Springer KSME

Journal of Mechanical Science and Technology 24 (6) (2010) 1261~1264
www.springerlink.com/content/1738-494x
DOI 10.1007/s12206-010-0332-5

Newly developed walking apparatus for identification of obstructions by visually impaired people †

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(Manuscript Received August 6, 2009; Revised December 21, 2009; Accepted March 21, 2010)

Abstract

In this work, two visual systems to help visually impaired people walk were developed: the first is a white cane with a non-contact detection system, and the second is a three-dimensional (3D) visual system. In place of the sense of sight, the sense of touch, either via vibration or of pins, can relay information on objects and obstacles around people. In a white cane non-contact detection system, two sets of ultrasonic sensors and vibrators, respectively, are employed to indicate the positions of both low- and high-level obstructions in front of the visually impaired person. When objects are detected by the sensor, the vibrator is strongly activated. In this system, the range of obstruction detection can be adjusted between 0.5 m and 5.5 m. By comparison, the 3D visual system uses two different components, an infrared camera sensor to detect obstructions and a tooling apparatus, incorporating a number of 1 mm diameter pins, by which their 3D shapes are derived. The pins are arranged in a 10×10 matrix and move longitudinally between the retracted and extended positions based on the depth data between the infrared sensor and the obstruction. Pins are elongated individually, so that each pin tip represents a specific area of the outer surface of the object. This tactile 3D image can provide effective object information.

Keywords: Visually impaired person; Walking apparatus; Ultrasonic sensor; Infrared sensor; White cane

1. Introduction

There is a large and growing number of visually impaired people in the world: 76 million worldwide by 2020, according to one estimation [1]. The visually impaired people when walking outside encounter certain dangers, such as (i) cars, (ii) holes and (iii) head-height obstructions. These dangers are the more serious due to the limited effectiveness of the standard walking aid used by the visually impaired that is the white cane. In attempts to address this issue, various devices [2-7] in which mechanical and electronic systems provide additional information have been developed. For example, audible-message systems can provide warnings of obstructions and traffic lights. Such technologies designed to assist handicapped people; however, those are seldom used, owing to high prices and complexity. In fact, almost all visually impaired people still rely on the simple white cane. The aim of the present study therefore was the development of effective visual object-detection systems. In fact, two such systems were developed: (i) a white cane with a non-contact detection system that relays information on obstructions in the vicinity of the user by means of sensors and vibrators, and (ii) a 3D visual system that provides a clear 3D profile of objects using a number (e.g. 100) of small pins.

2. Principles of object-detection systems

2.1 White cane with non-contact detection system

Fig. 1 is a schematic illustration of the mechanism of the non-contact detection system as incorporated into a white cane, and Fig. 2 displays the non-contact detection system developed in the present work. In this system, the object information is relayed by the sense of vibration. This system comprises two sets of ultrasonic sensors and vibrators installed on a commercial graphite white cane 1270 mm in length (Revolution Enterprises Inc.). The vibrators are small ($5\times6\times14$ mm^3) of the type widely utilized in mobile phones (Minebea Electronics Motor Co. Ltd.). They are inserted into the grip of the white cane and wrist band via a specially designed plastic holder, employed to strengthen the vibration. The ultrasonic sensors are $19.9\times22.1\times16.4$ mm^3 (MaxBotix Inc. EZ1). The sensors' range (i.e. the distance between obstructions and sensor activation) can be adjusted from 0.5 m to 5.5 m. They send a signal every 50 ms. The related electronic components, in-

† This paper was recommended for publication in revised form by Associate Editor Young Eun Kim

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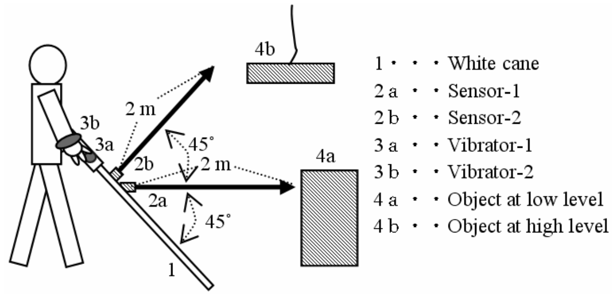
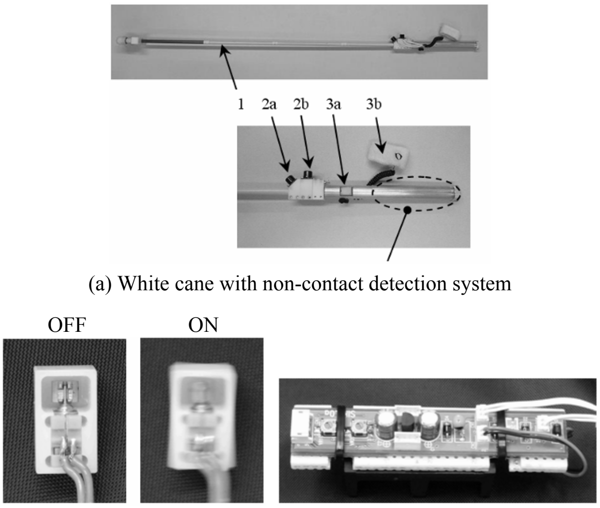


Fig. 1. Schematic illustration showing mechanism of non-contact detection system in white cane.



(a) White cane with non-contact detection system

(b) Vibrator (3a and 3b) (c) Electrical parts on print board

1 : White cane
2a: Sensor for detection of low-level obstructions
2b: Sensor for detection of high-level obstructions
3a: Vibrator for low level objects
3b: Vibrator for high level objects

Fig. 2. (a) Non-contact detection system, (b) vibrator and (c) electrical components on print board stting in grip of white cane.

cluding the print board, are inserted with the sensors and vibrators into the grip of white cane.

With this system, when an obstruction is detected by the sensors, the vibrators are triggered, sending the pertinent object information to the person holding the cane. The two sensors (2a and 2b in Fig. 2) activate the two vibrators (3a and 3b), respectively. Two sensors are employed, not one, so that objects at both low and high levels can be detected. It should be noted that the detection of high objects is especially important, because the white cane usually is swung to the right and left at low levels, making detection of particularly dangerous high objects (e.g., cross bars) almost impossible. In order to enable detection of high-level objects, that sensor is attached at a 45 degree angle to the other (low-level-object detecting) sensor (which is itself attached at a 45 degree angle to the cane). The detection distance for both sensors was set at less than 2 m. All of the parameters were established on the basis of the results of trials conducted with visually impaired subjects. Further experimental will be reported in a later paper.

Table 1. Number of collisions in inside walking test (10 participants).

Obstruction	Number of minor collisions	Number of major collisions
Person	1	0
Desk	0	0
Cross bar	2	0

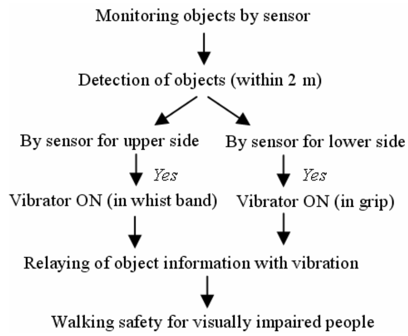
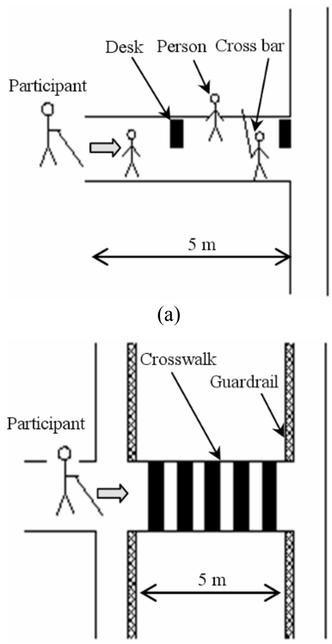


Fig. 3. System flow chart for white cane with non-contact detection system.

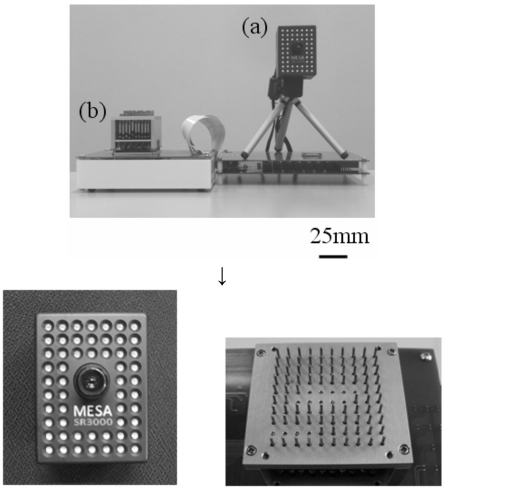


(a)

(b)

Fig. 4. Schematic illustration of test fields with various obstructions: (a) inside walk trial test and (b) outside walk trial test.

The overall process of this system of visual detection is summarized by the flow chart in Fig. 3. The mechanical performance of the white cane with its non-contact detection system was evaluated by means of trial walking tests. The tests were carried out inside and outside of a building in Akita, Japan. Inside the building, 10 visually impaired participants walked along a hallway in which there were various obstacles including a desk, a person and a thin cross bar (about 13 mm in diameter). Fig. 4(a) illustrates the test fields showing the obstructions and walking path. It should be noted that the cross bar was set at a high level, the height of the participants' faces.



(a) An infrared camera sensor (b) A tooling apparatus for creation of a 3D shape of the obstruction with small 100 pins, arrayed with 10×10 with 4.0 mm pitch.

Fig. 5. The three-dimensional visual system.

In the trial test, all of the participants successfully detected the obstacles, including the thin cross bar, passing through without any major collisions. The results of the trial test are summarized in Table 1. As can be seen, a few minor collisions (light contact) occurred, but there were no major problems. In the outside trial test, the two participants walked on a sidewalk and crossed a pedestrian crossing (see Fig. 4(b)). In this test, the participants found the guardrails and crossed the crosswalk successfully. The lack of any major problems in either of the tests confirmed the new white cane to be a helpful walking aid for visually impaired people. However, the system has a limitation in that it cannot detect clearly concave objects (e.g., holes) or downward steps. This problem will be solved in future work.

2.2 Three-dimensional (3D) vsual system

Fig. 5 illustrates the 3D visual system developed in the present work. This system consists of two main components: (i) an infrared camera sensor to detect obstructions and (ii) a tooling apparatus of 100 small pins (ϕ1 mm) in a 10×10 array (4 mm in pitch) for creation of the 3D shapes of the obstructions. The 100 pins can be moved with the driving force of a small ultrasonic actuator (ϕ5 mm × 0.5 mm) setting on the bottom of the pins (Technohands Co. Ltd.). A compact camera infrared sensor (165 g and 600×600×400 mm^3; Mesa Imaging AG, SR3000) was incorporated, attachable to a cap or belt. Table 2 lists its specifications. With the sensor, images of obstructions can be taken at a frame rate of 29 Hz (at 300 mm). The obstructions are easily detected, especially those located within a radius of 7.5 m. An image of the object is displayed in black and white based on the distance data, where nearer distances equal brighter images. Object images are resolved into 176×144 = 25344 pixels. The distance data for each pixel of the image were obtained with high accuracy by the time of flight (TOF) principle. This method measures the time that it takes for light from an object to reach a detector. The distance is proportional to the time needed for light to travel between the camera sensor and the obstruction. One hundred (100) pins, arranged in a 10×10 matrix, make longitudinal movements between the fully retracted and fully extended positions on the basis of the distance data. The pin can be elongated to 8 mm (maximum) in 0.8 mm increments. The pin tip represents an area on the outer surface of the object, and the length of the pin from the base face is determined by the distance from the sensor to the object.

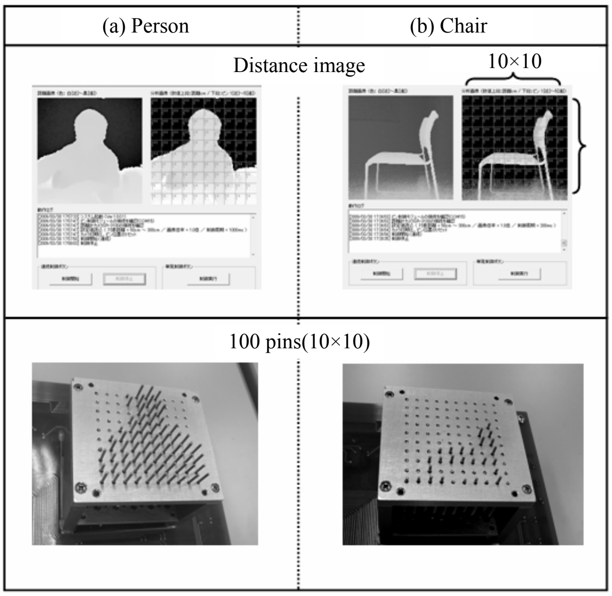


Fig. 6. Three-dimensional visual system showing images of (a) person and (b) chair.

Fig. 6(a), (b) shows image data of obstructions (a person and a chair) obtained by the infrared camera sensor, along with the 3D shape of the object formed by the pin array. The tactile images of the objects' shapes are precise reflections of the pin tips. Each pin position is determined by the average depth over the area of each mesh shown in Fig. 6, such that each pin represents 1/100 of the entire area. The resolution of the pin movement was designed to be 1/1000 of the actual depth data, in which the higher the pin level, the closer the position of the object to the sensor. For instance, the (i) 4 mm and (ii) 8 mm (maximum) pin positions correspond to (i) 4 m - 5 m and (ii) 0 m - 1 m distances from the sensor, respectively. The object information can then be obtained by touching the pins.

3. Conclusions

In the present work, two new systems were developed to facilitate the safe walking ability of visually impaired people: (i) a white cane with a non-contact detection system and (ii) a 3D visual system.

(1) To detect obstructions, a white cane, fitted with two sets of ultrasonic sensors and vibrators, respectively, was

used to detect both low- and high-level objects. Two vibrators were inserted into the grip of the white cane and a wrist band, respectively. These were activated when objects were detected by the ultrasonic sensors. Obstructions at distances ranging from 0.5 m to 5.5 m could be detected by the sensors.

(2) The 3D visual system provides clear information on the shape and distance of obstructions. This system has two main components: (i) an infrared camera sensor to detect obstructions and (ii) a 10×10 array of 100 pins. Obstructions can be detected when it is located within a radius of 7.5 m. The pin tip represents an area on the outer surface of the object, and the length of the pin indicates the distance to the obstruction.

Acknowledgements

The author would like to acknowledge the financial support of the Okawa Fundation and Japan Science and Technology Agency (JST). The author also greatly appreciates the technical support provided by many visually impaired people, including Prof. Takashi Niioka and Dr. Yukinori Sato.

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