Enhancing Mall Security Based on Augmented Reality in the Post-pandemic World

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Abstract. 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 bring their business back in this post-pandemic world. How to protect customers from COVID-19 in shopping malls has been a problem. This study presents an enhanced mall security system to help enforce wearing masks and proper social distancing in shopping malls using augmented reality (AR). We created a novel visualization way: Radar vision to display detected people in the perspective of mall guards, to 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 people violating wearing masks or social distance mandates through the wall. Mall guards can use gaze to select the target person and then use the voice command to activate the navigation arrow to help them quickly go to the scene. In addition to helping mall guards to enforce mandates, the system also provides assisted functions to protect customers. When the violation situation appears around a customer, the system will alert them to avoid and show an avoidance arrow until the user goes in the correct direction. We demonstrated a preliminary system with four surveillance cameras in our school building area. The pilot study shows that our system can effectively detect and display radar images, increasing the efficiency of mall guards and reducing customer safety concerns.

Keywords: Augmented reality · See through the wall · COVID-19 · Shopping mall

1 Introduction

Coronavirus disease (COVID-19) is an infectious disease caused by the SARS-CoV-2 virus. The virus was first detected in the city of Wuhan in December 2019. On 30 January 2020, the world health organization (WHO) declared the outbreak a public health emergency to draw international attention. The statistics by WHO on 13 January 2022 confirm 312 million infected people and a massive number of deaths worldwide.

The retail industry was then shocked by the COVID-19 crisis. Shopping malls suddenly lost customers because the world had to lock down for the prevention of the virus's spreading [1]. As restrictions began to lift, mall owners have been thinking of finding new ways to bring their business back. As a result of the isolation measures, customers

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accelerated the shift in spending patterns to online shopping. With the emergence of new virus variants repeatedly appearing [2], customers' concerns for their health and safety are taking business away from shopping malls. Their expectations for offline shopping have changed to demand more safety than they do convenience and the price of the goods [3]. Safety is the overriding priority for customers returning to the shopping malls. The key to getting customers back to the malls 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 spread.

Based on the advice by the WHO, there are several rules that people should follow outdoors to protect themself and others: 1. keeping social distance of more than 1 m, and avoiding crowded places. 2. wearing fitted masks correctly. Many research works have proved that wearing masks and social distancing are effective approaches for controlling the spread of infectious diseases such as influenza, MERS, and COVID-19. However, controlling the spread of the virus in public places such as shopping malls is a problem. Although shopping malls worldwide imposed mandatory wearing of masks and social distancing to limit the transmission of COVID-19, there are still several individuals who are not abiding by the rules. Shopping malls usually have higher foot traffic than other public places. It is not sufficient to rely on mall guards alone to enforce the mandates. To address customers' concerns for their health and safety in offline shopping, this study focuses on helping malls enforce mandates for COVID-19 prevention. We made an enhanced mall security system based on augmented reality. With the radar vision of the system, the mall guards on patrol can see people who violate the mandates, no matter how many walls separate them. They can also go to the scene quickly with aid of the system to maintain the mandates. However, this system provides user protection functions to help general users avoid high-risk situations.

2 Related Work

2.1 Medical Research

After the WHO published the health recommendation for the public, many researchers have proven that wearing a mask and maintaining social distance are two significant effective ways for reducing the transmission of the COVID-19 virus. Eikenberry et al. [4] developed a compartmental model to assess the impact of community-wide mask use on the spread of COVID-19. They used 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 was not good, it can still reduce the spread of the virus and decrease mortality. Berry C, Berry H, and Berry R [5] explored the relationship between mask mandates and COVID-19 infection rates using a large dataset collected by government agencies. The result suggested that mask mandates significantly impacted on reducing the spread of COVID-19 during the early summer of 2020 in the United States. Thu et al. [6] assessed the effectiveness of the social distancing measures in 10 countries through the confirmed cases and deaths. They demonstrated that after the government announced the highest level of social distance measure, the effect of this measure resulted in the number of people infected after 1 to 4 weeks.

2.2 Indoor Localization

Our research requires devices to have the ability to locate specific people in the building. There are several positioning methods. Kulyukin et al. [7] proposed a robot-assisted indoor navigation system based on radio frequency identification (RFID) technology. These types of passive RFID tags can give the robots stimulation at the right place and assist them in taking the right path. Chumkamon, Tuvaphanthaphiphat, and Keeratiwintakorn [8] proposed an RFID-based system to support the visually impaired to reach the target location correctly. The RFID chips are filled with location information that they import.

Some studies use wireless signals for localization. Barsocchi et al. [9] proposed a wireless network-based positioning algorithm. They measured 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. Another positioning technology has emerged in indoor positioning, named ultra-wideband (UWB). UWB is a radio technology that can use a low energy level for short-range, high-bandwidth communications over a large portion of a radio spectrum [10]. It has good accuracy and good anti-jamming performance. Its disadvantage is that it is high costly to apply to the actual environment.

In addition to signaling positioning techniques, computer vision for localization has also been studied. Cooper and Hegde [11] used low-cost webcams paired with a series of algorithms to detect people in a video stream and determine their location. The research showed that the method achieved 95% accuracy of people detection and half-meter positioning accuracy. This system can be applied to a large area such as a shopping mall.

2.3 Object Detection

Research on artificial intelligence (AI) has been a hot topic in recent years. Among the many subfields of artificial intelligence, the object detection method has been widely used. The mainstream algorithms are divided into two types: one-stage methods and two-stage methods.

As for one-stage methods, Liu et al. [12] presented single short multibox detector (SSD) for detecting objects in images only using a single deep neural network. 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. Redmon et al. [13] presented you only look once (YOLO) for detecting the object. YOLO redefines object detection as a regression problem. It applies a single convolutional neural network (CNN) to the entire image, divides it into grids, and 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 and it is significantly fast.

As for two-stage methods, Ren et al. [14] proposed a fast region-based convolutional network (Fast R-CNN) method for object detection. In Fast R-CNN, the ssp layer of the last convolutional layer is changed to the ROI Pooling layer. Moreover, the multi-task loss function (MTLF) was proposed. These improvements make CNN faster.

After the COVID-19 outbreak, these AI echniques have also been of great help in reducing the virus transmission. Boyko, Abdelpakey, and Shehata [15] propose a multi-object tracking social distancing violation detector that improves accuracy by adding more group detection. Bhambani, Jain, and Sultanpure [16] proposed a YOLO-based deep learning solution to help enforce the social distance and wearing masks in public.

2.4 Augmented Reality on Occlusion Management

Augmented reality technology has received unprecedented growth in recent years. The AR market is growing rapidly, and more research on AR close to people's life has emerged. The ability to see invisible things is one of the features of AR. Wu and Popescu [17] used an RGB-D sensor to dynamically capture the hidden content to provide X-ray vision to improve exploration efficiency in VR and AR scenes. Kameda, Takemasa, and Ohta [18] integrated the images from remote surveillance cameras into the user's hand-held device screen to achieve the augmented reality effect of displaying invisible life information inside the building. Avery, Sandor, and Thomas [19] proposed an augmented reality system with multi-view modes. This system has two types 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 to be displayed more realistic by providing occluding layers between the user and the remote location. Zollmann et al. [20] evaluated various methods for implementing x-ray view in augmented reality. Their research results showed that image-based ghosting can help users understand the depth order between physical and AR objects.

3 Goal and Approach

Mall owners should ensure a safe environment to keep their business relevant in this post-pandemic world. This study therefore aims to create an AR system to assist malls in maintaining a safe shopping environment to address customers' health and safety concerns in this post-pandemic world. To achieve this goal, we present an AR-based mall security system to help enforce wearing masks and social distancing in the shopping mall.

This system has three enhancement functions based on AR technology.

The first function is Radar vision. It is a novel visualization method to see the unmasked people or crowd gathering through the wall (see Fig. 1).

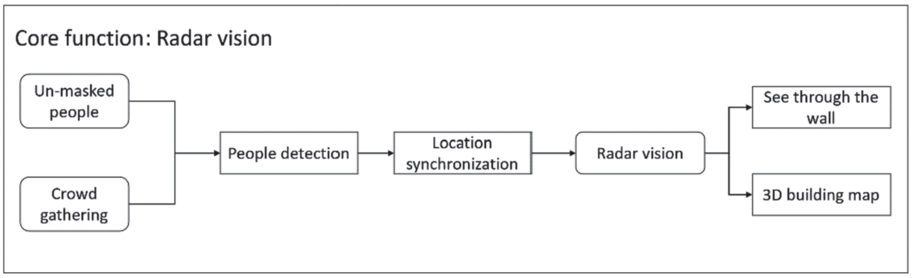


Fig. 1. Radar vision flow chart

The second function is AR tracking. After mall guards grasp position information of violative people, they can use eye-tracking to select the target person they want to track, and turn on the auxiliary navigation arrow heading to the target position.

The third function is user protection. 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.

4 System Design

4.1 System Overview

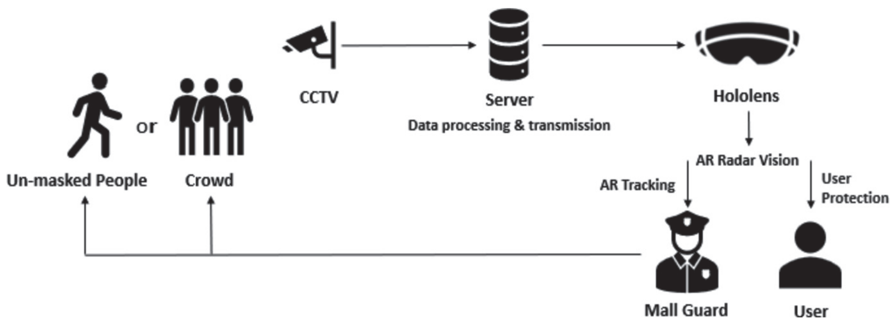


Fig. 2. Overview of the system

This system uses three types of hardware: CCTV cameras, servers, and Hololens. The system detects two violations in a mall: un-masked people and crowd gathering. First, the CCTV cameras collect the input video sequences and pass them to the server with a deep neural network model. The model's output would be the detected violative people in the scene. Then the server will transfer the people's position data to the Hololens to open the AR Radar vision. The radar vision can support the AR tacking function to help mall guards and avoidance suggestions to customers (Fig. 2).

4.2 System Hardware

Fig. 3. System hardware

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. We used Microsoft hololens 2 as the mixed reality smartglasses. Hololens 2 is a wireless, ergonomic self-contained holographic device. In addition to displaying augmented reality content, it can also provide real-world environmental awareness in mixed reality applications. We also used the monocular camera as CCTV cameras to capture video information from the scene. This video information is transmitted directly to the server. In addition to the above two hardware devices, the system also requires 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. These three devices are shown in Fig. 3.

4.3 Radar Vision

Fig. 4. Radar vision

In this system, we present a Radar vision: a novel visualization way to help mall guards keep track of the movement of detected people in a mall. Compared to ordinary radar machines, this Radar vision gives mall guards an enhanced vision to observe the violative people through the wall (see Fig. 4). It is like Superman's X-ray vision in the comics.

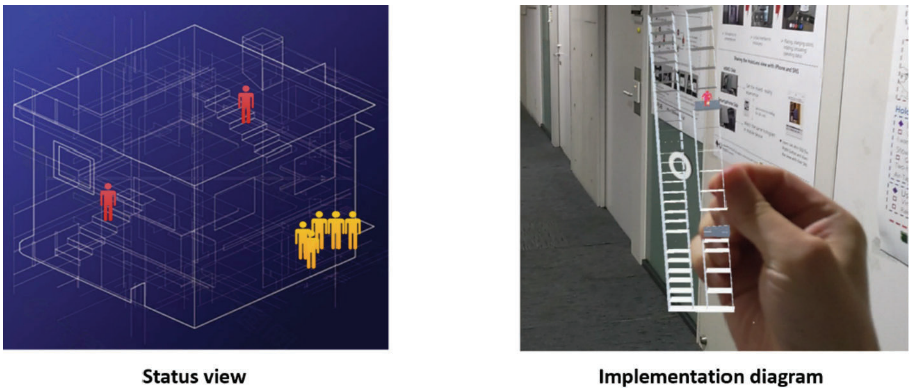


Fig. 5. Status view

In addition to the X-ray view, the system provides a status view of the shopping mall. It helps mall guards get a quick, clear idea of what is going on in the mall. This status view is not like a bird's-eye view that the exterior of the building will block. It can directly view the internal structure of the building and get clear position information of the marked people. The red human-shaped small image indicates people not wearing a mask. The yellow multi-person image indicates a crowd gathering in that place (see Fig. 5).

This Radar vision consists of three main components: people detection, location synchronization, and radar image visualization. First, The system keeps monitoring unmasked people and crowd gathering based on a complete surveillance system in the mall. Second, by setting landmarks for location mapping and distance estimation of the detected people's location, the system can synchronize the people's location to the virtual world in Hololens. Third, we use the hologram avatar to represent the detected people to visualize the person's radar image. Next, we explain these three components in detail.

People Detection

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

Fig. 6. People detection

to the server with a deep neural network model. Therefore, we can enhance the cameras in the mall. These enhanced CCTV cameras can monitor people and determine whether people comply with epidemic prevention measures or not (see Fig. 6). Finally, mark these people for other functions.

Location Synchronization

After the monitoring system detects the violative persons, it then helps the user's device locate where the person is. Because the world in Hololens is virtual, and the violative person's location is in the real world. Therefore, to synchronize the location of the violative person into the virtual world, we established 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, and bridges are used for localization, landmarks are also a great help for indoor localization. In this system, we chose 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 placed spatial anchors scattered in the building, and through the connection of these points, a virtual map network was formed.

When the camera detects the violative person's location, the system compares it with the location of the preset spatial anchor points. The system chooses the closest anchor to the violative person to be his position.

Radar Image Avatar

After some people are detected, the ordinary radar machine can only display light dots on a 2D screen. This system enables users to locate detected people through the wall. Therefore, we designed a human-shaped radar avatar to represent the detected people (see Fig. 7). This avatar comes with holographic effects, and it will be displayed at the location of the detected people based on the mapped landmarks.

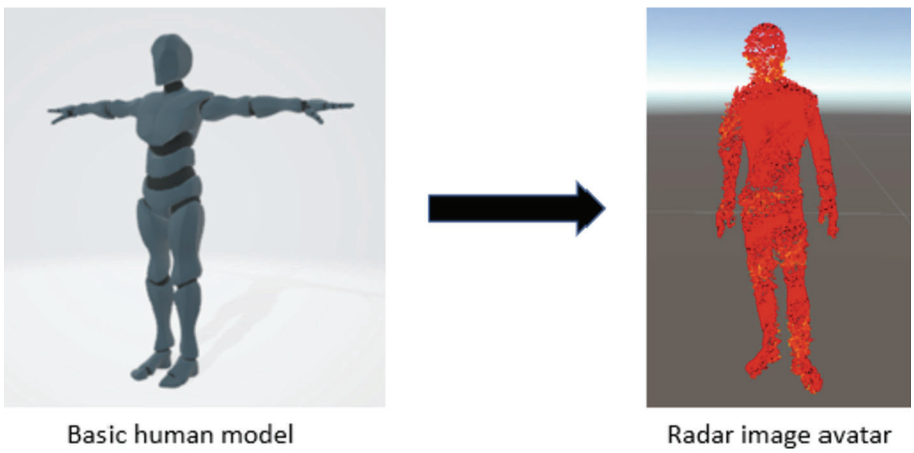


Fig. 7. Radar image avatar

4.4 AR Tracking

Mall guards ensure the safety of everyone at a mall. They work for the shopping mall, 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. The specific measures are as follows: First, evacuating the gathered crowds in a timely way. Second, identifying people who have taken off their masks in a mall and observing whether it is necessary to ask them to leave the mall.

When the system detects violations in a mall, it sends a warning message to mall guards. They can then open Radar vision to see radar images of violative people, getting a general idea of these people's position. Then mall guards can use eye-tracking to select the target people to track and activate the spatial arrow heading to the target (see Fig. 8).

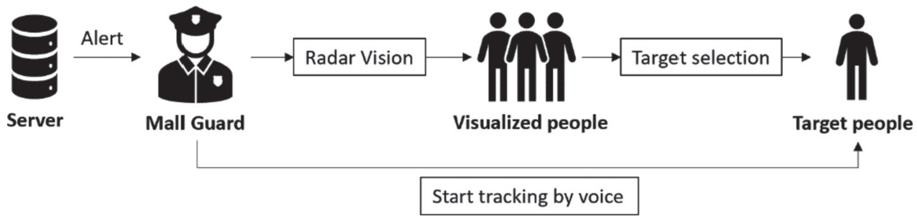


Fig. 8. AR tracking

4.5 User Protection

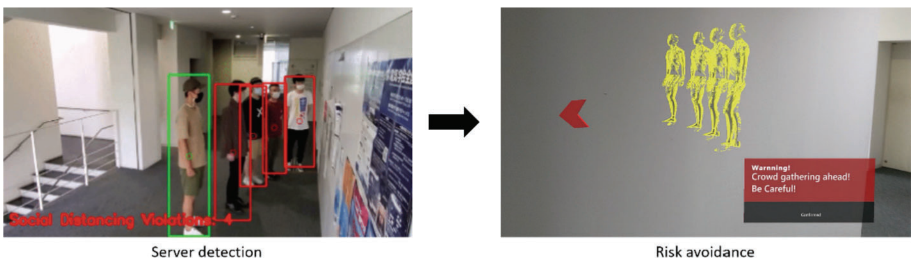


Fig. 9. Risk avoidance for customers

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 address the situation. However, 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. To protect customers in time, the system will send a warning message to attract the customers' attention. The system will also temporarily activate the Radar vision to help them clearly perceive high-risk situations nearby (see Fig. 9).

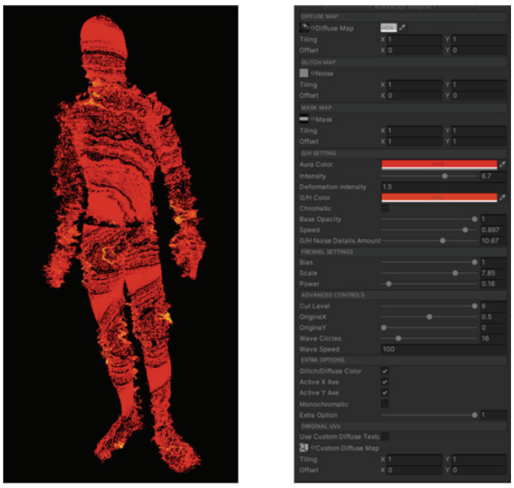
5 Implementation

We developed the main application of this system on Unity 2020 and used C sharp as the development language for the main application. We used python to build the people detection program to run on the server-side.

5.1 Radar Vision Visualization

We presented Radar vision as a type of new X-ray visualization method. It uses surveillance cameras to capture people out of view and displays a radar image avatar at the detected people's location to achieve an X-ray vision with spatial information. This method is different from the previous X-ray visualization method, 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 [17, 18]. The implementation steps are explained below.

Radar Image Avatar Generation
Generation of the radar image avatar is an essential part of radar vision visualization. This avatar represents the detected people and displays them as radar images. To allow users to see realistic radar effects. First, we determined a realistic 3D human character model from Mixamo.com. This model is high-quality and full-rigged, then we applied idle action to this model to make it appear more natural. Next, 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. It helps us to make this avatar a realistic radar effect (see Fig. 10). Finally, because this system's core is a through-wall perspective, to ensure the interaction experience, this avatar should not be blocked by



Radar image avatar **Hologram effect panel**

Fig. 10. Radar image avatar

the system's UI components. We made a unity shader component to let the avatar always be at the forefront.

3D Building Map

This system is to be deployed in shopping malls. In theory, we can apply it to any building of interest. This study selected the IPS school building as the shopping mall to prototype and demonstrated this system. To realize the status view, we required a 3D map model of the IPS building. Therefore, we modeled the IPS building manually based on the IPS building plan structure (see Fig. 11).

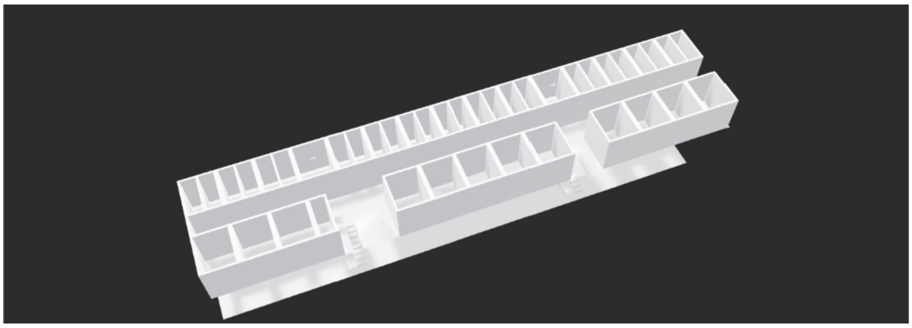


Fig. 11. School building 3D model

Location Mapping

When the server with a surveillance system captures un-masked people or crowd gathering status, the mall guard does not know the location of these people. In this system, we provided 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. We divided the school building area based on the distribution area of the CCTV cameras. We arranged webcams in three main areas to act as surveillance cameras to demonstrate this system, our laboratory and two lobbies were near the stairs (see Fig. 12).

Fig. 12. School building area

Then we went to these three selected monitoring areas to create local spatial anchors and upload the local spatial anchors to the cloud service (see Fig. 13). Thus, multiple Hololens observe the same persisted avatar over time. Finally, we classified these anchors to the corresponding camera monitoring area. Therefore, the system could form a virtual location network of these three areas based on presetting this positional relationship.

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. 13. Cloud spatial anchors

In the 3D building map in the status perspective, we also placed a series of anchor points. The yellow sphere (see Fig. 14) implies that 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.

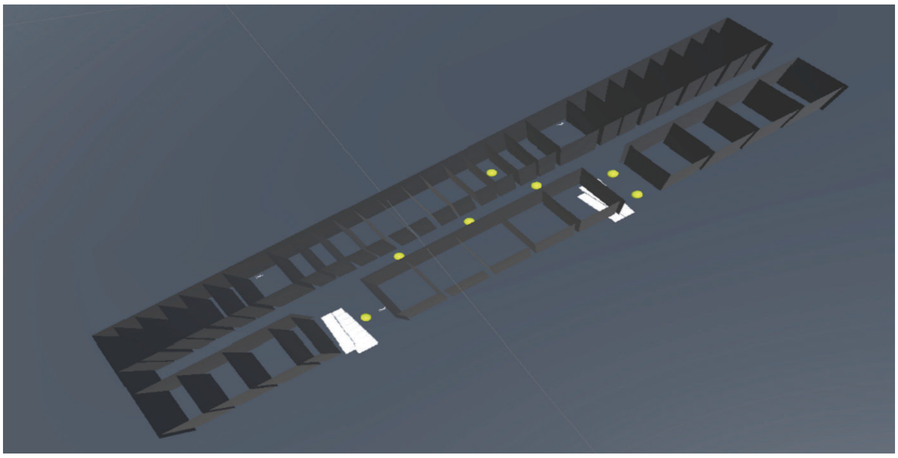


Fig. 14. Anchors in 3D building map

Interval Distance Estimation

To determine the position of the detected people, we should know the interval distance between the people and the CCTV camera. There are two prevalent technologies for ranging distance: binocular cameras ranging and Lidar camera ranging. They are common in smart cars with safety assistance. However, our system will be deployed in the shopping mall or other public places. Owing to the cost factor, these public places are equipped with binocular cameras or Lidar cameras. We used the monocular solution to enable our apply to all public places using only a general CCTV camera. To realize the monocular distance estimation, first, we did camera calibration work to determine the focal length of the camera and position of the optical center in the imaging plane. We knew these two parameters from calibration, the pixel value of the bottom (P_Bottom) of the detected people in the imaging plane and the mounting height of the camera. Thus we can calculate the distance between the detected people and camera. The principle diagram is shown in Fig. 15.

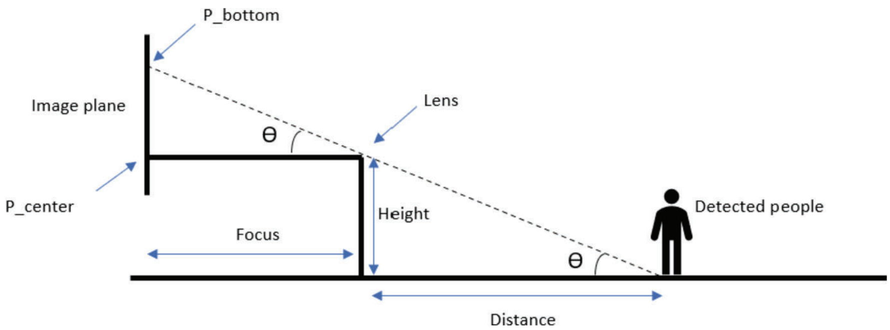


Fig. 15. Monocular ranging solution

The distance measurement formula is as follows:

$$tan\theta = \frac{H}{Dis} = \frac{|P\_bottom - P\_center|}{f} \tag{1}$$

Display Radar Image Avatar

The final step in realizing the radar vision is to display the radar image avatar to the corresponding location. The distance (C_A_distance) from the anchor to the camera and the distance (C_P_distance) from the detected people to the camera is known, Therefore, we can determine the closest anchor to the detected people by comparing these two distances. Then we let the radar image avatar be displayed on the location of this anchor (see Fig. 16). Thus, people with radar vision activated can see the radar image displayed through the wall.

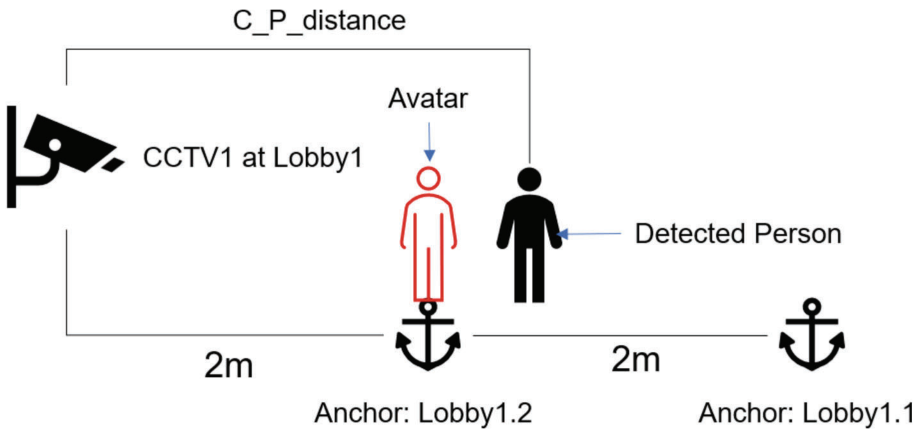


Fig. 16. Display radar image avatar

5.2 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 people detection part in our system. Because there has been a deep neural networks module in the library of OpenCV, implementing forward pass (inferencing) with deep networks, pre-trained using some popular deep learning frameworks. Our system uses the YOLOv3 deep neural network model to do object-detection work based on the PyTorch framework.

Mask-Detection

Among object detection algorithms, one-stage methods such as SSD and YOLO are generally faster than two-stage methods, such as CNN and RCNN [12–14]. The YOLO detector achieves a fast speed and good accuracy in human face mask detection [16]. Referring to this study, we made a deep learning model trained by YOLO for mask detection. We selected an open dataset of medical masks to train our deep learning model. This dataset contained 1,148 pictures. In these pictures: some people were wearing masks, some were not, or some were not wearing masks properly. These pictures have been annotated corresponding to the label mask, none, poor. After we trained the model, we loaded this pre-trained model to perform a forward pass for the whole network to compute the output result.

Social Distance Detection

We used the YOLO with COCO model to detect people in the CCTV video stream for social distance detection. The MS COCO dataset is a large-scale object detection, segmentation, and captioning dataset published by Microsoft. The model trained with it also performs well in our system. When more than two people appear in the video stream, the system obtains the center point by object-detection model and uses the center point to calculate the Euclidean distance between two people. Suppose the Euclidean distance is greater than the presetting safe social distance, therefore, the system will determine these two people as a social distance violative.

6 System Interaction

6.1 Gesture Interaction

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 mall guards receive 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 (see Fig. 17).

Hand menu **Gesture to call menu**

Fig. 17. Hand menu

Gaze Interaction
In our system, to allow mall guards focus more on their work and improve tracking efficiency, we used eye-tracking technology to help them select people displayed by

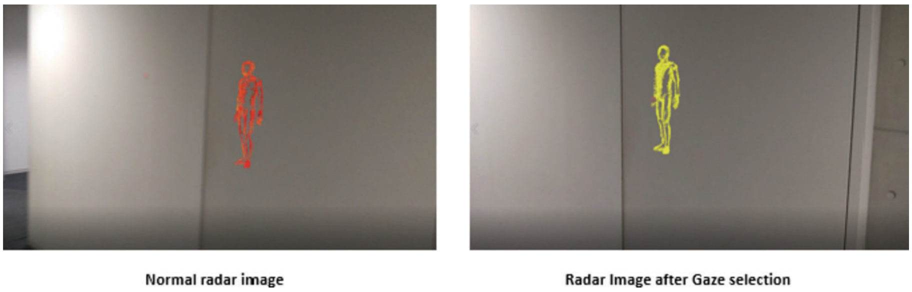


Fig. 18. Target selection by eye-tracking

radar vision. When the mall guards gaze on the radar image, the radar image turns its color from red to yellow to indicate that it has been selected (see Fig. 18).

Voice Interaction

When users use eye-tracking to select the target, it is not easy to move their gaze to their palm to activate the hand menu. We implemented the voice command in our system: "follow this person" as a trigger to activate the assisted navigation arrows (see Fig. 19).

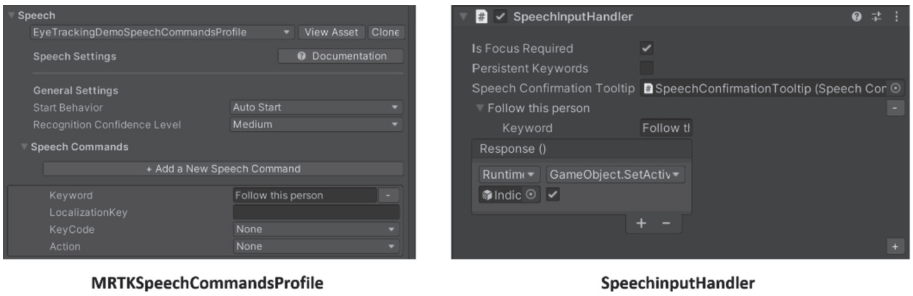


Fig. 19. Voice command setting

7 Pilot Study

To explore the usability and effectiveness of our system, we conducted a pilot study in terms of functionality, learnability, efficiency, and impact. We gathered 12 volunteers to experiment with our preliminary system in the school building.

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. These three roles are mall guards, customer user without system, and customer user with the system. The mall guard task was to enforce mandates in the mall. Customer users without our system shopped freely in the mall. The customer users with the system were tasked with shopping in the mall, walking around, and avoiding violative people. These two customer users' experiences were in contrast.

After the experiment, we invited the 12 participants to complete the questionnaire. The experiment results are shown below:

The pilot study result (see Fig. 20) shows that our system can effectively detect and display radar images, increasing the efficiency of mall guards and reducing customer safety concerns.

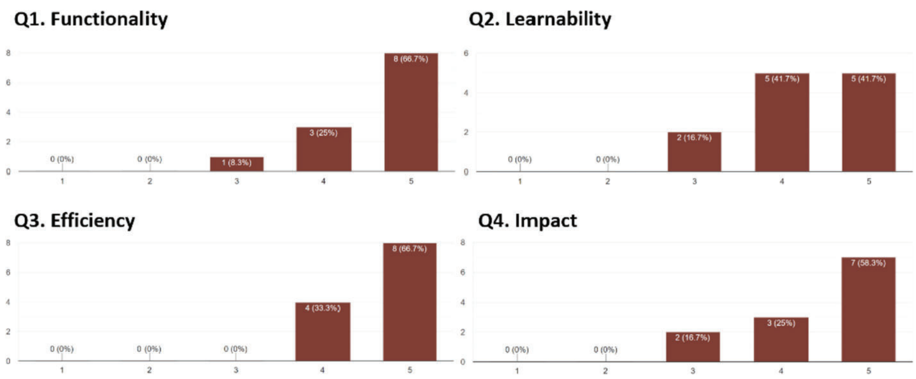


Fig. 20. Pilot study result

8 Conclusion and Future Work

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 should evolve their business quickly to meet the demands of the "new-normal shopper."

In this study, to meet the consumer's demands for safe offline shopping, we enhanced the mall security system to help enforce wearing masks and proper social distancing in shopping malls using augmented reality. This study presents a new concept of visualization manner to monitor and maintain order in the shopping mall. It explores the image of the "Mall of the future" by reinvigorating the shopping environment in terms of safety.

In the future, 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 a mall, enhancing 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 can provide a safe shopping experience and 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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