Journal of Human Centered Technology

https://www.humentech.utm.my E-ISSN: 2821-3467

Development of an Advanced Robotic System with Line Tracking and Sanitization in Healthcare Industry

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Cite: https://doi.org/10.11113/humentech.v3n1.61 Research Article

Abstract:
COVID-19 is highly transmittable, especially for frontline healthcare workers. Far-UVC light at 222 nm wavelength effectively inactivates the virus and is safe for human skin and eyes. To reduce the contact between healthcare workers and infected patients while sanitizing the area, this work introduces UVood, an advanced robotic system with automated line tracking and sanitizer to enhance the safety of frontline healthcare workers during the COVID-19 pandemic. Utilizing far-UVC light, the system achieves effective sanitization without harm to humans. Controlled by an Arduino Mega microcontroller and incorporating infrared (IR) and passive infrared (PIR) sensors, UVood allows precise navigation and continuous disinfection. This prototype also integrates a touchscreen as a user interface for user control. Through the functionality verification, the developed proof-of-concept prototype has successfully demonstrated its great potential in healthcare automation and infection prevention.

Keywords: COVID-19; Food distributor; Motion detection; User input; UVC-F light; Sanitization

1. INTRODUCTION

The coronavirus disease (COVID-19) is a highly transmittable and pathogenic viral infection that leads to the loss of human life worldwide. According to the Occupational Safety and Health Administration (OSHA) (1), frontline healthcare workers are at higher risk of getting COVID-19 infection as they are considered a high-exposure group to COVID-19, especially for those working in an inpatient setting. This is because the virus can be spread through close contact with the infected patient, through the inhalation of contaminated air that is exhaled by infected people. Consequently, there is a possibility that healthcare workers get an infection when they distribute medical supplies or food to the infected patient. Besides, research conducted by Nguyen et al. (2) has also supported the fact, stated that the percentage of frontline healthcare workers getting positive for COVID-19 is 1.1%, which is considered high compared to the general community, which only has 0.2%.

Ultraviolet-C (UVC or UV-C) radiation has been known to effectively reduce the spread of bacteria for decades. It has also been proven to destroy the outer protein coating of SARS-CoV and inactivate it. Far-UVC light is a type of UVC with a 222 nm wavelength that is also able to inactivate SARS-CoV. It inactivates 99.9% of the airborne human coronavirus with a low dose of 1.2 to 1.7 mJ/cm^2 (3). This type of UVC is safe for human skin and eyes because far-UVC does not penetrate the skin layer and cause tissue damage (4). It is also environmentally friendly, as it does not leave any residue after use.

As a result, many advanced robotic systems have been developed based on the far-UVC technique. However, most of the current disinfection robots used in hospitals apply UV-C radiation with a 254 nm wavelength. For example, the UVD Robots ApS (5) and Tru-D SmartUVC (6). This kind of UVC radiation is inconvenient, as it cannot be used to disinfect the hospital area at any time. It can only be used in unoccupied spaces because direct exposure to this UV-C radiation is harmful to humans, such as causing injury to the eyes and skin (7). Therefore, the robot is equipped with a sensor to detect people and will stop disinfection if someone enters the room. On the other hand, these existing robots still have their advantages as the UVD Robots ApS and Tru-D SmartUVC can record the parameters of the disinfection process automatically. The detailed disinfection reports provide quality assurance and also the validation of the disinfection process (8, 9).

An advanced robotic system refers to a sophisticated and highly developed technology that combines artificial intelligence, machine learning, and automation to perform complex tasks with precision and efficiency. These systems are designed to mimic human behavior and possess the ability to adapt and learn from their environment. Contemporary

Received 03 July 2023; Accepted 16 December 2023
Available online 06 February 2024

developments in robotics and autonomous systems are presently being applied across various domains, including but not limited to search and rescue operations, industrial automation, domestic services, and healthcare. These sophisticated systems are engineered to address tasks within environments characterized by challenges, labor-intensive requirements, and potential hazards (10).

Autonomous robotic systems, commonly known for their advanced capabilities to operate independently in diverse environments, are composed of key components such as locomotion, kinematics, perception, Simultaneous Localization and Mapping (SLAM), and navigation. Locomotion and kinematics are integral for navigating various surfaces and managing diverse models, while perception involves understanding the surroundings through sensors and computer vision. SLAM handles simultaneous mapping and localization, mapping areas for the robot's traversal and determining its pose within the map. Finally, navigation utilizes this information to make decisions and execute tasks based on the robot's designated objectives (11).

Therefore, this study aims to improve the existing applications that can ensure the safety of both healthcare workers and patients by making an automated distributor with sanitizer that can help the healthcare workers distribute food or other needs to the patients and also sanitize the area around them at the same time. The sanitizer robot in this study can also be improved by referring to the existing robots (9-11).

2. METHODOLOGY

The automated distributor with a sanitizer robot, or UVood, is a device designed to assist healthcare workers in delivering food or necessary items to patients while simultaneously sanitizing the surrounding area. The device utilizes an Arduino Mega microcontroller as the master controller to control the device movement and perform sanitization functions. To enable the distributor to navigate, infrared (IR) sensors are employed to detect the designated path. The direction of the distributor is determined through user input on a touchscreen interface. For sanitization purposes, a UVC-F LED is constantly activated, emitting UVC-F light, except when a person is detected nearby by the PIR sensor, which prompts it to turn off. Figure 1 below shows the top-level architecture of the system, which consists of the user interface, sensors, motherboard, and output of the system.

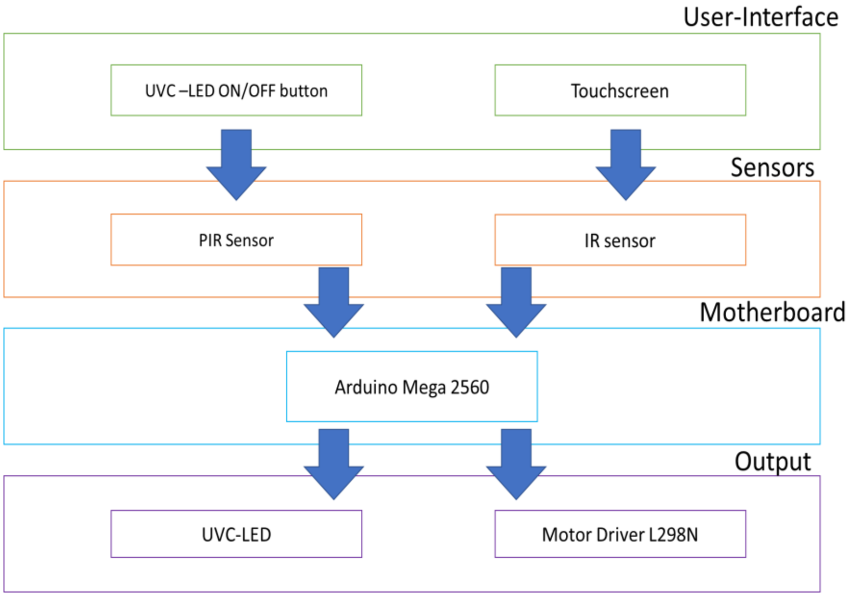

Figure 1. Top level architecture.

Figure 2 shows the top-level workflow of the device system, which consists of the touchscreen system for controlling the motor of the robot, the PIR motion sensor detection for controlling UVC-F LED, and the IR sensor for line detection. The details of the touchscreen based on user inputs and motor driver, as well as the operation of the PIR sensor and UVC-F LED will be discussed in subsections 2.2 and 2.3, respectively.

2.1 Hardware Circuit Design

Figure 3 shows the schematic diagram of all the related parts of this prototype. This project makes use of several important components, including an Arduino Mega as the master controller, two DC Servo motors with wheels for the device movement, a PIR sensor for object detection, two IR sensors for path detection, and a UVC-L LED for sanitization.

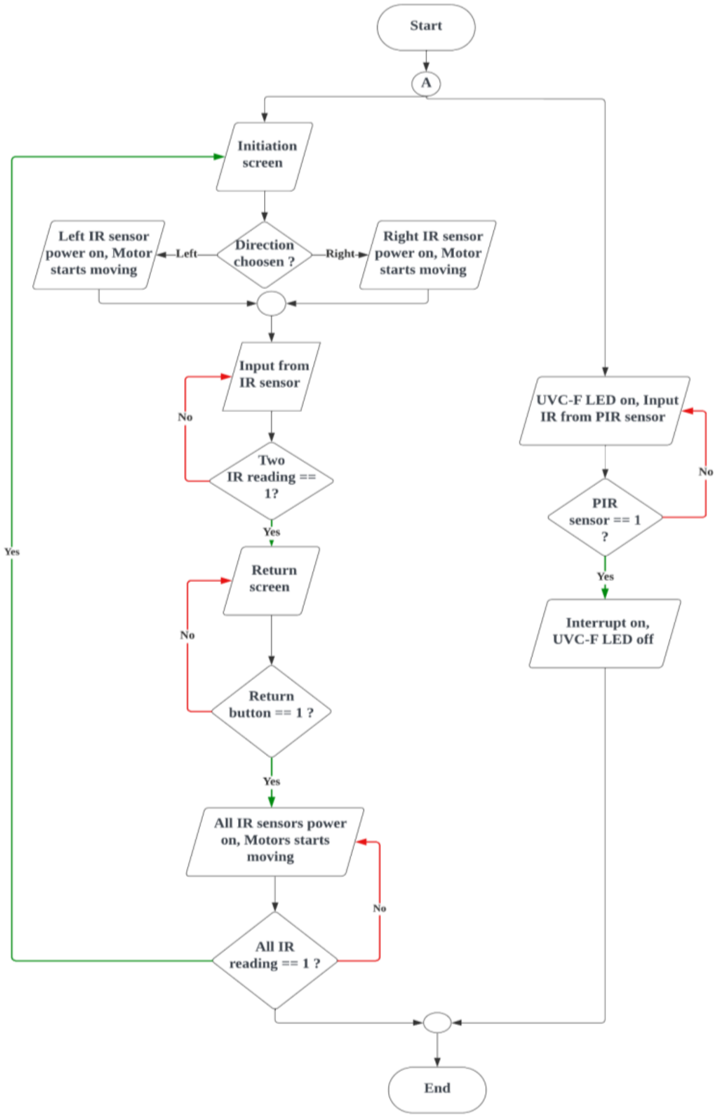

Figure 2. Flowchart of UVood system.

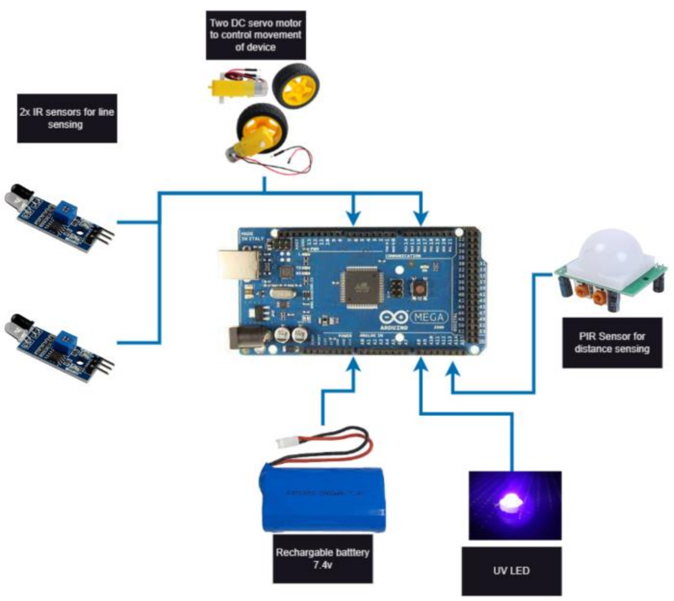

Figure 3. Schematic diagram of components.

2.2 Analog Sensor Design and Development

Figure 4 illustrates the process flow of the system using the touch screen and the Motor Driver L298N. The Arduino Mega functions as a conduit for communication between the touchscreen and the Motor Driver L298N. The touchscreen sends touch input signals to the microcontroller, which then processes those signals. Based on this input, the microcontroller will create control signals to indicate how the anticipated motor movement should occur. After this, the control signals are interpreted by the Motor Driver L298N which then supplies the required current and voltage to the motors to create the desired movement.

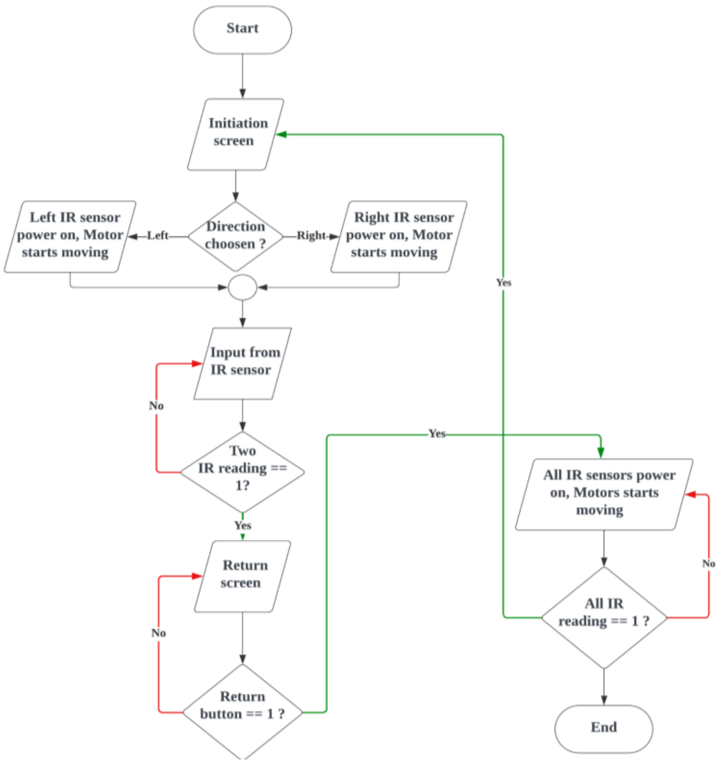

Figure 4. Low level system flowchart of touchscreen and motor driver L298N.

2.3 Digital Processing Design and Development

Figure 5 shows the system flowchart of the PIR motion sensor. For the sanitization purpose, the interrupt function of UVC-F LED was utilized, where the output pin of the PIR is connected to the Interrupt pin. Initially, the state is set to low, where the LED will be lit up constantly. When the PIR sends a reading to the interrupt pin, it will set the state to HIGH, which will turn off the LED. When the PIR stops receiving any movement, it will return to its normal state.

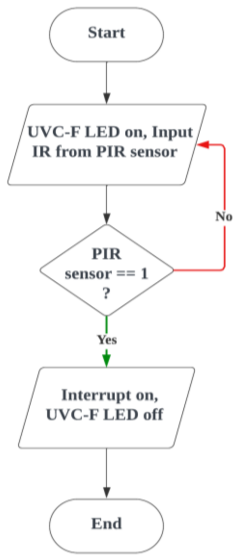

Figure 5. Low level system flowchart of PIR sensor and UVC-F LED.

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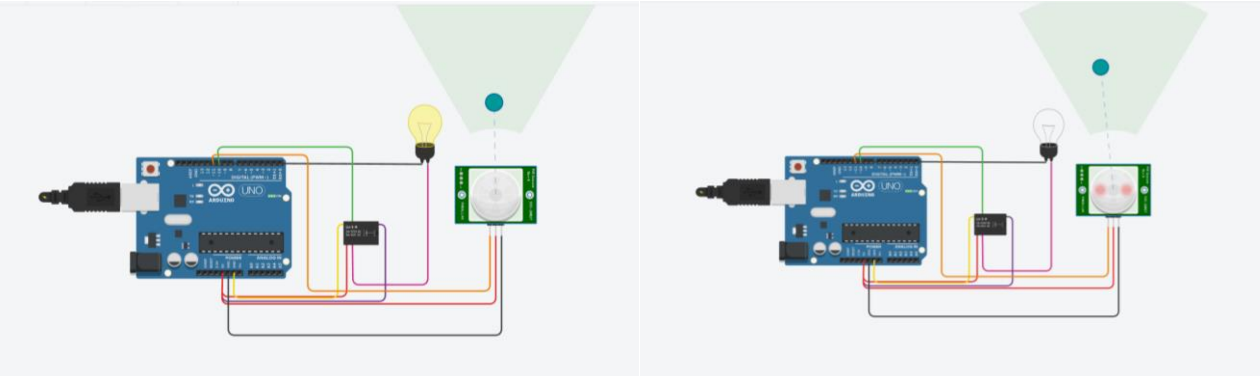
3. RESULTS AND DISCUSSION

The final prototype of this project includes a PIR sensor, UVC-F LED, and microcontroller that is supported by a touch screen for control and monitoring. The functionality of the UVC-F light assisted by the PIR sensor is demonstrated in Figures 6 and 7.



(a) (b)

Figure 6. (a) UVC-F LED is always turned ON when there is no motion detected and (b) in the range of 5m, the UVC-F LED will turn OFF when there is motion detected.

The UVC-F light remains on when the PIR sensor is in the LOW state, ensuring continuous sanitization of the device's path. However, when motion is detected within a 5-meter range, the PIR sensor switches to the HIGH state, causing the UVC-F light to turn off. Figure 7 depicts the device's path determination through the IR sensor's detection of a black color line. User interaction via the touchscreen, such as pressing the Left button, directs the device along the predefined path, while the Return button prompts the IR sensor to guide the device back to its initial position.

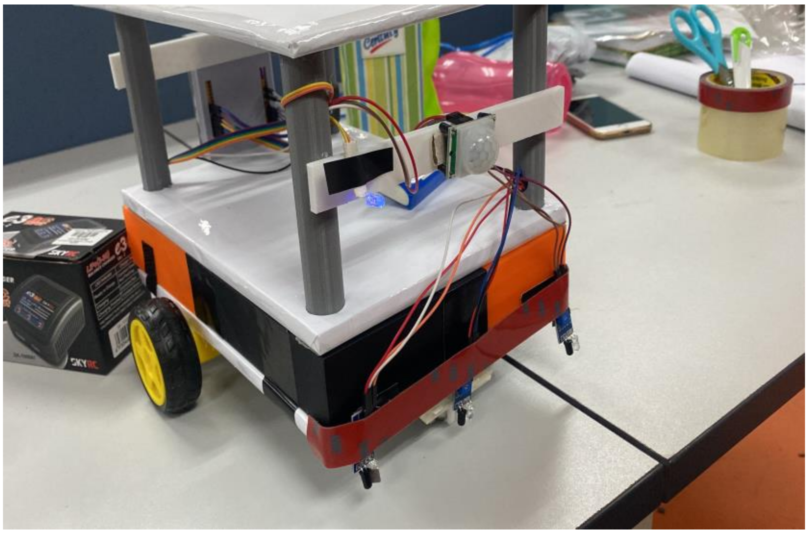
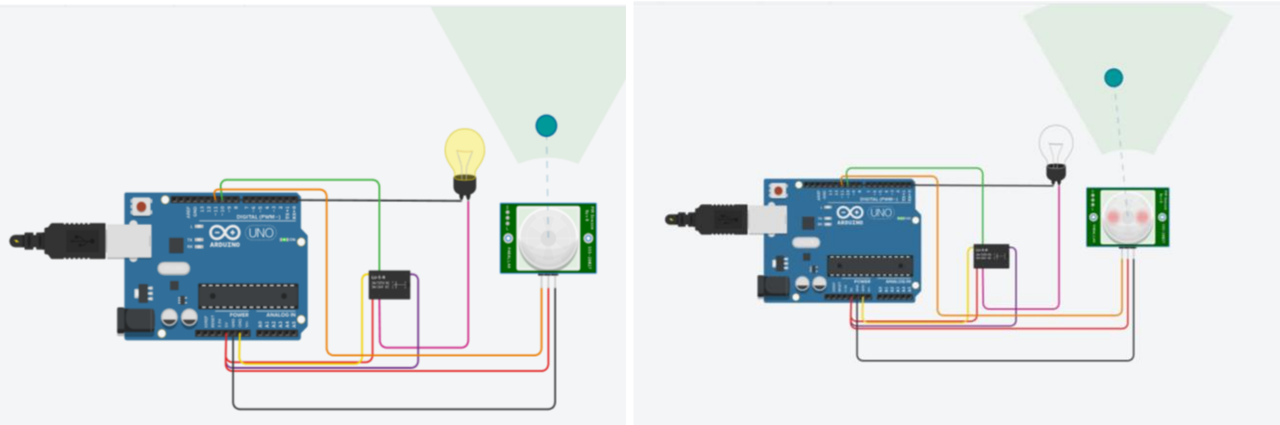


Figure 7. IR sensor that is placed in front to detect the path.

In terms of performance analysis, key aspects to consider and observe are the PIR sensor, UVC-F LED, and IR sensors. The distributor operates in a semi-autonomous manner, utilizing the touchscreen to set the path and relying on the IR sensors for guidance. For autonomous sanitization, the distributor autonomously utilizes the PIR sensor. Thus, the IR and PIR sensors play vital roles in executing their programmed tasks effectively.

3.1 Functional of the PIR Motion Sensor Controlling the UVC-F LED

The UVC-F LED was initially programmed to be always on except when there are at least two conditions which are; an object within the range of detection and the obstacle must be in motion. When these two conditions apply, the UVC-F LED will turn OFF. The range of 5m is the area that the UVC-F LED will detect if there's a motion of an obstacle, and when detected, the UVC-F LED will immediately turn off. However, when there is no motion detected under the range of 5m, the UVC-F LED will always be ON as the PIR's sensitivities lie in this range, and it will always be in the LOW state. Figures 8 and 9 show the simulation of the UVC-F LED. When there's a detected motion of an object, it will turn off; otherwise, it will always be ON when there is no motion of an object detected in the range of 5 m.



(b) (b)

Figure 8. UVC-F LED will always turn ON but it will turn OFF when there is any motion detected in the range of 5m.

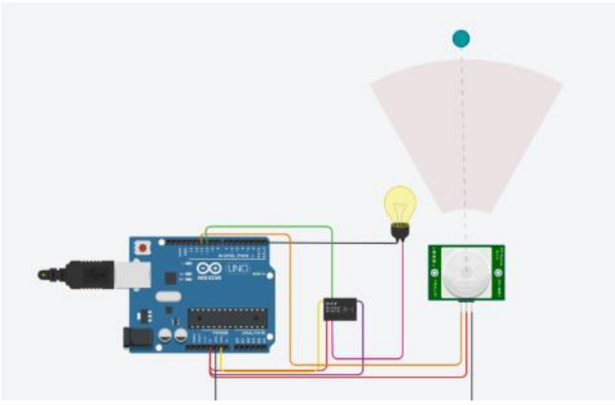


Figure 9. UVC-F LED will always be ON unless the 2 conditions were fulfilled within the range of 5m.

3.2 Functionality of the Touchscreen Controlling the Motor

The integration of infrared (IR) sensors into autonomous robotic systems has revolutionized automation, providing a sophisticated means of enhancing functionality through the seamless detection of infrared radiation. These sensors play a pivotal role in automating diverse robot functions, including proximity sensing, object detection, and obstacle avoidance. By emitting and measuring infrared light, these sensors effectively discern the presence or absence of objects within their surroundings. The control system will process the incoming signals, empowering it to make real-time decisions and execute precise actions.

In this project, IR sensors are used to make the detection of the black line, which helps to expedite the distribution process. Once the sensor determines that the line is present, it drives the servo motors to steer to specific directions accordingly. When the "Left" button is pressed, just the IR sensor on the left side of the device will become active, which will cause the motors to begin spinning. Just as when you press the Left button, pressing the Right button will only activate the IR sensor on the right, which will cause the motor to move the device in that particular direction. Figure 10 presents an illustration of the touchscreen user interface. When the return button is hit, the motors will be triggered to guide the device back to its original position.

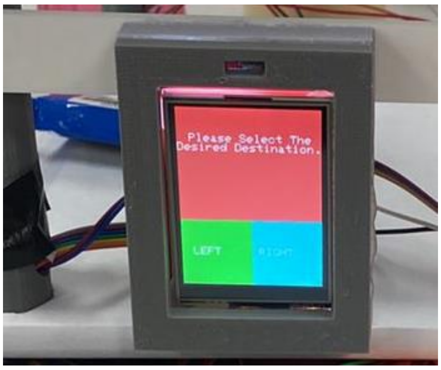


Figure 10. Touchscreen interface showing left/right and return buttons.

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4. CONCLUSION

This paper has presented an automated distributor with sanitizer, which is a self-operating robot that utilizes Arduino Mega microcontroller, IR and PIR sensors, and far-ultraviolet (UVC) sterilization technology. Its purpose is to deliver meals and attend to the requirements of patients. Compared to conventional UVC light, this solution based on far-UVC light has a reduced impact on human skin, reduces the risk of infection, and reduces the likelihood of interaction between patients and healthcare professionals. During prototype development, number of difficulties and challenges has been encountered, such as faulty IR sensors for black line recognition and the requirement for a more powerful battery. Consequently, employing high-level AI programming with powerful sensors for effective navigation is one of the future recommendations for an automated food distributor equipped with a sanitizing robot. Infrared (IR) sensors can also be integrated with motors to provide controlled sensing sites by improving the motors' stability and movement precision. In addition to that, adding hidden speakers and LED strips can also help to increase the levels of interactivity and safety. Last but not least, a mobile app can also be developed and integrated with the developed prototype to wirelessly control the robot control through user smartphones.

ACKNOWLEDGMENT

Thanks to Department of Biomedical Engineering & Health Sciences, Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM) for the provided laboratory facilities.

CONFLICT OF INTEREST

The authors have no conflict of interest.

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