Smart Home Electricity Meter Based on IoT with Bill Prediction Using Random Forest Algorithm

Muhtaredi[1], Arisa Olivia[2], Ariep Jaenul[3]
[1,2,3] *Electrical Engineering Department, Faculty of Engineering and Computer Science, Jakarta Global University, Depok, Indonesia*

Abstract— Electricity consumption in households continues to increase along with the growth of electrical appliances used in daily activities. However, most users do not have real-time information about their electricity usage, which often results in inefficient energy consumption and unexpected electricity bills. This study aims to design and implement a smart electricity metering system based on the Internet of Things (IoT) with a billing prediction feature using the Random Forest algorithm. The proposed system measures electrical parameters such as voltage, current, and power consumption using sensors connected to a microcontroller. The collected data are transmitted to an IoT platform to provide real-time monitoring of electricity usage through a mobile application. Furthermore, the Random Forest algorithm analyzes the collected data to predict future electricity bills. The results show that the developed system can monitor electricity consumption in real time and provide accurate billing predictions. The prediction model achieved a Root Mean Squared Error (RMSE) of 0.31% with an accuracy level of 99.69%. The system also provides electricity consumption information for three selected rooms in the household.

Keywords— smart meter, internet of things, electricity monitoring, random forrest, bill prediction.

Corresponding author. Tel.: +6281316067405
Email : muhtaredi11@gmail.com

1. Introduction

Electric energy has become an essential component of modern human life. The increasing use of electrical devices in households has significantly increased electricity consumption [1]. However, most electricity users only receive information about their energy consumption through monthly electricity bills [2]. This limited information makes it difficult for users to monitor their electricity usage patterns and control energy consumption efficiently [3].

Smart meter technology has emerged as a promising solution to address this problem. A smart meter is a digital device that can measure electricity usage and provide detailed information about energy consumption in real time [4]. By integrating smart meters with Internet of Things (IoT) technology, electricity consumption data can be transmitted to cloud platforms and accessed remotely through mobile applications [5].

Several previous studies have proposed IoT-based energy monitoring systems to improve energy efficiency and provide real-time monitoring capabilities [6]. However, many existing systems only focus on monitoring electricity usage without providing predictive insights regarding future electricity bills. As a result, users still face difficulties in estimating future energy costs and managing their electricity consumption effectively [7].

To address this limitation, this research proposes an IoT-based smart electricity metering system equipped with a billing prediction feature using the Random Forest algorithm [8]. Random Forest is a machine learning algorithm known for its high prediction accuracy and robustness in handling complex datasets [8]. By integrating real-time monitoring with predictive analytics, the proposed system is expected to provide better insights into electricity usage and assist users in managing their energy consumption more effectively [7].

2. Method

2.1. System Design

The proposed system consists of hardware and software components integrated to measure, transmit, and analyze electricity consumption data. The hardware system includes sensors for measuring electrical parameters and a microcontroller for data processing and communication.

The main hardware components used in this system include:

- ESP32 microcontroller [9]
- Voltage sensor ZMPT101B [10]
- Current sensor SCT-013-000 [11]
- Power sensor PZEM-004T [12]
- LCD TFT display [13]
- IoT platform using Blynk application [14]

The sensors measure electrical parameters such as voltage, current, and power consumption. The ESP32 microcontroller processes the data and transmits it to the cloud server using an internet connection

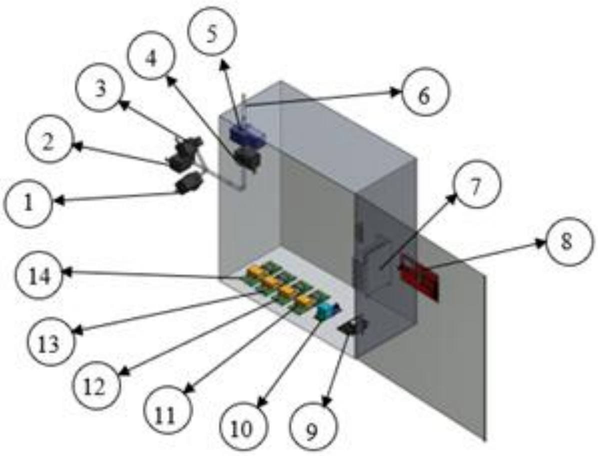

Fig. 1. Hardware Design.

2.2. Data Acquistion

Electricity consumption data are collected from three main rooms in a household. The sensors continuously measure electrical parameters and transmit the data to the IoT platform [15]. The data include:

- Voltage (V)
- Current (A)
- Power (W)
- Energy consumption (kWh)

The collected data are stored and used as input for the machine learning prediction model.

2.3. Random Forrest

Random Forest is a machine learning algorithm introduced by Leo Breiman in 2001 that is widely used for both classification and prediction tasks. The algorithm belongs to the ensemble learning category because it combines multiple decision trees to improve prediction accuracy and reduce the risk of overfitting [16].

In the Random Forest method, several decision trees are constructed using randomly selected subsets of training data. Each tree independently produces a prediction result based on the input data [16]. The final prediction is determined by aggregating the outputs of all decision trees, typically using a voting mechanism for classification or averaging for regression problems [17].

One important technique used in Random Forest is Bootstrap Aggregating (Bagging). In this process, random samples of both attributes and data instances are taken from the dataset to build different decision trees. This diversity among trees helps improve the robustness and accuracy of the model [18].

Random Forest is known for its high accuracy and strong performance when handling large datasets and complex prediction problems [19]. Compared with other machine learning methods such as K-Nearest Neighbor (KNN), Support Vector Machine (SVM), and Linear Regression, Random Forest often provides better precision and prediction stability [20].

In the smart meter system developed in the research, IoT technology enables the monitoring of electricity consumption in real time. The system collects electrical parameters such as voltage, current, and power using sensors connected to a microcontroller [19]. The data is then transmitted to a cloud-based platform and visualized through a mobile application for user monitoring.

The integration of IoT technology allows users to access energy consumption data anytime and anywhere, making it easier to monitor electricity usage and manage household energy consumption efficiently [21].

Random Forest is a supervised machine learning algorithm that uses multiple decision trees to perform regression or classification tasks [22]. In this research, the Random Forest algorithm is used to predict electricity bills based on historical electricity consumption data.

The prediction process involves several steps:

- Data preprocessing
- Feature extraction
- Model training
- Model testing
- Prediction of electricity bills

The prediction model is implemented using Python programming language.

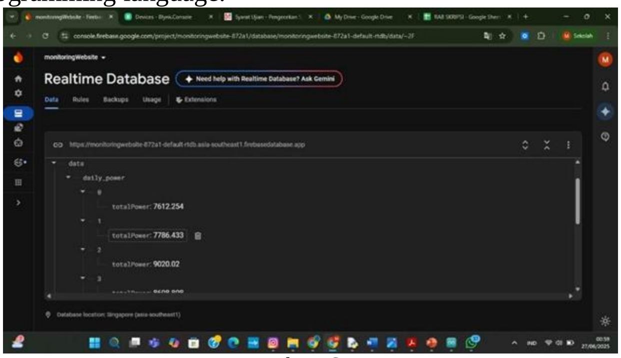

Fig. 2. Firebase Server.

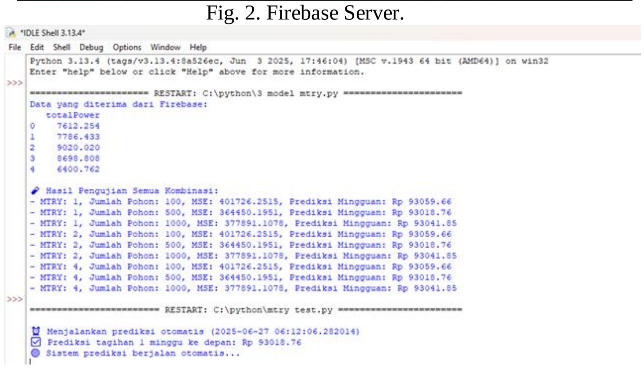

Fig. 3. Python Server.

3. Result and Discussion

The developed smart meter system was tested to evaluate its performance in monitoring electricity consumption and predicting electricity bills. The testing process involved measuring electrical parameters from three selected rooms in a residential building.

The system successfully measured voltage, current, power consumption, and energy usage in real time. The data were transmitted to the Blynk IoT platform, allowing users to monitor electricity usage through a mobile application.

The Random Forest prediction model was evaluated using Root Mean Squared Error (RMSE) [23] as the performance metric.

$$RMSE = \sqrt{\sum_{i=1}^{n} \quad (P - O)^2/n}$$

Information:
P = predicted value
O= observed value
N= number of observation

Table 1
System Performance Test Results in Rupiah (Rp)

Day	Initial kWh (Rp)	Electricity Consumption kWh PLN	Electricity Consumption System	Prediction Result	Actual Result
Day 1	Rp 64.701	Rp 7.716	Rp 7.612	Rp 60.455	Rp 55.030
Day 2	Rp 56.985	Rp 8.310	Rp 7.786		
Day 3	Rp 48.675	Rp 8.515	Rp 9.020		
Day 4	Rp 40.160	Rp 8.906	Rp 8.699		
Day 5	Rp 31.254	Rp 6.832	Rp 6.401		
Day 6	Rp 24.422	Rp 5.119	Rp 4.910		
Day 7	Rp 18.763	Rp 9.632	Rp 10.534		
TOTAL CONSUMTION		Rp 55.030	Rp 54.962		

The following steps describe how to calculate the Root Mean Squared Error (RMSE) value using the data in Table 1 with Rupiah (Rp) as the unit.

1. Calculate the Squared Error Value $(P - O)^2$
   Where:
   - P = Predicted value
   - O = Observed (actual) value

   $(Rp\ 60.455 - Rp\ 55.030)^2 = (Rp\ 5{,}425)^2 = 29.430$
2. Substitute the Value into the RMSE Formula

   $$RMSE = \sqrt{\sum_{i=1}^{n} \quad (P - O)^2/n}$$

   $$RMSE = \sqrt{\frac{29.430}{1}}$$

   $$RMSE = \sqrt{29.430}$$

   $$RMSE = 171{,}55$$

   Based on the calculation results, the Root Mean Squared Error (RMSE) value obtained is: Rp171,59.
3. Calculate the Percentage Error
   To determine the percentage error obtained, the RMSE value is converted into a percentage relative to the observed value:

   $$RMSE\% = \frac{Rp\ 171{,}55}{Rp\ 55.030} \times 100 = 0{,}31\%$$
4. Calculate the Prediction Accuracy:

   $$100\% - 0{,}31\% = 99{,}69\%$$

The experimental results showed that the proposed prediction model achieved an RMSE value of 0.31% with an accuracy level of 99.69%. These results indicate that the Random Forest algorithm is capable of predicting electricity bills with very high accuracy.

In addition, the IoT platform provided a user-friendly interface that displayed electricity consumption data in the form of monetary value (Indonesian Rupiah) and predicted future electricity bills. This feature allows users to better understand their electricity usage patterns and make informed decisions to reduce energy consumption [24].

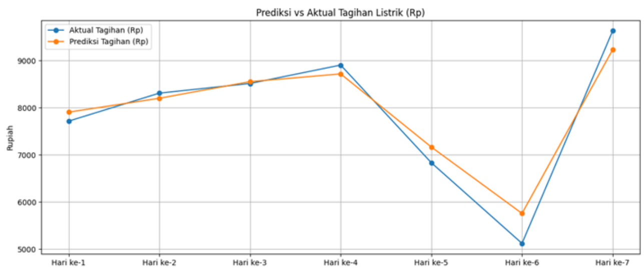

Fig. 4. Visualization of the Random Forest Algorithm.

4. Conclution

The IoT-based household smart electricity meter system with electricity bill prediction using the Random Forest algorithm was successfully designed and implemented, and it operates properly in monitoring electricity consumption and predicting electricity costs. The implementation of the Random Forest algorithm requires a server to store real-time measurement data and a Python-based server to process and analyze the collected data to generate predictions. Based on the system performance testing conducted over one week, the results show a prediction error rate of 0.31% and an accuracy level of 99.69%, indicating that the developed system performs effectively and provides highly accurate electricity bill predictions [25].

References

[1] N. Abdurrahman, A. Jaenul, and D. J. Vresdian, "Rancang Bangun Sistem Monitoring Stasiun Pengisian Listrik Umum (SPLU) Hybrid Berbasis IoT di SMKN 2 Kota Bekasi," vol. 2, no. 1, pp. 18–31, 2019.

[2] N. Aini, M. Arif, I. T. Agustin, and Z. B. Toyibah, "Implementasi Algoritma Random Forest untuk Klasifikasi Bidang MSIB di Prodi Pendidikan Informatika," vol. 11, no. 1, 2024.

[3] W. T. Amalia, "Studi Perbandingan KWh Meter Prabayar dan KWh Meter Pascabayar," 2022.

[4] Andreansyah, "Prototype Smart Home Sistem Monitoring Arus Listrik Menggunakan Sensor PZEM-004T Berbasis IoT," 2024.

[5] A. Nugroho et al., "Teknik Random Forest untuk Meningkatan Akurasi Data Tidak Seimbang," vol. 2, no. 2, pp. 128–140, 2024.

[6] D. Aribowo et al., "Edusaintek: Jurnal Pendidikan, Sains dan Teknologi," vol. 8, no. 1, pp. 67–81, 2021.

[7] S. Fasa et al., "Pengaruh Variasi Tegangan dan Arus pada KWh Meter Mekanik dan Digital," vol. 3, no. 1, pp. 32–46, 2024.

[8] A. Kurniawan, R. Putra, and M. Hidayat, "Perancangan Sistem Monitoring Konsumsi Daya Listrik Berbasis Android," 2022.

[9] K. A. Yasa, I. M. Purbhawa, I. M. S. Yasa, I. W. Teresna, A. Nugroho, and S. Winardi, "Prototype Pemantauan Konsumsi Energi Listrik pada Firebase Menggunakan PZEM-004T," Jurnal Eksplora Informatika, vol. 12, no. 2, pp. 104–112, 2023.

[11] J. Brownlee, Machine Learning Algorithms From Scratch with Python. Machine Learning Mastery, 2020.

[12] A. Géron, Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow, 2nd ed. O'Reilly Media, 2020.

[13] I. Goodfellow, Y. Bengio, and A. Courville, Deep Learning. MIT Press, Updated Edition, 2021.

[14] A. Rajput and M. Singh, "IoT Based Smart Energy Meter for Smart Grid Applications," IEEE Access, vol. 9, pp. 105189–105200, 2021.

[15] M. A. Al-Garadi et al., "A Survey of Machine and Deep Learning Methods for Internet of Things (IoT) Security," IEEE Communications Surveys & Tutorials, vol. 22, no. 3, pp. 1646–1685, 2020.

[16] S. Madakam and R. Ramaswamy, "Internet of Things (IoT): A Review of Architectures, Applications, and Security Issues," Future Internet, vol. 13, no. 2, 2021.

[17] N. Kumar and A. Sharma, "IoT-Based Smart Energy Meter Monitoring System," International Journal of Electrical and Computer Engineering, vol. 11, no. 5, pp. 4185–4192, 2021.

[18] H. Ning and H. Liu, Internet of Things: From Theory to Applications. Springer, 2021.

[19] O. Vermesan and P. Friess, Internet of Things – The Call of the Edge: Everything Intelligent Everywhere. River Publishers, 2020.

[20] S. Li, L. Da Xu, and S. Zhao, "The Internet of Things: A Survey," Information Systems Frontiers, vol. 22, pp. 243–259, 2020.

[21] R. Buyya and A. V. Dastjerdi, Internet of Things: Principles and Paradigms, Updated Edition. Morgan Kaufmann, 2021.

[22] F. Chollet, Deep Learning with Python, 2nd ed. Manning Publications, 2021.

[23] S. Russell and P. Norvig, Artificial Intelligence: A Modern Approach, 4th ed. Pearson, 2021.

[24] A. Géron, "Machine Learning for Predictive Analytics in Energy Systems," IEEE Access, vol. 10, pp. 55234–55248, 2022.

[25] Y. Liu et al., "Smart Energy Metering Based on Internet of Things and Machine Learning," IEEE Internet of Things Journal, vol. 10, no. 4, pp. 3321–3332, 2023.