IIEEJ **Paper**

Stereovision Cane System : Obstacle Detection and Seat Recognition for the Visually Impaired

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<**Summary**> This paper proposes a stereovision-based assistive system for the visually impaired. The system is composed of a conventional white cane, stereoscopic cameras, keypad-type controller, tactile device, laptop computer, and so forth. The system can not only detect obstacles, but also recognize seats that a visually impaired user can use to take a rest. Ordinarily, a user can use the system as a white cane. When the user instructs the system to detect obstacles or to recognize seats in the vicinity, the system attempts to find such objects. If the target objects are found in the field of view of the stereoscopic cameras, the tactile device provides vibration feedback. The proposed system was applied to actual scenes that included obstacles or seats. The experimental results indicated that the proposed system is promising as means of helping visually impaired users find obstacles and seats.

Keywords: the visually impaired, assistive system, stereovision, obstacle detection, seat recognition

1. Introduction

In 2017, the World Health Organization (WHO) reported that the number of visually impaired individuals was estimated to be approximately 253 million worldwide1). Many individuals would use white canes to detect obstacles around them, but their detectable ranges are short, at most 1.5 m. Guide dogs are useful to walk safely with avoiding hazards. However, it is difficult to provide the sufficient number of guide dogs due to the training costs. In addition, it is difficult for the visually impaired to take care of the living dogs appropriately.

In order to overcome these problems, extensive research has been dedicated to creating assistive systems for the visually impaired2). Many research groups proposed obstacle detection systems based on various active sensors. Laser emitters were combined with canes3)–6), robots7)–9), hand-held devices10),11), and so forth12). Ultrasonic sensors were combined with canes13)–18), belts19),20), garments21), robots22)–25), and so forth26)–29). Depth sensors, such as Kinect and XTion PRO LIVE, were combined with canes30), helmets31)–33), vests34), belts35)–37) , goggles38), and so forth39)–42). Instead of these active sensors, stereoscopic cameras, which were passive sensors, were used with chest harnesses43),44), neck straps45), helmets46)–49), goggles50), and so forth51)–53). The aforementioned obstacle detection systems can inform visually impaired users about obstacles in front of them, but cannot tell them what the objects are.

Velzquez et al. proposed an assistive system composed of stereoscopic cameras and a tactile display54). The stereoscopic cameras obtained three-dimensional (3D) data, which were represented to a visually impaired user by use of the tactile display. The user was able to know his or her spatial location in an outdoor scene by confirming the tactile display. Kawai et al. also proposed an assistive system based on stereoscopic cameras and a tactile display55). The stereoscopic cameras observed daily objects, such as blocks and cups, and a user was able to recognize such objects by touching the tactile display. These systems were able to display 3D stereo data, but not to describe the data, and therefore users should recognize objects by themselves.

This paper proposes an assistive system based on stereoscopic cameras attached to a conventional white cane56). The system can not only detect obstacles, but also recognize seats that a visually impaired user can use to take a rest. Ordinarily, the system can work as a conventional white cane. When the user instructs the system to detect obstacles or to recognize seats in the vicinity, the system attempts to find them. If obstacles or seats are found in the field of view of the stereoscopic cameras, vibration feedback is provided. This stereovision cane system was applied to actual scenes that included

(a) A user using the stereovision cane system

(b) The stereoscopic cameras of the system

Fig. 1 Stereovision cane system

obstacles or seats.

This paper is organized as follows; section 2 describes the configuration of the stereovision cane system, section 3 explains user-system interaction, section 4 explains an obstacle detection method, section 5 explains a seat recognition method, section 6 shows the experimental results, section 7 describes the discussion, and finally section 8 concludes the entire work.

2. System Configuration

The stereovision cane system is composed of a white cane and a bag as shown in **Fig. 1**. The white cane is equipped with two conventional USB cameras that are arranged along the cane. The cameras at the higher and lower positions are called the top and bottom cameras, respectively. The baseline of the stereoscopic cameras is set along the cane, and their optical axes are set to be parallel to each other. The intrinsic and extrinsic camera parameters are calibrated beforehand by use of the 'findChessboardCorners', 'stereoCalibrate', 'undistort', and 'stereoRectify' functions in the OpenCV package[57](ver. 2.4.5). The bag contains a laptop computer, a numeric keypad, and a tactile device. The numeric keypad is used as a controller to input the user's instructions, and the tactile device is used to represent the results of obstacle detection and seat recognition. These components are connected by wires for signal communications and power supply.

(a) Top

(b) Bottom

Fig. 2 Stereo images of a scene

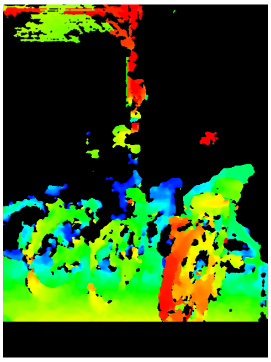

Fig. 3 Depth data of the stereo images shown in Fig. 2

Figures 2 (a) and (b) show color images obtained by the top and bottom cameras, respectively, in an outdoor scene. **Figure 3** shows the depth data of the color images. The depth data was obtained by the 'reprojectImageTo3D' function with default settings in the OpenCV package. In the depth data, distances from the cameras to points in the scene are color coded. Black pixels represent that the system cannot measure the distances at these pixels. The color-coded pixels, where the distances are obtained, are called 'features' in this paper.

3. User System Interaction

Ordinarily, a user can use the stereovision cane system as a conventional white cane. When the user instructs the system to detect obstacles or recognize seats, he or she stops walking to ensure his or her safety and stabilize the cameras, and then sets the cane system perpendicularly. The user can select an obstacle detection mode or a seat recognition mode by pushing corresponding keys on the keypad. If the system finds a target object in the field of view of the stereoscopic cameras, the tactile device provides vibration feedback to the user. Although the angles of cameras are limited, the user can pan the stereoscopic cameras to search the object. The strength of the vibration increases with the distance to the object.

The mode selection method is useful for a visually impaired user, because the user only pays attention to whether vibration occurred or not. If the system simultaneously outputs the information about obstacles and seats by changing, for example, vibration patterns, the user should select the necessary information by himself or herself. It would disturb the user who must concentrate on environmental sounds.

4. Obstacle Detection

In this paper, obstacles are defined to be objects that prevent a user from walking safely and are nearer than a predefined threshold D_{ob}. In order to detect such obstacles, pixels whose distances are less than the threshold are extracted from the lower half of depth data. Such pixels correspond to points on the surfaces of the obstacles. If the system detects such pixels, it provides vibration feedback to a user.

In Fig. 2, there are several bicycles near a pedestrian path. The distances to these bicycles from the system are approximately 330 cm. The system can detect the bicycles as obstacles, and warn the user about the obstacles by use of the tactile device.

5. Seat Recognition

Figures 4 (a) and (b) show the top and bottom images of a bus stop scene where there is a seat (bench). **Figure 5** shows the depth data of the stereo images.

Here we consider a situation where a visually impaired user wants to wait a bus with sitting on the bench. In this context, the bench is not just any obstacle, but a useful object that can be of benefit to the user. The system should notify the user that there is an available seat, not an obstacle. This concept was introduced as 'object recognition aid' $^{58),59)}$, and a seat recognition method was proposed for the Kinect cane system. In this paper, the method is applied to depth data obtained from stereo images.

The seat recognition method is described below.

(a) Top (b) Bottom

Fig. 4 Stereo images of a bus stop scene

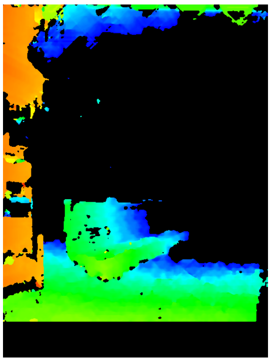

Fig. 5 Depth data of the stereo images shown in Fig. 4

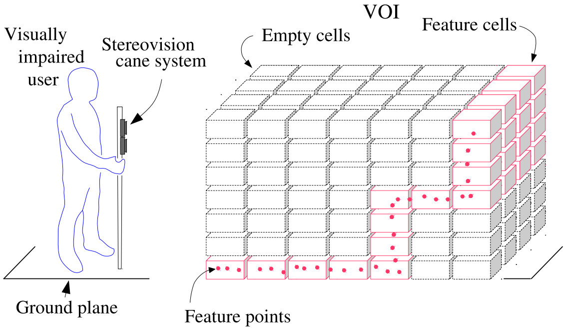

Fig. 6 Searching process of a seat in a visually impaired user by use of the stereovision cane system

5.1 Ground plane recognition

Figure 6 represents that a visually impaired user searches a seat by use of the stereovision cane system. Red dots depict points that correspond to features in depth data (called 'feature points'). The 3D positions of the feature points are calculated on the basis of the parameters of the stereoscopic cameras. The formulations related to stereo vision can be found in, for example, the study$^{60)}$. A cuboid is virtually constructed so as to include all the feature points, and is called a volume of interest (VOI). The VOI is divided into smaller cuboids whose heights, widths and depths are set to be H_{cl}, W_{cl}, and D_{cl}, respectively. The smaller cuboids are called 'cells'. If cells include more than N_{fp} feature points, the cells are defined to be 'feature cells'. In Fig. 6, the feature cells are represented by cells with red solid lines, and empty cells are represented by cells with black dotted lines. The feature cells at the ground level are merged into a cell group if they are adjacent to each other in the horizontal direction. The ground level is determined from the distance from the stereoscopic cameras to the lower end of the cane. The ground plane is obtained by fitting a plane to the feature points in the cell group.

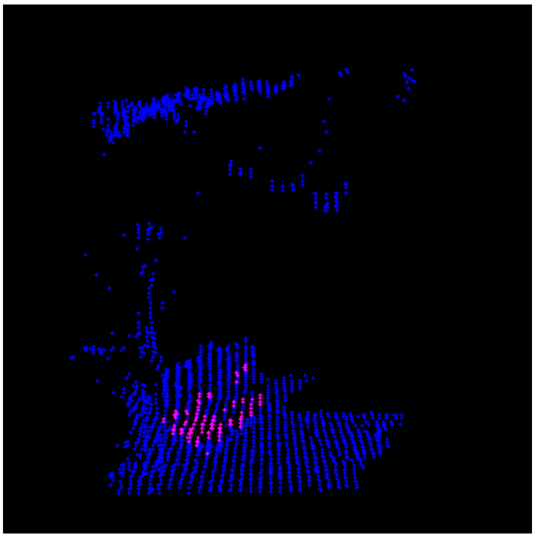

Fig. 7 Recognition result of the seat in Fig. 4

5.2 Sitting surface recognition

Sitting surfaces are considered to be the most essential parts of seats, and are recognized as described below.

The feature cells between H^l_{ch} and H^h_{ch} in height are extracted as 'seat candidate cells'. If there are obstacles above the seat candidate cells, the cells are eliminated, because the obstacles prevent a user from sitting safely. The remaining seat candidate cells are merged into cell groups if they are adjacent to each other, and the largest cell groups are determined to be the sitting surface of a seat. If the seat is found, the system gives vibration feedback to the user.

Figure 7 shows the result of the seat recognition. Pink and blue regions represent objects recognized by the system as a sitting surface and other objects, respectively. The sitting surface of the bench is recognized as a pink region.

The system sometimes misrecognizes an object that is not a seat. Therefore, it is necessary for a user to confirm by himself or herself whether the object is a seat or not.

6. Experimental Results

The manufacturer, model number, maximum resolution, frame rate, and viewing angle of the USB cameras used in this paper are Buffalo, BSW20KM11, 1920 × 1080 pixel, 30 fps, and 120 degree, respectively. The manufacturer and model number of the laptop computer are SONY and SVT131B11N, respectively.

6.1 Obstacle detection

The parameter of the obstacle detection method, D_{ob}, is set to be 400 cm, but it can be adjusted by a visually impaired user.

(a) Top (b) Bottom

Fig. 8 Stereo images of a scene including bushes beside a pedestrian path

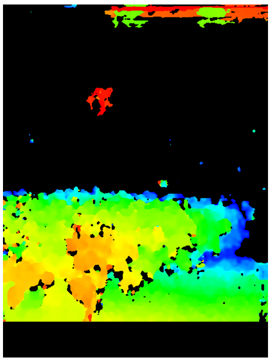

Fig. 9 Depth data of the stereo images shown in Fig. 8

Figures 8 (a) and (b) show the stereo images of a scene that includes bushes beside a pedestrian path. The distances to the bushes are approximately 320 cm. **Figure 9** shows the depth data of the images. The system can detect the bushes as obstacles.

When the stereovision cane system was used in an environment where there were no obstacles within D_{ob}, it did not provide vibration.

6.2 Seat recognition

The parameters for the seat recognition method, H_{cl}, W_{cl}, D_{cl}, H^l_{ch}, H^h_{ch}, and N_{fp} are experimentally set to be 4 cm, 10 cm, 10 cm, 30 cm, 50 cm, and 10, respectively.

The seat recognition method was applied to 35 scenes that included at least one seat and 56 scenes that did not include any seats. The sighted authors confirmed whether these scenes included seats or not. The following two states were defined to be success: (1) the system produced vibration feedback in the seat-including scenes, and (2) the system did not produce any vibration feedback in the other scenes. The other states were defined to be failure. The confusion matrix is listed in **Table 1**. The performance of the seat recognition method is listed in **Table 2**.

Figures 10 (a) and (b) show the stereo images of an

Table 1 The confusion matrix of the seat recognition.

		Recognition	
		Seats	No seats
Actual scenes	Seats	34	1
	No seats	12	44

Table 2 The precision, recall, and F measure values of the seat recognition method

Precision	0.74
Recall	0.97
F measure	0.84


(a) Top (b) Bottom

Fig. 10 Stereo images of scene including a bench

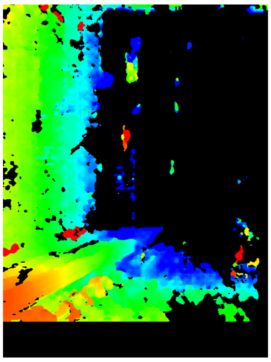
Fig. 11 Depth data of the stereo images shown in Fig. 10

indoor scene that includes a bench, and **Fig. 11** shows the depth data of the images. The distance of the bench is approximately 260 cm, and the system can recognize the bench successfully as shown in **Fig. 12**.

7. Discussion

The major advantage of our stereovision cane system over many other systems is to be able to recognize seats in everyday scenes. These systems can only detect seats as obstacles, and therefore visually impaired users should confirm whether the detected objects are seats or not. The stereovision cane system can recognize seats, and notify users about the seats.

In addition, the stereovision cane system can be used seamlessly from indoor scenes to outdoor scenes, and can find objects even under strong sunlight. On the other hand, our previous assistive systems (such as the Kinect cane system[58),59)]and the XTion PRO LIVE cane system[61)]) used infrared sensors, and therefore cannot find objects under sunlight because infrared rays are disturbed by the sunlight. This point is also the advantage of the proposed assistive system.

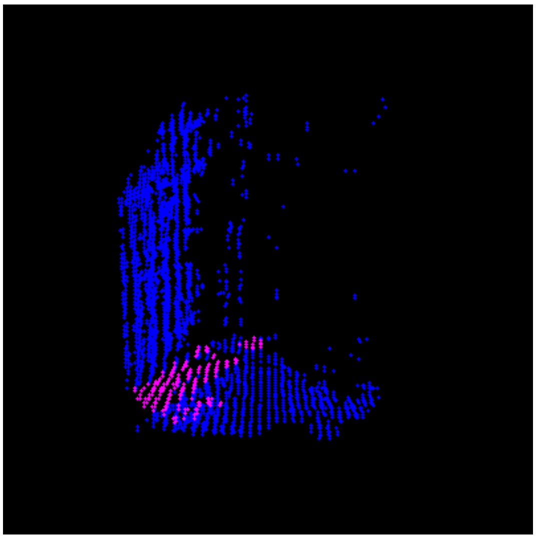
Fig. 12 Recognition result of the bench in Fig. 10

There have been many stereovision-based object recognition systems. The novelty of our system against these systems is to combine stereovision-based object recognition with aid for the visually impaired.

The seat recognition method described in section 5. is the same as that used in our previous assistive systems except several parameters such as the sizes of the cells, and therefore there is a little novelty in the seat recognition method itself. However, it is important to confirm that the same recognition method can work well not only for 3D data obtained by active sensors (such as infrared sensors) but also for those obtained by passive sensors (such as stereoscopic sensors) without any extensive customization. The present paper can demonstrate that the seat recognition method has versatility against the differences of sensor types.

Table 1 indicated that 97% (34 out of 35) of seats were recognized correctly, but also that the proposed system failed in 21% (12 out of 56) of scenes. In many cases, the steps of upward staircases were misrecognized as sitting surfaces. The system should be improved to be able to discriminate such objects from seats.

In our previous study[56)], we conducted experiments with several scenes. In this study, we applied the stereovision cane system to more scenes, and obtained 0.84 as the F measure value in Table 2. This value indicated that the system would be useful for daily use, but should be improved in the future.

The stereovision cane system can recognize only seats. The Kinect cane system can recognize other objects, such as desks$^{62)}$, elevators$^{63)}$, handrails$^{64)}$, occupied seats, upward and downward staircases$^{59)}$. The stereovision cane system should be improved to be able to recognize such objects.

The plane recognition method described in section 5.1 can recognize the ground plane sufficiently accurately, if the cane is set perpendicularly on the ground plane. However, if not, the accuracy would be decreased. In that case, it is necessary to use more accurate plane-detection methods$^{65),66)}$.

The calculation times of obstacle detection and seat recognition are approximately from one to two seconds. They would be sufficient in static or nearly static environments, but not in dynamic environments where, for example, many people are walking. We should improve the efficiency of these methods.

8. Conclusion

The present paper proposes the stereovision cane system that can not only detect obstacles but also recognize seats in the vicinity of a visually impaired user. The system can also notify the user about these objects by use of a tactile device.

The proposed system was applied to actual indoor and outdoor scenes. The experimental results indicated that the stereovision cane system was promising as means of helping visually impaired individuals find obstacles and seats.

Acknowledgments

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