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Development of an Automated Temperature and Humidity Control System Model for the Radiography-Fluoroscopy (R-F) Laboratory of The Radiology Department Based on Internet of Things (IoT) Technology in the Postgraduate Program of Poltekkes Kemenkes Semarang

Khansa Qonita Ramadhani[1]; Edy Susanto[2]; Gatot Murti Wibowo[3]; Sudiyono[4]; Rasyid[5]

[1,2,3,4,5]Postgraduate Program, Poltekkes Kemenkes Semarang, Indonesia
Semarang, Indonesia

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Abstract: The use of the Internet of Things (IoT) in the healthcare sector, particularly in the field of radiology, can improve quality control, operational efficiency, and patient care. The development of an IoT-based automation system for temperature and humidity control in radiology laboratories aims to address environmental control issues that often require intensive manual repairs and monitoring. The objectives of this study are to evaluate the performance of temperature and humidity control, develop a prototype model of an IoT-based temperature and humidity control automation system, and test the effectiveness of the automation system model in the R-F Room of the Radiology Laboratory at the Semarang Ministry of Health Polytechnic. The research method used a Research and Development (R&D) approach, employing an experimental design with steps including evaluation of the existing system, development of a prototype model, and testing of the model's effectiveness. Data was collected through direct measurement and user surveys. Data analysis was performed using validity and reliability tests and descriptive statistical analysis. The results of the study indicate that the development of an IoT-based temperature and humidity control system is quite effective in controlling environmental parameters in accordance with established standards. Statistical tests show no difference between the temperature and humidity of the room on the HTC 01 device and the IoT. The development of an IoT-based temperature and humidity control automation system developed in this study has been proven effective based on the N-Gain Test and can be applied to improve quality control and operational efficiency in radiology laboratories.

Keywords: *Internet of Things (IoT), Automation, Temperature, Humidity, Radiology Laboratory, Quality Control, Operational Efficiency.*

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I. INTRODUCTION

The use of the Internet of Things (IoT) in the healthcare sector aims to develop and implement healthcare devices and systems, including the development of applications such as rehabilitation systems, wireless sensor networks, and healthcare systems for remote monitoring. IoT enables the automation of rehabilitation strategies, efficient management of medical and healthcare personnel, and continuous monitoring of vital signs and collection of physiological parameters from patients [1].

The development of IoT in the field of radiology has had a revolutionary impact on the healthcare sector. Through the establishment of efficient communication, IoT has changed the paradigm of radiology workflows by significantly influencing quality control, operational efficiency, and patient care experiences [2]. The research by Azra et al. (2020) aimed to

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improve the maintenance process of conventional X-ray and Panoramic equipment by leveraging IoT. Business Process Reengineering (BPR) was used to enhance the maintenance process of medical equipment, achieving the highest time efficiency of 56.25% [3].

Ashwini et al. (2018) developed a low-cost radiation monitoring system that provides early warning of nuclear radiation leaks in power plants and submarines. In this system, a wireless sensor network is integrated with IoT, enabling continuous monitoring. The system's key advantage lies in providing workers at power plants with access to data without exposure to radiation. Using the Things Speak web server, the system collects data on atmospheric parameters and hazardous gases, offering an innovative solution for radiation monitoring by leveraging IoT technology and wireless sensors [4].

The importance of maintaining the temperature and humidity of radiology rooms is closely related to the effect of temperature on the performance of medical equipment. Temperature instability can have a negative impact on the performance of electronic components in medical imaging devices, such as semiconductors, resistors, and capacitors, which in turn affects the stability and reliability of circuit systems. High humidity has the potential to cause oxidation or break down the chemical bonds of system components, leading to corrosion or changes in chemical structure (4). Wireless temperature and humidity control systems for imaging rooms in hospitals are designed to monitor and control temperature and humidity in real time [5].

Temperature and humidity control are regulated in the Indonesian Minister of Health Regulation No. 24 of 2020 concerning Clinical Radiology Services. In these standards, Article 18 on the Air Conditioning System in Radiology Examination Rooms specifies that the ideal temperature should be between 22°C ± 2°C, the optimal humidity is 55% ± 5%, and the air exchange rate from outside should be 2 times per hour, with a total air exchange rate of 6 times per hour [6]. Quality Assurance (QA) and Quality Control (QC) are important aspects that include the temperature and humidity of radiology examination rooms.

Although Article 18 on Air Systems in Radiology Examination Rooms has been recognized as a guideline in the provision of clinical radiology services, in reality, there is no automated system that effectively regulates the temperature and humidity of radiology rooms in accordance with the needs of the equipment. This condition can cause potential damage to radiology modalities, which in turn can affect the quality of radiology services in health facilities.

The use of IoT in temperature control plays a very important role, as it allows users to control the Air Conditioner (AC) system remotely via the internet connected to a smartphone. With IoT, data on temperature, humidity, and air speed can be collected and displayed in real-time through a web server [7]. The presence of IoT not only provides convenience in remote control but also enables the use of artificial intelligence to independently and efficiently regulate thermal comfort while optimizing energy usage. As a result, IoT is key to enhancing user comfort and energy efficiency in room temperature control, positively impacting operations at the Radiology Department of the Healthcare Facility.

Controlling temperature and humidity in medical equipment facilities is important for maintaining air quality in these rooms. In particular, temperature and humidity play an important role in affecting the performance of X-ray equipment. Guidelines from Siemens regarding the Luminos RF Classic X-ray equipment also emphasize that the ideal temperature range for X-ray tubes is between 20-25°C, while humidity should be maintained within the range of 30-75%. By maintaining proper temperature and humidity levels, it can be ensured that X-ray equipment will operate optimally and consistently [8], [9].

The Radiology Laboratory of the Postgraduate Program at Poltekkes Kemenkes Semarang is equipped with various radiology modalities, such as conventional X-rays with fluoroscopy, ultrasonography, CT-Scan Computer Radiography (CR), and a computer lab server. These modalities serve as the primary means for developing students' competencies through practical activities, providing them with hands-on experience to enhance their understanding and skills in the field of radiology.

Based on preliminary studies, the equipment in Room R-F has experienced damage on several occasions, with the costs of such damage being significant. One of the causes of the damage is the unstandardized temperature and humidity in the room. Currently, the laboratory is equipped with a room temperature and humidity control device using the Temp and Humidity Htc 01 to ensure that the temperature and humidity meet the standards. However, this device only records real-time temperature and humidity data, does not store any data, and cannot generate a summary of temperature and humidity data that can be viewed again on a website.

Researchers found that temperature and humidity control conditions in the Radiography-Fluoroscopy (RF) Room of the Radiology Laboratory were still not well controlled. Control was carried out manually, namely by recording the temperature and humidity readings every day. This was done to achieve efficiency rather than focusing on the objectives of quality assurance and control in the laboratory. No Standard Operating Procedures (SOPs) or control charts were found to be used for monitoring and controlling temperature and humidity within the laboratory room. The presence of SOPs and control charts is crucial to ensure that environmental conditions in the radiology laboratory can be maintained consistently in accordance with established quality standards.

The development of IoT systems offers potential solutions to address temperature and humidity control issues. IoT-based automation systems will reduce the workload of Educational Laboratory Administrators (PLP) in accordance with Regulation of the Minister of State Apparatus Empowerment and Bureaucratic Reform of the Republic of Indonesia Number 7 of 2019 concerning Functional Positions of Educational Laboratory Administrators [10]. PLPs need to

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perform routine room checks, and the use of this technology is expected to ease their daily tasks.

As in the study by Araar et al. (2019), the study used a new control system for IoT-based air conditioning control that uses MEMS sensors to measure parameters such as temperature, humidity, and air velocity. However, this study did not include an air conditioning temperature controller to adjust the temperature and humidity according to the desired standards, as in the study to be developed by the author [7].

The IoT system to be developed in this research will provide an innovative solution where temperature and humidity control will be carried out automatically. This innovation also offers temperature and humidity adjustment through automated AC temperature settings to ensure that temperature and humidity meet standards. Additionally, PLP no longer needs to manually record temperature and humidity data every hour, as the data is already recorded in a web-based system in the form of live charts, making monitoring easier to perform. The temperature and humidity data in this web system can be used for quality assurance (QA) and quality control (QC) on radiographic equipment.

Thus, there is a need to conduct research focusing on the development and implementation of an IoT-based system consisting of sensors and controllers for controlling the temperature and humidity of the R-F room in the Integrated Radiology Laboratory of the Postgraduate Program at the Semarang Ministry of Health Polytechnic. This research will contribute to improving the operational sustainability of radiology installations in healthcare facilities and radiology laboratories in health education institutions in general, and Poltekkes Kemenkes Semarang in particular, ensuring optimal maintenance of existing radiology modalities.

II. METHOD

This study used the Research and Development (R&D) method, adopting six integrated stages for the development of an IoT-based monitoring system [11]. The research was conducted at the Radiography-Fluoroscopy (R-F) Laboratory of the Postgraduate Program at the Semarang Ministry of Health Polytechnic during the period of March-April 2024.

The first stage involved needs analysis through direct observation and Focus Group Discussion (FGD) involving four experts: PLP, Head of the Laboratory Sub-Unit, QA/QC expert, and IoT expert. The results of the analysis served as the basis for formulating system development requirements.

The second stage involves designing and implementing a system using ESP32 components, DHT 11 sensors, 5v relays, and I2C LCDs to monitor and control temperature and humidity in real time. The system is validated by IoT experts using the Blackbox method, assessing functionality, connectivity, performance, security, and compatibility.

The third stage involves testing effectiveness by comparing pretest results (using the Temp and Humidity HTC 01) and posttest results (using the developed IoT system). Effectiveness evaluation uses the Usability indicators: Flexibility, Operability, Learnability, and Understandability [12], with effectiveness measured using N-Gain and considered effective if it reaches a value of ≥70%.

III. RESULT

This study addresses three main objectives: evaluating the current room temperature and humidity control system, developing a prototype model of an IoT-based automated room temperature and humidity control system, and testing the effectiveness of the prototype model in the R-F Room of the Radiology Laboratory of the Diagnostic Imaging Program, Applied Master's Program, Postgraduate Program, Poltekkes Kemenkes Semarang.

The Diagnostic Imaging Program at Poltekkes Kemenkes Semarang, established in 2014 as the first applied master's program in Diagnostic Imaging in Indonesia, has three specialized laboratories, including the Radiography and Imaging Laboratory. The R-F (Radiography-Fluoroscopy) equipment in this laboratory requires specific environmental conditions for optimal operation and longevity.

Based on direct observation, the current conditions still rely on manual temperature and humidity control using the HTC-01 Temp and Humidity device. When room conditions do not meet standards, adjustments are made manually to the AC settings, and data is recorded manually in reports. A comparative analysis between the HTC system and the proposed Temirad system highlights significant limitations in the current approach, including the lack of IoT connectivity, the absence of an integrated information system, and the inability to automatically control environmental conditions.

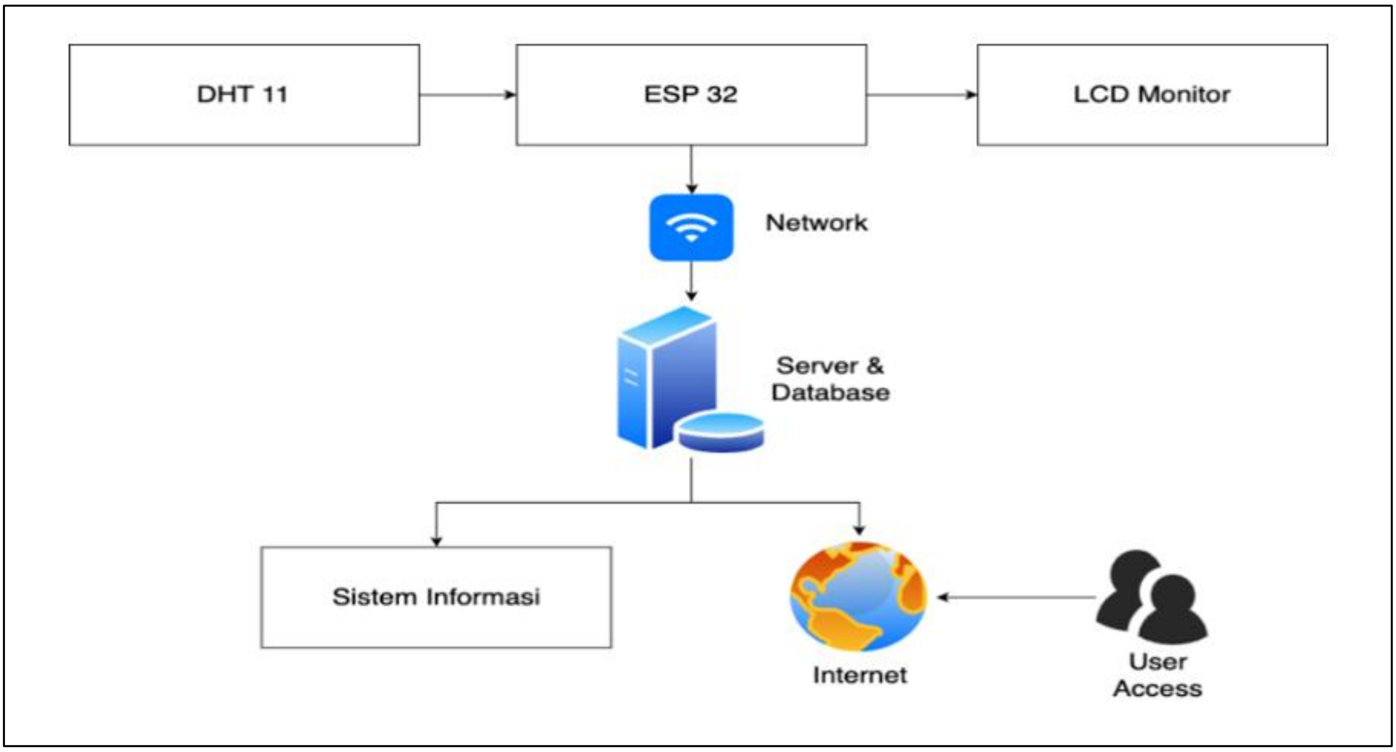

Fig 1 Draft Model for Development of IoT-Based Room Temperature and Humidity Control Information System

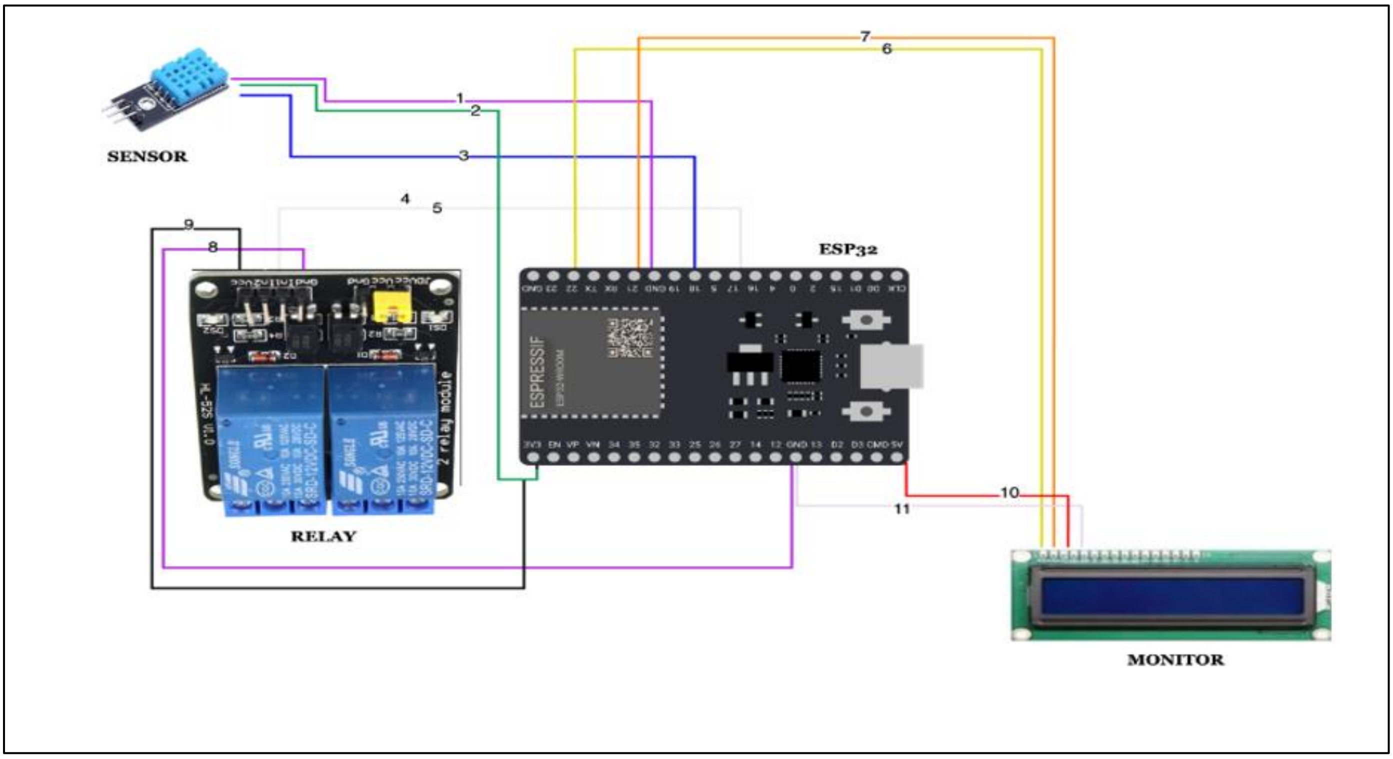

Fig 2 ESP32, DHT11 Sensor, and Relay Implementation Design

➢ *Image Notes:*

- Sensor and Controller connecting cable
- Sensor negative current cable (GND)
- Sensor positive current cable (V)
- Controller and Dehumidifier Relay connecting cable
- Controller and AC Relay connecting cable
- Controller and AC LCD Monitor connecting cable
- Controller and Dehumidifier LCD Monitor connecting cable
- Relay positive current cable (V)
- Relay negative current cable (GND)
- LCD Monitor positive current cable (V)
- LCD Monitor negative current cable (GND)

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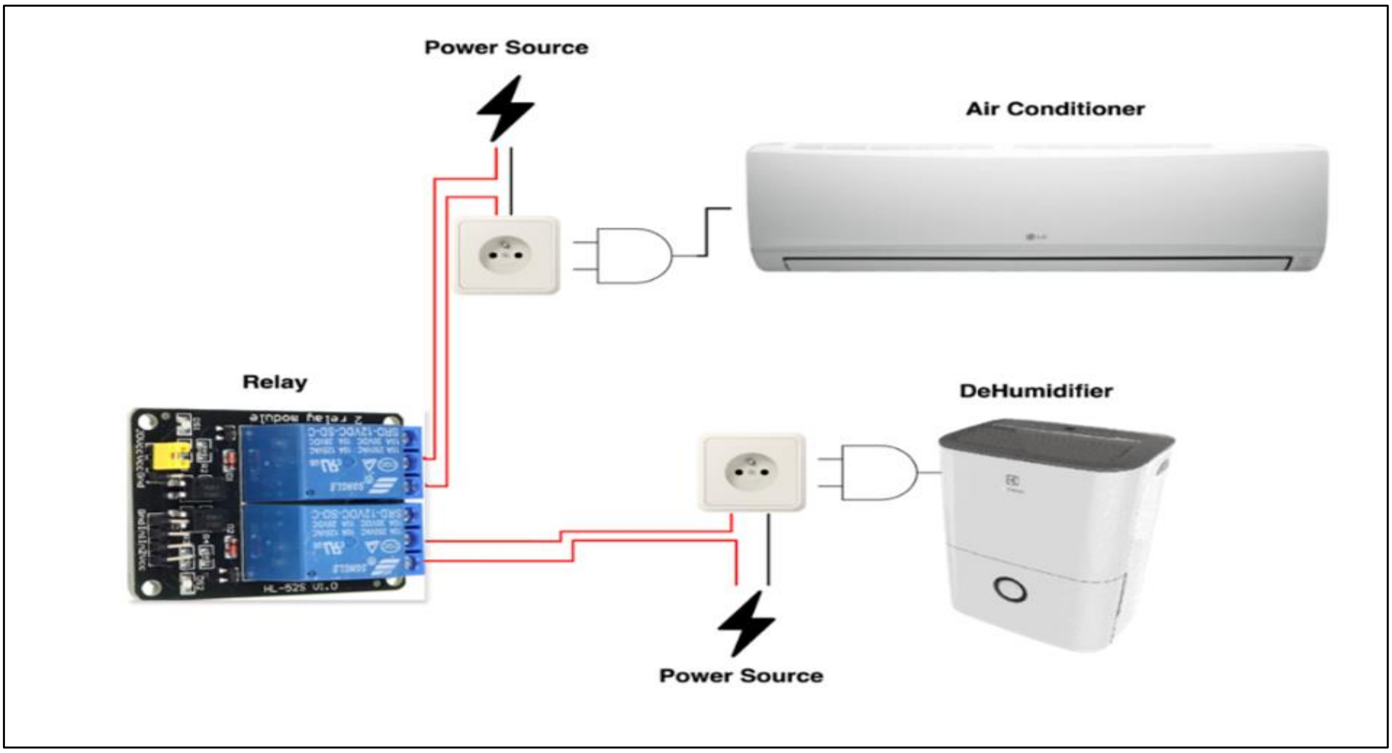

Fig 3 Relay Connection to Air Conditioner and Dehumidifier

The developed Temirad system has a functional structure consisting of several main components that are mutually integrated. The physical components include a DHT11 sensor that digitally measures temperature and humidity with high accuracy, an ESP32 microcontroller as the data processing center that receives input from the sensor, a relay as an automatic controller for the AC and dehumidifier devices, and an LCD monitor that displays real-time temperature and humidity data. All these components are connected via specially designed connecting cables, including positive and negative power cables that distribute power to each component.

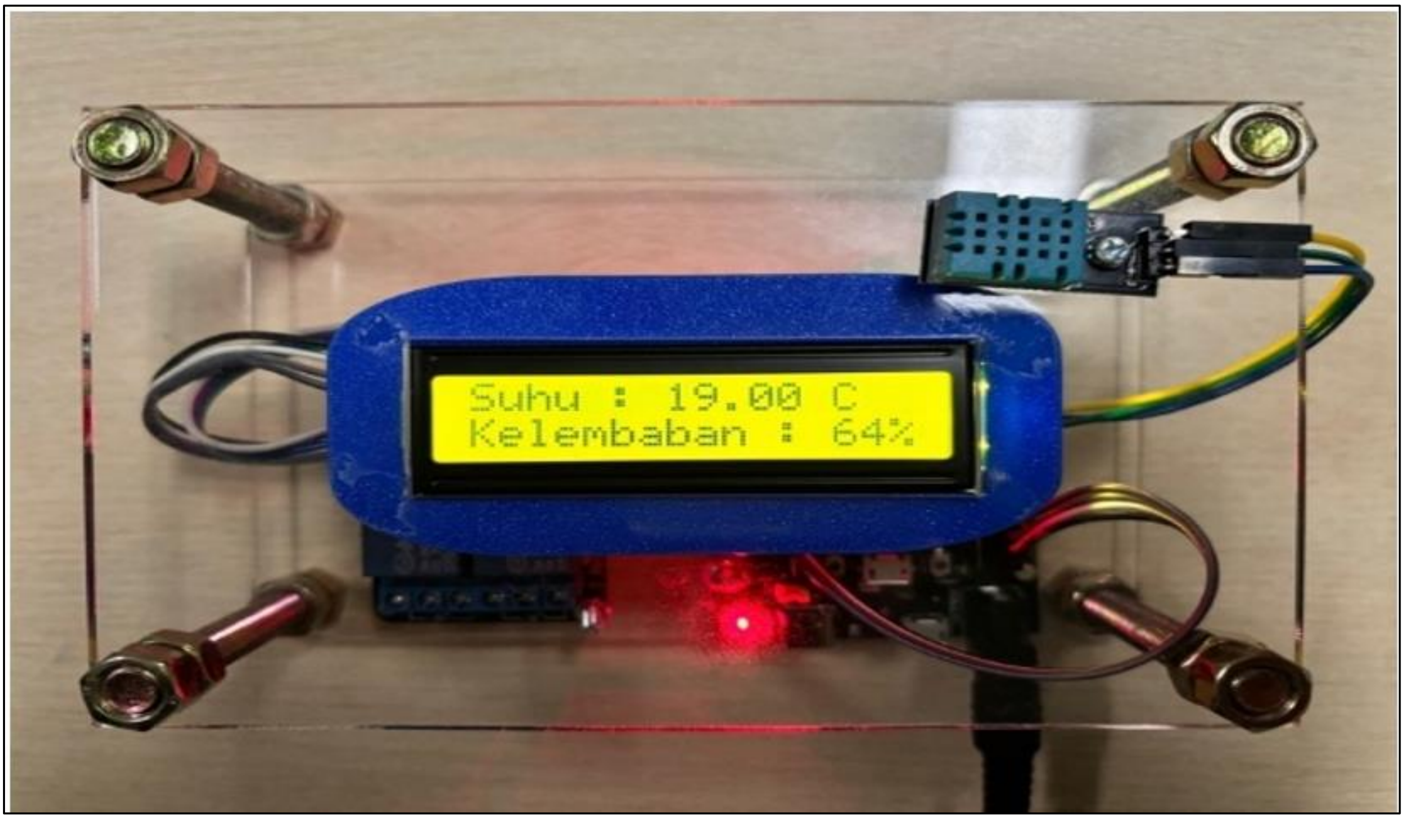

Fig 4 IoT System Assembly Results

On the software side, Temirad is equipped with a Wifi Manager system (Temirad Configuration) that automatically searches for and connects devices to a wifi network when the device is moved to a new location. This feature allows for device mobility and flexibility without the need for complicated manual settings. The Temirad system is also equipped with a comprehensive web interface, starting with a login page that ensures user access security through username and password authentication.

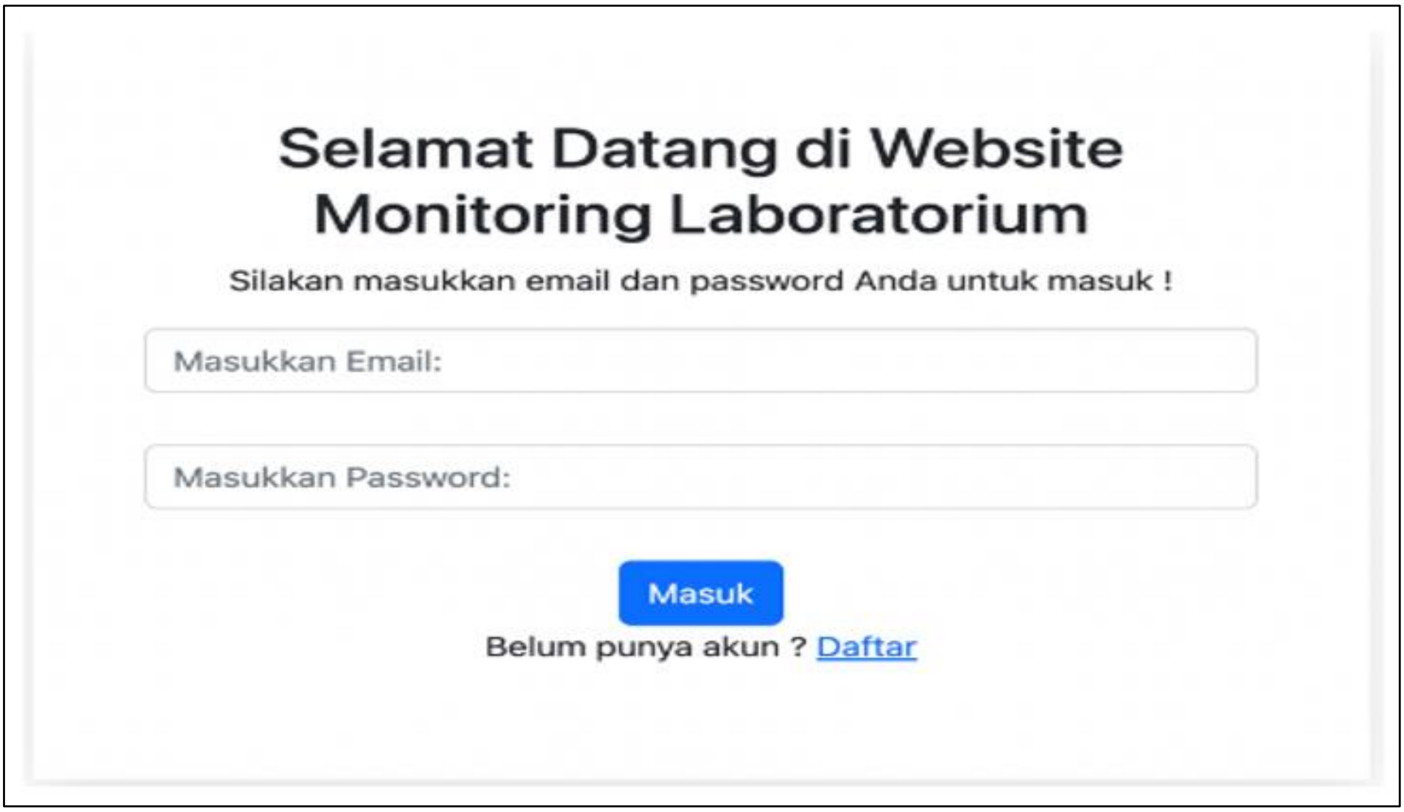

Fig 5 Login Page Web System

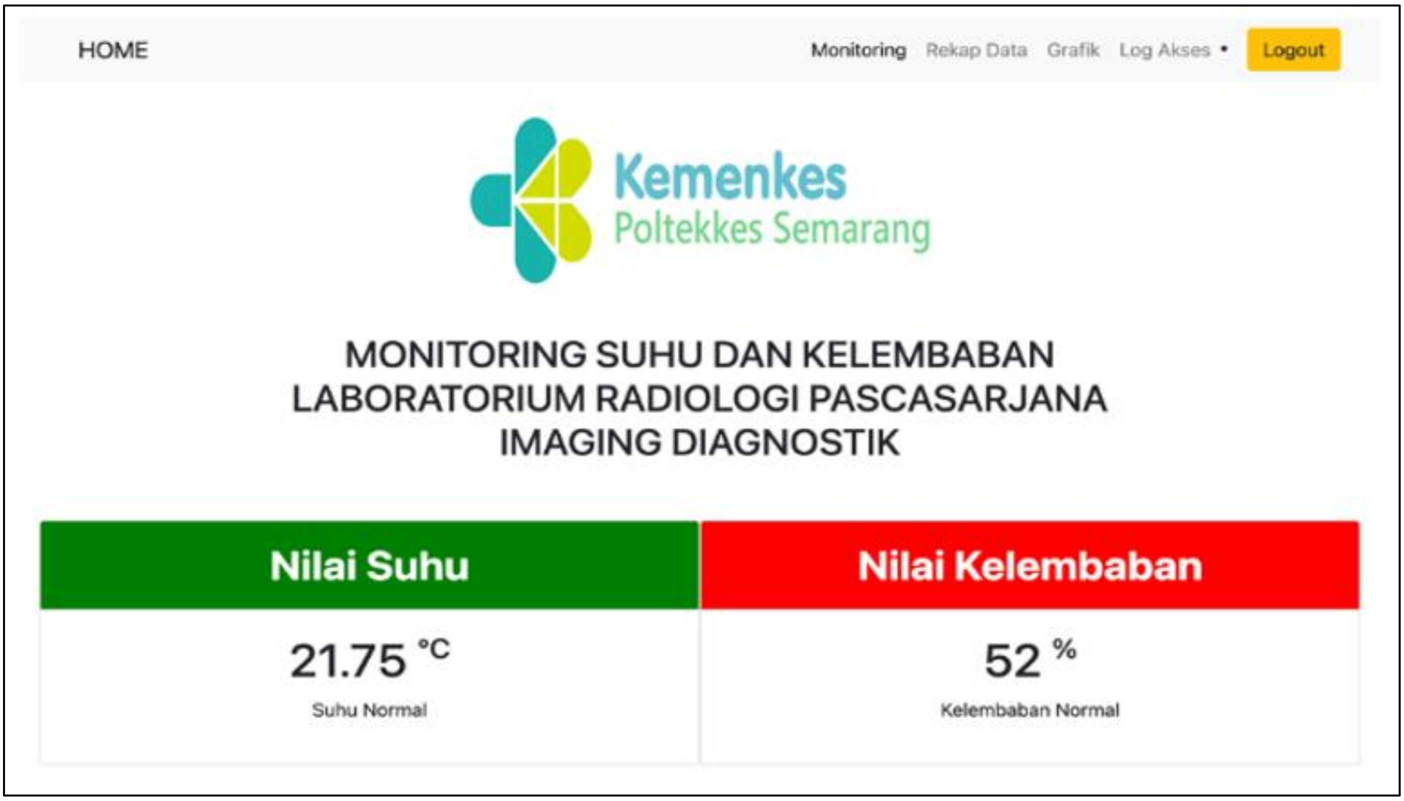

Fig 6 Dashboard View of Real-Time Temperature and Humidity Data Sent from IoT

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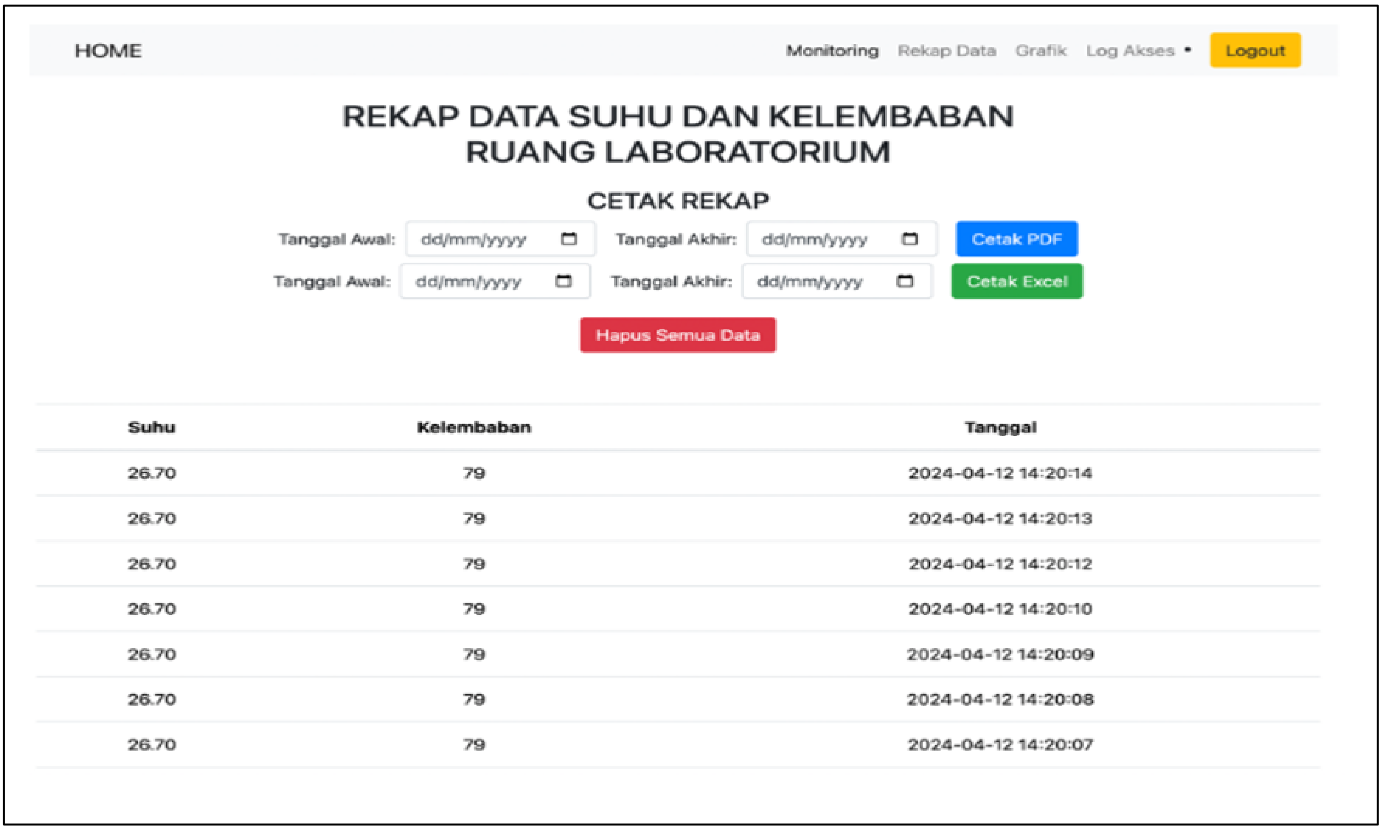

Suhu	Kelembaban	Tanggal
26.70	79	2024-04-12 14:20:14
26.70	79	2024-04-12 14:20:13
26.70	79	2024-04-12 14:20:12
26.70	79	2024-04-12 14:20:10
26.70	79	2024-04-12 14:20:09
26.70	79	2024-04-12 14:20:08
26.70	79	2024-04-12 14:20:07

Fig 7 Temperature and Humidity Data Summary Page

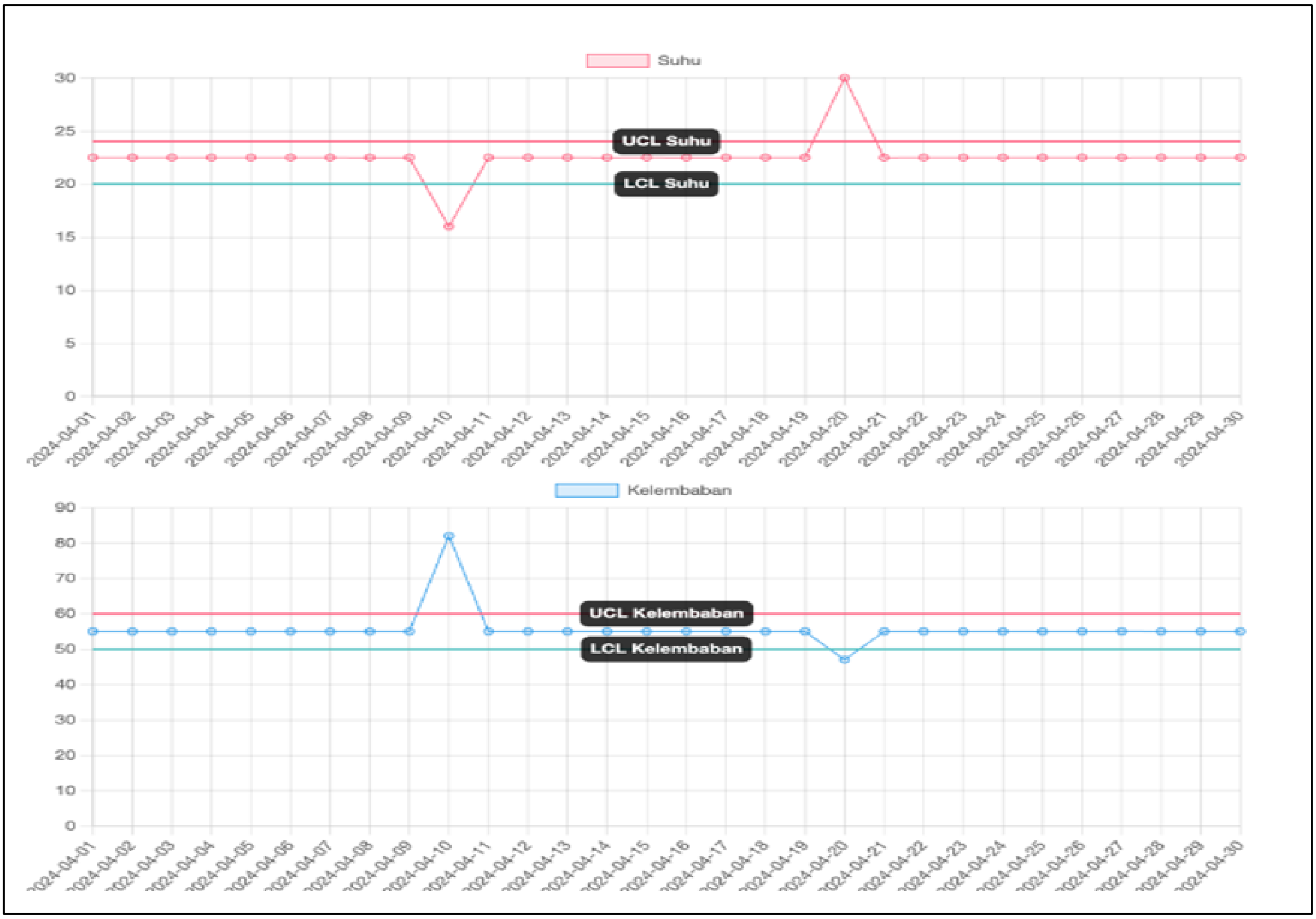

Fig 8 Realtime IoT Data Graphics Page

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The Temirad system information dashboard displays several key features: (1) Real-time temperature and humidity monitoring, displaying the latest data from the sensors, (2) Data summaries in formats that can be exported to Excel and PDF for documentation and long-term analysis, (3) Graphical visualization in the form of temperature (red) and humidity (blue) graphs that illustrate fluctuations in room conditions over a certain period of time, and (4) User access log system to monitor and record user activity in the system.

To improve accessibility and mobility, Temirad is integrated with the Blynk platform, which enables monitoring and control via a smartphone device. Through the Blynk app, users can view real-time temperature and humidity information, access data summaries for the past three months, and remotely control the AC relay and dehumidifier.

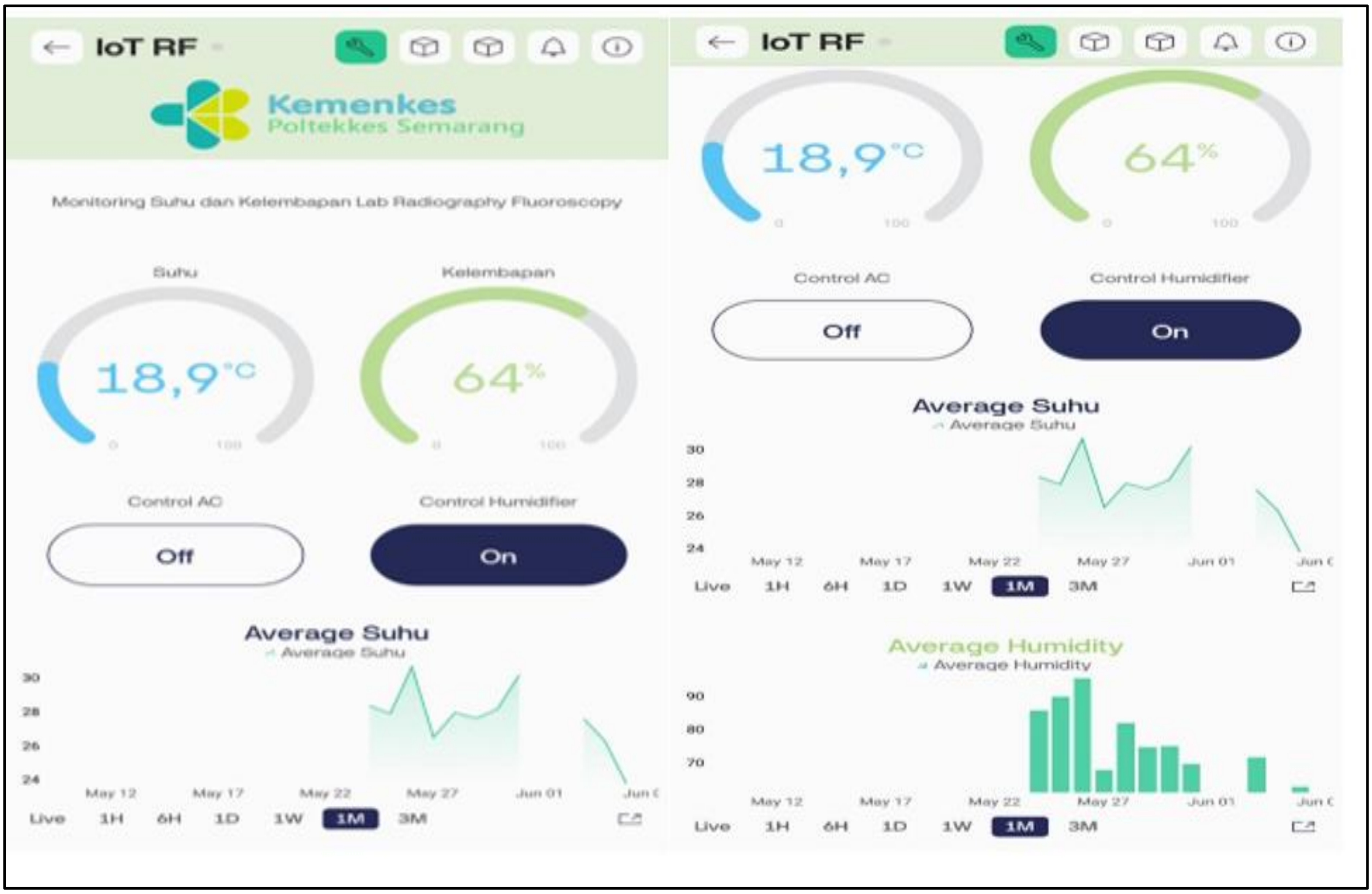

Fig 9 IoT Integration to Blynk Platform

The system operates by continuously measuring room temperature and humidity using a DHT11 sensor. The data collected is sent to the ESP32 controller, which processes the information based on predefined parameters. If the room conditions do not meet the standard parameters (temperature above 20°C or humidity above 50%), the controller automatically sends a signal to the relay to activate or deactivate the AC or dehumidifier. At the same time, temperature and humidity data are displayed on the LCD monitor for local monitoring and sent to the server via a Wi-Fi connection for storage and access through a web-based information system.

Validation testing by three experts (two IoT specialists and one radiology QA/QC expert) initially revealed connectivity issues, with the lead-lined walls of the R-F room blocking wireless signals. After installing additional router equipment, the system achieved a 100% validation score across all testing parameters, including functional testing, connectivity testing, performance testing, security testing, and compatibility testing that's show at table 1.

Table 1 Blackbox Testing

No	Item Test	Value	Information
1	Functional Testing	100%	Valid
2	Connectivity Testing	100%	Valid
3	Performance Testing	100%	Valid
4	Security Testing	100%	Valid
5	Compatibilty Testing	100%	Valid

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Accuracy testing involved comparing measurements between the HTC-01 and Temirad systems over a period of 30 days. Statistical analysis using the Mann-Whitney test showed no significant differences between the two systems in temperature measurements (p=0.143) or humidity measurements (p=0.530), despite the data distribution being non-normal. Mean rank values showed slight variation (IoT: 31.82 vs. HTC: 29.18 for humidity; IoT: 27.45 vs. HTC: 33.55 for temperature) that was not statistically significant.

Table 2 Test Results of the Differences Between IoT System and HTC 01

Variable	Item Test	p-value	Mean Rank
Humidity	IoT System	0.530	31.82
	HTC 01		29.18
Temp	IoT System	0.143	27.45
	HTC 01		33.55

Response testing demonstrated the system's ability to detect and correct abnormal conditions. On day 10, the temperature was lowered below 20°C and humidity was raised above 50%, while on day 20, the temperature was raised above 20°C and humidity was lowered below 50%. The system successfully detected these changes and automatically adjusted the conditions back to normal parameters, as evidenced by the temperature and humidity graphs showing significant fluctuations on the test day and stabilization on subsequent days.

The effectiveness of the Temirad system was evaluated through pre-test and post-test questionnaires administered to 10 laboratory stakeholders, consisting of 5 men and 5 women, with 90% being Educational Laboratory Staff (PLP). The questionnaire measured four dimensions of usability: flexibility, operability, learnability, and understandability. The instrument achieved validity (average r value of 0.816 ≥ r-table 0.632) and reliability (Cronbach's alpha 0.683 > 0.632).

Table 3 Interpretation Of N-Gain (%) Average Based on four Factors of Accompanying Variables of Real Condition Response of Usability Usage

Factors	Item	Avg *N-Gain* %	Interpretation (Hake, 1999)
Flexibelity	2	79	Effective
Operability	2	80	Effective
Learnability	2	80	Effective
Understandability	2	83	Effective
$\sum$	8	321,00	Effective
$\bar{X}$		80	Effective

Analysis using N-Gain percentages showed high effectiveness across all dimensions: flexibility (79%), operability (80%), learnability (80%), and understandability (83%), with an overall average of 80%, categorized as "effective" according to Hake's interpretation. The average score increased from the pre-test (16.7) to the post-test (38.5), representing an increase of 21.8 points.

Table 4 Comparison of Features/Advantages of HTC and Temirad System

Feature	HTC	Temirad System
Sensor Type	Thermistor or IC Sensor	Digital Humidity and Temperature Sensor (DHT11)
Connectivity	Wired (Cable)	Wi-Fi, Bluetooth
Output Data	Analog or Digital	Digital
Compatibility	Only with certain devices	Compatible with various platforms (Arduino, Raspberry Pi)
IoT Application	No	Yes, supports IoT
Application	Simple temperature measurement	Temperature and humidity measurement with IoT connection
Information System	Cannot be integrated	Has a Temperature and Humidity Information System
Chart Recap	Not available	Has a Chart-based Recap System
Time-based Recap	Not available	Has a Time-based Recap System, customizable based on needs

Qualitative feedback indicated that users found the system allowed for quick and easy adjustment of environmental parameters, was relatively easy to operate, could be monitored remotely via a web interface, and significantly improved control of the laboratory environment. The main challenge identified was the complexity of moving the system to different rooms, especially for staff unfamiliar with electrical equipment installation.

IV. CONCLUSION

This study reveals the challenges of controlling temperature and humidity in the R-F Room of the Radiology Laboratory, which was previously done manually. Through the development of an IoT-based automation system, the research team successfully designed a prototype involving sensors, controllers, relays, and LCD monitors. The model development process included observations and Focus Group Discussions

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(FGDs), which were then validated by IoT experts and QA/QC specialists, resulting in 100% validity. Evaluation of the system showed a significant improvement in usability, with an average N-Gain score of 80% based on pre-test and post-test results from ten respondents.

Further recommendations from this research include implementing IoT-based systems in various institutions such as hospitals, research laboratories, diagnostic centers, educational institutions, and office server rooms. This automation system has great potential to improve operational efficiency, ensure compliance with regulatory standards, and minimize the risk of equipment damage due to uncontrolled environmental conditions. Thus, this innovative approach can be a comprehensive solution for smarter and more measurable room condition management.

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