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Contactless logging and disinfection solution with automated face mask detection

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ABSTRACT

Coronavirus disease-19 (COVID-19) mitigation includes health screening procedures at entrances of public and private establishments. Conventional methods include manual operations on temperature and face mask checking, personal identification, and hand disinfection. In this paper, a gateway kiosk is designed by integrating and automating the primary screening procedures. It uses radio-frequency identification (RFID) for contactless access control and attendance, with an infrared thermometer for body temperature monitoring. Face mask detection is automated through artificial intelligence (AI), while proximity sensors activate the disinfection system. Internet-of-things (IoT) interfaces these subsystems, and local access is available via an Internet browser. RFID overcomes the slower response rate of the quick response (QR) code-based solution. The repeated-measure analyses showed that the system's thermometer has only +0.28 °C error while its residual neural network-10 (ResNet-10) and MobileNetV2 models for detecting masked faces achieved a 98.2% accuracy. The system reduces the primary key performance indicators–service and queuing times by 56.86% and 79.95%, respectively. Its audio and visual notifications ensure the proper screening implementation, thus reducing unnecessary and risky interactions with entrance personnel. It improves the screening procedures by significantly reducing human interactions and enhancing queuing.

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1. INTRODUCTION

In March 2020, the World Health Organization (WHO) characterized the coronavirus disease-19 (COVID-19) spread as a pandemic, affecting more than 115,094,614 cases in 114 countries with 5,560,995 deaths. The Philippines has over 584,667 confirmed cases and 12,404 deaths as of March 2021 [1]. COVID-19 is from SARS-CoV-2 and represents the causative agent of a potentially fatal disease [2]. Person-to-person transmission occurs primarily via direct contact or droplets spread by coughing or sneezing from an infected individual [3]. Social distancing and disinfection are considered the best ways to reduce the spread of this virus [4].

In most private and public facilities, preventive measures start from the entranceway. An establishment security personnel implement procedures like temperature checking, disinfecting, and logging the persons entering the premises [5]. They typically use handheld thermal scanners to check the temperature without having physical contact. However, it is still risky for them because of the undesired exposure to unfamiliar people. To further ensure the effectiveness of this precaution, the local government unit (LGU) requires every government and commercial establishment to practice logging all the persons entering the vicinity for contact tracing [6]–[8]. They first used a non-digital approach, which used ordinary logbooks or record slips for written data. However, due to its inefficiency and the possibility of surface virus transmission, they later implemented a centralized mobile application and quick response (QR) code systems like E-Salvar and StaySafe, with only the LGU having access to the data for contact tracing. Moreover, wearing face masks and disinfecting became part of the "new normal" for most establishments where alcohol dispensers and disinfecting foot pads are used for sanitizing hands and footwear. However, surface transmission is still a risk factor in manual-operated dispensers [9], [10].

From these perspectives, the researcher focused on designing a smart entrance Kiosk to mitigate the COVID-19 spread. The study aims to develop an open station for entranceways by automating and integrating the primary screening measures. It consists of three subsystems: i) noncontact logging system (NLS) that records the identification and body temperature of the person in a local database; ii) face mask detector (FMD), which is an artificial intelligence (AI)-assisted system that determines if a person is appropriately wearing a face mask, and iii) touchless disinfecting system (TDS) with two sections for the sanitation of hands and objects like bags and packages.

Several existing studies share objectives similar to the developed system. Notably, researchers have developed the smart epidemic tunnel, an internet-of-things (IoT)-based disinfection system [11], [12]. Additionally, studies have explored the disinfection gateway, which incorporates ultraviolet (UV) disinfection [13]–[16]. However, both these systems are chamber-type and lack functionalities such as thermal scanning, face mask detection, and a logging system. Furthermore, various studies have investigated methodologies for face mask detection, including RetinaFaceMask [17]–[20], FMD using Inception-V3 [21]–[23], and SSDMNV2 [24]–[26]. However, these studies focus solely on the design of the FMD service. Similarly, Tang and Hung [27] designed a system centered only on non-contact body temperature measurement and logging.

In contrast, this study presents the design of a multi-functional kiosk that integrates different systems commonly used to mitigate the spread of the highly contagious virus. This integration aims to provide a comprehensive solution. The system utilizes reliable deep-learning models for masked face identification, specifically residual neural network-10 (ResNet-10) and MobileNetV2. The coupled infrared (IR) thermal scanner to the latter establishes a contactless entry process. The system restricts access to individuals without a face mask or those with an elevated body temperature. Furthermore, the kiosk employs an IoT-powered attendance subsystem that utilizes contactless access through radio frequency identification (RFID) technology. It facilitates the creation of a readily accessible database for potential contact tracing purposes. Additionally, the sensor-activated disinfection subsystem enhances the user experience by providing a contactless approach to disinfection. The key innovation of this study lies in the integration of these diverse systems into a single, comprehensive solution. This combined approach aims to significantly reduce the risk of viral transmission within a facility.

As the country is continuously battling against the pandemic, this study would benefit the public by automating the conventional screening measures implemented on government and commercial premises. The Kiosk's computer-assisted features further ensure the safety of the personnel and its clients by minimizing the inevitable face-to-face interactions [28]. Its NLS provides an efficient and secured data recording, including body temperature readings. Using noncontact access control and thermal sensors reduces the time-consuming queue at entrances. Its artificially intelligent face mask detector makes detection more consistent and less confrontational. Lastly, its TDS reduces the risk of indirect or surface transmission of the virus.

2. METHOD

The developmental research approach was followed throughout the study to develop an automated gateway system to help mitigate COVID-19 spread in establishments and premises. The discussion of the methodology consists of the system's process flow, subsystems' architecture, and system network architecture. Furthermore, this section discusses the system's effectiveness through various performance metrics.

2.1. System’s architecture and its subsystems

The researcher applied a user-centered and inside-out approach in designing the system. User-centered design (UCD) is a broad term to describe design processes in which end-users influence how a design takes shape and the inside-out approach by which inside design is defined prior to outside design. The design criteria were based on the users' needs and preferences following the requirements of government and health institutions. The researcher synthesizes first the engineering aspects like functionality and system architecture before the industrial design aspects. The latter includes ergonomics and user interfaces. The design's first parameter is the proposed system's process flow. The primary basis of it is the conventional process flow being implemented on-premises in which the entrance personnel first ensures that the person entering is appropriately wearing a face mask. Then, they do manual temperature checking using a thermal scanner. Next, they let the person write their personal information on the logbook, including their temperature. In a later setting, they used a QR-Code system and a cloud-based mobile application for data recording. However, this application does not automatically record the temperature of the person. The last step is hand sanitation using manual or automated dispensers. While in the proposed system, the process flow had some variations. The first step is determining whether the person is pre-registered in the database or a visitor. Visitors undergo an additional process of manually entering their data into the system and using a visitor's RFID. Then, they continue to the standard face mask inspection, temperature checking, recording, and disinfecting procedures. Notification systems are integrated into the FMD and thermal scanner to alert the personnel whenever a client is not wearing a face mask properly or has a temperature above the standard (36.1 ℃ to 37.2 ℃). The personnel decides whether to allow rechecking of the face mask or temperature or deny the client's entry.

The proposed system has three subsystems, i.e., NLS, FMD, and TDS. These are independent system architectures that were interfaced to form the Kiosk. Figure 1 illustrates the subsystems and the system architectures.

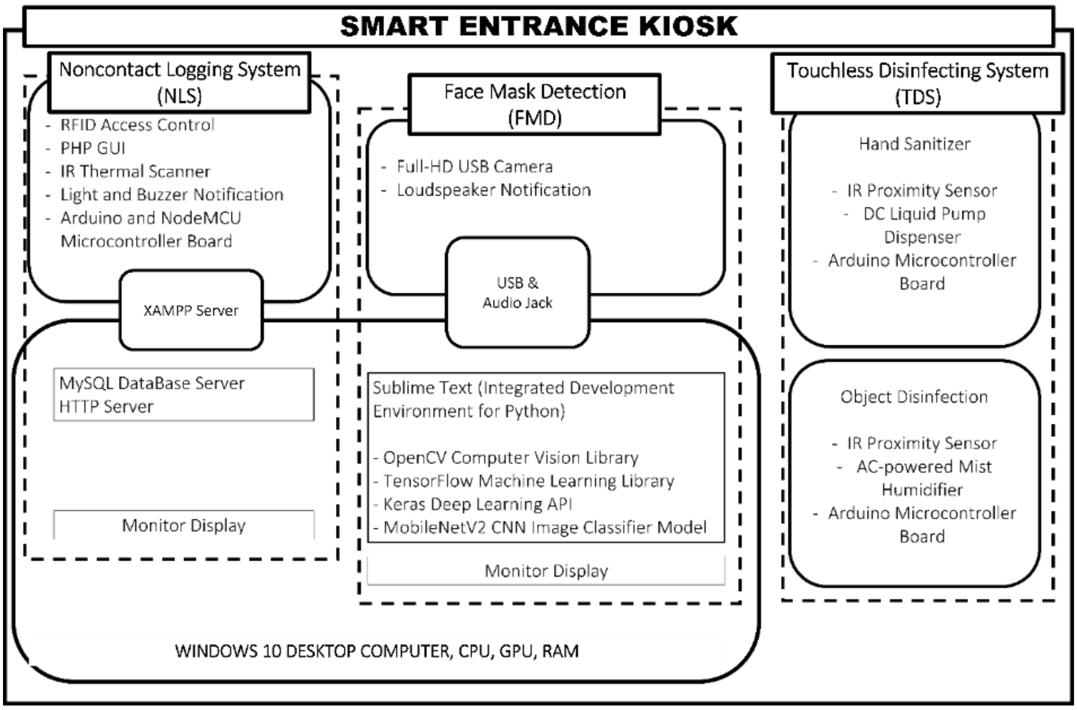

Figure 1. The Kiosk's system architecture and its subsystems

2.1.1. NLS architecture

The NLS comprises an access control, thermal scanner, and database. RFID technology is used as the access control to initiate the system's services. The ability of RFID systems to deliver precise and accurate data about tagged items will improve efficiency and benefit the business community and consumers. It improves the queuing process due to its faster response time than the QR code and facial recognition systems that rely on image processing attributes. Its noncontact feature makes it more suitable than the fingerprint access system. The proponent used MFRC522 RFID and MLX90614 Infrared Thermometer modules interfaced with the MariaDB database via the NodeMCU microcontroller. The database administration tool used is phpMyAdmin, while a localhost server was set using the XAMPP application with Apache as its HTTP server. The graphical user interface (GUI) was created using Cascading Style Sheet (CSS) and JavaScript. The MFRC522 RFID module is a cheap breakout board operating at 13.56 MHz that supports serial communications. It requires a low voltage of 2.5 to 3.3 V DC with up to 10 Mbps data rate. It can recognize RFID tags at a maximum range of 5 cm. The temperature sensor used in the system is MLX90614, which is a noncontact digital thermometer with an IR-sensitive thermopile detector and application-specific integrated circuit (ASIC) for signal conditioning. It works in a wide temperature range of -70 ℃ to 382.2 ℃ for object temperature with 0.02 measurement resolution. An open-source database-MariaDB, an upgraded version of MySQL- handles the data. The latter was complemented with open-source tools-XAMPP and phpMyAdmin as database servers over the World Wide Web (WWW). NodeMCU ESP8266 microcontroller serves as the interfacing device between inputs and the database. The RFID input communicates with the NodeMCU through the serial peripheral interface (SPI), while the thermometer is connected to the Arduino UNO microcontroller through the inter-integrated circuit (I2C). UNO and NodeMCU exchanges data via serial link. The latter has a built-in Wi-Fi 802.11 b/g/n to transfer input data and display values to the database server.

2.1.2. FMD architecture

The FMD architecture consists of an image-capturing device, an image extractor and classifier models, and a result display. The FMD uses a 1080p 60fps USB camera to capture the client's video. A pretrained ResNet-10 model detects and extracts face in the set region of interest (ROI), while MobileNetV2 is used as the face mask classifier. The system uses OpenCV-Python for image processing and TensorFlow through Keras API for machine learning. The pre-trained model used 1,915 masked and 1,918 unmasked datasets, of which 80% were used for training and the remaining 20% for testing. The output is displayed on a computer monitor.

2.1.3. TDS architecture

The TDS uses a proximity sensor for noncontact access control and a liquid motor pump for dispensing. It uses a low-voltage IR proximity sensor with 3.3 to 5 VDC inputs, which can detect an object within 2 to 30 cm at a 35° angle. Its compact size of 39×15.5 mm makes it suitable for an optimized design package. For the hand dispenser, a 5-12 VDC submersible water pump that only draws a low current of 0.1 A and delivers a 3 L/min water output is used. The system uses a 12V diaphragm-type water pump for the object disinfectant that draws 0.5-0.7 A with 1.5-2 L/min water output.

2.1.4. Overall network architecture

The overall network design is a multiple-star topology. The NLS' core is the microcontroller with simplex communications for the thermal sensor and audio-visual notifications. It has full-duplex communication with the database server via Wi-Fi 802.11 b/g/n. Similarly, the TDS has a microcontroller as the central unit for the proximity sensors and pump motors. The camera, display monitor, and loudspeaker for the FMD are integrated into the OpenCV software. Servers for NLS and FMD are installed on a Microsoft Windows 10-based computer.

2.2. Calibration

The temperature sensor was calibrated using the two-point calibration method to ensure accuracy. This method is commonly used in correcting offset and slope errors of sensors. The formula is shown with the corresponding parameters: CV is the corrected value, RV is the raw value (actual reading), RL is the raw low (low-value reading), and Ref_R is the reference range. It is the difference between the reference high and reference low. RR is the raw range. It is the difference between raw high and raw low. Ref_L is the reference low.

$$CV = \left[\frac{(RV-RL)*Ref_R}{RR}\right] + Ref_L \tag{1}$$

In the calibration of the MLX90614 thermal sensor, two sets of measurements were performed for both MLX90614 and a conventional handheld thermal scanner as the reference instrument. Heat-controlled water was used as the subject for both sets to measure the high and low values for the thermometers. It was set to temperatures around 36 ℃ and 37 ℃. The mean values obtained were used in the CV formula to set the correct measurements for the MLX90614. This formula was included in the program code for the thermal sensor.

2.3. Reliability metrics

This stage aims to assess the improvement in the health screening services after implementing the Kiosk. The initial part of the evaluation was the repeated-measure analyses to determine the reliability of each Kiosk's subsystem. The final part was the overall evaluation of its effectiveness by assessing the three key performance indicators (KPIs) for both the Kiosk and the conventional system. The observations were done at the BISCAST campus with 20 clients. The results of the KPI measurements for both systems were presented statistically. The repeated-measure analysis for the FMD was done by measuring the system's accuracy in distinguishing masked and unmasked faces. There are two sets of observation with 30 trials each. The accuracy is computed using the formula with the parameters: V_A is the actual value, which is the number of masked/unmasked faces detected, and V_E is the expected value, which is the total number of masked/unmasked sets.

$$\%Accuracy = \left(1 - \left|\frac{V_A - V_E}{V_E}\right|\right) \times 100\% \tag{2}$$

The TDS has similar assessment characteristics to the FMD. A set of observations with 30 trials was implemented for each hand and object disinfection. The accuracy is computed using the formula (2) with the parameters, i.e., V_A is the actual value, the number of successful disinfections, and V_E is the expected value, the total number of trials.

2.4. Key performance indicators

2.4.1. Service time (ST)

Service time represents the time consumed during the whole process of screening a client. It is limited to temperature and face mask checking, logging, and disinfecting services. The conventional method used the QR code system for logging with manual thermal scanning and face mask detection. Each of the 20 clients underwent the conventional process before the Kiosk screening. The results were compared through a t-test.

2.4.2. Queuing time (QT)

The goal of the Kiosk is to reduce the queuing time in the screening area. Queuing time is a variable affected by the service rate and the number of persons waiting in line. It was calculated using little's law of queuing theory with the parameters: W is equal to L divided by λ. W is the estimated queuing time (in minutes), L is the number of persons waiting in line, and λ is the service rate (persons/minute). The queuing time was observed 20 times at one-minute intervals. The number of persons in the waiting line was recorded for every observation period. At the same time, the service rates are the mean service times of the Kiosk and conventional system obtained from the service time testing.

2.4.3. Personnel exposure (PE) count

Before implementing the Kiosk, all the screening services were managed by personnel, which caused face-to-face interactions and made them susceptible to virus transmission. The Kiosk's innovative features aim to minimize the personnel's exposure to the clients. PE count represents the number of times the personnel interact with clients directly. This measurement observed interactions for every group of five clients. Interactions using the Kiosk and on the conventional system were manually counted.

3. RESULTS AND DISCUSSION

This section presents a discussion of the test results conducted on the Kiosk. The first section shows the calibration of the MLX90614 IR thermal module using the two-point method. The quantitative findings of the repeated-measure analyses on the three subsystems are presented in the second section of this chapter. The last part of this chapter discusses the evaluation of the key performance indicators (KPIs).

3.1. Design of the prototype

The design process includes the system's digitally designed and fabricated packaging. Figure 2 shows the actual prototype of the Kiosk. The frames and casings of the devices were modeled using the Sketch-Up® application. The developmental and evolutionary approach was implemented in prototyping, wherein the functional prototypes are field-tested and become components of the final product [29]. IR sensors were chosen as proximity sensors due to their compact size, lower cost, and ease of installation compared to ultrasonic sensors. The MLX90614 used in the device is the only available noncontact thermal sensor breakout board. The Arduino and NodeMCU microcontroller boards were used due to the vast array of peripherals and numerous open-source libraries and drivers available online. In comparison, breakout boards and prototyping components are cheaper and more accessible than fabricating integrated circuits (ICs). The proponent used rapid prototyping for the packaging, in which most casing materials are polymers. A FDM or material extrusion 3D printer was used to fabricate the adapters, fittings, and packaging for small components. At the same time, the medium casing for the circuit boards was made from cut-cast acrylic sheets using a 40-W laser cutting machine. The overall frame of the Kiosk is made up of welded angular metal bars and covered with painted plywood. The latter were cut and shaped using CNC milling.

Figure 2. Final Prototype of the study incorporating the ideas from the planning and designing phase

3.2. Calibration results

As reflected in Table 1, the high-value measurements, the Kiosk's thermometer subsystem using the MLX90614 thermal sensor has a mean reading of 35.73, which is lower than the average of the reference instrument of 37.87 ℃. Low-value measurements also show that the Kiosk's thermometer has lower readings at an average of 31.59 ℃ compared with the 35.05 ℃ of the reference instrument. As showcased in Table 2, reading human temperature at 0.5 cm from the thermometer shows that the Kiosk has an average reading of 33.76 ℃, which is lower than the reference instrument of 35.11℃. It also shows that the Kiosk's readings are more spread with a standard deviation of 0.75 compared with the 0.26 reference. Temperature readings at a 1 cm distance from the thermometer shows that the Kiosk has closer readings to the reference instrument than 0.5 cm readings. The average reading of 35.54 ℃ is slightly lower than the reference of 36.02 ℃. Also, the data spread is closer to 1 cm reading at standard deviations of 0.22 and 0.23 for the reference and Kiosk, respectively.

Table 1. Average low and high-temperature measurements before the calibration

Temperature measurements before the calibration	Reference instrument, ℃	MLX90614, ℃
High-value	37.87	35.73
Low-value	35.05	31.59

Table 2. Temperature comparison of MLX90614 and a reference thermometer after the calibration

	Reference Instrument, ℃		MLX90614, ℃	
	Mean	Std. Dev.	Mean	Std. Dev.
Thermometer comparison at 0.5-cm distance of reading	35.11	0.26	33.76	0.75
Kiosk's thermometer at 1-cm distance of reading	36.02	0.22	35.54	0.23

Table 3 shows the responses of the two thermometers at 25 °C ambient temperature, at 0.5 and 1 cm distances. Meanwhile, the response of MLX90614 was at colder room temperature (> 25 °C). It shows that at equal and above 25 ℃ ambient temperature, the Kiosk's average reading in the 1-cm range has a difference of -0.02 ℃ from the reference instrument's 35.95 ℃. While in the 0.5-cm range, a difference of 0.08 ℃ from the reference's 35.86 ℃ was recorded. The measurements are more clustered around the mean in the 0.5 cm range at 0.15 standard deviation than the 1 cm range at 0.16. The kiosk thermometer's measurements at 0.5 cm and 1 cm ranges have lower mean values at ambient temperatures lower than 25 ℃. The means are 33.51 ℃ and 34.08 ℃ only. Also, the data are more spread out at 0.26 and 0.21 standard deviations.

Table 3. Temperature comparison of MLX90614 and a reference thermometer at 0.5-cm at ≥25 ℃

	Reference instrument, ℃		MLX90614, ℃	
	Mean	Std. Dev.	Mean	Std. Dev.
Thermometer Comparison at 0.5-cm at ≥ 25 ℃	35.86	0.06	35.78	0.15
Thermometer Comparison at 1-cm at ≥ 25 ℃	35.95	0.06	35.97	0.16

3.3. Reliability results

The data from the final repeated-measure analyses for the Kiosk Thermometer, FMD, and TDS were analyzed. Observations for FMD are categorized into two groups: a masked faces group and an unmasked faces group. The TDS also has two groups of observations for hand and object disinfections. In terms of the Kiosk thermometer, after 20 measurements, the average difference between the Kiosk thermometer and the reference instrument is +0.28 ℃. In terms of face mask detection, this first group is intended for the masked face group, and the system successfully detected 18 out of 20 masked individuals, with an accuracy of 90%. While the second group is intended for the unmasked face group, the system successfully detected 20 out of 20 unmasked individuals, which has an accuracy of 100%. From the ResNet10 and MobileNetV2 models, a 98.20% accuracy was noted. The Kiosk's TDS has a 100% accurate response for both hand and object disinfections with 20 trials each. The latency of the system's response is 1.49 sec. and 2.83 sec. for hand and object disinfections, respectively.

3.4. Key performance indicators result

The effectiveness of the Kiosk is evaluated through measurements of the three key performance indicators-ST, QT, and PE count. In ST, the duration of the screening process using the Kiosk is compared with that of the conventional method-the comparison of the queuing duration under the two methods. The number of times the entrance personnel interacts with the clients is for the personnel exposure count.

3.4.1. Service time (ST)

Table 4 shows that the Kiosk primary health screening service took only an average of 4.93 seconds compared with the 11.93 seconds in the conventional system. The slowest service period using the Kiosk is 6.33 seconds, and the shortest is 3.76 seconds. The t-test was used as a statistical tool. It was set on having a 95% confidence level. A t score of -17.76 (p-value of 0.000) was recorded; this means there is a significant difference in the utilization of the Kiosk compared to the conventional manner in terms of service time.

Table 4. Descriptive statistics on service time of Kiosk and conventional system

Sample	N	Mean	StDev	SE Mean
Kiosk	20	4.930	0.680	0.15
Conventional	20	11.93	1.97	0.44

3.4.2. Queuing time (QT)

The average queuing time with the implemented Kiosk is 16.27 seconds, while without it is 81.12 seconds. The average number of persons in the waiting line without using the Kiosk is 6.8, and 3.3 when using the Kiosk. The t-test was used as a statistical tool. It was set on having a 95% confidence level. A t score of -18.86 (p-value of 0.000) was recorded; this means there is a significant difference in the utilization of the Kiosk compared to the conventional manner regarding queuing time as shown in Table 5.

Table 5. Descriptive statistics on queuing time of Kiosk and conventional system

Sample	N	Mean	StDev	SE Mean
Kiosk	20	16.27	5.33	1.19
Conventional	20	81.12	13.18	2.95

3.4.3. Personnel exposure (PE) count

The PE Count metric, designed to track personnel interactions with incoming clients through manual counting, revealed a low exposure rate. Across 20 batches, each containing five individuals, only one client, on average, interacted with the entrance personnel. It suggests that only 20% of the individuals (1 out of 5) sought assistance from the personnel or had issues using the Kiosk. Other clients independently underwent the screening process with ease.

4. CONCLUSION

The Kiosk is an automated system that improves the conventional screening procedures by integrating the three subsystems-NLS, FMD, and TDS. The study encompasses multiple computing methods like AI, IoT, database management systems, computer-aided modeling (CAM), sensors, and access controls. This study shows that the Kiosk improves health screening procedures by significantly reducing the service and queuing time. The 58.68% and 79.95% drop in the service and queuing time, respectively, confirms that the Kiosk is more convenient than the conventional manner. Moreover, the automated feature of the Kiosk makes it safer to use. It eliminates personnel and client interactions, thus reducing the risks of exposure to the virus. The Kiosk is a reliable solution for mitigating the spread of the COVID-19 virus inside establishments and premises. Testing on the Kiosk infers that its thermometer is accurate, with only a +0.28 ℃ discrepancy in its readings. It has more precise readings on the standard ambient temperature of 25 ℃. Its capacity to detect face-masked users has high accuracy with only 10% error, frequently on dark-colored masks and poor environment lighting. However, the capacity to distinguish unmasked faces is 100% accurate. The disinfection system of the Kiosk is 100% responsive with a minimal delay of 1.49 sec only for hand disinfection. At the same time, an average delay of 2.83 seconds was recorded for the object disinfection.

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