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Research Article

An Autonomous Mecanum-Wheeled Robotic System For Air Quality And Health Monitoring, Sanitation, And Delivery In Hotels And Other Hospitality Facilities To Improve Social Service Provision In Oman's Tourism Sector

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ARTICLE INFO | **ABSTRACT**

This paper presents the design, programming, and deployment of a VEX mecanum-wheeled autonomous robotic system (MAROH) to perform the following task within indoor hospitality facilities: (a) navigate the indoor premises and measure body temperatures of guests and staff, while also monitoring indoor air quality metrics; (b) perform sanitation functions which include decontaminating objects in rooms using UV light and collecting trash; (c) do security functions by issuing an alert notification to a safety and security officer in cases of fever detection among individuals, as well as instances where social distancing and facial mask restrictions were not being followed, and (d) deliver various items and food not more than 2kg from one location to another. The robotic system was controlled and monitored using a Vex Cortex microcontroller, which was interconnected with various types of sensing and actuation devices. To address the challenges of obstacle avoidance and robot speed control, a rule-based system was implemented. A user-friendly interface has been developed for the purpose of managing robotic task and configuring delivery routes using smartphone applications. The Internet of Things technology allows real-time monitoring of air quality conditions and individual body temperatures, as well as access to the collected data on ThingSpeak and Particle cloud servers. Phone and web cameras were employed to enhance the visual perception of robots for security purposes. A machine learning technique was used to identify compliance with the facemask and social distancing guidelines. Furthermore, a solar-powered wireless charging docking station was designed as an economical solution for powering the robot. The experimental data and findings showed the performance of the robotic system in completing its assigned tasks with an improved average speed of 0.407 m/s and a reliability rate of 95.0%.

Index Terms— Internet of Things, Robotics, Artificial Intelligence, Machine Learning, Social Services

Introduction

During the onset of COVID-19 pandemic, the Supreme Committee for COVID-19 implemented a compulsory institutional quarantine in hotels for all incoming passengers with the objective of mitigating the transmission of the coronavirus and its variants within the borders of Oman [1]. This decision also aided the hotel and tourism sector financially as a result of the outbreak [1]. The implemented guidelines announced by the Ministry of Heritage and Tourism include utilization of facial coverings upon arrival in the hospitality facility, providing sanitizers in all indoor spaces, temperature checking for every person at the hotel entrance, enforcement of social distancing between guests and hotel personnel, and the routine disinfection of luggage and rooms [2]. Even after the COVID-19 outbreak has passed, it is recommended that the hospitality industry adhere to the guidelines and regulations in order to keep guests and employees safe. Given the existing health hazards and concerns regarding COVID-19 mutations and other airborne viral infections, there is a potential to use robotics, artificial intelligence (AI), the Internet of Things (IoT), and mobile technologies to establish new norms for social services in the hospitality sector.

The objective of this research project was to develop smart autonomous robotic systems with the ability to monitor air quality and health conditions, carry out sanitation tasks, improve security, and offer delivery services within various hospitality establishments, including hotels, restaurants, and shopping centers. As an improvement on the research done by [3], the Multi-Encoder-Based Mecanum-Wheeled Autonomous Robot (MAROH) was able to perform the following operations: (a) faster navigation of the indoor premises of a facility while monitoring indoor air quality metrics and taking individual body temperature scans; (b) additional sanitation tasks like waste collection aside from UV light decontamination of objects; (c) alert notification to security personnel in case of fever detection, non-compliance with social distancing measures, or failure to wear face masks; and (d) quicker delivery of items from one room to another. MAROH's control and monitoring was achieved through the utilization of a Vex Cortex (Vex-C) microcontroller integrated with various types of sensing and actuation components. The improvement of the robot's speed control and obstacle avoidance over the ENVIHbot [3] was achieved by the utilization of a rule-based approach. Moreover, a robot-user interface was developed for managing robotic operations and choosing the delivery routes via smartphone applications. Continuous monitoring of air quality metrics and individual body temperature within indoor hospitality facilities were accomplished using a Particle Photon Red Board (PP) microcontroller interfaced with sensing components that measure the temperature of air (Tair), relative humidity (RH), carbon dioxide equivalent (eCO2), total volatile organic compound (TVOC), carbon monoxide (COppm) and body heat (Tbody). The accessibility of all data was facilitated through the utilization of the ThingSpeak and Particle cloud platforms. The control of air quality metrics was carried out wirelessly by connecting a PP microcontroller to actuating devices such as an exhaust fan (EF), cooler fan (CF), air purifying device (AP), heating fan (H) and air humidifying device (AH). For security and surveillance purposes, phone and IP cameras were utilized to enhance the robot's visual capability. A transfer learning technique was used through the MIT App Inventor's Personal Image Classifier (PIC) extension toolbox for identifying the existence or nonexistence of face coverings and compliance to social distancing regulations in the indoor hospitality facility. Upon identifying any violation of health and safety protocols, a cautionary alert was transmitted to the ThingSpeak cloud platform, which subsequently initiated the operation of a buzzer alarm. A solar-powered wireless docking station for charging was also placed within the indoor facility to allow the robot to operate continuously and cost-effectively. The use of MAROH in hospitality establishments has the ability to lower the risk of infectious disease transmission when engaging with guests. Because of the robot's ability to run continually without being unwell, it has the potential to enhance hotel operations and increase productivity.

I. Related Works

Extensive researches were undertaken to investigate the application of IoT and robotics technologies in the indoor hospitality industry, with a particular focus on hospitality establishments [3]-[15]. The implementation of a robotic system offers numerous benefits, such as enhanced operational efficiency, increased economic viability of robotics, and the establishment of an innovative benchmark in the field of social services [4][5].

The research undertaken by [3] involved the design of ENVIHbot, a line-tracking VEX robot equipped with particle photon-based indoor environment control and monitoring modules. A health protocol monitoring module was also integrated onto the ENVIHbot to detect wearing of face masks. The robot was initially designed for implementation on school campuses; however, it could be improved for use in hospitality establishments. This robot functions as a UV light sanitation system as well as a security system in addition to its main function. The inadequate response of ENVIHbot to changes in corridor illumination settings and its inability to maneuver sharp angles were factors that contributed to its 88.89% mean reliability rate and 0.17m/s slower speed [3]. On the other hand, [6] developed an Arduino-based guided robot with GUI Robotic operating systems (ROS) that can carry items in places like hotels, industries, and other places. Another hotel delivery robot was designed by [7] employing a Fuzzy Logic method for arm manipulation and a Coordinate Transform Neural Network (CTNN) for accurate interior localization. To assist in the hotel check-in process, [8] developed an intelligent ROS robot that utilized Kinect Xbox and LiDAR sensors for navigation and route planning.

A hotel robot was developed to greet customers by [9] integrating facial registration and recognition, speech recognition and synthesis, smartphone apps for monitoring, and other information processing. [10] developed the Android Robot Controller (ARC) to manage and navigate their robot system using IoT technology and a smart watch. [11] used Savioke Relay Robot technology to build a hotel service robot that collects feedback from guests. In the research conducted by [12], an Arduino -based autonomous VEX robot was designed for collecting solid waste on a school campus, which can be enhanced for use in various indoor hotel facilities.

In comparison to prior studies [3–12], this research introduces an innovative multi-encoder-based mecanum wheeled robot with the ability to perform a variety of tasks such as scanning individual body temperatures and monitoring indoor environmental conditions, performing sanitation duties such as waste collection and object decontamination, alerting security personnel in cases of fever detection, social distancing violations, or face mask noncompliance, and facilitating object delivery between different rooms. The robot's operation can be monitored and controlled via an Android-based robot-user interface. The PP microcontroller was used to implement the indoor air quality monitoring sub-module (IAQMS) installed on top of the robot and connected to several sensors, including the Si7021 for Tair and RH sensing, the MQ7 for CO level measurement, and the CCS811 for measuring eCO2 and TVOC levels. The IAQCS was developed by connecting a PP microprocessor to a relay board, which remotely activates or deactivates the actuators EF, CF, H, AP, AH, and light bulb (LB) based on data obtained by the IAQMS [3]. In addition to the face mask detection and non-contact thermal body heat sensing performed in [3,] the IoT-based health security monitoring system (HSMS) includes a social distancing detection module based on transfer learning and sensor technologies. Furthermore, while docked, the robotic system can get power from a solar-powered wireless charging device.

II. Materials and Methods

A. Development of a Multi-encoder Mecanum-wheeled Autonomous Robot (MAROH) for Indoor Air Quality Control and Monitoring, Health Security Checking, Sanitation and Delivery functions

As shown in Fig. 1, the VEX-C microcontroller (VEX-CMc) functions as the main processing unit for the developed robotic systems. It receives input signal from several sensing components including as infrared (IR) sensors, sonar sensors, optical encoders, and detection switch. Once the data has been processed, the microcontroller controls the arm and wheel motors of the robot as required, enabling it to execute several autonomous functions including monitoring air quality parameters, executing sanitation tasks, enhancing health security, and providing services in a variety of indoor facilities including hotels, restaurants, and malls.

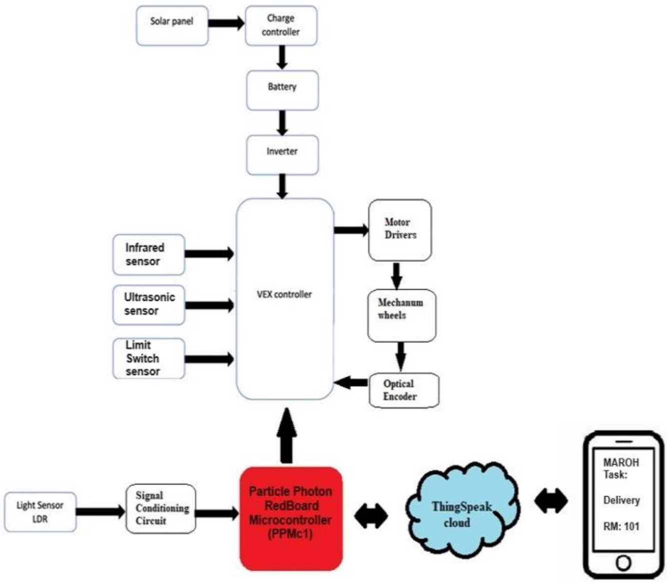


Fig. 1. Block diagram of the robotic system

Fig. 2. Mecanum-wheeled Autonomous Robot for Hotel and Other Hospitality Facilities (MAROH)

Based on Figs. 1 and 2, MAROH consists of four mecanum wheels and several encoders, enabling it to achieve omnidirectional movement. The optical encoders are attached to the motor shafts of the right and left rear mecanum wheels in order to measure the number of rotations. This enables the robot to calculate the distance traveled based on the number of rotations and the circumference of the wheels. The encoders determine and control the speed and direction of the robot's wheels. MAROH also employs a forward-facing ultrasonic sensor and an infrared sensor to facilitate object detection and obstacle avoidance, respectively. The encoders are connected to digital input ports, whereas the infrared and ultrasonic sensors are connected to analog input ports. The VEX-CMc receives a three-bit control signal from PPMc1 for each robotic operation. Subsequently, it analyzes the input from each encoder, performs calculations, and adjusts the speed and direction of each wheel accordingly. The integration of a Light Dependent Resistor (LDR) with the PPMc1 enhances the visual capability of the robot. The Light Dependent Resistor (LDR) senses and controls the intensity of light in the surrounding environment. The activation of the Light Bulb (LB) is accomplished through remote means, specifically when the output voltage of the Light Dependent Resistor (LDR) circuit exceeds 1.8 V. If there is insufficient illumination in the indoor facility, PPMc1 issues a command signal to the VEX-CMc to halt the movement of the robot unit until the light source is activated.

B. Design and Implementation of an Internet of Things-based Air Quality Monitoring and Control System

The monitoring and management of air quality in confined places, such as hotels, restaurants, and other indoor hospitality facilities, is crucial due to the airborne nature and transmission of COVID-19-related respiratory illnesses through sneezing, coughing, and speaking [13]. Fig. 3 depicts the Indoor Air Quality Monitoring Subsystem (IAQMS) consisting of Particle Photon RedBoard (PPMc2) connected to electronic sensing components for monitoring various micro-climatic factors in the interior environment [3]. The environmental parameters include Tair and RH levels measured by the Si7021 sensor, equivalent CO2 and TVOC levels detected by the CCS811 sensing component and the presence of CO gas in the air monitored by the MQ7 sensor [3]. The measured parameters are subsequently uploaded and stored in cloud-based platforms.

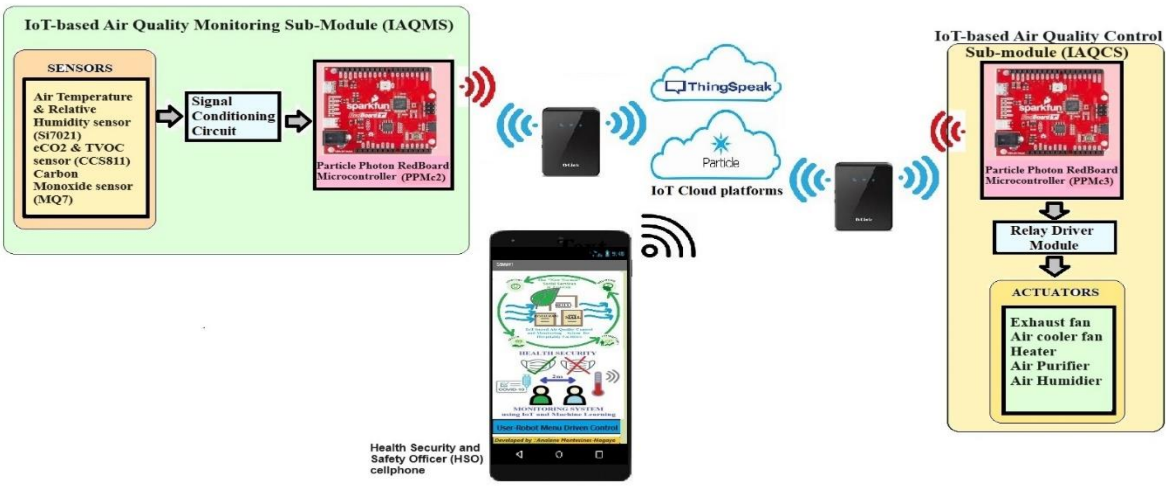
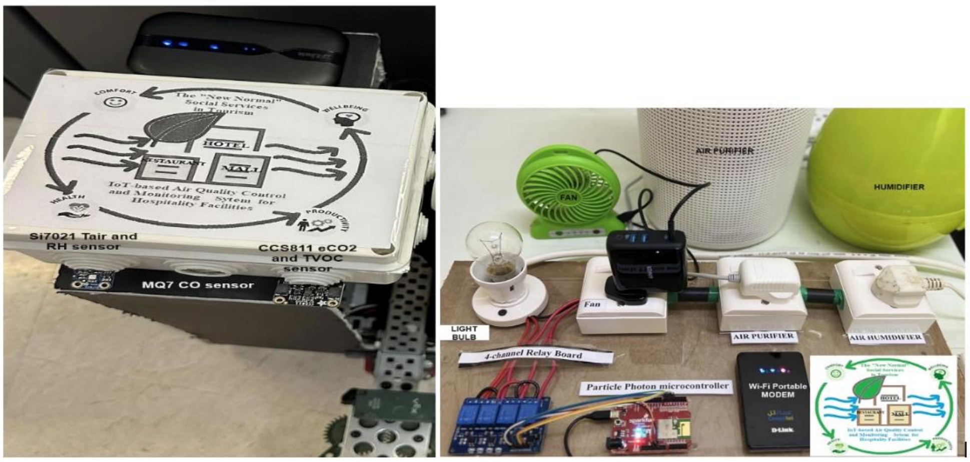


Fig.3. IoT-based Air Quality Monitoring and Control System Block diagram



(a) (b)

Fig. 4. Working prototypes of the (a) IAQMS installed on top of MAROH, and (b) IAQCS [3]

Fig. 3 also illustrates an Air Quality Control Subsystem (IAQCS) that is based on the IoT technology. The IAQCS consists of a Particle Photon Redboard microcontroller (PPMc3) connected to several actuators, including EF, CF, H, AP, and AH through an active-low relay driver module. The IAQCS regulates indoor air quality remotely by acquiring sensor-read data from the ThingSpeak cloud and performing appropriate control measures depending on the information gathered. With the aim of improving data visualization and facilitating easy access to air quality metrics and health security guideline violations, a mobile phone application program was developed using MIT App Inventor and installed on mobile phone of the hotel's health and safety administrator. Fig. 4(a) shows the IAQMS prototype on top of MAROH, whereas Fig. 4(b) shows the IAQCS prototype. The flowchart of the indoor air quality management and monitoring system in Fig. 5 shows the threshold values for environmental factors and air quality control operations. The threshold values specified in the current research are based on ASHRAE recommendations [14],[15] and several scholarly papers [13]-[22] that investigated the effect of indoor microclimatic ambient factors on the transmission of COVID-19 and other respiratory viruses.

C. Development and Deployment of the Health Security Monitoring Module

Fig. 6 shows the Health Security Monitoring System (HSMS) block diagram, which includes three input components: an infrared non-invasive sensor, an ultrasonic sensor, and a phone camera. The IR non-invasive sensor (MLX90614) determines whether people's body temperature (Tbody) is within the normal range of 35.90C to 37.30C, and the ultrasonic sensor (HC-SR04) measures social distance. In addition, the camera of the Android phone is utilized to capture images for the purpose of identifying if individuals are wearing masks or not, as well

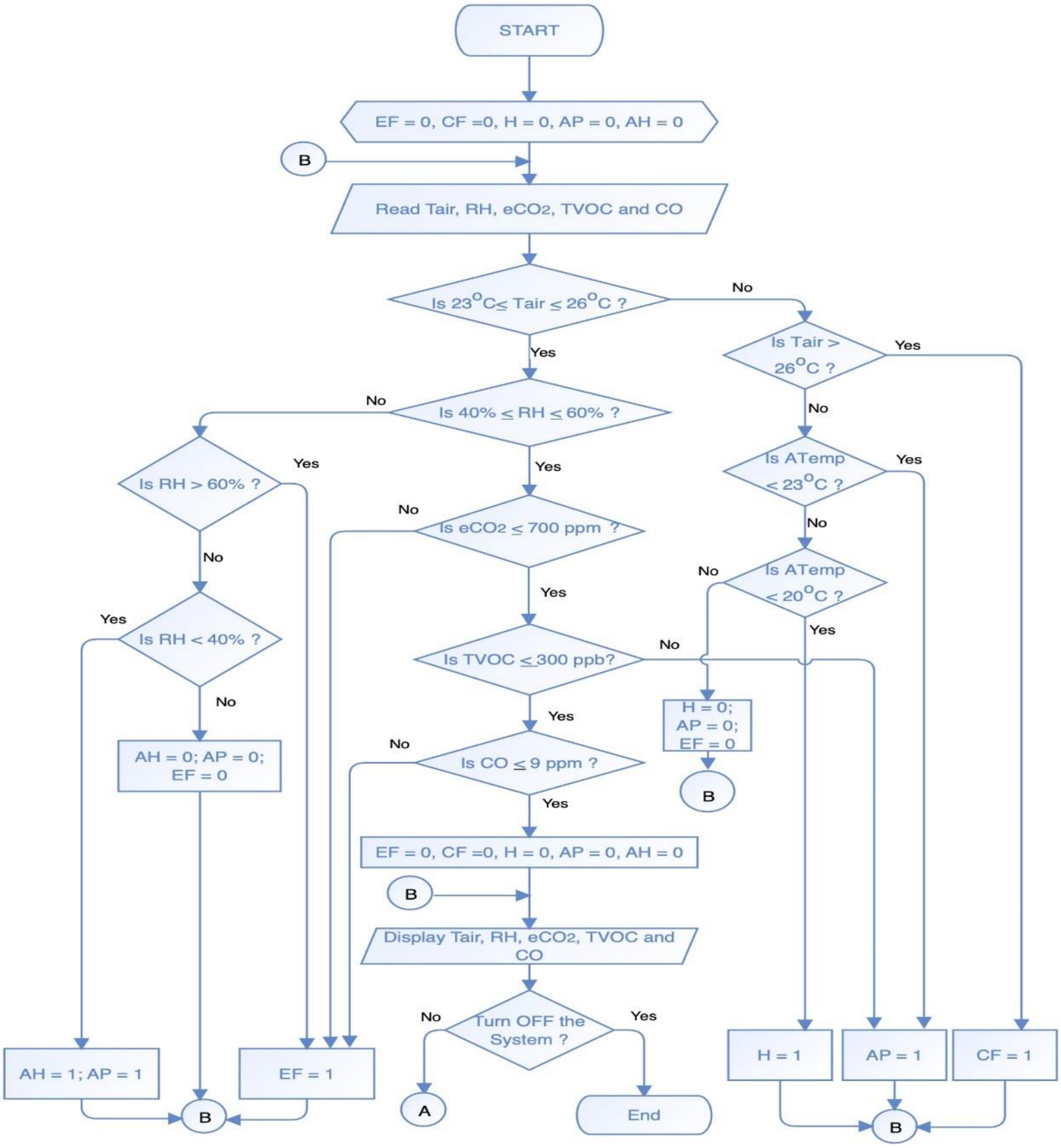


Fig. 5. Flowchart of the Air Quality Monitoring and Control System

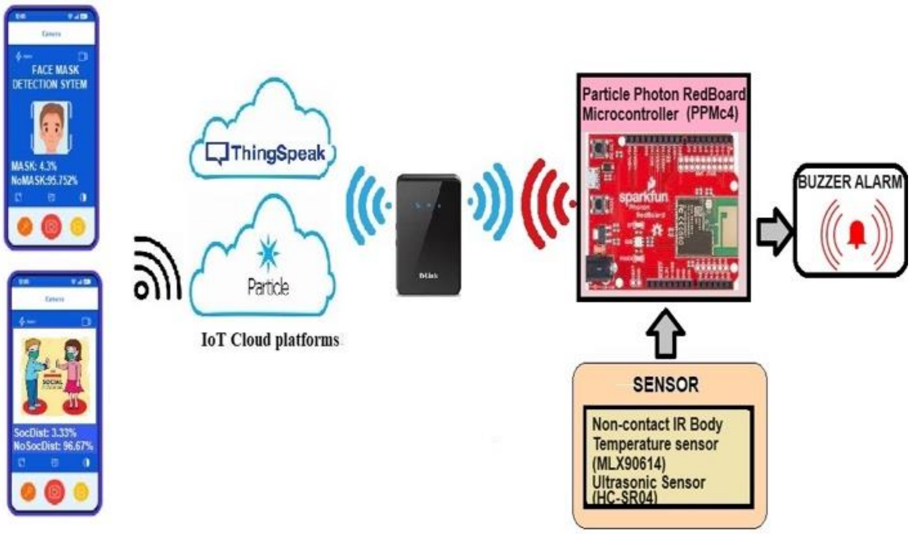


Fig. 6. Block Diagram of the Health Security Monitoring System (HSMS)

as

determining if people are near each other within a distance of less than 1 m. The machine learning-based face mask and social distance detection applications were developed using the PIC extension toolbox in MIT App Inventor. When any violations are detected, the data is sent to the PPMc4, which then activates a buzzer, sounding an alarm. Simultaneously, the data is sent to cloud platforms for further analysis and information storage. The HSMS prototype mounted on MAROH is shown in Fig. 7.

Figure 8(a) illustrates the developed machine learning-based facial mask detection (MLFMD) application software running on an Android phone with a built-in camera. MLFMD employs transfer learning, a type of machine learning in which a model previously trained on one task is utilized again as the basis for training a model on a new task. The image classifier was trained using a dataset comprising two distinct classes, namely Mask and NoMask. Each class consisted of 300 photographs of people wearing masks and others who were not wearing masks. The trained model was then integrated into the MLFMD app developed with MIT App Inventor. During testing, MAROH captures image or video feeds while holding the smartphone, and the MLFMD program detects whether the individual standing in front of the robot is wearing facial mask. When the system identifies no trace of a face mask in a person with a classification confidence score of greater than 60%, it sends a high-level signal to field 7 of the ThingSpeak cloud channel. The buzzer is activated when the PPMc3 microcontroller reads a high-level notification signal from ThingSpeak cloud field 7 for failure to meet the health safety guidelines.

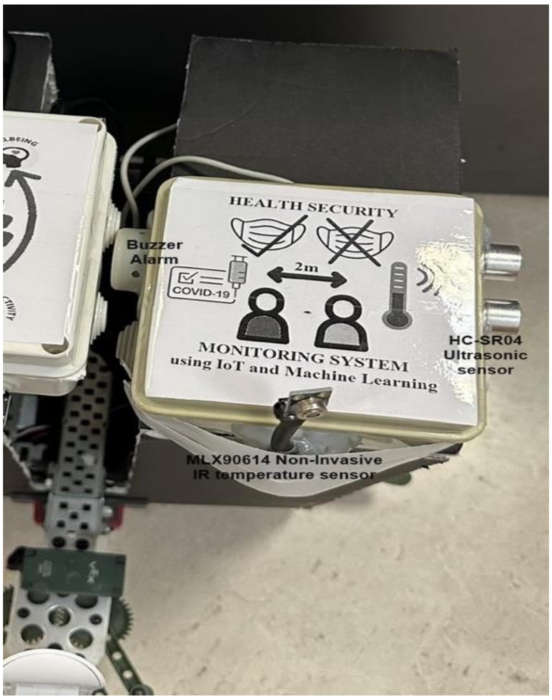


Fig. 7. HSMS prototype mounted on top of MAROH

(a) (b)

Fig. 8 Machine Learning-based (a) Facial Mask Detection and (b) Social Distance Detection App Mobile Applications

The social distancing identification sub-module (SDIS) of the HSMS was achieved through the utilization of transfer learning and sensor-based technology. To train the image classifier that assesses the presence or absence of a person in front of the robot, a dataset with two unique classes was employed. Each class contains 300 samples. As shown in Fig. 8(b), the trained model was then uploaded into the machine learning-based social distance detection (MLSDD) application developed with MIT App Inventor. When the MLSDD app on an Android phone detects a video feed of a person in front of MAROH and the ultrasonic sensor in front of the robot reads less than 35 cm between the robot and the person P1, PPMc3 sends a 3.3V signal to the Vex-CMc, causing MAROH to move 50 cm to the right. When another person P2 on the right is identified in front of MAROH captured by the camera and the ultrasonic sensor's second reading is less than 35cm, the PPMc3 sends a high-level notification signal to field 8 of the ThingSpeak cloud channel and activates the buzzer alarm for failure to follow the social distancing protocol. When no individual P2 is seen on the right side, PPMc3 transmits a 3.3V signal to the Vex-CMc, instructing the robot to return to its original location. Subsequently, the process for detecting social distancing is repeated, with PPMc3 instructing the robot to shift to the left by 50 cm.

D. Development of the Android-based Mobile Application for a Menu-driven User-Robot Interface and Data Visualization

Fig. 9 presents the Menu-Driven User-Robot Interface Mobile Application developed using MIT App Inventor specifically designed for Android smartphones. This application enables users to choose and initiate various robotic operations. The user can choose one of the following robot tasks presented in Table I at a time. Fig. 10 shows the navigation console, from which the user can choose the room to which the robot will travel and do the tasks for operations 2 to 5. The mobile application transmits a series of three binary digits, specifically B0, B1 and B2, to the ThingSpeak cloud in response to a selected robotic operation initiated by pressing the corresponding button. The PPMc1 reads three data bits from the ThingSpeak cloud and subsequently passes the control signals to the Vex-CMc. These signal prompts the microcontroller to initiate the necessary actions to drive MAROH and execute the assigned task. The mobile application sends a set of three binary digits, namely R0, R1 and R2, to the ThingSpeak cloud platform for each chosen room in order to facilitate the delivery and monitoring tasks of the robots. This transmission is initiated by clicking the corresponding button, as presented in Table II. The PPMc1 obtains the three bits from the cloud and transfers them to the Vex-C, instructing the MAROH system to travel to the selected room.

Fig. 9. Menu-Driven User-Robot Interface Mobile Application

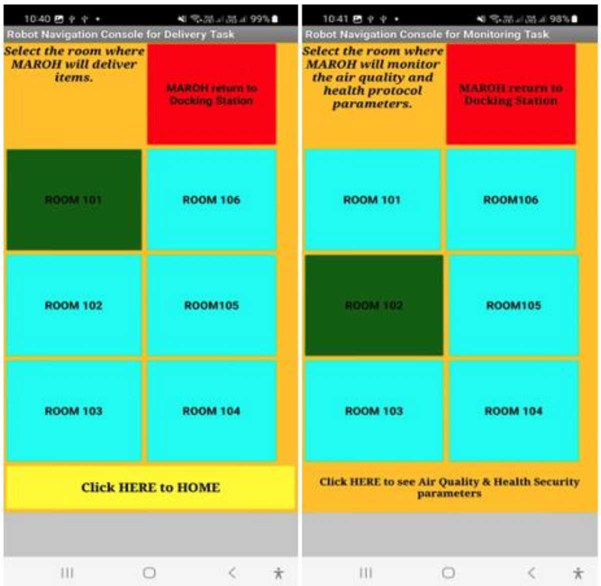


Fig. 10. Robot Navigation Console

TABLE I: MENU OPTION FOR ROBOTIC OPERATIONS AND THE THREE BITS SENT BY THE MOBILE APP TO THE THINGSPEAK CLOUD FOR EVERY TASK

Menu Option	Robotic Operation	B2	B1	B0
1	Monitor the battery levels of robots and the lighting conditions in rooms	0	0	1
2	Monitor the indoor air quality metrics	0	1	0
3	Monitor compliance with health security and safety protocols	0	1	1
4	Provide room delivery services	1	0	0
5	Perform sanitation and trash collection services	1	1	0

TABLE II: ROBOT ROOM NAVIGATION TASK AND THE THREE BITS SENT BY THE MOBILE APP TO THE THINGSPEAK CLOUD FOR EACH ROOM SELECTED

Room to Navigate (Docking Station at the entrance hall of the EE bldg. to selected room)	R2	R1	R0
Docking Station	0	0	0
RM101	0	0	1
RM102	0	1	0
RM103	0	1	1
RM104	1	0	0
RM105	1	0	1
RM106	1	1	0

E. Design and Installation of Solar-powered Charging Station and Battering Monitoring Module for the Robots

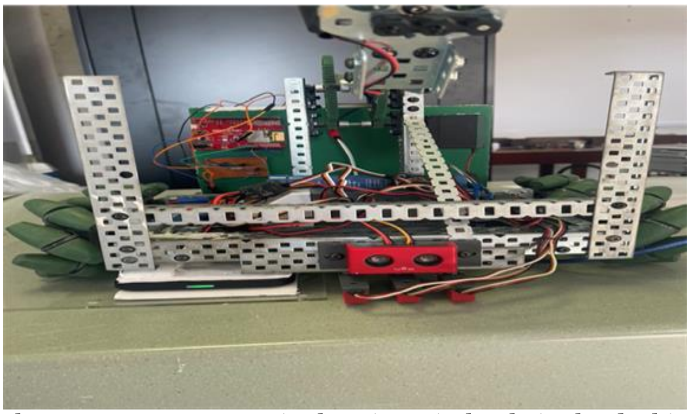


Fig. 11. The MAROH prototype is charging wirelessly in the docking station

TABLE III: COMPONENT SPECIFICATIONS FOR THE SOLAR-POWERED CHARGING STATION

Solar Panel	Charge Controller	Inverter	Battery
1 unit of 300W solar panel Total capacity = 300 watts	1 unit, 30-Amp rating	1500 W capacity	8800/24 =366.6 AH 366.6 AH / 200 AH =1.833 2 units of 200 AH DEEP Cycle Batteries

The photovoltaic effect is used by the solar panel to transform the sun's light energy into electrical energy. A solar charge controller is utilized to avoid overcharging of solar batteries and to determine their status of full charge. The controller regulates the flow of electricity from the solar panels, adjusting it as needed to decrease or stop the transfer of charge to the batteries. The batteries store potential energy and provide electrical power when needed. The inverter converts the direct current (DC) electricity from the batteries to alternating current (AC). The robot battery, VEX-C microcontroller (VEX-CMc), and PP microcontroller are the three essential components powered by batteries. The inverter's alternating current power drives the actuators which regulate the indoor air quality index. Table III shows the component parameters for the solar-powered charging station, which were calculated to meet the 1.6K W-hr load requirement. Fig. 11 illustrates the robot charging wirelessly at the docking station.

The voltage level (Rbatt) of the robot battery is monitored to determine its status. A voltage divider circuit was designed to split the Rbatt in half, ensuring that it matched the PP microprocessor's necessary 3.3 V input value. The PP microcontroller reads and processes the divided voltage before storing the value in the cloud platforms. When the Rbatt falls below 8.0, the robot returns to the solar charging station to be recharged. The robot's battery is charged wirelessly, with the solar station's direct current (DC) output connected to a wireless charging pad. The wireless charger adaptor, also known as the receiver, is connected to the robot's battery to facilitate the charging process. Power is transmitted via electromagnetic induction between the wireless charger and the wirelessly charging device.

III.RESULTS AND DISCUSSION

A. Multi-encoder Mecanum-wheeled Autonomous Robot for Hotel and Other Hospitality Facilities (MAROH) Trial Results

The MAROH prototype was subjected to testing in specifically designated rooms situated within the Electrical Engineering (EE) building of the UTAS-Al Musanna campus. The rooms were set up to simulate the operational environment found in hotels and other hospitality-related establishments. A total of twenty (20) trials were carried out for each route to evaluate the robot's speed and precision in reaching the specified rooms selected using the mobile application program. Table IV presents the average responses of MAROH, with a mean speed of 0.407 m/s and a reliability rate of 95.0%. The utilization of mecanum wheels in MAROH allowed omnidirectional movement, enabling it to accomplish tasks without the need for a predefined black-line path. The robot successfully completed its route from the entrance hall of the EE building to and from room RM101. It covered a distance of 25 m in a mean time of 75.34 s, resulting in an average velocity of 0.332 m/s. The performance of the robot was characterized by a reliability rate of 100%. In the case of route 2, the robot successfully maneuvered from the EE building's entrance hall to RM102 and back within an average duration of 125.48 s. The route involved traveling a total distance of 53 m, resulting in a mean velocity of 0.422 m/s. The robot successfully completed the designated route in nineteen out of twenty attempts, yielding a 95% success rate. According to Table IV, the MAROH traveled 83 meters from the EE entry hall to RM103 and back in 177.72 s, resulting in an average speed of 0.467 m/s and a reliability level of 90%. In the case of routes 2 and 3, the robot experienced a failure rate of 5% to 10% due to the instability of the Wi-Fi signal. This instability resulted in delays for the PPMc1 module to retrieve three-bit data from the ThingSpeak cloud and transmit control signals to the Vex-C microcontroller for each robotic operation. Also, it was observed that the robotic system exhibited a decrease in speed when tasked with transporting objects weighing more than 1 kg from one area to another. Based on the Fig. 12, the voltage reading of the Light Dependent Resistor (LDR) during testing was recorded as 0.8 V. This value indicates the rooms and halls had an adequate amount of light, enabling the robot to navigate its path properly. As shown in Fig. 13, MAROH was able to accomplish the user-selected job of sanitation, health protocol monitoring, and food delivery.

TABLE IV: THE AVERAGE RESPONSE OF MAROH

Destination (EE building entrance hall to and from the selected room)	**Distance covered (m)**	**Mean travel time (s)**	**Mean Speed (m/s)**	**Reliability (%)**
Room 101	25 m	75.34 s	0.332 m/s	100%
Room 102	53 m	125.48 s	0.422 m/s	95%
Room 103	83 m	177.72 s	0.467 m/s	90%

Fig. 12. LDR voltage reading seen in the ThingSpeak cloud and Mobile App

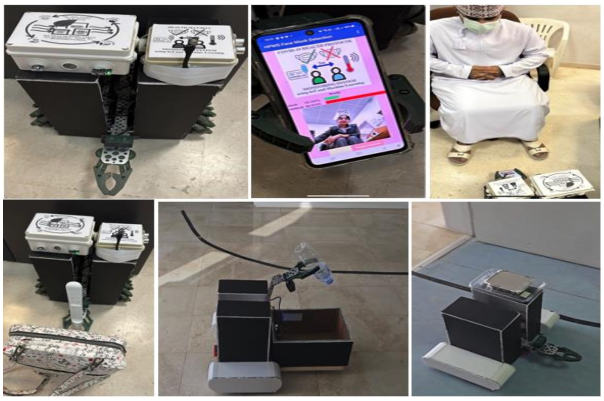


Fig. 13. MAROH performing air quality monitoring, health security checking, sanitation, and food delivery services

B. Test Results of the IAOMS and IAQCS

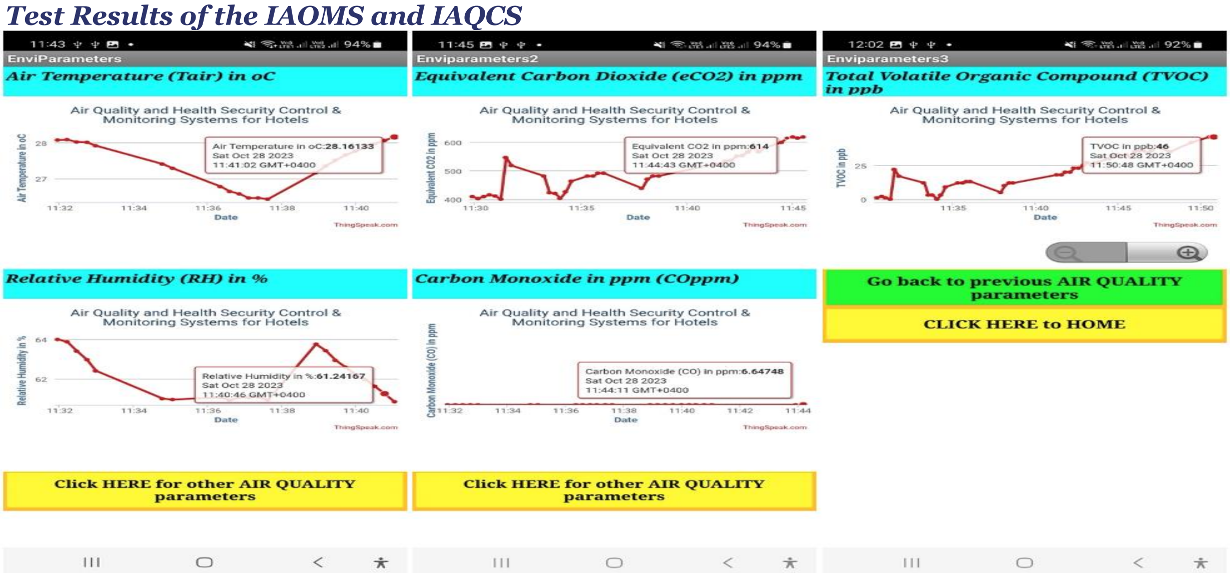


Fig. 14. Sample output of the IAQMS taken from Room101 seen in the ThingSpeak cloud and Mobile App

Fig. 15. State of each actuator displayed in the cloud platform based on the air quality parameters measured in Room101

Figs. 14 and 15 show the IAQMS and IAQCS sample test results respectively. Before conducting the tests, the sensors employed in the IQAMS prototype were subjected to calibration using commercially accessible equipment designed for monitoring indoor ambient characteristics. Because the ambient temperature in Room 101 was 28.16oC at the time of testing, which was outside the permitted limit, the actuator CF was activated. Since the RH value was 61.24%, which was higher than the allowable threshold, the EF was switched on while AH and AP were turned off. RH and Tair levels, as described by [3], [16] and [22], should be controlled should be controlled because they create ideal conditions for the continued survival of the SARS-CoV-2 and COVID-19 viruses. Furthermore, increased RH levels have been found to cause discomfort in humans while simultaneously creating a conducive environment for mold and fungal growth and survival [3],[13]. These microorganisms possess the capability to trigger various respiratory diseases when present on surfaces under such conditions [3],[13]. The eCO_2 and COppm concentrations in Room 101 were both within the acceptable range for indoor environments at 614 ppm and 6.65 ppm, respectively. The TVOC level detected was 46 ppb, which is within the allowable threshold. Because CO_2 and CO gasses may function as a transport medium for virus particles, they must be kept within their normal range for health safety [3], [13], [21].

C. Test Findings of the Health Security Monitoring System

Fig. 16 illustrates a sample of MLFMD app result with a confidence level of 84.91% for NoMask class, indicating the degree of certainty that a person is not wearing or is wearing a face mask incorrectly. When the face mask protocol was violated, a warning signal was sent to the ThingSpeak cloud, and the buzzer was activated by PPMc4 to alert the health and safety officer. A total of one hundred test trials were done using the MLFMD application in order to assess its accuracy in distinguishing between individuals wearing and not wearing facial masks. Among the 100 test samples, 40 individuals who wore masks were correctly identified, while 56 individuals without masks were accurately identified. However, in two cases, individuals were recognized as using face coverings but their masks had been placed incorrectly, covering only their mouths. As a result, these individuals should be classified as having no masks. Furthermore, two people were mistakenly recognized as not putting on masks when, in fact, they were. This misidentification occurred due to the poor video image captured by the robot while in motion and in a room with low illumination. The confusion matrix for the MLMD is shown in Table V. Based on the obtained findings, the accuracy of the developed MLFMD app was determined to be 96%. The obtained results demonstrate a better level of accuracy compared to the results presented in [3]. This improvement can be attributed to the MLFMD model being trained with a larger number of images per class in the dataset.

Fig. 17 shows the measured Tbody of the HSMS prototype, which was 36.2 °C. This body temperature falls inside the normal range. The fever warning was switched off because the Tbody was within permissible levels. Based on Table VI, during test run 1 of the social distance identification sub-module (SIDS), the ultrasonic sensor installed on MAROH measured a 30 cm distance between the robot and person P1. The MLSDD app also detected that a person was in front of the robot. When the robot moved to the right by 0.5 m, the ultrasonic sensor read a 28 cm distance between the robot and another person P2, and this person was also detected by the MLSDD app. Individuals P1 and P2 did not adhere to the prescribed social distance guidelines based on the measured and analyzed outputs. As a result, PPMc4 issued the social distancing warning signal, as seen in Fig. 17, encouraging people to keep a safe distance from one another. A total of twenty trials were done with the SIDS to assess its accuracy in recognizing individuals who maintain a minimum safe distance of 1 m. The system failed to detect four cases of noncompliance with social distancing guidelines out of a total of 20 test runs. These failures can be attributed to the existence of motion artifacts and poor video capture quality, especially when the robot shifts position while holding the phone. Furthermore, the algorithm used to detect social distance violations is currently limited to a range of 0.5 to 1 m, which can be improved in the future phase of the project. Based on the test results, the accuracy of the developed SDIS was determined to be 80%.

TABLE V: CONFUSION MATRIX FOR THE MLFMD

		MLFMD prediction	
		Mask	**No Mask**
Actual Inspecti	**Mask**	40	2
	No Mask	2	56

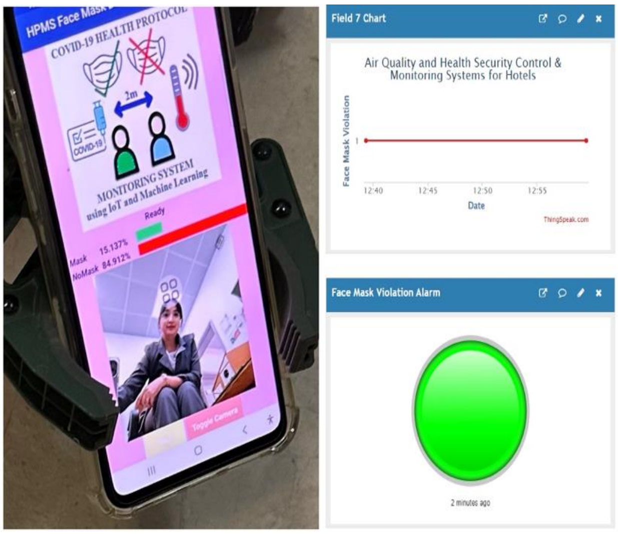


Fig. 16. Sample Result of the MLFMD app and the Health Security parameters seen in the ThingSpeak cloud

D. Test results of the Solar-powered Charging Station and Battering Monitoring Module for the Robots

Fig. 18(a) depicts the solar battery's voltage rating, which was 24 V when tested with a DC voltmeter. The charge controller reading of 23.9 V in Fig. 18(b) is crucial in regulating the system's overall output DC voltage. It maintains the voltage supplied to the load or battery within the specified range and protects the system from overcharging or discharging. The output of the robot battery monitoring system is shown in Fig. 19, with a Rbatt value of 7.97 V. At the time of testing, this value indicated the actual voltage level of the robot's battery. Because the Rbatt measurement was less than 8 V, the robot was parked at the charging dock, as illustrated in Fig. 11.

Table VI: Sample Outputs of the social distancing identification sub-module (SDIS)

Test Run	**HSMS MLSDD App Output at the initial location D1 1 = A person is detected in front of the robot 0 = No person is detected in front of the robot**	**Ultrasonic Sensor distance measurement at initial location D1**	**Ultrasonic Sensor distance measurement At location D2 D2 = D1 + 50cm to right**	**HSMS MLSDD App Output at location D2 1 = A person is detected in front of the robot 0 = No person is detected in front of the robot**	**Social Distancing Violation**	**Buzzer Alarm Status**
1	1	30 cm	28 cm	1	1	ON
2	1	29 cm	34 cm	0	0	OFF
3	0	36 cm	36 cm	0	0	OFF

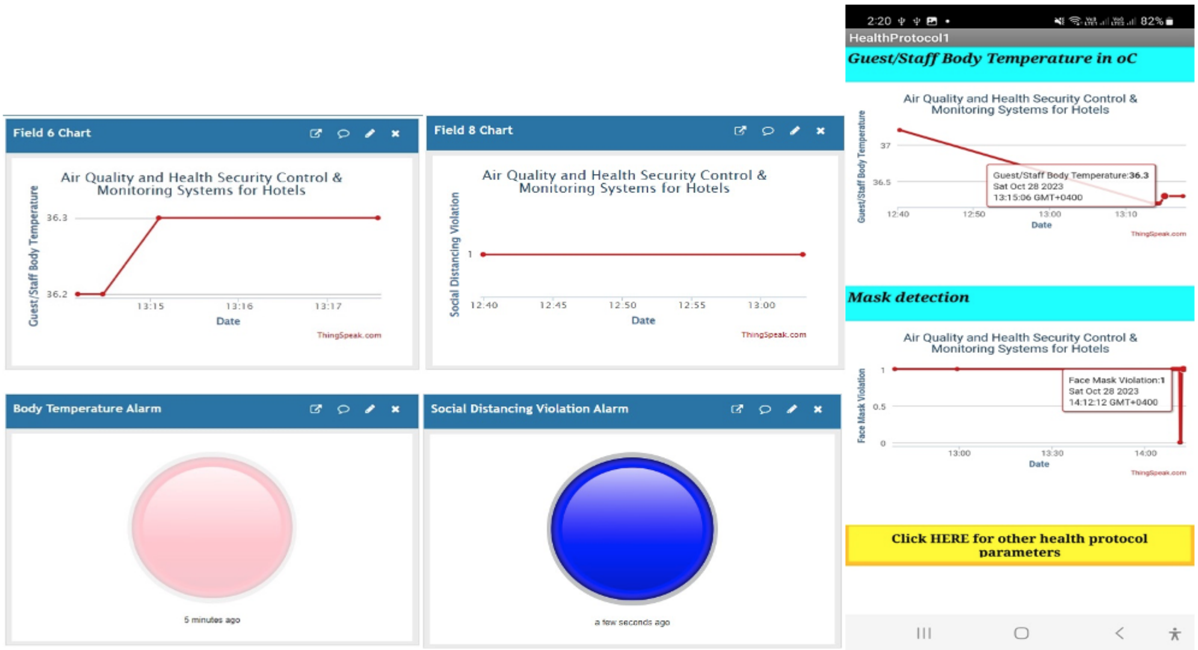


Fig. 17. Sample Results of the HSMS as seen in the developed mobile app and ThingSpeak cloud

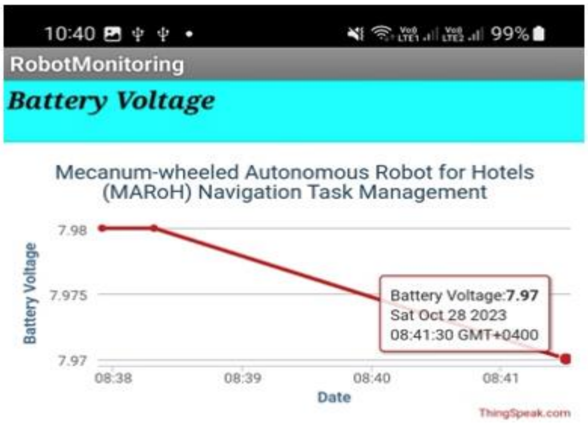


Fig. 18. (a) Solar battery output voltage and (b) Solar charge controller voltage

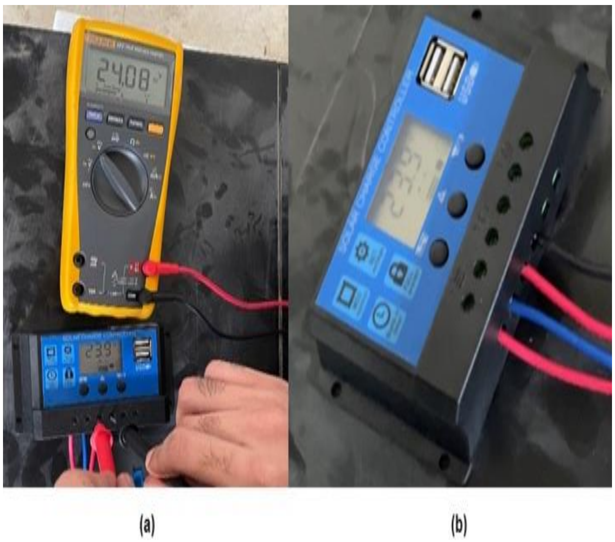


Fig. 19. Sample output of the IoT-based battery sub-module

IV. CONCLUSION

In conclusion, the project successfully investigated and implemented the integration of robotics and IoT for air quality and health security monitoring. By merging Machine Learning, IoT, and sensor technologies, the research improved the robot's capability to recognize the presence and absence of face masks, as well as the social distance between persons. The combined usage of the Particle and ThingSpeak Cloud services aided in the gathering, storage, and analysis of data related to air quality, body temperature, and other relevant health security indicators. The project used actuators operated remotely by an IoT-enabled Particle Photon microcontroller to ensure clean air and improve people's comfort in indoor facilities. This configuration allowed the system to respond to environmental variables dynamically and alter air quality as needed.

MAROH, the designed and programmed robot, performed several activities with minimal human intervention to ensure that guests and personnel in hospitality facilities were in a healthy and safe environment. The robotic system played an essential role in enforcing health and safety guidelines, minimizing the danger of spreading viral infections. Using a menu-driven user-robot interface mobile application, MAROH can be directed to clean and disinfect rooms, collect garbage, and sanitize things, reducing employee workload and lowering the risk of contamination. MAROH can also be instructed by the user to navigate the property and deliver things to specific locations, increasing overall customer satisfaction. Furthermore, the usage of the solar-powered wireless charging station resulted in a cost-effective method of powering the robot and its components. MAROH, on the other hand, should not be viewed as a replacement for hotel and other hospitality facility staff, but rather as supplemental resources to assist and support them in enhancing Oman's tourism services.

As a recommendation for future research, a ruled-based or AI-based decision support system may be integrated into the existing framework to predict health risks induced by air quality metrics. To further increase the accuracy of the MLFMD and MLSDD, it is recommended to expand the training datasets with a larger number of samples. It is also suggested that a robust robotic system equipped with a faster processor be designed for practical deployment to increase the robot's responsiveness, reliability, and ability to carry heavy loads. Furthermore, employing voice commands to manage the robot's operation can increase its interaction with the user.

Conflict of Interest

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

A. M. Nagayo initiated the study, designed and implemented the IAQMS, IAQCS, HSMS, SDIS, MLFMD and MLSDD modules, and wrote the manuscript before submission; A. M. Nagayo, A. S. Al Quatiti and A. G. Al Hadid developed and programmed the robotic system and the user-robot interface mobile application; M. Z. Al Ajmi and M.S Al Farsi designed and implemented the solar charging station and battery monitoring module; A. M. Nagayo and M. Z. Al Ajmi revised the manuscript and prepared it for submission; All authors had approved the final version.

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