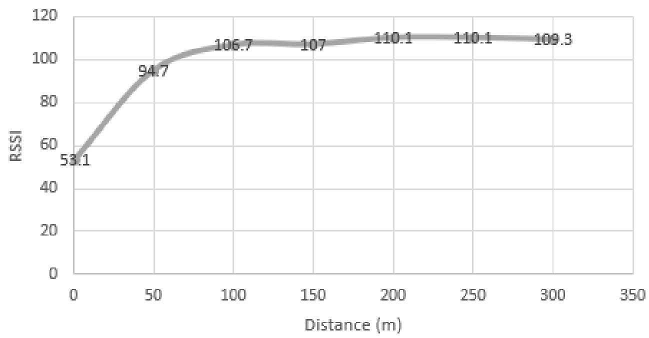

Fig. 9. Receiver Signal Strength Indicator (RSSI) Testing Result

At a distance of 50 meters, the RSSI value obtained is -53.1 dBm therefore it is included in the very good category. Because the receiver and transmitter are close. At a distance of 50 meters, RSSI -94.7 dBm therefore it is included in the good category. At a distance of 100 meters, the RSSI is -106.7 dBm therefore it is included in the bad category. But still can receive the signal well even though some packets are not received. At a distance of 150 meters, the RSSI is -107 dBm therefore it is included in the bad category. But still can receive the signal well even though some packets are not received. At a distance of 200 meters, the RSSI obtained is -110.1 dBm therefore it is included in the bad category. But still can receive the signal well even though some packets are not received. At a distance of 250 meters, the RSSI obtained is -109.3 dBm therefore it is included in the bad category. But still can receive the signal well even though some packets are not received. At a distance of 300 meters, the receiver is no longer able to connect to the transmitter. At this distance, no packets are received by the receiver. Therefore it can be said that at a distance of 300 meters, the receiver and transmitter are disconnected. From the results of the distance testing that has been carried out, the maximum distance for LoRa to work is at a distance of 250 meters, this is due to several factors, including obstacles in the form of buildings and improper placement of the gateway.

IV. CONCLUSION

The information system is designed by the user with several system improvements based on user requests using the RAD method and Laravel Framework that collects the data from IoT sensors with MQTT and HTTP-Post protocol communication. The information system is implemented in a building with monitoring and controlling energy usages that called as LoRa-Building Energy Management System (Lo-BEMS). The software testing using a Black-Box and UAT showed that the system function worked properly and got positive responses from the respondents. The UAT showed that the respondents gave their positive responses to the design aspect (84%), the convenience aspect (81.5%), and the function/usability aspect (85.75%). The information system successfully displays data with the same value as the serial monitor. It proved that the data on the serial monitor has the same value as the data in the database.

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