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WALKING NAVIGATION SYSTEM FOR VISUALLY IMPAIRED PEOPLE BASED ON HIGH-ACCURACY POSITIONING USING QZSS AND RFID AND OBSTACLE AVOIDANCE USING HOLOLENS

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Abstract. *It is extremely difficult for visually impaired people to move around in new places. Because traditional pedestrian navigation systems such as Google Map are designed using visual information such as map displays, they are difficult for visually impaired people to use. The purpose of this research is to develop a wearable system to assist a visually impaired people in navigation. We propose a positioning method combining Radio Frequency Identifier (RFID) and Quasi-Zenith Satellite System (QZSS) to obtain highly accurate positioning both outdoors and indoors. Furthermore, to guide visually impaired persons, it is necessary to sense and guide the direction in which the user is facing, and to detect and avoid obstacles. Therefore, we adopted HoloLens, which can generate a 3D mapping of the environment to estimate the user's direction and to generate a route to avoid obstacles. The system directions are based on the shortest route from the current position to the destination, while dynamically generating a route that avoids obstacles if they are detected. In this paper, the navigation system construction and approaches are described, and then the results of the demonstration experiments are reported. According to the results, positioning accuracy based on RFID and QZSS was achieved with an error of less than 1m. Furthermore, we also confirmed that it is possible to generate an obstacle avoidance route using sequential spatial mapping using HoloLens.*
Keywords: Navigation system, Visually impaired people, Obstacle avoidance

1. **Introduction.** According to a survey by the Japanese government, there are about 310 thousand visually impaired people in Japan, which is about 8% of all of disabled people [1]. Globally, it is estimated that there are 285 million visually impaired or blind people [2]. It is extremely difficult for visually impaired people to go to places they have never visited. Most of them would like to use a navigation application, such as Google Maps, to traverse new places alone. However, this is generally very difficult because such applications are designed for sighted people; the positioning accuracy is insufficient, and the conventional guidance method is not applicable to the visually impaired.

Many researches on navigation for visually impaired people are aimed at improving the accuracy of position estimation or proposing a user interface for guidance. Most of the research is limited to evaluation experiments using temporary facilities constructed for

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the experiment. On the other hand, the purpose of this study is not only to overcome the technical problem, but also to implement the system in the real environment and repeat the evaluation experiment with the visually impaired person as a participant to clarify the problem for practical use. Furthermore, we aim to achieve social implementation afterwards. There are few research examples that have implemented and evaluated navigation systems for visually impaired people in public environments. In this study, the proposed system was implemented at a station in Tokyo, and the problems for social implementation were clarified through repeated demonstration experiments.

In this research, we have developed a navigation system with sufficient positioning accuracy and a dedicated guidance method using Radio Frequency Identifier (RFID) and Quasi-Zenith Satellite System (QZSS) [3]. However, as a result of a demonstration experiment on navigation using RFID and QZSS described in Section 5, it was found that the system needs to be able to estimate the direction the user is facing and to avoid obstacles. Therefore, we have utilized HoloLens, a Head-Mounted Display (HMD) developed by Microsoft, which can be incorporated into the navigation system to avoid obstacles and creates safe routes by capturing surrounding environments as a 3D map.

This paper is organized as follows. Section 2 introduces related researches and describes their relationship to our research. Section 3 describes the outline of the navigation system. Sections 4 and 5 describe positioning method using QZSS and RFID and discuss the accuracy based on our experimental results. Sections 6 and 7 describe obstacle avoidance using HoloLens and discuss the effectiveness and the availability based on several demonstration experiments. Finally, Section 8 summarizes this paper.

2. **Related Researches.** Various studies on the realization of navigation systems for visually impaired people have been conducted globally. For example, Chen et al. [4] have developed a white cane with built-in measurement unit and vibration motors as a haptic device. However, our research has shown that many visually impaired people want to continue using their own white cane; therefore, we do not modify their own white cane in our research.

In another study, navigation systems using Bluetooth Low Energy (BLE) for indoor positioning are proposed [5, 6, 7]. BLE positioning can be performed with a smartphone without any dedicated devices. However, since the BLE beacon requires its own power supply, battery replacement is required regularly. Therefore, we adopted a positioning method using passive RFID and developed a nearly maintenance-free system.

Shimakawa et al. have developed an obstacle detection application for visually impaired people using a general smartphone with built-in RGB camera [8]. As the paper points out, since RGB-D cameras are relatively large and heavy, implementation with a widely used small RGB camera increases availability and usability. However, since the purpose of this study is to verify the feasibility in a real environment, we adopted HoloLens with a built-in RGB-D camera to prioritize detection accuracy.

It is also important to develop a navigational interface with high usability for visually impaired people. Katzschmann et al. conducted a demonstration experiment using a haptic device in a relatively complex environment [9]. Although the results are insightful, this research mainly targets accurate positioning, obstacle detection and route setting, which can be accomplished by using simple voice notifications.

3. **System Outline.** Figure 1 illustrates the outline of the proposed system. The system consists of a smartphone for route calculation and input-output interface, a RFID reader module, a QZSS receiver for accurate positioning and a HoloLens for providing 3-dimensional mapping to avoid obstacles.

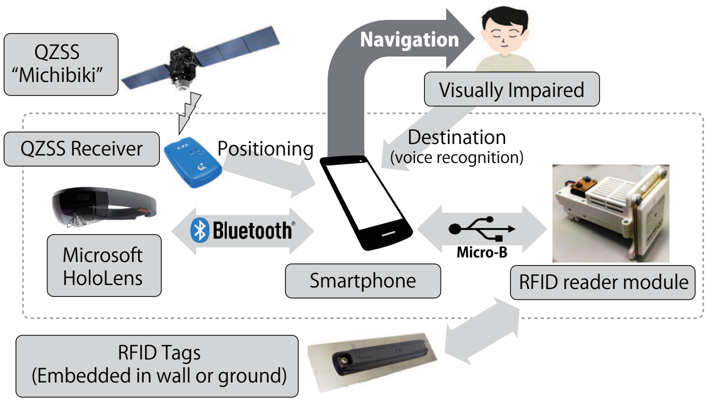

FIGURE 1. Outline of calculation process of the system

The route search algorithm calculates the shortest route between the current position and destination ("a global route") using Dijkstra's algorithm and preliminary prepared route map data. The current position is estimated based on an algorithm combining Global Navigation Satellite System (GNSS)-based positioning including the QZSS Michibiki and RFID tag-based positioning which are embedded in the ground or wall. The details of this process will be described in Chapter 4.

If there are obstacles along the global route, it is necessary to dynamically generate an alternative route to avoid them. This route is called the "obstacle avoidance route" in this paper. HoloLens has "spatial mapping" function, which provides a 3D environmental map and the user's position. The spatial mapping originated with Microsoft; however, it is based on the Simultaneous Localization and Mapping (SLAM) problem [10], which is one of the most important problems for camera-based autonomous mobile robot. Many types of algorithms have been researched to solve SLAM problem [11] and some studies suggest that these algorithms contribute to navigating visually impaired person [12].

The proposed system navigates to the destination by integrating global route and obstacle avoidance route which is sequentially calculated using HoloLens (see Figure 2).

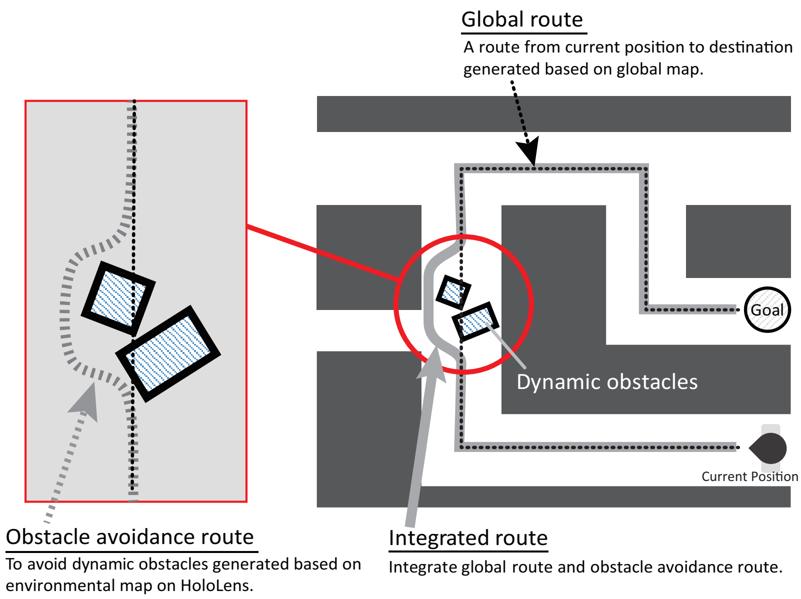

FIGURE 2. Route integration between global route and obstacle avoidance route

4. Position Estimation and Navigation Using QZSS and RFID.

4.1. Position estimation by QZSS. Since the practical error of conventional GNSS is greater than 10m, the accuracy is insufficient for navigating visually impaired people. From the interviews with visually impaired people, it was found that required accuracy is within 1m of where their white cane can reach. Similarly, a study by Fallah et al. reported that an accuracy of 3 feet (90cm) was required [13].

Therefore, we adopted more accurate positioning method using Japanese QZSS "Michibiki", which is a satellite orbiting near Japan's zenith that enhances the positioning accuracy by coordinating with the GPS.

In addition to transmitting signals compatible with conventional GPS, QZSS transmits two types of augmented signals, L1S (L1-SAIF) and L6 (LEX), to improve its accuracy. Sub-meter-level positioning is possible by using L1S augmented signals, and the receiver is relatively compact. In contrast, although centimeter-level positioning is possible using L6 augmented signals, it is impractical for individuals because the receiver is too large and expensive. In this study, the QZ1 receiver module which can receive L1S augmented signal developed by NEC was adopted.

Figure 3 shows the results of positioning experiments conducted on the ground at the National Institute of Technology, Tokyo College using QZ1. It was confirmed that sub-meter-level positioning can be achieved in the environment where there are no buildings nearby that block GNSS radio waves.

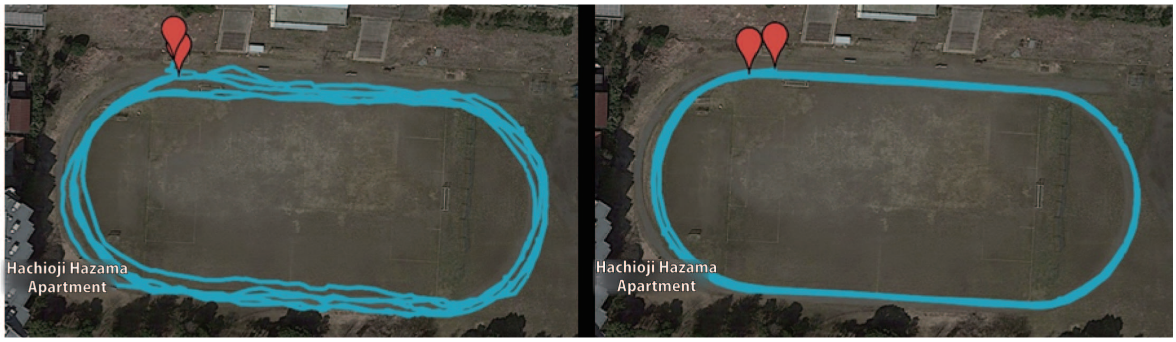

FIGURE 3. Results of positioning accuracy by conventional GPS (left) and with L1S (L1-SAIF) augmented signal transmitted from QZSS (right)

4.2. Position estimation by RFID. RFID is a power-saving wireless communication technology where a reader intakes information through RFID tags. Several studies have applied RFID tags to navigation for visually impaired people [14]. Since passive RFID tags do not require a power supply, they have both the advantages of easy installation in the environment and low maintenance costs. In this research, we adopted passive RFID tags to realize accurate positioning both outdoors and indoors. These tags were embedded in a wall or floor along a street or building in a practical environment to carry out several demonstration experiments. The details of these experiments will be discussed in Chapter 5. In general, passive RFID tags are often used at a communication distance of about several centimeters, but the UHF band RFID tags can communicate at a maximum of about 10m. Based on our RFID tag performance feasibility studies, position estimation within an error of 1m can be achieved [3].

4.3. Calculating a global route. The system calculates a global route between the current position of the user obtained by QZSS and RFID and the destination inputted by the user. The global route is calculated by Dijkstra's algorithm using a graph model

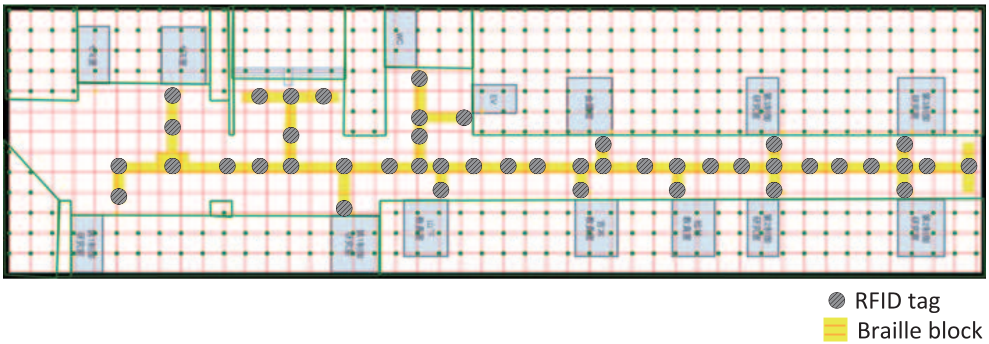

FIGURE 4. Definition and representation of the global map

composed of nodes arranged in a lattice pattern and edges representing that the user can move between two nodes (see Figure 4).

In the shortest path search, the cost of edges is defined by both the distance of the edge and an availability weight representing the difficulty and safety of passing through the edge for the visually impaired. An automatic calculation mechanism for the availability weight should be developed based on additional road information or image recognition, but this is the subject of future work. In this study, the weight was set manually in advance.

5. **Experiment1: Route Navigation in Practical Environment.** We conducted demonstration experiments at the Kitano railway station in Tokyo, Japan to validate the proposed system availability and usability.

In practice, it is not easy to install a large number of tags in the environment. However, we prototyped a new Braille block with a built-in RFID tag and showed that it was practical [3]. Furthermore, it was shown that a seal-type RFID tag can be used for navigation. Therefore, the proposed system can be used in limited areas such as stations and buildings by using the Braille blocks with built-in RFID tags at intervals of several meters or by sticking seal-type tags under some carpets.

The experimental route originates on the train platform and ends at bus stop while passing through elevators, stairs, ticket gates, etc. The total distance is about 240m (Figure 5). We used "IQ-600" by Omni-ID and "SURVIVOR" by Confidex Ltd. based on the results of preliminary experiments comparing the performance of RFID tags [3]. We installed 157 tags under the braille block outdoors, and about 150 seal-type tags along the aisle inside the station at about 5m intervals. The number of necessary tags depends

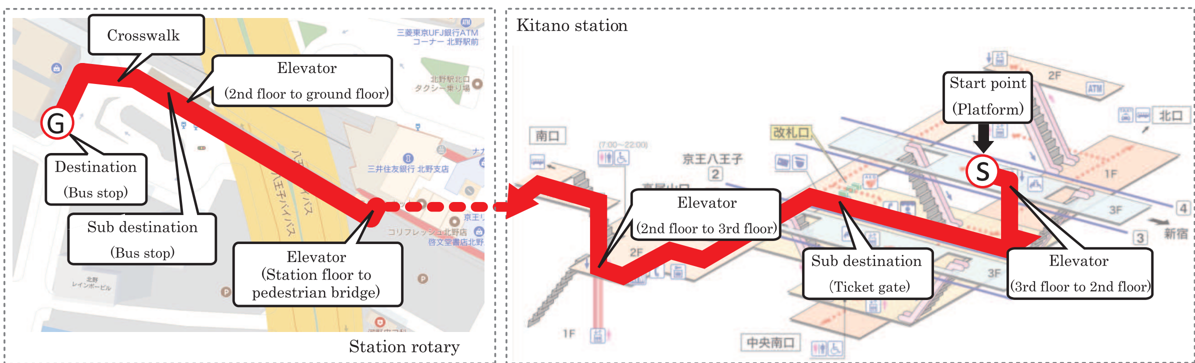

FIGURE 5. Total route in the demonstration experiment at Kitano station

on the surrounding environment, but the number of tags used in this experiment is more than necessary and can be reduced.

The experiments were conducted for 3 days by two participants, one with blindness and the other with strong amblyopia. Route guidance was provided by voice guidance every time the direction changed or at regular intervals.

A total of five experiments were conducted with two participants. In both experiments, participants were able to reach their destination without departing from the route. These experiments showed the possibility that the visually impaired person can reach the destination by him/herself using the proposed system. The authors have already conducted an evaluation experiment of position estimation using QZSS and RFID, and have shown that accuracy of 1m or less can be achieved [3]. However, in order to evaluate the navigation accuracy quantitatively in the real environment, additional experiments by more participants are necessary.

Additionally, since RFID tags use wireless communication, they are vulnerable to moisture. Therefore, the communication performance degrades when it rains or water pools. Extra measures, such as installing the tags in a well-draining place outdoors, were necessary to mitigate these issues.

In terms of usability, the following findings were obtained from interviews with the research participants.

- The most important system factors are its customizability and adjustability. As individuals walking abilities can vary greatly, users would like the opportunity to easily customize properties such as route setting and guidance speed.
- Many visually impaired people can now use smartphones on a daily basis. Even a visually impaired person can perform touch operations when they are combined with a voice guide. In the future we hope to realize such a screen operation interface.
- When turning continuously in certain direction, consecutive instructions can lead to confusion and necessitate ingenuity.

There were many requests for guidance method, timing, interface and size and weight of hardware during the interview. In order to put the system into practical use, it is necessary to equip the system with additional customizability and adjustability and to improve the guidance interface according to user feedback.

On the other hand, it became clear that visually impaired people cannot accurately grasp the direction they are facing. Therefore, the system must have a function to detect the direction of the user and guide the user in the direction to go. Furthermore, it is also difficult for them to avoid obstacles on the route, so an obstacle avoidance function is also required for the system. In order to solve this problem, we implemented the direction estimation and obstacle avoidance function using HoloLens in this research. This function is described in the next section.

6. **Obstacle Avoidance Using HoloLens.** It is difficult for visually impaired people to recognize the direction they are heading. In addition, it is also difficult for them to reach their destination while avoiding obstacles. In this research, HoloLens is introduced to perform 3D scanning of the surrounding environment, and both a direction indication function and an obstacle avoidance function are implemented and evaluated.

Spatial mapping is a function of HoloLens to provide both a 3D environmental map and a relative self-position in real time. Moreover, it automatically recognizes floors, walls and ceilings and provides information on walkable floors. The proposed system sets a point called "sub-goal" at a few meters ahead from the current position on the global route. HoloLens searches for a route to the sub-goal passing through walkable floors using the

3D environmental map built in real time on the current position. Therefore, it is not necessary to construct an entire 3D environmental map in advance.

Spatial mapping function is available on a user application by Unity API. Unity is a game engine with an integrated developmental environment, and although it is not directly related to HoloLens, it is possible to handle the 3D environmental map generated by HoloLens in Unity. We use the Unity function to generate obstacle avoidance routes because HoloLens does not have a route search function. Unity has a function to generate a route for moving 3D objects such as game characters to a certain point in the 3D virtual space. By applying the function for 3D environmental mapping by HoloLens, we can implement the obstacle avoiding navigation (Figure 6). In the Unity route generation function, the A^* algorithm is adopted. The resulting route is represented as a list of coordinate points.

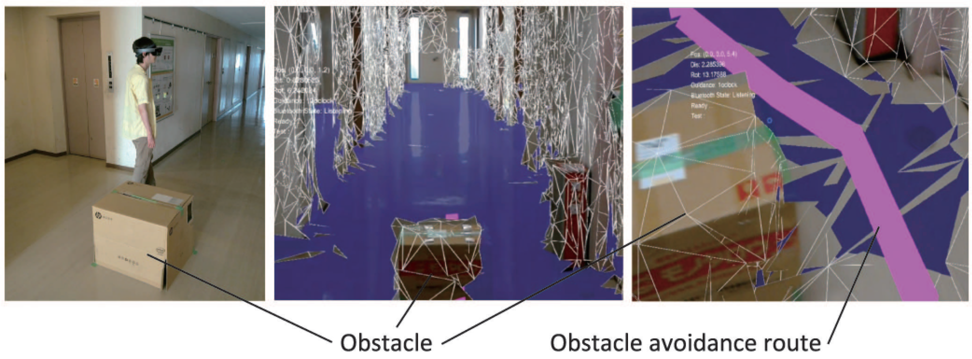

Figure 6. Preliminary experiment of obstacle avoidance using spatial mapping

7. **Experiment2: Avoiding Obstacles Using HoloLens.** This experiment aims to confirm that participants can avoid obstacles and move toward the destination based on spatial mapping by HoloLens when there is an obstacle on the route. In Figure 7, obstacles are placed in any of the places 1 to 3, and participants are not aware of this in advance.

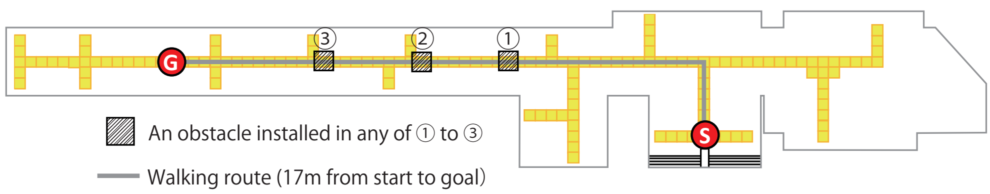

Figure 7. Experimental environment for obstacle avoidance

In this experiment, three blindfolded participants wore a HoloLens and walked to the destination, relying on voice guidance. The system indicates the direction to go once a second as "clock positions" which is commonly used for visually impaired people. In the case of 30 degrees to the left, voice guidance is given as "11 O'clock" to the user.

This experiment was conducted three times for three participants. Thus, a total of nine movement trajectories were obtained. Figure 8 illustrates an example of one of the walking trajectories. For eight out of the nine trials, participants were able to walk to their destination without colliding with obstacles. The following findings were obtained from participant interviews.

- The direction indicated by the clock position needs to be adjusted, and the 30 degree steps (the value obtained by dividing 360 degrees by 12) is too precise to understand.

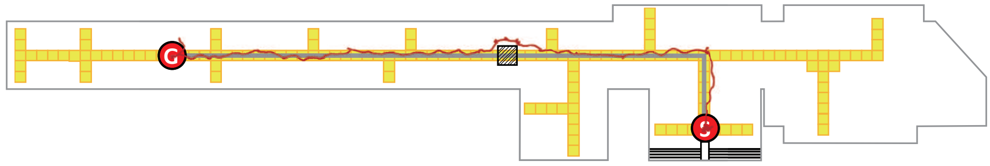

Figure 8. A walking trajectory obstacle avoidance example

- This system is functional if the user walks slowly, but if the user walks at normal speed, the HoloLens spatial mapping performance is lacking in spatial recognition up to 5m, and the space recognition sequential calculations occur too infrequently at once per second.

In this experiment, HoloLens was used as a sensor to obtain a 3D environment map, but the VR/AR display function was not required. For practical use, it is necessary to develop a device that is easier to wear using a small camera. Moreover, HoloLens can only sense the environment about 5m away in practice. When considering outdoor use, a sensor that can measure a longer range is required.

In addition, usability improvement in guidance such as the introduction of a haptic device to supplement voice guidance is an important research topic for the future.

8. **Conclusions.** This paper reported that a navigation system for visually impaired people was developed using RFID and QZSS for accurate positioning and HoloLens for obstacle avoidance. In the experiments, accurate positioning using RFID and QZSS was achieved with an error of less than 1m. Additionally, we performed demonstration experiments to validate the guidance for visually impaired people from a train platform to a bus stop in a practical environment and confirmed that participants could reach the destination by solely relying on the guidance. Furthermore, we also confirmed that it is possible to generate an obstacle avoidance route using sequential spatial mapping using HoloLens. The results of the participant interviews suggested that voice guidance alone may be insufficient for sudden guidance such as obstacle avoidance. We also found that the adjustability and customizability of the system are important to adapt to a variety of visual impairments and walking abilities. In the future, we will improve the guidance method by considering the introduction of haptic devices in addition to voice guidance and develop a practical system.

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