

Prototype Design of a Prepaid KWh Meter Keypad Pusher with the Internet of Things to Refill Tokens

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Abstract— Prepaid kWh meters require manual token entry via a physical keypad, which limits operational flexibility, particularly for remote or unattended installations. Delayed token input may result in unintended power interruptions. This paper presents the design and implementation of an Internet of Things (IoT) keypad actuation system that enables remote token entry without modifying or replacing the existing prepaid meter. The suggested system uses servo motor actuators that are controlled by an ESP8266 microcontroller and a Firebase cloud server to send data between the embedded device and an Android-based user interface made with Kodular. An ESP32-CAM module is integrated for real-time visual monitoring of the meter display. Experimental evaluation shows that the prototype achieves a keypad actuation accuracy of 98.33% and a 100% success rate in token charging. Voltage measurements indicate system deviations below 5%, confirming stable electrical operation. Measured communication latency includes an average delay of 1706.63 ms from the graphical user interface to the cloud server and 483.6 ms from the server to the microcontroller. The results demonstrate that the proposed system provides a reliable and cost-effective solution for remote prepaid electricity token management.

Keywords: ESP8266 Microcontroller, Firebase Cloud Server, Internet of Things (IoT), Prepaid kWh Meter, Remote Token Entry.



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INTRODUCTION

The rapid advancement of digital technology and Internet of Things (IoT) applications has significantly influenced the modernization of electrical power systems, particularly in smart grid and smart metering infrastructures [13], [20]. In Indonesia, the implementation of prepaid electricity systems by PT PLN (Persero) has improved transparency and energy consumption control compared to conventional postpaid systems [1]. Several studies have examined differences between prepaid and postpaid electricity services, highlighting improvements in customer satisfaction and consumption awareness [2]-[4].

However, despite these advantages, prepaid kWh meters still require manual token entry through a physical keypad, which limits operational flexibility, especially for installations located in remote or unattended areas. Smart metering technologies have been widely developed to enhance monitoring, billing, and energy management capabilities [10], [21]. IoT-based energy meters enable real-time data acquisition, remote monitoring, and integration with cloud

platforms for improved efficiency and user accessibility [9], [11], [20]. Communication infrastructures supporting such systems typically rely on wireless technologies and cloud-based data exchange mechanisms [15], [17], [22]. These developments demonstrate the importance of integrating embedded systems, communication networks, and cloud services to improve the reliability and responsiveness of modern electrical energy systems.

Several previous studies have attempted to address the limitations of prepaid electricity systems through IoT-based token charging and monitoring mechanisms. Remote token charging systems have been implemented using microcontrollers and cloud platforms to enable online electricity top-up services [6], [8]. Smartphone-based top-up machines have also been proposed to enhance user convenience [5]. In addition, mechanical actuator approaches utilizing servo motors and microcontrollers have been developed to simulate keypad pressing on prepaid kWh meters [7]. While these studies demonstrate the feasibility of remote token management, most solutions either require hardware modification of the meter or involve bulky and less compact mechanical structures. Furthermore, broader smart grid studies have emphasized real-time monitoring, energy analytics, and demand management but have not specifically addressed retrofit-compatible keypad automation for existing prepaid meters [13], [20].

Therefore, this paper proposes the design and implementation of a compact IoT-based keypad actuation system that enables remote electricity token entry without modifying the internal structure of existing prepaid kWh meters. The proposed system integrates servo-based mechanical actuation, cloud-based communication using Firebase, and an embedded microcontroller platform to ensure reliable remote operation. Experimental evaluations are conducted to analyze actuation accuracy, electrical stability, and communication latency. The main contribution of this study lies in providing a practical, cost-effective, and retrofit-compatible solution for remote prepaid electricity management, bridging the gap between IoT-based smart metering research and real-world prepaid meter constraints.

METHOD

This Research Flow displays the flow of activities during the research, including: stages of literature study, system design, determining tools and materials to be used, assembling and testing tools. The research flowchart is shown in Figure 1. The flow diagram in Figure 2 shows the working process of the system based on the Internet of Things network architecture designed for remotely pressing the keypad of a prepaid kWh meter. Figure 2 displays the ESP32 Cam control circuit, which utilizes the ESP8266 microcontroller with a relay output. The relay is used to turn the ESP32 Cam on and off.

Network architecture design for prepaid kWh meter keypad pressing is a network interconnection concept between several devices to be able to connect to each other. The tool work flow diagram can be seen in Figure 3. Figure 3 shows the architecture of the proposed IoT-based prepaid electricity meter keypad pressing system. The architecture comprises five interconnected components that communicate through the Internet to support the automatic electricity token refill process.

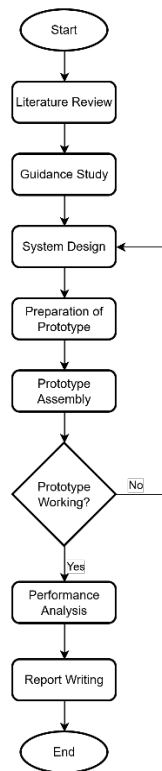


Figure 1. Research Flowchart

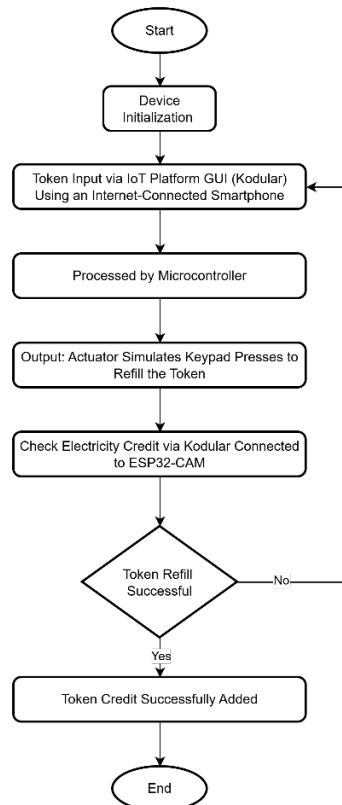


Figure 2. Flowchart of the IoT-Based Prototype for Automatic Prepaid Electricity Meter Keypad Pressing

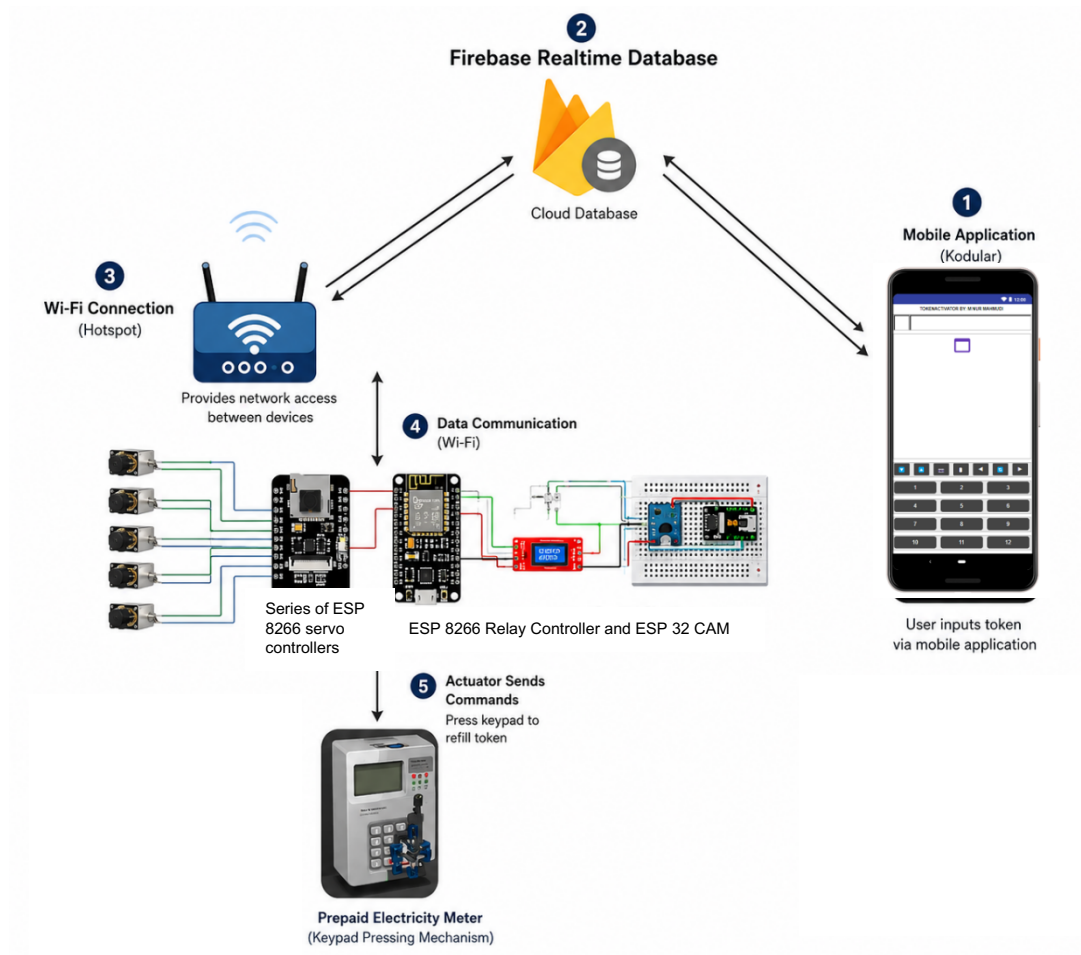


Figure 3. Electrical power system

Table 1. Explanation of Network Architecture Components

No	Description
1	Graphical User Interface (GUI) implemented using the Kodular mobile application for entering electricity token data.
2	Google Firebase Realtime Database used for storing and synchronizing token data between the mobile application and the IoT device.
3	Wi-Fi network that provides wireless communication between the mobile application, cloud database, and the IoT device.
4	Microcontroller circuit, consisting of an ESP32-CAM, relay module, and servo motor, responsible for processing commands and controlling the keypad pressing mechanism.
5	Prototype hardware of the prepaid electricity meter keypad pressing device, which physically presses the keypad buttons to automatically enter the electricity token.

A. Electrical Circuit Design

The design of the electrical circuit system aims to assemble the electrical system in a simulated manner so that errors do not occur when the physical wiring is carried out. The circuit design can be seen in Figure 4.

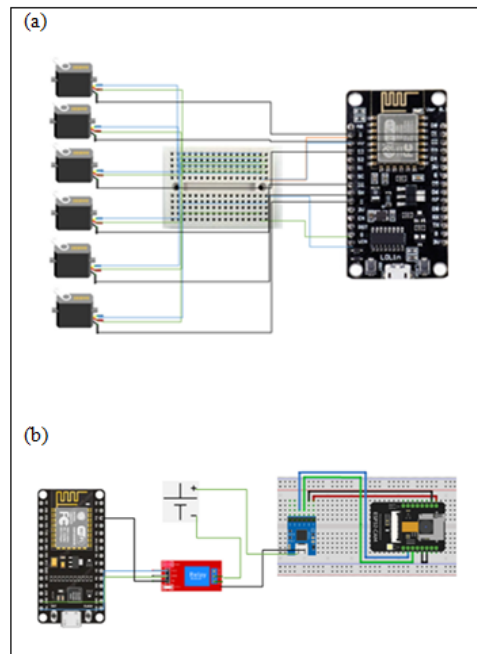


Figure 4. (a) Series of ESP8266 servo controllers; (b) ESP8266 relay controller and ESP32-CAM.

Description of Figure 4: Namely, the system uses one microcontroller connected to six servo motor actuators. The six servo motors function to press the buttons on the kWh meter keypad. This servo motor is programmed to be able to perform three conditions, namely, horizontal conditions at an angle of 110° , tilted to the right at an angle of 180° , and tilted to the left at an angle of 40° . Each servo will press two keypads.

B. Mechanical Design

The mechanical system is a series of hardware that functions physically in pressing the prepaid kWh meter's keypad. The mechanical design will be created and developed using 3D models. In designing this mechanical system, there are several components that will be made, namely, the cover, actuator mounting bracket, microcontroller, ESP32 Cam, and battery. The mechanical system can be seen in Figure 5.

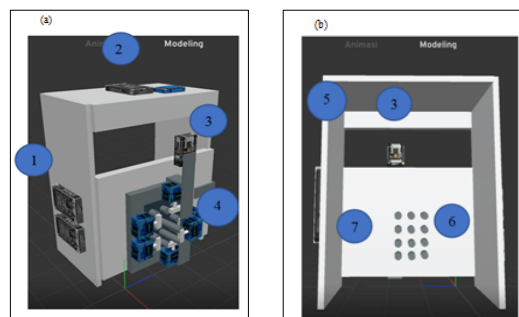


Figure 5. Front and back views of the proposed prototype: (a) Front view; (b) Back view.

Figure 5 shows the 3D mechanical design of the proposed prototype. The descriptions of the numbered components shown in Figure 5 are provided in Table 2.

Table 2. Description of the 3D Prototype Components

No	Description
1	ESP32 microcontroller for controlling the servo motor
2	ESP8266 microcontroller for controlling the power supply of the ESP32-CAM through a relay module
3	ESP32-CAM used for image capture and system monitoring
4	Servo motor used to actuate the keypad pressing mechanism
5	Power bank used as the power source for the entire system
6	Push–pull rod driven by the servo motor to press the prepaid electricity meter keypad
7	Cover is closed

C. Guide User Interface (GUI) Design

Network architecture design for prepaid kWh meter keypad pressing is a network interconnection concept between several devices to be able to connect to each other. The GUI design can be seen in Figure 6.



Figure 6. User Interface Developed Using Kodular

In Figure 6 can be seen this design includes several number keys (0-9), "back" (backspace), and "enter" keys. The appearance and arrangement of these buttons is adapted to the physical keypads on prepaid kWh meters, providing an intuitive user experience. Apart from that, this GUI is also equipped with a sound feature to provide feedback when the button is successfully clicked. This application also includes a browser that allows web access, used to access the IP address of the ESP 32 Cam, which functions to monitor the LCD screen on the prepaid kWh meter.

RESULT AND DISCUSSION

A. Prototype

Figure 7 presents the completed prototype of the proposed IoT-based prepaid electricity meter keypad pressing system. The prototype is shown from the front, rear, left, and right-side views

to illustrate its mechanical structure and hardware configuration. The descriptions of the numbered components shown in Figure 7 are provided in Table 3.

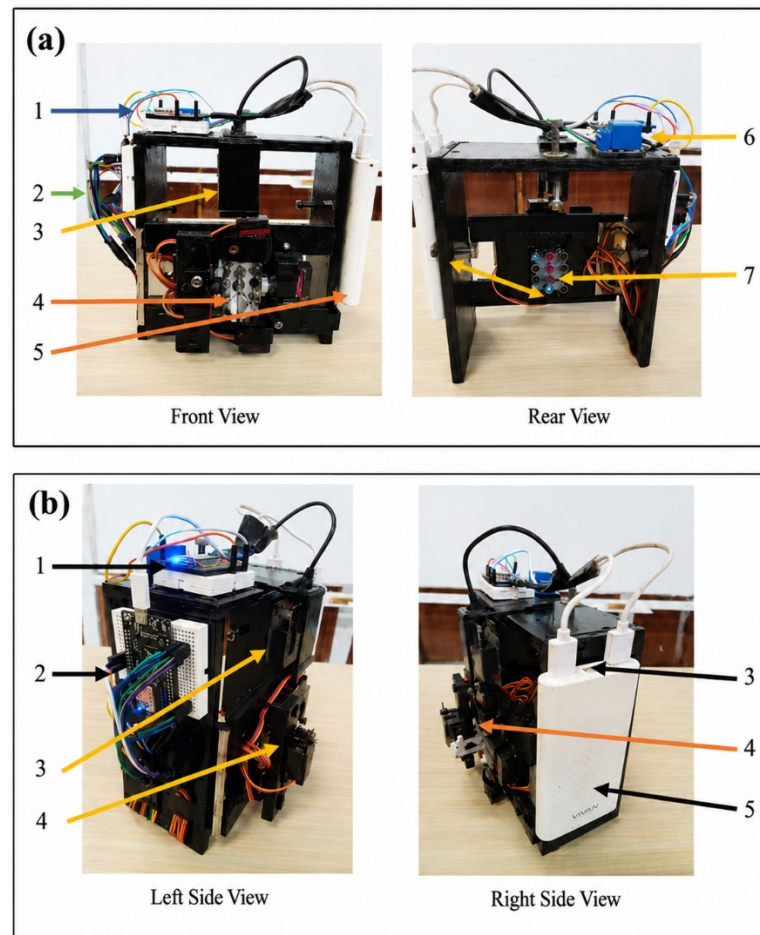


Figure 7. (a) Front and rear views of the proposed prototype; (b) Left and right-side views of the proposed prototype.

Table 3. Description of Prototype

No	Description
1	ESP32 microcontroller for controlling the servo motor
2	ESP8266 microcontroller for controlling the power supply of the ESP32-CAM through a relay module
3	ESP32-CAM used for image capture and system monitoring
4	Servo motor
5	Power bank used as the power source
6	Push & pull rod that can be moved with a servo actuator
7	Cover is closed

B. Voltage Measurement

The voltage measurement results of the prototype electronic device can be seen in Table 4 below. In Table 4 it is known that the error of the prototype electronic device is below 5%. The device can still work optimally.

Table 4. Experimental Voltage Measurement Data

Devices	Dataset Voltage (V)	Measured Voltage (V)	Error (%)
Adapter	5	5.025	0.46
Power Bank	5	4.752	0.5
Pin for servo on ESP 8266	5	5.025	4.96
Pin for relay on ESP 8266	5	4.752	4

C. Software

Figure 8 presents the graphical user interface (GUI) of the *Token Activator* android application developed using Kodular. The descriptions of the numbered interface components shown in Figure 8 are provided in Table 5.

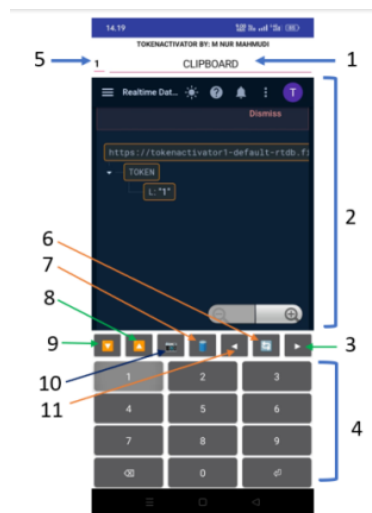


Figure 8. The graphical user interface (GUI) of the *Token Activator* Android application.

Table 5. Description of the Software Interface Components

No	Device Description
1	Clipboard
2	Web viewer
3	Forward web viewer icon
4	Token input button
5	Text box for displaying the entered token digits.
6	Refresh icon
7	Realtime Database icon
8	Minimize web viewer icon
9	Maximize web viewer icon
10	Capture image icon
11	Back web viewer icon

D. Token Activator GUI Button Input Success Rate

The results of the GUI button input experiment, conducted over ten trials, are presented in Table 6. The experimental results indicate an overall input success rate of 98.33%. Ten trials

were considered sufficient because the system consistently achieved a 100% success rate for nearly all button inputs, demonstrating the reliability of the Token Activator GUI.

Table 6. Experimental Results of GUI Button Input Success Rate

Input GUI	Output ESP8266	Success (%)
1	1	100
2	2	100
3	3	100
4	4	20
5	5	100
6	6	100
7	7	100
8	8	100
9	9	100
10	10	100

E. Electricity Token Entry Success Rate

The experimental results for entering purchased electricity tokens are presented in Table 7. The prototype achieved a 100% success rate, indicating that all purchased electricity tokens were entered successfully without any input errors.

Table 7. Experimental Results of Electricity Token Entry Success Rate

No	Token Number	Success (%)
1	5863-4664-0250-3792-9221	100
2	0861-1138-7168-2467-5239	100
3	0464-7730-2306-9797-6718	100
4	1478-6020-5984-3454-2598	100
5	0116-2222-7814-5929-3936	100

F. Delay

The delay measurement results for data transmission from the Token Activator GUI to Firebase, from Firebase to the Token Activator application, from Firebase to the ESP8266, and for image uploading are presented in Table 8. Based on the experimental results, the total delay from entering a token in the Token Activator GUI to its execution by the ESP8266 was 2190.234 ms. In addition, the image upload delay from the ESP32-CAM to Firebase was measured at 2.356 ms.

Table 8. Experimental Delay Measurement Results

No	Measurement Parameter	Delay (ms)
1	Delay GUI to Firebase	1706.634
2	Delay Firebase to GUI	1103.89
3	Delay Firebase to ESP 8266	483.6
4	Delay Uplud ESP 32 Cam	2.356

CONCLUSION

This research successfully developed an IoT-based prepaid kWh meter keypad pressing prototype that enables remote electricity token input without replacing existing meters. The proposed system integrates mechanical actuators and cloud-based software to achieve reliable operation, as demonstrated by a keypad pressing accuracy of 98.33% and a 100% success rate in electricity token charging. These results are consistent with previous studies highlighting the effectiveness of IoT-based control systems, while the retrofit-oriented design distinguishes this work by reducing implementation cost and mechanical complexity. The prototype shows strong potential for real-world applications, particularly in remote facilities where manual token input is impractical. However, this research is limited to prototype-scale testing and does not consider long-term durability or deployment in harsh environments. Future work should focus on system miniaturization, long-term reliability testing, and integration with commercial prepaid electricity infrastructures.

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