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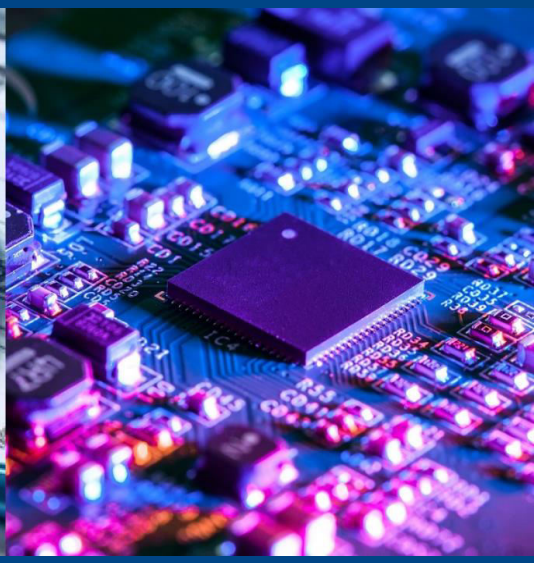

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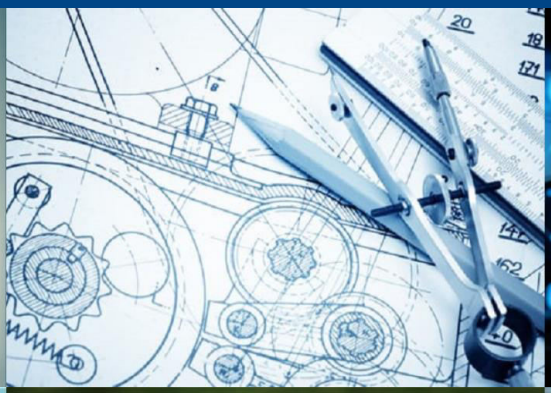

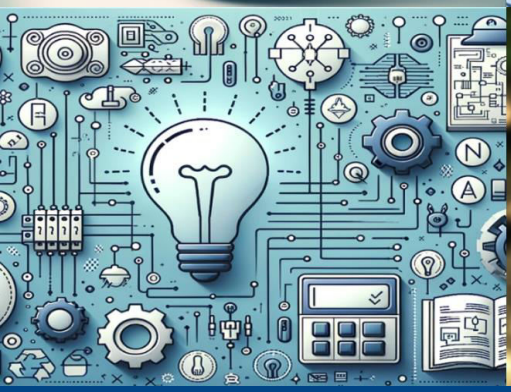

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Design, Development and Acceptability of an AIoT-Based Prepaid Electric Consumption Monitoring Application

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ABSTRACT: This paper presents the design, development, and evaluation of an Artificial Intelligence with Internet of Things (AIoT)-based prepaid electric consumption monitoring application intended to improve electricity monitoring and billing support for residential users and electric cooperatives. The study addressed limitations of traditional billing such as delayed meter reading, possible human error, limited consumer visibility, and inconvenient payment processes. A descriptive developmental research design was used. The system integrated IoT-enabled metering hardware, prepaid balance deduction, online and offline reloading, mobile dashboard monitoring, notification settings, appliance registration, anomaly-related alerts, and report submission. The development process was guided by the Agile model, AIoT layered architecture, and Rogers' Diffusion of Innovations Theory. The respondents consisted of 200 household users composed of owners, tenants or renters, and household helpers. System quality was evaluated using ISO/IEC 25010 characteristics, while acceptability was measured through a structured survey instrument. Results showed that all seven software quality characteristics were rated Excellent: functional suitability (M = 3.55), performance efficiency (M = 3.58), compatibility (M = 3.55), usability (M = 3.58), reliability (M = 3.60), security (M = 3.61), and maintainability (M = 3.59). The system also obtained a Highly Acceptable overall mean of 4.56. These findings indicate that the developed AIoT prepaid monitoring application is functional, efficient, secure, maintainable, and acceptable for consumer-centered electricity monitoring and prepaid billing support.

KEYWORDS: AIoT, prepaid electricity, electric consumption monitoring, ISO/IEC 25010, smart metering, mobile application

I. INTRODUCTION

Electricity billing and consumption monitoring remain important concerns for residential consumers and electric distribution providers. In conventional billing processes, utility personnel visit service areas to read meters, record consumption, process billing statements, and notify consumers. Although this process is familiar, it may be affected by human error, delayed data collection, inaccurate reading, limited consumer visibility, and high manpower requirements. These issues become more critical when consumers need timely information about their electricity use and payment obligations.

The continuing development of smart metering, artificial intelligence, and Internet of Things technologies has created opportunities to modernize electricity monitoring. IoT sensors and microcontrollers can collect real-time voltage, current, and consumption data, while AI can support prediction, anomaly detection, and decision support. In a prepaid electricity setting, these technologies can help consumers monitor remaining balance, understand appliance-level usage, receive early warnings, and plan reloading activities before disconnection occurs.

This study developed an AIoT-based prepaid electric consumption monitoring application that integrates metering hardware, a mobile and web-based interface, prepaid reloading mechanisms, automated balance deduction, dashboard display, notifications, and reporting features. Instead of relying only on delayed monthly billing, the system gives

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consumers immediate access to consumption and balance information. The paper focuses on the development and acceptability of the system, particularly its software quality based on ISO/IEC 25010 and its perceived usefulness among residential users.

The study is significant for households because it provides a tool for monitoring electricity use, controlling prepaid balance, and improving awareness of consumption patterns. It is also useful for electric cooperatives because it may reduce manual meter-reading activities, support consumer-centered billing services, and improve monitoring transparency. For IT practitioners and future researchers, the study offers a development model for integrating AI, IoT, prepaid payment, and mobile application functions in an energy management context.

II. LITERATURE REVIEW

Recent literature emphasizes the value of AI in energy management. Biswas et al. [3] described AI-driven techniques as useful for analyzing consumption patterns, optimizing power use, and supporting decision-making. Mathumitha et al. [13] further explained that deep learning techniques can improve energy consumption forecasting in smart buildings by learning from historical usage data. These concepts support the present system because prepaid electricity users benefit from forecasting and consumption awareness when managing limited prepaid balance.

IoT is likewise central to smart electricity monitoring. Sithole et al. [18] highlighted the role of IoT devices in monitoring and controlling energy management systems through connected sensors and communication networks. El-Khozondar et al. [5] demonstrated the practicality of using an ESP32 microcontroller to collect voltage, current, active power, and accumulated power consumption in real time. Garcés et al. [7] also developed an IoT-enabled smart electricity meter for real-time energy monitoring and efficiency. These studies show that low-cost microcontroller and sensor-based systems can provide timely consumption information.

Local studies confirm the feasibility and relevance of IoT-based energy monitoring in the Philippines. Magtibay et al. [12] developed Green Switch, an IoT-based energy monitoring and control system in a university building. Merencilla et al. [14] developed an energy management and power outage detection system for commercial buildings. Monton et al. [15] implemented an IoT-based energy monitoring system for university facilities using current sensors, ESP8266 Wi-Fi modules, Firebase, and a web-based interface. These studies show that energy monitoring systems can be implemented in local settings, although many focus on institutional or building energy management rather than household prepaid monitoring.

Prepaid electricity systems have been studied as a way to improve payment control and consumer budgeting. Irianto [10] designed a prepaid smart energy meter monitoring system for household use based on IoT. Tripathi et al. [19] reviewed ESP32-based prepaid electricity meters with remote monitoring and security features. However, many existing systems remain focused on monitoring, billing estimation, or hardware implementation alone. The present study addresses this gap by integrating prepaid balance tracking, real-time IoT monitoring, mobile access, online and offline reloading, appliance-level awareness, reporting, and AI-supported anomaly detection in one system.

Relevance to current Research

The reviewed works show the importance of combining IoT hardware, intelligent analysis, and user-facing applications for energy monitoring. However, the present study differs from earlier works by emphasizing prepaid balance deduction, hybrid reloading, mobile notification, household-level appliance awareness, and system acceptability using ISO/IEC 25010. This makes the study directly relevant to consumer-centered prepaid electricity monitoring and electric cooperative service improvement.

Table 1: Summary of Related Literature and Studies

No.	Author/s	Focus of Study	Relevance to Current Research
1	Biswas et al. [3]; Wang et al. [20]	AI-supported load forecasting, anomaly	Supports the AI component for prediction and

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		detection, and consumption optimization	abnormal consumption awareness.
2	El-Khozondar et al. [5]; Garcés et al. [7]	Smart energy monitoring using ESP32 and IoT-enabled electricity meters	Provides basis for real-time metering and sensor-based data collection.
3	Magtibay et al. [12]; Monton et al. [15]	Local IoT-based energy monitoring in institutional facilities	Shows the feasibility of local implementation using sensors, wireless communication, and dashboards.
4	Irianto [10]; Tripathi et al. [19]	Prepaid smart energy meter design and ESP32-based prepaid meter features	Supports prepaid monitoring, remote access, and security-oriented metering.
5	Galvez [6]; Magnaye et al. [11]	Residential energy management and cloud-based electricity usage monitoring	Provides related local and application-based context for household monitoring and user access.

III. METHODOLOGY OF PROPOSED STUDY

Research Design: The study employed a descriptive developmental research design. It was developmental because it involved the design and creation of an AIoT-based prepaid monitoring application and supporting hardware. It was descriptive because the developed system was evaluated using respondent ratings and weighted means based on software quality and acceptability indicators.

Respondents and Locale: The study was conducted in Tandag City, Surigao del Sur, Philippines, with 200 respondents composed of household owners, household tenants or renters, and household helpers. The respondents represented household users who had practical experience in monitoring monthly bills and electricity consumption.

System Development: The system was developed using an iterative process. The hardware component included a microcontroller, current and voltage sensors, display module, communication module, coin acceptor, bill acceptor, and outlet-based monitoring components. The application component included login, dashboard, kWh monitoring, reloading history, online top-up, notification settings, appliance registration, appliance marking, data statistics, and report submission. The system supported both online reloading through a mobile application and offline reloading through coin and bill acceptors.

Research Instrument and Data Treatment: The evaluation instrument was based on ISO/IEC 25010 software quality characteristics, namely functional suitability, performance efficiency, compatibility, usability, reliability, security, and maintainability. A Likert-type scale was used to interpret quality ratings from Poor to Excellent. Overall system acceptability was measured through indicators on design and quality, service or performance, cost-effectiveness, accuracy, and hardware-software synchronization. Data were summarized using frequency, percentage, and weighted mean.

Table 2: Distribution of Respondents

Respondent Classification	Frequency	Percentage
Household owner	144	72%
Household tenant/renter	32	16%
Household helper	24	12%
Total	**200**	**100%**

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IV. RESULTS AND DISCUSSION

Developed System Features: The developed AIoT-based prepaid monitoring application provides an integrated interface for electricity consumption monitoring and prepaid billing support. Through the dashboard, users can view remaining load, kWh used, active appliances, hourly consumption, reloading history, and kWh rate information. The kWh monitoring page allows users to view consumption records by plug number, kWh used, and date, while the filter function supports historical tracking. Notification settings allow users to update contact details for low-balance and abnormal-current alerts.

The reloading component is one of the central features of the system. Online reloading allows users to enter a reload amount and payment information through the application. Offline reloading is supported by a coin and bill acceptor integrated into the prepaid machine. The LCD display shows remaining load, kWh used, kWh rate, and active appliances. This combination provides flexible payment options and reduces the need for consumers to visit the cooperative office for routine payment-related transactions.

The system also supports appliance registration and appliance marking. Users can add appliance details and associate an appliance with a specific plug after turning it on. This feature allows appliance-level awareness and improves the interpretability of energy usage. The report or damage/error feature allows users to submit system-related concerns and monitor submitted reports. Collectively, these functions distinguish the system from ordinary postpaid billing systems and basic energy monitoring prototypes.

Table 3: Summary of ISO/IEC 25010 Evaluation Results

Software Quality Characteristic	Weighted Mean	Verbal Description
Functional suitability	3.55	Excellent
Performance efficiency	3.58	Excellent
Compatibility	3.55	Excellent
Usability	3.58	Excellent
Reliability	3.60	Excellent
Security	3.61	Excellent
Maintainability	3.59	Excellent

Table 3 shows that all ISO/IEC 25010 quality characteristics were rated Excellent. Security obtained the highest weighted mean of 3.61, indicating that respondents positively evaluated access control and protection of consumption-related data. Reliability followed with a mean of 3.60, suggesting that the system was perceived as dependable in tracking consumption and supporting monitoring functions. Maintainability obtained a mean of 3.59, reflecting the value of modular design and the possibility of future improvement. The remaining characteristics also obtained Excellent ratings, showing that the system was functional, efficient, compatible, and usable.

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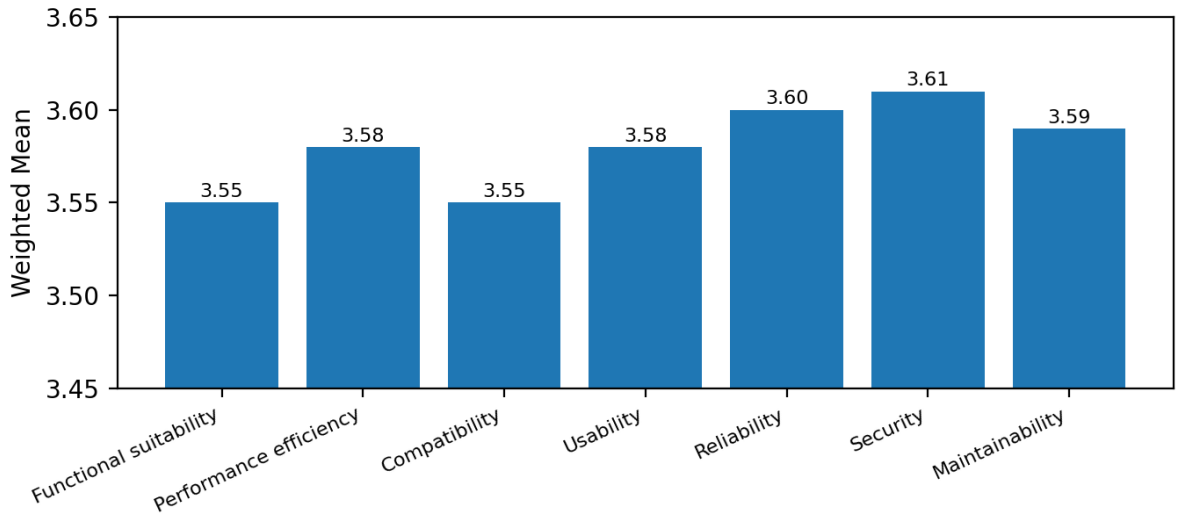

Figure 1: ISO/IEC 25010 Evaluation Results of the Developed System

Table 4: Overall Acceptability of the Developed System

Acceptability Indicator	Mean	Verbal Description
Design and quality	4.49	Highly Acceptable
Service or performance	4.54	Highly Acceptable
Cost-effectiveness	4.49	Highly Acceptable
Accuracy	4.61	Highly Acceptable
Hardware-software sync	4.68	Highly Acceptable
Average Mean	**4.56**	**Highly Acceptable**

The system obtained an overall mean of 4.56, interpreted as Highly Acceptable. Hardware and software synchronization received the highest mean of 4.68, indicating that respondents recognized the coordination between the prepaid meter hardware and the application interface. Accuracy also received a high mean of 4.61, showing confidence in the system output. Service or performance, design and quality, and cost-effectiveness were likewise rated Highly Acceptable. These findings suggest that the developed system is acceptable to users and has potential for practical application in prepaid electricity monitoring.

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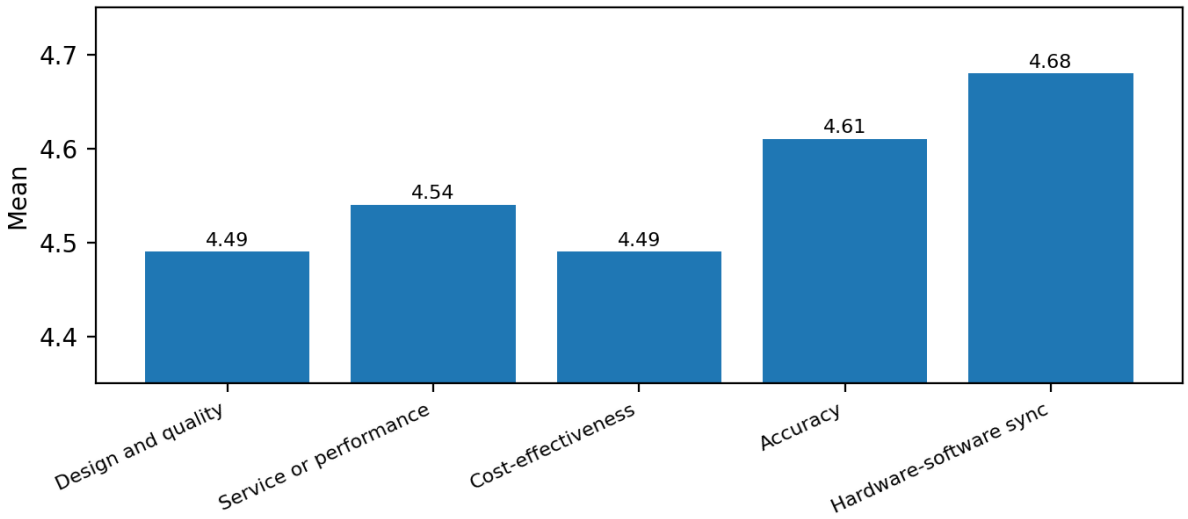

Figure 2: Overall Acceptability Indicators of the Developed System

Table 5: Reliability Analysis of the Evaluation Instrument

Construct	No. of Items	Cronbach Alpha	Interpretation
Functional suitability	4	0.742	Acceptable
Performance efficiency	4	0.753	Acceptable
Compatibility	3	0.804	Good
Usability	7	0.867	Good
Reliability	5	0.779	Acceptable
Security	4	0.785	Acceptable
Maintainability	4	0.801	Good
Level of acceptability	5	0.790	Acceptable

The reliability analysis showed acceptable to good internal consistency across the evaluation constructs. Usability obtained the highest Cronbach alpha of 0.867, followed by compatibility at 0.804 and maintainability at 0.801. These values indicate that the instrument was sufficiently reliable for measuring respondent perceptions of the developed AIoT prepaid monitoring application.

Hypothesis-related findings indicated that the AIoT-based prepaid monitoring system improved billing accuracy and efficiency compared with the existing billing approach. The descriptive results support this claim because accuracy, hardware-software synchronization, and service or performance were rated Highly Acceptable. The integration of real-time monitoring and automated prepaid deduction reduces dependence on manual reading and delayed billing information. The LSTM-based anomaly detection feature was also considered feasible because respondents rated reliability, real-time monitoring, and accurate tracking as Excellent. Future publication should include complete inferential statistics, including test statistic, p-value, and effect size, to strengthen hypothesis claims and meet journal reporting standards.

V. CONCLUSION AND FUTURE WORK

The developed AIoT-based prepaid electric consumption monitoring application provides a practical and acceptable solution for improving consumer access to electricity usage and prepaid balance information. By integrating IoT-based metering, mobile monitoring, online and offline reloading, automated balance deduction, appliance registration, notifications, and reporting features, the system addresses common limitations of traditional billing and delayed

consumption feedback. The ISO/IEC 25010 evaluation results showed that the system met expected software quality characteristics, while the overall acceptability rating showed strong user approval.

The study concludes that an AIoT-based prepaid electricity monitoring system can contribute to more transparent, efficient, and consumer-centered energy management. It can support households in controlling electricity expenses and assist electric cooperatives in reducing manual processes. The high ratings in security, reliability, maintainability, accuracy, and hardware-software synchronization suggest that the system is suitable for pilot implementation and further refinement.

Future work may include pilot testing in selected households, improvement of scalability and cybersecurity, compliance review with electricity and data privacy regulations, and integration with authorized payment systems. Future researchers may also conduct experimental or quasi-experimental comparisons between traditional billing and AIoT-based prepaid monitoring using actual billing accuracy, processing time, anomaly detection accuracy, user retention, and cost-benefit measures. Additional studies may integrate renewable energy sources, advanced load forecasting, and broader appliance-level analytics.

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