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# Implementation of internet of things for leakage current monitoring system in medical equipment

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**ABSTRACT**

The rise in electricity consumption, especially in the health sector, has heightened concerns about electrical safety, particularly leakage current in medical equipment. The main objective of this research is to develop an IoT-based leakage current monitoring system specifically designed for low-voltage medical devices, aiming to enhance safety and prevent electrical hazards such as electric shocks and equipment damage. The system used two current sensors module (PZEMT-004T) to measure leakage at points near the voltage source and medical components. Data were processed by a microcontroller and transmitted to a web server for real-time monitoring via mobile devices. Testing on humidifiers and ECGs showed average accuracies of 90.11% and 92.49%, respectively, within a 10 mA range. However, the system could not detect currents below the 3 mA safety threshold because of the sensors reading limitation at 10 mA, indicating a need for sensor improvements. The IoT-based system enhances medical equipment safety, with future work focusing on better sensors and AI for predictive maintenance.



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## 1. INTRODUCTION

The increase in electricity consumption in Indonesia, especially in the health sector, has created various challenges related to the security and reliability of the electricity system. Based on data from the Central Statistics Agency (BPS), electricity consumption in Indonesia increased by more than 20% from 2019 to 2020, with the health sector in West Java experiencing an increase in electricity consumption of 8.15% in the same period [1], [2]. This increase in energy consumption not only has an impact on operational costs, but also increases electrical risks, one of which is electrical current leakage [3], [4]. Electrical leakage occurs when current flows through a path it should not [5], [6], such as through a damaged insulator or the human body [7]–[9]. This phenomenon can cause dangerous, even fatal, electric shocks, especially in medical equipment that has a low working voltage [10]. Electric shocks can cause burns, muscle spasms, and in severe cases, death from heart failure [11]–[13]. Therefore, early detection and monitoring of leakage current in medical equipment is very important to prevent these risks.

Several previous studies have developed methods to monitor leakage current, but most of them still rely on manual reading tools such as oscilloscopes or Leakage Current Monitor Test Sets which require direct supervision [14] and are less suitable for medical equipment with low working voltages. [15]. In addition, several studies have also been conducted to understand the mechanism of leakage current and develop a monitoring system without having to use manual readings such as oscilloscopes or Leakage Current Monitor Test Sets. Research by [16] shows that degradation of insulators due to environmental conditions such as salt-fog can increase the risk of current leakage. Then there is also research by [17] found a correlation between increased leakage current and environmental conditions such as humidity and rainfall intensity. In addition, [18] propose an online leakage current monitoring method using the approach tanδ (degree of insulator damage) at low frequencies.

However, these studies are still limited to high voltage electrical installations [11],[19], [20] which is less effective when used in the context of medical equipment. This also shows that currently the effective and accurate leakage current monitoring system for medical equipment with low working voltage is still not optimal. Therefore, this study aims to fill this gap by developing an IoT-based leakage current monitoring system that can provide real-time and accurate information. Based on these problems, a study was conducted that aims to produce an IoT-based leakage current monitoring system specifically designed for medical equipment.

This system uses two electrical energy sensors to measure leakage current at two different points [7], [9], [21], namely a point near the voltage source and a point near the main component of the medical equipment. The difference between the two current values will be processed by the microcontroller to determine the leakage current value. The results of the data processing will then be sent to the web server and can be accessed by users via online gadgets. With this system, it is expected to reduce the risk of electric shock and damage to medical equipment due to current leakage, as well as provide new references in the development of IoT-based monitoring systems in the health sector.

## 2. METHOD

This study aims to develop an Internet of Things (IoT) based leakage current monitoring system on medical equipment with low working voltage. The research design includes several main stages, namely literature study, system design, implementation, testing, and data analysis. The monitoring system is designed to detect leakage current in real-time and provide notification to users through an online platform to update the conventional leakage current monitoring system still relies on manual reading tools such as oscilloscopes or Leakage Current Monitor Test Sets, which are less effective for medical equipment with low working voltage [8], [9]. The following is an illustration of the research that has been conducted in flowchart form in 2.2. procedure section:

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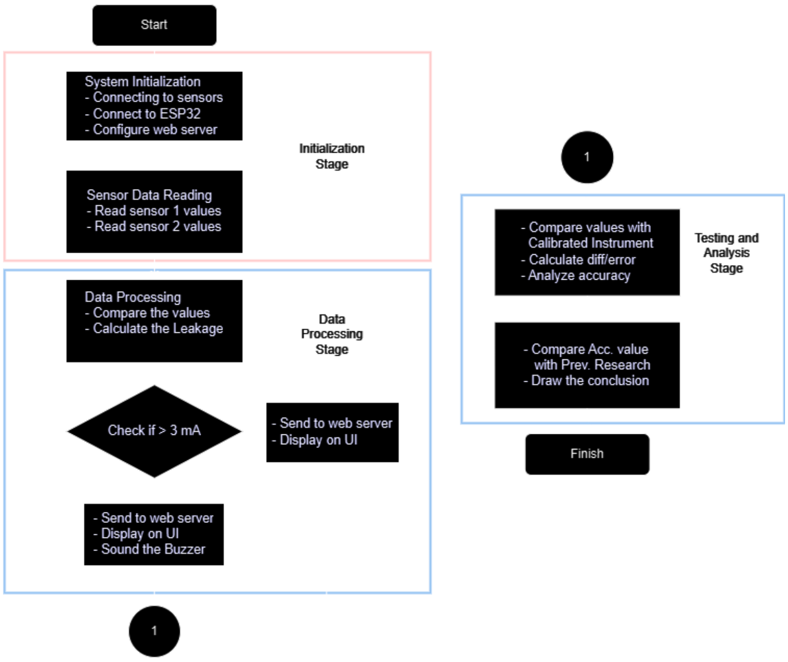


Figure 1. Flowchart of research methods

### 1.1 Tools and Materials

The samples used in this study were medical equipment with low working voltage, such as life support devices in the form of respiratory humidifier and basic diagnostic tools in the form of electrocardiograms (ECGs) commonly used in health facilities. Testing was carried out under normal conditions and when a current leak occurred by shorting the device to ground. Meanwhile, the tools and materials used in this study include an electric current sensor module (PZEM-004T) with a reading accuracy of up to 1 mA. This sensor is connected to an ESP32 microcontroller for IoT connectivity [22], [23]. Data from the microcontroller is sent to a web server using the MQTT or HTTP protocol, which is then displayed on a user interface that can be accessed via a mobile device. For system validation, a calibrated measuring instrument in the form of an ampere clamp is used.

### 1.2 Research Procedures

The research procedure begins with system initialization, where two current sensors are installed at strategic points: one near the voltage source and one near the medical component. These sensors are connected to a microcontroller (such as ESP32 or Arduino) equipped with a Wi-Fi module for IoT connectivity. A web server is then configured to receive data from the microcontroller where the use of the 2 measurement points is to accurately detect leakage current [3]. Next, the system enters the sensor data reading phase where every second the system will read the current value from both sensors and calculate the difference between the two to determine the leakage current in real-time to show the effectiveness of continuous monitoring in detecting electrical disturbances [8].

In the data processing stage, analogue data from the sensor is converted to digital using an Analog-to-Digital Converter (ADC). The system then compares the calculated leakage current with a safety threshold of 3 mA [11]. If the leakage current exceeds this threshold, a notification will be sent to the web server to inform the user of a possible electrical hazard to the medical equipment. Sending data to a web server involves sending leak stream data and notifications using protocols such as MQTT or HTTP. The data is then displayed on a user interface that can be accessed via mobile devices [18], [24].

The testing and analysis phase involves validating the accuracy of the system by comparing its readings to a calibrated measuring instrument, such as an AVO meter or tang ampere (voltage clamp meter). This process is repeated 20 times to ensure reliability. The system error and accuracy are calculated using the standard accuracy formula [9], [21] as follows:

$$Error = \frac{|Validated\ value - Experimented\ value|}{Validated\ value} \quad (1)$$

$$Accuracy = |1 - Error| \times 100\% \quad (2)$$

The results of the analysis are used to evaluate system performance and identify areas that need improvement to ensure that the resulting system is reliable in its operation.

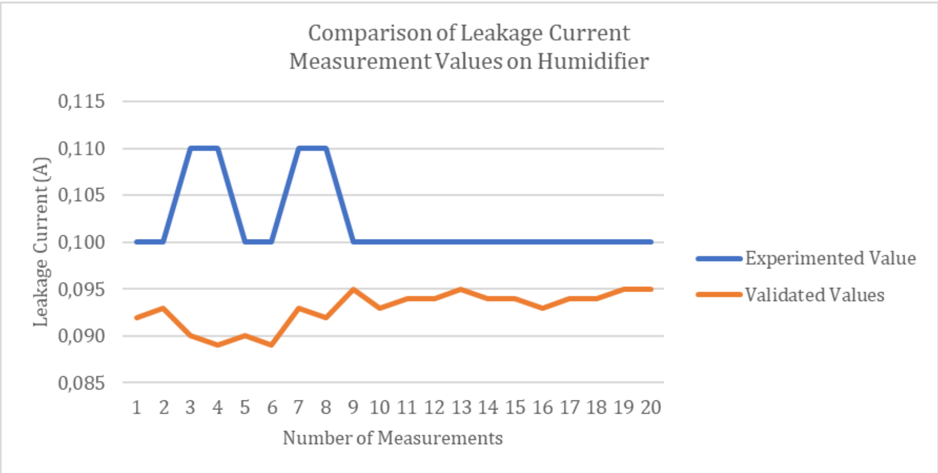
## 3. RESULTS AND DISCUSSIONS

The results of the IoT-based leakage current monitoring system test show that the system is able to detect leakage current in medical equipment with fairly high accuracy. Based on 20 data retrievals, the monitoring system successfully detected leakage current with an average accuracy of 90.11% in the Humidifier and 92.49% in the ECG. These results were obtained by comparing the monitoring system readings with a calibrated ampere clamp meter. The leakage current value detected by the system is within the smallest measurement range of 10 mA, which cannot be said to be maximum because the leakage current safety limit should only be a maximum of 3 mA. The following is a table containing observation data and graph results:

Table 1 Experiment data and accuracy of the system

| Humidifier | | | | ECG | | | |
|---|---|---|---|---|---|---|---|
| No | Experimented Values (A) | Validated Values (A) | Accuracy | No | Experimented Values (A) | Validated Values (A) | Accuracy |
| 1 | 0,1 | 0,092 | 91,30% | 1 | 0,29 | 0,269 | 92,19% |
| 2 | 0,1 | 0,093 | 92,47% | 2 | 0,29 | 0,267 | 91,39% |
| 3 | 0,11 | 0,09 | 77,78% | 3 | 0,29 | 0,268 | 91,79% |
| 4 | 0,11 | 0,089 | 76,40% | 4 | 0,29 | 0,268 | 91,79% |
| 5 | 0,1 | 0,09 | 88,89% | 5 | 0,29 | 0,271 | 92,99% |
| 6 | 0,1 | 0,089 | 87,64% | 6 | 0,29 | 0,27 | 92,59% |
| 7 | 0,11 | 0,093 | 81,72% | 7 | 0,29 | 0,274 | 94,16% |
| 8 | 0,11 | 0,092 | 80,43% | 8 | 0,29 | 0,272 | 93,38% |
| 9 | 0,1 | 0,095 | 94,74% | 9 | 0,29 | 0,271 | 92,99% |
| 10 | 0,1 | 0,093 | 92,47% | 10 | 0,29 | 0,27 | 92,59% |
| 11 | 0,1 | 0,094 | 93,62% | 11 | 0,29 | 0,271 | 92,99% |
| 12 | 0,1 | 0,094 | 93,62% | 12 | 0,29 | 0,268 | 91,79% |
| 13 | 0,1 | 0,095 | 94,74% | 13 | 0,29 | 0,267 | 91,39% |
| 14 | 0,1 | 0,094 | 93,62% | 14 | 0,29 | 0,269 | 92,19% |
| 15 | 0,1 | 0,094 | 93,62% | 15 | 0,29 | 0,268 | 91,79% |
| 16 | 0,1 | 0,093 | 92,47% | 16 | 0,29 | 0,272 | 93,38% |
| 17 | 0,1 | 0,094 | 93,62% | 17 | 0,29 | 0,274 | 94,16% |
| 18 | 0,1 | 0,094 | 93,62% | 18 | 0,29 | 0,268 | 91,79% |
| 19 | 0,1 | 0,095 | 94,74% | 19 | 0,29 | 0,268 | 91,79% |
| 20 | 0,1 | 0,095 | 94,74% | 20 | 0,29 | 0,27 | 92,59% |
| Average | | | 90,11% | Average | | | 92,49% |

Table 1 displays the experimental data and accuracy of the IoT-based leakage current monitoring system developed in this study, focusing on two medical devices: a respiratory humidifier and an ECG (Electrocardiogram). The testing process involved comparing the leakage current values detected by the system with those measured by a calibrated ampere clamp meter for validation.




(a)

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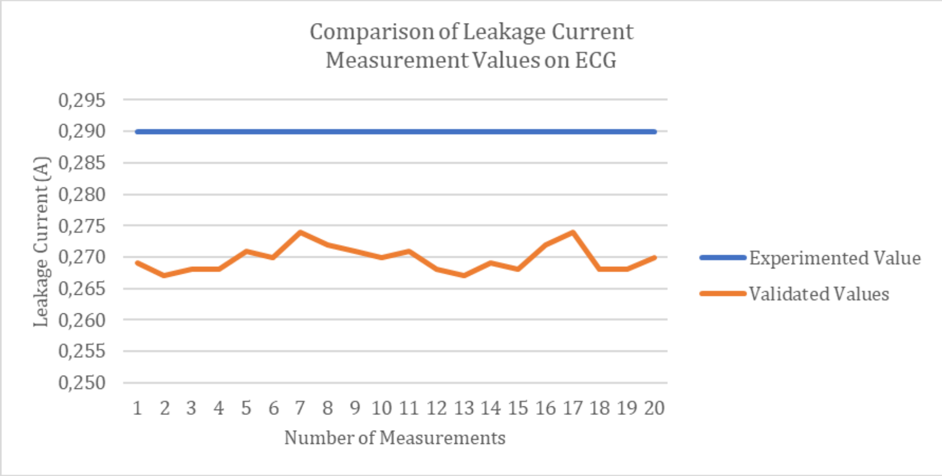


(b)

Figure 2 Comparison of leakage current measurement on (a) Humidifier and (b) ECG

Table 2 Comparison of proposed methods result with previous research result

| No. | Ref. No. | Parameters | | |
|---|---|---|---|---|
| | | Test Voltage (V) | Leakage current (mA) | Accuracy |
| 1 | [21] | $50.10^3$ | 32 | 80,88% |
| 2 | [9] | $20.10^3$ | 56 | 98,2% |
| 3 | [8] | 2 | 183 | 98,33% |
| 3 | Proposed Method | 220 | 29 | 92,49% |

Based on Figure 2 (a) and (b), it can be seen that the system's reading capability is quite good because it is still within acceptable limits, namely having an average error value of 10%, but when compared with the results of previous studies, the accuracy produced from this study is still not optimal. It is likely because that the leakage current that occurs in medical devices has a very low value, so a more precise sensor is needed to be able to read the leakage current. Based on this, it can be said that the resulting system is able to provide real-time leakage current information via a web interface that can be accessed via a gadget, but it still cannot be used optimally due to the limitations of the sensor used because it is still only able to read in the range of 10 mA. Automatic notifications are sent to the user if the leakage current value exceeds the safe limit, so that repair or maintenance actions can be taken immediately [18]. With further development in the form of using sensors that have higher accuracy to be able to read leakage currents in a maximum range of 3 mA, the results of this study are expected to be an effort to improve the safety of using medical equipment in health facilities. With an IoT-based leakage current monitoring system, the risk of electric shock and equipment damage can be minimized. In addition, further testing on various types of medical equipment and different operational conditions and the addition of features such as artificial intelligence as an effort for predictive steps to estimate insulator damage before current leakage occurs.

## 4. CONCLUSION

Overall, the IoT-based leakage current monitoring system developed in this study has shown quite good performance in detecting leakage current in medical equipment, but it is still unable to detect leakage current in the range below 3mA. The fairly high level of accuracy and real-time monitoring capabilities make this system an effective solution to improve the safety and reliability of medical equipment. This system can be expected to be a new reference in the development of leakage current monitoring technology in the health sector. Some developments that must be carried out in this study are to conduct further testing on various types of medical equipment and different operational conditions, as well as the addition of artificial intelligence features to predict insulator damage before current leakage occurs.

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## CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

**Author1**: Conceptualization, Methodology, Software, Project administration, Writing – original draft. **Author2**: Conceptualization, Methodology, Software, Writing – review & editing. **Author3**: Conceptualization, Validation. Author4: Conceptualization, Software, Writing – original draft.

## DECLARATION OF COMPETING INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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