2020/21 COMP4801 Final Year Project
Individual Final Report

Body Temperature Measuring System with Smart Patrol Robot

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Abstract

The rampant COVID-19 is threatening the normal way of life in many countries. To curb the spread of this disease, different public health and social measures are implemented. As air travel places a major role in the global transmission of COVID-19[1], the Hong Kong Airport Authority intends to strengthen its capabilities in identifying potential COVID-19 patients. In this project, a body-temperature measurement system will be developed for the Hong Kong Airport Authority Smart Patrol Robots. Infra-red cameras will be installed on these patrol robots. Through image segmentation and object selection algorithms, infra-red radiation emitted from the human head area can be isolated out and analysed. Therefore the body temperature of the subject can be evaluated. When a potential fever case is spotted, airport staff will be notified with the location and the picture of the suspected fevering passenger, and further appropriate actions can be taken. Face recognition technology is also incorporated to process the images so that double counting of fever cases from a single patient can be avoided. The final processed data is then presented on an interactive web portal, where the users can view and manage these suspected cases with ease. The main purpose of this system is to effectively screen out fevering airport users, which may in turn help prevent international transmission of COVID-19. Since most infectious diseases have fever as one of their symptoms, this system could also be used in the future for aiding the containment of any future pandemics.

Acknowledgement

I would like to express my sincere gratitude to my project supervisor Dr. T.W. Chim, for his patient guidance and constructive advice. His assistance has been vital to the progress of this project. I would also like to thank the Hong Kong Airport Authority for providing advice and input to facilitate this project.

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List of Abbreviations

COVID-19	Coronavirus Disease 2019
AAHK	Hong Kong Airport Authority
HKIA	Hong Kong International Airport
WHO	World Health Organization

1. <u>Introduction</u>

1.1 Background

COVID-19 is an infectious disease originated from Wuhan, China, in December 2019 [2]. As of 17th of April, 2021, there have been at least 140 million confirmed global cases of COVID-19, causing more than 3 million global deaths [3]. Declared to be a global pandemic by the WHO [2], the spread of COVID-19 brings challenges to humanity.

A study in June 2020 confirmed fever as the most prevalent symptoms among confirmed COVID-19 cases, where 78% of patients reported fever [3]. Research shows that air travel plays a vital role in the spread of COVID-19 [1], thus, speedy identification of airport users who are having a fever can help screen COVID-19 patients, which may in turn benefit the containment of the pandemic.

Currently, there are already fixed thermal cameras installed in the airport. However, these fixed cameras provide limited camera coverage where only a small part of the airport could be covered. Blockage of camera view and blind spots are common. These stationary cameras are also not automated, and require constant manual monitoring.

As one of the Smart Airport initiatives, The Hong Kong Airport Authority is developing Smart Patrol Robots, which are capable of patrolling the airport terminals and collect different environment data, such as light intensity, humidity and Wi-Fi signal strength [4]. This project aims to develop a new body temperature measurement system for these patrol robots, so that whenever an airport user with an abnormal body temperature is spotted, airport staff can be notified. This mobile measurement provides wide airport coverage. Data would be automatically collected and stored, which helps minimize labor cost and prevent human error. To prevent the issue of double counting, where a single fevering passenger leads to multiple alerts, face identification tools are also adopted.

1.2 Motivation

HKIA is currently using stationary thermal cameras for checking the body temperature of travellers. Airport users are instructed to walk past these fixed thermal cameras, so that their temperature can be assessed. However, since there is usually a large number of passengers walking past the stationary cameras at the same time, measurement may be obstructed due to blockage of the camera view. Additionally, these fixed thermal cameras require a human operator to constantly look at the display screen in order to spot fever cases. This measurement method may not be very cost-effective, and is usually prone to a large degree of human error. To tackle these issues, we target to add mobile thermal cameras. When mobile thermal cameras are added for monitoring, thermal images of airport users can be captured from different angles. Since the robot is patrolling to different locations of the airport, it would be unlikely to have camera blind spots. Therefore, adding mobile thermal cameras to the existing stationary ones can provide the airport with better monitor coverage. In addition, our enhanced system enables thermal images to be analysed programmatically without staff involvement. When a fever case is spotted, the relevant data and images are stored in our database automatically. Staffs are subsequently alerted. This effectively diminishes the need for human involvement as well as the risk of human error. This new and enhanced mobile body temperature measuring system can act as the second line of defense against fevering passengers on top of the existing fixed cameras.

1.3 Outlines

Section 2 of this paper covers the methodology in terms of our system architecture, infra-red thermography, image object selection, and face recognition. Section 3 covers the results and achievements of the group. Section 4 talks about any potential future work and section 5 concludes the report.

2. Methodology

This section introduces the technical concepts involved in this project.

2.1 System Architecture of the System

This project aims to develop an end-to-end automatic body temperature measurement system. Figure 1 shows the workflow of our system.

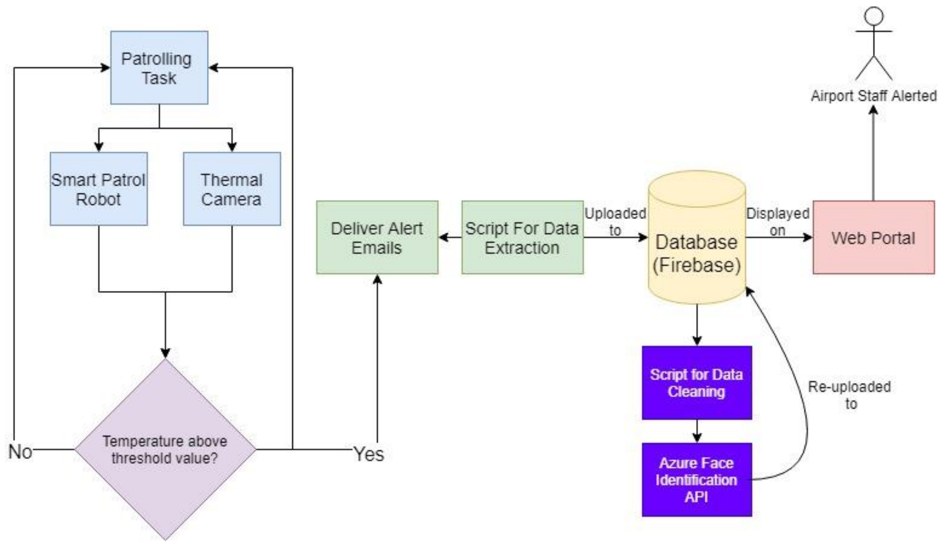


Figure 1. System Architecture of the system

The developed system would enable the patrol robot to patrol along certain designated routes, and while patrolling, make use of the thermal camera to measure the body temperature of nearby airport users. If a fever case is spotted, images would be taken by the camera, and along with other relevant data such as the location of the fever case, time of the event, whether the patient is wearing a mask or not, would all be sent automatically as an email to our target email address. The data from these emails are subsequently automatically extracted by our Python script, and will then be uploaded to our Firebase data storage. The data from Firebase will be further processed by our data cleaning script and then face identification will be carried out by the Azure face identification API. Cases that belong to the same patient will be combined as a single case to avoid the issue of double counting. The processed data will then finally be displayed on our web portal.

2.2 Infra-red Thermography

According to the black body radiation law, all objects of temperature above absolute zero emit infrared radiation [5]. The amount of radiation emitted by an object increases with its temperature. Infrared thermography allows infra-red radiation emitted from objects to be captured with thermal cameras, in the form of a thermogram (see Figure 2), where the surface temperature of the measuring subjects can be monitored [6]. Since there is great correlation between thermal physiology and skin temperature, in the medical field, infrared thermography is used to diagnose breast cancer, diabetes neuropathy and peripheral vascular disorders, etc. [7]. With COVID-19 going on a rampage, we utilize infra-red thermography as a means for monitoring human body temperature, in order to screen potential fevering patients.

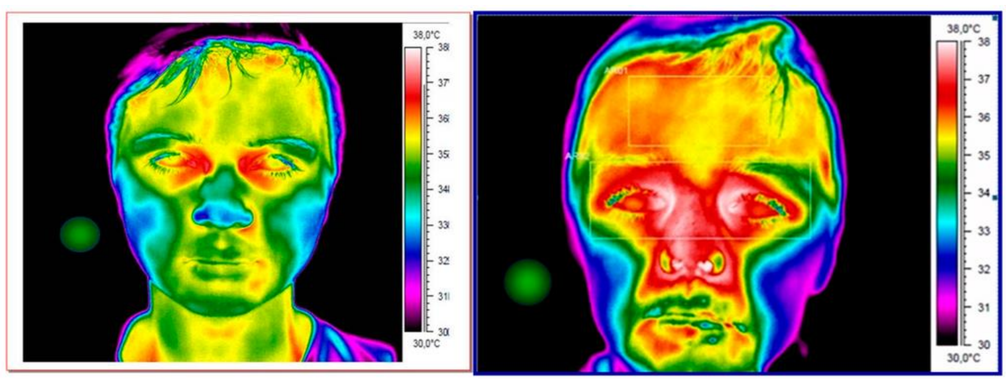


Figure 2 [8]. Thermograms of human faces. The left shows the thermogram of the facial area of a person with normal body temperature, while the right shows raised temperature around the eyes and nose, indicating a possible fever.

2.3 Object Selection

Facial skin temperature has significant correlation with the core body temperature in human bodies [13]. Therefore, we prefer to focus our measurement on the facial area. After differentiating human bodies from their background using segmentation, template matching algorithms can be used to further identify and extract the facial area of the measured subjects. Based on the unique elliptical and circular geometry of the human face, as well as the normal human body temperature range, automatic detection of the human face can be achieved [14] (see Figure 3).

(a)	(b)	(c)
Thermal image before processing	Thermal image after grey level thresholding	Thermal image after facial area is identified using template matching algorithms

Figure 3 [15]. Demonstration of object selection for body temperature evaluation.

After the facial area is identified, we can analyse the facial temperature of the subjects by processing the amount of infra-red radiation emitted from this particular area.

2.4 Face Recognition

Since the robot patrols along the same route repeatedly, it is possible that a fevering passenger is spotted by the robot for multiple times. This leads to multiple fever cases generated by a single fever patient. To deal with this issue of double counting, we adopt facial recognition technology. Facial recognition algorithms analyse an image and extract the face of the person within the image. Then, the facial features of the person will be quantified and stored as a face vector. Face vectors of other images are compared and those images that have similar face vectors will be identified as from the same face (see Figure 4).

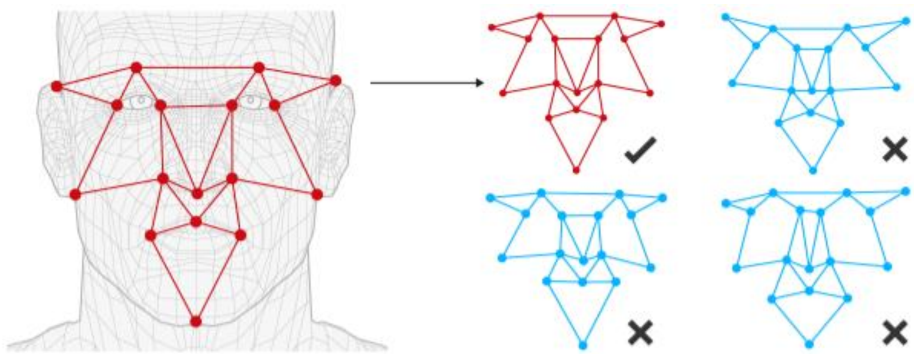


Figure 4[16]. Demonstration of facial recognition. The facial features of a person is extracted and compared with other sample images from other faces. If a face vector is not similar enough, it is considered as from another person.

After adopting facial recognition technology, cases that are repeatedly generated by the same person can be identified, and combined as one single case. This effectively eliminates the issue of double counting and improves the reliability and accuracy of our system. However, a limitation for existing facial recognition technology is that the majority of the facial area needs to be captured in the image, otherwise, if there is any obstruction of the facial area, the algorithm cannot extract enough details of the facial area, and thus no meaningful analysis can be carried out. Therefore, when a person is wearing a mask, his or her nose and mouth area cannot be identified and their faces cannot be analysed.

3. **<u>Result</u>**

This section discusses the results and the achievements of this project.

3.1 Installation of thermal camera

At the start of the project, we carried out research to look for a thermal camera that is suitable for our use. The cheaper cameras were mostly designed to be used as stand-alone hand-held cameras, and have poor compatibility with a computer. For example, the model C2 manufactured by Flir is a hand-held thermal camera, but it cannot provide a live stream of thermal data when connected to a computer [17], which does not fit our requirements. Other cheaper models are designed for mobile phone usage, and have low thermal pixel density, thus would not provide a reliable result. Also, these mobile phone thermal cameras are not designed to be integrated with computers (namely Windows machines), and may lead to certain unexpected exceptions. After comparing different models from different manufacturers, we chose the HikVision DS-2TD1217B-3/PA Thermographic Turret Body Temperature Measurement Camera. It is specifically designed to be used for temperature monitoring, and comes with Windows supported SDK. It fits our needs and purposes, and therefore we picked this model.

The purchase and installation work of this thermal camera was completed in the middle of the first semester. To install the camera onto the robot, we first removed the original top camera of the robot, and replaced it with our new thermal camera (See Figure 5). The existing DC 12V power supply, which was originally used to power the old top camera, is now used to power the newly mounted thermal camera.

Figure 5. The patrol robot after the thermal camera is installed.

The thermal camera is now entirely powered by the internal battery of the patrol robot. After the physical installation, we then moved on to integrating the camera with the robot’s computer. We assigned the camera with an IP address which is on the same subnet of the router of the robot. The camera is connected to the existing router of the robot via LAN, and thus the thermal camera is connected to the robot computer through this Ethernet connection. With this connection, the live view of the camera can be fed to the robot’s computer, and though the SDK provided by the camera manufacturer, the live view of the camera can be accessed by the robot computer (See Figure 6).

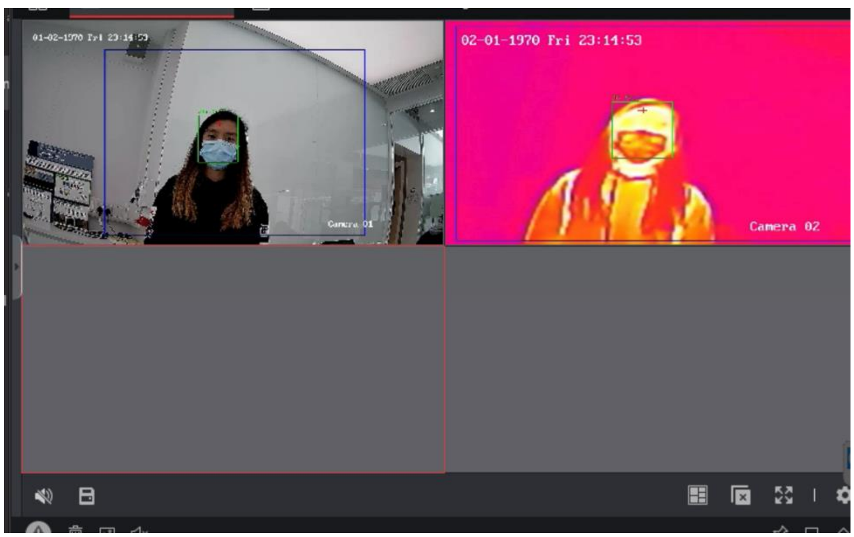


Figure 6. Live view of the camera can be accessed by the robot computer. Both the normal vision and thermal vision of the thermal camera can be accessed by the robot computer in real-time.

3.2 Map drawing and Automatic Patrol Task

Using the navigation software provided by the vendor of the robot, namely Unodopo Navi Studio, a map of the indoor open area of the Innovation Wing is drawn (See Figure 7)

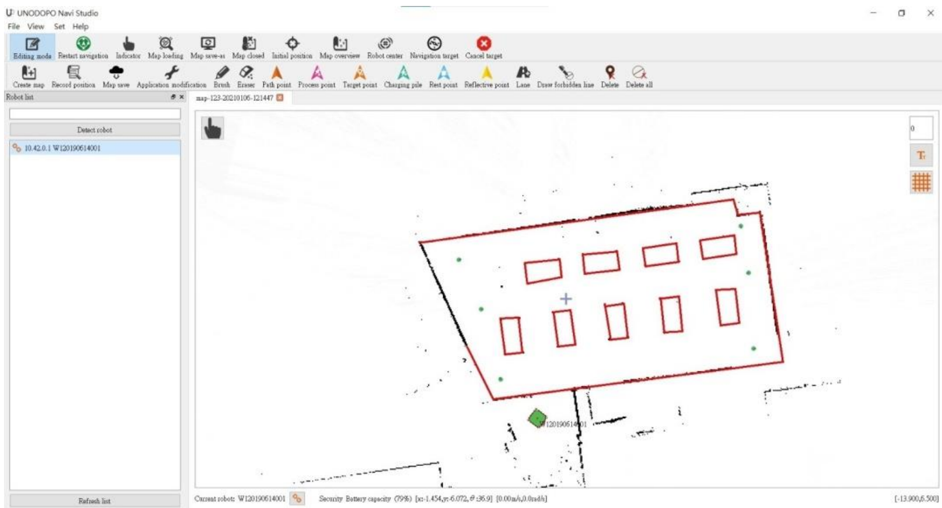


Figure 7. The map of the innovation Wing open area drawn in Unodopo Navi Studio. The green rectangle is the patrol robot. The black dots and red lines represent the obstacles. The small green dots are target navigation points for the patrol route.

Using the same software, we placed a number of target navigation points onto the map drawn. We then created a series of patrol tasks, and put these tasks into an automatic task chain. Under the instructions of this task chain, the robot would be automatically guided to visit the target navigation point sequentially (See Figure 8).

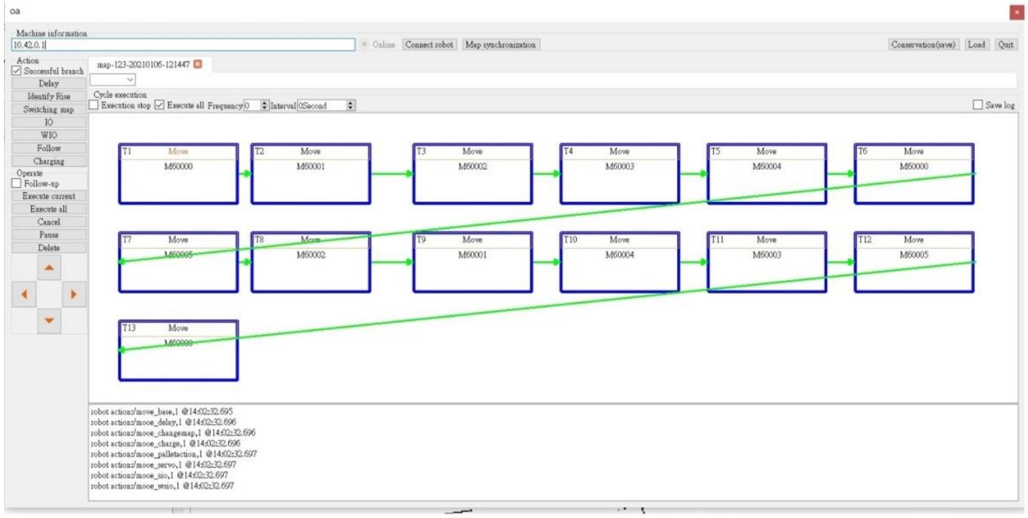


Figure 8. Task chain of the patrol. Each node represents a "move" to a certain target navigation point. Sequence of target point visits is indicated by the green arrows.

The target point visiting sequence has been optimized so that during patrol, the thermal camera would be able to point at different corners of the patrol area from different angles. This would maximize the camera coverage and minimize the occurrence of camera blind spots, thus improving the reliability of our system.

3.3 Verbal Alert

We have managed to configure the camera to perform verbal alert when an abnormal body temperature is measured. Whenever the camera finds a measuring subject to have a surface temperature above the measurement threshold, it will automatically play a verbal alert “temperature is abnormal, please check”.

3.4 Mask Detection

The thermal camera has built-in mask detection algorithms. We have incorporated the built-in mask detection function with our temperature measurement system. When an abnormal temperature event is triggered, images taken are also processed by the mask detection algorithms. The results of this mask detection are then extracted as additional information for the reference of the users.

3.5 Email Alert

When the camera identifies abnormal temperatures in the measuring subjects, email alerts are made automatically (See Figure 9). Self-generated emails will be sent to the designated email recipients. These emails contain the details of the triggering events, such as the event time, skin-temperature of the subject, threshold of the alarm, and whether the subject is wearing a mask. Additionally, images captured from both the normal vision camera and the thermal camera are also attached. Recipients of these emails can utilize these images for identifying the fevering visitors, and carry out any necessary follow-up measures.

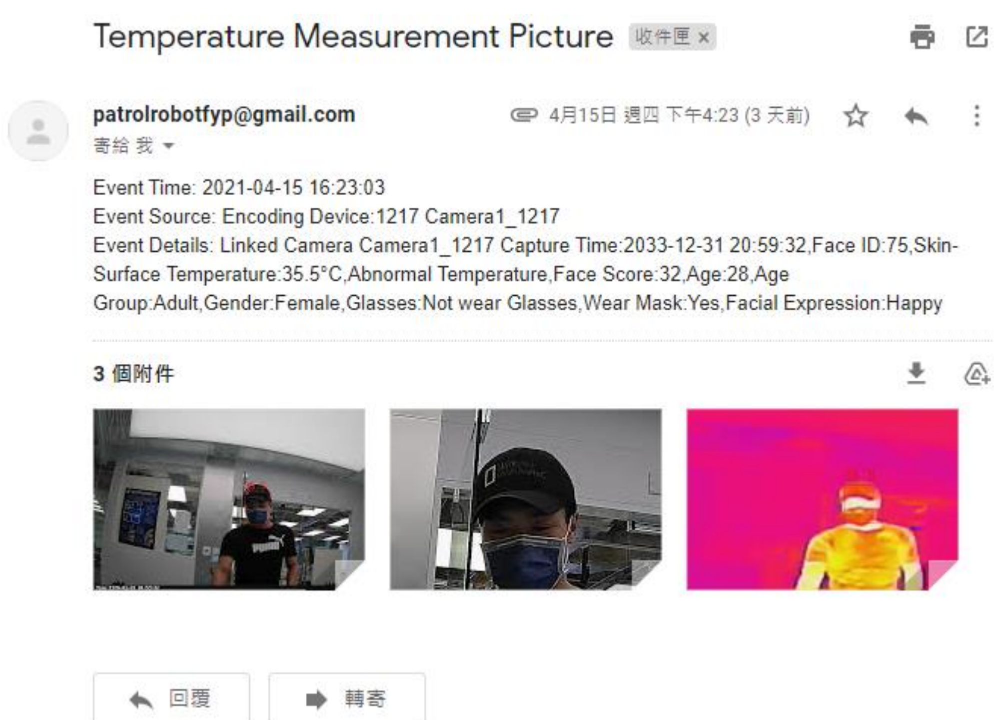


Figure 9. Email alert sample. Automatic email sample sent whenever abnormal body temperature is detected, which includes text information regarding the triggering event and captured images.

3.6 Robot Location Capture

In the future, the robot may be used to patrol a large indoor area, such as the airport terminals. Merely getting the images of the suspected fever case is not enough for the users to carry out the necessary healthcare actions, since they may not be able to identify the physical location of the case purely based on the captured images. Therefore, it is essential for us to provide the users with the locational details of the event as well. The Flask server developed by the robot vender provides an API that the status of the robot is returned, from which the location of the robot can be extracted in a form of coordinates. The coordinates are converted into zone numbers relative to the patrol area (see Figure 10), so that users can be informed of the relative location where the suspected case is spotted.

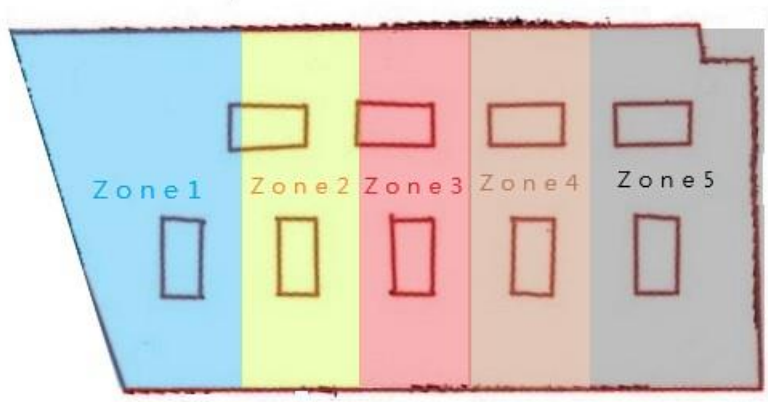


Figure 10. Zonal layout of the indoor patrol area. The indoor area of the Innovation wing is separated into 5 zones. Users can be informed of the relative location of the case.

3.7 Face Identification

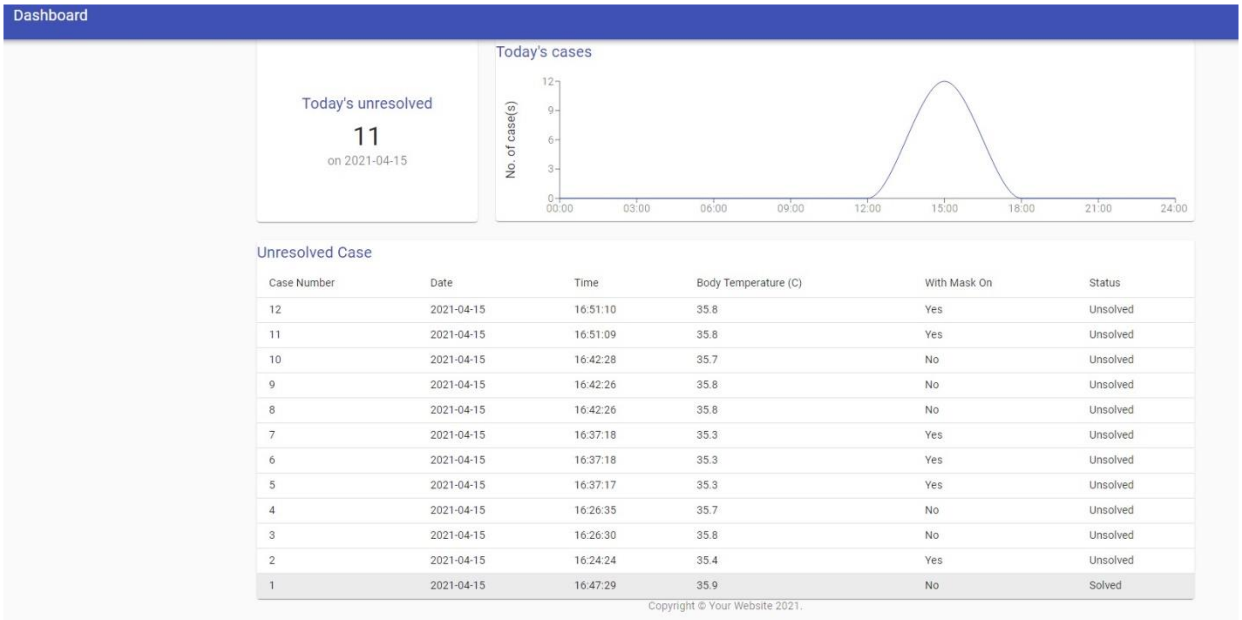
Since the robot patrols along a same path repeatedly, a single fever patient may trigger the abnormal temperature alarm time after time, creating multiple cases. This double counting issue can be solved if the facial identity of the person can be obtained. If a new case has the same facial identity as one of the previous cases, we can conclude that the case is already recorded. Instead of creating a new case, we can add the new data to an existing case.

To task the reliability of face recognition on masked faces, the group tried three methods of face recognition in total, including Openface toolkit, Azure Face API, and the python library face_recognition. We tested the accuracy of these tools with a dataset of masked faces (obtained from https://github.com/X-zhangyang/Real-World-Masked-Face-Dataset). All three methods failed to detect the presence of human faces in the images. Therefore, similarity of different faces cannot be compared. In particular, when using the Openface toolkit, only 1066 faces can be detected out of a sample of a total 2466 masked faces. A model is then trained to match faces, using the labeled data and known identities from the same dataset. The trained model is subsequently tested with new data of masked faces, and the result is highly inaccurate, nearing a 0% accuracy. For the Azure Face API and the face_recognition python library, when masked faces are passed as input, both of these tools failed to locate any human faces, and thus do not provide any meaningful analysis. We thus concluded that we failed to run face recognition tools with masked faces.

On the other hand, for unmasked faces, facial analysis can be run smoothly and accurately. Among the three methods, we chose the Azure Face API, because it can easily be integrated with our python script. It also provided level of confidence of the analysis. This allows high flexibility and customizability for our analysis. For our adaptation, when there are any new cases, and the images suggest the person is not wearing a mask, we run the new face with previous unmasked cases. If the result of the analysis has a confidence level high than 0.7, we consider the new case comes from the same person, and combine these cases as one case. The data of all the cases from the same person will be shown as a single case on the web portal (see section 3.8 for further details).

3.8 Web Portal

Using the React framework, we developed an interactive web portal, which displays the data of all cases in a form of a dashboard (see Figure 11).



Case Number	Date	Time	Body Temperature (C)	With Mask On	Status
12	2021-04-15	16:51:10	35.8	Yes	Unsolved
11	2021-04-15	16:51:09	35.8	Yes	Unsolved
10	2021-04-15	16:42:28	35.7	No	Unsolved
9	2021-04-15	16:42:26	35.8	No	Unsolved
8	2021-04-15	16:42:26	35.8	No	Unsolved
7	2021-04-15	16:37:18	35.3	Yes	Unsolved
6	2021-04-15	16:37:18	35.3	Yes	Unsolved
5	2021-04-15	16:37:17	35.3	Yes	Unsolved
4	2021-04-15	16:26:35	35.7	No	Unsolved
3	2021-04-15	16:26:30	35.8	No	Unsolved
2	2021-04-15	16:24:24	35.4	Yes	Unsolved
1	2021-04-15	16:47:29	35.9	No	Solved

Figure 11. Dashboard view of the web portal. The web portal displays all cases for the users to view. Total number of cases is also shown. A graph also indicates the number of cases spotted at different time.

On the dashboard, users can see if the suspected person is wearing a mask or not on the “With Mask On” column. Also, cases that are unsolved are highlighted with bright color, and solved cases have shaded color.

User can click into individual cases for more details and further case management (see Figure 12).

Figure 12. Web portal page of an individual fever case.

Apart from the captured images, users can see which relative location the case is spotted. They can also see other relevant details such as latest recorded temperature, date and time of the event.

After necessary healthcare measures are carried out, users can click the “SOLVE” button, and mark this case as solved.

If the measured subject is not wearing a mask, face recognition algorithm will be automatically run to cross check the new case with existing ones, so that double count of fever cases from a single individual can be avoided (see Figure 13).

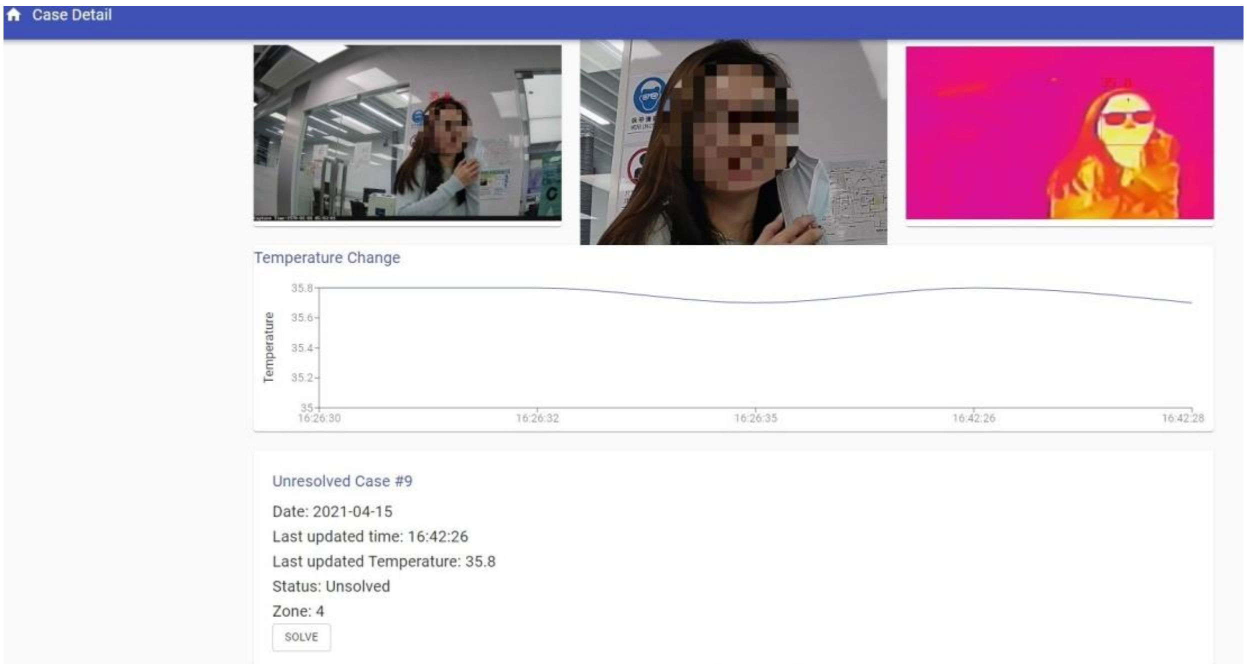


Figure 13. Web portal page of a combined case.

After face recognition is run, cases of the same person will be combined and displayed as one case on the web portal. The change of the body temperature of the person is also shown in a graph.

3.9 Workflow Summary

A number of tools and technologies are adopted in this project. This section gives a detailed workflow which illustrates how all these tools methods above are integrated with one another (see Figure 1).

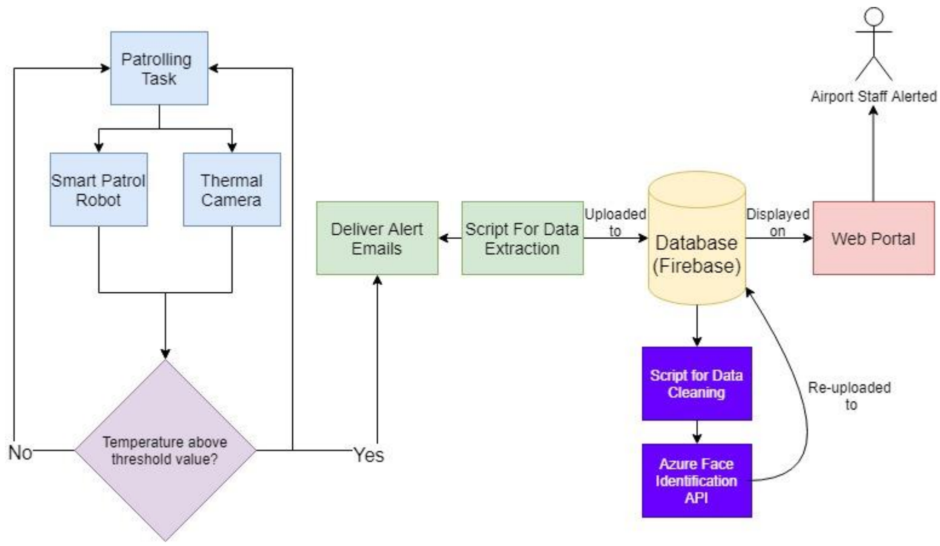


Figure 1. System Architecture of the system

First, an automatic task chain is started on the Unodopo Navigation Studio, this causes the robot to patrol along the designated patrol path automatically and repeatedly.

Along the patrol, the thermal camera mounted on the robot scans the patrol area from different view angles. Temperature measurement and mask detection are performed. If the subject has temperature higher than the threshold value (which can be customized in the camera SDK), alert emails will be sent to the designated email address.

A python script is developed to listen to this email inbox and extract all useful information, and upload to Firebase.

After the data is uploaded to Firebase, the python data cleaning script will be triggered to execute, and it would remove any duplicate sets of data. This is necessary because the camera sometimes would unexpectedly generate multiple email alerts from the same event. Without this remove-duplicate script, one event could lead to the creation of multiple cases on the web portal.

After duplicate data sets are removed, Azure Face Identification will be run. Another python script will be used to cross check the new case with the existing cases. If the new case matches any previously recording case with confidence level high than 0.7, we conclude that the new case should be combined with the previous case. After the face identification process, the data is then re-uploaded to Firebase.

The processed data on Firebase will then be presented on our interactive web portal, where users can access all the relevant information, and manage the cases.

4. Future Work

4.1 Improvement on Data Upload Method

Currently, the system adopts the approach of sending email, downloading and re-uploading to Firebase, which seems indirect and complicated. We considered other more direct methods of uploading data, such as uploading to FTP, memory card and NAS, or extracting the data to the local computer storage, and then reload it to the database. However, the SDK provided by the manufacturer has poor customizability for these actions. Technicians from HikVision could only give advice on how to configure the email alert, but were unable to provide any useful instruction or feedback about sending data through FTP/ memory card or NAS; the camera also does not allow any automatic local transfer of images to the connected computer. After considering all the options, we found out that sending automatic emails was the only customizable action of the camera. Therefore we made a compromise and adopted this seemingly complicated method of uploading the data. This method potentially includes delay due to the time required for sending and downloading emails. It also increases the risk of data loss due to potential exceptions occurred in the process of sending email, downloading email, or re-uploading to Firebase. Debugging and exception handling is also complicated in this scenario.

In the future, a more direct method of data uploading can be adopted.

One method worth looking into is the use of Real Time Streaming Protocol (RTSP), in conjunction with Massage Queuing Telemetry Transport (MQTT), and stream the media data directly to our computer for further processing work.

4.2 Improvement of face recognition

We incorporated face recognition in our project to avoid the double counting problems. However, we were unable to perform facial recognition on images where the nose and mouth area is obstructed by a face mask. This leads to a problem because this system was implemented with the aim of tackling a pandemic, and when an infectious disease is spreading, most people will be wearing masks in public. When used in real-world situation, without the help of face recognition technology, this may lead to hundreds and thousands of double counting cases. In recent years, different organizations have started to develop ways to perform face recognition on covered faces. For example, Japanese company NES has claimed that they have developed a facial recognition system where people wearing masks can also be identified [18]. In the future, this kind of facial recognition tools that have the capabilities of identifying masked faces may be available for public usage. At that time, such facial recognition tools ought to be implemented with this system, so that double counting issues can also be prevented for masked cases.

5. Conclusion

Due to COVID-19, the Airport Authority Hong Kong intends to enhance their health strategies. This project aims to develop an automatic body-temperature measuring system for the Smart Patrol Robots of AAHK. While patrolling, the thermal cameras on these patrol robots can perform automatic body temperature measurement for airport users, and aid the screening of potential COVID-19 patients.

As of now, the Hong Kong Airport has already some fixed thermal cameras installed. However, these thermal cameras can only offer limited coverage, and camera blind spots are common. In addition, the existing stationary cameras are not automated, and would require constant monitoring by an airport staff. On the other hand, mobile thermal cameras allow measurement to be taken from different camera angels, and can eliminate blind spots. Body temperature measurement can be performed along the patrol path of the patrol robots, which would cover the majority of the airport terminals. When a suspected fever case is spotted, relevant information of this suspected case is captured. Together with the images taken and the geographic location of the robot, all these data will be uploaded to our database. After further data processing and facial analysis, duplicate cases and double counting cases are eliminated. The final result will be presented on an interactive web portal, where users can view and manage the suspected cases according to their needs. On top of these, the new measurement system is fully automated, and can effectively minimize the need of human intervention and prevent the risks of human error.

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