# Fighting with COVID-19: An AR System to Prevent the Spread of the Virus at Shopping Malls


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**44201016-3**


Master of Engineering


Supervisor: Prof. Jiro Tanaka

*Graduate School of Information, Production and Systems*

*Waseda University*


January 2022

# Abstract

The COVID-19 has shocked the retail industry. Customers' concerns for their health and safety are taking business away from shopping malls. Mall owners are thinking of finding new ways to provide a safe shopping environment to bring customers back. How to protect customers from COVID-19 in shopping malls is a problem.

In this research, we present an augmented reality (AR) system to prevent the spread of this virus at shopping malls. This system helps implement wearing masks and proper social distance mandatory rules in shopping malls. We create a novel visualization way: Radar vision to display detected people in the field of view of mall guards, help guards react quickly to violations, and better enforce the mandatory rules. When the mall guards wearing hololens activate the radar vision function, they can see all the people who violate wearing masks or social distance mandates through the wall. Then they can go to the scene in time to enforce these two mandates. We have done three parts of work to achieve this core function. They are: People detection, Location synchronization, Build Augmented view. The people detection function monitors two main violations: un-masked people and crowd gatherings. We chose YOLO with the COCO model to do detection work. With this deep learning model deployed on the server, our system can enhance the shopping mall's surveillance system to recognize the violation of these two mandates. For the location synchronization, we selected the school building as the shopping mall and placed virtual spatial anchors in the building as landmarks to map people's position from reality to virtual. Enable Hololens to know the position of detected people based on the virtual spatial anchors. The final part of the radar vision is building the enhanced view by visualization method. This method estimates the distance between the spatial anchor and detected people, then lets the 3D radar image represent the detected people on the closest anchor. In this way, mall guards with radar vision can see these radar images regardless of the number of walls that separate them. After radar vision shows the detected people, mall guards can use gaze to select the target person. Then use the voice command to activate the navigation arrow to assist them to go to the target location to enforce wearing masks and proper social distancing in the shopping mall. In addition to helping mall guards enforce mandates, this system also provides assisted functions to protect customers. When our system users enter the Mall, the system will display an augmented reality with a radius of 2m below the user's body to be a social distance guideline. When the violation situation appears around the customer, the system will alert them to avoid and show an avoidance arrow until the user goes in the correct direction.

We conducted a preliminary evaluation of the system's Functionality, Efficiency, Interface design, and impact. The result shows our system can make users feel safer when shopping and positively impact people's intention to go the shopping malls.

**Keywords:** augmented reality; see through the wall; covid-19; shopping mall

# Acknowledgements

First of all, I would like to express my most sincere gratitude to Professor Jiro Tanaka. To be his student is the thing I am most proud of. His profound expertise and academic spirit have had a great impact on me. Professor Tanaka has always given me tender guidance in seminars, academic conferences, master's thesis topic selection, implementation, and writing. His comments have often enlightened me and benefited me greatly in setting academic goals and understanding many life lessons. Also, when I encountered problems in my life, his solicitude was a great consolation to me.

Second, I would like to thank all the friends I met at IPS for their help in my life and for making life in Japan less lonely, especially our laboratory members. I am fortunate to have this happy memory with you all.

Finally, I would like to thank my parents for their support in my studies abroad so that I can focus on my studies without worries. I will do my best to work hard and live up to your expectation.

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# Chapter 1

# Introduction

## 1.1 Introduction

Coronavirus disease (COVID-19) is an infectious disease caused by the SARS-CoV-2 virus. This novel virus was first identified in the city of Wuhan in December 2019. On 30 January 2020, the world health organization declared the global public health emergency due to this pandemic outbreak. The statistics by WHO on 18 December 2021 confirm 271 million infected people and a massive numeral of deaths worldwide.

The world has changed dramatically after the spread of this novel virus. With the emergence of new virus variants appearing repeatedly, existing vaccines can not provide complete protection against new variants. Therefore, many other infection prevention methods such as lockdown of countries or cities, mask-wearing, and social distancing are present in the present situation. These methods have been implemented worldwide and play an essential role in the war against the virus.

However, as the world continues to cope with this unusual crisis, the global lockdown measures have paralyzed the global supply chain. With the isolation restriction, the shopping mall suddenly had no customers. COVID-19 has caused significant disruption in the retail industry. As restrictions began to lift, customers' expectations have changed considerably during this period. The lockdown measure has accelerated the transition to online shopping. The customers' concerns for their health and safety are taking business away from shopping malls. Many shoppers are now rethinking their consumption patterns, reprioritizing consumer goods, and feeling a sharp hit to confidence.

On the other hand, due to this crisis, many retailers and mall owners are now accelerating their business plans to find new ways to bring their customers back. The overriding priority for customers returning to the shopping mall is safety. The key to getting customers back to the mall is to create a safe shopping environment for mall owners and retail store owners to invest in safe ways to protect their customers. Many retailers are looking for some precaution ways to impose into shopping malls to limit the virus's spread.

According to the advice by the WHO, there are several rules that people need to follow to protect themself and others safe:

1. Get the vaccine as soon as possible.
2. Keep a social distance of more than 1 meter from others, and then avoid crowded places.
3. Wear a fitted mask correctly.

They are the best ways to prevent the transmission of COVID-19. Countries worldwide are gradually applying them to society as a mandatory rule. Many research works have proved that wearing masks and social distancing are effective non-pharmacological approaches for controlling the spread of infectious diseases such as influenza, MERS, and COVID-19. Mall owners have imposed these constraints as regulations in the mall. However, monitoring the efficiency of these regulations is not an easy task. Shopping malls usually have higher foot traffic than other public places. It is not enough to rely on employees or security guards in the mall alone to check and maintain the rules.

Many novel technologies have been used to support these virus prevention constraints in such situations. GPS location tracking: Many governments use GPS positioning to curb the spread of the virus effectively. This personal tracking technology can determine whether people are following epidemic prevention rules. And after the case is found, the Government can track the transmission route's trajectory to help institutions conduct epidemiological investigations. Artificial Intelligence: Deep neural networks can extract complex features from video data and classify these features to recognize some objects. It can also support social distancing monitoring as well by object-detection. Virtual reality(VR) and Augmented reality(AR): VR technology has been used for preventing infections by simulation of data, telehealth, telecommunication during the pandemic. AR technology has also been used in this pandemic period, such as providing remote healthcare and facilitating remote collaboration to keep the social distance constraint.

To address customers' concerns for their health and safety in offline shopping. We proposed an AR system to support the prevention of the virus at shopping malls. According to the two best anti-virus constraints from WHO mentioned above, this system is to help mall owners maintain two regulations: 1. Wear a mask 2. Avoid crowded by preventing un-masked people and crowd gathering situations within the shopping mall. This system is to be deployed in shopping malls. In theory, we can apply it to any building of interest. We selected the school building as the shopping mall to prototype and demonstrate this system. In this thesis, we mainly make the following contributions:

1. Explore the image of the "Mall of the future" by reinvigorating the shopping environment in terms of safety.

2. Provides a new concept of visualization way to monitor and maintain order in the shopping mall.

3. A prototype of a COVID-19 prevention system in the shopping mall based on augmented reality.

# Chapter 2

# Background

## 2.1 New trends of consumers

Since the pandemic, there are new trends have emerged in consumers.

**Focussing on essentials:** The Covid-19 fears are not going to disappear soon. Understandably, consumers prioritize necessities or health supplies. They also try to avoid spending on clothing, household appliances, and furniture.

**Accelerate the shift to online shopping:** As the government implemented the lockdown measures worldwide, consumers have accelerated the shift in spending patterns to online shopping. A significant portion of consumers has already made the switch successfully. They have overcome the initial friction of using shopping websites and online payment systems.

**Safety expectation:** At home isolation, half of the consumers still said they wanted to return to retail stores to make purchases. But their expectations for offline shopping have changed. They now demand more safety than they do convenience in the mall and the price of the goods.

## 2.2 New retail paradigm

Countries worldwide have now introduced supportive policies for their economies, and the retail industry is sure to come out of the woods in the future. Getting out of the predicament is also the process of industry reshuffling. Many retailers who are not flexible enough will be eliminated by retailers who have flexible strategies. A number of retailers with a new retail paradigm will be born in the industry.

### 2.2.1 Self-service

Because viruses can spread via coins and banknotes, self-checkout services are gradually gaining popularity in supermarkets worldwide, and staff formerly in charge of checkouts are being reassigned to help restock and control customer traffic. In addition, Japan's Trail supermarket has eliminated the checkout line process. The supermarket uses an intelligent shopping cart to scan the checkout code while selecting products. This is a new retail trend that avoids cash transactions.

### 2.2.2 Delivery service

Many shopping malls are starting to develop online shopping services with fewer customers to capture the market. They have added more delivery slots and more staff to handle the business's e-commerce site, such as delivery pickup and packing. But the Malls' delivery services are not just joining the e-commerce business. They also take advantage of their geographical location to launch 30-minute delivery services. Because supermarkets play such an important role in supplying people's livelihoods across the country, their same-day delivery services provide convenience to large numbers of vulnerable people and increase their profits.

## 2.3 Augmented reality in infectious diseases

Augmented reality is a very practical and novel technology. Many researchers have explored the prospect of its application in people's lives. Infectious disease prevention is an important field of these prospects. For infectious diseases, it is important to cut off the transmission route. There is an AR system to promote hand hygiene. The researchers of this system used projection AR to create a virtual interactive space over the alcohol-based hand rub. When some people enter this space, the system will display virtual viruses. This display way reminds people to do hand cleaning with alcohol hand rub. There is also a serious AR game to help people make strategies for preventing the spread of dengue. This AR game simulated the transmission of dengue. People can understand transmission dynamics easily and develop a corresponding response strategy. Through this simulation training to gain experience for the real situation. For defense COVID-19, there is an AR system to support high-resolution audio and video communication. It has been provided to doctors in china to make remote consultations with senior experts in safe areas. The company Snapchat has launched a new AR feature for their AR lens function in the application. It names AR donations. Suppose we use the AR lens in the Snapchat application. In that case, when we put the phone camera above the banknote, various 3D models will appear on the banknote to represent which way your donations will be used to fight with the COVID-19. The retail industry is eager to embrace new technologies to survive in the post-pandemic world. There is a virtual fitting AR system. This research allows people to use their own 3D avatar to try 3D clothes models in their homes. In this way, they can reduce the risk of infection.

# Chapter 3

# Related Work

In this chapter, we review research in the following related fields: Medical-related research, Indoor localization technologies, artificial intelligence(AI) research, augmented reality(AR) research. First, We will briefly review the medical community's efforts to prevent the spread of the COVID-19 pandemic, including progress in vaccine development and the current situation of the pandemic. This review will provide a clear understanding of the difficulties facing the world today. Next are related indoor positioning technologies, Object detection, and finally augmented reality in related fields and research on occlusion management.

## 3.1 Medical research

After the world health organization published the health recommendation for the public, many studies have proven that wearing a mask and maintaining social distance are two very effective ways to reduce the transmission of the COVID-19 virus. Cheng V, Wong, S, Chuang V, et al. They evaluated the effect of community-wide mask use on the outbreak of COVID-19 in Hong Kong. They proved that wearing a mask can effectively prevent the spread of the virus through saliva. [2]. Eikenberry S et al. developed a compartmental model to assess the impact of community-wide mask use on the spread of COVID-19 [3]. They use COVID-19 transmission data from Washington state and New york city. The simulation result of the data demonstrated that even if the mask's performance is not good, it can still reduce the spread of the virus and decrease mortality. For social distance, many studies evaluated its effectiveness. Thu, Tran Phuoc Bao et al. assessed the effectiveness of the social distancing measures in 10 countries through the confirmed cases and deaths [4]. They demonstrated that after the government announced the highest level of social distance measure, the effect of this measure showed up in the number of people infected after 1 to 4 weeks. In contagious disease studies, the susceptible-infected-recovered(SIR) model is often used to assess the theoretical number of infections. In 1927, William Ogilvy Kermack and A. G. McKendrick proposed one of the earliest SIR models [5]. Ceyhun Eksin et al. introduce social distance as a new parameter in the SIR model to forecast the number of infected people [6]. As more and more virus variants emerge, vaccine efficacy is getting poor. Wearing a mask and maintaining social distancing can effectively prevent the spread of COVID-19.

## 3.2 Indoor localization

Our research requires devices to have the ability to locate specific people in the building. There are many positioning methods. V. Kulyukin et al. proposed a robot-assisted indoor navigation system based on radio frequency identification (RFID) technology [7]. These kinds of passive RFID tags can give the robots stimulation at the right place and assist them in taking the right path. Sakmongkon Chumkamon et al. also proposed an RFID-based system to support the visually impaired to reach the target location correctly [8]. The RFID chips are filled with location information that they import. Some studies use wireless signals for localization. Paolo Barsocchi et al. proposed a wireless network-based positioning algorithm [9]. They measure the Received Signal Strength Indicator(RSSI) and then translate it into distance data. By using a calibration method, their system can locate the mobile device's location. Because of wireless networks' wide distribution and applicability, these signal strength-based measurement and localization methods have further research. Sandy Mahfouz et al. reconstructed the relationship model between distance and signal strength in the separated sensors [10]. This study can track a moving target in a wireless network by the estimated RSSI/distance models. To confirm the target's location, they also used the acceleration information of the target. Some studies use AI technology to improve localization accuracy. Torteeka P et al. used the K-Nearest neighbor algorithm in the Wi-Fi Fingerprint technique to classify data tags, thus improving the accuracy of Wi-Fi location [11]. In recent years, another positioning technology has emerged in indoor positioning, named Ultra WideBand(UWB). UWB is a short-range wireless communication technology with low energy and high bandwidth [12]. It has good accuracy and good anti-jamming performance. The disadvantage is that it is too costly to apply to the actual environment. In addition to signaling positioning techniques, computer vision for localization has also been studied. Avi Cooper et al. used low-cost webcams paired with a series of algorithms to detect people in the video stream and then determine their location [13]. This research shows that this method achieves 95% accuracy of people detection and half-meter positioning accuracy. This system can apply to a large area such as a shopping mall.

## 3.3 Object detection

Research on artificial intelligence has been a hot topic in recent years. Among the many subfields of artificial intelligence, the target detection function is very widely used. The mainstream algorithms are divided into two types: One-stage methods and two-stage methods.

About one-stage methods, Wei Liu et al. presented Single Shot MultiBox Detector(SSD) for detecting objects in images by only one neural network. [14]. The core of this algorithm is the multiscale feature map. Convolutional layers convert the original image, and this data is called a feature map, which contains the information of the original image. The SSD network contains multiple convolutional layers, and the feature map is used to locate and detect the objects in the original image. Joseph Redmon et al. presented You Only Look Once(YOLO) to detect the object [15]. YOLO uses a method that deals with regression problems for object detection, and only one convolutional neural network is applied to the whole image. The image is divided into grids, then YOLO predicts class probabilities and bounding boxes for each grid. This algorithm can also predict the probability of the presence of objects in the bounding box. YOLO is very fast. There are some two-stage methods. The standard RCNN algorithm proposes to create multiple bounding boxes in an image and check whether these boxes contain the target object. RCNN uses a selective search method to extract bounding boxes from images. Ross Girshick presented a Fast Region-based Convolutional Network method (Fast R-CNN) for object detection [16]. In Fast R-CNN, the ssp layer is replaced by the ROI Pooling layer. They also proposed the multi-task loss function(MTLF). These improvements make CNN faster.

After the COVID-19 outbreak, these AI techniques have also been of great help in reducing the virus's transmission. Li Cuimei et al. proposed a face detection algorithm that combines Haar cascade algorithm and three classifiers [17]. These three classifiers correspond to mouth detection, eye detection, skin hue histogram matching. They used OpenCV to test it on human photos. The result shows this algorithm is effective and achieves standard performance. After the virus outbreak, some research related to mask detection has emerged. Bhambani K, Jain T, Sultanpure K proposed a YOLO-based deep learning solution to help execute social distance and wearing masks in public [18]. Preeti Nagrath et al. proposed a face mask detection method by using deep learning [19]. They used Single Shot Multibox Detector to detect the face mask and use the MobilenetV2 framework to make it runnable in embedded devices. Based on object detection, Monocular distance estimation research has made some progress. Julie Chang, Gordon Wetzstein proposed a monocular depth estimation method based on a neural network [20]. They added optical parameters to make the depth estimation better.

## 3.4 Augmented reality on navigation, shopping, pandemic

Augmented reality technology has seen unprecedented growth in recent years. The AR market is growing rapidly, and a lot of research on AR close to people's life has emerged.

Prashant Verma et al. proposed an augmented reality navigation application based on a 3D map created from point clouds [21]. However, collecting point clouds requires Lidar equipment, so the kind of system is currently used more in robot navigation. Sebastião Rocha and Arminda Lopes presented a navigation application based on augmented reality [22]. They proposed a solution running on a smartphone that calculates a person's location by using spatial computing. The system can track users' movement throughout the environment.

Many AR studies focus on enhancing the user's shopping experience. Edmanuel Cruz et al. used deep learning technology and AR techniques to enhance the users' shopping experience in retail stores [23]. In this system, users use their smartphones to take a picture of their surrounding environment and upload it to the server. The server uses a deep learning model to recognize the user's location by the image information. The system provides related information based on the user's environment, such as the route to the user's area of interest, a 3D model of the surrounding products, and rating analysis. Soh Masuko and Ryosuke Kuroki proposed to visualize the popularity of physical stores by Overley 3D human-shaped icons with user comments on a physical map [24]. By this visualization way, users can recognize the popularity of shops intuitively.

There are many AR studies to cope with the COIVD-19 pandemic. The use of AR for remote assistance at work reduces the need for people to go out and maintains the highest level of social distance. Tiago Madeira et al. proposed to use annotations to improve the sharing experience between on-site people and professionals [25]. Peng Wang et al. proposed a system that experts operate a 3D model using gestures in a VR workspace and transmit the expert's operations to the local worker's AR devices so that local workers can see the remote expert's operations as a reference through AR [26].

AR also provides great help in the remote education field in the case of a complete lockdown. Annalisa Liccardo et al. proposed displaying instruments remotely in augmented reality on students' consumer devices and letting students access the instruments continuously and control them by the internet of thing technique [27].

## 3.5 Occlusion management

The ability to see invisible things is one of the features of AR. Wu and Popescu V integrated additional perspectives to the user's perspective seamlessly in immersive virtual reality and augmented reality experience [28]. This method gives the user multiple views and allows them to see a lot of content with a little movement.Their research allows the user to see a lot of content with a little movement. However, their mixed vision is chaotic, and it can cause dizziness in people who are constantly moving. There are also some studies on perspective vision. Avery B et al. proposed an augmented reality system with multi-view modes [29]. This system has two kinds of visualization methods. The edge overlay visualization makes AR objects appear behind walls rather than in front of the user. The tunnel cut-out visualizations make the object display more realistic by providing occlusion layers between the user and the remote location. Stefanie Zollmann et al. evaluated various methods of implementing x-ray view in augmented reality [30]. Their research result shows that image-based ghosting can help users to understand the order of depth between AR objects.

# Chapter 4

# Research Goal and Approach

## 4.1 Goal

By identifying changes in consumer sentiment, emerging future retail trends, COVID-19 impacts the retail industry. Mall owners need to ensure a safe environment and impose virus prevention regulations on their Malls to get their consumers back.

Retailers and Mall owners are expanding their thinking to keep their business still relevant in the post-pandemic world. This research is to create a safe offline shopping environment in the shopping mall based on the novel augmented reality way. It addresses customers' health and safety concerns, protecting them from the virus.

To achieve this goal, we proposed an AR system to prevent the spread of the virus at shopping malls.

## 4.2 Approach

According to the WHO advice for the public about COVID-19, customers at the Mall need to pay attention to two points: 1. Wear a mask 2. Avoid crowded. We designed this system to prevent two situations: un-masked people and crowd gathering within the shopping mall. This AR system consists of three parts of work.

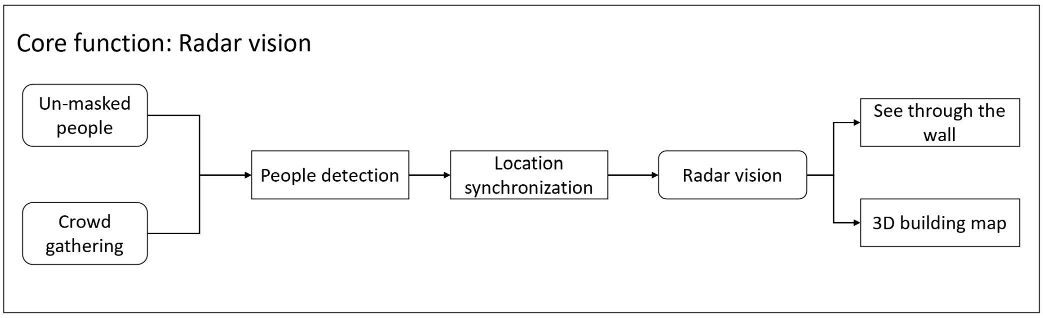



Fig. 4.1 Approach of Radar vision

1. The first part is to build the base function radar vision of the system. The system can detect the two situations: Unmasked people and crowd gathering in the shopping mall at all times. Mall guards and users wearing our Hololens can see the radar images of people detected by the system's server through the walls.

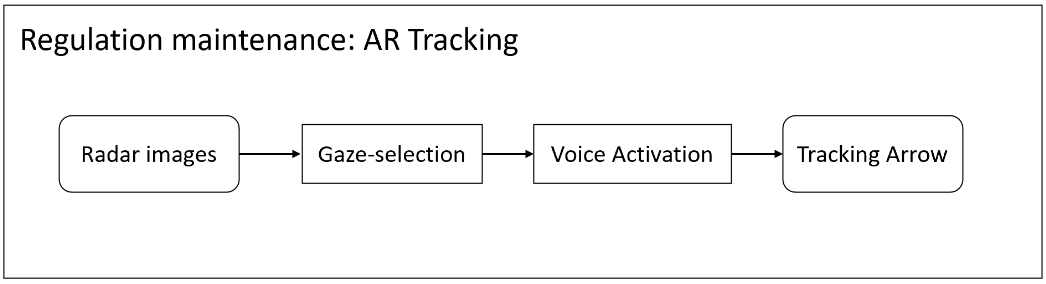



Fig. 4.2 Approach of AR Tracking

2. The second part is to build the AR Tracking function for maintaining a safe environment in the Mall. Mall guards can grasp information about the location of high-risk situations in the Mall through the size of the see-through image and the virtual mini-map in their right hand. After confirming the situation in the field, the Mall guard can use eye-tracking to select the target person they want to track and turn on the auxiliary navigation arrows to the target location to maintain order.

3. The third part is to build the user protection function for our system users in the shopping mall. When our system users enter the Mall, the system will display an augmented reality ring with a radius of 2m below the user's body to be a social distance guideline. When the user is about to meet the un-masked people or a crowd gathering in the Mall, they will

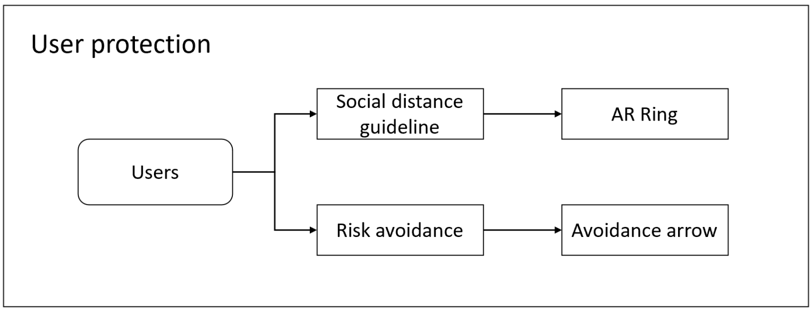



Fig. 4.3 Approach of User protection

receive an alert to remind them of the dangers. They will also see these high-risk situations in the surrounding by radar vision and have an avoidance arrow to guide them to the correct avoidance direction.

# Chapter 5

# System Design

In this chapter, we will introduce the system design. In the system overview part, we present an overview of the system's structure and explain how it works. Then we introduce the various hardware devices used in the system. Finally, we explain how we designed the innovative radar vision and the AR tracking and user protection features.

## 5.1 System Overview

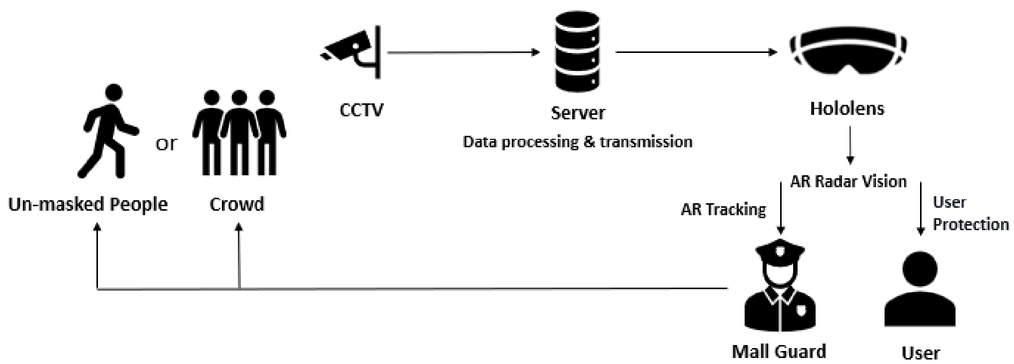



Fig. 5.1 system overview

This system uses three types of hardware CCTV cameras, servers, and Hololens. According to the WHO advice for the public about Covid-19, it monitors two high-risk scenarios in the mall: unmasked people and crowd gathering. After recognizing and processing the CCTV Video on the server-side, the front-end display device Hololens can display the information of these two risk situations in a radar vision way. The system is mainly provided to two kinds of users: the Mall guards patrolling in the mall, and the other is the general users of our system in the mall. Based on radar vision, Mall guards can use the AR tracking function to select targets and get to the scene quickly to maintain order based on radar vision. The general user can avoid this high-risk situation to protect themself.

The system includes one core function: radar vision and two advanced features: tracking and user protection.

**Core function**

**Radar vision:** After detecting and marking people without masks or crowd gatherings inside the building, no matter how many walls separate the user from the marked people, the user can intuitively see these people through the walls and grasp their location, just like giving the uses superpower. This kind of location information will also display on the mini-map to allow the user to get location information more clearly. The radar vision consists of three base components: people detection, location synchronization, radar image, and two views: augmented view and status view.

- People detection: detecting unmasked people and crowd gathering based on a complete surveillance system in the mall.
- Location synchronization: By setting up the landmark mapping, the detected people's location is synchronized to the virtual world in Hololens.
- Radar image: Create a hologram avatar to represent the person's radar image.
- Augmented view: it is the main view of radar vision. It allows people to see through walls and observe radar images of unmasked people and crowds inside a building.
- Status view: the secondary view of radar vision displays crowd gathering and unmasked people location information on a 3D map.

**Advanced features:**

**AR Tracking:** After the radar vision shows the marked people, the Mall guards can use gaze to select the target person they want to track. They can also use the voice command to activate the navigation arrow to assist them to quickly reach the target location and deal with the situation at the scene.

**User Protection:** it includes two functions. One is the AR ring, and the other is risk avoidance. They are all designed to protect general users in the mall to keep them safe from virus infection.

- AR Ring: when general users move inside the Mall, the system displays an augmented reality ring with a radius of 2m below the user's body to indicate social distance. If the social distance is normal, the ring is white, and the ring turns red if others break the social space. This ring is used to warn users to keep social distance and prevent the risk of infection.
- Risk avoidance: when the user is about to meet unmasked people or a crowd gathering in the Mall, the system will alert the user to avoid them. The system will also keep displaying the avoidance arrows until the user faces the correct avoidance direction. This is a risk warning function to protect general users.

## 5.2 System hardware


Fig. 5.2 System hardware

The system consists of three hardware components: Hololens2, Camera, PC.

In order to allow users to free their hands and not hinder their regular security work or shopping activities, the system uses mixed reality smartglasses to display the hologram content. This system uses Microsoft Hololens 2 as the mixed reality smartglasses. Hololens

2 is a wireless, ergonomic self-contained holographic device. In addition to being able to display augmented reality content, it can also provide real-world environmental awareness in mixed reality applications.

We also use the monocular camera as CCTV cameras to capture video information from the scene. This video information is transmitted directly to the server. Here we use Webcam.

In addition to the above two hardware devices, the system also needs a server to process and transfer data. Here we use a laptop PC as a server. We connected the webcam to the laptop PC and kept the laptop and hololens on the same local network for data transmission between each other. Table 5.1 shows the configuration information of the computers we used.

| | |
|---|---|
| Operation System | Microsoft Windows 11 |
| CPU | Intel® Core™ i7-10750H @2.60GHz 4.80GHz |
| Graphics Card | NVIDIA GeForce RTX 2070 MAX-Q |
| Ram | 16 GB |

Table 5.1 Information of PC

## 5.3 Radar Vision

In this system, the radar vision is the novel visualization way to help Mall guards keep track of the movement of detected people in the mall. We integrate basic radar functions such as people detection and position calculation into an augmented reality view compared to ordinary handheld radar devices. This allows mall guards equipped with our system to have X-ray vision like Superman in the comics. They can see the detected people regardless of the walls separating them. Then improve the efficiency of their patrol. This radar vision has a primary view: augmented view and a secondary view: status view. As shown in Figure5.3. These two views are supported and implemented by the system's basic functions: people detection and location synchronization. Next, we explain the design of the views and the basic functions in detail.

Fig. 5.3 Augmented view

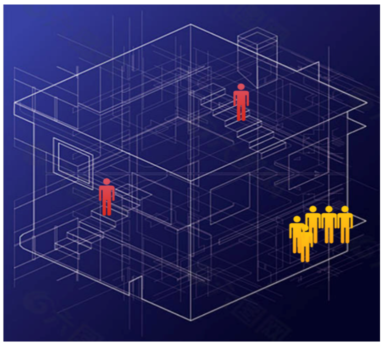


Fig. 5.4 status view

### 5.3.1 Augmented view

When the system detects the target person, the spatial anchor point of the target person's location will display the radar image avatar. The radar image avatar can intuitively display the target person's location, supporting long-distance perspective. With this augmented view, the mall guard can see through the wall and see the marked people's radar image to get a clear idea of where people are. For example, as shown in Figure 5.3, this view can see the person behind the pillar.

### 5.3.2 Status view

In addition to the augmented reality view, this system also provides a status view of the shopping mall. It helps Mall guards get a quick, clear idea of what's going on in the mall. It is like an upgraded version of the bird's eye view. Because it is composed of a 3D model of the building, it is not like a bird's-eye view that the exterior of the building will block. This status view can directly see the internal structure of the building and get clear position information of the marked people. As shown in Figure 5.4, the red human-shaped small image indicates people not wearing a mask and the yellow multi-person image indicates a crowd gathering in that place.


Fig. 5.5 Mask and social distance detection

### 5.3.3 People detection

According to WHO's advice, there are some necessary regulations to protect yourself and prevent the spread of COVID-19 in public places.

1. Keep a social distance of more than 1 meter from others, and then avoid crowded places.
2. Wear a fitted mask correctly.

So the system mainly detects two situations in the Shopping mall: un-masked people, crowd gathering. For fundamental security reasons, shopping malls usually are equipped with a complete surveillance system. The people detection functions take advantage of this surveillance system. The CCTV cameras in the shopping mall collect the input video and pass them to the server with a deep neural network model. In this way, we can enhance the cameras in the mall. These enhanced CCTV cameras can monitor people and determine whether people comply with epidemic prevention rules or not. Finally, mark these people for other functions.

### 5.3.4 Location synchronization

After the monitoring system detects the target person, the next step is to have the user's device locate where the person is. Because the world in Hololens is virtual, and the target person's location is in the real world. So in order to synchronize the location of the target person into the virtual world, we establish a mapping from the real world to the virtual world through virtual landmarks.

**Landmarks:** Similar to outdoor navigation, where landmarks such as famous buildings, rivers, bridges are used for localization, landmarks are also a great help for indoor localization. In this system, we choose the Azure spatial anchor service to create landmarks in the building. Spatial anchor is a cross-platform developer service that allows users to create objects that persist in their location on the cloud. We place spatial anchors scattered in the building, and through the connection of these points, a virtual map network is formed.

When the camera gets the target person's location, the system compares it with the location of the preset spatial anchor points. The system will choose the closest anchor to the marked person to be his position.

### 5.3.5 Radar image

After some people are detected, the ordinary radar machine can only display light dots on a 2D screen. This system enables users to see through the wall to see marked people. So we designed a human-shaped radar avatar to represent the marked people. This avatar comes with holographic effects, and it will be displayed at the location of the marked people based on the mapped landmarks.

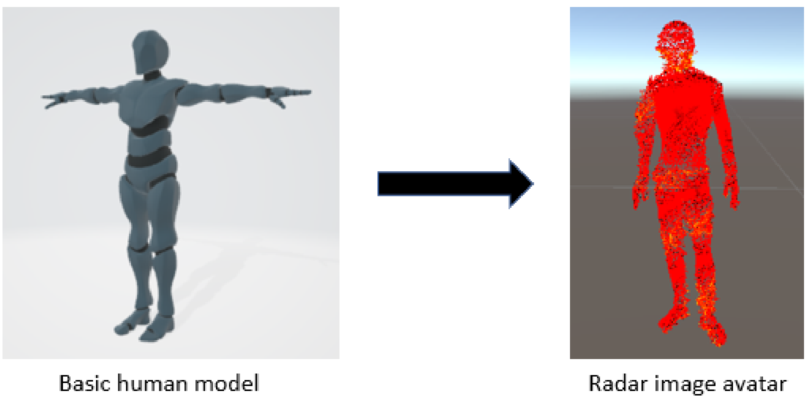



Fig. 5.6 Radar image avatar

## 5.4 AR Tracking

Mall security guards ensure the safety of everyone at the Mall. They work for the shopping mall itself, patrolling the premises, checking surveillance equipment. In the post-pandemic world, the mall guards were given new duties to maintain virus prevention and control regulation in the Mall while patrolling. Specific measures include:

- Evacuating the gathered crowds in a timely way
- It is finding people who have taken off their masks in the Mall and observing whether it is necessary to ask them to leave the Mall.

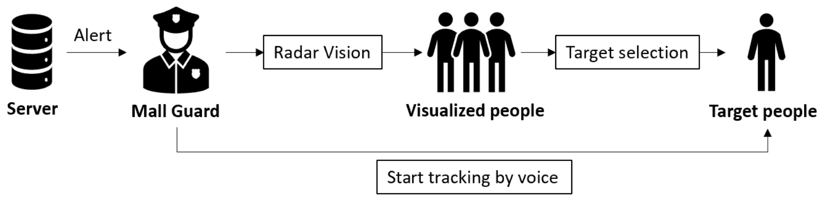



Fig. 5.7 AR Tracking

When radar vision detects an un-masked in the Mall, it sends an alert message to the Mall guard in the Mall. After receiving the warning notification, the Mall guard can quickly use his left hand to bring up the hand menu and click on the radar vision button to turn on the radar vision. Now Mall guards can see radar images of marked people, getting a general idea of the location of the marked people in the Mall. Then Mall guard can choose which people to track by using gaze. When the guard gazes at the marked people, it will turn yellow from red to indicate that it has been chosen. After selecting the target, the guard can use the voice command "follow this man" to activate the spatial arrow to help guide the guard to the target person.

### 5.4.1 Target selection

In reality, the Mall staff will kindly persuade people to wear a mask at the entrance to the mall, so inside the mall, the vast majority of people will comply with these regulations.

If multiple un-masked people or crowds are gathering in the mall, all these situations will be shown by radar image in the radar vision. At this time, letting the Mall guard quickly select the target is a problem we have to solve. The Mall guard can grasp the general situation by looking around after the radar vision visualizes all marked people. So we add the gaze-tracking method to solve this problem. When the Mall guard is looking around, they can also select the target person they want to track with their gaze. It makes them feel natural and convenient.

### 5.4.2 Voice command

After selecting the target person, the Mall guard needs to activate the tracking navigation arrows. Our system provides voice input to start the navigation arrows. Voice input is a natural way for humans to communicate intent. This input method is excellent for helping users skip irrelevant options and save steps. The Mall guard does not have to take his eyes off the target. They can say "follow this person" while looking at the marked people instead of looking at the hand and hitting the button in the hand menu.

## 5.5 Users protection

Based on radar vision, Users of our system can also obtain special protection and can move around the Mall without the worry of infection. In terms of protecting customers, the system proposes two functions: to maintain the social distance between users and others by AR Ring and to help users avoid the appearance of the two high-risk situations mentioned above.

### 5.5.1 AR Ring

The flow of people in shopping malls is generally higher than that in other public places. When people’s attention is focused on stores or goods, they may not consider their social distance from others. So after people enter the shopping mall, it is better to give them social

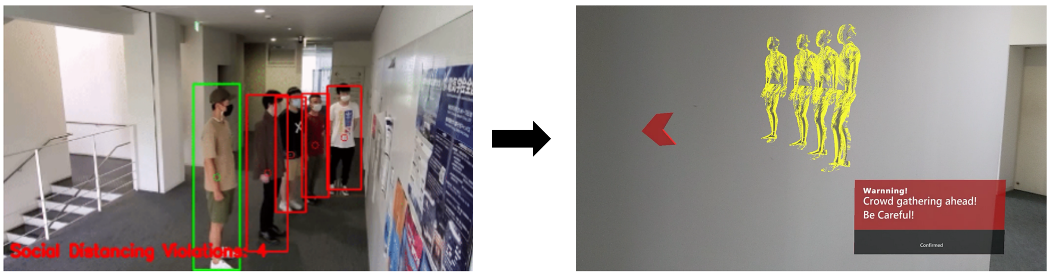
Normal AR ring　　　　Warning AR ring

Fig. 5.8 AR Ring

distance guidelines in the shopping mall environment. In order to realize this guideline, this system creates an augmented reality two-meter radius ring around them.

This AR ring is generally displayed in white, as shown in Figure 5.8 left side. When the distance between the user and others exceeds the safe social distance, the ring will turn red to warn the user to pay attention to the surrounding environment (5.8 right side). It not only helps users protect themself but others as well.

### 5.5.2 Risk avoidance




Server detection　　　　Risk avoidance

Fig. 5.9 Risk avoidance

When there is a high risk of infection situation, such as unmasked people or crowd gathering in the mall, the Mall guards on patrol will rush to the scene as soon as possible to deal with the situation. But it takes time for the mall guards to reach the target location. It is a problem to ensure the safety of other ordinary people in the mall during this time. In order to solve this problem, this system provides a risk avoidance function to users. When these two high-risk situations appear in the users' surroundings, the system will send a warning message to attract the user's attention. The system will also activate the radar vision to help users grasp risk position information about their surroundings. Finally, the system will display the avoidance arrows to guide the users to turn in the right direction to avoid risks around them.

# Chapter 6

# System Implementation

## 6.1 Software Environment

We developed the main application of this system on Unity 2020 and used C sharp as the development language for the main application. For the deep learning model on the server, we use python to build the detection program. The other software supports as follows:

- Mixed Reality Toolkit 2.6: it is a developer tool that provides the cross-platform input system and building blocks for our system's user interface and interactions. It also supports the OpenXR specification that provides high-performance access to augmented reality.
- Azure spatial anchors: It allows devices to mark points of interest in real space as landmarks through spatial awareness and access these spatial landmarks from the cloud.
- Azure table storage: It is a cloud storage space that can store non-relational structured data.
- Blender: Blender is a toolset used for creating 3D models and interactive 3D applications.
- OpenCV4: It is an open-source computer vision software library.

## 6.2 Radar vision visualization

We provide a new spatial X-ray visualization method. This X-ray method uses surveillance cameras to capture people out of view. It displays a radar image avatar at the detected people's location to achieve a perspective view with spatial information. This visualization method is different from the previous X-ray method [28, 30], which directly fuses the camera video information. Our visualization method is based on spatial anchors. It has factual geospatial information, making it more stable and more realistic than previous studies. In this method, first, we generate the radar image avatar for the augmented view and prepare the 3D building map for status view. Then we place spatial anchors in the building to synchronize the position information in reality to the virtual world and also map these anchors to the 3D building map. Third, we calculate the detected people's position. Finally, display the radar image avatar in the people's location to realize the radar vision. The detailed process of these steps is shown in the following subsections.

### 6.2.1 Radar image avatar generation

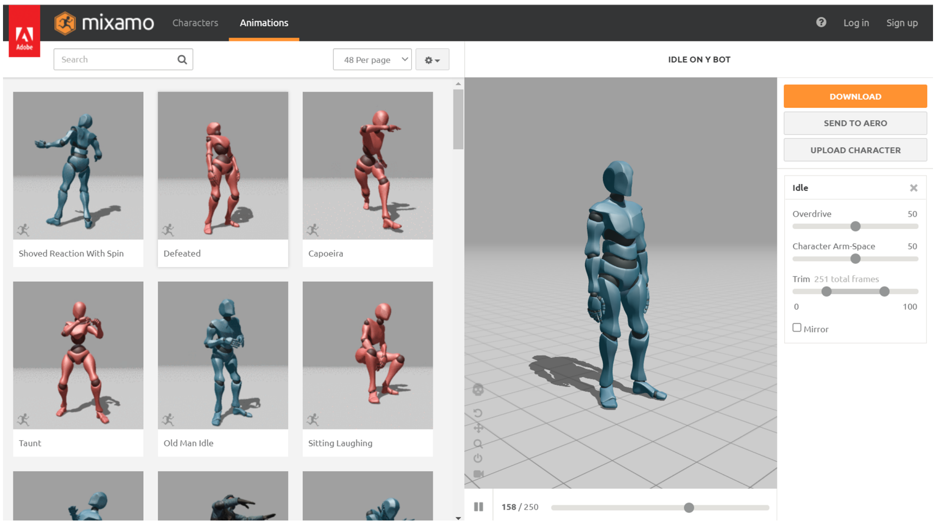
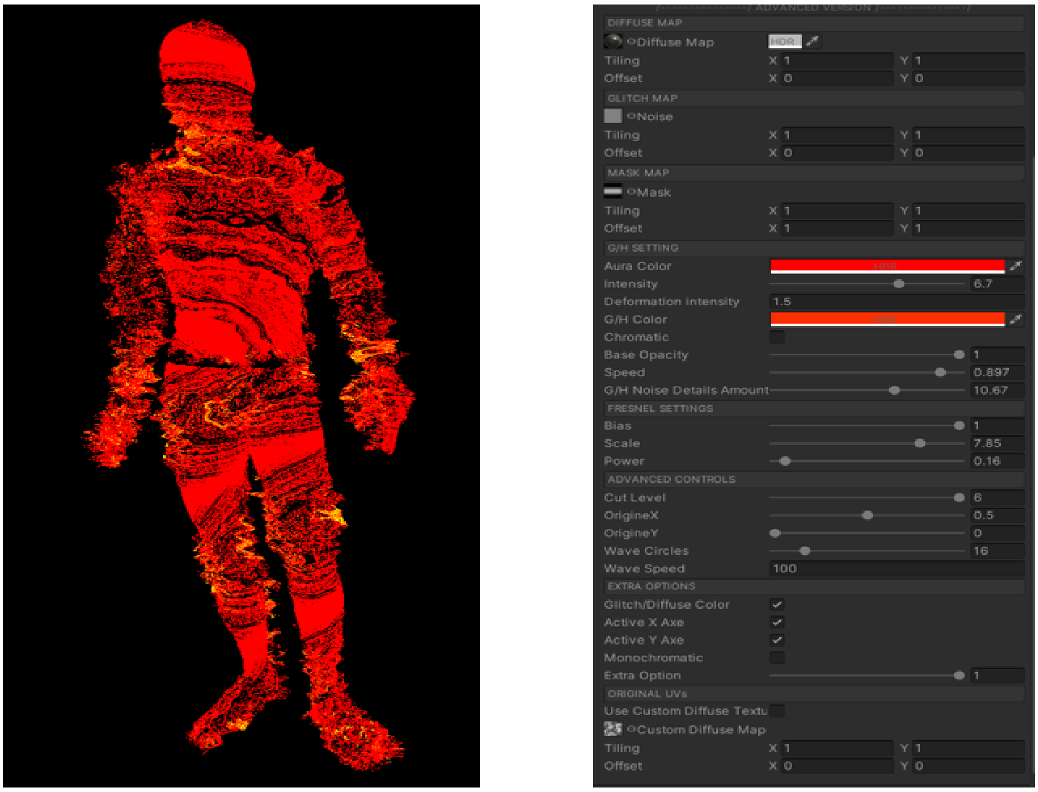



Fig. 6.1 Animation selection

The generation of the radar image avatar is an essential part of radar visualization. This avatar will represent the detected people and display them as radar images. To allow users to see realistic radar effects. The method of creating this avatar consists of the following steps:

- **Find the accurate3D human models:** In this system, we use a realistic 3D human character model from Mixamo.com. This model is high-quality and full-rigged so that we can use it immediately in our mixed reality system.
- **Select Animation and get the avatar:** After choosing the 3D human avatar on the Mixamo website, we can select animation to make it appear more natural. In this system, we choose idle action. We can use the editor panel on the right side to adjust the action's parameters and apply it to the avatar. The process is as Figure 6.1 shows. Select the Download button, and then we get the avatar with animation.




**Radar image avatar** **Hologram effect panel**

Fig. 6.2 Radar image avatar

- **Holographic effect:** We used a Holo special effects package from the Unity store to achieve a realistic effect. This Holo fx pack has many holographic and radio interference effects. After adding a holographic effect to the avatar, we adjusted the parameter on the right panel to make it appear better. The essential parameters: "Diffuse" controls the visibility; "Intensity" controls signal fluctuation; "Power" and "Speed" control the noise interference-effect.

- **Always visible:** Because the core of this system is a through-wall perspective, to ensure the interaction experience, this avatar should not be blocked by the system's UI components. We use the unity shader to let the avatar always be at the forefront. The shader program is as Figure 6.3 shows.

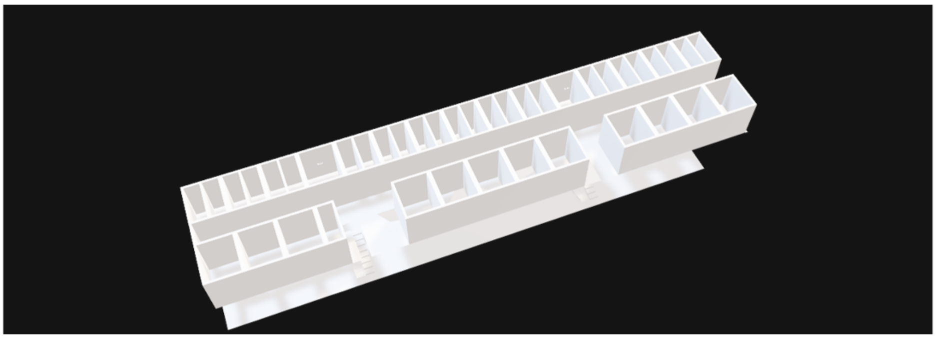
```
ZWrite Off
ZTest Always
Blend SrcAlpha OneMinusSrcAlpha

Pass
{
    CGPROGRAM
    #pragma vertex vert
    #pragma fragment frag
    #include "UnityCG.cginc"
    struct appdata
    {
        float4 vertex : POSITION;
    };
    struct v2f
    {
        float4 vertex : SV_POSITION;
    };
    v2f vert (appdata v)
    {
        v2f o;
        o.vertex = UnityObjectToClipPos(v.vertex);
        return o;
    }
    float4 _EdgeColor;
    fixed4 frag (v2f i) : SV_Target
    {
        return _EdgeColor;
    }

    ENDCG
}
```

Fig. 6.3 Always visible shader program

### 6.2.2 3D building map

This system is to be deployed in shopping malls. In theory, we can apply it to any building of interest. We selected the IPS School building as the shopping mall to prototype and demonstrate this system. To realize the status view, we need a 3D map model of the IPS building. We modeled the IPS building manually based on the IPS building plan structure.


**IPS building plan view**



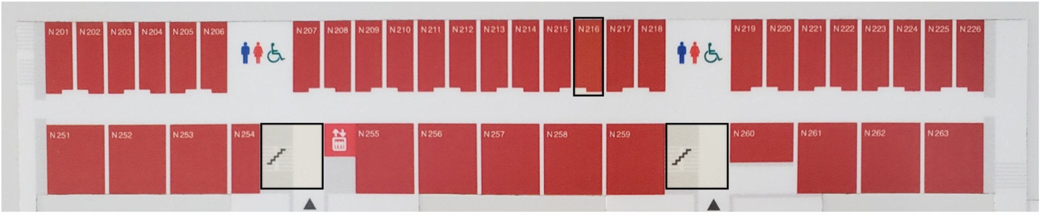
**IPS building 3D model**

Fig. 6.4 Make 3D models of buildings

### 6.2.3 Location mapping

When the server with a surveillance system captures un-masked people or crowd gathering status, the Mall guard doesn't know the location of these people. In this system, we provide a location synchronization method to synchronize the place of the tagged people in reality to the virtual world. This method allows the device to know the location of these people. These are the conceptual steps:

- **Divide the building area:** This system divides the building area according to the distribution area of the CCTV cameras. We have arranged webcams in three main areas to act as surveillance cameras to demonstrate this system. The three black areas of the figure 6.5 shows that our laboratory and two lobbies near the stairs are these three main areas.



**IPS building plan view**

Fig. 6.5 Divide the building area

- **Create local anchors:** We go to these three selected monitoring areas to create local spatial anchors. This system can calculate those anchors' locations in the real world.
- **Upload anchors to azure:** By uploading the local spatial anchors to the cloud service, the anchors become azure spatial anchors. We can use a durable azure spatial anchor to let multiple Hololens observe the same persisted avatar over time.

| PartitionKey | RowKey | Timestamp | SpatialAnchorId | Name |
|---|---|---|---|---|
| main | Lobby 1.1 | 2021-10-02T10:39:49.30... | de5baa3a-8512-4aa1-9... | Lobby 1.1 |
| main | Lobby 1.2 | 2021-10-02T11:29:46.71... | d5d55d42-a3c9-4d4c-8... | Lobby 1.2 |
| main | N216 | 2021-09-15T06:02:37.21... | 2ecf649a-de14-4487-8a... | N216 |

Fig. 6.6 anchors in azure cloud service

- **Connect anchors to the camera:** Classify cloud spatial anchors to the corresponding camera monitoring area. The system can form a virtual location network of these three areas based on presetting this positional relationship.

```
CCTV1_anchor_dis = {"Lobby1.1": 4, "Lobby1.2": 2}
CCTV2_anchor_dis = {"Lobby2": 2}
CCTV3_anchor_dis = {"N216": 2}
Building_Area_CCTV = {"cam_lobby1":
CCTV1_anchor_dis, "cam_lobby2": CCTV2_anchor_dis,
"cam_lab": CCTV3_anchor_dis}
```

Fig. 6.7 relationship between cameras and anchors

### 6.2.4 Anchors in 3D building map

In the 3D building map in the status view, we also placed a series of anchor points. As shown in the yellow sphere in Figure 5, these anchor points represent the azure spatial anchors we set in the study area. By these anchor points in a 3D map, we can also synchronize the location in the actual building area to the 3D representative map of the building.

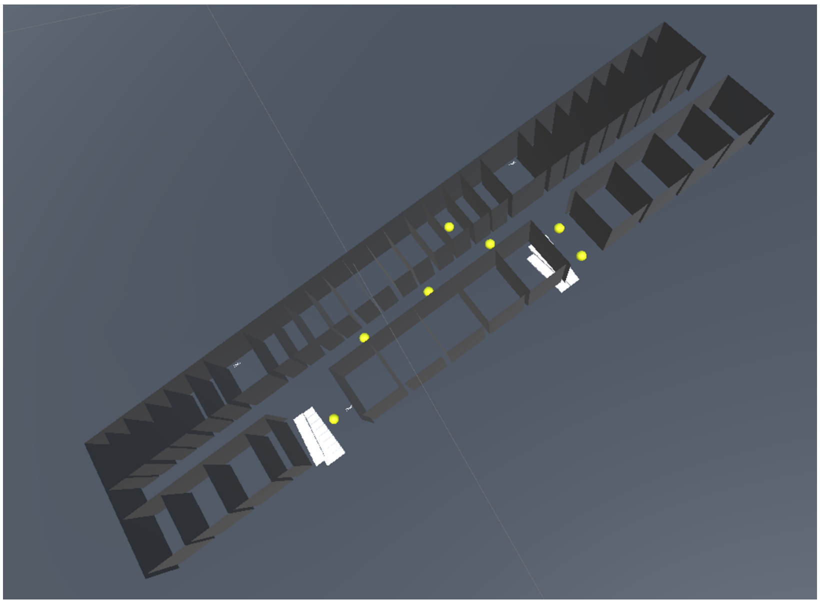


Fig. 6.8 Anchors in 3D building map

### 6.2.5 Interval distance estimation

There are two very popular technologies for ranging: binocular cameras rang and Lidar camera ranging. They are very common in smart cars nowadays. However, Our system aims to be deployed in the shopping mall or other public places. Due to the cost factor, these public places are not equipped with binocular cameras or Lidar cameras. We use the monocular solution to let our system be able to apply to all public places using only a general CCTV camera.

**Camera calibration:** The camera may have Tangential distortion and Radial distortion that can affect the camera imaging and ranging results.

1. **Tangential distortion** occurs when the lens and the image plane are not parallel.

2. **Radial distortion** occurs when light rays bend more near the edges of a lens than they do at its optical center.

```
# Find the chessboard corners
ret, corners = cv2.findChessboardCorners(gray, (11,8), None)
# Draw and display the corners
cv2.drawChessboardCorners(img, (11,8), corners, ret)
# Calibration function
ret, mtx, dist, rvecs, tvecs = cv2.calibrateCamera(objpoints,
imgpoints, img_size,None,None)
```

Fig. 6.9 Camera calibration

Camera calibration can correct the camera's distortion to make the distance estimation more accurate. After calibration, we can get the focal length of the camera and the position of the optical center in the imaging plane. With these two parameters, we can realize the monocular distance estimation. Following the instructions in the documentation, we created a 12x9 chessboard picture to do calibration work. The key code is shown in the figure 6.9.

**Principle of monocular ranging:**

We implemented the people detection function in the previous AI detection chapter when the people detection function is available, the pixel value of the bottom (P_Bottom) of the detected people in the imaging plane. Through the above camera calibration, we got the focal length and the pixel coordinates of the lens in the pixel coordinates system. We also know the mounting height of the camera, so it is possible to solve for the distance between the detected people and the camera.

The principle diagram is shown in the figure 6.10.

The distance measurement formula is as follows:

$$tan\theta = \frac{H}{Dis} = \frac{|P\_bottom - P\_center|}{f} \tag{6.1}$$

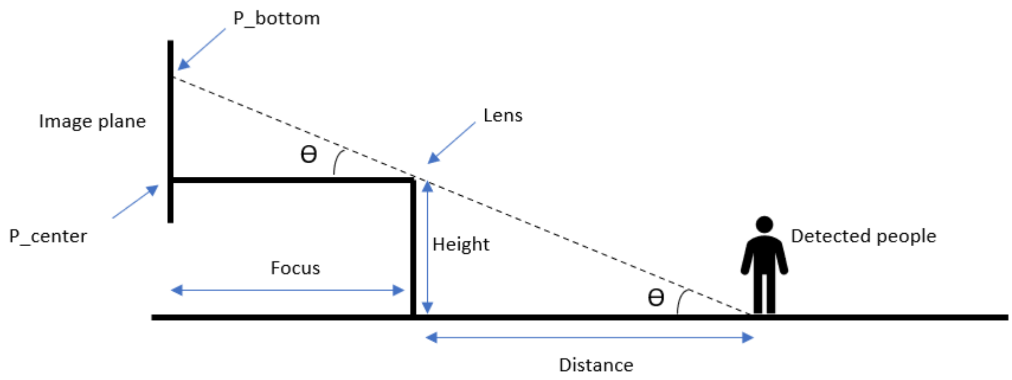



Fig. 6.10 Monocular ranging solution

### 6.2.6 Display radar image avatar

The final step in realizing the radar vision is to display the radar image avatar to the corresponding location. Section 6.2.3 knows the distance (C_A_distance) from the anchor to the camera. In section 6.4.1, we calculated the distance(C_P_distance) from the detected people to the camera. We can find the closest anchor to the detected people by comparing these two distances. Then we let the radar avatar be displayed on the location of this anchor. This way, people with radar vision can see the radar image displayed through the wall.

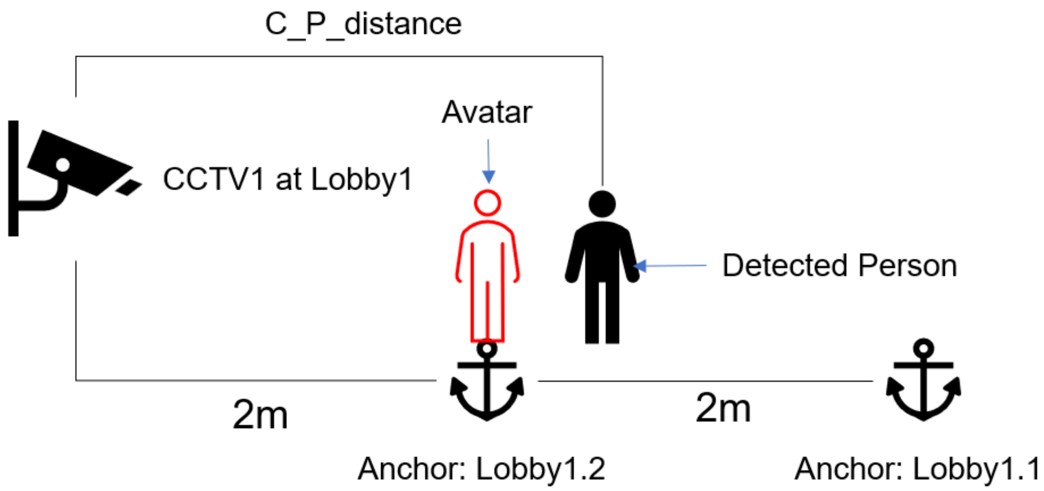



Fig. 6.11 Display radar image avatar

## 6.3 AI-Based detection

To work with the surveillance system in the shopping mall to detect un-masked people and crowd gathering in real-time, we used OpenCV to develop the real-time computer vision part in our system. Since OpenCV3.1, there has been a deep neural networks module in the library. These modules can do inferencing with deep networks and use some mainstream deep learning frameworks for pre-training. Based on the PyTorch framework, our system uses the YOLOv3 deep neural network model to do object-detection work.

### 6.3.1 Mask-detection

In reference [15–17], among object detection algorithms, one-stage methods such as SSD, YOLO, is generally faster than two-stage method, such as CNN, RCNN. In human face mask detection, the YOLO detector achieves a fast speed as well as a good accuracy [18]. referring to this study we made a deep learning model trained by YOLO for mask detection.

**Model training:** To train our model, we select an open dataset of medical masks to train our model. This dataset contains 1148 pictures. In these pictures: some people are wearing masks, some are not wearing masks, or some are not wearing masks properly. These pictures have been annotated corresponding to the label mask, none, poor.

**Detection:** After the model training, the first step is to load pre-trained models. To perform a forward pass for the whole network to compute the output result, the data we input to the network should be a blob type. The blob can be seen as a collection of images that have been adequately preprocessed to be fed to the network.

```
img = cv2.resize(frame, None, fx=0.4, fy=0.4)
height, width, channels = img.shape
blob = cv2.dnn.blobFromImage(img, 1 / 255.0, (608, 608), (0,
0, 0), True, crop=False)
net.setInput(blob)
detections = net.forward()
```

Fig. 6.12 Detection processing

### 6.3.2 Social distance detection

**Model training:** We use the YOLO with COCO model to detect people in the CCTV video stream for social distance detection. The COCO model is trained by the MS COCO dataset. The MS COCO dataset is large-scale object detection, segmentation, and captioning dataset. It is used as an evaluation dataset to test application performance in many computer vision applications. The COCO model performs good in our system.

**Compute social distance:** When there are more than two people who appear in the video stream. The system will obtain the center point by object-detection model and use the center point to calculate the euclidean distance between two people. Suppose the euclidean distance is greater than the pre-setting safe social distance. In that case, the system will judge these two people as a social distance violation.

```
if len(detected_people) >= 2:
    centroids = np.array([r[2] for r in results])
    D = dist.cdist(centroids, centroids, metric="euclidean")

    for i in range(0, D.shape[0]):
        for j in range(i+1, D.shape[1]):
            if D[i, j] < SAFE_MIN_DISTANCE:
                violation.add(i)
                violation.add(j)
```

Fig. 6.13 Social distance computation

## 6.4 System interactions

### 6.4.1 Gesture Interaction

The gesture is a form of non-verbal communication way. It is usually defined as various postures and movements produced by the hand or by the combination of hand and arm to express ideas, emotions, or emphasis. Gestures are a means of interaction in line with everyday human habits. People usually use gestures to convey some information or express a specific intention. The gestures can be divided into static gestures and dynamic gestures. Static gestures recognition considers the appearance features of a gesture at a certain point in time; For dynamic gestures recognition, it considers a series of people's actions over a while. Compared to static gesture recognition, it adds time information and action features.

In the context of augmented reality, the birth of gesture interaction provides a new way of interaction for augmented reality applications. Our system mainly uses dynamic gesture recognition to implement hand menu and manipulation of 3D building map.

**Hand menu:** when the security guard receives a warning message from the system. They can activate the hand menu by raising their left hand and looking into the palm of their hand. There are three buttons in the hand menu: The first button opens the radar vision, the second button activates the tracking function, and the third button opens the 3D building map.


Fig. 6.14 Hand gesture to call out the hand menu

**Hand interaction with 3D map:** After the 3D building map has synchronized the location of the detected people, the Mall guard can pick up the 3D building map and take a closer look at the location information.To interact and grab an object with tracked hands, the object must have a Collider component and two MRTK scripts to make an object movable, scalable, and rotatable using hands. As shown in Figure 6.15

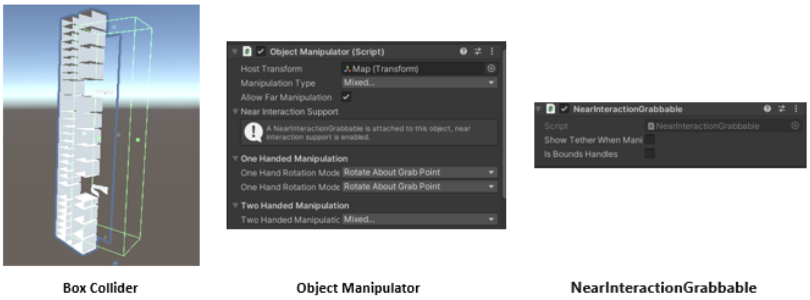



Fig. 6.15 Add hand interaction

As shown in Figure 6.16, Users can touch holograms directly with their hands.

Fig. 6.16 Grab the 3D building map

### 6.4.2 Gaze interaction

In our system, to allow Mall guards to focus more on their work and improve tracking efficiency, we use eye-tracking technology to help Mall guards select people displayed by radar vision.

The MRTK development tool provides us with eye-tracking input. By this input way, we can design our system more intelligently. The Mall guards can effortlessly choose holograms across their view.The key steps to implement this interaction are as follows:

1. Open the eye-gaze input capability in the MRTK configurator.

2. Modify the MRTK input system profile to enable eye-tracking.

3. Add EyetrackingTarget component to the radar image avatar.

To use eye-tracking to select the detected people, We set the user's gaze trigger; when the Mall guards gaze on the radar image, the radar image will turn its color from red to yellow to indicate that it has been selected. As shown in Figure 6.17.

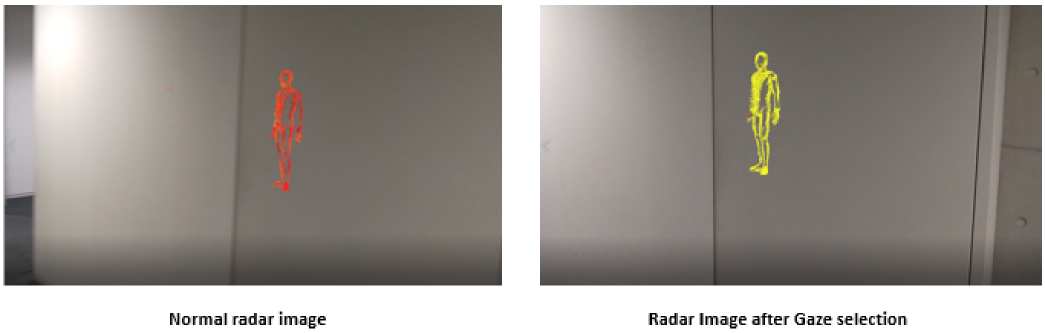
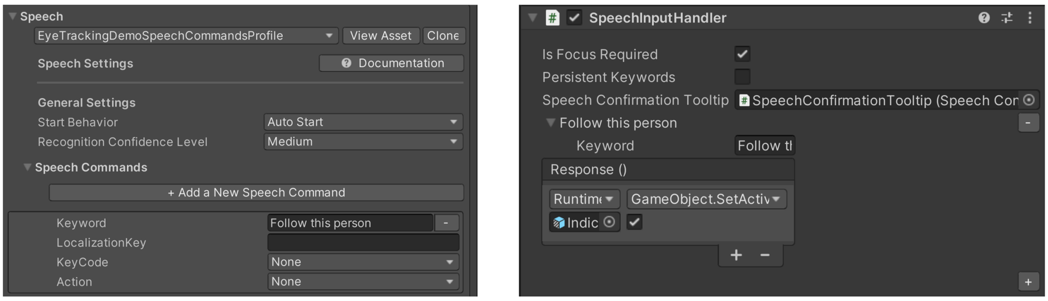



Fig. 6.17 Gaze-selection

### 6.4.3 Voice interaction

Although the operation with the hand menu has been very simple and clear, we can also achieve the touch button to activate the tracking function, but after the Mall guards have selected the target person to be tracked using eye-tracking, it is difficult to move their gaze to their palm to activate the hand menu, so in our system, we have implemented the voice command as a trigger to activate the assisted navigation arrows.The implementations steps are as follows:

1. Create speech commands: Add a new speech command In the MixedRealitySpeech-CommandsProfile.




**MRTKSpeechCommandsProfile** **SpeechinputHandler**

Fig. 6.18 Voice command

2. Add SpeechinputHandler component to the game object in the scene.

3. Define the actions triggered by voice commands in the SpeechinputHandler component.

The voice interaction settings are shown in the figure 6.18.

# Chapter 7

# Preliminary Evaluation

To explore the usability and effectiveness of our system, we conducted a preliminary evaluation in terms of functionality, learnability, efficiency, interface design, impact.

## 7.1 Participants

We gathered twelve volunteers to participate in our experiment. Their age distribution is between 20 and 30 years old. All participants had experience with general consumer electronics such as smartphones and computers and had experienced AR applications.

## 7.2 Method

We choose the school building as the study area. In the preparation of the experiment, we taught each volunteer the essential operation of the Hololens. Then we showed them a demo video of the system to familiarize them with the various interactions.

In the experimental session, volunteers were asked to play three roles to experience the system's functions. These three roles are Mall guards, customer Users of our system, and regular customers.

When the participants played the role of Mall guards, they mainly experienced the tracking function provided by the system to the Mall guards. At this time, Our staff removed their masks in the building, allowing the system to detect violations and send warnings to the participants. The participant accepts the warning message, activates the radar vision, observes the violation status in the building, and finally selects the target person to track.

When participants played the role of customer users, staff created crowd gathering situations in the building area. When users walked near the crowd, they received and followed system prompts to avoid crowd gathering violations. On the other hand, experience the social distance detection function of the AR Ring during the walking.

When participants played the role of regular users, they walked through the building without Hololens. Our staff created crowd gathering situations and randomly assigned unmasked people to wander around the mall.

# QUESTIONNAIRE

Name:

Age:

Gender:

Date:

Questions (strongly disagree 1, disagree 2, neutral 3, agree 4, strongly agree 5):

1. Do you think this system has achieved its predefined goal?

   1----2----3----4----5

2. Do you think this system is easy to get started?

   1----2----3----4----5

3. Do you think this system has effectively enhanced the mall's security (Infection prevention)?

   1----2----3----4----5

4. Do you think the system interface and tips are easy to understand?

   1----2----3----4----5

5. Do you think this system has increased your willingness to go shopping at the mall?

   1----2----3----4----5

6. Would you be more likely to go to a mall equipped with this system?

   1----2----3----4----5

Fig. 7.1 Questionnaire

After the experiment, we invited the twelve participants to complete the questionnaire. This questionnaire contains six questions. The first four questions correspond to functionality, learnability, efficiency, interface design. The last two questions assess the impact of the system. Participants need to grade from 1 to 5. Fig shows the questionnaire used in the experiment.

## 7.3 Result

We collected the questionnaire answers from these six participants. The results are shown in the figure 7.2 and figure 7.3.

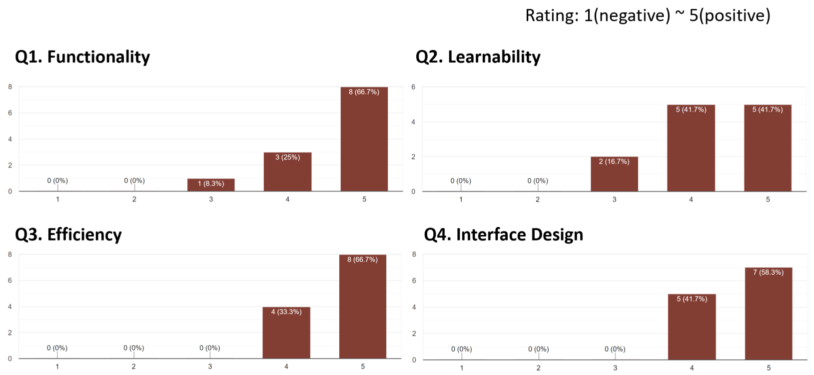



Fig. 7.2 Evaluation of the system

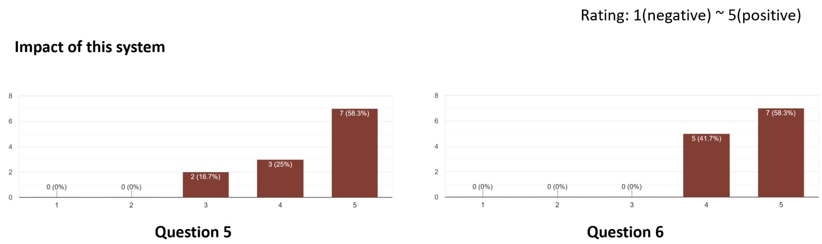



Fig. 7.3 Evaluation of the system impact

### 7.3.1 Functionality

For the functionality, the question is, "Do you think this system has achieved its predefined goal?" eight participants graded 5, three participants graded 4, and one participant graded 3.

### 7.3.2 Learnability

For the learnability, the question is, "Do you think this system is easy to get started?" five participants graded 5, five participants graded 4, and two participants graded 3.

### 7.3.3 Efficiency

For efficiency, the question is, "Do you think this system has effectively enhanced the Mall's security (Infection prevention)?" eight participants graded 5, and four participants graded 4.

### 7.3.4 Interface Design

For the interface design, the question is, " Do you think the system interface and tips are easy to understand?" seven participants graded 5, and five participants graded 4.

### 7.3.5 System impact

For the system impact, the fifth question is," Do you think this system has increased your willingness to go shopping at the mall?" seven participants graded 5, three participants graded 4, and two participants graded 3. The sixth question is, "Would you be more likely to go to a mall equipped with this system?" seven participants graded 5, and five participants graded 4.

# Chapter 8

# Conclusion and Future Work

## 8.1 Conclusion

Reaching a post-COVID-19 future for retail is an evolutionary process. Suppose Mall owners hesitate too long in deciding the direction of their strategic development. In that case, they will lose the opportunity to grasp new markets, retain loyal customers. They need to evolve their business quickly to meet the demands of the "new-normal shopper."

In this research, to meet the consumer's demands for safe offline shopping, we proposed an AR system for mitigating the risk of COVID-19 in the shopping mall. According to th e advice of WHO and medical research, Wearing a mask and social distance are two good ways to protect against the COVID-19 pandemic. This system enhanced the mall security system to help enforce wearing masks and proper social distancing in shopping malls using augmented reality.

First, to prepare the 3D components in this system, we designed the radar image avatar to represent a real person in the virtual world. It has an always visible property and a holographic display effect. We also created a 3D map model of the school building to prepare for the status view.

Second, we built the system's basic function, Radar Vision. This function uses the surveillance system in the mall to locate people who violate the two mandates: wearing masks and social distancing. Synchronize the location of the detected people to the virtual device. Hololens can give security guards an enhanced vision to observe the location of these people through the wall and grasp the overall dynamics by viewing a 3D mall map.

Finally, we built mall customer protection features to help them maintain social distance around them while shopping, avoid high-risk crowd gathering areas. Integrated the full functions of the system design into the Hololens application and performed a preliminary system evaluation using this application.

If one day the COVID-19 virus disappears from the world, I hope the existence of this paper will give a little inspiration to the future society and retail industry. I sincerely and eagerly look forward to the arrival of the day when the virus disappears.

## 8.2 Future Work

The "mall" as we know it will change forever. Mall owners will rethink the entire customer journey and provide a seamless shopping experience. This direction will connect the online world to the individual stores within the Mall, enhancing the overall shopping experience for the user. The shopping mall is also a popular meeting hub. The social experience of the Mall, such as dining out, is a point that cannot be replaced by online shopping. In the future, Augmented reality cannot only provide a safe shopping experience but also balance consumers' desire for social interaction and a convenient shopping experience. Our work will continue to enhance the security aspect, and use augmented reality as a bridge between the online world and the physical stores to get a glimpse of a future Mall scene.

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