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Research Article

Design and Development of IoT based Smart System for Monitoring Laboratory Environment

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ABSTRACT

This study was conducted to address the critical issue of the poor safety management system in laboratories, through the design of a smart laboratory management facility based on the Internet of Things (IoT). In this design, three major safety parameters-fire, temperature and carbon (ii) oxide (CO) levels were monitored by appropriate sensors, which transmit data to the microcontroller (Arduino) for interpretation. The Arduino microprocessor processed the data received from the sensor(s), makes decisions based on the predefined algorithms. Based on the decisions made by the Arduino, the microprocessor sends instructions to a relay module triggered the necessary actions to be taken by the output hardware devices-fire extinguisher, air conditioning system and exhaust fan unit. The temperature monitoring system was designed at an operational range of 18°C to 25°C, the CO control unit was designed to maintain the CO concentration inside the laboratory at a level not exceeding 4 parts per million (ppm), as approved by the World Health Organization; while fire control unit was designed to detect the presence of smoke of naked fire inside the building. In the event that any of these parameters breach safety thresholds, the smart structure's safety system will trigger the appropriate responses. The designed structure was built in compliance with international safety standards. Results obtained through the testing and evaluation of the system revealed that the smart system had overall performance efficiency of 91% and false output of 9%. The system's failure rate of 9% can be reduced by employing advanced sensors and adjusting the delay rate. The findings of this study revealed that IoT and automation can successfully monitor and protect the working environment inside laboratories.

Keywords: *Arduino UNO, Automation, C++ Programming, Environmental control, Health hazards, Sensors and hardware*

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INTRODUCTION

Laboratory is a specialized place equipped with various instruments/apparatus that enhanced research and developments, analyzed data and contribute immensely to knowledge and development of new technologies (Junwei *et al.*, 2022; Wang, 2022). Laboratory provides a conducive environment for methodical investigation and experimentation, enabling researchers to test hypotheses, validate theories, and make meaningful contributions to their respective fields (Shana and Abulibdeh, 2020). Laboratories which are integral spaces within colleges and universities play a pivotal role, in the education and professional development of the students. Apart from practical skills that students learn in laboratories, they are major source of internal generated revenue to higher institutions, as they carry out consultancy services for individuals and corporate organizations. Laboratories are hubs for research and modernization, as they enable individuals/students to conduct experiments, investigations, and research that will aid their practical knowledge in their respective areas of specialization (Liboreiro *et al.*, 2022).

There are several tasks required for an upkeep of any standard laboratory. Some of these tasks are environmental monitoring and control, attendance taking, materials inventory, waste management and other safety precautions. Uguru *et al.* (2023) reported that high temperature usually affects the results of most food items during laboratory analysis, hence temperature should be considered as a serious factor during mechanical and textural evaluation of most agricultural food products. According to Befekadu *et al.* (2020), appropriate inventory management minimized bottleneck laboratory operations, and by ensuring that there are adequate materials for the smooth running of the laboratory system, by ensuring timely replenishment of laboratory commodities. Proper inventory management and environmental monitoring greatly influence the overall efficiency of laboratory operations (Leung *et al.*, 2016; Restiana and Djukri, 2021).

Smart system is a new innovation where the system meets remote monitoring needs, hence reducing the time taken and risks involved in the system operation. Smart systems enable real-time monitoring of laboratory equipment and processes from a remote location. The integration of automaton and smart systems into machine operations brings about several advantages, particularly in the context of remote monitoring and quality control (Ekruyota *et al.*, 2021; Idama and Ekruyota, 2023). Well-furnished laboratories contribute immensely to the academic and socio-economic excellence of any institution of learning or research. Modernized laboratories are often equipped with sensitive apparatus and equipment that require specific environmental conditions (Timotheou *et al.*, 2023). Many smart systems come with user-friendly interfaces that make it easy for researchers and technicians to interact with and control laboratory equipment remotely.

Recently there are several innovations in agricultural productions that evolved from Internet of Things (IoT), automation, laboratory analysis, and biotechnology (Awad *et al.*, 2022; Dhanaraju *et al.*, 2022; Rejeb *et al.*, 2022). Research findings from the laboratory have led to the development plants and animals with anticipated traits, and production of numerous high quality food items with improved shelf life. This has enhances the state of food security and reduces the occurrence of malnutrition (Pawlak and Kołodziejczak, 2020; Lenaerts *et al.*, 2019;

Rajeev *et al.*, 2022). Standard laboratories play a crucial role in supporting and advancing improved agricultural practices; thus their automation and application of IoT have become paramount interest (Dhanaraju *et al.*, 2022). IoT is a new engineering innovation which allows hardware to be remotely activated and deactivated across the internet, as it has the ability to collect, share, and act on data, creating a network of interconnected systems (Nižetić *et al.*, 2020; Ehsan *et al.*, 2022). The (IoT) is a complex structure which involves the interconnectivity of various components (software and hardware) to create a network of interconnected devices. According to Sisinni *et al.* (2018), IoT has a lot of influence in the educational, agricultural, industrial and medical sectors, as it plays a pivot role in monitoring and controlling essential parameters in the workshop, laboratories and production unit operations.

Several smart systems have been developed and evaluated by numerous researchers, and each system having its own assets and liabilities (Wenwen *et al.*, 2016; Ma *et al.*, 2017; Zhichuang, 2018; Li *et al.*, 2020; Zhou, 2022; Zhang and Zhou, 2023). The resources and liabilities of smart systems are dependent on the specific context, goals, and requirements of the intended application of the smart structure (Reisinger *et al.*, 2022). The major liabilities of smart structures are high initial costs of the smart equipment, and non-compatibility of the system with most obsolete apparatus and machines, though retrofitting package have been developed to boost the compatibility of older tools and machines with modern advance smart technologies (Pandiyan *et al.*, 2023). Through numerous smart technologies has been developed and evaluated (Shazali Dauda and Toro, 2020; Tun and Myint, 2020), research into the development of hybridized smart university laboratory system is still scanty, mostly in the area of security and safety. Therefore, the goal of this research is to develop a smart technology for a modern laboratory of a university that will effectively monitor the temperature, fire and poisonous gas level. The monitoring of these crucial parameters will enhance the overall functionality and safety of the laboratory environment.

MATERIALS and METHODS

This smart structure design focused mainly on the implementation of intelligent control system in a laboratory to enhance the learning capability, and guarantee the safety of the occupants of the building-human beings and materials. Fatemi *et al.* (2022) during their investigation into laboratories safety, identified fire incidence and gas poison as some of leading cases of health hazards in major laboratories and workshops.

The methodology adopted in this study was design of the smart system (with the goals clearly stated), testing and data collection, evaluation and monitoring systems. Remarkably, the system will provide alerts and warnings for any abnormal situations encountered (fire and excess CO), allowing for quick responses and interventions. Furthermore, the IoT unit will help to facilitating seamless communication between the system and administrator. Designing a system to ensure that critical parameters within the laboratory align with international safety standards reflects a commitment to maintaining a healthy and secure environment in the workshop.

The system software

The Arduino Compiler (Integrated Development Environment-"IDE"), Blynk application for Android, and MATLAB were the software packages/platforms used for developing the system. The Arduino Compiler IDE is a powerful software platform that provides a user-friendly interface for programming Arduino microcontroller, and it is compatible with C++ programming language.

Blynk Application for Android enables the development of more flexible Internet of Things (IoT) applications. Blynk Application has a strong potential of creating a graphical user interface (GUI) for IoT structures on mobile device. The MATLAB software was used to complement the capabilities of the Arduino in this smart laboratory facility. Remarkably, since Arduino which is compatible with C++ programming language was selected as the microprocessor, the C++ programming language was chosen as the programming language of the smart system.

The system hardware

Microcontroller

An Arduino UNO R3 (model-ATmega328P) as shown in Figure 1 was used as microcontroller for the design of the smart facility. The Arduino UNO have these specifications: voltage rating-6 V to 20 V, direct current-20 mA, main processor clock speed-16 MHZ, Memory-2KB SRAM and 32KB FLASH-, and operating voltage of 5 V was used as microcontroller for the design of the smart facility.

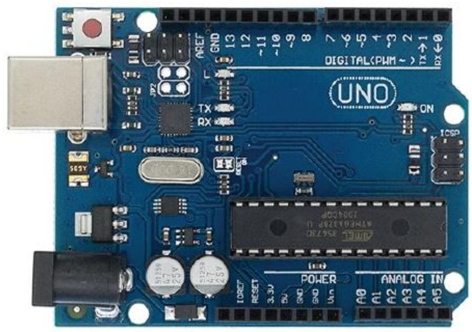

Figure 1. *An Arduino microprocessor.*

MQ-2 Gas Sensor

The MQ2 gas sensor which is commonly used for detecting carbon (ii) oxide and smoke was used to monitor the CO and smoke level inside the laboratory. It has these specifications: operating voltage of 5 V DC, heating resistance of 33Ω, power consumption of 800mw, and the sensing resistance ranges from 10 kΩ to 60 kΩ. The MQ2 gas sensor can be classically connected to an Arduino microcontroller to read the sensor's output.

DHT11 sensor

The DHT11 sensor is basically used for Temperature and Humidity monitoring, and has a resolution of 1oC and 1% humidity. It has an operating current of 2.5 mA and operating voltage of 5 V DC.

Arduino Buzzer

A buzzer for Arduino was used for the design and development of the smart system. The buzzer has a maximum sound output level of approximately 88 decibel, and operating voltage that ranged from 3 V to 24 V.

Wi-Fi module

The wireless router supports 2.4 GHz Wi-Fi with a transmission rate of 300 Mbps. It 3 ports, with each port supporting network speeds of approximately 100 Mbps and, CPU frequency of 650 MHZ.

Relay module

Various types of relay modules were used to develop the system. Relay modules are specifically designed to control high-power output devices with lower-power rating microprocessor (Tjandi and Kasim, 2019). Their functions are to activate "switch ON" and deactivate "switch OFF" the control hardware, based on the instruction that it received from the microcontroller.

Smart system architecture

Figure 2 shows the block diagram of the smart laboratory, with the various entities of the prototype IoT based control system. The system architecture is a closed-loop system where the microcontroller interprets sensor(s) data, makes decisions based on programmed logic, and then controls the appropriate hardware device(s) in the laboratory.

The various sensors are deployed in the laboratory to collect data from the system, and transmit them to the central processing unit (Arduino UNO R3). Thereafter, the microprocessor process and interprets the raw data received from the sensors, and activates the relay modules and Wi-Fi module in accordance with the interpreted data. The Wi-Fi module helps to facilitates basic communication between the Arduino UNO and the internet, and communicates wirelessly with to the designated mobile phone or personal computer. Interestingly, the system architecture depicted that the Arduino board is responsible for hardware control and interfacing, the Blynk app provides a user-friendly interface on a mobile device, and MATLAB may contribute additional analytical or computational capabilities.

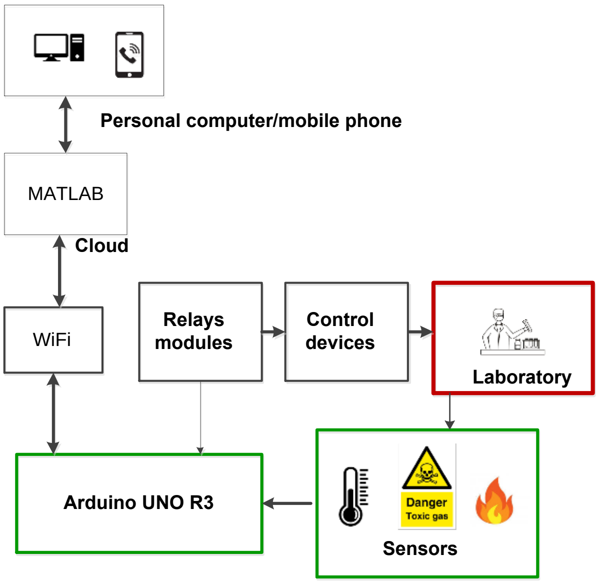

Figure 2. The system block diagram.

Hardware design

The schematic view of the smart system hardware layout is illustrated in Figure 3. In the development phase of the system, the DHT11 sensor was connected to one of the digital pins on the Arduino board. The DHT11 interacts with the microcontroller through this digital pin, where its reads the digital signals to determine the temperature and humidity values inside the smart facility, and transmits the results to the microcontroller (Arduino), to process and determine if to initiate the relay module controlling the air conditioning unit based on predefined temperature threshold. The temperature relay module, when activated, controls the air conditioning unit according to the temperature conditions detected by the DHT11 sensor.

Furthermore, the buzzer functions as the alarm system. The buzzer and relay modules were linked to a digital output pin on the Arduino. Once it received data, the microcontroller sends a signal to the relay module by setting the digital pin to "HIGH" or "LOW", which will translates if to activate or deactivate the appropriate hardware device after due interpretation of the signal. The hardware device relay module activates were air conditioning unit, fire extinguisher and exhaust fan for the temperate, fire and high CO presence signals, respectively. By combining these elements, the smart technology for the laboratory can create a dynamic, efficient, and secure learning environment for students while preparing them for the technological advancements in their studies.

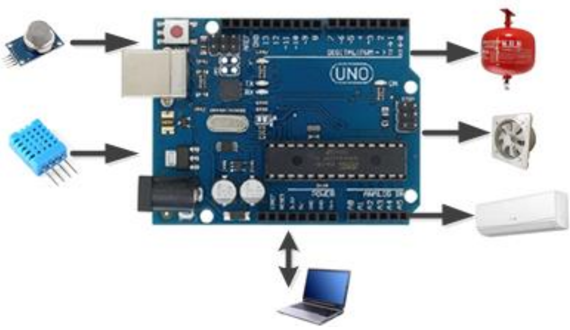

Figure 3. Diagram of the smart structure.

Targeted monitored parameters inside the laboratory

Temperature control

The system is designed to activate the air conditioning unit when the temperature rose above a specified threshold of 25ºC, and deactivate the AC unit when the temperature falls below a specified threshold of 18ºC. This is to maintain a comfortable and safe working environment. Figure 4 shows the flowchart of the temperature management inside the laboratory. Figure 4 depicted that the air conditioning unit will switched "ON" by a temperature relay module when the internal temperature exceeded the maximum predetermined level of 25ºC; similarly, the flow chart revealed that the air conditioner will be switch "OFF" by the temperature relay module when the interior temperature of the laboratory falls below the minimum pre-set level of 18ºC. Furthermore, the internet system will send alerts via email or SMS notifications to a selected administrator, indicating the interior temperature condition of the room.

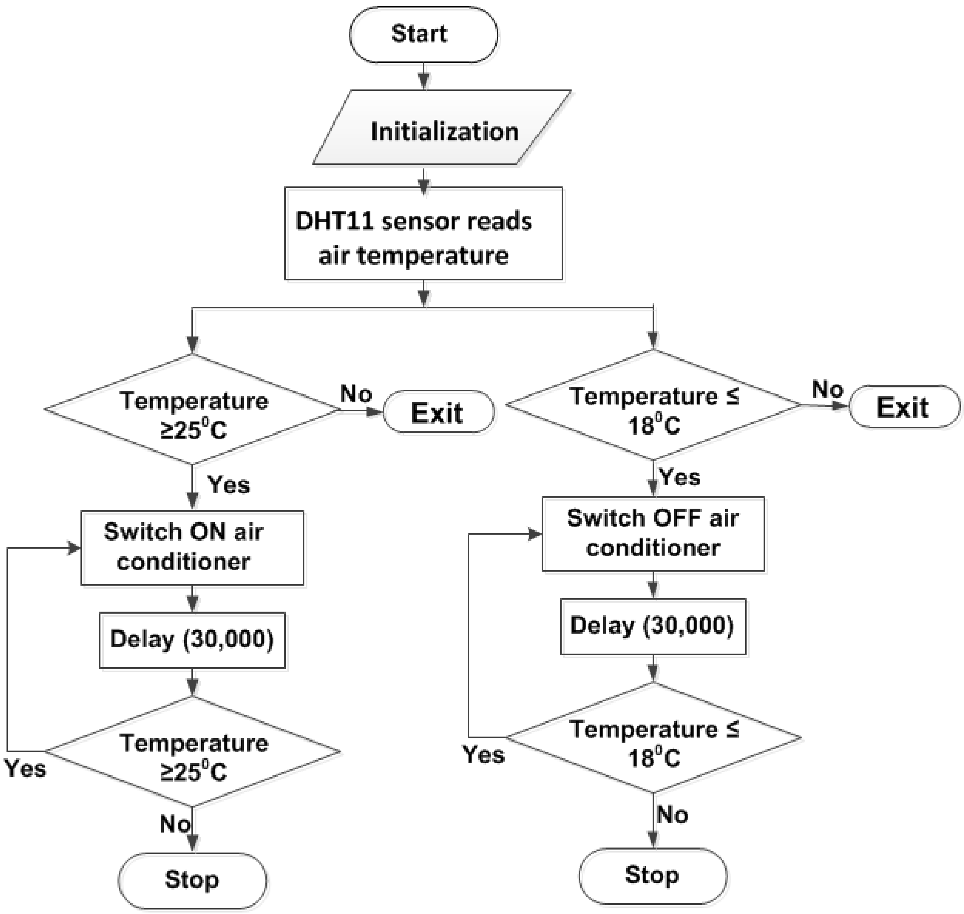

Figure 4. *The temperature control flowchart.*

Carbon (ii) oxide control

The CO concentration in the laboratory was constantly monitored to protect the lives of the students and other workers inside the structure. The flowchart in Figure 5 turns the exhaust fan "ON" when the CO level inside the laboratory exceeded the World Health Organization (WHO) maximum limit of 4 parts per million (ppm), the CO relay module switches its state, enabling power to flow to the exhaust fan. Furthermore, the flowchart will send a signal to the targeted administrator if the high CO accumulation problem exceeded 10 minutes after the force ventilation. This is a common safety measure to ensure that the air quality in the laboratory remains within acceptable limits. The alert system will assist in promptly notifying responsible personnel, enabling them to investigate and address any potential issues contributing to prolonged high CO levels.

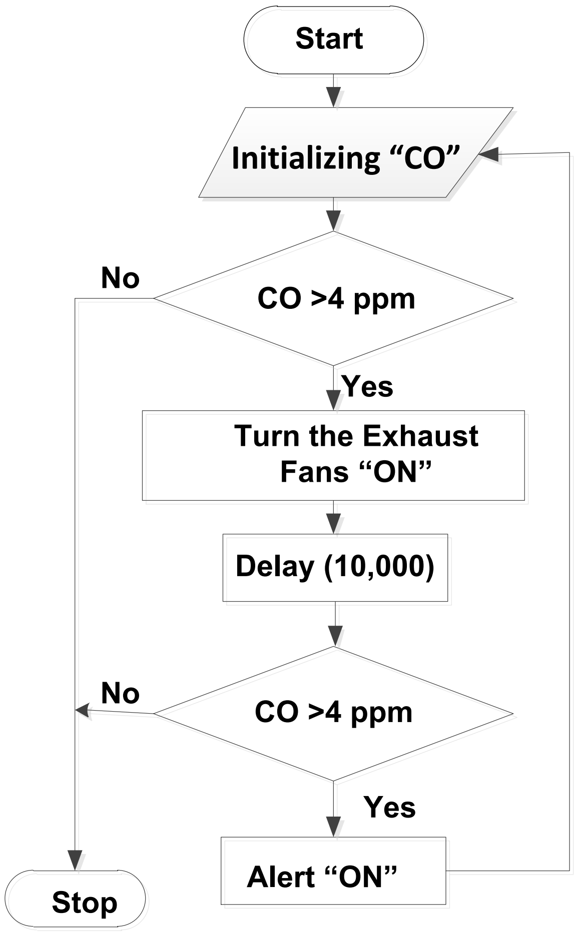

Figure 5. *The CO monitoring unit flowchart.*

Fire control

Fire control is a pivot factor of safety in any laboratory or workshop. As shown in Figure 6, the flowchart activates the alarm system once smoke or naked flame is detected inside the building. Additionally, there is an IoT (Internet of Things) component calibrated to notify the administrator instantly, and if the issue persists after a set delay period of 10 minutes, the fire extinguisher unit is activated through the aid of the fire relay module. This will initiates the release of fire suppressant agents into the enclosed environment. This is a crucial step in attempting to control or extinguish the fire before it can spread further.

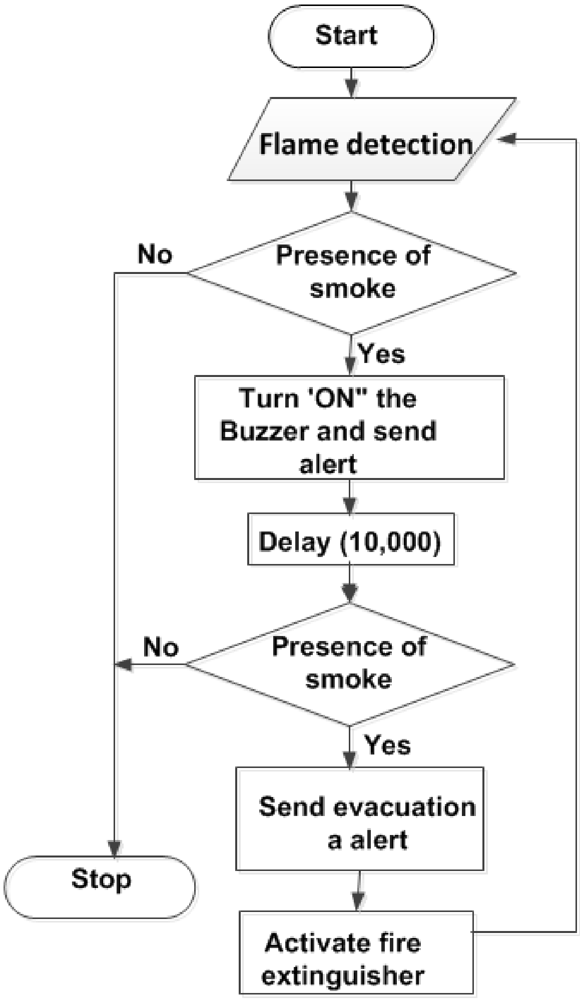

Figure 6. *The fire control flowchart.*

Testing of the system

The laboratory was tested for duration of 15 hours, during which the temperature, smoke and gas level inside the laboratory open space randomly varied through the aids of coal stove and electric heater. Incomplete combustion of coal produce carbon (ii) oxide (National Cancer Institute, 2022), which is the targeted poisonous gas designed for in this study. The internal temperature of the laboratory was preset a temperature ranged of 18°C to 25°C.

The Wi-Fi module was responsible for connecting all the activities within the workroom to a cloud server, and the cloud server then relays this information to a designated administrator. Additionally, the buzzer helps in providing the necessary sound signal to alert the occupant of the building of the impeding danger. According to Tun and Myint (2020) and Ehsan *et al.* (2022), buzzer, an essential component of the IoT-based safety system (Arduino alarm system), provides audible alerts to notify a building occupants about potential environmental disasters. Similarly, the cloud server incorporated into this system acts as an intermediary and a central hub for processing and storing the data (Tariq *et al.*, 2023).

The performance of each hardware device in the smart structure, and the overall performance of the structure were calculated through expressions shown Equations 1 and 2.

$$P = \frac{T_0}{T_o + F_o} \times 100 \quad (1)$$

$$\sum P = \frac{P_1 + P_2 + P_3}{3} \quad (2)$$

Where: T_o = True outcomes,
F_o= False outcomes,
P_1= Performance of the temperature regulation unit
P_2= Performance of the fire control unit
P_3= Performance of the CO monitoring unit.

RESULTS AND DISCUSSION

The results of the testing of smart facility are presented in Figures 7, 8 and 9. The findings of the study revealed that the temperature, fire and CO monitoring units exhibited a commendable efficiency 87%, 93% and 93% respectively. These findings depicted that temperature control unit recorded the poorest (lowest) performance, while the fire and CO control units had the highest performance results. This reflects the system's robust performance in detecting smoke/fire and carbon monoxide levels, and fairly good performance in regulating the room temperature. The fire protection results obtained in this study are in conformity with those previously recorded by Ehsan *et al.* (2022). The poor results recorded for the temperature monitoring unit could be attributed to poor delay setting (timing) and communication gap between the temperature monitoring unit and other components of the system (Fang *et al.*, 2021).

Early fire and poisonous gases detection and containment are critical for the safety of the occupants of any structure, as it allows timely evacuation of human beings and reducing the risk of injury or loss of life (Firesafety, 2023). These goals were achieved by this system, as fire and CO detection recorded 93% success rate. Additionally, it was noted that the total performance efficiency of the smart scheme was 91%. Similar results were reported by Li *et al.* (2020) where they used ZigBee and RFID technologies to monitor the performance of some instruments and equipment in a smart laboratory. In the work of Poongothai *et al.* (2018), they developed a smart system using an Internet of Things (IoT) and mobile application technologies to control the environmental condition and energy consumption in a laboratory.

This study finding highlights the positive synergies between different control subunits and how their collective performance contributes immensely to the overall success of the smart system. Damaševičius *et al.* (2023) stated that applying a robust smart system helps significantly in timely addressing of any anomalies; therefore, ensuring the overall safety of human beings and the environment. The failures (9%) observed during the testing of the scheme could be attributed to system of program errors, and partial compatibility of the software with the hardware, probably caused by coding issues and algorithmic shortcomings. These problems can be reduced through thorough examinations and optimization of the sensors and algorithms used in the software system. According to Ruskin *et al.* (2021), modifying the delay rate and sensors in a smart system is crucial for balancing responsiveness and avoiding false results.

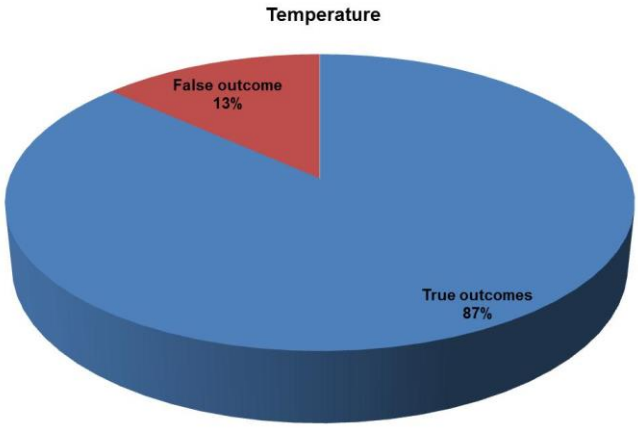

Figure 7. *The result of the temperature monitoring unit.*

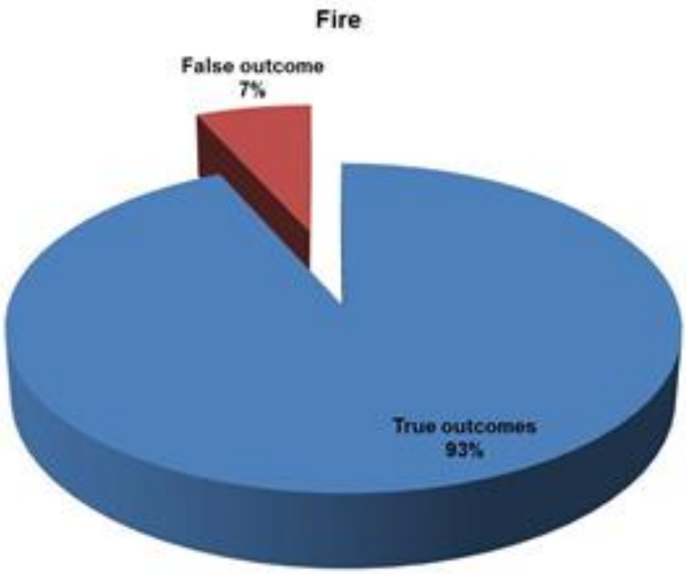

Figure 8. *The performance of the fire control unit.*

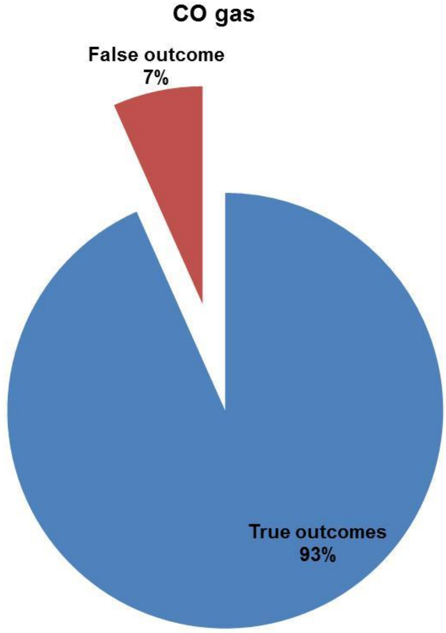

Figure 9. *Performance rating of the CO monitoring unit.*

The overall performance of the smart system = $\frac{87+93+93}{3}$
= 91%

CONCLUSION

The study focused on developing a smart system that can monitor and control the temperature, poisonous gas (carbon monoxide - CO) level, and fire incidence inside a laboratory environment. These three parameters were designed to ensure a comfortable and operational environment for individuals working inside the laboratory. The fire detection and control unit was designed for effective fire extinguishing and evacuation of individuals and materials from the laboratory in case of fire incidence. Similarly, the system was programmed to maintain the laboratory temperature within the range of 18°C to 25°C. Simultaneously, the system will ensure that the CO level inside the laboratory is maintained below 4 ppm. Following the device's construction, the system underwent successful testing. Results obtained from the system testing revealed that: the fire detection and control unit successfully suppressed instances of fire within the laboratory, the temperature control unit successfully kept the room temperature within the desired comfort range, and the CO monitoring unit effectively prevented the buildup of the toxic gas within the laboratory environment. Summarily, the smart system indicated a 91% operational efficiency, earning it a performance rating that is generally considered above average.

Considering the system's reliability and robustness in various scenarios, an automated monitoring system was developed by integrating three sensors, a microcontroller, and relay modules. This system responds to specific conditions inside the laboratory, contributing to both comfort and energy efficiency. Utilizing of advanced sensors and careful adjustment of delay rates can indeed be effective strategies for addressing and reducing the shortcomings (9% failure rate) identified in the system. Regular maintenance, testing and documentation are essential tools in ensuring the reliability and effectiveness of the smart structure. Additionally, information obtained from this study will contribute to the advancement of smart agricultural production structures; thereby, improving food productivity and strengthening the prospects of achieving adequate food security.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The authors declared that the following contributions are correct.
Friday Elohor Odoh: Designed the research Methodology and writing of the original draft.
Ogaga Akpomedaye: Edited the manuscript.
Ovuakporaye Godwin Ekruyota: Data analysis and review of the original draft.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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