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Classroom Environment Analysis Via Internet of Things

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Abstract - In this era of rapid technological advancement, the potential of the digital age has opened up numerous possibilities for our society. However, despite these advancements, traditional classrooms still lack the necessary technology to create an optimal learning environment for students. Consequently, students may struggle to effectively acquire knowledge within classrooms. This paper aims to conduct a classroom environment analysis using Internet of Things technology to gather data and uncover valuable insights. The proposed solution involves an embedded system for controlling and monitoring the classroom environment, as well as exporting historical data for further research. By ensuring accurate data collection, this paper seeks to facilitate meaningful improvements in the classroom environment, aligning with the principle of "garbage in, garbage out" in computer science.

Keywords—Classroom, Environment, Arduino, Sensors, Internet of Things

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I. INTRODUCTION

The classroom plays an important role in creating a conducive environment that promotes learning among students. The classroom is the most vital component of an academic institution for knowledge dissemination from educators to students [1]. A classroom with a conducive environment is one that promotes student collaboration through technological engagement with the classroom environment [2]. Additionally, an ideal classroom environment could significantly boost academic performance of students. According to research conducted by [3], the impact of a comfortable smart classroom learning environment on the academic performance of low achievers among children varies enormously. Other than that, the improvement of the ambiance and environment would significantly boost the performance and reputation of an educational institution as suggested by [4]. Therefore, it is extremely vital for the stakeholder of an educational institution to combat the issue to ensure the students and learners can grasp the knowledge in a comfortable manner. Aside from this, there is also a significant lack of resources in terms of the methodology to conduct classroom environment analysis. According to [5], it agreed that both environmental and physiological factors played a very important role in making humans achieve comfort. However, there is a lack of mechanisms and findings regarding the methodology to be utilized for environmental analysis. Lastly, the integration of smart sensors will enable the ability to identify the wastage of electricity by analyzing the time the electrical appliances in the room were on when being left unattended. The data could be utilized to generate useful insight to reduce the wastage of electricity in order to combat climate change.

The problem statement revolves around three key issues. Firstly, there is a lack of a conducive environment for education, leading to demotivation among students and educators. This hampers the efficiency and effectiveness of

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knowledge transfer, resulting in poor academic outcomes. Secondly, there is a shortage of resources for classroom environmental analysis and monitoring. Many classrooms lack the necessary technologies for real-time monitoring and fail to store historical data for deeper insights. Lastly, there is unnecessary wastage of electricity due to negligence and lack of responsibility. This occurs when classrooms are left unoccupied for extended periods or during minimal occupancy. To address these challenges, it is crucial to implement smart sensors, heuristic algorithms, and approaches to optimize energy usage and create a technologically advanced and supportive learning environment.

The objectives of the paper are firstly to develop a smart Internet of Things (IoT) system that analyzes and improves the classroom environment. This involves creating a user-friendly system that connects appliances for remote monitoring and management. Secondly, the paper seeks to utilize the analyzed results to enhance the classroom environment. By sharing valuable insights with stakeholders, discussions can be facilitated to generate suggestions and heuristic actions for improving classroom conditions. Lastly, the paper aims to reduce electricity wastage by developing a system capable of recognizing the status of electronic appliances in a room. By detecting if appliances are still switched on when the room is unattended, appropriate heuristic actions can be implemented to mitigate unnecessary electricity usage.

II. LITERATURE REVIEW

A. Related Works

a) Indoor environment monitoring and manipulation

In the research conducted by [6], a simple and affordable solution for remote temperature and humidity monitoring is proposed. The system leverages AWS for easy deployment but primarily focuses on monitoring without utilizing the collected data for further enhancements. Another study by [7] introduces an IoT solution for environment management using big data analysis. The system demonstrates high accuracy in predicting occupants but lacks integration of the deployed camera with the prediction model. Furthermore, it does not provide remote appliance control functionality. In the research presented by Anderson [8], an automation control system for air conditioners is introduced. This system adjusts air conditioning based on the surrounding ambiance to reduce greenhouse gas emissions and electricity usage. However, it does not measure occupancy rates, limiting its suitability for rooms with varying occupancies. In their study, [9] propose a luminous recommendation system for improving personal well-being. The system analyzes personal lifelog data to enhance indoor ambiance, yet it does not incorporate emotions or fatigue levels through cameras or face recognition, and subjective user input may result in inaccurate predictions. In the research by [10], indoor temperature and humidity analysis and prediction based on outdoor temperature are explored. The study employs a practical data collection mechanism that does not require modifications to room circuitry. However, it does not address the application of the algorithm in combating electricity wastage. The authors from [11] present a comprehensive analysis of temperature variations in different locations within a building using artificial neural networks. However, they fail to consider other factors such as the impact of the number of occupants on temperature outcomes. Lastly, in their paper, authors from [12] introduce a technique for improving electricity usage through indoor environment prediction. Their prediction model incorporates factors such as carbon dioxide concentration and the number of occupants. However, the assumption of consistent outdoor temperature during simulations does not accurately reflect real-world conditions.

b) Existing implementation of Smart Classroom (Ambiance and Environment)

The paper for [13] focuses on automating and managing classroom ambiance using the Internet of Things (IoT). It utilizes Google Assistant and Dialog Flow for easy implementation. However, starting from June 2023, Google Assistant will no longer work with third-party applications. One disadvantage is that the solution does not store historical data, limiting further analysis. Aside from this, the research from [14] introduces a voice user interface to control appliances in the classroom. It presents a novel method for interacting with classroom appliances. However, the system is considered impractical and vulnerable to vandalism. Additionally, the voice speech model does not account for ambient noise in the classroom, and it requires more effort to use compared to a traditional switch. Other than that, the paper [15] proposes a self-controlled energy management system using deep learning. It can recognize student activity and predict future ambiance conditions based on current sensor data. However, it lacks a provided user interface for remote monitoring and controlling. Another drawback is that it requires a significant amount of processing power, which increases energy usage and may contradict the original purpose. Besides that, the paper [16] presents a smart automated energy control system using PIR sensors to detect occupancy. It can detect and track the number of occupants in a room. However, it is unable to regulate and control the intensity of appliances such as fan speed. Additionally, it does not allow manual intervention from students and educators in case of special requirements.

Last but not least, the paper [17] proposes a smart energy management system for the classroom utilizing RFID technology. It can control fan speed and regulate light based on occupancy and temperature data. However, it requires every student and educator to carry an RFID tag when entering a classroom. It also lacks the ability for manual intervention and tracking for special needs.

B. Embedded System and Sensors Review

a) Arduino vs Raspberry Pi

Arduino is an open-source electronic prototyping platform that allows people with little programming or electronics experience to create interactive projects. It provides both the hardware and software components needed to build a variety of devices, from simple LED displays to complex robotics and home automation systems. Arduino boards consist of programmable microcontrollers and can be customized by adding sensors, actuators, and other components. The platform offers a user-friendly interface with a simple programming language and graphical development environment. It is widely used in engineering, art, and design fields due to its simplicity, versatility, and affordability. Arduino has a vast library of pre-built code and numerous online resources for beginners and advanced users. While Arduino is best for real-time applications with precise control, Raspberry Pi is more suitable for projects requiring computing power and advanced networking capabilities. The choice between Arduino and Raspberry Pi depends on the specific needs of a project and the skills and preferences of a user.

Raspberry Pi is a low-cost, credit-card-sized computer designed to promote computer science education and accessibility. It is versatile and can be used for various projects, from home automation to robotics. Powered by a Broadcom ARM processor, it supports different operating systems and programming languages. The Raspberry Pi Foundation provides extensive documentation, community support, and educational resources, making it suitable for beginners and advanced users. Its affordability, customization options, and community-driven nature have contributed to its popularity. While Raspberry Pi excels in computing power and networking capabilities, Arduino is better suited for real-time applications requiring precise hardware control. The multimedia capabilities of Raspberry Pi further distinguish it from Arduino. The choice between Raspberry Pi and Arduino depends on project requirements and user preferences.

Both Arduino and Raspberry Pi are widely used in IoT applications, but they have different strengths. From Table 1, Arduino is well-suited for real-time control, low power consumption, and cost-effectiveness. It excels in collecting data from sensors and actuators, making it ideal for monitoring physical quantities. Its low power consumption and cost-effectiveness make it suitable for projects with multiple components. The scalability of Arduino allows for integration with other devices and systems. On the other hand, Raspberry Pi is better for IoT applications requiring processing power, advanced networking, and multimedia support. It handles tasks like machine learning and computer vision and can connect to other devices and the internet. Ultimately, the choice between Arduino and Raspberry Pi depends on the specific requirements of the IoT project.

Table 1. Summary of comparison between Arduino and Raspberry Pi

Arduino	Raspberry Pi
Microcomputer	Microcontroller
Require Operating System	Not require Operating System
Low processing power	High processing power
Low power consumption	High power consumption

b) ESP9266 vs ESP32

The ESP8266 is a cost-effective, Wi-Fi-enabled microcontroller chip widely used in IoT projects. Introduced by Espressif Systems in 2014, it combines a 32-bit processor, Wi-Fi transceiver, and peripheral interfaces in a single package. It is highly customizable and can be programmed in various languages using development boards like NodeMCU or WeMos D1 mini. The ESP8266 finds applications in home automation, smart sensors, and remote-control systems. It can function as a standalone device or be integrated into larger systems, offering low power consumption and support for firmware updates over the air. With its versatility and affordability, the ESP8266 is a popular choice for IoT projects.

The ESP32 is a popular and versatile microcontroller widely used in IoT applications. Introduced by Espressif Systems in 2016, it combines a 32-bit processor, Wi-Fi, and Bluetooth connectivity, and various peripheral interfaces in a single package. With low power consumption, high processing power, and built-in wireless connectivity, the ESP32 is well-suited for IoT projects such as home automation and smart sensors. It is customizable with firmware options and can be programmed using software development tools like Arduino IDE or MicroPython. The dual-core processor of ESP32, built-in peripherals, and support for Wi-Fi and Bluetooth enable the creation of complex IoT devices. Its ability to handle OTA updates and compatibility with different programming languages make it a flexible choice for developers. Overall, the ESP32 is a powerful microcontroller with a wide range of features for diverse IoT applications.

When comparing the ESP8266 and ESP32 microcontrollers for IoT applications (Table 2), there are notable differences to consider. The ESP32 surpasses the ESP8266 in processing power, featuring two cores with a clock speed of up to 240 MHz, enabling efficient multitasking and handling of complex tasks. Moreover, the ESP32 offers more built-in peripherals, including touch sensors and converters, expanding its interfacing capabilities. In terms of connectivity, both microcontrollers have built-in Wi-Fi, but the ESP32 gains an advantage with its additional built-in Bluetooth connectivity. This makes the ESP32 suitable for IoT applications that require wireless communication beyond Wi-Fi, such as Bluetooth sensors or interactions with smartphones or tablets. Ultimately, the choice between the ESP8266 and ESP32 depends on the specific requirements of the IoT application, with the ESP8266 being a cost-effective option for simpler projects and the ESP32 excelling in more demanding applications that necessitate increased processing power and Bluetooth connectivity.

Table 2. Summary of comparison between ESP8266 and ESP32

	ESP8266	**ESP32**
Processor	Xtensa Single-Core 32-bit L106	Xtensa Dual-Core 32-bit LX6
Field of Wi-Fi	802.11b/g/n with HT20 (20MHz)	802.11b/g/n with HT40 (40MHz)
Bluetooth	No	Yes, Bluetooth 4.2
RAM	160kB	512kB
GPIO	17	36
ADC	10-bit	12-bit
Cost	Lower	Higher

c) PIR Sensor vs Ultrasonic Sensor

A Passive Infrared (PIR) sensor is an electrical device used to detect infrared radiation emitted by objects within its range. Commonly used in motion detecting applications like security systems, automated doors, and lighting control systems, PIR sensors detect changes in infrared radiation levels caused by the movement of live beings, such as humans or animals. These sensors consist of a pyroelectric material sensor element that generates a voltage when heated or cooled. The sensor is divided into two parts with a transparent filter, allowing infrared radiation to pass through. These halves are connected to a circuit that amplifies and processes the voltage signal generated by the sensor element. When a moving object enters the field of view of the sensor, the infrared radiation levels in the two halves change, creating a voltage signal that is detected by the circuit. PIR sensors offer advantages such as low cost and ease of use, making them widely accessible and suitable for various applications. They are highly sensitive and can detect even slight movements accurately. However, PIR sensors have limitations, including a restricted field of vision and susceptibility to temperature changes that can lead to false alarms. In security systems, PIR sensors are preferred due to their affordability, simplicity, and passive nature, which reduces the likelihood of false alerts. Another significant advantage is their energy-saving capability, as they can activate electronic devices only when motion is detected and subsequently turn them off after a set time. Overall, PIR sensors are versatile and cost-effective options for motion detection and energy conservation in various settings.

An ultrasonic sensor is an electrical device that uses sound waves to detect objects and measure distances. It emits high-frequency sound waves and detects the echo reflected from objects within its range. Ultrasonic sensors are commonly used for proximity sensing, object detection, and distance measurement in various industries, including robotics, automotive, and industrial applications. They consist of a transmitter and a receiver, where the transmitter emits sound waves and the receiver detects the echo to calculate the distance. Ultrasonic sensors are preferred for their precision, speed, and reliability. They can detect objects several meters away and are unaffected by changes in color, texture, or ambient light. They are also immune to electromagnetic interference. These sensors find applications in automated guided vehicles (AGVs) for obstacle detection, parking sensors, and industrial automation. They are used in the automotive industry for parking, collision avoidance, and blind spot detection systems, as well as in robotics for proximity sensing and object recognition. Ultrasonic sensors excel in accurately estimating distances, detecting objects of various shapes and sizes, and operating rapidly in real-time applications. They are known for their reliability and long service life with minimal maintenance requirements. Overall, ultrasonic sensors are versatile and dependable tools for a wide range of industrial and robotics applications.

From Table 3, PIR sensors and ultrasonic sensors are commonly used for people detection, each with its own strengths and weaknesses. PIR sensors are ideal for detecting motion in a fixed region, as they are highly sensitive to temperature and movement changes. They can accurately identify human presence even in the dark by detecting infrared radiation emitted by human bodies. PIR sensors are energy-efficient, activating only when motion is detected. On the other hand, ultrasonic sensors are effective in measuring distances and detecting objects in a larger area. They can cover a wider range and are not affected by changes in ambient light or temperature. However, they require more complex setup and calibration. The choice between PIR sensors and ultrasonic sensors depends on the specific application and environmental factors at play.

Table 3. Summary of comparison between Ultrasonic Sensor and PIR Sensor

	Ultrasonic Sensor	**PIR Sensor**
Measure Technique	Ultrasonic sound wave speed	Infrared energy
Parameter	Presence of object or people	Movement of object or people
Constrains	Subject to interference	Require line of sight
Response Time	Long	Short

d) DHT11 vs DHT22

The DHT11 sensor is a widely used digital temperature and humidity sensor in electrical applications. It is a low-cost sensor that provides real-time temperature and humidity data. The sensor consists of a resistive humidity element and a thermistor temperature element integrated on a single chip. By measuring the resistance of the humidity element and the temperature of the thermistor, the DHT11 sensor delivers accurate temperature and humidity measurements in real-time. It is known for its simplicity, affordability, and high precision. The sensor is easy to integrate into projects, has a basic digital communication interface, and requires minimal cabling and programming. It communicates with a microcontroller through a one-wire protocol, generating a 40-bit digital signal containing temperature and humidity values. The DHT11 sensor operates on a 3-5V DC supply voltage, consumes low power, and has a wide operating temperature range. It is suitable for various applications, including environmental monitoring, climate management, and plant growth monitoring. Overall, the DHT11 sensor is a versatile and reliable choice for temperature and humidity monitoring in electrical projects.

The DHT22 sensor, also known as the AM2302, is an improved version of the DHT11 sensor, offering more precise temperature and humidity measurements. It is a digital sensor that communicates using a one-wire protocol. The DHT22 sensor combines the resistive humidity element and thermistor temperature element on a single chip and includes a signal amplifier and conversion circuit for enhanced accuracy. It generates a 40-bit digital signal containing temperature and humidity values. With a typical temperature precision of 0.5°C and humidity accuracy of 2%, the DHT22 sensor is suitable for demanding applications. It can measure temperatures from -40°C to 80°C and relative humidity from 0% to 100%, making it suitable for industrial and outdoor weather monitoring. The DHT22 sensor is designed to be user-friendly, featuring a compact plastic enclosure and low power consumption. It operates on a 3-5V DC supply voltage and communicates via a single data line using a simple one-wire protocol compatible with popular microcontroller platforms. Overall, the DHT22 sensor is a versatile and high-performance solution for temperature and humidity monitoring needs.

From Table 4, both the DHT11 and DHT22 sensors are commonly used for temperature and humidity sensing in IoT applications, but they differ in terms of precision, range, and cost. The DHT11 has lower accuracy and a narrower measurement range compared to the DHT22. With a temperature precision of 2°C, humidity accuracy of 5%, and limited range, the DHT11 is suitable for applications with less stringent requirements. On the other hand, the DHT22 offers higher accuracy, a broader measurement range, and a temperature precision of 0.5°C and humidity accuracy of

2%. Although the DHT22 is more expensive, it becomes a better choice for applications that demand greater accuracy or a wider measurement range. Cost considerations make the DHT11 an attractive option when accuracy and range can be compromised. Ultimately, the selection between the two sensors depends on the specific requirements of the IoT application in terms of accuracy, range, and budget.

Table 4. Summary of comparison between DHT11 and DHT22

	DHT11	DHT22
Temperature	0 – 50°C (±2°C)	-40 – 125°C (±0.5°C)
Humidity	20 – 80% (±5%)	0 – 100% (±2-5%)
Working Rate	1Hz	0.5Hz
Voltage	3-5V	3-5V

III. RESEARCH METHODOLOGY

A. Data Collection Methodology

a) Presumptions

To ensure an optimal classroom environment for data collection, several factors should be considered. Firstly, the classroom size should be suitable, avoiding excessively large spaces to maintain consistent ambiance throughout different areas. Secondly, a well-defined time schedule specifying the number of students present in the classroom is essential for accurate data analysis. It is assumed that the attendance reflects full occupancy during the data collection period. Additionally, to enable online storage of data acquired from various sensors, wireless network coverage is necessary within the classroom. Furthermore, the availability of electricity and plug points is crucial to power the embedded system responsible for data collection. Lastly, when selecting a hosting platform for data storage, a free PHP MySQL hosting platform is recommended over IoT platforms that may require credit card details for access.

The proposed methodology for data collection involves the utilization of an embedded system, specifically the ESP8266. This choice is based on its lightweight and cost-effective nature, making it a favorable option compared to other embedded systems available in the market. In addition to the hardware, the implementation will require essential software components such as a database and a web server. These software elements will enable CRUD (Create, Read, Update, Delete) operations to effectively record and manage telemetry data.

b) Hardware Requirement

In Figure 1, the NodeMCU ESP8266, a compact embedded system with WiFi connectivity, will play a crucial role in the data collection process. It will be utilized to receive sensor data and transmit it to a web server, where it will be stored in a database. For monitoring the classroom environment, the DHT11 sensor has been chosen as a reliable option to measure temperature and humidity. This sensor utilizes a thermistor to accurately detect the temperature of the surroundings, providing a digital signal that can be easily converted to Celsius. In contrast to a digital light sensor like the BH1750, a photoresistor is a viable alternative for measuring light intensity. By reading light intensity as an analog value, the photoresistor can effectively assess the level of light in the classroom.

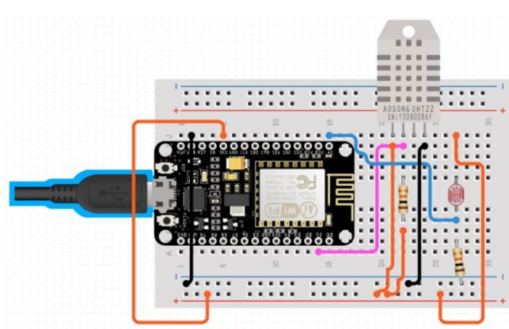

Figure 1. NodeMCU ESP8266 schematic design for data collection process

c) Software Requirement

The Arduino IDE will serve as the programming platform for writing and uploading code to the NodeMCU ESP8266, enabling it to effectively capture sensor data and establish communication with a web server. To facilitate this communication, PHP will be employed as the web programming language for its widespread usage and compatibility with various free hosting platforms. As for data storage, the MySQL database is deemed highly suitable for storing the telemetry data received from the embedded system. Furthermore, the stored data can be conveniently downloaded as a spreadsheet, facilitating easy access and analysis for data processing and evaluation.

d) Algorithms

The algorithm implemented in the NodeMCU ESP8266 embedded system ensures efficient telemetry data management and prevents excessive utilization of network resources is shown in Figure 2 below.

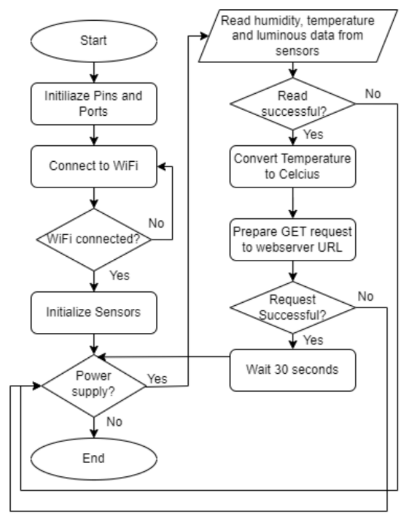

Figure 2. The algorithm for data collection on NodeMCU ESP8266

e) Setup and Collection Process

In Figure 3 and Figure 4, the web server and database have been successfully set up and deployed on the 000webhost server, ensuring a reliable platform for data storage and retrieval. The circuitry of the NodeMCU ESP8266 has been meticulously constructed, referencing the schematic design depicted in the previous figure to ensure accurate functionality. In the initial phase of the data collection process, data has been systematically collected over a span of three days, specifically from the 5th of July to the 7th of July 2022 in one of the labs in the Faculty of Computing and Informatics in Multimedia University Cyberjaya Malaysia. This timeframe was chosen to capture a comprehensive snapshot of the indoor environment during this period. Additionally, as part of the analysis, the current AccuWeather conditions in Cyberjaya were also gathered during the same three-day period, allowing for an examination of the correlation between outdoor weather conditions and their impact on the indoor environment.

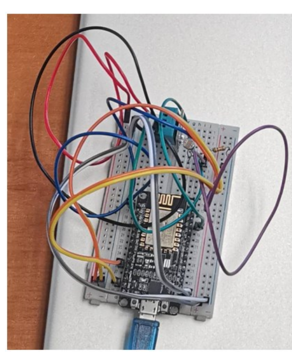

Figure 3. The circuitry for data collection on NodeMCU ESP8266

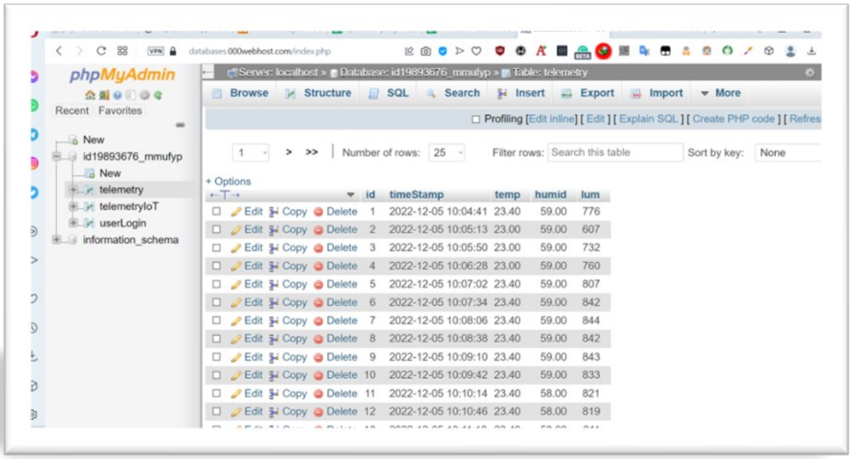

Figure 4. The snapshot of database of the collected sensor data

B. Classroom Simulation Methodology

a) Presumptions

In order to overcome the limitations of implementing an IoT solution in a real-world classroom setting, a practical approach will be taken by creating a miniature cardboard-based classroom. This model will replicate the functionality of the IoT solution, with the air conditioning and lighting systems represented by an LED and LCD display respectively, providing simulated indications of their condition. To enable remote control of the simulated classroom environment, a mobile application will be developed, allowing users to manipulate the lighting and air conditioning virtually through the internet. However, it is important to note that the data and outcomes obtained from this simulation will not accurately reflect the actual conditions and performance of an intelligent classroom in a real-world implementation. Instead, the proposed IoT solution serves as a proof of concept, showcasing the feasibility of implementing such a solution in an authentic classroom environment.

The proposed methodology for simulating a classroom environment involves the utilization of an embedded system. Specifically, the NodeMCU ESP8266 has been chosen for this simulation due to its affordability and compatibility with the Arduino platform. This selection offers the advantage of access to a wide range of libraries and extensive support from the Arduino community. In addition to the hardware, the implementation requires the integration of software components. A MySQL database will be utilized for efficient storage of relational data, while Google Firebase will enable real-time, instantaneous NoSQL functionality. This combination of database systems allows for effective monitoring and control of various electronic appliances, including lights, air conditioners, and other devices within the simulated classroom environment.

b) Hardware Requirement

Figure 5 below referred. The hardware requirements for the classroom simulation will involve components that have already been utilized for data collection in a real classroom setting. Additionally, additional components such as ultrasonic sensors, a button, and an LCD display will be incorporated into the setup. Among these, the HC-SR04 ultrasonic sensor will play a key role as a range detector. With its capability to detect distances ranging from as close as 2 cm to as far as 400 cm, two HC-SR04 sensors will be employed to effectively monitor the entrance and exit of individuals in the simulated classroom. Furthermore, a 16x2 LCD display will be utilized to present the current information pertaining to the simulated classroom conditions. This will include crucial details such as humidity, temperature, luminosity levels, occupancy count, lighting status, as well as the air conditioner settings. The LCD display will serve as a comprehensive visual interface to provide real-time updates and facilitate user interaction with the simulated environment.

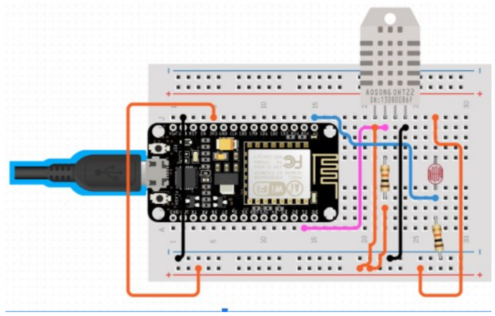

Figure 5. NodeMCU ESP8266 schematic design for classroom simulation

c) Software Requirement

React Native is a JavaScript-based mobile application framework that empowers web developers to create mobile applications. It stands out as one of the largest projects on GitHub, indicating extensive community support and resources available for developers. This framework offers the advantage of building mobile applications that can be natively rendered on both Android and iOS platforms. Leveraging the vast array of features and libraries from React and NodeJS, the mobile application for this project will be developed on this platform. This choice will significantly reduce development time and enhance overall productivity.

To enable real-time communication between the embedded system and the mobile application, Google Firebase will be utilized. This integration will facilitate seamless interaction between the two, allowing the mobile application to retrieve and modify information from the embedded system. The Firebase Authentication feature of the Google Firebase SDK will be employed for user authentication, ensuring secure access to the mobile application using university email credentials. By leveraging robust authentication infrastructure provided by Google, user credentials are securely stored and managed. Furthermore, Google Firebase provides a real-time NoSQL database, enabling the storage and synchronization of data in real-time between the mobile application and embedded systems. Through the mobile application, users will be able to control electronic appliances and retrieve information, utilizing the capabilities of Google Firebase.

For sequential data storage, the PHP MySQL relational database is chosen. MySQL is preferred due to the availability of numerous free hosting services, allowing the embedded system to store and retrieve data without the need for a personal computer to be continuously online as a server. The mobile application will also feature the ability to access and analyze historical data on a daily, weekly, or monthly basis. Data analysts and scientists can retrieve data from the MySQL database for various analytical purposes, enabling comprehensive data-driven insights.

d) Mobile Application Requirement

i. Login with Google Authentication - For user authentication, the mobile application will use the university email domain, which is hosted on the Google platform. Only employees would be able to use the application, which served as a security measure. It will also keep unwanted intruders from outside of the institution from tampering with the system.

ii. View the classroom environment condition - The user will be able to see the current state of the classroom environment. The light and air conditioner statuses are included in the mobile application. Aside from that, environmental data such as light, temperature, and humidity will be included in the application. Based on the ultrasonic sensor detection, the application will also display the number of people in the classroom.

iii. Control the electrical appliances - Aside from that, it will also allow the control of electrical appliances through the mobile application. For the prototype, it will only be able to control the virtual lighting and the temperature and the fan speed of the air-conditioner in the classroom. However, in the practice of real-world implementation, the mobile application should be able to control more appliances such as projector and computer in the classroom through integration with various mechanisms.

iv. View historical data with charts - In addition to that, the mobile application will also include the ability to view historical data. This will also include features such as viewing the historical temperature, humidity, and luminous level in the classroom. Aside from that, the mobile application will be able to show the historical status of the air conditioner and lights, as well as the number of people in the classroom over time.

v. Export historical data - The mobile application will also allow users to export historical data into a spreadsheet format for further analysis. The exported historical data could be shared to various platforms through the sharing intent of the mobile application.

e) Setup and Implementation Process

A Google Firebase project was created to facilitate the integration between the mobile application and embedded system. Each Firebase Project account includes a real-time NoSQL database, which was set up according to the schema outlined in the proposed methodology. This setup enables both the embedded systems and mobile applications to perform CRUD activities on the database seamlessly. A Google Firebase project was created to facilitate the integration between the mobile application and embedded system. Each Firebase Project account includes a real-time NoSQL database, which was set up according to the schema outlined in the proposed methodology. This setup enables both the embedded systems and mobile applications to perform CRUD activities on the database seamlessly.

In the mobile application development, it was discovered that the latest version of React Native Expo SDK was incompatible with the React Navigation library, causing frequent crashes. As a solution, an older version of Expo SDK (version 45) was utilized. A project named "SmartMMU01" was created, and all the necessary libraries were installed to facilitate application development as shown in Figure 6. Integration with Google services was essential for authentication and real-time database functionality, requiring the development of a custom-built standalone developer configuration to ensure successful utilization of Google verification on Android devices.

The integration of Google Firebase NoSQL was implemented in the Class Detail Screen of the mobile application (Figure 6). Users can perform CRUD operations on the Firebase database through the user interface, which will be utilized by the NodeMCU ESP8266 to execute further operations. Integration with the MySQL database was accomplished through a PHP web interface, enabling the mobile application to read and insert new data into the database. One notable implementation involves tracking user login within the mobile application, providing a comprehensive authentication system.

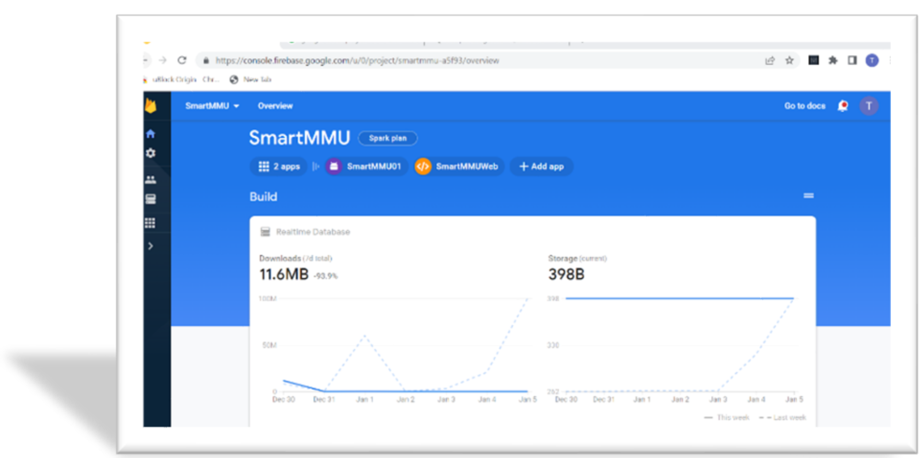

Figure 6. Google Firebase Project for Classroom Simulation Integration

IV. RESULTS AND DISCUSSIONS

A. Moving average of temperature against time

Figure 7 below referred. The line plot of temperature against time in the classroom revealed a significant drop in temperature between 7:30 a.m. and 8:00 a.m. This can be attributed to the staff turning on the air conditioner and lights in preparation for the 8:00 a.m. class. Furthermore, a gradual increase in temperature was observed over time. However, due to the absence of actual data on the temperature and wind speed of air conditioner, it is challenging to determine the exact factor influencing the classroom temperature. It is plausible that changes in the air conditioner settings at any time of day could have contributed to the fluctuations. Additionally, the limitations of the DHT11 sensor became evident from the line plot. With a sensitivity of only 1°C, the recorded data from the sensor may not provide highly accurate measurements.

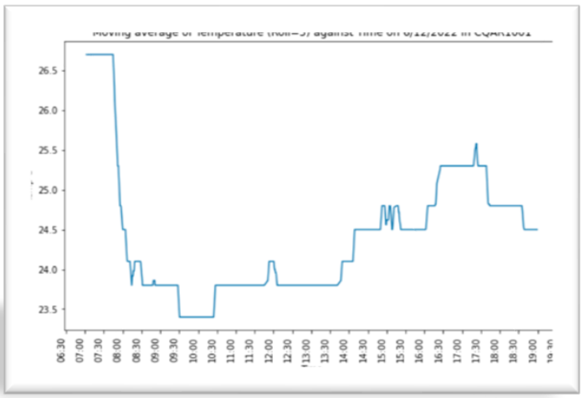

Figure 7. Line plot of the moving average temperature in the classroom on 6th December 2022

B. Moving average of humidity against time

According to the line plot of temperature against time in the classroom in Figure 8, there was a significant drop in humidity between 7:30 a.m. and 8:00 a.m. This can be attributed to the air conditioner being switched on during that specific time range. The functioning of an air conditioner involves the condensation process, which removes heat and moisture from the indoor air to cool down the environment. Once the air conditioner reaches the desired temperature, it operates at a reduced capacity, leading to a gradual increase in humidity over time. It is also possible that changes in the air conditioner settings by individuals throughout the day contributed to the fluctuations in temperature and subsequently affected the humidity levels. For instance, higher temperature settings during the middle of the day would result in less intense air conditioning, potentially causing the humidity level to rise.

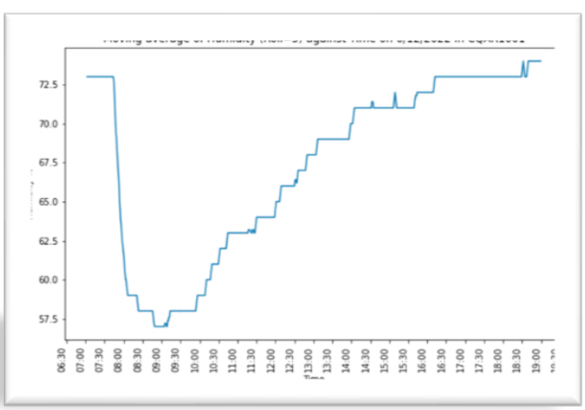

Figure 8. Line plot of the moving average humidity in the classroom on 6th December 2022

C. Average temperature in the classroom when there is class or no class

The class schedule in the classroom runs from 8:00 a.m. to 6:00 p.m. To analyze the average temperature during these class hours, a bar chart will be generated in Figure 9. On 6/12/2022, the average temperature in the classroom during class was recorded as 24.2960 °C, slightly higher than the temperature outside of class which stood at 23.8466 °C. Additionally, referring to the AccuWeather data for that day, the average outdoor temperature during class hours was 29.85 °C, significantly lower than the average outdoor temperature outside of class hours, which measured 31.20 °C. Assuming that the air conditioner settings remained constant throughout the day, the presence of individuals in the classroom resulted in an increase in temperature despite the average outdoor temperature being lower during class hours.

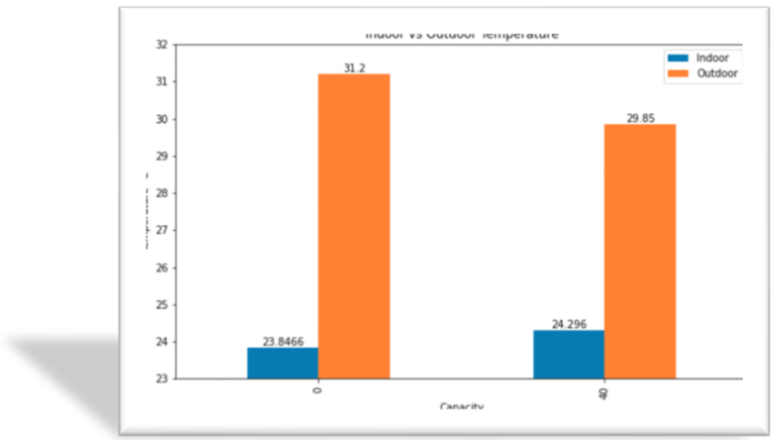

Figure 9. Average temperature in the classroom during and outside of class on 6th December 2022

D. How does other factors influence the classroom humidity and temperature

Figure 10 and Figure 11 below depict the correlation between indoor temperature and indoor humidity in the classroom. It is evident that these two variables are highly correlated, showing a positive relationship. However, when comparing outdoor temperature and outdoor humidity, they display a strong negative correlation. This can be attributed to the functioning of an air conditioner, which removes both heat and moisture from the indoor air, resulting in a decrease in temperature and humidity.

Furthermore, the figures reveal a moderate correlation between indoor temperature and outdoor temperature. This suggests that changes in the outdoor temperature still impact the indoor temperature, despite the presence of an air conditioner in the classroom. This can be attributed to the operational limitations of the air conditioner. Lastly, the figures indicate a weak correlation between the capacity or occupancy of the classroom and the indoor temperature. This implies that an increase in the number of people in the classroom leads to a slight increase in the indoor temperature.

	Temperature	Humid	Luminous	outHumid	outTemp	outRealTemp	outWindSpeed	Capacity
Temperature	1.000000	0.822424	-0.632187	-0.542896	0.616356	-0.052174	0.667187	0.322496
Humid	0.822424	1.000000	-0.861559	-0.913868	0.942962	0.464089	0.280335	-0.110917
Luminous	-0.632187	-0.861559	1.000000	0.844896	-0.888747	-0.446828	-0.165793	0.068165
outHumid	-0.542896	-0.913868	0.844896	1.000000	-0.979792	-0.724078	-0.028402	0.361032
outTemp	0.616356	0.942962	-0.888747	-0.979792	1.000000	0.662763	0.087508	-0.215114
outRealTemp	-0.052174	0.464089	-0.446828	-0.724078	0.662763	1.000000	-0.551275	-0.629150
utWindSpeed	0.667187	0.280335	-0.165793	-0.028402	0.087508	-0.551275	1.000000	0.612430
Capacity	0.322496	-0.110917	0.068165	0.361032	-0.215114	-0.629150	0.612430	1.000000

Figure 10. The correlation between each variable in the dataset

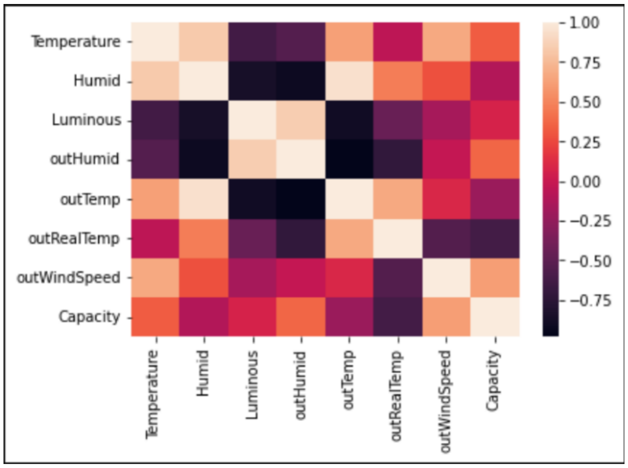

Figure 11. Heatmap of the correlated variables

E. Improvement and Enhancement Suggestions from analyzed result

After analyzing the collected data, it was identified that the main environmental issue in the classroom is inconsistent temperature. A study conducted by [18] proposed a solution by utilizing a smart Wi-Fi thermostat, building geometry, and historical energy consumption data to improve the calculation of mean radiant temperature (MRT), which plays a crucial role in determining thermal comfort in buildings. The study developed machine learning predictive models based on a nonlinear autoregressive exogenous model (NARX) to determine the optimal temperature and humidity set-points for maintaining comfortable conditions at all times. The initial findings showcased significant energy savings of 83% and 95% for high- and low-efficiency residences, respectively. This solution could potentially be implemented in the classroom, as historical data could be obtained using IoT sensors.

In accordance with the research conducted by [19], it has been deduced that thermal conductivity, specific heat, and mass loss are significant thermal properties influencing temperature rise and distribution in concrete. A desirable insulating material exhibits a higher specific heat capacity, as it necessitates a prolonged heat absorption period before experiencing a temperature rise and transferring the heat. Moreover, materials characterized by low thermal conductivity and thermal diffusivity manifest commendable thermal performance, resulting in minimized energy losses and temperature reduction comparable to the ambient surroundings through the concrete structure of a building. Consequently, it is imperative to employ materials such as limestone during the construction of classroom buildings, as they possess an elevated specific heat capacity. This choice effectively mitigates the cost associated with cooling the classroom during daytime, particularly in regions characterized by tropical climates.

Aside from this, in the research conducted at Universiti Putra Malaysia, a noteworthy discovery regarding the efficient management of high latent loads prevalent in tropical regions had been discovered by [20]. To address this challenge, they proposed a Dual Air Handling Unit (AHU) system that operates at low energy consumption while effectively ensuring indoor thermal comfort through effective handling of excessive humidity. The proposed system incorporates two AHU units, with each unit responsible for monitoring room temperature and room humidity setpoints, respectively. The target conditions for the room were set at 26°C temperature and 50% relative humidity. Comparative assessments conducted against standalone AHU systems commonly used in air conditioning revealed that the proposed Dual AHU system resulted in significant energy reduction. The achieved savings ranged between 10.7% and 13.2%. Therefore, despite the higher initial cost, it is recommended to install a Dual Air Handling Unit system in classroom buildings due to the considerable long-term savings and its environmentally friendly and sustainable nature due to energy efficiency.

Other than that, the research conducted by [21] proposed a solution for HVAC predictive control in room usage by implementing an Internet of Things (IoT) framework along with Self-Powered Wireless Sensors (SPWS) through a Mobile Based Prediction Control (MBPC) system. The researcher emphasized the economic feasibility of this solution as it does not require external wiring or complex installation due to its self-powered nature. To simplify data sharing and transmission, the solution employed RF transceivers and receivers instead of conventional Wi-Fi technology. The sensor data collected by transmitter nodes located throughout the building is aggregated, processed, and stored, making it accessible to the HVAC MPC system. The collector node is connected to a common Ethernet or Wi-Fi network to transmit the Wireless Sensor Network (WSN) data to a database system for permanent storage, enabling accessibility for the HVAC MPC system. This solution is highly suitable for classroom implementation as it preserves the existing wiring infrastructure while effectively enhancing energy efficiency and reducing long-term electricity consumption.

F. How do the collected data could provide valuable insights into classroom pedagogy management?

Maintaining appropriate temperature and humidity levels in the classroom is important for students to feel comfortable and focused. When students feel physically comfortable, they are more likely to participate and pay attention during class, facilitating effective classroom management. However, integrating real-time tracking and data collection systems can significantly improve this aspect of educational management. With such a system, educators can continuously monitor temperature and humidity levels, and receive alerts and immediate feedback when conditions deviate from the optimal range. This real-time information allows teachers to proactively adjust the classroom environment, such as adjusting the thermostat or turning on a humidifier, ensuring student comfort is maintained. Additionally, historical data collected by the system can be analyzed to identify trends and patterns, helping schools make informed decisions about long-term improvements to classroom conditions, thereby improving learning environment and teaching effectiveness.

According to a study cited in reference [22], which focused on assessing the impact of smart classrooms on pedagogy management, it was found that the classroom environment's design and equipment play a significant role in the effectiveness of smart classroom setups. The research involved surveying 495 students in China, with more than 80% of the participants indicating that maintaining an appropriate classroom temperature is essential for concentration during learning. Additionally, 79.5% of the students agreed that they experienced reduced drowsiness and fatigue in the classroom, attributing it to the presence of fresh air. To address these concerns, one potential solution proposed is the integration of smart sensors within the classroom environment.

Other than that, from the research conducted by [23] which emphasized on the use of a smart classroom system that can recognize lecture quality based on physical parameters. The study highlights the negative impact of inadequate temperatures and air quality on student performance and achievement. The study also discovered that the humidex level which is a combination of temperature and humidity level along with the concentration of carbon dioxide are the two major environment factors that show a significant influence on satisfactions of students in the quality of lecture. Aside from this, the research also discovered that the level of humidex produces an importance value of 0.3479 which could be implied as the most important environment factor when it comes to education experience. By incorporating smart sensors and various IoT architecture, the system can monitor and control classroom temperature, humidity, and other physical parameters to optimize the learning environment. The system can also be customized to fit different classroom environments and teaching styles, providing suggestions to the teachers to adjust their teaching strategies and activities.

By addressing the previously mentioned issues, the proposed IoT solution offers a means to enhance the classroom environment. It involves the deployment of an IoT system within the classroom environment, which will actively monitor key parameters such as temperature, lighting, and humidity in real-time. This real-time monitoring capability is crucial because it allows for immediate responsiveness to changing environmental conditions. One of the noteworthy features of this IoT system is its ability to provide automated feedback. When the system detects abnormal values of these environmental variables, it will automatically trigger alerts to the administrators through a mobile application. The significance of this automation lies in its potential to greatly enhance the comfort and well-being of students during their classroom activities. For instance, if the classroom temperature becomes too hot or too cold, or if the lighting is too dim or too harsh, it can lead to discomfort and fatigue among students. By addressing these issues in real-time, the IoT system aims to create a more conducive learning environment. When students are comfortable and the classroom environment is optimized, they are more likely to maintain better concentration on their studies. As a result, students can receive a higher quality of education, which is likely to manifest in enhanced academic performance.

Aside from this, research conducted by [24] in Sweden had suggested that warm weather conditions can negatively impact the thermal comfort and physical activity of young children in a preschool yard in Gothenburg, Sweden. The findings presented in this study demonstrate that weather conditions have a notable impact on the heat stress levels and physical activity of preschool children. On warmer days, the children actively seek out shaded areas to mitigate heat exposure and enhance their overall comfort. Additionally, their physical activity diminishes as the weather becomes hotter, as evidenced by shorter distances covered, fewer steps taken, and a decrease in the highest recorded heart rate, particularly when compared to cooler days. This reduction in physical activity is significantly associated with outdoor temperature, accounting for a 31% variance in the highest recorded heart rate.

By integrating the suggested solution, real-time outdoor temperature monitoring could serve as a reliable indicator for permitting or restricting physical education classes and outdoor activities for students with diverse health conditions. This proactive approach would substantially decrease the risk of students experiencing complications like heatstroke or heat stress. Furthermore, the continuous collection of environmental data can serve as a valuable reference for future construction and improvements within the educational institution, providing essential insights for optimizing building design and facilities.

G. How does the integration of proposed solution impact the property planning of educational institution?

According to the research conducted by [25] which analyzed the impact of certification of green building towards the rent of commercial properties which involved the review of methodology and analysis of various research papers published between the year 2003 and 2021. The majority of the studies, 36 out of 47 (77%), indicated that any form of green certification had a positive effect on rental rates for office buildings. Conversely, only 11 out of the 47 studies (23%) discovered no significant link. This suggests that tenants are willing to pay a premium for green-certified buildings due to the perceived benefits of energy efficiency, sustainability, and healthier indoor environments. While the research did not specifically examine the impact of green building certification on educational institutions, the findings suggest that green building certification can have a positive impact on rental rates for office buildings. Educational institutions that own or lease office buildings may be able to attract more tenants and generate higher rental income by pursuing green building certification. Additionally, green building certification can help educational institutions demonstrate their commitment to sustainability and environmental responsibility, which may be important for attracting students, faculty, and staff who prioritize these values.

Consequently, the proposed solution involving real-time analysis and monitoring of the classroom environment represents a pivotal stride for educational institutions as they transition toward a more environmentally sustainable model. This approach could prove valuable, as research conducted by [25] has indicated that the adoption of the Internet of Things (IoT) can address certain hurdles associated with the establishment of eco-friendly building infrastructures. Moreover, the study has highlighted that IoT technologies facilitate the real-time monitoring and fine-tuning of building systems, resulting in substantial energy conservation and a diminished ecological footprint. As a result, the significant energy savings achieved through these measures could translate into a financial advantage for an educational institution. This surplus capital could then be channeled towards more valuable endeavors, such as enhancing academic programs, introducing advanced technologies to benefit students, or providing educators with state-of-the-art teaching resources.

H. Mobile Application Integration with Classroom Simulation

According to findings from the research referenced as [26], it is recommended that the visual design of mobile applications intended for elderly users should be tailored to meet their specific requirements. This entails using a font size of no less than 12pt and ensuring that buttons or icons on the screen have a minimum height of 25mm. Furthermore, the application should offer customization options, allowing users to adjust text size, color, and contrast to suit their preferences. In cases where the app is intended for elderly users aged 60 and above, it is advised to use a larger font size ranging from 36pt to 48pt. Additionally, the app should employ a one-level navigation system rather than complex menu structures, and all menu buttons should be positioned at the bottom of the screen to prevent the user's finger from obstructing the central view. Given the likelihood of visual impairment among elderly users, adhering to these design principles is essential to ensure a positive user experience for individuals spanning various age groups.

The Google Authentication setup in Google Firebase ensures secure access to the mobile application (Figure 12), as only users with authorized institution email addresses are granted login privileges. This helps maintain the privacy and integrity of the application by preventing unauthorized access from external sources. In addition to the Class Detail Screen, the mobile application leverages the power of Google Firebase NoSQL integration in other functionalities as well. This integration allows users to not only conduct CRUD operations on the Firebase database but also retrieve and update real-time data related to classroom monitoring. The seamless communication between the mobile application and the embedded system, facilitated by Google Firebase, enables users to control and monitor various aspects of the classroom environment conveniently and efficiently.

Aside from this, users will have the ability to access and monitor the current state of the classroom environment. This includes the visibility of the light and air conditioner statuses, as well as environmental data such as light intensity, temperature, and humidity. Additionally, the application will provide real-time information on the number of people present in the classroom, utilizing ultrasonic sensor detection. This comprehensive view of the classroom environment will enable users to stay informed and make necessary adjustments as needed.

Furthermore, the mobile application offers the convenience of remotely controlling electrical appliances within the classroom. While the prototype version focuses on virtual lighting control and the adjustment of temperature and fan speed for the air-conditioner, the application is designed for future scalability. In real-world implementation, it is expected to integrate with various mechanisms to allow control over additional appliances such as projectors and computers. This integration aims to enhance the functionality and practicality of the mobile application, providing users with more control over their classroom environment.

Moreover, the mobile application will provide access to historical data, allowing users to review past information and track trends. This includes the ability to view historical temperature, humidity, and light levels within the classroom. Additionally, users can monitor the historical status of the air conditioner and lights, as well as track the number of people present in the classroom over time. By analyzing this historical data, users can gain valuable insights into the patterns and fluctuations of the classroom environment, enabling them to make informed decisions and optimizations.

To further facilitate analysis and collaboration, the mobile application will enable users to export the historical data in a spreadsheet format. This feature allows for more in-depth analysis and compatibility with other platforms. By utilizing the sharing intent of the mobile application, users can easily share the exported historical data with various platforms for further analysis and collaboration. This capability enhances the usability and flexibility of the mobile application, empowering users to extract meaningful insights from the collected data.

In conclusion, the mobile application offers a comprehensive solution for monitoring and controlling the classroom environment. Users will have access to real-time information on the state of the classroom, including the light and air conditioner statuses, as well as environmental data such as temperature, humidity, and light intensity. The application also provides the ability to remotely control electrical appliances, initially focusing on virtual lighting and air-conditioning settings but with the potential for future expansion to include other devices in the classroom.

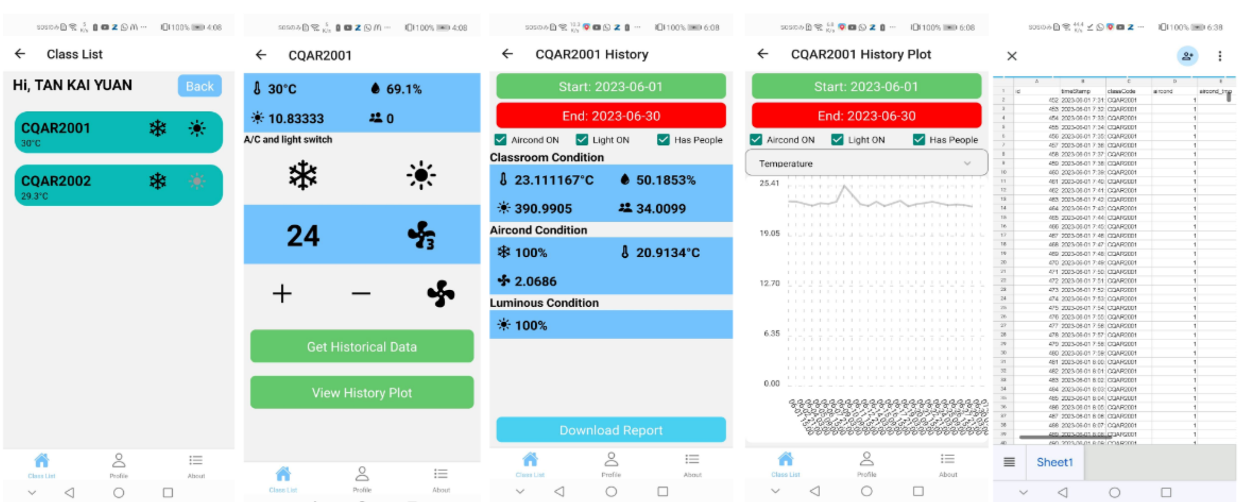

Figure 12. Screenshots of the mobile application

V. CONCLUSION

Several significant achievements have been made. Firstly, extensive research and study were conducted to explore the state-of-the-art IoT implementations of classroom monitoring methods. This provided valuable insights into the current landscape and best practices in this domain. Additionally, by examining existing implementations, it gained a comprehensive understanding of the strengths and limitations, enabling to make informed decisions for the project.

The proposed solution utilizes a set of user-friendly visualization tools, which play a crucial role in simplifying the process of analyzing classroom environments. These tools not only present the data in an easily understandable manner but also enhance its visual appeal, making it more engaging for stakeholders involved in decision-making. This approach proves highly beneficial for classroom environmental analysis as it assists in identifying areas that require improvement or optimization.

Aside from the significance of the proposed solution mentioned, incorporating a carbon dioxide (CO_2) sensor into the existing proposed solution could be one of the critical future steps for a better solution in addressing some of research concerns. Monitoring indoor air quality, specifically CO_2 levels, is essential for healthier and more sustainable educational environments. The CO_2 sensor will provide real-time data, helping ensure a comfortable and productive classroom atmosphere. This enhancement aligns with our commitment to energy efficiency and well-being, contributing to the future of eco-conscious educational facilities.

A working prototype was built, although it was only partially functional. This prototype served the ability to translate concepts into a tangible product. This provided a foundation for further refinement and development in the future. Furthermore, an innovative solution has been introduced to address the issue of unnecessary electricity wastage within these classroom settings. By integrating remote monitoring and management tools into a mobile application, the project offers a practical means of curbing energy wastage. This integration enables real-time monitoring of energy consumption and provides the convenience of remotely controlling electrical devices within the classroom. Through this feature, users gain the ability to actively manage their energy usage, resulting in a more sustainable approach and the efficient utilization of resources.

The amalgamation of heuristic sensors, intuitive visualization tools, and the capabilities of remote monitoring highlight the comprehensive and interdisciplinary approach of the research. This, in turn, showcases the expertise in diverse domains including data analysis, user interface design, and mobile application development. Overall, the achievements represent significant progress, setting the stage for future advancements and improvements in the field of IoT-based classroom monitoring.

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AUTHOR CONTRIBUTIONS

Kai Yuan Tan: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Validation, Visualization, Writing – Original Draft Preparation;
Kok Why Ng: Project Administration, Resources, Supervision, Writing – Review & Editing;
Kanesaraj Ramasamy: Project Administration, Supervision, Writing – Review & Editing

CONFLICT OF INTERESTS

No conflict of interests were disclosed.

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