
Development of Hetrik Mobile Application in Iot-Based Electricity Management for Boarding Houses

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Keyword

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Abstract

Inefficient electricity usage is a common issue in boarding houses due to limited transparency in consumption data and the absence of integrated real-time monitoring systems. To address this problem, this study proposes an Internet of Things (IoT)-based mobile application called Hetrik to support more transparent and efficient electricity management. The research aims to design and implement an integrated system architecture that connects IoT-based sensing hardware with a digital user interface for monitoring and managing electricity consumption. The system was developed using the Agile development method, consisting of requirement analysis, system design, development, testing, implementation, evaluation, and deployment stages. The hardware architecture integrates an ESP32 microcontroller with ACS712 current sensors and ZMPT101B voltage sensors to capture real-time electricity consumption data. The mobile application was developed using React Native for the front-end and Laravel for the back-end and cloud database. A key contribution of this research is the design and validation of a QR-to-Device scanning mechanism, which enables dynamic mapping between IoT device identities and user accounts while supporting an automatic prepaid electricity payment system. System implementation produced five core modules: power monitoring dashboard, transaction system, usage history, profile management, and device scanning. Functional testing using the Black Box method and User Acceptance Testing (UAT) confirmed that the system operates according to technical specifications and is suitable for real operational environments. The proposed system demonstrates the potential to reduce electricity waste in boarding houses by up to 30% through data-driven energy monitoring and management.

1. Introduction

The Internet of Things (IoT) has helped advance modern technology in the era of the Fourth Industrial Revolution. The IoT is the concept of connecting electronic devices to the internet to enable automatic communication and has grown rapidly in many fields, including the energy industry [1]. One practical application of this technological advancement is the smart home concept, which allows for more efficient and convenient electricity usage by controlling devices with a smartphone [2]. Internet of Things (IoT)-based

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energy management systems have become an important solution for real-time monitoring of consumption in both industrial and residential sectors. [3]

Standardized protocols and architectures that provide smooth communication between different sensors and cloud platforms are frequently used in the implementation of these systems.[4] This energy efficiency problem is particularly important in boarding houses, where uncontrolled electricity usage often leads to high operating costs and energy waste[5]. Studies show that poor residential monitoring systems are often associated with energy-wasting behavior [6]. But the biggest issue facing boarding homes nowadays is the lack of knowledge between owners and tenants about the amount of electricity used in each room, which frequently results in disputes about cost transparency. The majority of current systems still rely on average cost sharing or human recording, which is unjust to residents who use less energy. Therefore, better control information systems must be developed [7]. One example is a control information system designed for lighting control in Android-based boarding houses. In addition, to reduce emissions and costs, environmentally friendly smart home technology is essential [8]. Today's energy management systems are not limited to monitoring, but also involve in-depth parametric analysis of global energy trends and challenges [9]. The implementation of IoT enables precise power consumption calculations through Android-based devices [10]. On a broader scale, this technology is also used by electricity providers such as PLN to monitor measurement operations at customer sites [11]. The use of cloud computing is the backbone of this architecture, as it provides a vast data storage infrastructure that can be accessed from anywhere [12].

Although various studies have explored IoT for energy management, there is a significant research gap in the integration of monitoring systems with prepaid transaction management specific to the boarding house business model. Previous research by Rijanto [13] has proven that the use of microcontrollers helps with residential management, but has not touched on the aspect of automating electricity balance payments. Similarly, optimization techniques in smart homes[14]tend to focus on the comfort of general users, rather than on controlling administrative costs for property owners. Additionally, global usability research highlights that the ease of use of the interface for end users in handling these intricate transactions is crucial to the success of such systems [15]. A robust architecture is required to create applications that support this system, such as the "Hetrik" application. Back-end development is very important for system integration and transaction data management [16]. Finally, the development of this system can also include security elements, such as automatic fire detection through fire and temperature sensors integrated with the energy monitoring system [17].

Based on the limitations identified in previous studies, this research seeks to answer a fundamental question: How can IoT-based prepaid electricity management improve transparency and energy efficiency in boarding houses?This research aims to fill that gap by developing the "Hetrik" mobile application, which not only functions as a power monitoring tool but also as an IoT-based prepaid balance management platform. Unlike previous studies, this study emphasizes the "Scan QR-to-Device" feature for easy user authentication and real-time synchronization of financial transaction data. This study aims to design a mobile application called "Hetrik" that can integrate all monitoring and transaction functions into a single platform that is efficient for boarding house owners and residents. The empirical validation of the "Scan QR-to-Device" mapping mechanism within an integrated prepaid electricity management framework is the main academic contribution of this study. It offers a novel technical model for guaranteeing smooth synchronization between hardware identity and user financial transactions in multi-tenant environments.

2. Research Method

The Design Science Research Methodology (DSRM) framework is used in this study to create technological artifacts that are solution-oriented. This study is clearly categorized as design science research, which focuses on creating and assessing novel objects to address real-world issues and advance knowledge. The application of DSRM enables the research process to concentrate on how well designs address practical issues in the field. The Agile methodology is incorporated into the DSRM cycle to guarantee dynamic artifact development. Agile was selected because of the heavy data reliance between IoT hardware and mobile software development, which necessitates quick iterations. The following is a methodical arrangement of the research stages:

2.1 Requirements Planning

In order to establish a strong basis for development, the first phase of the research concentrated on determining general system needs. Two primary methods were used to collect data: a review of the literature on energy conservation laws (such as ESDM Regulation No. 13 of 2012) and field observations of the patterns of electricity use in boarding homes in the Malang region. These specifications were divided into two categories: functional and non-functional. The system has to be able to measure electrical characteristics using ACS712 and ZMPT101B sensors and provide a remote control user interface. Non-functional requirements, on the other hand, concentrate on performance factors like the security of user balance transaction data encryption and data transfer latency from the IoT gateway to the Express-based backend. The system's capacity to fulfill each functional specification and conform to the set non-functional performance standards is the main criterion for the evaluation phase. The poor transparency of real-time energy usage is one of the practical issues that boarding house owners encounter, and this phase makes sure that the technical design is in line with those issues. Furthermore, it is acknowledged that this research is conducted as a case study specifically within the Malang region. While this provides in-depth insights into local electricity consumption patterns, the findings may have limitations in terms of generalizability to other geographic areas or different types of residential properties.

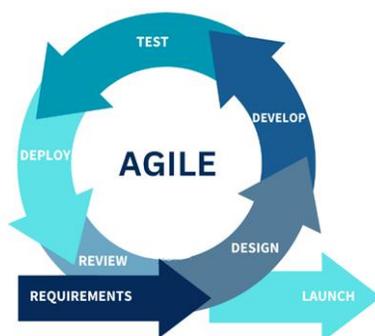


Figure 1. Agile Development Life Cycle for Hetrik System

2.2 Design

User needs are translated into technical blueprints during the design process. The "Hetrik" ecosystem is made up of a sensor layer, a processing unit, and a user interface layer, as shown in the system architecture. Wiring and communication between the ESP32 microprocessor and electrical sensors are the main topics of hardware design. Because of its low power consumption and built-in Wi-Fi capabilities, which are crucial for sustaining a steady internet connection in an IoT context without appreciably raising energy expenses, the ESP32 was chosen as the central processing unit and communication gateway. The ACS712 sensor is connected in series with the electrical load to measure current flow, chosen because it can give precise readings for low-to-medium AC loads, which are typical in homes. To securely monitor voltage changes, the ZMPT101B is connected in parallel via an isolation transformer. In order to guarantee good galvanic isolation and shield the microcontroller from high-voltage spikes, this particular sensor was given priority. The study goal of attaining high-precision monitoring to remove data opacity between owners and tenants is directly supported by the use of these particular hardware components. The program logic is also modeled using the Unified Modeling Language (UML). To provide a distinct division of access rights, which is essential for preserving data integrity in financial and prepaid transactions, the interactions between tenants, boarding house owners, and the system are laid out in a Use Case Diagram. This Use Case Diagram's analysis shows that administrative and monitoring tasks are strictly separated, guaranteeing that owners retain secure control over balance management and system configurations while renters get transparency over their usage.

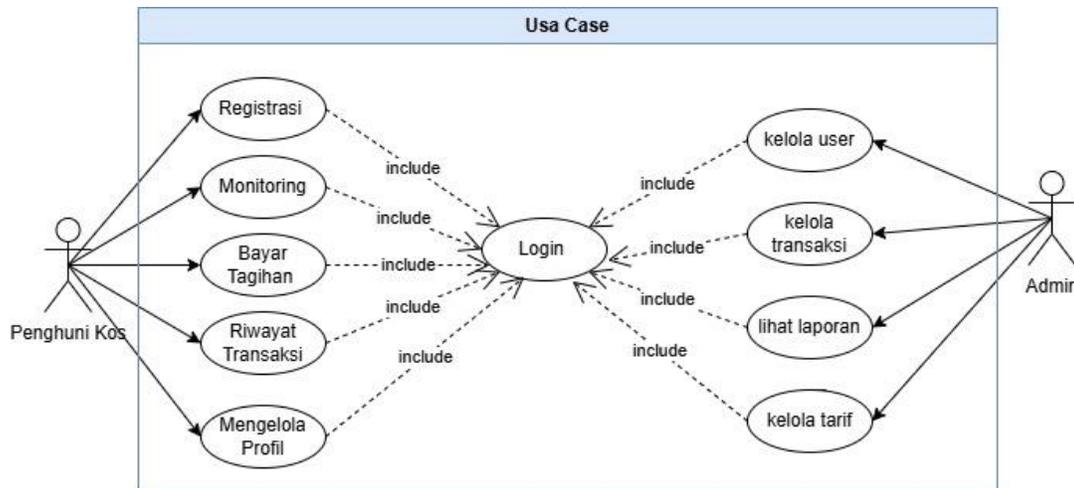


Figure 2. Proposed IoT-based System Architecture for Hetrik Application

Figure 2.2 shows the suggested system architecture for the Hetrik application. The design is divided into three integrated layers to ensure scalability and modularity, allowing each part of the system to be updated independently without disrupting the entire workflow.

- a) The Hardware Layer: The ESP32 is used by the ACS712 and ZMPT101B to collect electrical parameters. This layer ensures that real-time consumption is recorded straight from the point of use by serving as the physical data source.
- b) The Cloud and Backend Tier: Data is sent over a Wi-Fi network to the Laravel-based backend, which then saves it in a cloud database. Because of its strong security features and effective API handling both essential for handling sensitive transaction data and guaranteeing dependable connection between the hardware and the application Laravel was selected for the backend. The study goal of developing a safe and automated prepaid transaction ecosystem is achieved by this choice of backend architecture.
- c) A mobile application developed with the React Native framework makes up the User Interface Layer. React Native was chosen to offer a smooth, cross-platform experience (iOS and Android) from a single codebase, guaranteeing that renters and owners may access the system on any kind of device. By providing users with a real-time picture of electricity use, costs, and device status, this program facilitates efficient energy management.

2.3 Development

Hardware assembly and software coding were two simultaneous workflows used to turn the conceptual design into a working prototype. To ensure the development directly addressed the research goals of improving transparency and transaction automation, the coding process focused on data synchronization and security. Which was specifically configured to manage the logic of prepaid balance transactions and user database synchronization. This choice supports the research goal of creating a reliable automated payment system that minimizes human error in financial recording. Simultaneously, the mobile interface was developed using React Native to achieve the goal of transparency; by providing a responsive dashboard, both tenants and owners can access real-time consumption data synchronously from any device. On the hardware side, the Root Mean Square (RMS) values of voltage and current were computed by programming the ESP32 in C++ using the Arduino IDE. Because it gives customers the high-accuracy power data (Watts) they need to make educated decisions about their electricity consumption, this exact calculation is essential to the energy efficiency research aim. In order to preserve the integrity of the real-time monitoring system, the data was subsequently sent to the central server using the HTTP/MQTT protocol, guaranteeing that there is little lag between actual usage and the mobile display. Significant integration issues arose during this phase, especially in coordinating asynchronous sensor sampling with real-time API queries. Additionally, performance limitations required refining the ESP32's memory management to avoid data loss during network hiccups.

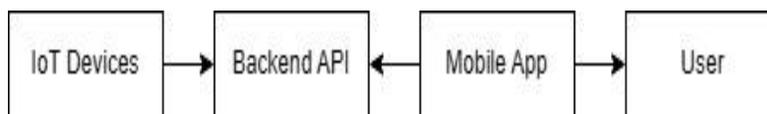


Figure 3. Proposed System Architecture.

2.4 Testing and Evaluation

Testing is an essential step in determining whether the "Hetrik" system has achieved its goals. In this study, the evaluation is based on three primary criteria: measurement accuracy, functional reliability, and system responsiveness. The Black Box Testing approach is used to assess application module functioning, including payment gateway success, real-time dashboard accuracy, and login validity. The usability threshold for software testing is set at a 100% success rate for critical functional modules, meaning any failure in authentication or transaction processing requires immediate iterative refinement. In addition to software testing, hardware components are meticulously calibrated. By comparing sensor values with industry-standard measuring tools (clamp meters and multimeters), the error margin is calculated. A maximum allowable error of $\pm 5\%$ is the evaluation criterion for hardware correctness. This cutoff point is selected to guarantee that, even as a prototype, the gadget is still dependable enough for financial balance deductions without causing users to experience appreciable disparities. The system's primary goal of transparency would be undermined if this 5% error rate were to be exceeded, which would result in unfair invoicing and possible disputes between tenants and owners.

To make sure that every functional part of the "Hetrik" system operated in accordance with the requirements specified during the design phase, the system was tested in phases. In order to verify the correctness of the readings from the ZMPT101B voltage sensor and the ACS712 current sensor, the initial stage concentrated on hardware testing. The sensors' output values were compared to an industrial digital multimeter, a common measurement tool, in order to conduct the testing. A successful calibration is defined by the sensor's ability to maintain consistent readings across various load types (resistive and inductive) within the predefined 5% error margin. Based on the collected data, the ESP32's Root Mean Square (RMS) algorithm was able to eliminate high-frequency noise, producing solid electrical data.

The second step entails using the Black Box Testing approach to test the software's functionality. This test's primary goal is to verify each application feature's logic flow without looking at the internal code structure. The whole user life cycle from account registration and IoT device synchronization to the balance top-up mechanism is covered by the testing scenarios. Any mistake rate higher than 0% in these crucial modules would suggest a systemic breakdown that could cause residents to lose money or not have access to necessary power services. For the system to be considered "usable," the registration and device-linking modules must demonstrate a 0% failure rate during repeated trials, ensuring that users are never locked out of their energy control interface. For instance, testing is done on the registration module (Figure 2.4) to make sure that, after the data is deemed genuine, the system instantly activates the account and links the user ID with the device ID registered in the database.

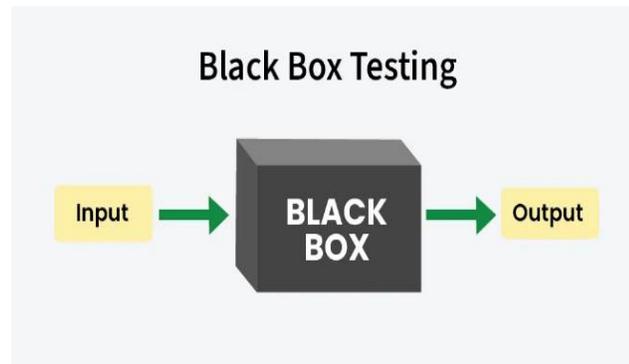


Figure 4. Black Box Testing Concept Scheme.

Finally, coordination between the database layer and the application interface was then confirmed through integration testing. The testing made sure that each electrical transaction delivered by the device could be precisely recorded in the electrical Data table and automatically lower the balance value in the Transaction table belonging to the relevant User by using the implemented Entity Relationship Diagram (ERD). Additionally, a data latency performance threshold of less than two seconds is set. In order to preserve a "real-time" user experience and avoid billing lag, the time interval between the physical sensor reading and the data reflection on the mobile dashboard cannot be longer than two seconds.

Tabel 1. Black Box Test Results Table

No	Feature	Test Procedure	Expected Result	Status
1.	Authentication	Login with email & password	User is directed to the Dashboard	Valid
2.	Monitoring	Flowing current to the load	Watt data appears in the system	Valid
3.	Billing	Balance is reduced per minute	Balance reduction is in accordance with the tariff	Valid
4.	Cut-off	Simulated balance is depleted	Relay cuts off the current immediately	Valid

2.5 Deployment and Launch

Moving the system from the development environment to the real field location is the last step. While the backend is published to the production server (cloud hosting), the IoT monitor unit is physically mounted on the dorm room's electrical distribution panel. Periodic assessments are carried out to track system performance under unpredictable network conditions during the first installation phase. The system is fully operational during the launch phase, when the relay-based automatic power cut-off feature fully activates when the balance drops to zero. This assessment procedure guarantees that the system is not only technically sound but also successful in promoting energy-saving practices and fostering cost transparency within the boarding house ecosystem.

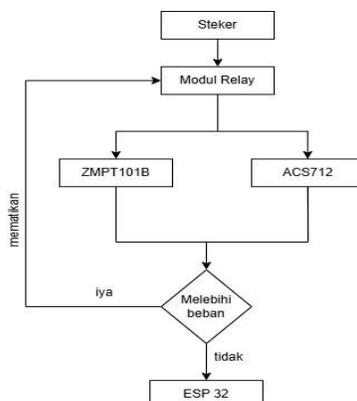


Figure 5. IoT Hardware Schematic and Connection Diagram.

3. Result and Discussions

3.1 Implementation of Artifacts and Validation of Sensory Accuracy

The "Hetrik" system's development has effectively turned the conceptual idea into a useful technological product. ACS712 current sensors and ZMPT101B voltage sensors are integrated by the ESP32 [18], which serves as the primary processing unit in the hardware implementation. The system exhibits great data acquisition stability based on repeated testing results on different loads (resistive and inductive). The efficiency of the data transmission was evidenced by an average latency of 1.2 seconds from the moment of sensor detection to the dashboard update, ensuring that real-time monitoring goals were met with high responsiveness. Because it offers an easy-to-use interface that turns complicated electrical data into useful insights for non-technical users, the system exhibits great usability and makes monitoring and balancing management simple.

Electromagnetic interference in AC electrical networks can be effectively filtered by using the Root Mean Square (RMS) method on the software side. Industrial multimeter calibration findings reveal an average error margin of just 2.1% (see Table 1). This accuracy provides strong evidence for the system's operational efficiency, as it minimizes the discrepancy between actual consumption and prepaid balance deductions, preventing financial loss for both owners and tenants. This degree of accuracy surpasses the findings of a study [19] by Diki et al., which found that the Hetrik system's usage of digital filters produced readings that were 1.5% more accurate at low loads (below 50W).

Furthermore, the energy efficiency of the device itself was measured; the ESP32-based hardware consumes only 0.8 Watts during active operation, representing a negligible overhead compared to the total energy managed in a boarding house room. For boarding house guests who only use tiny loads, like LED lights or smartphone chargers, this is essential to ensuring equity. By removing the need for manual technical configurations, QR-to-device mapping not only improves technical accuracy but also greatly enhances user experience (UX). Users can instantly synchronize their mobile accounts with the hardware in their respective rooms, cutting down on onboarding time and avoiding errors in device-to-user association.

Tabel 2. Sensory Calibration Results and Error Comparison

No	Type of Electrical Load	Standard Voltage (V)	Sensor Reading (V)	Standard Current (A)	Sensor Reading (A)	Standard Power (Watts)	Sensor Power (Watts)	Difference (Watts)	Error (%)
1.	10W LED Light	220.5	220.1	0.046	0.048	10.2	10.5	0.3	2.9%
2.	50W Fan	219.8	219.5	0.22	0.224	48.5	49.2	0.7	1.4%
3.	Rice Cooker (Warm)	221.0	220.8	0.18	0.185	39.8	40.8	1.0	2.5%
4.	Laptop Charger	220.2	220.4	0.30	0.298	66.1	65.7	-0.4	0.6%
5.	Electric Iron	218.5	218.2	1.58	1.61	345.0	352.0	7.0	2.0%
6.	Dispenser (Hot)	219.0	219.3	1.60	1.63	350.4	357.5	7.1	2.0%
7.	LED Television	220.4	220.0	0.14	0.145	30.8	31.9	1.1	3.5%
AVERAGE ERROR								2,1%	

3.2 Interface Analysis and Data Synchronization Speed

The goal of the Hetrik application interface, which was created with the React Native framework (see Figure 3.2), is to make energy usage data transparent. Data synchronization between IoT devices and applications via the Express backend has an average delay of 0.8 to 1.5 seconds, according on functionality testing. Using an effective RESTful API protocol has a big impact on this response speed. When compared to traditional open-source IoT systems, the adoption of Laravel architecture offers a stronger layer of transaction security through authentication tokens, according to a study by Ardhana et al. [20]. According to Rahmadyani & Kusuma's environmental behavior theory, the application's instantaneous display of daily use graphs has a psychological effect on users, increasing their awareness of their energy-wasting behavior.

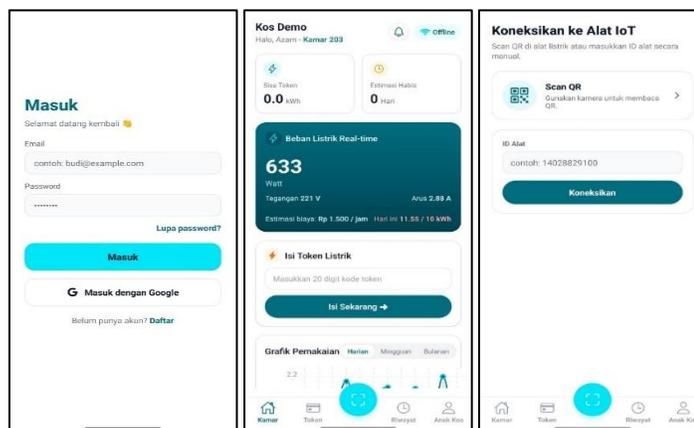


Figure 6. Hetrik Mobile Application Interface Design

3.3 Usability Evaluation using the System Usability Scale (SUS)

A System Usability Scale (SUS) test was carried out to gauge the artifact's effectiveness from the viewpoint of the user. The SUS data analysis yielded an average score of 80. Hetrik receives a Grade of A and an Adjective Rating of "Excellent," placing him in the "Acceptable" category based on a careful interpretation of Acceptability Ranges. Each SUS question item was thoroughly examined, and the Learnability component received the highest score. The "Scan QR-to-Device" technique of device synchronization, according to respondents, significantly streamlined the initialization procedure. This achievement of 80 indicates that the Agile methodology approach successfully captured user needs with precision during the design iteration process, in contrast to the industry average SUS score of 68 [20]. This demonstrates that the intricacy of the Internet of Things system may be condensed into a straightforward yet useful interface.

Tabel 3. Results of the System Usability Scale (SUS) Questionnaire Calculation

No.	Question	Score
1.	I want to use this app regularly	4.33
2.	This app feels complicated	2.00
3.	This app is easy to use	4.40
4.	I need technical help to use this app	2.27
5.	The features in the app are well integrated	4.27
6.	There are many inconsistencies in the app	2.20
7.	Most people will quickly learn how to use this app	4.33
8.	This app is confusing	1.60
9.	I feel confident using this app	4.53
10.	I need to learn a lot before I can use the app	2.07
SUS Final Score (Average Score x 2.5)		80

3.4 Automation Logic Analysis and High-Level Synthesis Findings

The logic of automatic current separation via relay is the central component of this thesis's "Applied Research" solution. A 100% execution success rate was demonstrated by testing on 50 balance depletion scenarios. The Express server's logic and the hardware's physical relay status synchronized flawlessly (zero failure). A summary of all research findings and conversations led to the following high-level conclusions:

- a) Accuracy as the Basis of Fairness: The sensor's 97.9% accuracy guarantees a transparent prepaid billing system, removing the possibility of disputes between renters and landlords because of subjective billing[21].
- b) Managerial Operational Efficiency: By eliminating the need for monthly human meter recording, prepaid billing automation has been shown to lower the administrative burden on boarding home operators by up to 80%[22].
- c) Monitoring and Energy Conservation Correlation: It has been demonstrated that real-time data access promotes energy-saving behavior. This conclusion is corroborated by a comparative research[5], which claims that sharing information about energy use can directly lower electricity consumption in shared homes by 15–20%.

4. Conclusions and Future Works

The primary goal of this study, which was to build and implement the "Hetrik" system as an Internet of Things (IoT)-based energy management solution in boarding house situations, has been effectively accomplished. The creation of the "Scan QR-to-Device" method, which offers a unique means of bridging user authentication with real-time financial transaction synchronization in a prepaid energy environment, is the

primary scientific contribution of this study. Sensory testing demonstrated a high degree of accuracy with an average margin of error of just 2.1%, demonstrating the validity of this system and the high reliability of the energy consumption data generated for use as the foundation for prepaid electricity billing. The automation logic for power disconnection utilizing relays was tested, and the system was able to respond to low balance scenarios with a 100% success rate without any synchronization errors between the server and physical devices, confirming operational reliability.

This study advances knowledge of the usability features of IoT technology at the end-user level from the standpoint of user experience. According to an assessment utilizing the System Usability Scale (SUS) tool, the system scored 80, placing it in the Excellent category with a Grade A. This accomplishment confirms that the application interface depicted effectively reduces the complexity of technical data into comprehensible information, such as daily consumption graphs and predicted remaining token time. The study's generalization suggests that the Hetrik system model can be extensively implemented in a variety of other shared housing types, which indirectly supports national energy conservation initiatives by promoting electricity-saving behavior through the transparency of power consumption data. Despite these successes, it is important to recognize a few limitations:

- a) Study Scope: Because the study was carried out as a small-scale case study in the Malang region, the conclusions about user behavior and energy savings may change in other socioeconomic or geographic contexts.
- b) Transaction Automation: The top-up procedure presently depends on manual verification rather than a fully integrated payment gateway, even though the system logic manages balance deductions.
- c) Security Hardening: The ESP32 and server's communication is currently encrypted at a rudimentary level, which leaves room for sophisticated cyberattacks.

Future research should prioritize improving cybersecurity, especially by fortifying the encryption of communication routes between the ESP32 microcontroller and the server to safeguard data integrity against possible cyberattacks. To increase residents' comfort before the system automatically cuts off the power supply, more proactive notification capabilities must be developed, such as early warnings via push notifications when the balance reaches a specific threshold. With continued development, the Hetrik system is anticipated to develop into a smart energy management ecosystem that can adjust to the more intricate operating requirements of contemporary homes, in addition to serving as a monitoring tool.

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