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A Navigation Aid for Blind People

Mounir Bousbia-Salah · Maamar Bettayeb · Allal Larbi

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Abstract This paper presents a navigation aid for the blind based on a microcontroller with synthetic speech output. The system consists of two vibrators, two ultrasonic sensors mounted on the user's shoulders and another one integrated into the cane. It is able to give information to the blind about urban walking routes and to provide real-time information on the distance of over-hanging obstacles within 6 m along the travel path ahead of the user. The suggested system can then sense the surrounding environment via sonar sensors and sending vibro-tactile feedback to the user of the position of the closest obstacles in range. For the ultrasonic cane, it is used to detect any obstacle on the ground. Experimental results show the effectiveness of the proposed system for blind navigation.

Keywords Blind people · Navigation · Obstacle detection · Microcontroller · Sensor

1 Introduction

Blindness is one of the most severe types of disabilities a person must endure and, despite numerous advancements in technology, it remains a serious problem to this day. According to information in 2009 from the World Blind Union, there are over 160 million of blind and partially sighted people in the world.

One of the most frustrating aspects of visual impairment is the dependence it creates on sighted individuals for navigation and object locations. Blindness is a disability that thus has far been relatively resistant to the benefits of rehabilitation

M. Bousbia-Salah (✉) · A. Larbi
Department of Electronics, Laboratory of Automatic and Signals,
University of Annaba, Annaba, 23000, Algeria
e-mail: bousbia.salah@univ-annaba.org

M. Bettayeb
Department of Electrical and Computer Engineering, University of Sharjah,
Sharjah, P.O. Box: 27272, United Arab Emirates

technology. Yet most of blind people rely on the traditional white cane [1] that has been used for navigation by blind people for decades. The white cane is very limited in its ability to provide navigational independence for its users. It cannot easily be used to detect obstacles above a user's waist (such as low hanging branches), nor can it detect people or objects more than a few feet away. Furthermore, the white cane cannot give specific geographical location information to its user, information that is vital for navigational independence. In addition, the blind still require the assistance of sighted persons or guide dogs [2] to lead them to most destinations. These shortcomings drive the need for research on developing innovative navigational systems for the blind.

Many technological solutions commonly known as electronic travel aids (ETA) [3] have therefore been proposed and implemented, but none have been widely successful in improving the mobility and lives of the visually impaired. Novel approaches that integrate guidance devices into the white cane have been proposed. Many systems exist that utilize this innovation, such as the GuideCane [4], a device which uses echolocation to detect objects directly in front of the cane and steer the user away from them. However, this device, and similar devices that build on the white cane, change the functionality of the cane and disrupt the personal navigation methods that the visually impaired have already developed using only the white cane. In addition, as this device can only direct users around objects on the ground, it offers very little functionality over the current white cane.

While many previous tools have been developed to include components such as echolocation, integration with GPS [5], and detection of Radio Frequency Identification (RFID) [6] tags, no system has utilized and integrated these components well enough to be accepted by the blind community as a viable navigational solution.

The need for a new device is then apparent, as the white cane has remained the most widely used and accepted navigation tool for the visually impaired despite significant advances in science and technology.

Problems that result from blindness in mobility are then obstacle avoidance and navigation. It is generally accepted that in order to assist blind pedestrians the following information is needed: the presence, location, and nature of obstacles; the texture, slope, and boundaries of the path or travel surface; and spatial orientation.

The purpose of this project was to create a prototype of a device that can help blind people to travel with increased independence, safety, and confidence. The proposed system involves a microcontroller with speech output. It is a self contained portable electronic unit. It can supply the blind person with assistance about walking routes by using spoken words to point out what decisions to make.

In addition, and in order to overcome the imperfections of existing electronic travel aids, the suggested method of measuring distance travelled in this system, is to use the acceleration of a moving body which in this case is the blind person. An accelerometer, followed by two integrators is used to measure a distance travelled by the blind. This technique is considered in inertial navigation systems [7] and suffers from drift problems caused by the double integration and offset of the accelerometer which are overcome by the footswitch [8]. When this footswitch is closed, the acceleration and the velocity are known to be equal to zero and this can be used to apply a correction.

In order to help blind travellers to navigate safely and quickly among obstacles and other hazards faced by blind pedestrians, an obstacle detection system [9] using ultrasonic sensors and vibrators has been considered in this aid. The proposed system detects then the nearest obstacle via streoscopic sonar system and sends back vibrotactile feedback to inform the blind about its localization. On the other hand, an ultrasonic cane equipped with wheels is considered to detect any obstacle which may be on the ground. The system has then an environment recognition and a clear path indicator functions [10].

2 Literature Review

Many navigation devices have been used to guide Blind people. Several research works are being performed by many institutions throughout the world to offer the best navigational system in terms of cost effectiveness. This section gives a brief review on various navigational aids for blind individuals.

Dogs are very capable guides for the blind, but they require extensive training. Fully trained guide dogs are expensive. Furthermore, many blind and visually impaired people are elders and find it difficult to care appropriately another living being.

In [11], the authors propose a shaped long cane with laser emitters and receivers aimed to detect overhangs, down curbs, and targets straight ahead to a selectable range of 6 or 12 ft, giving auditory and tactile warnings. This aid has the advantage of being incorporated with the cane, but disadvantages include weight and the skilled scanning methods needed for reliable detection of obstacles.

The SonicGuide [12] consists of an ultrasonic wide-beam equipment (transmitter and receiver) mounted on spectacle lenses. Signals reflected from the 3D world are read by the receivers and presented to the user as audio enclosing the presence of an obstacle and its approximate distance to the user.

The "talking signs" system [13], which uses a network of low-cost IR transmitter modules placed on normal navigational signs in the environment to give orientation to the blind user.

The Mowat sensor [14] is a light weight, hand held, pocket size device. It detects nearby object by sending high frequency ultrasound and receiving the reflected beam. The user can identify the distance of the object by the rate of vibration that is produced by the device. Although possessing the disadvantage of requiring both hands to be occupied (one with the long cane and one with the sensor), this device can be useful in a number of situations indoors and out and is small enough to be pocket-carried when not in use.

Kaspa [15] is a more complex sonic system for the Blind. It consists of a sweep FM ultrasound emitter and three laterally displaced sensors. The signal received from the echo is beat against the outgoing signal to produce audible sounds. The frequency of the sound is inversely proportional to the range and the timbre carries information about reflection properties of the object. The user must learn to interpret the sounds, a process that can take several weeks of training.

The sonic torch [16] is a battery operated hand held device basically operates by transmitting the ultrasound in the forward direction and receiving the reflected sound beam from the nearest object (s). This system uses frequency modulated signals, which represent an object's distance by the pitch of the generated sound and the object's surface texture by the timbre of the sound delivered to the headphones.

However, to an inexperienced user, these combined sounds can be confusing and difficult to interpret. Also, the sonar beam from this system is very specular in that it can be reflected off many surfaces or absorbed resulting in uncertain perception.

Like a Mowat sensor and sonic torch, the sonic pathfinder [17] also detects an object by receiving the reflected ultrasound that is transmitted by the device. But unlike Mowat sensor which is a hand held device, a sonic pathfinder is fitted on the user's head. The sonic pathfinder produces audio signal of different notes which produce a familiar tonal progression as the user approaches an object and is fed to the user through earphones.

The vOICe [18] consists of a digital camera attached to conventional eyeglasses, headphones, and a portable computer with the necessary software. The camera captures images and the computer uses a direct, unfiltered, invertible one-to-one image-to-sound mapping. The sound is then sent to the headphones. No filters were used to reduce the risk of filtering important information since the main argument is that human brain is powerful enough to process complex sound information. The system is very simple, small, lightweight, and cheap. Lately, the software was embedded on a cellphone, and thus the user can use the cellphone's camera and earphones. In addition, sonar extension is available for better representation of the environment and increased safety. Many individuals tried the system returning very promising feedback, but they required extensive training because of the complicated sound patterns.

The Navbelt [19] consists of a belt, a portable computer, and an array of ultrasonic sensors mounted on the front of the belt. The user wears a "fanny pack" on the abdomen and a portable computer as a backpack [4]. Eight ultrasonic sensors, each covering a sector of 15°, are mounted on the front pack, providing a total scan of 120°. The computer processes the signals that arrive from the sensors, and applies in the robotics obstacle avoidance algorithms. The disadvantages of the system are the use of audio feedback (exclusively), the bulky prototype and that the users are required extensive training periods.

The Guidecane is a device that the user can hold like a white cane and that guides the user by changing its direction when an obstacle is detected. A handle (cane) is connected to the main device which has wheels, a steering mechanism, ultrasonic sensors, and a computer. The operation is simple: the user moves the Guidecane,and when an obstacle is detected the obstacle avoidance algorithm chooses an alternate direction until the obstacle is cleared and route is resumed (either in a parallel to the initial direction or in the same). There is also a thumb-operated joystick at the handle so that the user can change the direction of the cane (left or right). The sensors can detect small obstacles at the ground and sideways obstacles like walls. This guidecane has a limited scanning area and is bulky difficult to hold or carry when needed.

CyARM [20] is an aid for use in guiding orientation and locomotion, using a nonstandard interface: ultrasonic sensors detect obstacles and calculate their distance from the user. The user is informed about the distance via the tension of a wire that is attached on him (e.g., his belt): high tension indicates close distance (the user can reach the obstacle by extending his/her hand), while a lower tension indicates longer distance.

The prototype is a handheld device weighting 500 g. It contains a microcontroller that processes the information from the sensors and operates a geared motor/reel that controls the tension of the wire.

Tyflos [21] is a wearable prototype that provides reading and navigating assistance for blind users. It integrates a wireless portable computer, cameras range and GPS sensors, microphones, natural language processor, text-to-speech device, an ear speaker, a speech synthesizer, a 2D vibration vest and a digital audio recorder. Data collected by the Tyflos sensors is processed by appropriate modules, each of which is specialized in one or more tasks.

Drawbacks of these navigation aids are numerous:

- Some required the user to actively scan the environment. This mode of human–machine interaction was very time-consuming.
- Expense is a significant drawback, especially for the class of orientation aids which requires conspicuous installation and maintenance costs.
- The degree of information given by the device is not adequate for the end user.
- The masking of natural echo-location cues and the necessity of training.
- Consumer indifference, due to a lack of performance measures, which could demonstrate the efficiency of navigation aids. Therefore, navigation aids that are available do not penetrate the market and many developers of such systems complain about the lack of interest from users. To date, navigation aids certainly need large efforts and much industrial research to boost their performances in order to give autonomy to the blind similar to that of sighted people, especially in unfamiliar surroundings.

A number of new navigation aids aimed at overcoming criticisms of existing systems are then being developed such as the ROVI [22] and PREDATOR [23]. In addition, the proposed navigation aid will help the blind to navigate safely.

3 Proposed System

We propose a complete system to aid the blind in navigation which uses more efficiently the surrounding environment via several types of sensory elements. The system works under condition of low noise surroundings. In addition, it detects obstacles within a range angle of 72°. The system also works under static as well as dynamic obstacles.

Portability, low cost, and above all simplicity of controls are most important factors which govern the practicality and user acceptance of such devices.

The electronic travel aid (ETA) is a kind of portable device. Hence it should be a small-sized and lightweight device to be proper for portability. The blind is not able to see the display panel, control buttons, or labels. Hence the device should be easy to control: No complex control buttons, switches and display panel should be present. Moreover, the ETA device should be low-price to be used by more blind persons.

Our system is developed for portable (small size and lightweight), inexpensive and easy to use, and low-power consumption (supplied by battery). It consists of a microcontroller as processor, an accelerometer, a footswitch, a speech synthesizer, a hexadecimal keypad, a mode switch, an ultrasonic cane, two ultrasonic sensors, two vibrators and a power switch. The block diagram of the system is shown in Fig. 1.

As the ‘Micromap’[24], the system has two modes of operation, record and playback. In addition, the playback mode has two directions, forward and reverse. The user selects then, one of these three possibilities by a switch.

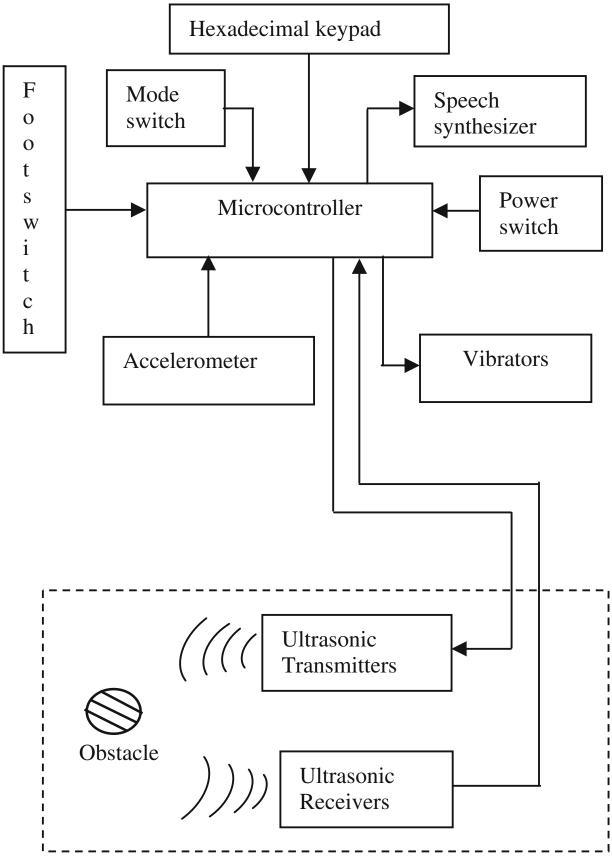


Fig. 1 Block diagram of the system

In the record mode, the blind walks the route of interest, and the aid measures the distance travelled by the user. When the blind reaches a decision point, for instance a point at which the route takes a left turn, the user presses a key on the aid coded with a left turn instruction. This has two effects:

– The distance travelled is stored in memory of the microcontroller, and the counter reset to zero.
– The left turn instruction is stored.

Afterwards, the blind walks to the next decision point and the above procedure is repeated.

In the playback mode, the aid measures again the distance travelled by the user. When this is equal to that stored in the memory for that particular section of the route, a corresponding decision word generated by the synthesizer is given to the blind. The audible signal indicates what action the user should take at this point, for instance turn left.

In the reverse direction, the procedure is exactly the same except that the route information stored in the memory is used in reverse order, and that right and left are interchanged.

At decisions points, the blind can make any of the following decisions:

Turn right; Turn left; Cross road; Cross road junction; Pedestrian crossing; Steps; Pause; Stop.

Each of these decisions has separate key. There are also two extra keys available, which are undefined in the present software, but which the blind could have available for their specific use.

The system can store a number of routes each of which are numbered, and be selected using the same set of keys as for the decisions. In practice the number is likely to be set by the size of the available memory.

Concerning the obstacle detection part, two types of equipment are considered. The first type subsystem is mounted on the blind's shoulders as shown in Fig. 2. It contains two ultrasonic transmitters-receivers and two vibrators.

The other is cane type subsystem [25, 26] as shown in Fig. 3. It is equipped with ultrasonic sensors and wheels. The user walks with holding this cane type system in front of him like the white cane. The cane type system notifies whether any obstacle is in the middle of the walking direction. Since the wheels are always contacted with ground, the user can recognize the condition of ground such as depression, cavity, and the stairs with his hand's tactile sensation intuitively.

This obstacle detection system use a 40 KHz ultrasonic signal to acquire information and can detect the presence of any obstacle within the specified measurement range of approximately 0.03 to 6 m. It operates by sending out a pulse of ultrasound. Eventually the pulse is reflected from a solid object in the path of the pulse. The time between the outgoing pulse being transmitted and its echo being received corresponds to the distance between the transmitter and the object or the obstacle. This information is then relayed to the blind in some vibro-tactile way and speech way for the cane.

On the other hand, the microcontroller used in the aid is the PIC 16F876 [27] from 'MICROCHIP'. The accelerometer used is the ADXL213 [28] from 'Analog devices'. It has a range of ±1.2 g and a sensitivity of 30%/g. With this accelerometer, no A/D converter is then required as the output is digital. The accelerometer needs to be attached to the shoe or to a rigid part of the leg where the condition of both acceleration and velocity equal zero is applied.

The speech synthesizer device chosen is the ISD 5216 [29]. It is activated by pulses from the microcontroller. The output represents the different actions to be taken (e.g. road right turn, left turn…). The speech synthesizer chip with a small vocabulary tells then the blind person about travelled distance, present location and decisions to

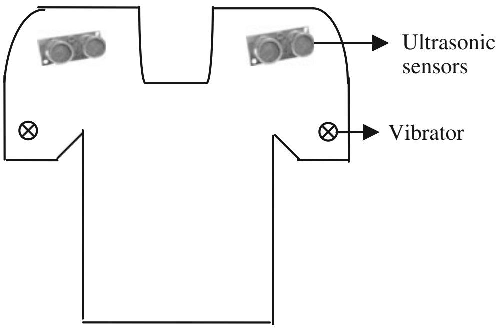
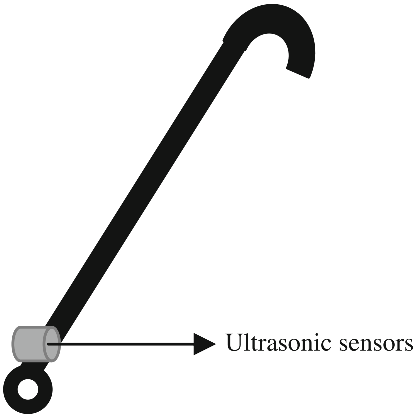


Fig. 2 Sonars mounted on shoulders

Fig. 3 The ultrasonic cane



make. Information about the route is stored in the memory in the form of a digital map of the device to guide the user to his destination via the planned routes.

Since hearing for blind people is very important, the headphones would dull this sense. For this system, it has been decided to consider headphones used for walkman. Spoken words from the speech synthesizer which represent the different action to be taken will therefore be heard by the blind.

In order to input information a hexadecimal 4×4 keypad is used in this aid. It is placed on the side of the case, and can be seen in Fig. 4. The keypad switches enable the user to select routes and to enter decision. It is of course possible to label these keys with Braille symbols if it is thought necessary.

Fig. 4 The navigation aid worn by the blind

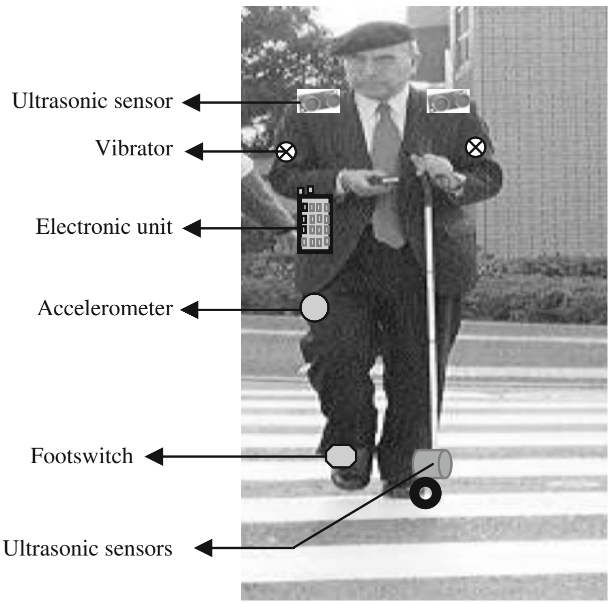


Fig. 5 The ultrasonic sensor

The footswitch is used to allow the PIC 16F876 to provide frequent corrections of drift effects. This footswitch 'S' needs to be attached to the heel of the shoe. When the blind starts to walk, 'S' is equal to zero. The microcontroller estimates then the acceleration and calculates the distance. When the footswitch is on the ground, 'S' is equal to one. The microcontroller estimates and calculates the errors. Afterwards, corrections are made. The micro-switch is one example of switch which can be used because it is more flexible.

The ultrasonic module used as sensor for this application is the MSU10 [30] from 'Lextronic' and can be seen in Fig. 5.

It has an angle of detection of approximately 72°. Also, in this system, vibrators from mobile phone technology have been used. Those devices are small and light enough to be fixed on cloth without any obstruction. In addition, the ultrasonic cane used for this system is based on an ultrasonic transmitter-receiver which detects obstacle on the ground.

4 Obstacle Detection

As aformentioned, the aid is provided with two types of equipment. The first one is an ultrasonic system attached to the jacket with two vibrators and the second one is an ultrasonic cane.

The first subsystem is then based on two ultrasonic sensors mounted together. One emits an ultrasonic wave while the other measures the echo. By differentiation of the input and output signals, the PIC16F876 computes the distance to the nearest obstacle. Then this information is transmitted as a Pulse Wide Modulation (PWM) signal to the receiver. The microcontroller gathers the information from the ultrasonic sensors as PWM signal directly proportional to the distance of the nearest obstacle. Afterwards, it measures the width of the transmitted pulses and converts it into empiric distance. Following a calibration phase, the real distance between the sensor and the obstacle can be determined. The direction is given by comparison of the signal from both sensors. This distance is then converted into a voltage command for appropriate vibrating feedback. The system redirects this information to the actuators via Serial Peripheral Interface. A multichannels D/A Converter recovers two integers (address and data) and sends the desired output voltage to the appropriate vibrator.

The second subsystem is also based on ultrasonic sensors mounted on wheels. It is used to detect any obstacle on the ground.

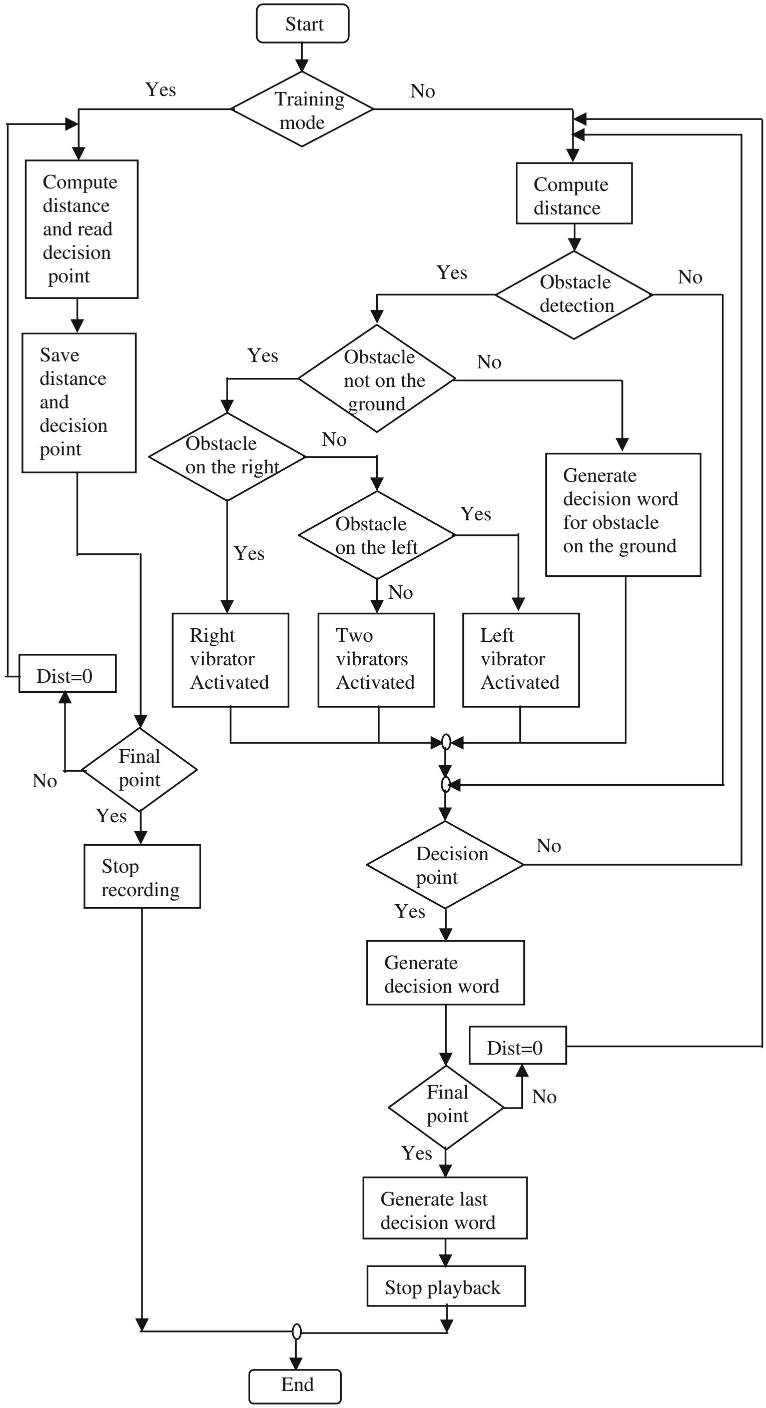


Fig. 6 The flowchart of the system

5 Use of the System

The system is easy and straightforward to use. It is attached to a belt which is fastened around the user's waist. There is provision for a test to ascertain that the blind person's step is detected by the accelerometer. The user then selects the route number, and the appropriate mode and direction.

A repeat key has been considered to enable the blind person to make the aid repeat the word indicating a decision. This is to ensure that the user can be certain of the decision, in case it is obscured the first time by, for example, traffic noise.

On the other hand, when an obstacle is detected, vibrotactile output occurs in pulses at a rate inversely related to the distance from the user. If there is no obstacle detected, no vibrational pulses are emitted.

In addition, the blind should know from which direction the obstacles are coming from. Localization on the horizontal plane is done by appropriate combination of vibration between the left and the right side. If the user feels a vibration on its right it means that the obstacle is on his right and vice versa. If the vibration is on both sides the obstacle is in front of him. A software program can be written for this navigation aid from the flowchart of the system represented in Fig. 6.

6 Experiment Results

The experiments consist in testing the proposed navigation system under the environment stated in section IV. The blind follows the walking path of 100 m length shown in Fig. 7. Obstacles were put in front of the blind with different range angles within 72° at different levels from the ground.

The first field trial of the route planning was tested on two blind persons and results are shown in Fig. 8.

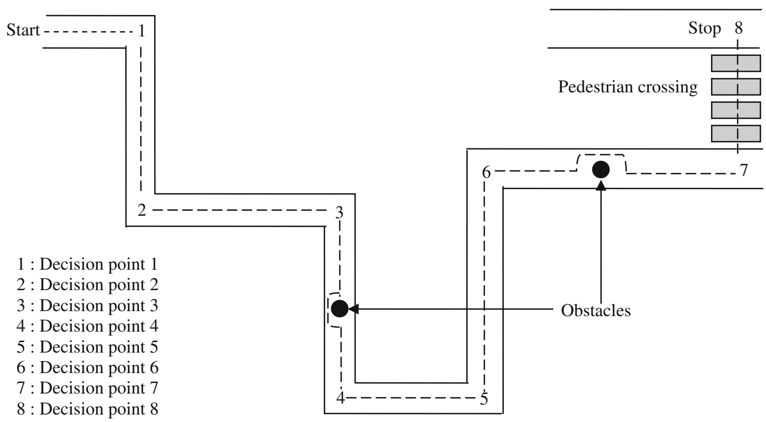
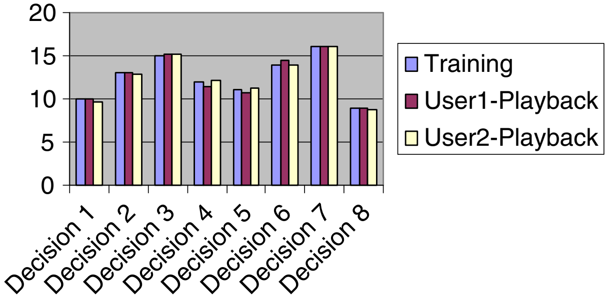


Fig. 7 The walking path

Fig. 8 Results of the field trial of the route planning



It can be seen a minor discrepancy from these results for the following two possible reasons:

- The aid may not have been correctly adjusted to detect every step.
- The user may have had a significantly different gait between the record and playback modes.

This is acceptable in blind navigation systems and can be improved by doing extensive training on the blind.

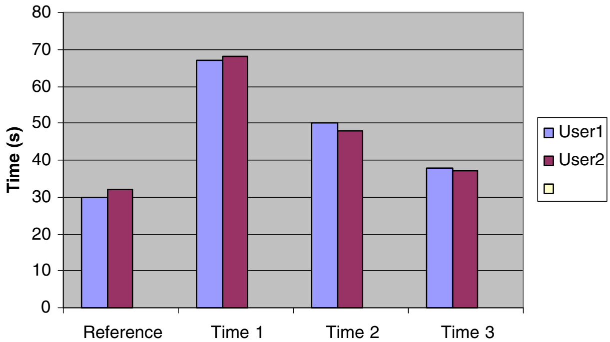
The second experiments were conducted to evaluate the performance of obstacle detection. The results were obtained by passing the same tests on two different blind people. Figure 9 shows the time of each blind on his attempts. The reference time on the first column represents the time to walk in normal condition which is without the presence of obstacles. The three others represent the successive performances of each blind wearing the aid.

The results show an important reduction of time to walk through obstacles after training with the aid.

The time of attempts of blind users when obstacles are present is higher than the reference time. This is due to the shortage in the confidence of the blind to the aid.

The experimentation was repeated under different environments such as another path and different bind people. Similar results were obtained which shows the robustness of the system.

Fig. 9 Results of the test for obstacles detection



7 Conclusion

In this paper, we presented a navigation aid which helps blind people to navigate safely. In order to measure the distance travelled, the technique well known in aircraft navigation used in this system has reduced errors caused by the accelerometer and double integration of its output. The use of the footswitch is also highly advantageous because without it, drift errors due to the accelerometer and double integration would be considerably greater in magnitude and would reduce the effective range of the navigation aid.

In addition, this aid allows the blind person to avoid obstacles by warning system through vibrations and voice. Although the system detects the nearest obstacle, it cannot solve the blinds' ultimate problem of the environment perception. It has limits due to the characteristics of the ultrasound reflections such that many object can barely be detected, which have very small or soft surfaces. Despite these difficulties, it is hoped that the proposed system will efficiently aid the blind in navigation.

The aid has been used on some preliminary trials. The results obtained are encouraging and in the near future, it is planned to carry out more extensive tests.

For future development, and as it is difficult to know where the blind is globally, it is then desirable to use the global positioning system (GPS) in order to get the user position information [31]. The problem of estimation of the blind position could also be investigated by using the Extended Kalman Filter (EKF) [32], the Unscented Kalman Filter (UKF) [33] or the cubature Kalman filter (CKF) [34]. In addition, a more recent estimation scheme, the Bayesian nonlinear filtering using quadrature and cubature rules [35], will also solve this problem.

We hope that this aid will be an effective, low-cost solution for reducing navigation problems for blind users.

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