Walking Support for Visually Impaired Using AR/MR and Virtual Braille Block

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Abstract. In recent years, the number of visually impaired people has been increasing, and supporting the movement of visually impaired people will be indispensable for the future society. At present, for visually impaired people, a general-purpose walking support is a combination of a braille block and a white cane; however, it is not enough. In this research, we provide a system that expands the above combination by utilizing the technologies of a see-through head-mounted display (HMD) and Augmented Reality/Mixed Reality (AR/MR). Specifically, utilizing the features of AR/MR, a virtual 3D object is projected as a braille block (virtual braille block) on the walking surface of visually impaired people via an HMD. Subsequently, when the white cane waved by visually impaired people and the virtual braille block intersect (collision), the guidance of forwarding, left, right, and turn is returned as feedback by voice and vibration. By realizing these, the goal is to provide a system that enables visually impaired people to move freely in the walking space.

Keywords: Augmented Reality · Mixed Reality · Visual impairments · Blind navigation · Accessibility

1 Introduction

Various measures have been taken for a long time to assist the mobility of visually impaired people. However, in recent years, it has become a social problem. For instance, traffic accidents while walking and fall accidents at the platform of train stations occur one after another. Many of the causes are misrecognition of braille blocks, difficulty walking due to obstacles, and misjudgments due to changes in the surrounding environment. To solve the problem, it is required to install braille blocks on the sidewalk and install platform doors at the station; however, it takes time and cost to develop the infrastructure.

Therefore, this research focuses on improving the mobility of visually impaired people without maintaining infrastructure and provide a walking support system for visually impaired people using AR (Augmented Reality)/MR (Mixed Reality).

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2 Goal and Approach

2.1 Background

According to official statistics from the World Health Organization (WHO) in 2013, there are about 285 million visually impaired people in the world, of which about 14% are blind, and 86% are of low vision [1, 2]. In addition, WHO's latest announcement (August 2019) shows that the total number has increased significantly to about 2.2 billion [3]. The reason is that not only congenital, but also acquired disorders, are increasing.

Based on these backgrounds, research using ICT has been accelerated in recent years, such as research aimed at improving navigation accuracy for visually impaired people [4, 5], and research on avoiding collision with visually impaired people based on walking prediction [6].

2.2 Research Goal

In this research, we focus on the combination of a white cane and a braille block, which is a general-purpose walking support for visually impaired people [7, 8]. For example, in Japan, walking of visually impaired people is required by the Road Traffic law, with the assistance of a guide dog or the walking with a white cane [9].

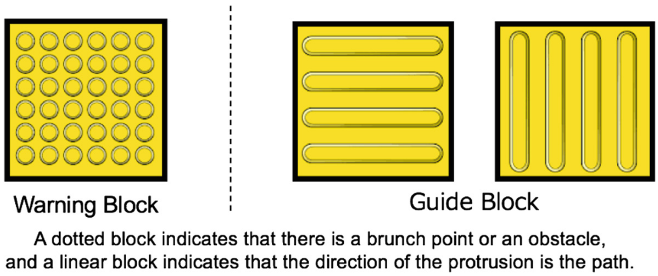

Fig. 1. Two types of braille blocks

Braille blocks (see Fig. 1) were invented in Japan in 1965, and are used by visually impaired people to walk on the road in front of them while waving a white cane. At present, it is a highly versatile system that is installed not only in Japan but also in over 100 countries around the world. However, there are the following restrictions and problems [10–12]:

- Space and environment are limited, depending on the installation cost.
- Due to design priorities, colors that are difficult to see for low vision people may have to be used.
- Warning block and guide block placement rules are not uniform.

To solve these problems, this research extends a general-purpose walking support using braille block and white canes using a see-through head-mounted display (HMD) and AR/MR technologies. Specifically, utilizing the features of AR/MR, a virtual 3D object is projected as a braille block (virtual braille block) on the walking surface of visually impaired people via an HMD. Subsequently, when the white cane waved by visually impaired people and the virtual braille block intersect (collision), the guidance of forwarding, left, right, and turn is returned as feedback by voice and vibration. By realizing these, the goal is to provide a system that enables visually impaired people to move freely in the walking space [13].

2.3 Assumed Users of This System

Users of this system are assumed to be visually impaired people, with mainly low vision [14]. The reason for it is that about 90% of visually impaired people will obtain low vision in the future, and there will be cases where they can recognize the virtual object projected on the HMD.

2.4 Novelty

In this system, the advantages of wearing HMD and walking support for visually impaired people by virtual braille blocks utilizing AR/MR technology are as follows:

- Braille blocks can be placed independently of space and environment.
- It can be changed to colors and shapes that are easily viewable by low vision people.
- Comprehension of proper placement rules, complementation of physical braille blocks.

Furthermore, even for blind people who cannot recognize virtual braille blocks, receiving feedback (voice, vibration) from this system will help walking assistance. Another advantage is that it can be used as a tool to provide comfortable walking spaces for visually impaired people by road managers and facility managers.

For these reasons, it can be said that this research, which wears HMD and supports walking for visually impaired people using AR/MR technology, has certain novelty and usefulness.

3 Related Work

3.1 Collision Avoidance Support System Based on Collision Prediction

Many kinds of research of walking support for visually impaired people assume their own use, such as guiding a walking route, detecting obstacles, and avoiding collisions—however, Kayukawa et al. [6] take an approach to inform other pedestrians that visually impaired people are walking and to encourage the pedestrians to avoid the collisions.

This research, which focuses on collisions with pedestrians, provides visually impaired people with a suitcase that includes image recognition and depth information acquisition functions. By tracking the position and movement of pedestrians facing each other, warning sounds are generated in various patterns according to the distance. It is beneficial for notifying a pedestrian who is touching a smartphone while walking or a group talking while walking that visually impaired people are walking. In our system, we refer to the distance to pedestrians (obstacles) and warning patterns.

3.2 Stair Walking Support System Using AR

Focusing on the difficulty of walking on stairs for visually impaired people (low vision), Yuhang Zhao et al. [15] have proposed stair walking support using two different AR platforms. One is a projection-based AR using a small projector, and the other is a smart-glass-based AR.

In projection-based AR, light using five animation patterns is projected at the edge of the steps of the stairs to alert visually impaired people. In smart-glass-based AR, the direction of the stairs and the number of stairs are notified to visually impaired people, and the stairs are classified into seven stages, centered on the top, middle, and bottom, and each is color-coded.

A comparison of the two shows that projection-based AR can move up and down at fast walking speeds. However, walking with a projector in hand is not easy, and AR using smart glasses is realistic. Although this system is limited to stairs, AR-based alerts using animation and the method of segmenting and visualizing colors in each experiment are effective.

4 System Design

This system provides the following two devices to visually impaired people with a white cane to assist in moving freely in the walking space.

- Microsoft HoloLens
- Smartphone

Microsoft HoloLens [16] is a see-through HMD that provides AR/MR technology. It projects virtual braille blocks dynamically generated as 3D objects onto real space, and use it as a device for notifying voice and beep sound source feedback. The smartphone is used as a device to alert the user during walking by blinking the screen and vibrating. The reason for choosing a smartphone is that the number of visually impaired people who use mobile phones or smartphones daily is increasing, and it is a device that they always carry with them [17, 18]. The functions and procedures for implementing this system are as follows.

4.1 Determination of Walkable Area

For visually impaired people to move freely in the walking space, it is necessary to determine whether the surrounding space is a walking area. In this system, obstacles (walls) and floors in space are identified as the first process to determine the walkable area.

Fig. 2. Field of view immediately after application launch

Figure 2 shows the real space in the field of view immediately after launching the application via Microsoft HoloLens. Then, using the combination of the depth sensor installed in Microsoft HoloLens and the Spatial Mapping/Understanding library of the Mixed Reality Toolkit (MRTK) [19], feature points of the surrounding space shape are extracted and accumulated. Figure 3 shows meshes based on the accrued feature points in the space.

Fig. 3. Mesh generated from feature points of the surrounding space shape

Subsequently, to improve the processing speed and reduce memory consumption, unnecessary mesh vertices are thinned out. Finally, the remaining mesh space is classified into walls and floors by flat surface processing. Figure 4 shows the state where this processing is added to Fig. 3, where the wall surface is drawn in red, and the floor surface is drawn in blue. The blue floor surface is the walkable area defined in this section. In this system, the environment data of the surrounding space is updated in real-time by repeating these processes once every three seconds.

Fig. 4. Walkable Area: walls and floors classified by flat surface processing (Color figure online)

4.2 Obstacle Detection

In addition to the walkable area, safe walking for visually impaired people requires detection of obstacles that obstruct the walking of the visually impaired. In this system, we define walls and physical objects as obstacles.

Wall as an Obstacle. For the recognition of the wall, the Raycasting function of Unity [20] is used to determine the collision (Physics.Raycast) between the wall object generated by flat surface processing and the gaze of visually impaired people. The gaze vector originating from the camera coordinates (Camera.main.transform.position) of Microsoft HoloLens always follows the movement of the HMD and measures the positions and distances of all the walls in the field of view. If there is a wall in forwarding direction and the distance to a wall is within 10 m, the wall is defined as an obstacle.

Figure 5 shows a state in which the gaze point shown in (1) collides with the front wall (red). In this case, the distance from the wall is about 3.3 m, as shown in the log (2), the wall is regarded as an obstacle, and the virtual warning braille block and the direction guide braille block are placed on the floor.

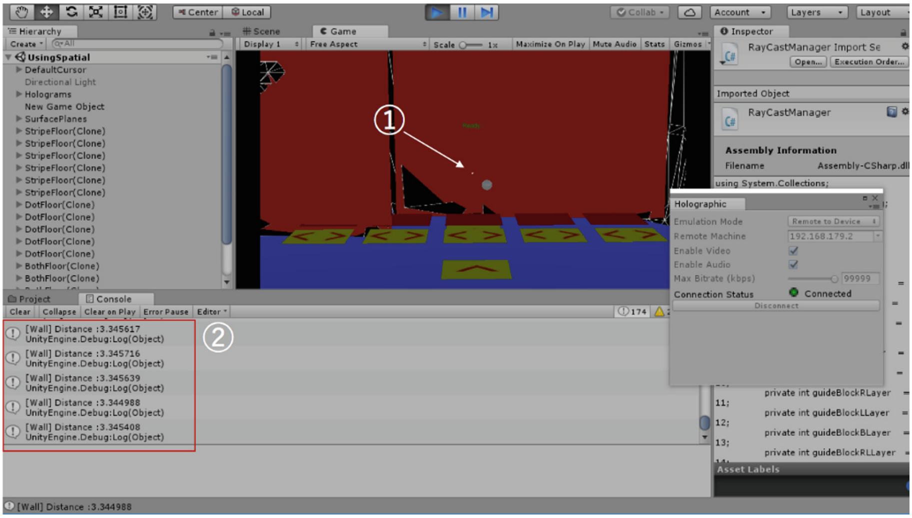

Fig. 5. Walkable area: walls and floors classified by flat surface processing (Color figure online)

Physical Objects as Obstacles. For recognizing physical objects in the field of view, we use the Azure Custom Vision Service – Object Detection [21], which is provided as a cloud service by Microsoft. Azure Custom Vision Service reads an image into a learning model of a physical target object. It determines whether the physical target object exists in the image by comparing the feature values.

This system uses the video camera function of Microsoft HoloLens to post the view image of visually impaired people captured every three seconds via the WebAPI to the created learning model. When the result is recognized as an obstacle, the object is notified by voice (see Fig. 5). Visually impaired people need sufficient time to avoid obstacles. Therefore, in this system, the condition threshold is set when there is a physical object within 5 m from the current position.

4.3 Virtual Braille Block

This system uses AR/MR technology to extend a braille block (see Fig. 1) and project it on a floor in real space as a virtual 3D object braille block (virtual braille block). In the walkable area, virtual forward guide braille blocks indicating the moving direction are projected. When walking is obstructed by obstacles, virtual warning braille blocks and direction guide braille blocks are projected. In this system, a virtual braille block is projected at 60 FPS to follow the gaze of visually impaired people.

Generating of Virtual Forward Guide Braille Blocks. Figure 6 shows that the gaze of visually impaired people collides with a floor object existing in the walkable area. Calculate the distance from the collision point (a) to the vertical point (b) from the HMD, and the angle of the HMD following the head movement. Then, virtual forward guide braille blocks are dynamically generated continuously on the floor between the points (a) and (b) in the direction of the gaze.

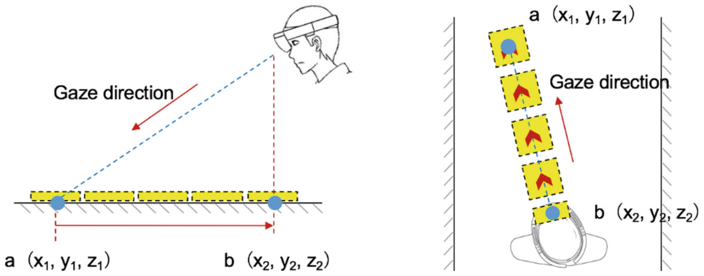

Fig. 6. Generating of virtual forward guide braille blocks

Generating of Virtual Warning and Direction Guide Braille Blocks. As shown in Fig. 7, the blocks that guide direction change of visually impaired people are a combination of virtual warning braille blocks (red) and direction guidance braille blocks (arrow).

These combinations consist of four patterns. If there is an obstacle such as a wall in the front and right-hand direction (1), the block displays direction change to the left. Similarly, if there is an obstacle such as a wall in the front and left-hand direction (2), the block displays direction change to the right.

On the other hand, if there is an obstacle such as a wall in the front but no obstacle in both sides (3), the block displays direction change to left and right both. If there is an obstacle such as a wall in the front and both sides (4), the block displays turn as a terminal.

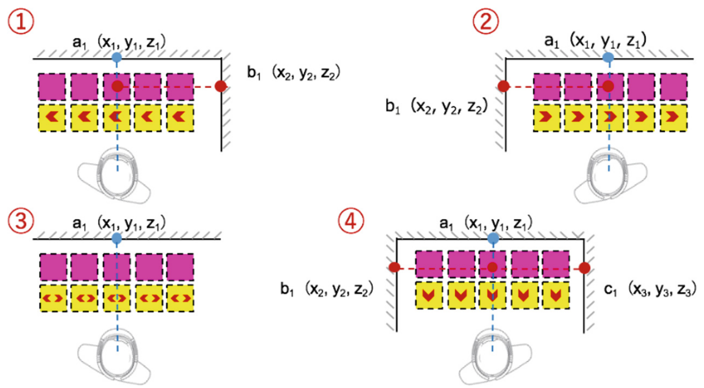

Fig. 7. Generating of virtual warning and direction guide braille blocks (Color figure online)

4.4 Change Color of Virtual Braille Block

Whether the braille block is easy to see or hard to see varies depending on the degree of color vision impairment and low vision. Utilizing the features of the system using AR/MR, this system can change the color of the virtual braille block, as shown in Fig. 8. This function is reflected by voice commands via Keyword Recognizer/Voice Recognizer.

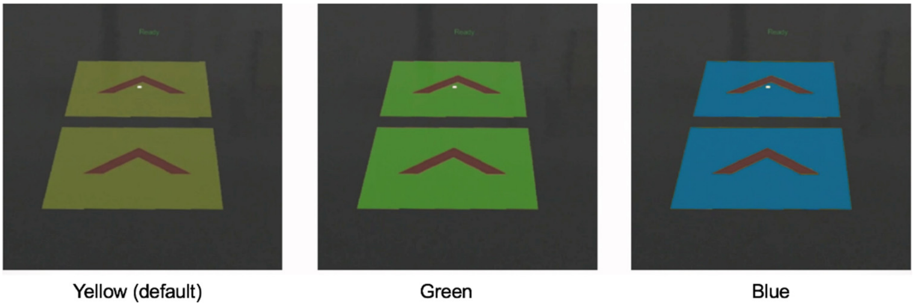

Fig. 8. Change color of virtual braille block by voice command

4.5 Intersection (Collision) Judgment of White Cane and Virtual Braille Block

This system focuses on visually impaired people walking while waving a white cane to rub the road in front. In this section, we use AR/MR to judge the intersection (collision) between the generated and placed virtual braille block, and the white cane waved by visually impaired people. In this system, the movement of the white cane is not detected by the system. Apply the feature that the tip of the white stick is on the extension of the hand of visually impaired people.

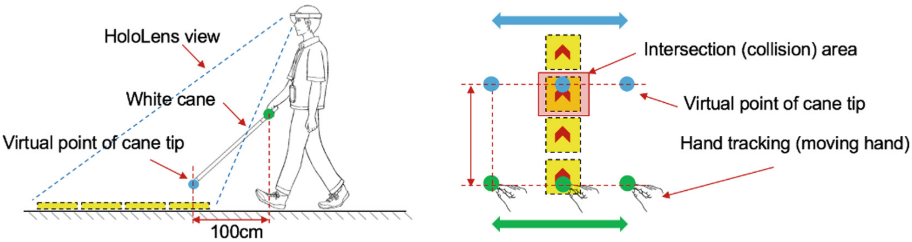

Fig. 9. Intersection (collision) judgment of white cane and virtual braille block

Assuming that the distance from the hand to the tip of the white cane is about 100 cm, the tip is the virtual point of the white cane. Subsequently, the horizontal movement of the hand holding the white cane is tracked. The virtual point at the tip of the white cane follows the movement of the hand, making it possible to determine the intersection (collision) with the virtual braille block (see Fig. 9).

To determine the intersection (collision), use Unity's Physics.Raycast from the virtual point at the tip of the white cane to the floor surface direction.

4.6 Feedback to Visually Impaired People

If the intersection (collision) between the white cane and the virtual braille block is determined, Microsoft HoloLens play the voice and beep sound and also notify feedback to the smartphone.

Voice and Beep Feedback via Microsoft HoloLens. If the intersection (collision) between the white cane and the virtual braille block is determined, the voice and beep sound feedback are sent to visually impaired people via Microsoft HoloLens according to the conditions in Fig. 7. Figure 10 shows the voice and beep sound patterns generated by this system.

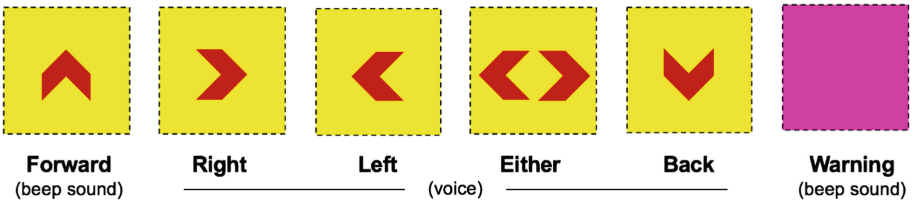

Fig. 10. Voice and beep sound patterns

Forward guidance and warning play two beeps. To notify right, left, either, and turn, use Microsoft HoloLens' Text-to-Speech API to play four types of voice guidance (Right/Left/Either/Turn).

Feedback to Smartphone. Similarly, if the intersection (collision) between the white cane and the virtual braille block is determined, the blinking screen and the feedback by vibration are notified to visually impaired people via a smartphone (see Fig. 11).

Fig. 11. Feedback to smartphone

This system uses WebSocket as a method of communication from Microsoft Hololens to a smartphone. As shown in Fig. 12, WebSocket Server is built on the cloud, and two-way communication is realized by connecting the Android application and Microsoft Hololens application to WebSocket Server.

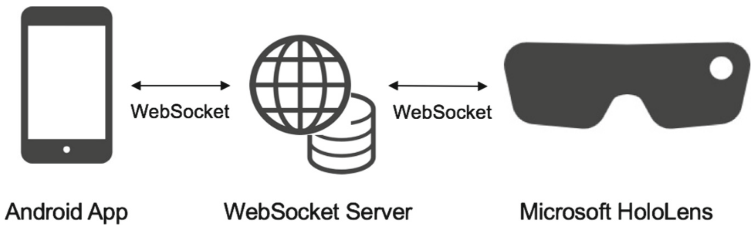

Fig. 12. Two-way communication between Microsoft Hololens and smartphone.

As shown in Fig. 13, if the intersection (collision) between the white cane and the virtual guide braille block is determined, a vibration occurs at 200 ms intervals, and the screen blinks yellow. On the other hand, if the intersection (collision) between the white cane and the virtual warning braille block is determined, a vibration occurs at 1,000 ms intervals, and the screen blinks red.

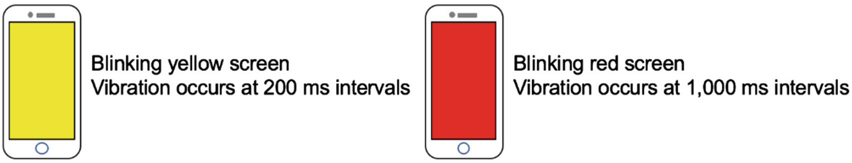

Fig. 13. Vibration and blinking screen (Color figure online)

The purpose of this blinking screen is not to notify the visually impaired, but to make the pedestrian aware that visually impaired people are walking around during walking at night.

4.7 Structure of Multi-thread Processing

In this section, we explain the timing of the above spatial recognition, generation of virtual braille blocks, obstacle detection, and hand tracking.

Figure 14 shows the multi-thread processing structure in this system. The gaze tracking starts immediately after the application and performs at 60 FPS (real-time) as the main thread. After that, a thread that performs spatial recognition (flat surface processing), obstacle detection, and hand tracking starts. Spatial recognition and obstacle detection are repeated once every 3 s, and hand tracking performs at 60 FPS (real-time) as with gaze tracking.

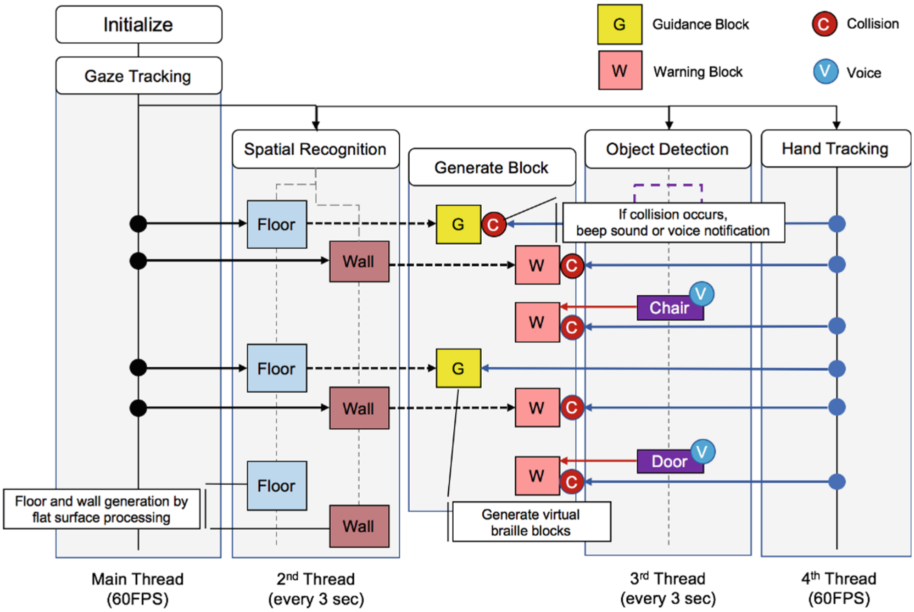

Fig. 14. Vibration and blinking screen

If the collision between the floor object generated by flat surface processing and the gaze of the visually impaired people is determined (Floor), the virtual direction guidance braille block is generated each time (G). If the collision between the wall object and the gaze of the visually impaired people is determined (Wall), the virtual warning braille block is generated each time (W). Similarly, if the physical object is detected by obstacle detection (Chair/Door), the virtual warning braille block is generated, and the obstacle is notified by voice (V).

On the other hand, hand tracking tracks the movement of the hand, waving the white cane. If the movement intersects (collides) with the virtual braille block (C), feedback to the voice, beep sound, and smartphone occur.

5 Hardware

The functions required for the device to be worn for this research are as follows:

- Sensor for extracting feature points in space
- Camera capture function for image recognition
- HMD capable of generating and projecting 3D objects
- Hand tracking
- Play audio/sound and Vibration function

Based on these factors, in this system, Microsoft HoloLens, a see-through HMD, and a smartphone with a vibration function worn by most visually impaired people were selected as devices.

5.1 Development Environment

The main framework in building this system is as follows:

- Mixed Reality Toolkit
- Unity 3D
- Azure Custom Vision Service

Mixed Reality Toolkit (MRTK) [19] is a library for developing cross-platform MR applications on Unity. This system uses the Spatial Mapping/Understanding library to perform spatial recognition and understanding using Microsoft HoloLens.

Unity 3D [20] is a 3D development platform. In this system, MRTK is loaded as a library in Unity, compiled as a UWP (Universal Windows Platform) application, and then installed on Microsoft HoloLens.

Azure Custom Vision Service [21] can use a part of the cognitive function of Azure Cognitive Service provided by Microsoft as WebAPI. In this system, object detection by image recognition is used in this function to detect obstacles that block the walking of visually impaired people.

5.2 Judgment of Walkable Area and Obstacle Detection

Judgment of Floor. To determine the floor surface as a walkable area, it is necessary to use the normal vector of the mesh plane generated based on the feature points of the surrounding space shape. This system refers to HoloToolkit.Unity.SpatialMapping. SurfacePlane class provided by MRTK. Whether the normal vector of the mesh plane is closer to the horizontal or vertical is determined by the direction of the normal and the threshold. When it is vertical and upward, it is determined to be the floor.

Wall Detection. To detect a wall, use the Raycasting function of Unity to determine the collision (Physics.Raycast) between the wall object generated by flat surface processing and the gaze of visually impaired people. Judge whether the gaze and the wall object collide within a distance of 10 m or less. If it is determined that a collision has occurred, it is regarded as an obstacle.

Obstacle Detection with Azure Custom Vision Service. Azure Custom Vision Service creates a learning model of a physical target object in advance. It determines whether the physical target object exists in a newly given image for the model. Figure 14 shows the result of the Azure Custom Vision Service determining the chair as a physical target object.

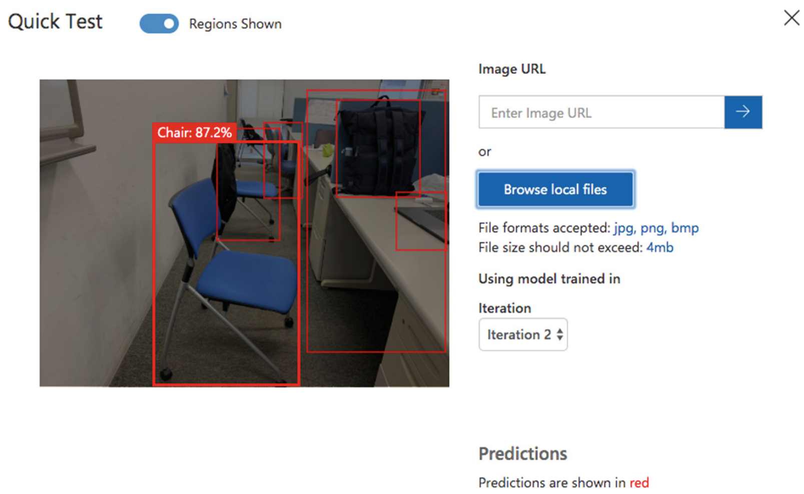

Fig. 15. Image recognition using Azure Custom Vision Service

After the image is determined, the identified object is surrounded by a red frame, and the accuracy is displayed. In this example, the chair in the center of the image has the highest accuracy (87.2%). In this system, obstacles that appear in the field of view once every three seconds are determined via WebAPI.

5.3 Generation and Placement of Virtual Braille Block

In this system, three types of virtual braille block models are created in advance as 3D objects and registered as Unity resources (see Fig. 15).

Fig. 16. Three types of virtual braille block models

These are called out from resources according to the conditions and are dynamically placed on the floor.

5.4 Intersection (Collision) Judgment of White Cane and Virtual Braille Block

In this system, the spherical 3D object in Fig. 16 is defined as a virtual point at the tip of the white cane of visually impaired people (Fig. 17).

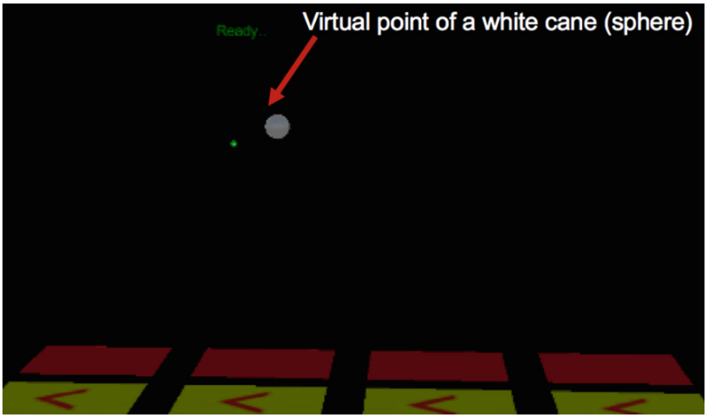

Fig. 17. Virtual point at the tip of the white cane

This sphere follows the horizontal hand movement while keeping a certain distance in the Z-axis direction (forward direction) from the hand of the visually impaired people who wave the white cane (see Fig. 9). Ray is cast vertical (Camera.main.-transform.up*-1) to the floor from the virtual point (x, y, z) at the tip of the white cane, and it is considered as an intersection (collision) if it collides with the virtual braille block layer.

5.5 Change the Color of Virtual Guided Braille Block by Voice Command

In this system, there is a function to change the color of the virtual guide braille block mainly for people with low vision. This function uses voice commands. It is because it is assumed visually impaired people operate without closing hand.

6 Preliminary Evaluation

This chapter introduces interviews with the viewpoint and convenience of visually impaired people and preliminary user evaluations to design and implement this system.

6.1 Interviews

We interviewed the Kobe Eye-light Association [22], a non-profit organization specializing in low vision and visual impairment support, for the problem of walking with white canes.

About Walking with White Canes. The white cane consists of three parts: a grip, a shaft, and a tip. There are about 150 types depending on the shape, weight, and length. For this reason, visually impaired people select those that are easy to use individually while receiving appropriate walking instructions. In our sense, it appears to be waving a white cane, but it is an action of rubbing or exploring the road. In addition to judging obstacles ahead, it also judges whether the road surface is asphalt or cobblestone.

About Walking with Guide Dog. Trained guide dogs are excellent, but they are expensive and can depend on their daily relationship with their owners, and only 1,000 are utilized in Japan. Therefore, it is not a realistic.

About Braille Blocks. We reconfirmed that the braille block is the most effective guide for visually impaired people with a white cane, but there is a problem with the number of braille blocks needed. Also, we found that a pedestrian crossing where braille blocks could not be installed was a problem. As a countermeasure for pedestrian crossings, a road crossing zone (escort zone) [23] for guiding the visually impaired has been introduced. Currently, the number of installations is small, and a new solution is required.

About Color Information. We reconfirmed that the color appearance differs depending on the visually impaired (low vision). We also found that the relationship between contrast, inversion, and the complementary color was important among colors.

About Mobile Phones. We reconfirmed that 90% of visually impaired people have a mobile phone and can be operated with voice guidance. However, visually impaired people often put their smartphones in their bags or pockets while walking to concentrate their consciousness on checking the road surface conditions. In this system, the vibration of a smartphone is used as a feedback notice. Still, we received advice that only auxiliary information (voice) that does not hinder concentration should be used.

About the Effectiveness of this System. We interviewed Kazunari Mori, the director of this association, who is a gait trainer and provides guidance in gait training, about his impressions of using this system. He said there was a problem with the response of hand tracking due to the limited viewing angle of HoloLens. However, he said that it would be practical and useful if the device could be miniaturized, expressed contrast, and adapted to the escort zone.

6.2 Preliminary Evaluation Participants

We invited eight participants (two women and six men) in their 20s and 50s to evaluate the usability and efficiency of the system. Participants did not include visually impaired people. However, it is crucial to simulate visual impairment [24]; therefore, in this preliminary experiment, participants temporarily removed the correction with eyeglasses and contact lenses and wore glasses for experiencing visual impairment.

6.3 Task and Questionnaire

All participants received a brief introduction to the system and instructions for operating Microsoft HoloLens. After the participants got used to the device, they walked using the system in the corridor and conducted a questionnaire after the experiment.

The questionnaire had the following five questions, which were evaluated by grading from 1 to 5 (1 = very negative, 5 = very positive).

1. Do you think this system is easy to use?
2. Do you feel that the virtual braille blocks complement the walking space where there is no braille block?
3. Do you think this system is attractive?
4. Do you think it is effective for walking assistance for visually impaired people?
5. Do you want to introduce this system to your acquaintances?

6.4 Result

Table 1. Questionnaire.

	P1	P2	P3	P4	P5	P6	P7	P8	Avg
Q1	4	4	4	5	3	4	4	4	4
Q2	4	4	4	4	4	5	5	5	4.38
Q3	5	4	4	4	5	5	5	5	4.63
Q4	4	3	4	4	4	5	4	5	4.13
Q5	4	5	4	4	5	5	5	5	4.63

Question 1 is about the usability of this system. The average score of 4 shows that the system is easy to use. However, concerning hand tracking, two participants pointed out that it takes time to get used to operating Microsoft HoloLens. Question 2 is about whether the virtual braille block can be a complement for the walking space where there is no braille block. The average score of 4.38 shows that this system can substitute braille blocks. Participants replied that they are particularly effective in unknown lands and environments. Questions 3, 4, and 5 are about the usefulness of this system. The average score of Q3 was 4.63, Q4 was 4.13, and Q5 was 4.63, which shows that this system is attractive and useful as a means to support walking support for visually impaired people (see Table 1).

Based on the results of these preliminary evaluation experiments, questionnaires, and interviews, this research aimed at realizing walking support for the visually impaired using AR/MR, despite a pseudo-visual impairment situation, received a certain high evaluation. In addition, it was shown that the system has utility and potential as a system to substitute braille blocks.

7 Conclusion and Future Work

In this research, we first focused on the fact that the combination of a braille block and a white cane is a general-purpose walking support for the visually impaired. Next, we showed that the walking space where there is no braille block could be complemented using AR/MR technology. In the implementation, the walkable area was determined by spatial recognition and obstacle detection. Based on the results, virtual guide braille blocks and warning braille blocks placed on the floor, and the system notified feedback of the intersection (collision) between them and the white cane by voice and vibration.

At present, the limitations and rules regarding the installation of braille blocks are a social problem. Based on the results of interviews and preliminary evaluations, this research, a walking aid using AR/MR and virtual braille blocks, can be a novelty and useful alternative to braille blocks.

We will apply the image recognition used in obstacle detection to the determination of road surface conditions in the future, and the color change of the virtual braille block is improved to a system that considers the relation of contrast, inversion, and the complementary color. In addition, by utilizing the features of this system, we will also consider a method to supplement the escort zone space that has not been installed, aiming to realize safer and more accurate guidance for visually impaired people.

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