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Article

A Smart Web Application for Real-Time Indoor Temperature and Humidity Monitoring

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Abstract. Learning comfort is influenced by the environment, including temperature and humidity. This study validates the temperature and humidity monitoring device (DHT 22) in the dashboard system of the Department of Electrical Engineering. The results show high accuracy, with 98.96% for temperature and 98.93% for humidity, and an average error rate of 1.04%. Validation was conducted at BMKG Tanjungpinang for four days, with data recorded every minute for 24 hours. User satisfaction evaluation using the System Usability Scale (SUS) yielded an average score of 57, categorized as "Not Acceptable." Nevertheless, users still provided relatively positive feedback. These findings emphasize the need for improvements in dashboard design, user experience, and additional training. Recommendations include utilizing third-party platforms and evaluating the hardware and interface to enhance system usability.

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1. Introduction

To create an optimal learning experience, a supportive and comfortable environment, as well as adequate space, is essential to help students concentrate fully during learning activities. Temperature and humidity are two factors believed to significantly influence the effectiveness of the learning process [1]. Comfort during learning is affected by several factors, one of which is the environmental condition where the learning takes place [2]. According to [3], excessively high room temperatures can trigger psychological reactions in humans, marked by physical responses such as sweating, fatigue, oxygen deficiency leading to drowsiness, and the emergence of negative thoughts that impact mental well-being in the classroom. Based on the Indonesian National Standard (SNI 03-6572-2001), the ideal temperature for comfort in tropical regions ranges between 20.5 °C and 27.1 °C. Meanwhile, the recommended humidity level for comfort is between 40% and 50%, and for rooms with a large number of people, the suggested humidity level is between 55% and 60% [4].

Based on research conducted by [5], the environment plays a significant role in influencing academic achievement. Data obtained from the assessment of nine campus environmental variables by respondents showed that 37.58% of students strongly agreed that environmental cleanliness has a positive impact, while 17.83% stated that classroom air temperature affects the learning process. In addition, classroom comfort has also been proven to have a significant impact on the effectiveness of learning activities [6].

To address this issue, a system capable of monitoring room temperature and humidity in real-time is required. This monitoring can be conducted through various platforms such as Ubidots, Thingspeak, Cayenne, and Blynk [7-9]. However, these platforms have certain limitations, particularly in terms of interface customization, and often require users to pay additional fees to access full features. Therefore, this study aims to develop an Internet of Things (IoT)-based moni-toring dashboard utilizing the official website of the Department of Electrical Engineering.

The current website of the Department of Electrical Engineering still has several shortcomings, such as an unappealing interface and limited functional features beyond serving as an informational platform about the department, making it less effective in attracting visitors. Adding a monitoring feature could be a solution to enhance both the functionality and appeal of the website. In general, the development of real-time monitoring features requires an Application Programming Interface (API) [10] or a Uniform Resource Locator (URL) to retrieve and share data from the database. Internet of Things (IoT) platforms typically use servers located overseas. However, according to the Regulation of the Minister of Communication and Information Technology No. 5 of 2015, Chapter IV, Article 20, institutions using domestic domains are required to use servers located within the jurisdiction of the Republic of Indonesia. Google Sheets has been widely utilized for various purposes, including data storage, educational media, and dashboard creation [11-13].

Google Spreadsheet offers a variety of advanced features such as integration with Google Drive, free access, report management, team collaboration, and real-time data editing. Supported by Google's extensive data center infrastructure spanning 35 global locations, including a data center in Jakarta, Google Sheets Indonesia can also function as a database. This allows the development of a monitoring dashboard integrated into the Department of Electrical Engineering website, providing a web-based information platform that can be accessed by students and the general public.

The novelty of this research lies in the development of a real-time IoT-based monitoring dashboard that is directly integrated into the official website of the Department of Electrical Engineering using Google Sheets as the main database that not only stores data but also becomes an integration point between systems. This approach is not common on an institutional scale because Google Sheets is usually only used as an analysis tool, not as the backbone of an IoT monitoring system. Unlike existing IoT platforms that often require paid subscriptions and lack interface flexibility, this approach offers a cost-effective, customizable, and locally compliant solution by utilizing Google's data center infrastructure, including its presence in Indonesia, to meet data sovereignty regulations. The use of Google Sheets as an integrative database also provides ease in development, maintenance, and user training, so that this system can be managed independently by the academic community without relying on external service providers.

2. Research Method

2.1. Research Stage

The design of the device in this study consists of three main components: hardware design, software design, and dashboard design. The hardware design focuses on determining the physical elements to be used. The software design involves creating a program to control the device's op-eration. Meanwhile, the dashboard design is centered on developing a website interface that dis-plays the data transmitted from the device.

The next stage is device testing, which aims to ensure that the designed tool functions according to the desired specifications. The testing process covers various components such as the ESP32, DHT22 sensor, SD card, 128x64 OLED display, and integration with Google Sheets, followed by an evaluation of the overall system performance. Field testing is conducted after the hardware, software, and dashboard interface have been successfully designed and developed. Once field testing is complete, the next step is data analysis. The research procedure flow is illustrated in Figure 1.

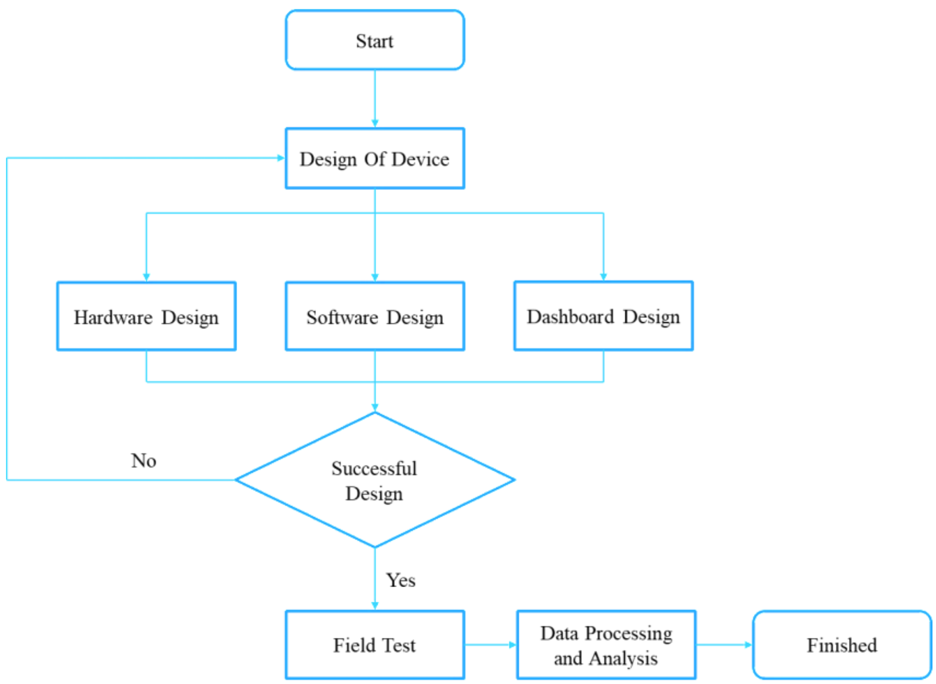

Figure 1. Research procedure

2.2. Data Processing and Analysis

Sensor validation is carried out to compare temperature and humidity data obtained from the DHT22 sensor with data generated by the Automatic Weather Station (AWS) owned by the Mete-orological, Climatological, and Geophysical Agency (BMKG). AWS is an automatic weather monitoring device that can record various meteorological parameters, such as air temperature, relative humidity, atmospheric pressure, wind direction and speed, solar radiation intensity, and rainfall [14]. This validation process aims to calculate the values of standard deviation, error, and accuracy to evaluate the level of accuracy and consistency of the data obtained from the DHT22 sensor. Thus, this process ensures whether the sensor can be used as a reliable tool for monitoring temperature and and humidity.

This validation is also important for assessing the technical performance of the equipment used [15]. The first step in the validation process is calculating the standard deviation, which is a statistical indicator describing the extent of variation or deviation of data from the mean value [16]. The equation for calculating standard deviation is presented below:

$$s = \sqrt{\frac{\sum(xn - \overline{xn})^2}{n-1}}$$

Where
s : Standard Deviation
xn : Measurement Result Value
(xn) : Average value of measurement result
n : lots of data

After obtaining the standard deviation value, the next step is to calculate the magnitude of the error in the sensor. This error indicates the extent to which the measurement results deviate from the actual value [17-18]. The equation for calculating the error and RMSE is presented below.

$$ER = |\sum_{i=1}^{n}\left(\left(\frac{\frac{IX_i - XO_iI}{2a}}{n}\right) * 100\%\right)|$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y^i - \hat{y}^i)^2}$$

Where
X_i : The true or reference value at period i
XO_i : The measured value during period i
ER : The relative error in percent
RMSE : Root mean Square Error
yi : Actual Value
$\hat{y}^i$: Prediction Value
n : lots of data

After calculating the standard deviation, RMSE (Root Mean Square Error), and error values, the next step is to determine the accuracy of the measurements. Accuracy describes how closely the measured data approaches the true value [19]. The higher the accuracy, the more precise the measurement results are when compared to the expected values [20]. Assessing accuracy is crucial to ensure that the data generated by measuring instruments, such as temperature and humidity sensors, is reliable and meets requirements [21]. The equation for calculating accuracy is shown below.

$$Accuracy = 100\% - ER$$

Website usability will be evaluated using the System Usability Scale (SUS) approach. The SUS method is an assessment instrument consisting of 10 questions designed to measure user perception of a system's or product's ease of use. This approach provides an overall picture and subjective assessment of the user's experience when interacting with the tested system. With the SUS method, researchers can gather important information regarding user satisfaction levels and design aspects that need improvement to enhance system quality [22]. The primary goal of usability testing is to evaluate how effectively and efficiently a service or product can be used by users during the testing process [23].

Usability Testing will involve 40 respondents consisting of lecturers, staff or employees, and students from the Faculty of Engineering and Maritime Technology. Respondents will be asked to fill out a questionnaire containing an assessment instrument based on the System Usability Scale (SUS). The selection of 40 respondents is based on the latest methodological approach in usability evaluation. Based on recent studies Martins et al., 2023, the number of respondents between 20 and 40 is considered sufficient to obtain reliable and statistically analyzable SUS scores. This number is also sufficient to capture variations in usability perceptions among different user groups. In this study, respondents were selected by purposive sampling from three main categories of system users, namely: Lecturers, who represent system users from the academic and teaching side. Staff or employees, as administrative users involved in system management. Students, as the main users who interact directly with the system in learning activities. The characteristics of these respondents were chosen to reflect the diversity of roles and needs of users in the Faculty of Engineering and Maritime Technology environment. By involving 40 respondents from various backgrounds, the results of the usability evaluation are expected to provide a comprehensive picture of the ease of use and effectiveness of the system from various user perspectives. Evaluation items can be seen in (Table 1).

Table 1. SUS instrument test

No	Instrument	Scale
1	In my opinion, I would likely use this monitoring dashboard regularly.	1 to 5
2	I feel that this dashboard does not need to be designed with a high level of complexity.	1 to 5
3	In my opinion, the use of this monitoring dashboard is quite simple.	1 to 5
4	I feel that I might need technical assistance to operate this dashboard.	1 to 5
5	I see that the features on this dashboard are effectively integrated.	1 to 5
6	I feel there are quite a few inconsistencies in this dashboard.	1 to 5
7	I imagine that most people would quickly understand how this dashboard works.	1 to 5
8	In my opinion, this monitoring dashboard is quite complex to use.	1 to 5
9	I feel quite confident and comfortable when using this monitoring dashboard.	1 to 5
10	I feel I need to learn a lot before I can start using this dashboard well.	1 to 5

According to research conducted by [24], the calculation process for the System Usability Scale (SUS) involves five contribution scales with a value range between 0 and 4. The calculation mech-anism is as follows: for odd-numbered statements (1, 3, 5, 7, and 9), the contribution score is ob-tained by subtracting 1 from the answer score. Meanwhile, for even-numbered statements (2, 4, 6, 8, and 10), the contribution score is calculated by subtracting the respondent's given score from 5. After all contribution scores are obtained, their total sum is then multiplied by 2.5 to yield the final usability score. This final SUS score ranges from 0 to 100. The equation for calculating the SUS value is presented below.

$$Score\ SUS = (Q1 - 1) + (5 - Q2) + (Q3 - 1) + (5 - Q4) + (Q5 - 1) + (5 - Q6) + (Q7 - 1) + (5 - Q8) + (Q9 - 1) + (5 - Q10) * 2.5$$

Upon gathering all respondent data in this study, the next step is to perform data analysis using the System Usability Scale (SUS) formula to calculate the usability score. The formula for calculating the SUS score can be seen in the following equation:

$$\bar{x} = \frac{\sum x}{n}$$

Where
x : Average Score
Σx : Total Score
n : Total Respondent

After obtaining the average SUS score from all respondents, this value will be classified into specific evaluation categories based on the test results. Each score obtained carries a different mean-ing according to its level. This SUS score can be presented in the form of percentile ranks or letter grades to describe how well the system's usability level is. Percentiles indicate the relative position of the score against all results, while letter classifications describe the quality of the system with a rating range from A (best) to F (lowest) [25].

Table 2. Score Sus [25]

SUS Score Range	Grade	Percentile Range
96 – 100	84.1 – 100	A+
90 – 95	80.8 – 84.0	A
85 – 89	78.9 – 80.7	A-
80 – 84	77.2 – 78.8	B+
70 – 79	74.1 – 77.1	B
65 – 69	72.6 – 74.0	B-
60 – 64	71.1 – 72.5	C+
41 – 59	65.0 – 71.0	C
35 – 40	62.7 – 64.9	C-
15 – 34	51.7 – 62.6	D
0 – 14	0.0 – 51.6	F

The System Usability Scale (SUS) can also be presented in the form of an adjective rating to facilitate the evaluation of a system's ease of use. The value obtained from this assessment can then be translated into an acceptability range category, which serves to determine whether the system is viable and acceptable to users [26]. The interpretation of SUS scores can be seen in Table 3.

Table 3. Interpretation of Sus Score [24]

SUS Score	Grade	Adjective Rating
90 – 100	A	Excellent
80 – 90	B	Good
70 – 80	C	Okay
60 – 70	D	Poor
<60	F	Awful

3. Results and Discussion

3.1. Hardware Design

This interface box is precisely designed with customized dimensions and shape. It measures 14.5 cm in length, 8.5 cm in width, and 3.4 cm in height, and is made from PP (Polypropylene) plastic material. The exterior is equipped with a protective cover that encloses the surface of the box, providing a cleaner and more aesthetically pleasing appearance. The physical form of the casing can be seen in the following figure:

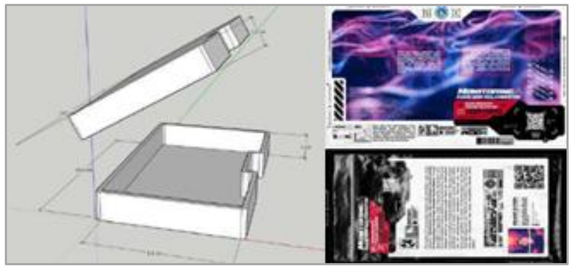

Figure 2. Interface Box

3.1.1. Electrical Design

The electrical development begins with the creation of a Printed Circuit Board (PCB) schemat-ic using EasyEDA software. This schematic is created to simplify the pin configuration of elec-tronic components used in the temperature and humidity monitoring instrument for the classroom. After the PCB schematic is completed, all components are integrated onto the fabricated PCB, including the ESP32, Wemos Micro SD Card, OLED Display, and DHT22. All components integrated on the front side of the PCB can be seen in Figure 3.

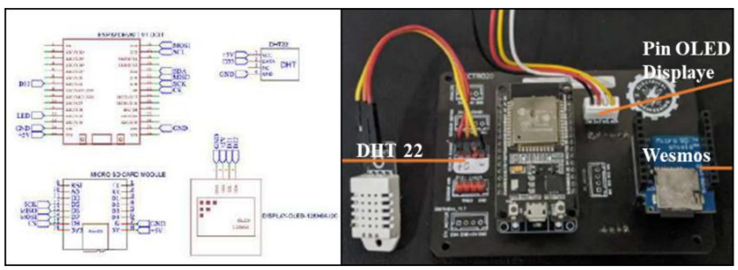

Figure 3. Electrical schematic of the temperature and humidity monitoring instrument

3.1.2. Functional Test

The DHT22 sensor was tested using the DHTlib example program. DHTlib is used to ensure that the DHT22 sensor can accurately read temperature and humidity values. The test results, showing the DHT22 sensor successfully reading temperature and humidity values [27]. DHT22 sensor has an accuracy tolerans $+5^0$C for Temperature and 2 - 5% for humidity [28]. The DHT22 sensor has high accuracy in measuring temperature and humidity [29].

The Wemos Micro SD Card was connected to the ESP32 microcontroller for testing using the D1 mini example program. The D1 mini was used to evaluate the Wemos Micro SD Card's capa-bility to write and read files on the SD card. The SD card was successfully initialized. It is of type SDHC and has a total capacity of approximately 30 GB. A directory named /mydir was created and then successfully removed, indicating that directory operations are functional. A file named hello.txt was written and then appended with additional data, showing that both write and append operations were successful. The content "Hello World!" was successfully read from the file, veri-fying that read operations work properly. The file hello.txt was successfully renamed to foo.txt. Reading from the renamed file foo.txt was successful, confirming that the rename preserved file content. Approximately 1 MB of data was written in 4.71 seconds. The SD card has 30 GB of total space and only 1 MB used, suggesting the card is mostly empty and functioning correctly. The test successfully demonstrates that the Wemos Micro SD Card module is able to handle file creation, writing, reading, appending, and renaming operations on an SD card using the ESP32 [30]. The minor error in file deletion and failed file open can be attributed to missing or incorrectly referenced files. Overall, the module is working as expected.

The OLED Display test was conducted by connecting it to the ESP32. the test was carried out using the Adafruit SSD1306 example. The Adafruit SSD1306 library is used to ensure that the OLED Display can receive and display data properly. The OLED Display successfully showed the default graphics and text provided in the Adafruit SSD1306 example code. This con-firms that communication between the ESP32 and the OLED module via the I2C interface was established correctly [31]. The display was able to render text clearly and without delay, indicating that the power supply and data transmission were functioning well.

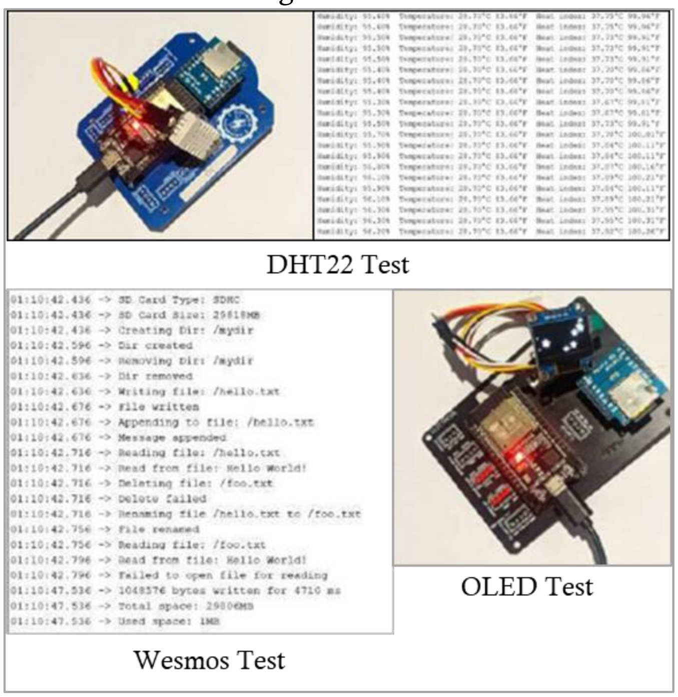

Figure 4. Functional Test DHT22, Wesmos SD Card, and OLED Display

3.2. Software Design

Firmware development was carried out by writing a program in C/C++ using the Arduino IDE platform [32]. The program was designed to perform several main functions, namely reading tempera-ture and humidity data from the DHT22 sensor, displaying information on the OLED Display, storing data on an SD Card, retrieving time from an NTP server, and sending data via a WiFi con-nection [33]. At the beginning of the code, various libraries were imported to support the hardware features used. The setup() function serves as the initialization block that runs once when the device is first powered on, initializing serial communication, configuring the LED pin, and calling modular testing functions for each component.

The loop function runs continuously to automatically perform periodic cycles of data acquisition, storage, and transmission. The test results show that the firmware successfully integrates various components (DHT22, OLED, SD Card, and WiFi) through the ESP32. Communication between devices using I2C and SPI was successfully implemented. Data from the sensor can be read, displayed, stored, and transmitted periodically [34]. Furthermore, the code demonstrates sufficient stability for use in class-room temperature and humidity monitoring applications [35]. The firmware is shown in Figure 5.

Figure 5. Firmware Design

3.3. Dashboard Design

The temperature and humidity monitoring device is designed not only to store data locally on the Wemos Micro SD Card but also to transmit data in real-time to Google Sheets. Each device is connected to a dedicated sheet, with a total of four sheets prepared one for each monitoring unit. The data from Google Sheets is then visualized using the Everviz platform in the form of interac-tive charts. These visualizations are integrated into the Electrical Engineering Department's website, which is built using WordPress, by utilizing the embed link feature. The visualization links from Everviz are copied and pasted into the WordPress HTML editor, allowing the charts to be displayed direct-ly on the website dashboard without requiring direct access to Google Sheets or Everviz. This approach facilitates easy and real-time data monitoring for end users through a well-structured and informative interface.

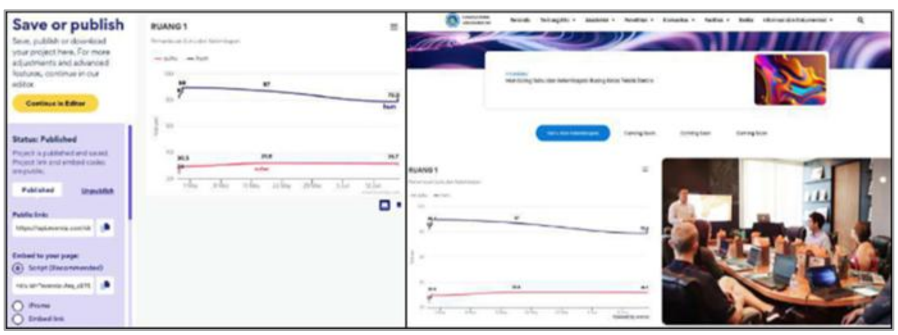

Figure 6. Dashboard Design

3.4. Field Test

The test results indicate that the monitoring instrument is capable of transmitting data to the website in real-time, with a data interval of one minute [36]. Data stored in both the Wemos and Google Sheets amount to 1,440 entries per day [37]. The outdoor area records the highest temperature and humidity levels, which are considered normal for tropical conditions. This data serves as a baseline for comparison with indoor room conditions [38]. The temperature in Room 14 is relatively high, even exceeding that of the outdoor area, possibly due to operating electronic equipment or suboptimal ventilation. The humidity remains within the acceptable range for human comfort but is approaching the upper threshold. Room 8 also shows high temperature and humidity levels, indicating the need for improved cooling systems or better air circulation. Room 10 has the lowest and most comfortable temperature; however, the humidity is extremely high, posing a risk of mold growth or corrosion of electronic equipment [39-41].

3.5. Validation Testing

Validation testing was conducted at the Meteorology, Climatology, and Geophysics Agen-cy (BMKG) Tanjungpinang from July 19, 2023, at 13:37 WIB to July 22, 2023, at 14:55 WIB. During this period, temperature and humidity data were collected every minute, con-tinuously over 24 hours. The purpose of this validation test was to compare the accuracy levels of four temperature and humidity monitoring devices using DHT22 sensors with BMKG's Automatic Weather Station (AWS) as a reference. The standard deviation analy-sis illustrates how far the measurements from the DHT22 sensors deviate from the AWS reference. The DHT22 sensors yielded the following standard deviation values: Device 1- temperature (1.62), humidity (6.06); Device 2-temperature (1.60), humidity (5.64); Device 3-temperature (1.72), humidity (6.31); and Device 4-temperature (1.52), humidity (5.27), These results indicate that the standard deviation values from the sensors are close to the AWS reference values of 1.71 (temperature) and 6.85 (humidity).

Error analysis for the four DHT22 devices produced the following error margins: Device 1- temperature (1.05%), humidity (1.08%); Device 2-temperature (1.07%), humidity (1.07%); Device 3 – temperature (1.02%), humidity (1.11%); Device 4-temperature (1.07%), humidi-ty (1.10%). These values, which are close to 1%, indicate a high level of precision in data collection. Accuracy measurements for the four devices revealed the following results: De-vice 1 -temperature (98.95%), humidity (98.92%); Device 2-temperature (98.93%), humidi-ty (98.93%); Device 3-temperature (98.98%), humidity (98.89%); Device 4-temperature (98.93%), humidity (98.90%). These accuracy levels are considered high, indicating reliable sensor performance [42].

Overall, the data collected using the DHT22 sensors demonstrate a satisfactory perfor-mance, closely aligning with the AWS reference in measuring temperature and humidity. However, differences in the graphical are attributed to several factors, including environ-mental placement differences, individual sensor characteristics, and potential disturbances or variability in the surrounding environment. Additionally, discrepancies in data acquisi-tion may arise from differing calibration settings and configurations between the devices. Despite these variations, the results provide a comprehensive evaluation of the DHT22's re-liability in environmental monitoring applications.

3.6. System Usability Scale (SUS) Test

The usability testing of the monitoring website was carried out using the System Usability Scale (SUS) method, involving 43 respondents consisting of lecturers, staff, and students from the Faculty of Engineering and Maritime Technology. The questionnaire was distrib-uted during the period of June 19 to June 26, 2023. The purpose of this test was to assess the usability and user satisfaction with the monitoring website. During the evaluation, re-spondents were asked to complete a 10-question survey related to their experience using the website. Each question was rated using a Likert scale from 1 to 5. The collected data was processed using Microsoft Excel to calculate the total score for each respondent. Out of the 43 respondents, 1 was a lecturer, 4 were staff members, and the rest were. The calculation of the System Usability Scale (SUS) score followed the standard proce-dures. After all scores were totaled and converted, the results were multiplied by a factor of 2.5, and then divided by the total number of respondents to obtain the average score [43]. The final result of the data processing yielded a SUS score of 56.8, which was then rounded up to 57.

Based on the System Usability Scale (SUS) results from 43 respondents, a final score of 57 was obtained. This score falls into category D. According to the Acceptability Ranges framework, it is classified as Not Acceptable. Meanwhile, based on the Adjective Ratings scale, a score of 57 falls between the OK level and is categorized as class F.

The evaluation results indicate that the system has a moderate level of usability, but it still requires several improvements to enhance efficiency and user acceptance. Most respond-ents gave neutral responses, while the proportion of positive and negative responses was relatively low. This contributed to the relatively low SUS score of 57.

A SUS score of 57 indicates that the system still requires improvements, particularly in terms of usability and interface design. This finding highlights the importance of user-centered design to ensure the system is not only functional but also comfortable and easily accessible for all users.

Several key issues identified during testing include:

1. Around 52.4% of respondents felt they still needed technical assistance to use the monitoring dashboard.
2. About 14.3% stated that there were quite a few inconsistencies in the dashboard.
3. Only 2.5% strongly disagreed with the statement that many people would find it easy to learn to use the dashboard quickly.
4. A total of 4.7% strongly disagreed that the dashboard was very complex to use.
5. Around 47.6% agreed that they needed to learn a lot to be able to use the dashboard effectively.

These findings provide insights into areas that need improvement, such as better technical support, interface consistency, simplified system usage, and improved learning resources for users. In addition, the results of this study have significant implications for the development of engineering education, especially in the context of implementing an Internet of Things (IoT)-based learning system. A positive user experience of the system will encourage wider adoption of technology among lecturers, staff, and students. This is important because engineering education relies heavily on efficient and easily accessible technology integration to support practical activities, real-time data monitoring, and digital collaboration. From a pedagogical perspective, improving the usability of an IoT-based system will support the creation of an interactive and contextual learning environment, where students can more actively explore data and understand the application of technology directly. Meanwhile, from an institutional perspective, these results encourage the importance of user training, user-friendly system design, and the development of digital infrastructure that supports modern engineering learning processes. Thus, these findings not only provide technical feedback on the tested system, but also provide strategic direction in the development of an inclusive, efficient, and user-experience-oriented IoT-based engineering learning ecosystem.

4. Conclusion

The study concludes that the DHT22 sensor demonstrates high accuracy in temperature and humidity measurements, making it a reliable tool for environmental monitoring. The web-based dashboard system received a SUS score of 57, indicating user acceptance despite some limitations. Therefore, further development is needed to enhance system quality and improve user satisfaction.

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