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Implementation of an IoT-based Temperature and Humidity Monitoring System in the Physics Education Laboratory

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Abstract

Physics laboratories require stable environments for accurate experiments, as temperature and humidity fluctuations can affect results and damage equipment. This research aimed to implement an Internet of Things (IoT)-based system to monitor these conditions in the FKIP UNRAM Physics Education Laboratory. The experimental method involved designing a system using an ESP8266 microcontroller and a DHT 11 sensor, which was programmed with the Arduino IDE to send data to the ThingSpeak platform via Wi-Fi for analysis. Over three days of testing, the system recorded an average temperature of 30.78°C and an average relative humidity of 82.76%, successfully revealing clear diurnal patterns and documenting inter-day environmental variability. Implementing this IoT system proved effective for acquiring detailed and relevant ecological data, which is crucial for ensuring the quality and validity. Future developments are suggested, including the integration of real-time notifications, interactive dashboards, and automated trend analysis, to further enhance laboratory management.

Keywords: ESP8266, humidity monitoring, internet of things (IoT), physics education laboratory, temperature monitoring.

INTRODUCTION

Physics laboratories heavily depend on stable environmental conditions to ensure the accuracy of experiments and the optimal performance of equipment. Fluctuations in temperature and humidity, however small, can cause shifts in measurement results, equipment degradation, and decreased data validity in sensitive instruments (Awaluddin et al., 2022; Jumaila & Maulida, 2018; Rangan et al., 2020). Humidity is the extent of water vapor (water as a gas) found, as a general rule, in the air (Baylakoğlu et al., 2021). Uncontrolled environmental conditions can significantly impact research outcomes, resulting in material and operational losses (Mulyono & Haviana, 2018; Pei et al., 2020). Furthermore, Hartawan (2012, as cited in Fauzi, 2019) states that temperature and humidity also affect learning motivation and participation in laboratories (Jiang et al., 2018; Liu et al., 2021), thus requiring a monitoring system capable of providing continuous and accurate data.

In response to these needs, the development of Internet of Things (IoT) technology offers innovative solutions by integrating digital sensors for real-time measurement (Zhang et al., 2024; Safitri & Akbar, 2023). Modern and ubiquitous communication methods enable the Internet of Things (IoT) to integrate the digital world with the physical one (Dhingra et al., 2020). This technology enables the automatic collection of temperature and humidity data and the remote transmission of data, thereby increasing monitoring efficiency (Fauzi, 2019). Monitoring systems are widely utilized for ongoing observation and the systematic collection of data, and their use has become common in today's world, which is shaped by numerous environmental phenomena and factors (Jabbar et al., 2022). Thus, the application of IoT in laboratory monitoring systems can reduce dependence on manual observation and accelerate responses to changes in environmental conditions (Jumaila & Maulida, 2018).

Although IoT technology offers innovative solutions for monitoring laboratory environmental conditions, its application is not without challenges. One of the main obstacles is integrating IoT systems with existing laboratory infrastructure, which often requires significant adjustments and additional investment (Sabran et al., 2018). Additionally, data security is a critical concern, given the potential risks to sensitive information collected by these sensors (Al-Garadi et al., 2020; Kassim, 2020; Sadewa et al., 2025). Other challenges include ensuring proper sensor calibration to maintain data accuracy (Feng et al., 2025) and training laboratory staff in the operation and maintenance of these new systems (Prihhapso et al., 2023). Therefore, although IoT implementation promises increased efficiency and accuracy in laboratory environmental monitoring, a well-thought-out strategy is needed to overcome these obstacles.

Several relevant studies have implemented monitoring systems in laboratories. Fauzi (2019) developed SIONLAP V2 to monitor laboratory temperature and humidity. Awaluddin et al. (2022) designed a prototype for monitoring temperature and humidity in a Calibration Laboratory. Another study by Jumaila and Maulida (2018) focused on a real-time, web-based monitoring system for a Calibration Laboratory, while Prihhapso et al. (2023) implemented an IoT system for recording environmental data compliant with the ISO/IEC 17025:2017 standard. In the physics education laboratory of FKIP UNRAM, the

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absence of a real-time temperature and humidity monitoring system has raised serious concerns about the reliability of equipment and practical materials, as well as the smooth execution of practical work. This system's lack could lead to environmental conditions that do not meet operational standards, affecting the quality of experiments and the learning process (Fauzi, 2019; Prihhapso et al., 2023; Winkler-Skalna, 2024). Therefore, this research aims to apply IoT technology as a monitoring solution that enhances the accuracy and speed of data collection, while also providing ease in laboratory management. The contribution of this research is expected to enhance the quality of practical work and support research activities, enabling the physics education laboratory at FKIP UNRAM to operate more efficiently.

MATERIALS AND METHODS

Time and Place of Research

This experimental research involves designing and testing a monitoring system. The study was conducted from March to April 2025 in the Physics Education Laboratory of FKIP UNRAM. This study has an independent variable, the IoT system, which is used for monitoring, and the dependent variables are the temperature and humidity levels of the physics education laboratory.

Research Design

This research focused on the implementation and evaluation of an IoT system for monitoring temperature and humidity in a physics education laboratory, with an analysis of the data collected by the system over a three-day observation period (06:30-19:00). The IoT system's ability to provide continuous and near real-time data is fundamental to the analysis of the laboratory's micro-environmental conditions presented. The obtained results, visualized in Graph 1 and Graph 2, not only depict the dynamics of temperature and humidity but also demonstrate the capabilities of the developed IoT system.

System Development and Instrumentation

The stages undertaken in this research began with the design of hardware and software. Magadán et al. (2020) state that the evolution of micro-electromechanical systems enables the widespread installation of low-cost sensors equipped for sensing, computation, and wireless communication, which are used to gather data for monitoring the environment and machinery. The hardware components in this study consist of an ESP8266 (G), DHT11 sensor module (F), battery charging module (D), 18650 lithium battery (A), switch (C), power indicator LED (B), internet indicator LED (F), resistors, and connecting cables. The assembled device is shown in Figure 1.

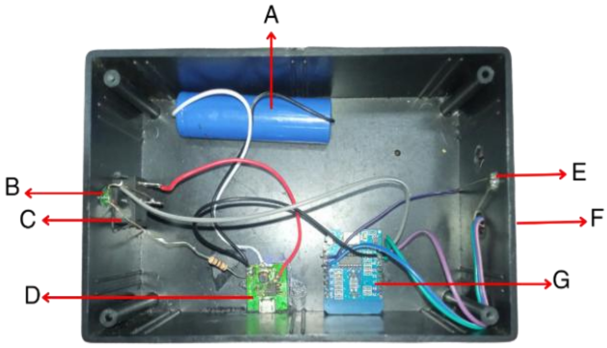


Figure 1. Designed device

The designed system utilizes a DHT11 sensor to collect air temperature and humidity data, which is then processed by the ESP8266 microcontroller. The ESP8266 processes the data from the sensor and sends the processed data to a server (Moon et al., 2023; Savari et al., 2019). The Software was designed to program the ESP8266 to process data from the DHT11 sensor and send it to the server via a Wi-Fi network (Lestari et al., 2022). The software design used Arduino IDE software (Bakar et al., 2022; Siskandar et al., 2023).

Data Collection and Analysis

Before final data collection, the designed system prototype was tested by measuring environmental temperature and humidity. The data from this testing was compared with measurement values from conventional measuring tools to calibrate and ensure the accuracy of the data obtained. Data was collected in the physics education laboratory by running the system nonstop for 24 hours over three days. This process yielded a sample of 4371 data points for temperature and humidity. The measured data were sent to the ThingSpeak portal, and the collected data would be stored on the ThingSpeak server (Ndunagu et al., 2022; Morchid et al., 2024). Figure 2 shows the data processing system performed by ThingSpeak.

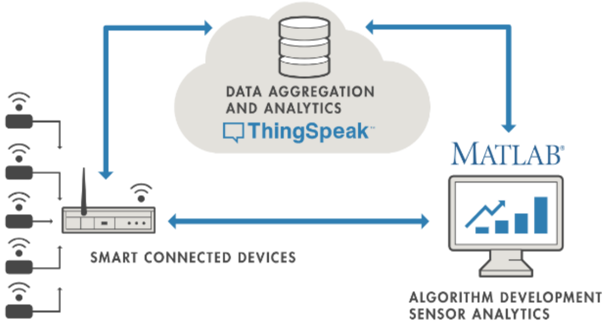


Figure 2. Data processing system on ThingSpeak

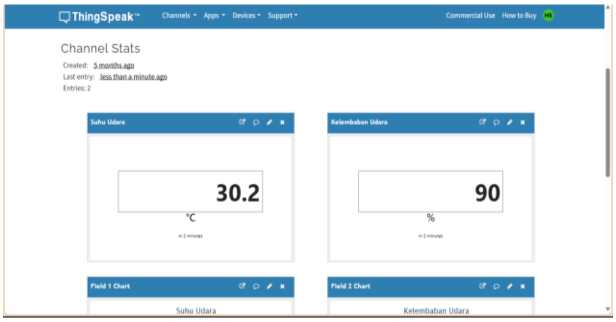
For analysis, the stored data were then averaged hourly, as shown in Table 1. The data in Table 1 can provide important insights into the dynamics and stability of the laboratory's micro-environment.

RESULT AND DISCUSSION

Result

Testing

Testing was conducted by connecting the system to the public WiFi available at the University of Mataram. The measured temperature and humidity data were sent to the ThingSpeak portal to store and display data in real-time, as shown in Figure 4. Over three days of testing, 4371 data points for temperature and humidity were obtained, with 1457 data points collected daily.



Channel Stats
Created: 5 months ago
Last entry: less than a minute ago
Entries: 2

Figure 3. The ThingSpeak portal display shows real-time data

The stored data was then averaged hourly, as shown in Table 1 below. The data in Table 1 can provide important insights into the dynamics and stability of the laboratory's micro-environment.

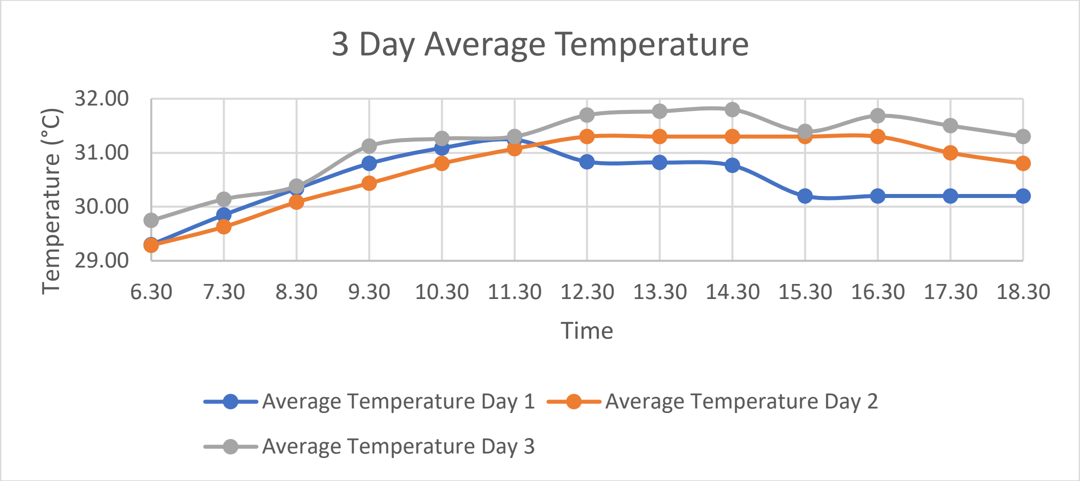
Table 1. Average hourly air temperature and air humidity

Time	Day 1		Day 2		Day 3	
	Average temperature (°C)	**Average humidity (%)**	**Average temperature (°C)**	**Average humidity (%)**	**Average temperature (°C)**	**Average humidity (%)**
06.30-07.30	29.30	29.30	29.29	29.29	29.75	29.75
07.30-08.30	29.85	29.85	29.63	29.63	30.14	30.14
08.30-09.30	30.34	30.34	30.09	30.09	30.38	30.38
09.30-10.30	30.80	30.80	30.43	30.43	31.12	31.12
10.30-11.30	31.09	31.09	30.80	30.80	31.26	31.26
11.30-12.30	31.24	31.24	31.07	31.07	31.30	31.30
12.30-13.30	30.83	30.83	31.30	31.30	31.70	31.70
13.30-14.30	30.82	30.82	31.30	31.30	31.77	31.77
14.30-15.30	30.76	30.76	31.30	31.30	31.80	31.80
15.30-16.30	30.20	30.20	31.30	31.30	31.39	31.39
16.30-17.30	30.20	30.20	31.30	31.30	31.68	31.68
17.30-18.30	30.20	30.20	31.00	31.00	31.50	31.50
18.30-19.00	30.20	30.20	30.80	30.80	31.30	31.30
Average	30,45	85,33	30,74	79,79	31,16	83,16

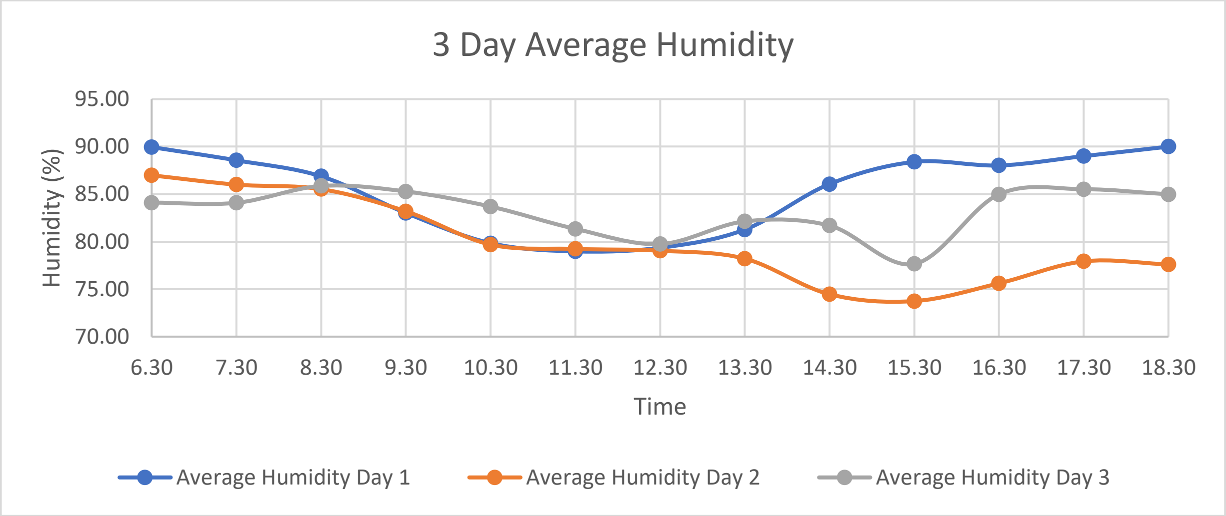
Discussion

This study successfully demonstrated the implementation of an IoT-based system for real-time monitoring of temperature and humidity in the Physics Education Laboratory. The analysis of the collected data reveals several key points for discussion regarding the laboratory's micro-environment, which will be contextualized with established theories and findings from similar research.

The primary finding is the system's ability to document a clear diurnal temperature pattern, consistently lower in the morning and peaking in the afternoon, as visualized in Graph 1. This observation aligns with fundamental thermodynamic principles, where the pattern can be attributed to a combination of ambient heating from solar radiation throughout the day and internal heat loads from laboratory activities.



Concurrently, the system captured a strong inverse relationship between temperature and relative humidity, which is illustrated in Graph 2. This phenomenon is well-explained by physics: as air temperature rises, its capacity to hold water vapor increases, which in turn causes a decrease in relative humidity, assuming the absolute moisture content in the air remains relatively constant. The system's capability to precisely record this theoretical relationship confirms its accuracy and utility.



Graph 2. Average humidity over 3 days of observation.

Furthermore, the successful documentation of significant inter-day variability—for instance, Day 2 being generally warmer and less humid than other days—underscores the dynamic nature of the laboratory environment and reinforces the core argument that manual or periodic monitoring is insufficient. These findings are consistent with other research that has implemented IoT for laboratory monitoring. For example, studies by Fauzi (2019) and Awaluddin et al. (2022) also highlighted the need for real-time data to manage fluctuating conditions in laboratory settings. Similarly, Jumaila & Maulida (2018) emphasized the importance of real-time web-based monitoring. The variability observed in our study likely corresponds to differences in laboratory usage, such as the type of physics experiments being conducted or the number of students present, further strengthening the case for a continuous monitoring solution.

The implications of these findings are critical for the Physics Education Laboratory. The observed environmental fluctuations are not trivial, as physics experiments are often highly sensitive to such changes. Winkler-Skalna (2024) noted that changes in heat and humidity can significantly impact measurements. For instance, temperature variations can affect material dimensions through thermal expansion and alter the resistivity of electronic components, while humidity can influence electrostatic phenomena and promote corrosion of metal equipment. Therefore, the detailed data provided by this IoT system is crucial for ensuring the quality and reproducibility of experimental results, aligning with the quality assurance goals mentioned in studies such as Prihhapso et al. (2023), which emphasize ISO/IEC 17025 compliance. Beyond simple data logging, this system is a foundational step towards an early warning tool. With the future integration of threshold notifications, staff can be proactively alerted to prevent equipment damage or experiment failure due to extreme conditions.

Despite its successful implementation, this study has several limitations that must be acknowledged. The three-day monitoring period provides only a snapshot and may not capture long-term or seasonal variability. The accuracy of the collected data is also inherently dependent on the calibration and intrinsic accuracy of the DHT11 sensor used. Furthermore, this analysis is based on data from a single point within the laboratory and may not fully represent the spatial heterogeneity of conditions across the room. Future research should address these limitations by extending the monitoring period, incorporating multiple sensor nodes for better spatial mapping, and potentially integrating other relevant environmental parameters such as light intensity or air pressure.

CONCLUSION

Implementing the IoT system for monitoring temperature and humidity in the physics education laboratory has proven effective in acquiring detailed and relevant environmental data. Data analysis shows that laboratory environmental conditions are dynamic, with clear diurnal patterns and significant inter-day variability. This information is crucial for the Physics Education Laboratory to ensure the quality of experiments. Future development of this IoT system can focus on: 1) Integration of real-time notification features for conditions outside threshold limits. 2) Development of a more interactive data visualization dashboard. 3) Addition of sensor nodes for spatial monitoring and other environmental parameters relevant to physics experiments (e.g., light intensity, air pressure). 4) Implementation of long-term data storage and automated trend analysis. This IoT system has great potential to become an essential laboratory management tool, helping to maintain optimal conditions and support high-quality research activities in the Physics Education Laboratory.

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