Virtual Haptic Map Using Force Display Device for Visually Impaired

Takayuki Satoi * **Masanao Koeda** ** **Tsuneo Yoshikawa** *

* *College of Information Science and Engineering, Department of Human and Computer Intelligence, Ritsumeikan University, Noji Higashi 1-1-1 Kusatsu, Shiga, 525-8577, JAPAN. (e-mail:satoi@robot.ci, yoshikawa@ci.ritsumei.ac.jp).*

** *Department of Computer Science, Osaka Electro-Communication University, Kiyotaki 1130-70, Shijyounawate, Osaka, 575-0063, JAPAN.(e-mail:koeda@isc.osakac.ac.jp)*

Abstract: We propose a new virtual haptic map system using a force display device and a GPS receiver. This system can haptically display the roads, city blocks, and buildings which are automatically constructed from a numerical map given in DXF format and the information on current location and orientation from a GPS receiver. Hence this system will be especially useful for supporting outdoor activities of visually impaired persons. Other features of the system are that the map can be customized easily with respect to various characteristics such as a concave-convex shape of the objects or friction of surfaces in accordance with the user's need and that the position and orientation of the map can be changed automatically in real time. To evaluate the usability of this system, recognition experiments using simple virtual haptic maps were conducted by ten blindfolded subjects. In the experiments, recognition rates were compared between two representation methods. In the first method the area of road is concaved, and in the second method it is convexed. As a result, high recognition rates were confirmed in both methods, and it shows that this system has reasonable usability. Additionally, we found that concaved areas were touched for longer time than convexed areas. This suggests that important information is better to be displayed by concave parts. We have also developed a mobile robot system with our virtual haptic map system which is aimed at navigating a visually impaired person and supporting outdoor activity. A preliminary experiment is shown for the validity of this mobile robot system.

Keywords: Virtual reality, Haptic device, Virtual haptic map, Visually impaired

1. INTRODUCTION

In 2006, there are 314 million visually impaired persons around the world(1). For walking and recognizing around the present location visually impaired persons frequently use tactual maps that are fixed to the environment. Tactual map is a map which can be read by the sense of touch through the use of three-dimensional spacial mark and braille. These days barrier-free maps, especially fixed tactual maps, are placed in public facilities such as train stations. However, current tactual maps are difficult to carry around or to change their contents quickly(2). Hence it is desirable to develop new tactile display devices which are easy to change the content.

Tactor-pin type display devices have been studied by some researchers as a means to convey various information through tactile sense. Shimada et al.(3) developed new tactile display system using a tactile display device (SC-10, KGS Inc.) with tactor pins. Tactor pins are arranged in a matrix (32 48) and go up and down for displaying a shape through tactile sense. Force sensors are also provided in this system to detect the position of touch, making it possible to implement a bidirectional information display. Although this system can change the content of display quickly when compared with the conventional fixed tactual map, it has several physical limitations. For example, the display resolution is decided by the size of pins and the force information the user can obtain from the pin's reaction force is limited. Velazquez et al.(4),(5) developed tactile maps for a real-time guidance of visually impaired persons. Their system can display possible paths by processing the stereo camera images into free area information on a pin-matrix type tactile display. Hayward et al.(6)(7) researched on making schoolbook illustrations accessible for visually impaired students with tactile device called STReSS2(Stimulator of Tactile Receptors by Skin Stretch) which uses lateral movement of a matrix of 8 × 8 piezoelectric bending motors.

Another approach is to use haptic display devices developed in the field of haptic virtual reality technology. Haptic virtual reality is a technology which makes it possible for us to touch a virtual environment constructed by a computer through a haptic display device(8),(9). Haptic virtual reality technology has various advantages compared to tactile display with tactor pins. For example, it is much easier to construct virtual objects or spaces of

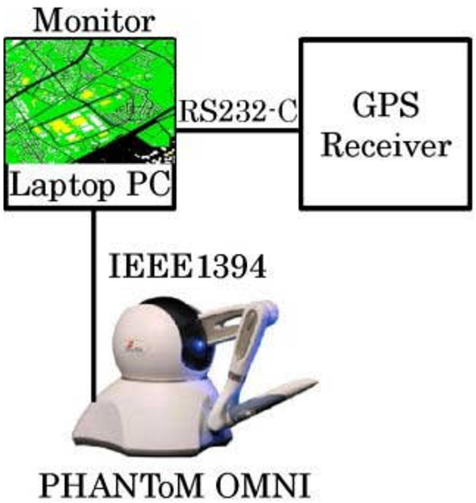


Fig. 1. System configuration

various types and to combine with other modalities such as audio channel.

Two-dimensional map based on force feedback and vibration was developed by Colledge et al.(10), Uri et al.(11). These systems create haptic-aural virtual environments for way-finding by children with congenital blindness. These systems display the maps in two-dimensional space, thus visually impaired persons get little information compared to three-dimensional map. Murai et al.(12),(13) developed “Haptic Walk-Guide Simulator” which gives a simulator training of an indoor pathway finding through haptic recognition for visually impaired persons. However, the displayed tactual map is static and it is intended for just indoor walk. There are also researches about a framework of map image analysis and presentation of the semantic information to blind users using alternative modalities(14),(15). Magnusson et al.(16)(17) reported test recognition of geometrical objects, recognition of VRML objects, mathematical surfaces and navigation in a traffic environment. However, these systems are also for displaying only static information and display of dynamically changing information is not discussed.

On the other hand, there are various researches about guide-dog robot(18),(19), guide robot for walking outdoor (20) or electronic canes(21),(22) recently. Most of these robots, however, can only navigate the user to a specified destination. Therefore, it is difficult to walk in unknown area. It is needed to develop a dynamic haptic map that visually impaired persons can recognize map information around the present location.

In this paper, we propose a dynamic haptic map using a force display device. We call this system as “Virtual Haptic Map”. This system can haptically display the roads, city blocks, and buildings which are automatically constructed from a numerical map given in DXF format and the information on present location and orientation from a GPS receiver. Hence this system will be especially useful for supporting outdoor activities of visually impaired persons. This system can create maps by various representation methods. We compared two representation methods experimentally: One method is to make the area of concave road and the other is to make it convexed. We also conducted

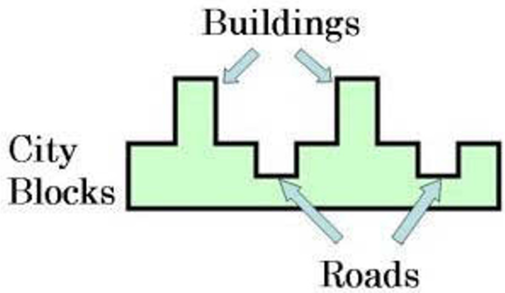


Fig. 2. Representation of Virtual Haptic Map

Fig. 3. Overview of Virtual Haptic Map

some experiments to evaluate the usability of this system. On the other hand, we have also developed a mobile robot system with our virtual haptic map system. A preliminary experiment is conducted to show the validity of this mobile robot system.

2. SYSTEM CONFIGURATION

In this section, we explain the system configuration of Virtual Haptic Map. As shown in Fig.1, the system consists of a haptic device (SensAble Technologies, PHANToM OMNI), a laptop PC (Dell, Precision M6300) and a GPS receiver (GARMIN, eTrex Vista). The haptic device has the range of movement 160w 120h 70d mm and maximum reaction force 3.3N.

The system creates a virtual space which includes roads, city blocks and buildings in the area around the present location and it is automatically generated by a numerical map and the GPS receiver output. This virtual space is constructed by OpenGL and the numerical map is DXF format. This format is a standard format used in CAD (Computer Aided Design) and it holds vector data of two dimensional or three dimensional figures. This numerical map is a commercially available product produced by NTT-Neo-Mate that is Japanese company.

Haptic roads, city blocks and buildings shown in Fig.2 are constructed in the three-dimensional space paralleled to the horizontal plane between the user and the haptic device. The Virtual Haptic Map feeds back reaction force to the user by touching the map.

3. VIRTUAL HAPTIC MAP

The Virtual Haptic Map aims to give map information to support outdoor activities of visually impaired persons.

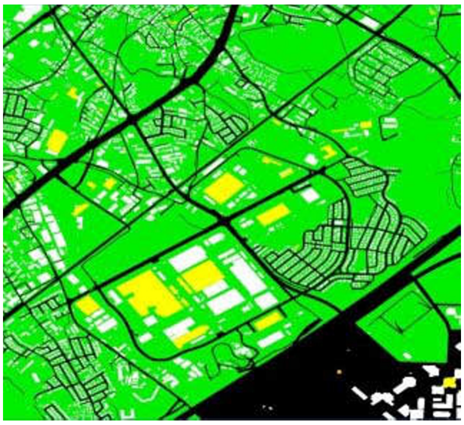
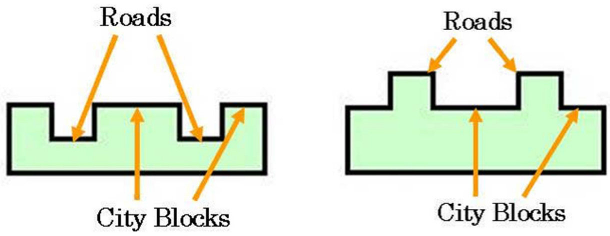


Fig. 4. Displayed image



(a)Method A (b)Method B

Fig. 5. Two representation method

The features of this system are that various rendering characteristics such as concave-convex shapes or friction of surfaces is easy to change depending on the user's condition. User can walk in unknown area, recognizing around the present location by touching Virtual Haptic Map.

The overview of the current system is shown in Fig.3 and the displayed image is shown in Fig.4. The map in the haptic virtual space is displayed 160 130mm. The roads are shown by black color in the monitor. The city blocks are green and the buildings are gray. The current pointing position of the haptic device is orange and landmark buildings are yellow.

We will explain the software functions of the Virtual Haptic Map in the following.

3.1 Displaying map in centering around the present location

The Virtual Haptic Map can construct a dynamic tactual map (roads, city blocks and buildings) in the area around the present location by a numerical map and GPS receiver. In this system, longitude, latitude and direction of movement are acquired from the GPS receiver once a second and the map is constructed in centering around the present location.

3.2 Checking present location

In the function of checking present location, the expanding factor is kept a constant value. When the blue button of the stylus is pushed, the user can feel a pulling sensation to the present location on the map.

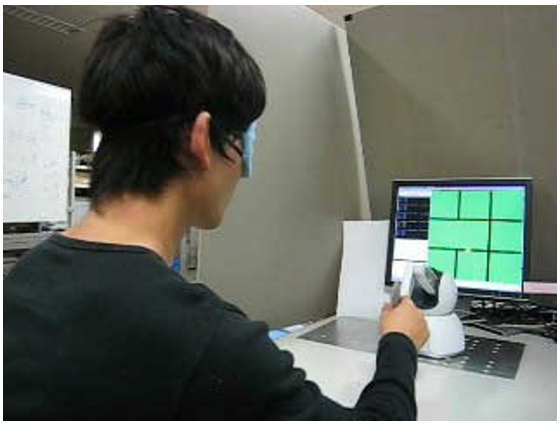


Fig. 6. Test overview

3.3 Scaling in centering around the present location

Scaling function is keeping viewpoint fixed and zooming in the map. User can zoom in five steps (2, 5, 10, 20, 30 times) by pushing blue button that is attached to the PHANToM OMNI's stylus.

3.4 Speech Output

Speech output is necessary to support giving information. "Zoom in" is announced in the scaling function and "Here is present location" is announced in the function of checking present location.

4. EXPERIMENT

In conventional tactual maps, objects are generally constructed by convex shapes. However, it is not clean if their representation method is good for every users. As the first step, in evaluating the usability of the system, we conducted experiments to compare the difference between concave and convex representation of the objects.

4.1 Two Representation Methods

We research in the representation which is adequate for visually impaired person's map recognition. We implemented two representation methods for a simple map. Fig.5(a) and (b) show the cross section of the map representation by the two representation methods. The only difference of them is whether the road is represented by a concave line or a convex line.

(1) Method A : City blocks are based and roads are concaved. (Fig.5 (a))
(2) Method B : City blocks are based and roads are convexed. (Fig.5 (b))

4.2 Contents of Experiment

In this experiment, we compared recognition rates between two representation methods. Moreover, we investigated the difference between the two methods regarding usage of the system. Fig.6 shows the overview of this experiment. The subjects were ten sighted persons (eight male, two female) aged 21-24. The subject was wearing an eye mask and blindfolded. A randomly-selected map from the eight maps

Table 1. Result of experiment

Subject	Number of Trial	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Recognition Rate(%)
A	Map Number	b	f	d	e	g	a	c	h	d	g	c	b	f	e	a	h	
	Map Recognition																	91.7
B	Map Number	c	f	a	g	d	e	h	b	c	e	a	g	b	f	d	h	
	Map Recognition																	91.7
C	Map Number	g	h	a	c	d	b	f	e	d	h	g	c	b	f	e	a	
	Map Recognition																	100
D	Map Number	d	g	b	h	c	e	f	a	e	f	b	a	c	h	d	g	
	Map Recognition																	100
E	Map Number	b	a	d	e	f	h	g	c	b	g	c	e	d	h	f	a	
	Map Recognition																	100
F	Map Number	g	b	d	a	h	c	f	e	a	f	h	c	d	b	e	g	
	Map Recognition																	75
G	Map Number	h	d	b	g	a	e	c	f	a	f	e	b	d	g	c	h	
	Map Recognition																	91.7
H	Map Number	e	h	a	b	c	d	g	f	h	c	g	e	d	a	b	f	
	Map Recognition																	75
I	Map Number	c	h	g	b	f	e	d	a	h	a	f	d	e	g	b	c	
	Map Recognition																	91.7
J	Map Number	h	b	f	a	d	e	g	c	f	b	g	a	c	e	d	h	
	Map Recognition																	100

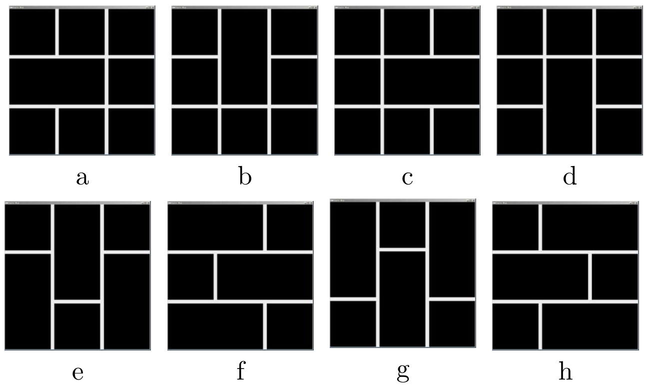


Fig. 7. Eight maps in the experiment
(white:road, black:town block)

shown in Fig.7 was displayed to the subject. There are roads, and city blocks in the maps. The size of the map is 120x120mm, the width of road is 3mm, the height of city block is 6mm. Roads and city blocks are displayed as white and black. One trial was taken for two minutes and repeated eight times in each representation method. After each experiment, the following question was asked to the subjects showing eight maps.
(Q-a). "Which maps did you touch among these eight maps?"

And after all experiments, the following question was asked to the subjects.
(Q-b). "Which representation methods did you feel easy to recognize roads or shape of map?"

To accustom subjects to the system, the experiment was conducted after practice for two minutes. To reduce the effect of order, five subjects(A-E) conducted in the order of method A first and then method B. The other five subjects (F-J) conducted in the order of method B first and then method A. To investigate the difference of usability between two representation methods, time in contact with each part (road, city block, other) was measured.

Table 2. Recognition rate of experiment

	All	A	B
Recognition Rate(%)	93.8	93.8	93.8

Table 3. Difference of Recognizing facility

	Method A	Method B
Road(people)	10	0
Map(people)	0	10

4.3 Result of Experiment

Table 1 shows the result of experiment. Map number means the kind of displayed map in each trial. or means whether the subject answered correctly or not to each question. Table 2 shows the average of recognition rates. the recognition rate is calculated as:

$$\text{recognition rate} = \frac{\text{the number of correct answers}}{\text{the number of all questions}}$$

As a result, high recognition rates were confirmed in both representation methods, and it also shows that this system has reasonable usability. We conducted preliminary experiments about recognizing buildings as shown in Fig.2, we got similar result to this experiment's result. Table 3 shows the result of question (Q-b). All subjects felt easy to recognize roads in method A (concave representation method), and all subjects felt easy to recognize shape of maps in method B (concave representation method).

Fig.8 shows times in contact with each part in experiment. In method A, subjects touched concave parts for a long time and didn't touch convex parts so much. In method B, subjects also touched concave parts for a long time and didn't touch convex parts so much. Thus,in both representation methods, subjects touched concave part for a long time.

From these results, we believe that the information represented by concave area will perform a crucial function for usability.

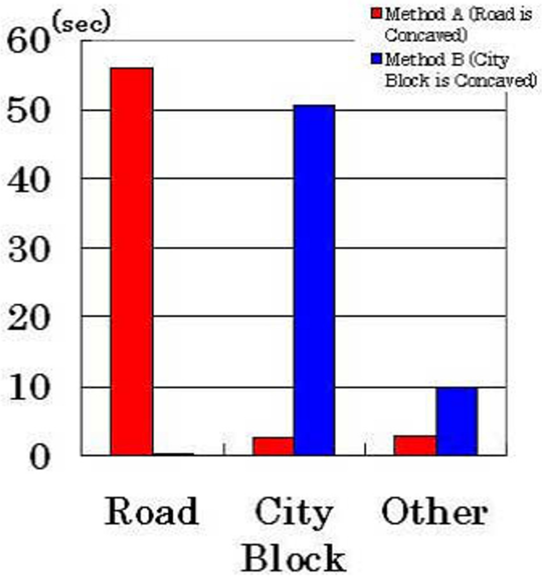


Fig. 8. Contact time of each part of the Virtual Haptic Map

5. MOBILE ROBOT SYSTEM WITH VIRTUAL HAPTIC MAP

The results of experiment show Virtual Haptic Map has reasonable usability. Hence we propose a way to leverage this system for supporting outdoor activities of visually impaired.

We have tried to develop an application of the Virtual Haptic Map. We have also developed a mobile robot with our virtual haptic map system. A preliminary experiment is conducted to show the validity of this mobile robot system. We will explain about the mobile robot system in the following.

As shown in Fig.9, the developed system consists of the Virtual Haptic Map and a mobile robot system. Virtual Haptic Map consists a haptic device (SensAble Technologies, PHANToM OMNI), a laptop PC (Dell, Precision M6300) and a GPS receiver (GARMIN, eTrex Vista), and the mobile robot system consists a wheeled platform(Pride, Jazzy1113) which is controled by the laptop PC. In this system, user recognizes around present location by Virtual Haptic Map and decides a destination in the virtual space, then the mobile robot approaches to the destination. This system's behavior consists of two phases in the following.

(1) Changing the direction to the destination
(2) Moving straight

In the phase (1), this system calculates direction of the destination using information of present location and orientation from the GPS receiver, furthermore the mobile robot changes direction until the mobile robot's orientation was equalized to the direction of destination. In phase (2), the mobile robot moves straight to the destination and stops, using location data (longitude, latitude) from the GPS receiver.

In addition, we conducted a experiment in outdoor. The mobile robot was orderd to run through the first destination from the start point and go to the final destination. The pathway is shown red lines and two destinations are shown green points in Fig.10(a).

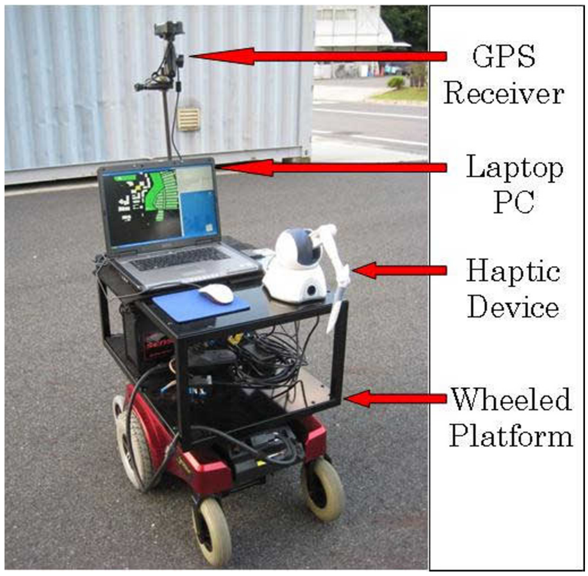
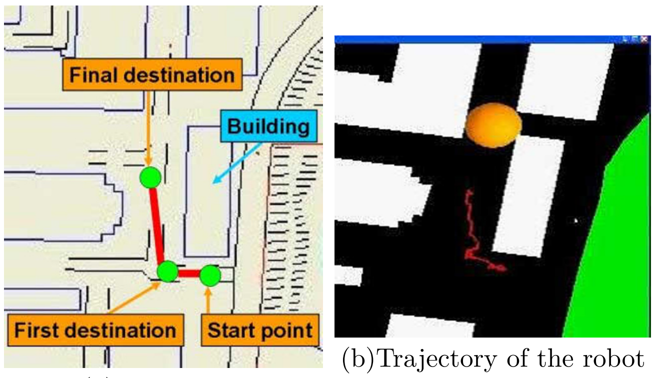


Fig. 9. Mobile robot system with virtual haptic map



(a)Test course

(b)Trajectory of the robot

Fig. 10. Track data in the experiment

The trajectory of the robot is displayed as red lines which is acquired from the GPS receiver is shown in Fig.10(b). The trajectory is similar to the given pathway in Fig.10(a), thus it means that the user could control the mobile robot and move to the destination.

6. CONCLUSION

We have proposed the Virtual Haptic Map. This system can haptically display the roads, city blocks, and buildings which are automatically constructed from a numerical map given in DXF format and the information on present location and orientation from a GPS receiver. This system aims to give map information to visually impaired persons for supporting outdoor activities.

To evaluate the usability of this system, map recognition experiments using simple virtual haptic maps were conducted by ten blindfolded subjects. In the experiments, recognition rates were compared between two representation methods. One method was to make the area of concave road, and the other was to make it convexed. As a result, high recognition rates were confirmed in both methods, and it shows that this system has reasonable usability. We also found that concave areas were touched for a longer time than convexed areas. This result suggests that important information is better to be displayed by concave parts.

A remarkable feature of this system is that various representation properties of the displayed maps such as a concave-convex shape or friction characteristics of surface can be easily changed in accordance with the user's preferences. This implies, however, that we need to continue our research to find a better way of representing the map information. Another topic for future work will be to provide the virtual haptic map with audio channel and/or with sensation of vibration. We have also developed a mobile robot with our virtual haptic map system. A preliminary experiment was conducted to show the validity of this mobile robot system. We are also planning to improve mobile robot system for supporting outdoor activities of visually impaired persons.

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