

A white cane modified with ultrasonic detectors for people with visual impairment

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ABSTRACT

Background: A white cane is the most common equipment used by the blind for navigation. However, a cane can detect obstacles only at ground level, while many physical barriers can be at mid-body or head level.

Objectives: The aim of this study was to create a white cane with ultrasonic sensors that could detect objects at waist and head levels.

Materials and methods: Ten blindfolded participants, 5 males and 5 females, were recruited by means of purposive sampling into the study. All these participants tested the efficacy of the modified cane by walking through 3 obstacle spots; the first was a barrier at head level; the second and third were barriers at waist level. The instruments used were: 1) The Satisfaction Assessment for Assistive Devices and 2) the electrical and assembly compartments for the ultrasonic detector. The data was analyzed using descriptive statistics.

Results: The results demonstrated that all blindfolded participants could get through the three testing stations by using the modified white cane. They also revealed high satisfaction with both the usability and efficiency of the modified cane. The highest satisfaction in usability was for the size of the cane ($\bar{x} \pm SD = 4.50 \pm 0.533$). Participants also reported very high satisfaction with the efficiency of the cane in detecting objects at mid-body ($\bar{x} \pm SD = 4.70 \pm 0.48$) and head levels ($\bar{x} \pm SD = 4.50 \pm 0.53$).

Conclusion: All these results indicated that the modified cane with ultrasonic detectors was beneficial for detecting objects at mid-body and head levels in visually impaired people.

Introduction

The number of people who are visually impaired is increasing. In the year 2015, an estimated 36 million people around the world were blind; 217 million had moderate or severe vision impairment, and 188 million had mild vision

impairment.¹ In Thailand, in the year 2019, there were 191,264 people with defective vision out of 2,058,082 people with disabilities² in the total population of 66,186,727.³ This makes it the third in the country in terms of the number of people suffering from a disability.² Visual impairment and age-related eye diseases affect economic and educational opportunities.⁴ They can also reduce the quality of life⁵, and increase the risk of death in these individuals.^{6,7} Visually impaired people face many challenges in their daily lives, such as reading, cooking, socialization, transportation, exploring unfamiliar environments, and, especially, moving from place to place.⁸ Navigating independently, without the assistance of others, is a major

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challenge for these people.^{9, 10} The most common and accessible assistive device for individuals without vision is the white cane.^{11, 12}

The white cane can detect physical barriers in front of people with visual disturbances, but only at ground level. It cannot explore aerial obstacles or architectural barriers near the middle and upper body parts of blind people, such as timber branches, suspended advertisement boards, etc., and these can be dangerous to those with blindness.^{13, 14} Manduchi and Kurniawan¹⁵ studied mobility-related accidents in 300 blind participants, and they revealed that 40% of these individuals reported head accidents at least once a year. In addition, they reported that 23% of the incidents had medical consequences. Many walking assistants have been developed for obstacle detection at the aerial level with sensor feedback signals.¹⁶⁻²¹ Sensor-based walking aids provide people with visual impairments with information about their surroundings through an audio signal, vibration, or both.²² Among the different sensors, ultrasonic sensors are widely used.²³ Dos Santos, *et al.*¹¹ developed an electronic white cane to detect objects above the waist for blind users. However, there were 3 electronic compartments affixed separately to the handle of the white cane -namely the ultrasonic sensor, the microcontroller, and the battery-and this may have caused maintenance difficulties. Kulyukin, Gharpure, and Nicholson²⁴ developed a walking aid for visually impaired people called RoboCart where the authors used radio frequency identification (RFID) to tag the objects. However, this system is impractical for use in real life as it is not easy to trace everything with RFID. The virtual white cane or the hand-held range sensing device²⁵ and the smart cane²⁶ are some other equipment for people with visual impairment. These also have some limitations, such as being bulky in size, uncomfortable use, and difficulties using them in public.

In Thailand, Punyanon²⁷ has developed ultrasonic sensor equipment that can be attached to a cap worn above the eye level of the blind persons in order to detect barriers in front of them above their waistline, and Kongkumsuk²⁸ has produced an ultrasonic box that is fixed to eyeglasses for persons with visual impairment to explore objects from mid-body and above. However, the equipment was bulky and the weight of it dragged down the cap and eyeglasses when the users were walking.

Researchers, therefore, were interested in the development of the white cane with ultrasonic sensors that could detect obstacles both at mid-body and at head levels. The ultrasonic detector should be attached to the handle of the white cane firmly and tidily and be easy to use. This is consistent with the Empowerment of Persons with Disabilities Act, B.E 2007, in Thailand, which states that assistive devices should be accessible by people with disabilities in order to promote independent living and a good quality of life (QOL) for these individuals.²⁹

Materials and methods

The present study aimed to create a white cane with an ultrasonic sensor to detect physical barriers at waist and head levels in front of people with visual impairment. This study also investigated the effectiveness of the modified white cane and evaluated satisfaction among the blindfolded subjects using the equipment.

Participants

Ten non-visually impaired adult participants, 5 males and 5 females, were recruited by means of purposive sampling from the 4th year occupational therapy students at the Faculty of Associated Medical Sciences, Chiang Mai University, in the academic year 2020. The selection of subjects was in accordance with the inclusion criteria as follows:

Inclusion criteria

- 1) All senses are intact throughout the whole body. Superficial, deep, and cortical senses were tested by the 3-scale (intact, impaired, and absent) sensation examination.
- 2) People with a normal gait pattern. Tested by allowing subjects to walk on a 6-meter walking path.
- 3) Height between 151 and 190 centimeters (cm), as most people's heights are between this range.
- 4) Willing to participate in the research project where all subjects are required to close their eyes with eye pads on and walk in the simulation environment during the testing procedure.

Instruments

1. The Satisfaction Assessment for Assistive Devices The Satisfaction Assessment for Assistive Devices was developed by Punyanon.²⁷ The instrument assesses the satisfaction of users with assistive devices in two aspects: 1) the appearance of the device size, weight, and assembly compartments), and 2) the efficiency of the device (precise detection of obstacles and accurate warning signal). Scores of satisfaction are ranked from 1 to 5 in each case, in which 1 refers to very low satisfaction, 2 to low satisfaction, 3 to moderate satisfaction, 4 to high satisfaction, and 5 to the highest satisfaction.

2. Electrical and assembly compartments for the ultrasonic detector

- a. one piece of ESP32 DOIT NodeMCU ESP32 circuit board
- b. two pieces of HC-SR04 Ultrasonic Module Distance Measuring Transducer Sensors
- c. one piece of flame retardant FR-4: used as an electrical insulator
- d. two pieces of 3-volt vibration motors
- e. one piece of Module Stepdown 6-30V to 5V 3A fix 5V
- f. one piece of 9-volt battery holder
- g. one piece of 9-volt battery
- h. one piece of on/off switch (DC power)
- i. one piece of 5-meter electric wire
- j. The wooden electronic box
- k. The white cane.

Research Procedure

The research procedure was conducted step by step as follows: 1) The research project was approved by the Ethics Committee, Faculty of Associated Medical Sciences, Chiang Mai University (CMU), Thailand (ethics clearance number: 541/2563), 2) After the ethics approval, the research team created the circuit diagram and established the electrical circuit board of the ultrasonic detector, 3) Assembled all of the electrical compartments together into a wooden box and fixed this box to the white cane, 4) The authors of this paper contacted two experts - one a specialist who works in the area of assistive technology and the other an occupational therapist who has worked with visually impaired people for more than 5 years- to evaluate and comment on the modified white cane, 5) There was a public announcement of the research project to the 4th year occupational therapy students at the Faculty of Associated Medical Sciences, CMU and they were invited to participate in the study, 6) In accordance with the inclusion criteria, we recruited 10 participants, 5 males and 5 females, 7) We set up the simulation environment for training and testing the usability and efficiency of the fabricated

white cane, 8) All subjects signed the consent form prior to participating in the testing procedure, and 9) The research team and research assistants (RA) collected data during the testing process.

Development of the White Cane Modified with an Ultrasonic Detector

The development of the white cane modified with the ultrasonic detector in the present study used ultrasonic principles. The ultrasonic transmitter sends a sound wave forward, and when it hits an object, a reflective wave is sent back to the ultrasonic receiver, which is converted into a vibration signal in real-time. The development process of the modified white cane was conducted step by step as follows.

- 1) The circuit board (model no. ESP32 DOIT NodeMCU ESP32 DEVKIT V1 ESP-32S NodeMCU ESP-WROOM-32 Wi-Fi) and Bluetooth Dual-Core (model no. ESP-32 ESP-32S ESP-32D) were fixed to the flame retardant FR-4. The electrical circuit diagram of the ESP32 DOIT NodeMCU is shown in Figure 1.

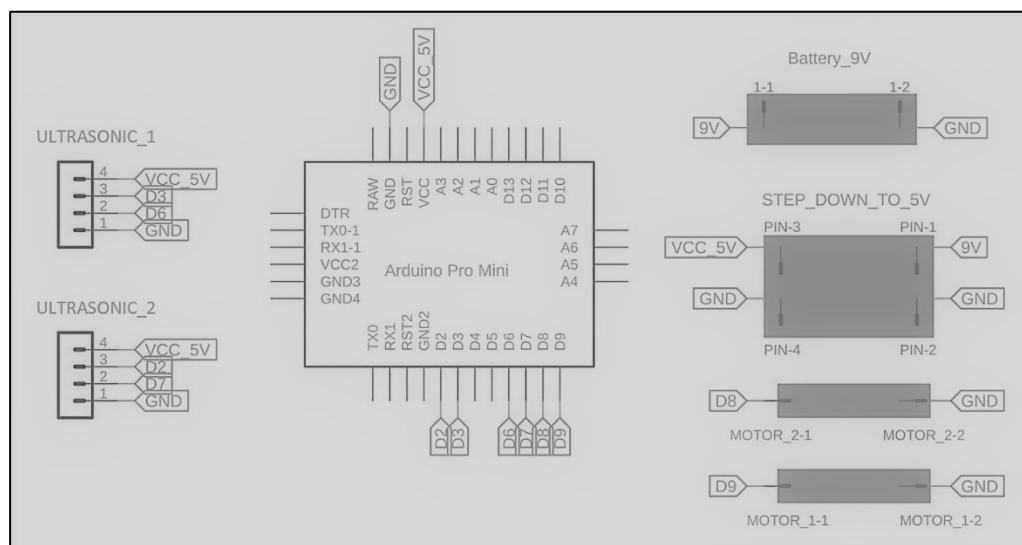


Figure 1. Ultrasonic sensor electrical circuit diagram.

- 2) Two ultrasonic sensors: module HC-SR04P, the 3-volt vibration motor and the Module Step-down 6-30V to 5V 3A fix 5V were connected to the circuit board.
- 3) We affixed the battery holder with a 9-volt battery and affixed the on/off DC power switch to the circuit board.
- 4) All of the assembly compartments were put in a small wooden electronic box (Figure 2) and attached to the handle of the traditional white cane (Figure 3). A three-dimension diagram of the wooden electronic box, which included size and shape, was shown in Figure 4. The weight of all the compartments and the wooden electronic box was 195 grams. Wooden electronic box was coated with lacquer

to make it more durable. The traditional white cane has a length of 124 cm and a weight of 300 grams. The total weight of the modified white cane, therefore, was 495 grams. This cane has three main parts: a handle (grip) made from anatomic rubber, a straight aluminum shaft, and a nylon tip that is in direct contact with the object or the ground.

- 5) The ultrasonic sensors inside the wooden box can detect obstacles from mid-body to head level in front of the subjects. The lower sensor explored barriers at mid-body level and the upper sensor detected obstacles at head level (Figure 5). The frequency of the ultrasonic wave for the detection of objects was set at 45 kHz. It can detect both transparent and opaque objects.



Figure 2. The wooden electronic box.

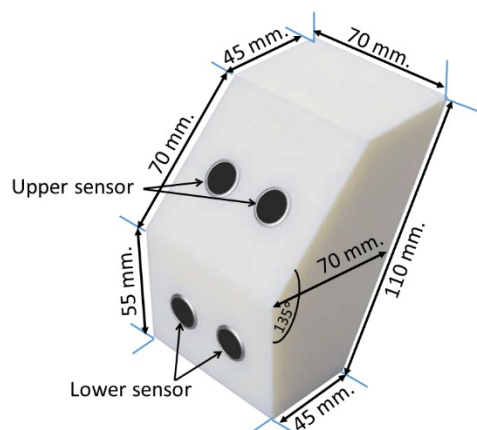


Figure 4. A three-dimension diagram of the wooden electronic box.

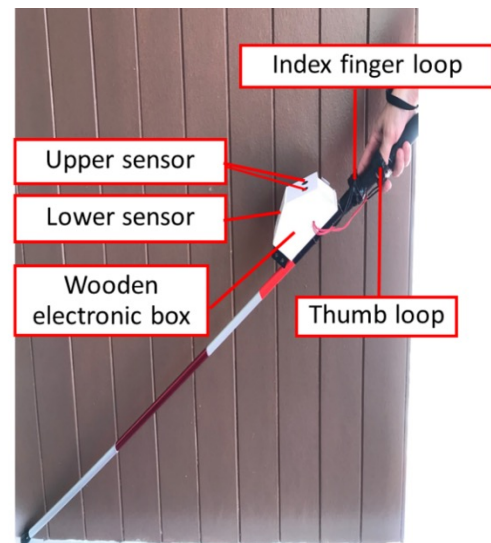


Figure 3. A white cane with the wooden electronic box.

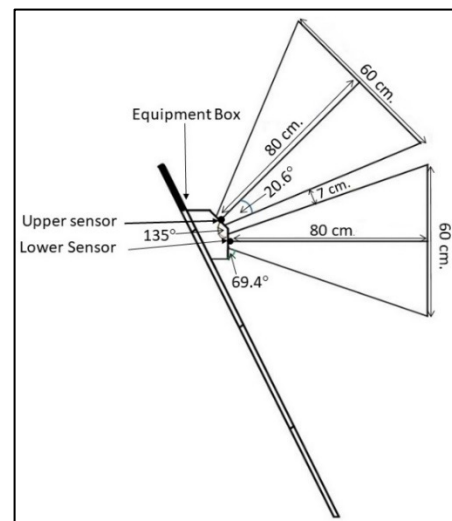


Figure 5. Ultrasonic sensor detection degree.

- 6) With a cane tilt angle of 43 degrees, the detection distance of the ultrasonic sensor was set at 80 cm in length in front of users, and 60 cm at maximum width (diameter), which meant each sensor covered an area of 2,826 cm² as calculated by the πr^2 formula ($r=30$ cm). The angle between the upper and the lower sensor was set at 135 degrees to allow the ultrasonic wave to detect objects in as much space as possible (Figure 5). However, the empty space between the detection areas of the upper and lower sensors was 7 cm wide. Users press the on/off button to start or stop the electrical circuit of the ultrasonic detector system.
- 7) When detecting obstacles, the sensor sends a vibration signal to the finger loops at the handle of the white cane. The index finger loop vibrates for objects at mid-body level, and the thumb loop vibrates for obstacles at head level (Figure 3).

Cost of the modified white cane with ultrasonic detector

The total price for the modified white cane with the ultrasonic detector in the present study was 800 baht (24.63 USD). This can be broken down into 1) electronic compartments and circuits, 380 Baht (11.70 USD), 2) vibration system and equipment box, 150 Baht (4.62 USD), and 3) the white cane, 270 Baht (8.31 USD). All these electronic compartments can be found in most electronic shops, and the white cane can be bought from a medical equipment shop or purchased online.

Test of the efficacy of the modified white cane with ultrasonic detectors

In the simulation testing room, we used a piece of cardboard (19 cm²), and we hung it from the ceiling as the test's obstacle at head level. We used a pipe tree as a testing barrier at the mid-body level. There were 3 testing spots along the walking path. The first spot was the head-level testing station. The second and third spots were designed

to test reactions at waist level. The total walking distance was 8 meters, and the width of the route was 1.5 meters. Researchers used a two-inch high feature board on both sides of the path as the walking frame. The first testing station, used for testing at head level, was set at 2 meters from the starting point. The second and third stations, for testing at waist level, were set at 4 and 6 meters, respectively (Figure 6). The participants were unaware of the number of testing points in the evaluation room prior to testing.

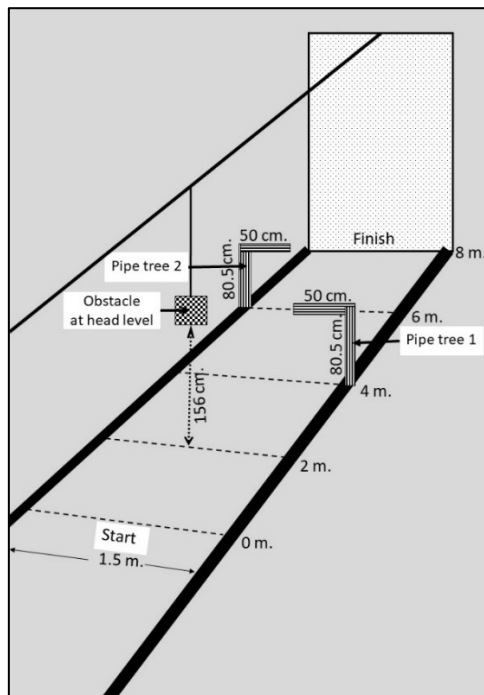


Figure 6. A simulated path for a blindfolded walking test.

The participants were divided into 3 groups depending on their height including:

- 1) For subjects who were between 151 and 160 cm, the cardboard was hung 146 cm from the floor in the middle of the walking track for head-level testing, and the pipe tree's branch, 2.2 cm in diameter, was set at 75.5 cm from the floor, protruding from the side of the testing track. The pipe tree was positioned on the right-hand side of the second testing spot but was located on the left-hand side of the third testing station. The pipe tree stood beside the simulation path where its branch protruded 50 cm into the track on the right side for the second testing spot, whereas the pipe tree branch protruded from the left side at the third testing station.
- 2) For subjects between 161 and 170 cm, the cardboard was hung at 156 cm from the floor in the middle of the walking track for head-level testing, and the pipe tree's branch was set 80.5 cm from the floor, protruding 50 cm into the track from the right side of testing spot number 2 and 50 cm into the track from the left side of testing spot number 3 (Figure 6).

- 3) For subjects between 171 and 180 cm, the cardboard was hung 166 cm from the floor in the middle of the walking track for head-level testing, and the pipe tree's branch was set at a height of 85.5 cm from the floor, protruding 50 cm into the track from the right side of testing spot number 2 and 50 cm from the left side of testing spot number 3.

All participants signed the consent form prior to the beginning of the study. They had been informed about the objectives and procedures of the research project and assured of the absence of any risks to their physical health and the possibility of leaving the study at any time. The experimental process consisted of 2 sections. Section 1 was conducted in the training room, where the obstacles at head level and at mid-body level were set up. The obstacles at head level used cardboard hung from the ceiling at 3 different heights-146, 156, and 166 cm from the floor, while the barriers at waist level used a pipe tree whose branch was positioned at the height of 75.5, 80.5, and 85.5 cm from the floor, and its branch protruded 50 cm into the path. The research team suggested participants choose a walking path that suited their height. The participants were also instructed on how to use the modified white cane and were allowed 10 minutes for familiarization. The instructions included: how to hold and position the cane (in front of the body); how to move the cane (rolling from side to side); how to turn on and off the electronic switch, and how the modified cane emits feedback as it approaches obstacles (increasing the vibration). The participants held the modified white cane in their dominant hands, kept their eyes open normally, and were instructed to walk toward the set-up obstacles at their self-selected walking speed to get familiar with the feedback vibration on their index fingers and thumbs. Section 2 was conducted in the testing room near the training room. Each subject covered both eyes with the standard eye-pads prior to entering the testing room. The research team brought the subjects into the testing venue one by one. At the start, each participant stood at the starting point in the middle of the path and could not protrude any part of their body or the modified white cane across the beginning line. They held the modified white cane in their dominant hand and waited for the researcher to inform them that they could start. All participants were also instructed not to touch the obstacles, relying only on the cane feedback, and to follow the floor path with the cane. Also, if they detected an obstacle, they had to stop and shift their steps to the right or left until the vibration signal on their finger stopped, then move forward. The research team announced, "Start walking," and the subject then walked forward at their self-selected speed.

All subjects were informed that a vibration signal occurring at the index finger indicated an obstacle at mid-body, while a vibration at the thumb indicated a barrier at head level. When the subject passed through the third station, the principal investigator informed each individual that the test was over and took off their eye pads, then asked them to leave the testing venue without a conversation with the next examinee.

Data Analysis

Descriptive statistics were used to clarify socio-demographic data, walking time, and speed, and illustrate the satisfaction in the participants on the modified white cane.

Results

There were 10 blindfolded subjects, 5 males and 5 females, who participated in the present study. The age of these participants was between 21 and 22 years old. There were 2 subjects who had a height between 151-160 cm, 5 were between 161-170 cm, and 3 were between 171-180 cm; 8 participants were right-handed and 2 of them were left-handed.

Results in the test of efficacy and satisfaction for the modified white cane are demonstrated in Table 1 and Table 2 respectively.

Discussion

Walking locomotion is important for the activities of daily living for almost all people, and evidence indicates that mobility difficulty affects social participation in persons with visual impairment.³⁰ It is, therefore, crucial that health professionals and responsible persons find assistive devices to promote independent locomotion for these individuals.

These tests of the efficacy of the modified white cane in 10 blindfolded subjects revealed that all participants could get through the 8-meter path with 3 testing obstacles at waist and head levels successfully. Time used for walking ranged from 65 to 103 seconds, with the average time at 85.9 ± 13.03 . The average speed in meters per second was 0.10 ± 0.02 (Table 1). The average walking speed of participants in the present study was quite low compared to a study by dos Santos, *et al.*¹¹ who investigated walking speed in 31 blindfolded subjects while using an electronic and traditional white cane in an outdoor environment and revealed that subjects achieved a walking speed of 0.42-meters per second with the electronic white cane. This might be because the participants in the present study were not experienced in using the white cane beforehand and were not familiar with the condition of being blindfolded. In addition, testing was conducted only once for everyone in a limited space.

The white cane used in the present study, with an ultrasonic detector made from electronic compartments and the degree of object exploration set to a certain amount, can help people with visual disturbances walk more safely than a traditional white cane can. The ultrasonic detector can detect objects up to 80 cm in front of users, and this allows visually impaired persons to stop in time as soon as the electrical circuit transforms the feedback wave generated at the obstacle, which sends a vibration signal to the thumb or the index finger loop. In addition, the ultrasonic wave in the present study can detect barriers in front of it across a space of 2,826 cm², so this can protect the whole body of users. One of the key performances of walking aids for the blind is the coverage range of their object detection.²³ The ultrasonic wave also can detect transparent and opaque objects, even when the object is very small. There was an empty space between the detection areas of the upper and

lower sensors of the modified white cane of 7 cm in width. However, when users swung the modified white cane left and right and stepped forward a little, the ultrasonic wave could detect the obstacles.

Table 1 Time used and walking speed in the testing of the efficacy of the modified white cane (n=10).

Subjects	Time used (seconds)	Speed (meters/second)
1	67.00	0.12
2	92.00	0.09
3	94.00	0.09
4	83.00	0.10
5	98.00	0.08
6	65.00	0.12
7	77.00	0.10
8	84.00	0.10
9	103.00	0.08
10	96.00	0.08
Average	85.9 ± 13.03	0.10 ± 0.02

In addition, the blindfolded participants reported high satisfaction with both the usability and efficiency of the modified white cane (Table 2). The highest score for satisfaction in usability was for the size of the wooden box on the white cane ($\bar{X} \pm SD = 4.50 \pm 0.53$). This might be because all the electrical compartments were arranged tidily in a small and light weight wooden box (Figure 2) and the wooden electronic box was affixed slightly below the hand-grasping point of a white cane, which did not obstruct the user's hand when they held the device (Figure 3). Kamal, Bayazid, Sadi, Islam, & Hasan¹⁶ noted in their study regarding the walking assistants for the visually impaired that the large physical size of the tools can be an obstacle for users. All of the subjects in the present study also reported very high satisfaction on the efficiency of the modified white cane in terms of its ability to detect objects at mid-body ($\bar{X} \pm SD = 4.70 \pm 0.48$) and at head levels ($\bar{X} \pm SD = 4.50 \pm 0.53$). This could be because the ultrasonic sensor can effectively detect objects in front of the users and transform the reflective wave into a strong vibration signal sent to the index finger-loop (for barriers at waist level) or thumb-loop (for obstacles at head level). Therefore, they stopped in time before hitting the obstacles and shifted their steps to the right or left to get through. These findings are consistent with a study conducted by Islam, Sadi, Zamli, and Ahmed²³ on walking aids for visually impaired people, which revealed that the common requirements of these individuals on walking aids were proper feedback signal, light weight, easy to carry, low cost, and cosmetic suitability.

Table 2 Satisfaction on the modified white cane in blindfolded subjects (n=10).

Testing items	Mean scores of satisfactions
1. Usability	
1.1 easy to use	4.10 (0.57)
1.2 suitable size (wooden electronic box and the white cane)	4.50 (0.53)
1.3 easy to carry	4.00 (0.82)
1.4 seems strong and durable	4.20 (0.42)
1.5 seems easy to maintain	4.00 (0.82)
2. Efficiency	
2.1 detecting obstacles at head level	4.50 (0.53)
2.2 detecting obstacles at mid-body level	4.70 (0.48)

Limitations

Participants in the present study were non-visually impaired people who had never experienced being blindfolded. Therefore, research outcomes may be somewhat different from those with blind subjects who are experienced in interpreting the world using other senses. In a further study, the inclusion of the blind as participants should be considered. Another limitation was the small number of obstacle testing spots. There were only 3 barrier testing stations, and this might not be sufficient to test the efficacy of the modified white cane and get reliable measurements. Therefore, increasing the number of obstacles in the trials should be considered in the next study. In addition, recruitment of more participants into the testing procedure can enhance the reliability of the study.

Conclusion

The modified white cane with an additional ultrasonic detector in the present study could help blindfolded users detect obstacles at waist and head levels more effectively than the traditional passive white cane could. Participants also reported high satisfaction with the modified white cane in terms of both usability and efficiency.

Declaration of conflicting interests

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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