Real-Time Safe Route Finding and Visualization Using Shared Edge Devices

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Abstract

Conventional safe route-finding systems display routes on a map to avoid dangerous areas based on offline data such as statistical data on crime rates. However, such dangerous level changes in a dynamic manner, which can be detected by people walking around. This paper presents a system that shares the detected data measured by edge devices owned by walking people for dynamic safe route finding in real-time. This system evaluates the safety of routes in real time using and displays the route in AR on HMDs and smartphones. This paper reports findings from a simulation and edge device (smartphone) implementation of spatial safety assessment, safe route finding, and route visualization.

Keywords

Safe Routing, Edge Device, Visualization, AR

1. Introduction

1.1. Research Background

Violent crimes such as assault and injury (Assault is defined in Japan as a crime in which the victim was not injured, while an injury is a crime in which the victim was injured) are crimes that occur close to people, have a significant impact on the victim's mind and body, threaten their peaceful daily life, and may increase social unrest. According to a study on violent crime conducted by the Ministry of Justice's Legal Research Institute in Japan[1], the number of assault cases has remained high at around 30,000 since 2006, and the number of injury cases has also remained in the 20,000s since 2008 (Figure 1). In addition, these are the number of crimes reported to the police; the actual number of assaults and injuries is expected to be much higher. The largest number of assault cases was from people who did not know each other, while the number of injury cases was from people who knew each other, as typified by domestic violence. About 30% of both assault and injury cases occur outdoors and 30% of cases occur in a house (Figure 2). A higher percentage of assaults occur on public transportation or in stores than assaults, and we often hear news stories of station staff, shopkeepers, passersby, and passengers suddenly being violently attacked. Although transportation and shopping are essential to daily life, the possibility of sudden violence and crime prevents people from leading their daily lives with peace of mind.

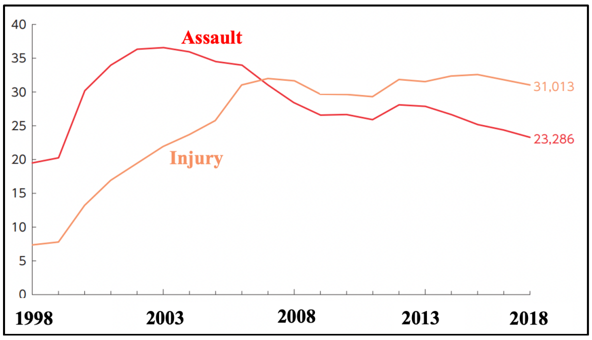

Figure 1: Number of assaults and injuries in Japan

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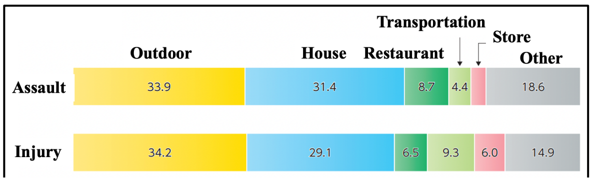

Figure 2: Location of injury and assault in Japan

1.2. Research Objectives

Conventional navigation systems are designed to arrive at a destination smoothly and quickly. To achieve a safe and secure society, we research, develop, and implement navigation systems that can avoid crimes and unpleasant events by detecting them in advance. The navigation system uses edge devices such as surveillance cameras and smartphones to measure the level of danger in real-time and search for safe routes. The system also visualizes the detected dangerous elements and the safe routes.

We are convinced that this system can contribute to solving various social problems. For example, the system can be used for urban planning to prevent crimes, support services to maintain social distance in infectious disease environments such as COVID-19, detect people in trouble and automatically ask for help from people around them, support services to protect wild animals, and services to find lost cats.

In this paper, we report on the findings and problems encountered in simulating the level of danger assessment, safe route search, and safe route visualization of a location using edge devices. We also report our findings and problems in a prototype system using a smartphone.

1.3. Related Works

Many methods have been proposed for safe route finding that minimizes the level of danger and distance on the path and displays the path on a map.

Galbrun et al. proposed a safe route search method based on Total-Paths (total level of danger on a path) and Max-Paths (maximum level of danger on a path) [2]. Yizhou et al. conducted a safe route search simulation experiment on an actual congestion dataset for each Paris train station based on another research result that "higher congestion leads to higher crime rate" and confirmed the effectiveness of the method [3].

Sukru et al. propose a mobile app for the social distancing of people in a COVID-19 environment. It allows each user to manually register their health status and then share their current location on the network in real-time, predicting the walking paths of other users and alerting them with sound and vibration to the possibility of approaching users with poor health status [4]. Maria et al. proposed a method that uses BLE beacons to detect and share a user's location and provide a route to reach a destination without passing other people indoors [5]. To successfully avoid people, robot pathfinding methods can be helpful: Kapil et al. proposed a pathfinding method that predicts the movement path of a group of people [6], and Lucia et al. proposed a method to move around humans and obstacles in a social compatible and safe manner [7].

As a mechanism for sharing information sensed by the user, the Joint Tactical Information Distribution System (JTIDS) and the Inter-vehicular Information System (IVIS), which are used in military applications, can be used as references. These systems share the position, heading, altitude, and speed of detected aircraft, ships, and vehicles with all platforms participating in the network.

For safe route finding, it is necessary to evaluate the safety of a location. According to Stacy et al., a person's gender, facial expression, gaze, appearance, clothing, attitude, and physique are known to help determine whether a person is suspicious [8]. For example, if a person is silent and stares at another person, has an aggressive or predatory facial expression or body language, or is carrying a weapon such as a gun or a knife, he or she is highly dangerous. Fan [9] and Fang [10] et al. proposed a method for detecting abnormal human behavior in real-time from video images, and it is also provided as a service, such as the Incident Detection Solution [11]. Salamon et al. proposed a method for sound classification [12], we think this method evaluates the safety of a location by analyzing sounds such as conversations or detecting gunshots or explosions. Kim et al. proposed a method to estimate the level of danger of a location based on the content of geotagged messages on social media [13]. RedZone Map [14], a service that guides users to safe routes for cars based on government-released crime map data; My Safety pin[15], a navigation application that uses the results of interviews with users about the safety of each location; CrimeReports[16], which works with police information systems to visualize crimes that have occurred in; My Safe Map[17], a map service that uses existing external data to search for safe streets and blocks, have also been put to practical use. Many methods have been proposed to evaluate the safety of a location, such as those in these previous studies. However, no method has been established that runs on an edge device and evaluates the safety of a location with sufficient accuracy.

The freshness, spatial resolution, and accuracy of the original data are important for assessing the level of danger. Ideally, the data should be updated in real-time and evaluated by an impartial third party with a spatial resolution of about 3.5 m [18], which is defined by Edward et al. as a social distance that is hard to reach but easy to talk to. However, most of the aforementioned studies and services use statistical data such as crime maps, which are not real-time, have a low spatial resolution, and have low accuracy because they are self-reported. And most of the existing services that detect abnormal behavior in real-time from video images are not available because they do not disclose the detection results. Therefore, conventional navigation services are limited to route guidance to avoid areas that are statistically known to be dangerous. No safe route-finding method has been proposed to successfully pass by dangerous people in a narrow space while maintaining social distance from them. As for visualization, the system is limited to displaying routes on a 2D map and alerting drivers with sound and vibration.

Therefore, we are conducting research, development, and social implementation of an information-sharing system and navigation system that can detect and avoid criminal damage and unpleasant events in advance, featuring the following three elements.

(1) Edge devices accurately measure and share the level of danger of a location in real-time.

(2) A wide-area safe route-finding method based on the level of danger measured by edge devices, and a narrow-area safe route-finding method for successfully passing dangerous people in a narrow space while maintaining social distance.

(3) Social Distance and safe route visualization and human guidance methods

2. Study of a navigation system that can detect and avoid criminal damage and unpleasant events in advance

2.1. System Overview

We have conducted a system study to achieve a navigation system that can detect and avoid criminal damage and unpleasant events in advance. This system consists of six subsystems as shown in Figure 3.

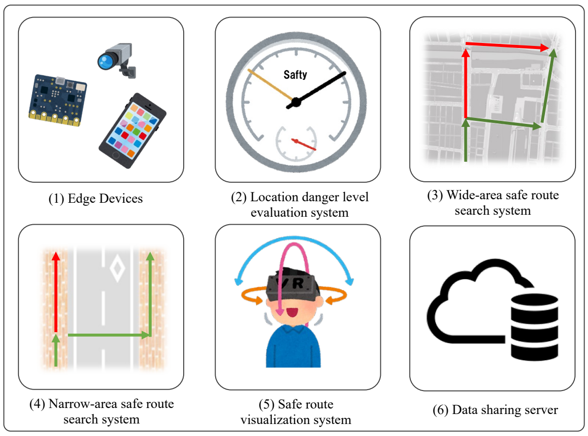

Figure 3: System Overview

(1)Edge devices

A device equipped with various sensors such as a camera, microphone, thermo, GPS, etc. We assume surveillance cameras, smartphones, and wearable devices.

(2) Location danger level evaluation system

The system evaluates and shares the safety of a location based on information acquired by various sensors in edge devices. We can use other information such as sound (conversations, gunshots, explosions) or temperature (human body, road surface, fire, freezing) to evaluate the safety of the location. This information can be used to set various conditions in addition to safety, such as easy walking routes, cool routes, and routes with many pedestrians.

(3) Wide-area safe route search system

This system performs a wide-area route search to maximize safety and minimize distance based on the safety level and distance of the location evaluated by the edge device.

(4) Narrow-area safe route search system

This system searches for a safe route in a narrow space (e.g., a street or a station) to pass by a dangerous person while maintaining a social distance from him or her.

(5) Safe route visualization system

This system visualizes shared information like dangerous persons detected by other edge devices. This system also visualizes the routes and social distance calculated by the safe route search system. Wide-area safe routes are displayed on a map, and narrow-area safe routes for passing each other are displayed on the HMD.

(6) Data-sharing server

A server that accumulates real-time spatial safety information. It stores information uploaded from each edge terminal and distributes it to each terminal in real-time.

2.2. Simulator

We will evaluate the usefulness of the designed system. However, our system includes subsystems that are difficult to implement at this time. In particular, as mentioned in section 1.3, there is no established method to evaluate the safety of a location with sufficient accuracy on an edge device. In Addition, there are also no small, lightweight, safe, optical see-through HMDs that can be easily worn. Because of these difficulties in implementing our system in the real world, we first conducted our system evaluation in a simulator.

We constructed a virtual Akihabara city [19] area of approximately 625 m x 625 m. All subsystems operate ideally in a virtual Akihabara. For example, virtual Akihabara has an ideal edge device that measures the safety of the location with 100% accuracy. Then, We randomly placed autonomously roaming people with various attributes PE, PF, PD, and PS shown in Table 1 in a virtual Akihabara. PE is a person with an edge device (100 people), PF is a person with a fever (10 people), PD is a person who can be judged dangerous for some reason such as a facial expression or attitude (10 people), and PS is a person who can reduce the level of danger in that location such as a police officer or security guard (10 people). The PE has an ideal edge device that detects PF, PD, and PS within a 30-meter radius without error and measures the level of danger. The location and attributes of PFs, PDs, and PSs detected by the device and their measured level of danger are sent to the data-sharing server as a Danger Point (DP). Although the DP is quantified by the location safety evaluation system by analyzing the facial expressions and attitudes of each person, we set the DP uniformly for each attribute as shown in Table 1 for simplicity in this simulation.

Table 1
Attributes and DP of people

Attributes	Color	DP	Number
PE person with an edge device		-	100
PF person with a fever		1	10
PD dangerous person		10	10
PS police officer or security guard		-10	10

Figure 4 shows the results of mapping the current positions of PF, PD, and PS detected by 100 edge devices on a 2D map. We drew bubbles (spheres) colored according to the attributes at the detected person's location. This bubble is drawn at the location of the PF, PD, and PS at the time the PE detected them, but they could move. Also, the map would be filled with bubbles of newly detected PFs, PDs, and PSs. Therefore, we set the transparency of the bubbles to indicate how new the information is, and set them to gradually disappear in one minute so that the map would not be filled with bubbles. Users can see that the disappearing bubble is old information.

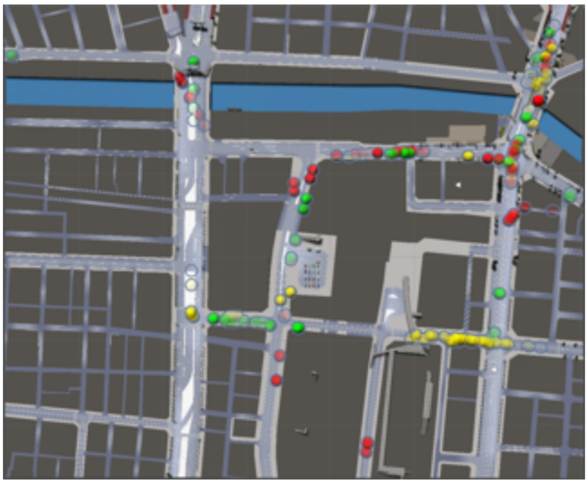

Figure 4: Mapping results of detected PF(Red), PD(Yellow), and PS(Green)

When a PE with an edge device sets a destination, a wide-area safe route system performs the route search. We have extended the Dijkstra method, which is used for route finding in navigation systems, to perform wide-area safe route finding considering distance and level of danger in space. Dijkstra's method is an algorithm in graph theory that can find the shortest distance from a start node to a goal node and its path. We generated a graph structure from map data in which the intersections are represented as nodes I and the roads connecting the intersections as edges E. We defined the Edge Danger Level (E_{DL}) as the level of danger between intersection I_n and the adjacent intersection I_{n+1}, where E_{DL} is the sum of the DP of PF, PD, and PS that exist between the intersections. We set a danger threshold value DL_{th}, and if E_{DL} exceeds the DL_{th}, the path is considered impassable and the node connection is disconnected. In this simulator, we set the threshold DL_{th} = 5. The system evaluates the E_{DL} of all edges, updates the graph structure, and finds the shortest and safest path using the Dijkstra method.

$$E_{DL}(I_n,I_{n+1}) = \Sigma(F_{DP}+D_{DP}+S_{DP}) \quad (1)$$

$$E(I_n,I_{n+1}) \begin{cases} \text{passable} & \text{if } E_{DL}(I_n,I_{n+1}) < DL_{th} \\ \text{impassable} & \text{if } E_{DL}(I_n,I_{n+1}) > DL_{th} \end{cases} \quad (2)$$

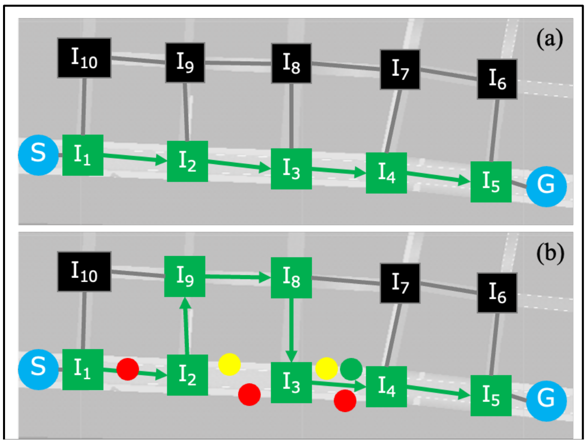

Figure 5: Wide-area safe route search

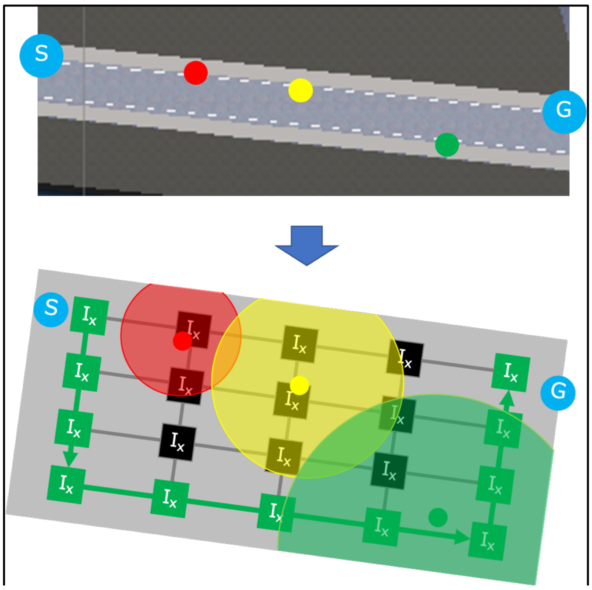

Figure 6: Narrow-area safety route search

Figure 5 shows an example of wide-area safe routing. When a PE with an edge device starts from point S and goes to G, Figure 5(a) is usually the shortest path. If one PF is detected at $E(I_1, I_2)$, one PF and one PD at $E(I_2, I_3)$, and one PF, PD, and PS at $E(I_3, I_4)$, the level of danger E_{DL} for each edge is as follows

$$E_{DL}(I_1, I_2) = 1 \quad : \text{passable}$$

$$E_{DL}(I_2, I_3) = 11 \quad : \text{impassable}$$

$$E_{DL}(I_3, I_4) = 1 \quad : \text{passable}$$

Considering the threshold DL_{th} = 5, edge $E(I_2, I_3)$ is cut off because it is impassable, and the shortest path search is performed on the remaining edges, resulting in the path shown in Figure 5(b). $E(I_2, I_3)$ and $E(I_3, I_4)$ are passable, but there are PF and PD, so a narrow-area safe path search is performed to find a path that allows them to pass each other while maintaining the social distance. Figure 6 shows an example of a narrow-area safe path search. The system generates a graph structure by dividing the space to be traversed into meshes. The size of the mesh was set to 3.5 m, a social distance defined by Edward et al[18]. as hard to reach but easily conversable. In the narrow-area safe path search, the Social Distance according to the attributes of PF, PD, and PS was considered for the E_{DL} evaluation. For PF with fever, the Social Distance in the COVID-19 environment is defined as 6 feet by the Centers for Disease Control and Prevention and 1 m by the WHO [20][21]. We defined Social Distance as 5 m, five times the WHO standard. According to Matsunaga et al., when the distance to a person is less than 6 m, the likelihood of assault increases[22]. Therefore, we set the social distance to PD (person with dangerous facial expressions/attitudes) as 10 m. We also set the social distance as 20 m assuming that the PS (police officer or security guard) has an eye range of 20 m. Based on these social distances, the system calculates E_{DL} for all edges in the same way as in a wide-area safe route search, updates the graph structure, and finds the shortest path using the Dijkstra method. In this way, we can avoid dangerous people by computing travel paths that can maintain safe social distances. In addition, these social distances can be changed dynamically according to the user's attributes, season, time of use, and level of danger of the person to make it safer and more convenient. For example, the social distance can be adjusted to take more time when the user is a child or a woman, or when it is late at night.

2.3. Simulation Results

Figure 7 shows the mapping results of the current positions of PF, PD, and PS detected and shared by 100 edge devices and the wide-area safe route on a 2D map. We deployed PE_0, a person tasked with moving from the start point S to the goal point G. PE_0 is equipped with an edge device and moves along the route indicated by the edge device's wide-area safety route search. PE_0 is equipped with an edge device and moves along the route indicated by the edge device's wide-area safe path search. Although the shortest route is to go straight from S to G, the blue color indicates that the route search is performed in consideration of the level of danger. When PE_0 needs to pass PF or PD on the route, the system performs a narrow-area safe route search and shows PE_0 a route to pass them while maintaining social distance. Figure 8 shows the view from PE_0. In this experiment, PE_0 is assumed to be wearing a see-through HMD. System display PF, PD, and PS detected and shared by other edge devices. The system also displays a narrow-area safe route search result. The system superimposed bubbles with sizes corresponding to the social distance for each attribute of PF, PD, and PS, and the safe passing route (green).

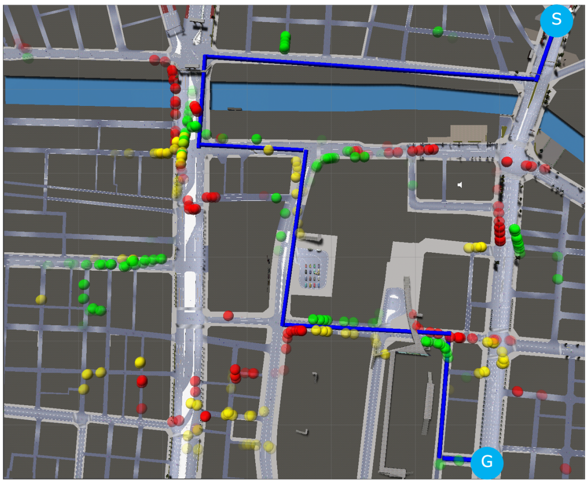

Figure 7: Results of wide-area safe route search

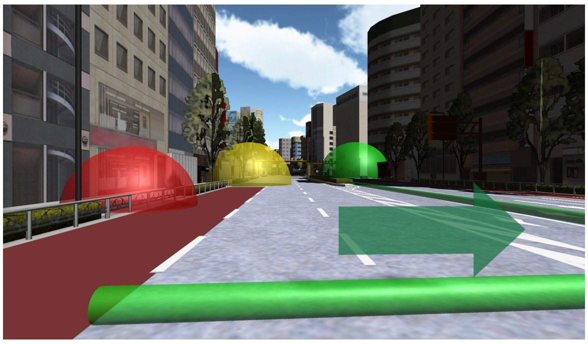

Figure 8: Visualization detected and shared PF, PD, and PS, and Narrow-area safety route search results

2.4. Smartphone prototype system

Simulator experiments have shown that the system works effectively within the virtual Akihabara. Therefore, we developed a prototype system using a smartphone as shown in Figure 9. The edge device on the simulator we implemented was an ideal device that could detect people and their attributes within a radius of 30 meters without error. However, since such an ideal device does not exist in reality, our prototype system simply detects a person from a smartphone's RGBD camera image (without a level of danger assessment) and shares the person's location coordinates. We developed a smartphone application in Unity and installed it on an iPhone 13 pro max (Figure 10). The app obtains the position coordinates (latitude, longitude, and altitude) of the smartphone from the Global Navigation Satellite System (GNSS), the azimuth and orientation of the device from the magnetic compass and gyro, and detects the person using the RGB camera and LiDAR, and also gets the distance to the person. The distance to the person is also obtained. The application then calculated the position coordinates of the detected person and displayed a translucent bubble (red sphere) with a diameter of 5 meters. The location information of the detected person is shared by Unity's photon plug-in and is superimposed on the same location from another smartphone. The location coordinates of the detected person are uploaded to the data server (Nifty Cloud mobile backend), and the information of the detected person can be viewed from a web browser (Google Map).

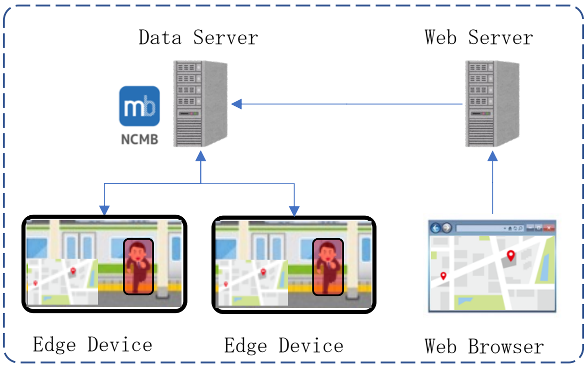

Figure 9: Smartphone prototype system

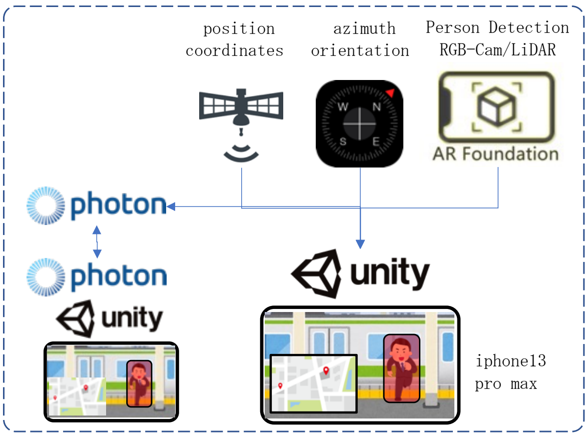

Figure 10: Prototype Application

2.5. Smartphone Prototype Result

As shown in Figure 11 we placed PF, a person assumed to have a fever, in the park. Next, smartphones were placed at PE1, PE2, and PE3. The location of PE1 is in the same park as PF and has no obstacles, so PF can be detected directly, but from the location of PE2 and PE3, PF cannot be detected directly due to the obstacles (height difference and trees).

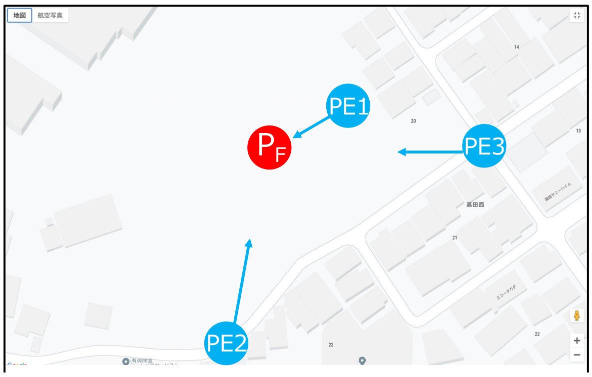

Figure 11: PF and edge devices position

Figure 12 shows the screen when looking at PF from PE1, where PF is detected and a red bubble with a diameter of 5 m is superimposed.

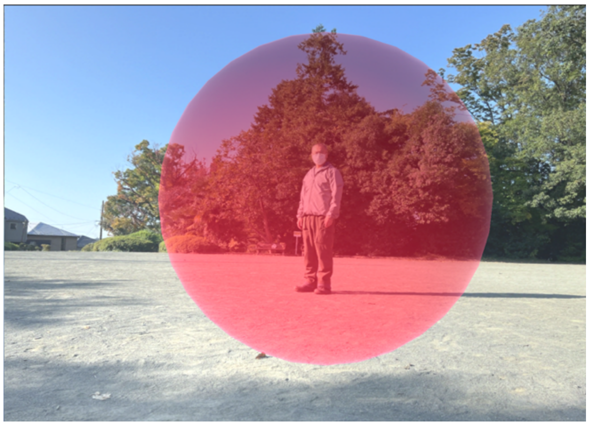

Figure 12: Detected PF from PE1

Figure 13 and 14 show the view of PF from PE2 and PE3. From PE2 and PE3, the PF cannot be seen directly due to the height difference and the trees, respectively. However, a red bubble is displayed at the location of the PF based on the information from PE1, so that the user can recognize the presence of the PF.

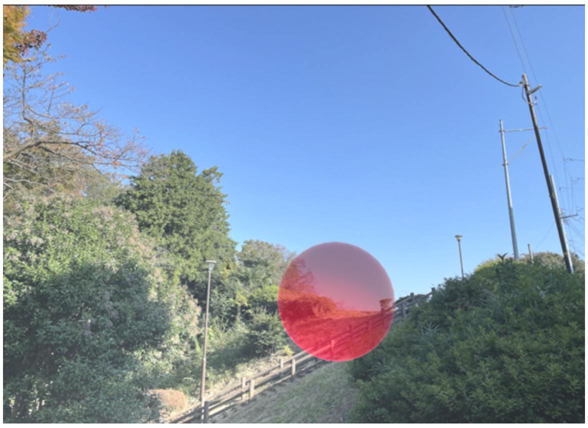

Figure 13: View of PF from PE2

Figure 14: View of PFs from PE3

A red bubble with a diameter of 5m representing the PF is shown in Figures 12, 13, and 14, but these bubbles are not occluded by obstacles such as the ground or trees in real space, making it difficult to get a sense of distance. In the simulator, the 3D geometry of the entire townscape is known, so the bubbles can be occluded, but the prototype system cannot measure the 3D geometry of the real world, so occlusion is not possible. The LiDAR in the iPhone13 can measure real-world 3D geometry at close range (about 15m). The AR Foundation tool provides an Automatic Environment Occlusion function using LiDAR, but it does not work on objects at long distances as in this experiment. Therefore, We generally assume that there are fewer obstacles in the sky, we floated the bubble at 30 m above the detected PF and displayed a thin cylinder up to the bubble. The results are shown in Figures 15 and 16.

Figure 15: Floated Bubble from PE2

Figure 16: Floated Bubble from PE3

Figure 17 shows the results of mapping the PFs detected by PE1 on Google Map (aerial photo) with images. This allows users in remote locations to determine the location of PFs.

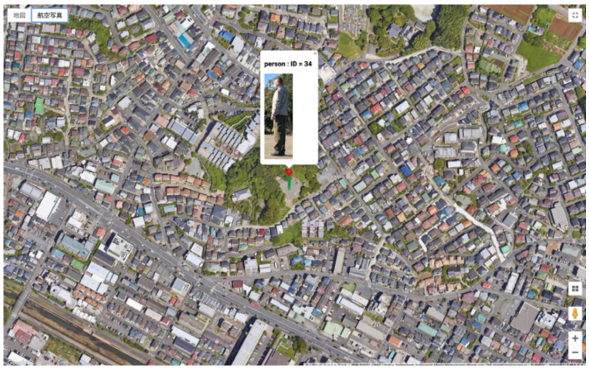

Figure 17: Detected persons on Google Map

3. Discussion, and Future Works

We have developed a prototype system that can detect and avoid criminal damage and unpleasant events in advance, using a simulator and a smartphone. Through experiments, we confirmed that the system works and that the information about the detected persons can be shared.

3.1. Simulator and future works

Once the simulator was run and the locations of PFs, PDs, and PSs were identified on the 2D map, we felt that "we should avoid that dangerous area where PFs and PDs are densely located," and did not feel that much need for wide-area safe route search. It may be sufficient to have information that "that area is dangerous". In addition, when we had to pass by a PF or PD, the AR display of social distance in the form of a bubble made us feel secure, but when we had to pass through their bubble, we felt great stress despite it being a simulation. On the other hand, when there was a PS that was supposed to be a police officer, etc., I was able to move with ease even if there was a PD. However, the bubble was often invisible behind a building, and when we turned a corner, we were sometimes surprised when the bubble suddenly appeared, and we felt that the AR display needed to be improved in this regard. The edge device on the simulator is an ideal device to detect PF, PD, and PS within a radius of 30m without error, but in reality, such an ideal device is difficult to implement. Therefore, in the future, we would first like to narrow down the detection target to people with fever and conduct experiments in the real world to determine the social distance from people with a fever to verify the effectiveness of the system. We would also like to study a safer route-finding method by incorporating PF, PD, and PS path forecasts into the wide-area and narrow-area safe route-finding method proposed in this study.

In this paper, we have evaluated the effectiveness of the system subjectively, but in the future, we would like to evaluate the effectiveness of the system quantitatively. For example, as indicators of quantitative evaluation, we are considering the frequency with which PDs can not be avoided, how many were able to take the safe route, the average of the shortest distance to a PD, and the distance increased by the safe route proposed by the system.

3.2. Smart Phone and Future Works

As mentioned in section 3.5, the bubble representing the location of the detected PF is not occluded by objects in the real world, making it difficult to get a sense of the distance. We floated the bubble at 30 m above the PF, but the same problem occurs when there is an object in the sky. In the future, we would like to estimate the 3D geometry of the object in front of the PF from the video and perform bubble occlusion. Another issue is the accuracy of GNSS. We experimented in a park with no obstacles in the sky, but the GNSS accuracy was at best about 5 m horizontally and 3 m vertically, with errors of 30 m or more in some situations. Therefore, a method to estimate self-position by measuring the 3D geometry of an object is possible. For example, position estimation can be performed by matching point cloud data obtained by LiDAR sensors installed in recent smartphones with real space, and something similar has already been implemented in automatic driving. For this purpose, it is necessary to convert the entire real space into point cloud data. However, point cloud data in cities and buildings are available through the PLATEAU project [23] promoted by Japan's Ministry of Land, Infrastructure, Transport, and Tourism, and we would like to consider improving the accuracy of self-position estimation using this method in the future.

Through these research activities, we will promote the social implementation of information-sharing and navigation systems that can detect and avoid criminal damage and unpleasant events in advance.

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