2020/21 COMP4801 Final Report

Project title: Body Temperature Measuring System with Smart Patrol Robot

Supervisor	Dr. T.W. Chim	
Student	Lee Ka Fun, Katherine	3035474925
Members	Leung Lok Yi, Harper	3035473359
	Tse Man Kit, Jacky	3035477757

Date of submission:
18th April, 2021

Abstract

The report researches the use of smart patrol robots for health checking measures at the Hong Kong International Airport. With Covid-19 raging around the world in 2020, it not only sheds light on the critical role of airports to curb the spread of commutable diseases but also reveals the system's loophole where travellers can cheat through the fever checking measures by taking a fever reducer. Therefore, the project explores the possibility of utilising the smart patrol robot to fill the existing loophole by incorporating another temperature measuring procedure before travellers come on board. The project incorporates a thermographic camera on the robot and performs different stages of data collection, data processing, and face recognition. A web portal has been developed for fever case management.

Acknowledgements

First, I would like to express my gratitude to Dr T.W. Chim from the Department of Computer Science. Without his supervision and support, we would not be able to collaborate with Hong Kong Airport Authority effectively.

I would also like to thank Hong Kong Airport Authority for offering us this invaluable opportunity and lending out the smart patrol robot for the project.

I am also grateful for the help of my teammates.

Lastly, I would like to acknowledge Miss Mable Choi who has guided me for the progress report

Contents

List of Figures

List of Abbreviations

AGV	Automatic Guided Vehicles
COVID-19	Coronavirus Disease 2019
HKAA	Hong Kong Airport Authority
HKIA	Hong Kong International Airport
MERS	Middle East Respiratory Syndrome
LIDAR	Light Detection and Ranging
RWMD	Real-World Masked Face Dataset

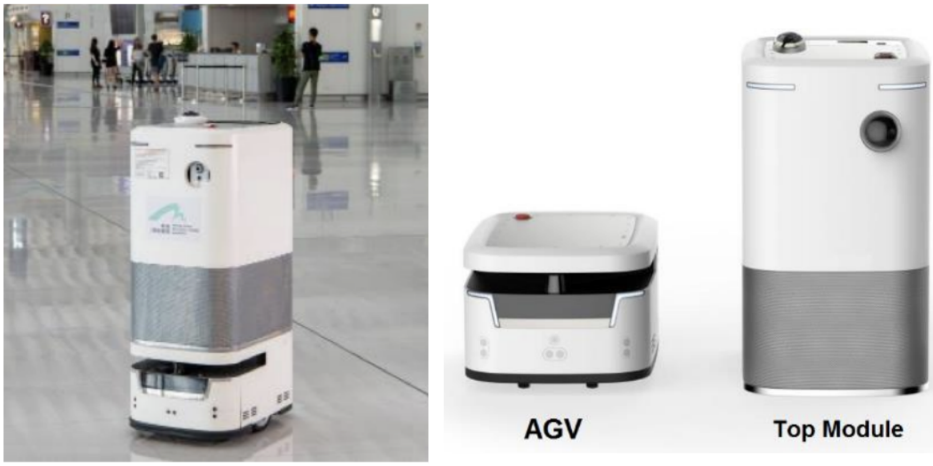
1. Introduction

1.1 Background: Smart Airport Initiative

The Smart Airport Initiative was launched in 2015 by the Hong Kong International Airport (HKIA) Technovation Board to further the technological advancement of the airport [1]. The initiative aims to optimise operational procedures and offers a hassle-free, enjoyable passenger experience to all its visitors by leveraging state of the art technology. Multiple projects under the initiative have been carried out for a few years, such as the digitally-enabled baggage tags, the smart check-in kiosks and the smart patrol robots [2].

1.2 Background: Smart Patrol Robot

The Smart Patrol Robot is a data-collecting robot with cameras and detectors installed for monitoring the environment of the airport and the status of different facilities [3]. The daily tasks of the robot include measuring the status of Wi-Fi signals, measuring the status of iBeacon signals and collecting environment videos. Fig. 1.1 below displays the smart patrol robot when it is operating in the airport and its basic structure.



(a) (b)

Figure 1.1 Smart patrol robot in operation and its main components [4]

As shown in Fig. 1.1(b), the robot consists of 2 main parts, the automatic guided vehicles (AGV) and the top module. The AGV is responsible for the mapping and navigation of the robot while the top module handles data collection and patrol task management. The AGV has a Light Detection and Ranging (LIDAR) scanner for collision prevention. As the top module is a programmable embedded personal computer, the smart patrol robot is capable of more complex tasks apart from collecting data.

1.3 Objectives

The project aims to build a temperature measuring instrument for HKIA Airport with the smart patrol robot in order to check the body temperature of travellers in the airport while they are waiting to be onboard.

The smart patrol robots will be fully utilised for the health checking measure in HKIA by first incorporating a thermal camera on the robots. The thermal camera will be used to collect data about suspect fever cases for processing. The project aims to implement face recognition technology for tracking the temperature changes of visitors at the airport. A web portal will be developed to display and manage the process data of suspected fever cases.

1.4 Requirements

There are 4 major requirements for this project.

1. The robot is able to detect suspected fever cases while patrolling
2. Relevant data of the suspected cases (temperature, location, images of the visitors) is collected and stored correctly
3. The solution is able to recognise unmasked faces and is able to link suspected cases together
4. A web portal is built to display and manage suspected cases

1.5 Project Contribution

Fever is a common symptom of numerous commutable diseases, namely, COVID-19, Ebola and Middle East Respiratory Syndrome (MERS) [5]. Air transportation has contributed to the rapid spread of various transmittable diseases including COVID-19 [6]. With the public health crisis in 2020, the global economy has taken a toll, especially the aviation industry [7]. The industry has suffered from a loss of $84 billion this year and a Hong Kong airline, Cathay Pacific has announced to lay off 6,000 employees due to the pandemic [8]. Airports play a vital role in preventing future global health crises and ensuring travel safety. By adopting a rigorous health checking policy with the help of robotic technology, it can help to curb the spread of infectious diseases. HKIA, which is ranked as sixth in the World Airport Awards in 2020 [9], has already acknowledged its importance and intends to incorporate the temperature-measuring patrol robot if the project carries out successfully.

1.6 Report Outline

The report is organised into five chapters. The first chapter has delivered an overview of the smart patrol robot and the motivation behind the project. Along with the background information, the chapter has presented the objectives and requirements of the project and the significance of our project output.

Chapter two gives a detailed description of the problem statement and the project idea, together with different implementations of robots in the aviation industry

Chapter three defines the methodology which will be implemented in the project. The hardware required, as well as the system design of the project solution, will be discussed. Different image processing and face recognition approaches will be explored as an essential part of the solution.

Chapter four presents the results and deliverables of the projects in reporting and displaying suspecting fever cases and face recognition. It will document the solutions to some previous challenges at the same time.

Chapter five rounds off the progress report. It will sum up the result and output of the project over the 8 months. It will offer insight into the future plan of the project if development continues.

2. Project Background and related work

2.1 Overview

This chapter will give a detailed view of background information for the project in section 2.2. A study of related work will be included in section 2.3. In section 2.4, the project idea will be discussed

2.2 Problems statement of HKAA

In light of COVID-19, Hong Kong Airport Authority (HKAA) has adopted a series of preventive measures to safeguard public health, including disinfection channels and autonomous sterilisation robots [10]. In addition, arriving, departing and transit passengers are required to have their body temperature checked for fever [11]. Despite strict measures of health screening being implemented in airports around the globe [12], there are reported cases of passengers cheating thermal screening by taking fever reducers [13][14]. To combat this situation, HKAA hopes to utilise the use of the smart patrol robot to enhance future monitoring.

2.3 Related work

The use of robots in airports is not a novel concept, robots have been implemented in airports around the globe to handle different tasks. Jumbo, a cleaning robot at Seoul Incheon Airport, is designed to polish the floors in the airport [15]. Munich Airport collaborated with Lufthansa to launch a humanoid robot, Josie Pepper for customer service. It is responsible for guiding visitors and answering some basic enquiries [16].Robird at Edmonton International Airport is a robotic bird that deters birds away from the runaways to ensure a smooth takeoff and landing process [17]. Fig. 2.1 below shows the unique appearance of Robird.

Figure 2.1 Robird in operation [18]

Robird is a hawk-like robot (see Fig. 2.1) and will fly around at a maximum speed of 80lm/h to scare off birds. With the COVID-19 situation in 2020, some airports have taken the initiatives and have implemented robots for public health purposes. For instance, Heathrow Airport introduced the disinfection robots which use ultraviolet light to sterilise high-risk areas, such as washrooms and elevators [19]. The use of robots in various airports reveals that robotics technology offers a multitude of possibilities for the airports to bring a more pleasurable experience to the travellers and to showcase their innovation even in times of uncertainty.

2.4 Project idea

With Covid-19 raging around the world in 2020, it not only sheds light on the critical role of airports to curb the spread of commutable diseases but also reveals the system's loophole where travellers can cheat through the fever checking measures by taking a fever reducer. Therefore, the project explores the possibility of utilising the smart patrol robot to fill the existing loophole by incorporating another temperature measuring procedure before travellers come on board.

An end-to-end solution is hoped to be developed. The solution consists of the robot collecting suspected fevered cases, connecting suspected cases with face recognition technology, and offering a web portal for viewing these cases. It is hoped that the project will help to safeguard public health by optimising the health checking procedures at the airport.

Most of the development and testing of the project will be conducted in the open area of Tam Wing Fan Innovation Wing for convenience.

2.5 Summary

This chapter elaborated on the problem statement of this project and reviewed some of the related work in the area of robot use in airports. Finally, a project was proposed with respect to the problem statement. In the next chapter, the methodology of the project will be explained.

3. Methodology

3.1 Overview

This chapter presents the hardware and technology that we will implement to utilise the functionality of the robot and the data collection, for instance, object selection and face recognition in section 3.2 and section 3.3. It also illustrates the workflow and the alert mechanism of the robot when it carries out the patrolling task in the future in section 3.3.2.

3.2 Hardware: Thermographic camera

Besides the inbuilt digital camera on the smart patrol robot, a thermographic camera will be installed on the robot for this project. A thermographic camera is an appliance that measures the infrared radiation emitted by an object [20]. As stated in the black body radiation law, objects with a temperature above the absolute zero (0K/ −273.15 °C) emits infrared radiation. The infrared radiation emitted by a human body, in fact, reflects the body's temperature. Thermograms will be generated with the thermographic camera. Fig. 3.1 below shows the thermograms taken with different people.

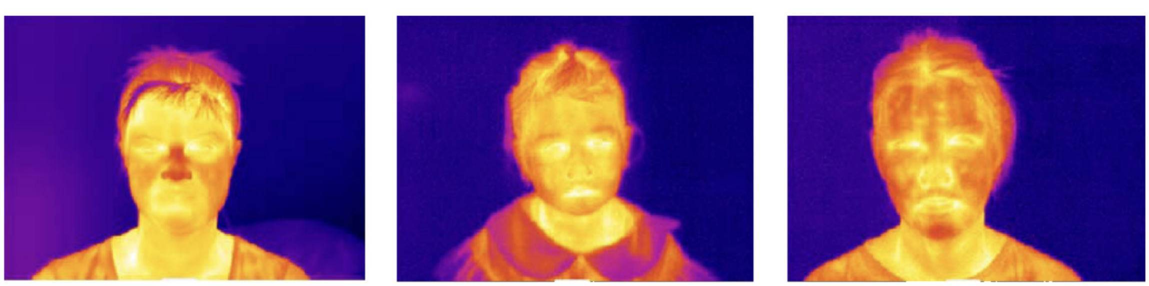


Figure 3.1 Examples of thermograms [21]

The thermograms were taken in a test room with the temperature varying from 20 °C to 24 °C while the camera was placed 1 metre in front of the test objects. As shown in Fig. 3.1, different parts of the face may emit different levels of infrared radiation. A thermographic camera is a suitable applicant for this project as it can measure the temperature of a mass crowd with infra-red technology.

3.3 System and algorithm design

3.3.1 System design

The project aims at developing an end-to-end solution which the robot will be capable of capturing thermograms, identifying visitors with abnormally high temperature and alerting staff when a suspected fever case is spotted. Referring to Fig. 3.2 below, it demonstrates the workflow of the smart patrol robot from patrolling around airport gates to sending alerts after calculation.

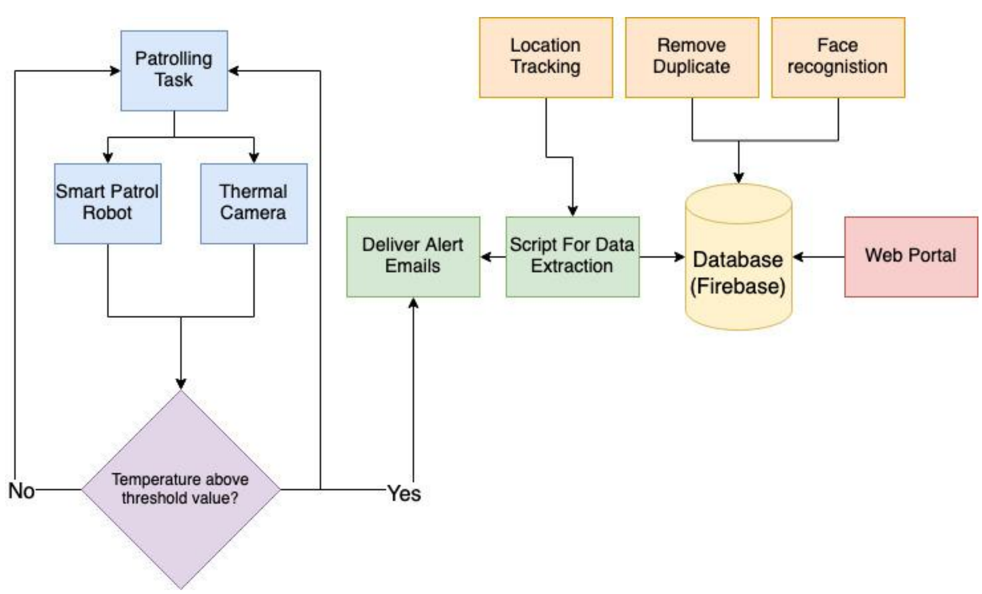


Figure 3.2 System design of the project

The solution consists of 3 major parts: data collection, data processing, and alert handling. As described in Fig. 3.2, the data collection part begins with the smart patrol robot receiving a patrolling task and begins its operation with its digital camera and thermographic camera. If anyone with a body temperature above the threshold value set comes into the view of the thermographic camera, a normal image and a thermal image will be taken and an email attached with these images will be sent to a designated email address. In addition, the current location of the suspected fever cases will be extracted.

For the data processing part, a script will be responsible to call the process for extracting data from the designated email address. The data will then be parsed and uploaded to the storage system of Firebase together with the location information. To eliminate the double-counting problem, a script will be responsible for removing the duplicates in the raw data. After duplicates removal, face recognition will be performed to link cases of the same person together.

For the alert handling part, the airport staff can use the web portal to view the temperature changes, location, and other information about all the suspected fever cases in the gate area.

3.3.2 Object selection with template matching

After image segmentation, images of human bodies can be differentiated from the background. As we focus on measuring the temperature of the facial area, we propose another algorithm to sort out facial regions from the image. Template matching can be used to extract the facial area by choosing elliptical and circular templates whose shapes are similar to typical face contour [22]. Fig. 3.3 below shows the result after object selection is performed.

(a) (b) (c)

Figure 3.3 Demonstration of object selection for temperature calculation [23]

Fig. 3.3(a) displays a thermal image before any processing while Fig. 3.3(b) presents the result after performing grey level thresholding on it. Object selection will then be used to fit a circular or an elliptical template in the white region of the processed thermogram. If the template can be fitted, a facial area is identified and will be used for body temperature calculation (as illustrated in Fig. 3.3(c). The silhouettes of other body parts, such as arms and legs, are usually in narrow, rectangular shapes while the face contour is usually in round shape. If a circular or an elliptical template can be fitted, the area is presumably a facial region.

As the facial area can be located, the average temperature can be calculated with reference to the original thermal image by evaluating the average colour intensity of every pixel in the enclosed area of the unprocessed thermogram. The average colour intensity can then be converted to the Celsius scale and be determined if the body temperature is within a healthy range.

3.3.3 Face recognition

Face recognition has been widely used in different aspects nowadays [24], for instance, unlocking a system of smart gadgets or photo search engines. A feature-based facial recognition method that considers facial features like the nose and the mouth is a more modern approach for face recognition due to its performance compared to the classical method [25].

This project will focus on face recognition with unmasked faces. By adopting a face recognition algorithm, the solution is expected to verify two face images from the same person has the same identity. This would be particularly useful for tracking the temperature change of visitors at the airport. There are some existing libraries and services for this purpose, such as AWS rekognition and open-source tool kit Openface. With the advancement of face recognition algorithms, it is believed that this part will be successfully implemented.

Considering the timeframe and of this project, the project will not focus on face recognition with images of masked faces due to the complexity of the problems. A general facial recognition algorithm consists of three main parts: face detection, feature extraction, and face recognition [26]. For images with masked faces, some of the major facial features have been covered. Hence, making it hard to detect a face[27]. If time allows, the team will explore and research this topic but the topic will be one of the requirements for this project.

3.4 Summary

This chapter covered the basics of the hardware and technology to be used in the project, as well as the system design of the solution. The following chapter will elaborate on the achievement and results of the project.

4. Experiments and Results

4.1 Overview

This Chapter focuses on the team's work on hardware set-up and the result we have obtained with the data collection. Section 4.2 and Section 4.3 present the current operation of the temperature measuring system and the result of facial recognition, with an emphasis on my effort on web portal development, data processing, and research on facial recognition.

4.2 System set-up

4.2.1 Thermal Camera

4.2.1.1 Choice of Camera

With the suggestion from our supervisor and our own research, we decided to order the HikVision Temperature Screening Thermographic Camera for the project. Fig. 4.1 below shows the picture of the camera.

Figure 4.1 Thermal camera from HikVision [28]

As illustrated in Fig. 4.1, the camera has a compact size and is suitable to be installed on the robot. The camera supports remote control and the company offers a software development kit for further analysis.

4.2.1.2 Installation of camera

The thermal camera with normal and thermal vision was purchased and was later installed. The camera is connected to the router of the robot and is powered by the battery of the robot. Below shows how the camera has been mounted on the smart patrol robot.

Figure 4.2 The patrol robot after the thermal camera is installed

Fig 4.2 shows that the camera is connected to the robot and is placed on the top of the robot so that it can capture the environment around when the robot starts patrolling.

4.2.1.3 Usage of the camera

With the software tool, IVMS-4200, provided by the camera's brand, the live feed of the camera can be viewed from the software tool. Below displays a screenshot of the software tool.

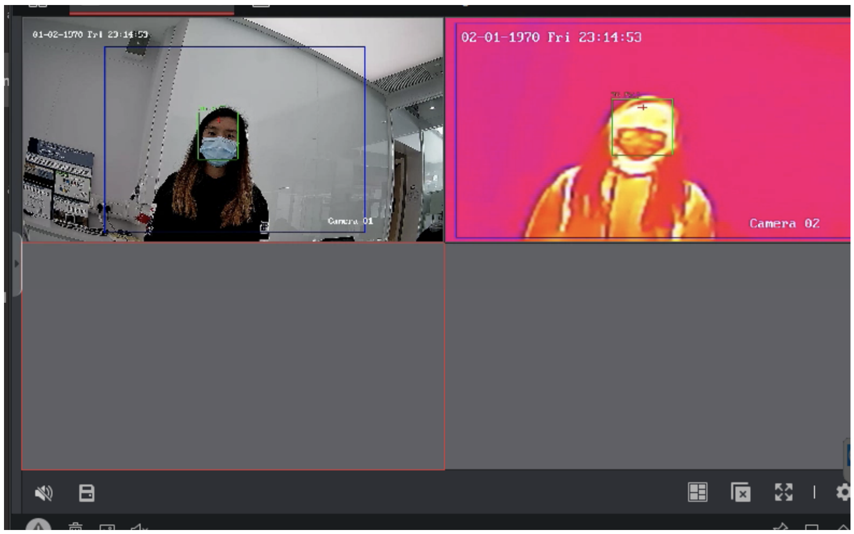


Figure 4.3. Live view of the camera

From Fig. 4.3, it is shown that both the normal vision and thermal vision of the camera can be accessed through the software tools on

4.2.1.4 Implementation of the camera in the project

The camera is used mainly for data collection in this project. By configuring the camera, it is set to send out an email automatically if it finds an object with a temperature above the temperature threshold that is set by the group. The following figure demonstrates an example of the email sent by the camera.

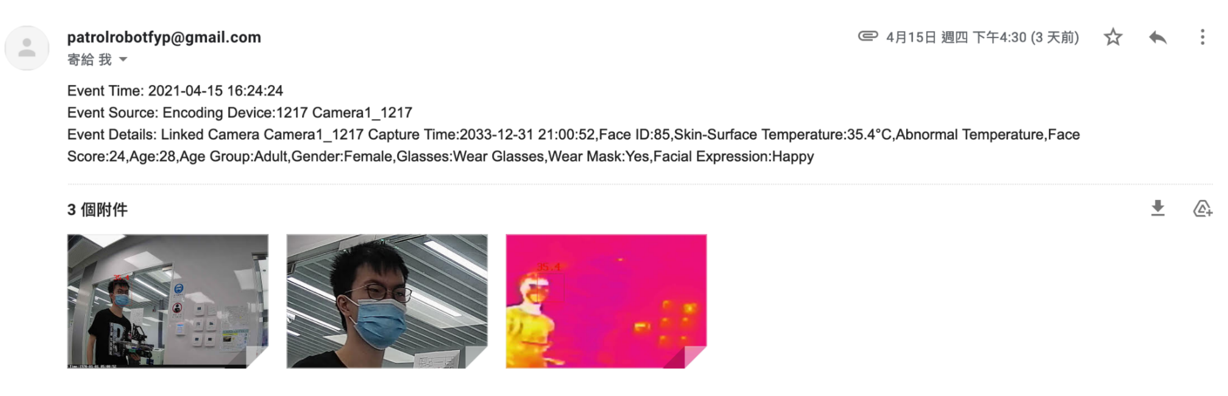


Figure 4.4 An example of the email sent by the camera

Referring to Fig. 4.4, information about the date, time, average temperature, wearing of masks, and images of the visitors were included in the email. This data is particularly useful for our project in the later stage.

4.2.2 Robot navigation

4.2.2.1 Map drawing

In this project, an essential requirement is that the robot needs to patrol around to collect data about its surroundings. To plan the patrolling route and schedule a patrolling task for the robot, a software tool, UNODOPO Navi Studio, has been used. At the beginning of the project, the team conducted a map drawing session at the open area of Innovation Wing to further planning of patrolling tasks. Below shows the result after the map drawing session.

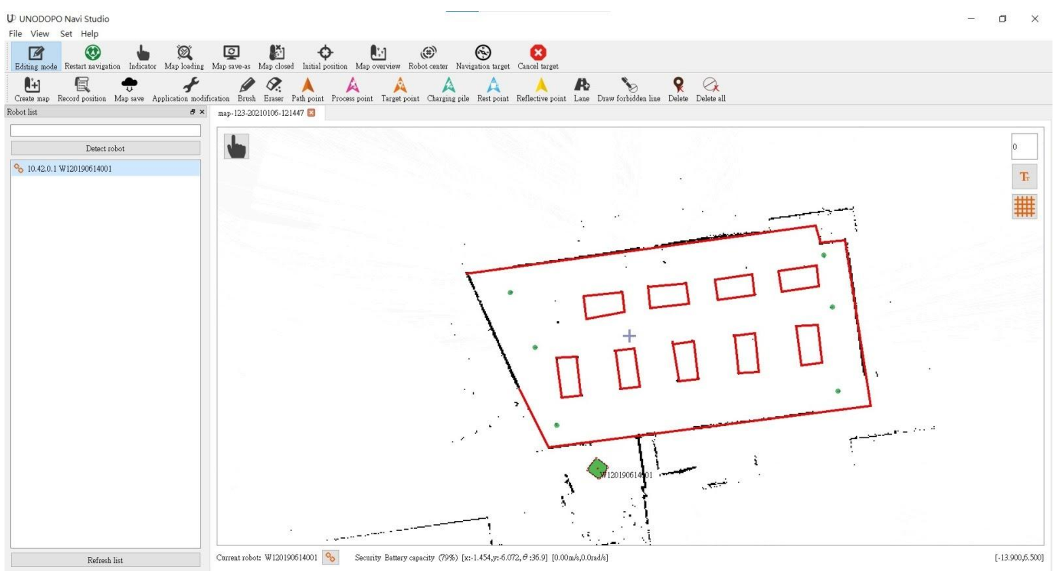


Figure 4.5 The map drawn with UNODOPO Navi Studio

From Fig. 4.5, it shows a floor plan of the open area of the Innovation wing mapped by the robot's LIDAR scanners. The red lines represent walls or obstacles in the area. The small rectangles represent the tables in the open area while the red lines enclosing the rectangles represent the walls of the open area. The green square reveals the location of the robot at that moment

4.2.2.2 Route planning

With the map drawn, a patrolling route can be planned with the software tool. The planning of the patrolling route is organised in the form of a task chain. Each task on the chain represents different points on the map and the robot will navigate from one point to another following the task chain. Below shows an example of a task chain.

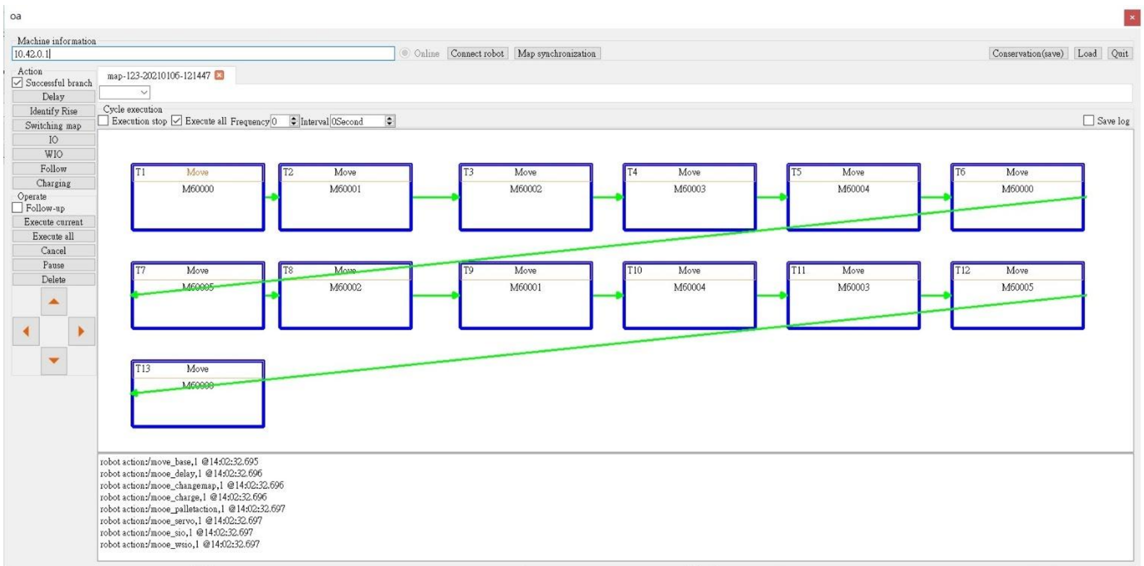


Figure 4.6 The task chain on UNODOPO Navi Studio

With reference to Fig. 4.6, the blue boxes represent a point on the map while the green arrows are commanded to the robot to move from one point to another.

4.2.2.3 Robot mobility

In the interim report, the team talked about 2 challenges that we were facing with the robot. The first being the robot immobility when going into a narrower route and the second the inability to track the exact location of the suspected fever cases. The LIDAR scanner of the robot has its own configuration and anti-colliding setting that cannot be changed by us. To prevent any obstacles or narrow routes that prompt the robot to trigger its anti-colliding setting and stop, we need to adjust the tables in the open area to make a wider gap between the tables. Besides the gaps between the tables are wider, the floor plan of the open area is generally the same with the floor plan drawn by the robot previously

4.2.2.4 Location tracking

For the second challenge we mentioned in the interim report, at that time, the team was not able to access the location information of the robot when a suspected fever case is found. After some research and consultation with the vendor of the robot, we made use of the in-built Application Programming Interface (API) of the robot to access the current location of the robot. By sending a GET request to the status API of the robot, it returns a JSON containing the geographic coordinate of the robot.

With the geographic coordinates, another python function is developed to convert the coordinates into different zones of the open area. The figure below shows how the open area is divided into different zones.

Figure 4.7 The location of different zones in Innovation Wing

From Fig. 4.7, the blue boxes represent different zones in the open area. The zones are numbered from 1 to 5, from left to right on the floor plan. After a suspected fever case is found, the script will obtain the current geographic coordinates of the robot and determine which zone the robot is currently located. The zone number will then be included in the fever case and is stored in the database. The web portal will display the zone number of the case at the same time. For the application in airport, the coordinate translation system can be altered to convert coordinates to gate numbers at the airport. It offers a convenient solution for the airport staff if they need to track down the location of suspected fever cases with the project's web portal.

4.2.3 Web portal for case review

A web portal has been built for airport officials to monitor and review the fever cases recorded around the gate area. The web portal is built developed Reac.js and MaterialUI for the front-end and it connects with the Firebase Firestore as the backend database. The web portal aims to provide an overview of all the cases recorded on the day and also a detailed view of each case. Users of the portal will be able to mark cases as “solved” if an official has been sent to deal with the case.

Below shows a real time capture of the dashboard of the web portal.

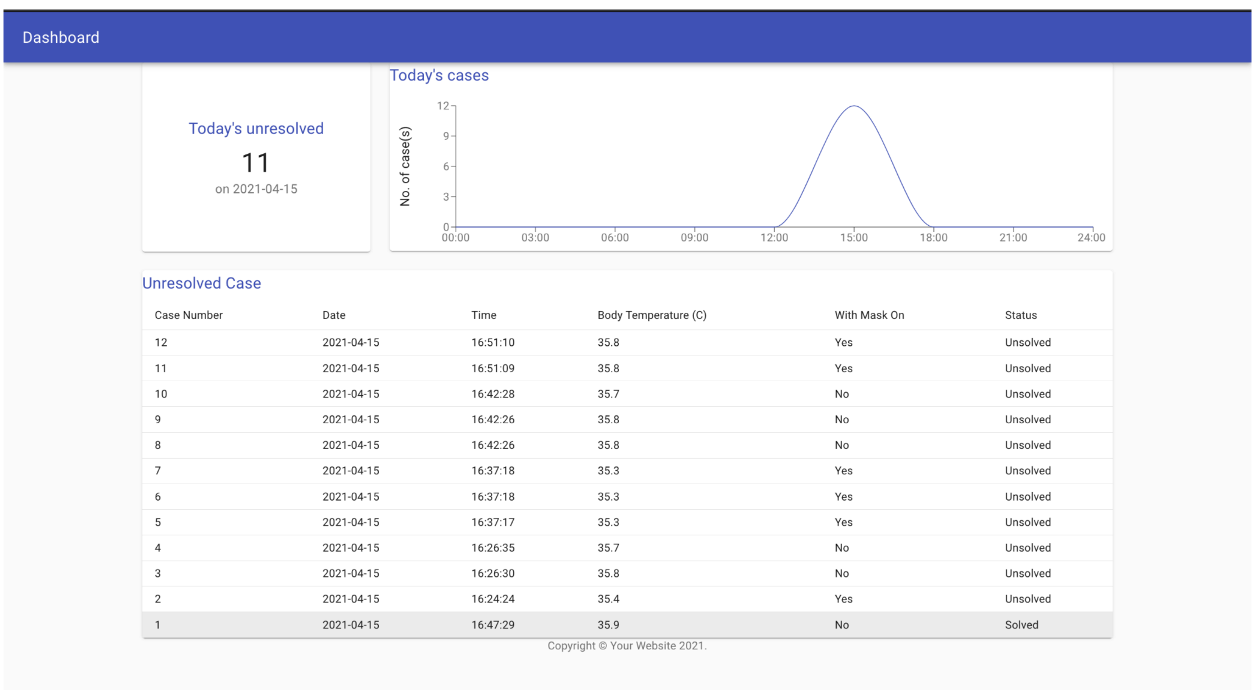


Figure 4.8 A screenshot of the dashboard of the web portal

Fig. 4.8 displays the major components of the dashboard including a panel that shows the total number of cases recorded for the day, a chart that plots the number of cases recorded against the different period of time and a list of the cases recorded. By clicking on one of the rows on the list, the portal will then display the details of the case selected. Below shows the user interface of the detail page.

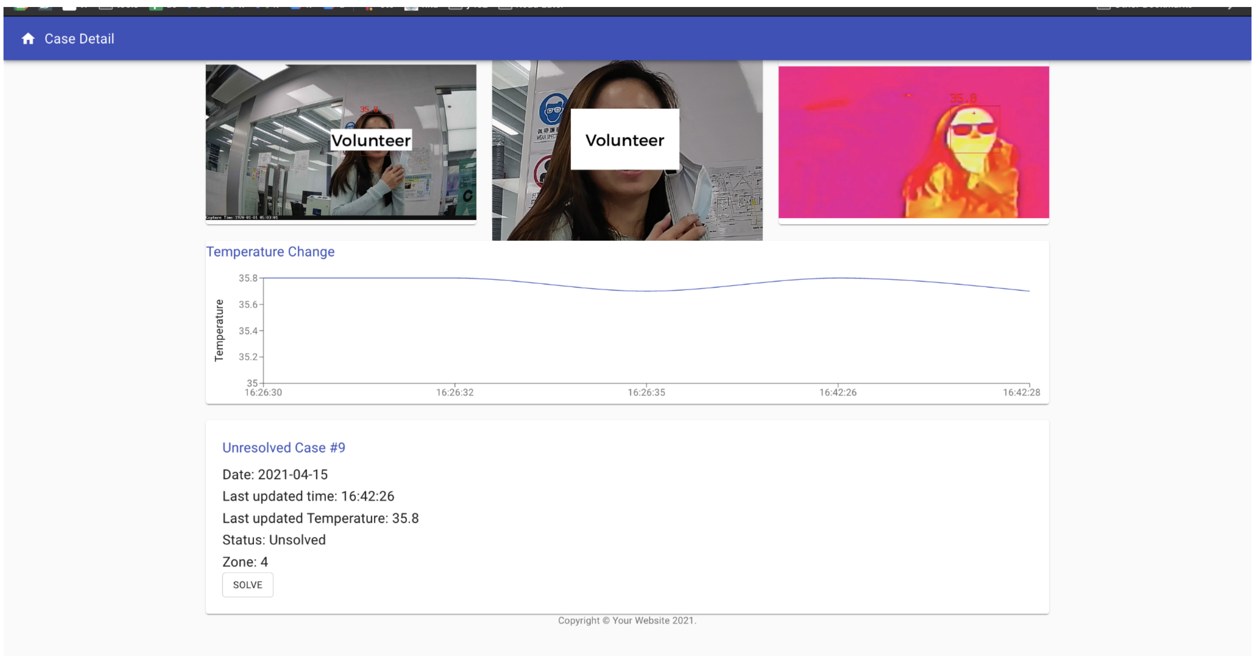


Figure 4.9 A screenshot of the case detail page of the web portal

Fig. 4.9 shows how the case detail page encapsulates the details of the case in different parts of the part. The top part displays images and a thermogram of the visitor that is suspected to have a fever. In the middle, a line chart that tracks the visitor's temperate change at different intervals with the help of the team's facial recognition module. The bottom part lists out other information, for instance, location and latest temperature of the case.

The web portal serves an essential element in this solution as it offers a graphical user interface for airport staff to view and utilise the data collected by the robot.

4.3 Data processing and result

4.3.1 Data Collection

The thermal camera mounted on the top of the robot is the equipment that is responsible for all the data collection of the project. By setting a temperature threshold on the camera, the camera will be triggered to take photographs and thermograms if an object with temperature above the temperature threshold comes into the view of the camera. Related information, such as, date, time, object's average temperature and whether the object is wearing a mask will be recorded.

All information including the images will be delivered to a designated email address for further parsing and processing. This part will be covered in the next sections.

4.3.2 Data storage and processing

As all the data collected will be delivered to a specific email address, a python script has been written to monitor the mailbox and to parse newly received emails. After parsing the content and extracting attachments from the emails, the database will be uploaded to the Firestore database of Google Firebase.

One of the challenges the group mentioned in the interim report is the double counting problem. Sometimes, the same object or person with temperature above the thresholding temperature might trigger the camera to send out multiple emails. The duplicated emails will become different cases in the database. This will cause inconvenience for airport staff as they have to browse through duplicates to find the recent new cases. To combat this problem, a python script has been developed to remove duplicated cases on Firestore by comparing the similarity of cases taken in the same interval.

After removing the duplicates, the data is ready for the next stage of processing - facial recognition. Details will be covered in the next section.

4.3.3 Facial Recognition

The use of facial recognition in this project mainly is to track the temperature changes of visitors by linking different cases through identifying the faces in the images taken. Airport staff will be able to notice the temperature changes of the visitors and prevent them from cheating the temperature measuring system.

For facial recognition, we have collected images of human faces from multiple data sources, from our thermal camera and open data from online. The data collected included faces with masks and faces without masks.

There are multiple existing libraries or APIs for verifying if the faces in two different are the same person, for instance, Openface (A face recognition toolkit using deep neural network), face_reconition (A Python library for face recognition) and Azure Face API. However, these tools tend to be only accurate for unoccluded faces or faces without masks as these tools often fail at locating a face if the face is covered by a mask or a pair of sunglasses.

4.3.3.1 Facial recognition with unmasked faces

The group firstly focused on face recognition of unmasked faces. After experimenting with different tools for face recognition and comparing the results, we chose to implement Azure Face API as it has the highest accuracy in computing similarity of faces. In a dataset with 87 images from five celebrities[29], Azure Face API is able to achieve around 80% accuracy in identifying faces of the same person. Fig. 4.10 below shows the examples of the celebrity dataset.

Figure 4.10 Examples of the celebrity dataset

As shown in Fig. 4.10, the dataset features images of celebrities labeled with their name. This dataset is useful for the project to test the accuracy of different face recognition tools

The Azure Face API works as it locates all the faces in a photo and then generates a face id for each of the faces detached. By calling the verification API, it compares two face ids and returns a confidence score, ranging from zero to one, that reflects the level of similarity of the two face ids. The team has set a threshold of 0.7 so that for any two face ids with a confidence score above 0.7, it will be regarded as faces from the same person.

If 2 cases are detected to be related to the same person, the database will be updated. The web portal will reflect the temperature change of the person in a line chart as well.

With the success of facial recognition with unmasked faces. The group began to research the possibility of facial recognition with masked faces. The next subsection will elaborate on the result for this topic.

4.3.3.2 Facial recognition with masked faces

As all of the requirements of the project have been satisfied, the group began to explore the possibility of matching masked images of the same person by comparing images with masked faces. Although researches about facial recognition with occluded or masked faces have been found, for instance, academic papers on face detection with images with occluded faces [27] and facial verification between a masked face and a unmasked face for the same identity [30], there is not much academic discussion on comparing the identity of two masked faces.

Despite our research finding, the group attempted to use a dataset Real-World Masked Face Dataset (RMFD) with masked faces with labelled identities [31] with the face recognition tools mentioned above. Fig. 4.11 below shows the examples of the RMFD dataset.

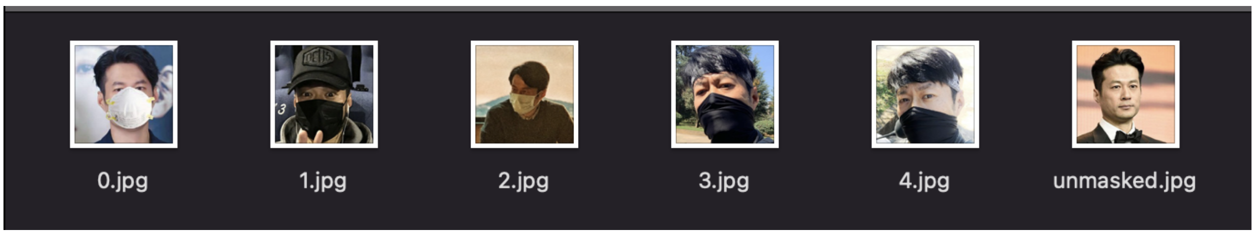


Figure 4.11 Examples of the RMFD dataset

As illustrated in Fig. 4.11, a dataset with masked faces is used.

As mentioned in a previous chapter, it is challenging to detect faces with covered facial images as a majority of facial features are hidden. For all the tools we have tried, including face_recognition library, Openface toolkit and Azure Face API, they failed to detect the faces in the dataset and hence, unsuccessful in comparing the similarity for two faces. In particular for Openface, among 2466 images of masked faces with known identities, only 1066 faces can be detected. A model was trained based on these data. The model takes an image with a masked face as the input and matches it with the known identities from the datasets. However, the accuracy of the model is highly unsatisfactory.

With the team's experience and research, It is believed that it still requires more time and effort to achieve a satisfactory performance on the topic of facial verification between 2 masked faces with the same identity.

4.4 Summary

The chapter presented the major components of the project's solution, including the set-up of the robot, handling procedures of the data collected and introduction of the web portal. In addition, the project's result on facial recognition with unmasked faces was displayed and a discussion on facial recognition with masked faces was offered at the end of the chapter. In the next chapter, it will conclude the project and give suggestions of future plans for the project.

5. Conclusion

5.1 Conclusion

With Covid-19 on a rampage in 2020, the team aspires to strengthen the current health checking measure in HKIA by collaborating with the smart patrol robot. Throughout the project, the group has been building an end-to-end solution that allows the smart patrol robot to identify suspected fever cases and trigger its alerting system. The solution of the project now is able to collect data of suspected fevering cases, including temperature and location of the case. Moreover, the raw data can be processed to be free of duplication and facial recognition is implemented for cases without facial masks. Airport staff is able to utilise the web portal to monitor the airport in an efficient manner. To conclude, the project is successfully implemented to fulfill all the requirements.

5.2 Future plans

Although the project's requirements are fulfilled, some aspects of the project can be further improved to provide a better service. Firstly, as previously mentioned, the feature of facial verification of two masked faces with the same identity will be particularly useful for the airport as it allows the staff to have an overview of the temperature change of a visitor with a mask on. Secondly, if the solution is put into a testing phase in the airport, some fine tuning on system stability and efficiency might be required as the robot will take in a large throughput of data.

Reference

[1] Hong Kong Airport Authority, "Smart Airport",, 2019. [Online]. Available: https://www.hongkongairport.com/iwov-resources/html/sustainability_report/eng/SR1819/airport-city/smart-airport-city/. [Accessed: Oct. 27, 2020].

[2] Hong Kong Airport Authority, "Sustainability Report 2017/18", 2018. [Online]. Available: https://www.hongkongairport.com/iwov-resources/html/sustainability_report/eng/SR1718/wp-content/themes/aahk/assets/pdf/HKIA_SR201718_En.pdf. [Accessed: Oct. 27, 2020].

[3] Hong Kong Airport Authority, "Indoor Patrol Robot Concept", 2017. pp 1.

[4] Hong Kong Airport Authority, "Indoor Patrol Robot Concept", 2017. pp 1-2

[5] "8 Historical Context: SARS, MERS, and Ebola | ATrain Education", Atrainceu.com, 2020. [Online]. Available: https://www.atrainceu.com/content/8-historical-context-sars-mers-and-ebola. [Accessed: Oct. 27, 2020].

[6] H. Nakamuraa, S. Managi, “Airport risk of importation and exportation of the COVID-19 pandemic”, Transport Policy, vol. 96, pp. 40-47, Sep 2020.

[7] "Industry Losses to Top $84 Billion in 2020", Iata.org, 2020. [Online]. Available: https://www.iata.org/en/pressroom/pr/2020-06-09-01/. [Accessed: Oct. 27, 2020].

[8] "Grim forecast for Cathay Pacific amid imminent layoffs", The Standard, 2020. [Online]. Available: https://www.thestandard.com.hk/section-news/section/11/223987/Grim-forecast-for-Cathay-Pacific-amid-imminent-layoffs. [Accessed: Oct. 27, 2020].

[9] "The World's Best Airports in 2020 are announced | SKYTRAX", SKYTRAX, 2020. [Online]. Available: https://www.worldairportawards.com/the-worlds-best-airports-in-2020-are-announced/. [Accessed: Oct. 27, 2020].

[10] "HKIA Applies Advanced Technology to Step Up Disinfection Against COVID-19", Hong Kong International Airport, 2020. [Online]. Available: https://www.hongkongairport.com/en/media-centre/press-release/2020/pr_1446. [Accessed: Sept. 30, 2020].

[11] "Department of Health - Health Control Measures for travellers at airport, seaport and land boundary control points", Info.gov.hk, 2020. [Online]. Available: https://www.info.gov.hk/info/sars/en/boundarycontrol.htm. [Accessed: Sept. 30, 2020].

[12] "Coronavirus: airports around the world carry out screenings", the Guardian, 2020. [Online]. Available:

https://www.theguardian.com/science/2020/jan/21/coronavirus-screenings-global-travelling-airport. [Accessed: Sept. 30, 2020].

[13] "Passengers cheat flu scan with fever reducers", Abc.net.au, 2020. [Online]. Available: https://www.abc.net.au/news/2009-06-15/passengers-cheat-flu-scan-with-fever-reducers/1714264. [Accessed: Sept. 30, 2020].

[14] "A Chinese embassy in Paris tracked down a woman who gloated on social media about cheating airport detection with a medicine that lowered her fever", Business Insider, 2020. [Online]. Available: https://www.businessinsider.com/wuhan-coronavirus-woman-avoided-airport-tests-travel-france-2020-1. [Accessed: Sept. 30, 2020].

[15] "5 Intelligent Robots That work at Airports | Ikusi Airports", Ikusi.aero, 2018. [Online]. Available: https://www.ikusi.aero/en/blog/5-intelligent-robots-you-can-find-airports-world. [Accessed: Oct. 27, 2020].

[16] “Munich Airport Tests Robot.” TTN. Travel & Tourism News Middle East, Mar. 1, 2018. [Online]. Available: https://www-proquest-com.eproxy.lib.hku.hk/docview/2010077593?OpenUrlRefId=info:xri/sid:primo&accountid=14548. [Accessed Oct. 26, 2020]

[17] B. Coxworth, "Robotic falcon will chase birds at Canadian airport", New Atlas, 2017. [Online]. Available: https://newatlas.com/robird-edmonton-airport/49472/. [Accessed: Oct. 27, 2020].

[18] B. Coxworth, "Robotic falcon will chase birds at Canadian airport", New Atlas, 2017. [Online]. Available: https://newatlas.com/robird-edmonton-airport/49472/. [Accessed: Oct. 27, 2020].

[19] "Robots help fight coronavirus at Heathrow Airport", Bbc.com, 2020. [Online]. Available: https://www.bbc.com/news/av/technology-53525018. [Accessed: Oct. 27, 2020].

[20] Skorupka, Zbigniew. "Thermographic Camera Use in Brake Oriented Friction Materials Tests / Użycie Kamery Termowizyjnej w Badaniach Hamulcowych Materiałów Ciernych." Journal of KONBiN, vol. 33, no. 1, pp. 81–90, 2015

[21] Marzec, Mariusz, et al. "Methods of Face Localization in Thermograms." Biocybernetics and Biomedical Engineering, vol. 35, no. 2, pp. 138–146, 2014

[22] H. F. Haghmohammadi, D. S. Necsulescu and M. Vahidi, "Remote measurement of body temperature for an indoor moving crowd," 2018 IEEE International Conference on Automation, Quality and Testing, Robotics (AQTR), Cluj-Napoca, 2018, pp. 1-6, doi: 10.1109/AQTR.2018.8402698.

[23] "A tutorial on Camera based Thermal Screening using Computer Vision", Medium, 2020. [Online]. Available: https://medium.com/@feat7/a-tutorial-on-camera-based-thermal-screening-using-computer-vision-d8b3304c08e3. [Accessed: Sept. 30, 2020].

[24] Wang, Mei, and Deng, Weihong. “Deep Face Recognition: A Survey.” Neurocomputing (Amsterdam), vol. 429, 2021, pp. 215–244.

[25] Albiol, Alberto, et al. “Face Recognition Using HOG–EBGM.” Pattern Recognition Letters, vol. 29, no. 10, 2008, pp. 1537–1543.

[26] Zhao, W, et al. “Face Recognition.” ACM Computing Surveys, vol. 35, no. 4, 2003, pp. 399–458.

[27] Shiming Ge, et al. “Detecting Masked Faces in the Wild with LLE-CNNs.” 2017 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2017, pp. 426–434.

[28] “DS-2TD1217B-3/PA Temperature Screening Thermographic Camera”, New York Technology Company. [Online]. Available: https://www.nytechco.com/product/hikvision-ds-2td1217b-3-pa/. [Accessed: Nov. 30, 2020].

[29] "5 Celebrity Faces Dataset". *Kaggle.Com*, 2021, https://www.kaggle.com/dansbecker/5-celebrity-faces-dataset.

[30] Yang, Lei, et al. “Deep Representation for Partially Occluded Face Verification.” EURASIP Journal on Image and Video Processing, vol. 2018, no. 1, 2018, pp. 1–10.

[31] "X-Zhangyang/Real-World-Masked-Face-Dataset". *Github*, 2021, https://github.com/X-zhangyang/Real-World-Masked-Face-Dataset.