PROTOTYPE OF LORA-BASED ELECTRICITY THEFT DETECTION DEVICE USING SUM OF ABSOLUTE DIFFERENCE (SAD) METHOD

Zahra Ari Maulida[1*] , Rifdian Indrianto[2] , Laila Rochmawati[3]

1,2,3) Civil Aviation Polytechnics of Surabaya
**Corresponding Author. Email: zahraarimaulida36@gmail.com*

ABSTRACT
Electricity theft is a significant issue globally, including in Indonesia. It can happen in various locations such as residential areas, offices, industrial sites, and more. Electricity theft can severely impact the owners of electrical installations, leading to considerable financial losses. A device designed to monitor electricity usage and detect potential theft by comparing customer consumption data against distribution substation data could mitigate this issue. The device is installed on the customer's meter, with real-time monitoring accessible via the web. The data is visualized in graphs, allowing easy detection of irregular consumption patterns. This research utilizes a PZEM 004-T current voltage sensor and an Arduino Uno microcontroller paired with a LoRa module for long-range communication. Additionally, the system is equipped with an ESP8266 microcontroller as a Wi-Fi module for web data display.

Keywords: *Electricity Theft, Microcontroler ESP8266, PZEM 004-T, LoRa*

1. INTRODUCTION

1.1. Background

Electricity theft is a significant problem that occurs in many countries, including Indonesia. This phenomenon not only harms electricity providers, such as PLN in Indonesia, but also has a negative impact on energy stability and public safety. Electricity theft can cause huge economic losses and pose safety risks, such as fires due to non-standard installations. Data shows that in 2020, PT PLN (Persero) recorded around 73,774 cases of electricity theft across Indonesia, with losses reaching Rp 2.8 trillion. The majority of these cases occurred in household consumers, but electricity theft was also found in the industrial and business sectors (PT PLN, 2020).

Despite various efforts, such as the installation of prepaid meters and strict supervision, electricity theft is still a major problem that requires innovative solutions (Diah Puspita, 2024). One approach that can be applied is the use of LoRa (Long Range) based technology combined with the Sum of Absolute Difference (SAD) method. This technology allows real-time and accurate detection of electricity theft, with a wide range and high energy efficiency (Surabaya, Politeknik Elektronika Negeri, 2023).

This research aims to design and develop a prototype of LoRa-based electricity theft detection device with SAD method. This tool is expected to contribute

This research aims to design and develop a prototype of LoRa-based electricity theft detection device with SAD method. This tool is expected to contribute. An advanced detection system that can identify unauhorizedelectricity consumption is essential to mitigate this problem.

Given these challenges, the authors developed a prototype for detecting electricity theft using a LoRa-based system and the Sum of Absolute Difference (SAD) method. This project fulfills the requirements for a diploma and aims to reduce electricity theft cases.

1.2. Problem Formulation

The main problems addressed in this final project include:

1. How to design a prototype for detecting electricity theft using the LoRa system and the Sum of Absolute Difference (SAD) method?
2. How does the LoRa-based electricity theft detection prototype work using the Sum of Absolute Difference (SAD) method?
3. What results can be obtained from the design of the LoRa-based electricity theft detection prototype using the Sum of Absolute Difference (SAD) method.

2. LITERATURE REVIEW

2.1 Prototype

A prototype is a preliminary model or sample built for early-stage development, demonstrating basic concepts and working principles of a product, whether in physical or digital form. Generally, a prototype allows the testing of the design, concept, and functionality of a product before mass production. It gives developers and users the chance to interact with the product model without first creating the final product. Moreover, it helps detect and correct any potential errors or feature gaps beforethe product is officially released. Prototypes undergo continuous updates and improvements if necessary (Nandi, 2021).

2.2 Electricity Theft Detection Devices

According to experts, detection devices are tools used to identify the presence of objects or signals using various sensors. D. Sharon (1982) described sensors as devices that detect signals or symptoms caused by changes in energy, such as physical, electrical, biological, chemical, or mechanical energy.

Electricity theft is a criminal offense frequently occurring in Indonesia. A search for the keyword "electricity theft" in the official website directory of the Supreme Court reveals more than 314,000 cases related to this term. This confirms that unauthorized use of electrical energy is a criminal act according to Indonesian law, as stipulated in Law No. 30 of 2009 on Electricity (Sidharta, 2023).

2.2.1 PZEM-004T Current Sensor

The PZEM-004T is a multifunctional sensor module commonly used to measure active power, AC voltage, frequency, active energy, and current in an electrical flow. It is specifically designed for indoor use, and the connected load should not exceed the designated power rating. The PZEM-004T data is read through a TTL interface that requires an external 5V power supply,This implies that all four ports (V, RX, TX, GND) must be connected. The sensor board PZEM-004T has dimensions of 3.1 x 7.4 cm and a thickness of 3 mm diameter current transformer coil to measure current in the range of up to 100A for an external transformer and 10A for a built-in shunt (Habibi FN, 2017). It is specifically designed for indoor use, and the connected load should not exceed the designated power rating. This sensor multifunctional sensor modulecommonly used to measure active power, AC voltage, frequency, active energy, and current in an electrical flow.

2.2.2 ESP8266 Microcontroller

The ESP8266 microcontroller, developed by Espressif Systems based in Shanghai, China, is an advanced version of its predecessor. It has several advantages, including more analog pins, greater memory capacity, more pin outputs, and low-energy. Bluetooth 4.0. The ESP8266 microcontroller features 44.8 kB. The chip also includes 18 ADC (12- bit) pins, allowing current measurement from 0 to 4095. Its main advantages are its low cost, adequate I/O pins, built-in WiFi adapter, and ease of programming (Yulistiani, 2023). This module can easily connect devices to the Internet and is suitable for projects requiring analogsignal processing and digital I/O devices. It is available as a separate module or as an integrated circuit board (PCB) ready for use.

2.2.3 Relay Module

A relay module is an electromagnetic device used to operate switch contacts. A simple relay be composed of a coilof wire wound around an iron core. When the coil is energized, a magnetic field is created that pulls an armature connected to the switch mechanism (Muslihudin, Renvillia, Taufiq, Andoyo, & Susanto, 2018). The relay acts as a switch to control AC motors or other loads with a different voltage between the control circuit and load voltage.

2.2.4 ZMPT101B Sensor

The ZMPT101B is a high-precision voltage transformer module designed for monitoring AC voltage up to 1000 volts. It is compact and supports up to 4kV insulation, with a 1:1 winding ratio (Romario Panjaitan, 2012).

2.2.5 Arduino Mega 2560

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560 chip, offering the highest pincount among all Arduino boards (M Reza Hidayat, 2018).

2.2.6 ACS712 Current Sensor

The ACS712 is a Hall Effect current sensor, commonly used for precise AC or DC current measurements in industries, automotive applications, and comercial system. The most common uses include motor control, load detection, switched-mode power supplies, and overload protection. (Richard Blocher, 2003: 103).

2.2.7 Mini PSU

A mini power supply unit (PSU) is a small-sized device designed to provide power to electronic components. Typically used in DIY projects, mini computers, or other small electronic devices, the PSU used in this project supplies 5V with a maximum current of 2A (Romario Panjaitan, 2012).

2.3 Long Range (LoRa)

LoRa is a modulation format developed by Semtech, a wireless technology enabling long-range communication with low power consumption. LoRa consists of gateways and transceivers that provide secure data transmission, wide coverage, low power usage, and low data rates. It is commonly used for low- cost IoT applications, where it can be integrated into existing networks (Surabaya, Politeknik Elektronika Negeri).

According to Ahmad Adhitya Nurhadi (2021), LoRa offers several features:

a. Geolocation for detecting object locations without additional costs.

b. Low-cost infrastructure, reducing operational expenses and sensor costs.

c. Compatibility with other systems, allowing rapid adaptation in IoT networks.

d. Long battery life, supporting devices for 10 to 15 years.

e. Extensive range, capable of reaching up to 100km with proper settings.

2.4 Sum of Absolute Difference (SAD) Method

The SAD algorithm measures block similarity between two images based on pixel differences. It works by taking the absolute difference between pixels in a reference image and those in the comparison image.SAD operates through reference image selection, subtraction operations, and threshold determination, which defines movement detection. The SAD formula isexpressed as:

$$\text{SAD} = \sum_{i=1}^{n} \sum_{j=1}^{n} | I - J |$$

Where i represents frame i, j represents frame j, and n represents the number of pixels within the frame. This method calculates the sum of absolute differences by subtracting the corresponding pixel values between two frames (I and J) and taking the absolute value of the difference. The resulting SAD value is then used to determine the similarity between the frames.

2.4.1 Website

According to Abdullah, a website can be defined as a collection of pages containing digital information, such as text, images, animations, sounds, and videos, provided through an internet connection, making it accessible worldwide. Web pages are created using HTML, which web browsers interpret to display readable information (Abdullah, 2018). According toSarwono, a website is a media that consists of pages containing information accessible through the internet and can be enjoyed globally (Sarwono, 2015:2).

2.4.2 Internet of Things (IoT)

The Internet of Things (IoT) is a concept aimed at expanding the benefits of internet connectivity tophysical devices equipped with sensors and actuators. These devices can collect data, manage performance, and collaborate based on new information acquired independently. Real-world objects can interact with each other via the internet as part of a unified system. For example, cameras installed along roads can be connected to a control room via the internet, smart homes can be managed through a smartphone. There are sensors for data collection, internet connections for communication, and servers for processing information received from sensors.. (Efendi, 2018).

3. RESEARCH METHODOLOGY

3.1 Research Design

This study employs the Research and Development (R&D) methodology to design anddevelop the device.

According to Sugiyono (2015), research and development is a research method used to produce specific products. To develop a product, an analysis of needs is conducted, followed by testing the product's effectiveness before it is implemented in the broader community.

Figure 1. Flowchart of Research Design

Adopted from Sugiyono (2015).

The R&D methodology consists of several stages, as described by Sugiyono (2015):

a. Potential and problems identification

b. Data collection

c. Product design

d. Design validation

e. Design revision

f. Product testing
g. Product revision
h. Final design validation
i. Final product revision
j. Limited production

3.2 Device Design

3.2.1 Device Design

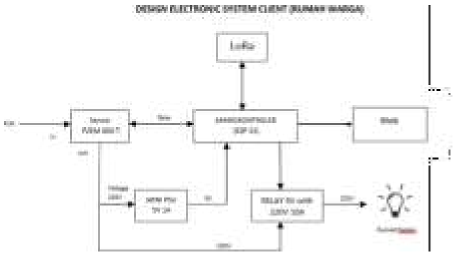

Figure 2. Block Diagram of Device Planning

Adopted from Muflihah (2013).

The device is installed on distribution cables before entering the KWh meter, with the PZEM 004-T The microcontroller receives power from a mini PSU that converts 220VAC to 5VDC at 1A, supplying the system's power needs. The sensor data is processed by the microcontroller, which applies the SAD method to determine whether to trigger an alarm buzzer, relay, or contactor to cut off the electricity supply. The sensor data and SAD calculations are sent to the master (substation) via LoRa, which communicates periodically with the master every 5 minutes.

Figure 3. Block Diagram of Device Planning

Adopted from Muflihah (2013).

In this block diagram design, the main substation supplies power through a mini PSU 5V 1A and the PZEM 004-T current sensor, which then sends data to the ESP8266 microcontroller for processing. The data is transmitted and monitored remotely using LoRa communication.

The master device, installed at the substation, is supplied with voltage from the mini PSU in the controller. The substation output is monitored using the PZEM 004-T sensor to measure the total current in one line of the distribution system. The total power data is then calculated and compared with the data from each slave (household) using the SAD method. The microcontroller communicates periodically with the slave devices using LoRa. The calculated data is uploaded to the database once the microcontroller connects to the internet via WiFi.

3.2.2 Device Operation

The device works by measuring the current flowing to the load using the PZEM 004-T current sensor. The sensor readings are processed by the microcontroller and transmitted to the master at the substation via LoRa, including data if the current exceeds the threshold. The master then sends the data to the database, which is displayed on the web interface. If the current at the client (household) exceeds thethreshold after SAD calculations, the system automatically cuts off the electricity supply.

3.2.3 Device Components

The components required for the device are divided into two categories:

Hardware Components

This design consists of several hardware components, including:

a. Lamp
b. Smartphone
c. ESP8266 Microcontroller
d. Current Sensor
e. Relay Module
f. Power Supply

3.3 Testing Techniques

3.3.1 Power Supply Testing

This test aims to measure the input and output voltage of the power supply before it is connected to the microcontroller. The author uses a DC 5V 2A power supply with the Hi-Link brand as the primary DC voltage source for the microcontroller. The testing table is provided to ensure that the power supply is in good condition.

3.3.2 PZEM 004-T Current Sensor Testing

This test involves measuring AC current using the PZEM 004-T sensor and comparing the results with a digital clamp meter. AC voltage is also measured using the PZEM 004-T sensor and compared with a digital voltmeter.

3.3.3 ACS712 Current Sensor Testing

This test involves measuring the current displayed on the LCD and comparing it with a digital clamp meter. AC voltage is measured using the ACS712 sensor and compared with a digital voltmeter.

3.3.4 ESP8266 Microcontroller Testing

This test determines whether the microcontroller ports function correctly as control mechanisms for the integrated trainer circuit using the Arduino IDE software. The microcontroller is connected to a laptop for testing.

3.3.5 LCD Testing

In this design, the LCD serves as a display for measured data such as current, voltage, and power. The test aims to check whether the data displayed on the LCD matches the microcontroller's programming.

3.3.6 LoRa Testing

This test assesses the range at which the device can maintain communication by measuring distances from 5 meters to the point where the LCD display no longer receives updates.

3.4 Data Analysis Techniques

Data collection methods used in this final project include:

a. Literature Study Method

Reviewing and re-examining theories to solve the research problem.

a. Library Method

Seeking various references and information from lecturers and colleagues involved in similar research, as well as internet sources and journals.

b. Observation Method

Directly observing the field to gather supportive information and data, minimizing errors in development.

c. Calculation Analysis Method

Analyzing components needed for the research design.

d. Experimental Method

Conducting trials to gather data from simulations to address the research problem.

e. Discussion

Consulting with supervisors and experts to resolve the research design.

3.5 Research Location and Timeline

The research and planning are conducted at Surabaya Aviation Polytechnic. The research timeline is as follows:

Table 1. Research Location and Timeline

No	Activity	2024							
		Jan	Feb	Mar	Apr	Mei	Jun	Jul	Aug
1.	Preparation Stage								
2.	Data Collection								
3.	Data Processing								
4.	Writing Stage								
5.	Testing and Evaluation								

4. RESULTS AND DISCUSSION

4.1 Research Results

This research tests the device's performance and evaluates whether each component meets expectations. The study involves two key aspects: hardware and software testing.

In this research, hardware components include the Microcontroller Arduino Nano, LCD, sensors, relays,and others. The software part of this device plays acrucial role in control system development.

4.1.1 Potential and Issues

Electricity theft causes financial losses for the country, as PLN loses its main commodity without receiving payment in return. According to Law No. 30 of 2009 on electricity, offenders face a maximum fine of IDR 2.5 billion or up to 5 years of imprisonment. However, various factors limit PLN's ability to takestrict actions (Sulistyo, 2016).

In Indonesia, many electricity theft cases have been recorded. In 2014, the Medan Metropolitan Police revealed several theft cases, including those at construction sites, shopping centers, and residential projects. In 2018, electricity theft involving 47 rooms in a public housing complex managed by the Medan City

Government was discovered. The theft had been ongoing since 2008 (Yafila, 2019).

Given these facts, the author designed a LoRa-based electricity theft detection prototype using the SAD method to facilitate theft prevention and detection. The device monitors current, voltage, and power using a smartphone. The detection process involves current and voltage sensors processed by the Arduino Mega microcontroller.

4.1.2 Data Collection

During data collection, the author gathered information as a reference and rationale for designing the device.

Table 2. Data Collection

No.	Case	Source
1.	Widespread Electricity Theft in Pacitan	Purwo Sumodiharjo, detikNews Dec 17, 2019
2	PLN Loses IDR 10 Trillion Due to Electricity Theft	Trio Hamdani, detikFinance Apr 24, 2018
3	Power Disruption in Depok Due to Crypto Mining Theft	Devi Puspitasari, detikNews Sep 19, 2023

From the data above, it is evident that electricity theft is a significant problem in Indonesia, with severe negative impacts on society, particularly PLN. The losses are substantial due to irresponsible parties engaging in illegal activities.

4.1.3 Product Design

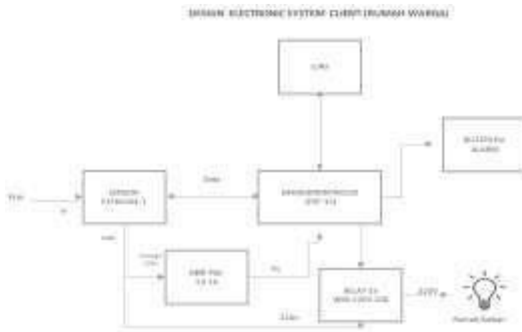

Figure 4 Product Design

The device design involves using the Arduino Mega microcontroller as the central processor. The microcontroller receives inputs from sensors connected to the components. The designed sensors include current and voltage sensors. The Arduino Nano then transmits the readings to the LCD.

In this design, a relay is used as an automatic current cut-off mechanism programmed in the Arduino Uno, allowing the detection of current, voltage, and signs of electricity theft.

4.1.4 Design Revision

This section includes feedback and suggestions from reviewers, such as removing the buzzer/alarm due to the risk of theft sabotage. The revised design excludes the buzzer while retaining all other components.

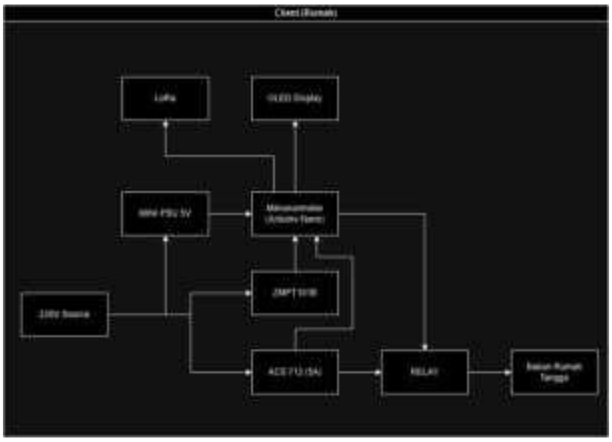

Figure 5 Revised Design

The revised design excludes the buzzer. Data processed by the ESP microcontroller is monitored through a smartphone and displayed on the LCD.

4.1.5 Product Testing

This section involves testing the designed device to gather data on its effectiveness and efficiency.

Testing Results and Analysis

The tests involved various scenarios, including distances of up to 50 meters. The results showed that the

LoRa module supports communication within 10 meters, but beyond that, communication becomes unstable, especially in densely populated environments.

Table 2. LoRa Module Testing

No	Jarak Pengujian	Tampilan serial monitor	Terhubung
1	5m		Ya
2	10m		Ya
3	20m		Tidak
4	50m		Tidak

Based on the table, the LoRa module functions correctly at distances up to 10 meters.

Overall Testing Results

The following table summarizes the test results with an SAD tolerance of 300 and a 5W load.

Table 3. SAD 300 Testing Results

Beban	Waktu	SAD	Relay
5 Watt	3	16	ON
5 Watt	6	30	ON
5 Watt	9	43	ON
5 Watt	12	50	ON
5 Watt	15	62	ON
5 Watt	18	76	ON
5 Watt	21	86	ON
5 Watt	24	101	ON
5 Watt	27	111	ON
5 Watt	30	115	ON

Analysis:

The table shows that the SAD value increases every 3 minutes. The maximum time tolerance to detect SAD is approximately 15 minutes. At a 5W load, the SAD value increases steadily every 3 minutes. The set SAD range is 300. Therefore, if the SAD value exceeds 300, the relay automatically turns off. However, in this 5W test, the SAD value did not reach the set range even after 30 minutes, and the relay remained ON.

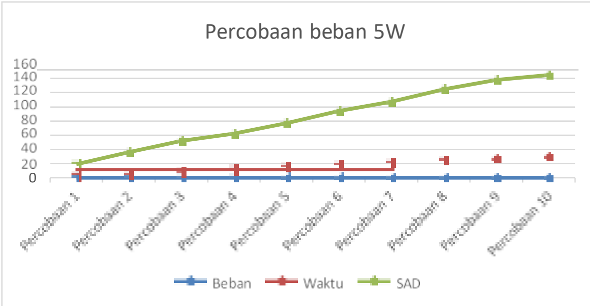

Figure 6. 5W Load Experiment Graph

The graph shows the SAD value in the top left corner, with the red line indicating the time when the SAD was measured.

Table 4. SAD 500 Testing Results with 40+33W Load

Beban Pencurian	Waktu	SAD	Relay
40 + 33 Watt	3 Menit	57	ON
40 + 33 Watt	6 Menit	110	ON
40 + 33 Watt	9 Menit	163	ON
40 + 33 Watt	12 Menit	216	ON
40 + 33 Watt	15 Menit	323	OFF

Analysis:

The experiment with a 40+33W load showed that the SAD value exceeded 500 within 15 minutes, triggering the relay to automatically turn off.

Figure 7. 40+33W Load Experiment Graph

The graph shows the SAD value in the top left corner, with the red line indicating the time when the SAD was measured.

4.1.6 Design Validation

This section discusses the validation process of the design, confirming that the LoRa-based electricity theft detection device using the SAD method is suitable for use. The author received feedback from validators indicating that the prototype is ready for limited implementation.

4.1.7 Product Revision

No additional components were added, as there were no major revisions suggested by the validators.

4.1.8 Final Design Validation

The final validation confirms that the design is ready for use, with the device passing the evaluation.

4.1.9 Final Product Revision

No revisions were made in this stage, but suggestions were provided to add clearer circuit diagrams and improve the graphics.

4.1.10 Limited Production

This stage involves the limited production of the prototype as a demonstration model. The final product from this design and development process is as follows:

Figure 8. Prototype Device

4.2 Advantages and Disadvantages of the Device

In this research titled "Prototype of LoRa-Based Electricity Theft Detection Device Using the Sum of Absolute Difference (SAD) Method," the device has several advantages and disadvantages:

Advantages:

a. Simple and flexible design.
b. Supports long-range communication between substations and households.
c. Remote monitoring is possible via an Android application.
d. Can transmit data over distances of up to 5 km in crowded environments with the help of an additional antenna.

Disadvantages:

a. Only detects electricity theft on power lines.
b. Monitoring is possible via the application, but control features are not yet available.

AUTHORS' CONTRIBUTIONS

Zahra Ari Maulida designed and developed the prototype, conducted the experiments, and wrote themain sections of the manuscript. Rifdian I.S. and Dr. Laila Rochmawati provided supervision, validated the methodology, and reviewed The manuscript should be critically reviewed for important intellectual content. Final manuscript was approved by all authors.

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