State of the art review on walking support system for visually impaired people

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Abstract: The technology for terrain detection and walking support system for blind people has rapidly been improved the last couple of decades but to assist visually impaired people may have started long ago. Currently, a variety of portable or wearable navigation system is available in the market to help the blind for navigating their way in his local or remote area. The focused category in this work can be subgroups as electronic travel aids (ETAs), electronic orientation aids (EOAs) and position locator devices (PLDs). However, we will focus mainly on electronic travel aids (ETAs). This paper presents a comparative survey among the various portable or wearable walking support systems as well as informative description (a subcategory of ETAs or early stages of ETAs) with its working principal advantages and disadvantages so that the researchers can easily get the current stage of assisting blind technology along with the requirement for optimising the design of walking support system for its users.

Keywords: electric assistive technologies; EATs; review; navigation system; walking support system; obstacle avoidance; visually impaired.

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1 Introduction

Electric assistive technologies (EATs) provide the blind people spatial information about the environment in assisting them for navigation. Early technology uses ultrasonic to detect the obstacles in their path and distance of the obstacle is provided as vibration or as sound signal to the blind. Later, due to the developments in high speed computer and sensors, the efforts are directed to develop sophisticated and more intelligent ETAs. ETAs must satisfy three requirements:

1 accuracy of detecting the presence of a stationary object

2 accuracy of detecting the inter-space between stationary objects

3 accuracy of tracking a moving object.

The progress of the ETA development can be divided into two stages (Wong et al., 2000; Sainarayanan, 2002; Harper, 1998) for blind navigation aids: early ETAs and modern ETAs. This study therefore aims at examining the viability of different types of devices for mobility aid of blind; either using sensors or cameras, but some of them used both.

2 Early ETAs

Guide dogs are one of the most useful assistances for blind people since ancient period. They are (Opie and Opie, 1952) trained to lead vision impaired people around obstacles. Dogs are partially colour blind and sometimes are not capable of interpreting street signs although they can be trained to navigate various obstacles around the user. Mobility training helps the dogs to acquire some directing skills prior used for navigation of blind people. In airport, one must know how to get from one place to another where guide dogs could help the user as a pilot. In many countries, guide dogs, shown in Figure 1, are exempt from regulations against the presence of animals in places such as hotels, transportations and some restituted place.

Furthermore, a guide horse is an experimental mobility option for blind people who do not wish to or cannot use a guide dog (Panda and Edie, 1999). The Guide Horse Foundation provide those horses, founded in 1999 to provide miniature horses as assistance animals to visually impaired peoples living in rural area. There are some especial pros of using a horse instead of using a dog. The average life time of miniature horses is around 30 years, (Figure 2), live much longer than dogs, and for those frightened to or allergic of dogs, a horse might make a better alternative. Nevertheless, while a dog can adapt too many different home situations very easily, a horse will still require a barn and pasture when not on duty. Moreover, the period of time a horse can actually wait is significantly shorter than a dog's though they can be trained to relieve themselves on command. Guide horse users may also find difficulty in transporting a miniature horse on limited-spaced public transportation, such as on buses or taxis.

Figure 1 A blind man is led by his guide dog at shopping mall in Brazil

Besides, a white cane (Biggs, 1921) is often associated with visually impaired people for their movement. Some form of stick is shown in Figure 3, for probing when travelling has been used informally for centuries. Real and more complex developments occurred after the Second World War and through the years 1950s and 1960s. Advances in electronics and circuit miniaturisation also aided the development of these devices into portable mobility machines. It can be concluded by surveying the literature that the period of early ETAs is between 1950s to 1970s (Baldwin, 1998; Sonic Vision, 1999).

Figure 2 A man with a guide horse in an airport in US

Figure 3 A white cane, the international symbol of blindness

Most of the early ETAs were used ultrasonic and sonar sensors for obstacle detection. The technology used is relatively inexpensive; ultrasound emitters and detectors are quite small and they can easily be mounted without the need for more complex and costly additional circuitry. Ultrasound systems are available in many forms and in many shapes and sizes. The late John Dupress, a totally blind psychologist, showed in 1962 that he was perceptive of the needs of a blind person, and it is very significant that most of what he said remains true, 20 years later. In the first place, it cannot be assumed that a blind person ought to want to travel some place because of some device or rehabilitation programme! If a blind person is to undergo constant stress and danger travelling in unfamiliar and familiar environments, he must have a good reason to do so. You will find therefore that only when more blind people secure jobs, fulfil their interests and are integrated into society will they have a readiness for travel'. The devices emit ultrasonic signals, upon reflections from the obstacles, the distance of the obstacle is manipulated and it is provided in terms of vibration or sound.

However, the way in which they aid is limited mainly due to inherent property of multiple reflections. There had been several devices during this period (Dupress, 1963; Duen, 1996; Kaczmarek, 1991). Laser cane (Figure 4) could be operated with one hand, freeing the other hand for other normal tasks (i.e., carrying a suitcase, brief case or shopping bags, etc.), and able to indicate if an obstacle is hand height, waist height, or low for drop-off. As a primary mobility device, the laser cane requires no other devices to be used in conjunction with it. The laser cane is made in the same shape of the universally familiar guide cane, with built in sensing electronics, making it a primary device.

Figure 4 Laser cane fitted with three laser transmitters and focused receivers to detect obstacles in a blind person's travel path

Russsel path sounder (Duen, 1996) was invented in 1965 and it is one of the most early ETAs. Chest mounted board with two ultrasonic sensors produce three levels of click sound to indicate the distance.

The Mowat sensor (Pressey, 1977) is a handheld torch like device that radiates ultrasonic signals and receives the reflected signal from the obstacle. It gives a few level of tactile vibration depending on distance. Frequency of vibration increases as the distance of the obstacle decreases. It has a scanning range from 1 metre to 4 metre.

The sonic guide (Goldstein and Wiener, 1981) or binaural sensory aid was advancement of the sonic torch, is shown in Figure 5. It has wide beam ultrasonic transmitter mounted in the centre of the spectacle and a receiver on each side of the transmitter. Depending on the distance of the obstacle the sound tones are fed back to the right and left ear of the blind. Children's version of the sonic guide has sensors mounted in a helmet (Baldwin, 1998; Shoval et al., 1998).

Figure 5 Kay's sonic torch

Nottingham obstacle detector (Dodds et al., 1981) works in an analogue technique as that of Mowat sensor, but produces an audible note when the obstacle is within the device range, the maximum range being around 2 metres. Through Nottingham obstacle detector can be easily used with the long cane, it is still needed to be held in hand as the sonic torch. It produces eight different sounds for eight levels of distances (Heyes, 1981).

C-5 laser cane (Figure 6) was introduced in 1973. It has three transmitters and three photodiodes as receives. It produces two different tones and vibrations upon detection of obstruction within 4 metre range (Lofving, 1998; Benjamin, 1973).

Figure 6 Binaural sensory aids for the blind (sonic guide) using wide band-width CWFM echo-location principles and a binaural display of distance and direction of multiple objects for sensing the environment up to 5 m with a field of view of approximately 50 degree

Polaran gives two forms of outputs namely sound and vibration. The frequency of sound and vibration increases, as the blind gets closer to the objects. It has a selectable detection of ranges of 1 metre, 2.5 metre and 5 metre. Sensory 6 is also a head mounted spectacles with ultrasonic sensors. It creates sound tones with pitch inversely related to distance of the sensed obstacle. It has two modes of range; 2 metre and 3 metres (Baldwin, 1998).

By the 1970s, approximately 1,000 mobility devices of these types had made their way into the market or were in development for the use by visually impaired people. In spite of the fact that these small ultrasonic devices provide an adequate amount of information regarding the distance of the obstacle, their responses are restricted as they only employ a relatively small number of ultrasonic emitters and receivers.

Some researchers attempted to solve this problem, in the late 1960s and the early 1970s, by building an array of tactile feedback devices and attaching them through standard camera. The captured image is processed and the significant information about the captured image was provided as stimulus by the vibrating device. Difficulties still existed with this new development since the information produced by the vibration is too complex to understand and therefore very difficult to use (Snaith et al., 1998).

There are some notable difficulties in the early ETAs such as:

1 Some of the ETAs transfer the feedback signal to the blind in terms of vibrations, which is complex to understand.

2 Most of the ETAs focus on the distance of the obstacles, while information on the size and other properties of obstacles are not provided.

3 The user has to scan constantly and continuously to locate the obstacle in the path (expect for sonic guide and path sounder), which is time consuming and it is similar to having a long cane.

4 Improper calibration of the transducers may lead to serious effects.

3 Modern ETAs

We can classify walking support system device based on its sensing medium where some people used sensor for detecting obstacles in front of the users while others used camera for that. By the early 1990s, the focus has switched from mobility and obstacle detection to orientation and location (Blasch et al., 1997, 1999). With the advanced development of the high sensitive sensors and computing devices, the research had been focused to new directions. Even though the complete performance satisfaction is not achieved, the inventers were able to tackle the limitation of the early ETAs. We can classify modern ETAs based on sensing device like sensor, camera, etc., and are narrated below, respectively.

3.1 Sensor used as a sensing medium

G 5 obstacle detector uses optical cane technology. Light is emitted from an incandescent light. Obstacles can be detected by sensing the changes in the reflected light, and a tactile output is produced. Whenever the obstacle detector comes into the range of an obstacle, it would cause the handle to vibrate. The device is quite large and cannot be used successfully without a long cane (Heyes, 1982).

The major aim of this project, which started in the around 1990 in Asian country, Japan was to design a new mobility aid modelled after the bat's echolocation system (Ifukube et al., 1991). Few sonic sensors are attached on normal eyeglasses, and their data, using a microprocessor and A/D converter, are down converted to a stereo audible sound, and headphones are being used to get feedback signal. The different intensities and time differences of the reflected ultrasound waves from sonic sensors indicate the directions and sizes of obstacles around the user. And sound image is produced respective those parameters which they got from receiver.

A lot of experiments were performed to evaluate the user's capability to discriminate between objects in front of the user, using different sonic frequencies. The results provided show that the users can identify and discriminate objects in some limited cases, but more experiments and statistical results are required to support the viability of the project. There are two main advantage of this proposed device such as simplicity and portability.

The potential usefulness of a navigation aid is unquestionable to help the perception of the environment for visually impaired people. Bats are well-known examples, which can perfectly navigate by the help of ultrasonic echolocation without vision, and this technique is successfully applied in mobile robots. Independently from this field, real-time 3D sound generation has been developed to an accessible technology even in home PCs. Their basic idea is to connect these two threads using fast and power efficient digital signal processor (DSP) to produce a small, portable instrument, which can be a useful navigation aid for the blind.

Figure 7 SuperBat on a user

The ultimate goal is to indicate the environment obstacles by such a stereo sound effect as if it had oriented from the obstacle itself. The DSP-based system is able to determine the distance and the horizontal position of the obstacles in front of the user and to indicate the location of the nearest one by stereo sound through earphones. The DSP is equipped with suitable interface circuit connected to one ultrasound transmitter and two receivers, which can be mounted (Figure 7), e.g., on the hat of the blind person. Main functions of the device:

- Detecting nearest obstacles in front of the user by means of ultrasonic echolocation and indicating the distance and horizontal (2D) position by spatial stereo sound effects.
- Information gathering from the environment via a radio subsystem. The radio subsystem consists of transceiver devices mounted on vehicles and public building and the mobile transceiver carried by the blind or visually impaired person who is used to identify the equipped building and vehicles. The system is particularly useful for providing information in navigation at traffic nodes. A built in voice synthesiser informs the user of the relevant data.

The components of the system are integrated in one, small size unit. The system, however, cannot solve the blinds' ultimate problem of the perfect environment perception. It has limits due to the characteristics of the ultrasound reflections. The deployment and widespread use of the information services built upon the radio component also requires further efforts (Sasaki et al., 1991).

Borenstein, Koren, Shoval and Ulrich developed Navbelt in the University of Michigan (Borenstein and Koren, 1988, 1991, 1995; Borenstein and Ulrich, 1997; Shoval et al., 1993, 1994a, 1994b, 1998, 2000; Ulrich, 1997; Ulrich and Borenstein, 2001) as a guidance system, using a mobile robot obstacle avoidance system. The proposed prototype as implemented in 1992 and it consisted of ultrasonic range sensors for sensing, a computer for algorithm processing and earphones to get feedback. The computer receives information from the eight ultrasonic sensors (Figure 8) and creates a map of the angles and the distance of any object at this angle. Then the obstacle avoidance algorithm produce sounds appropriate for each and every mode of operation.

Figure 8 NavBelt on a user

The guidance mode and the image mode are two mode of operation for Navbelt. During the guidance mode, the computer knows the user's destination and with a single recurring beep guides user in the generated optimal direction of travel. However, a realistic implementation would require more sensors. For image mode, eight tones of different amplitudes are played in quick succession from eight different virtual directions. The computer translates, depending on the mode, these maps to sounds that the user can listen from his earphones. The back draws of the systems are the use of audio feedback only, the bulky prototype and that the users are required extensive training periods.

Robotic guide is a robot that guides a visually impaired person to help them navigate dynamic and complex indoor environment such as supermarket, office, and many more. Robotic guide can solve problems which eventually can help the blind person in moving across an indoor environment easily. The solutions are as follows:

1 The robot can interact with other people in any environment if he needs.

2 Robot-assisted navigation offers feasible solutions to two difficult permanent problems to wearable assisted navigation devices for people who are visually

impaired: portable power supply as well as hardware miniaturisation. The portion of body gear carried by the user is significantly reduced, because most of it may be mounted on the robot and powered from on-board batteries. Therefore, the navigation-related physical load is reduced a significant level.

3 The user may use robotic guides in addition with his conventional aids such as white canes and guide dogs.

4 Robotic guides can carry useful payloads like heavy boxes and bags.

The robotic guide (Figure 9) was first tested as a prototype in the USU CS Department. The CS Department occupies an area of 21,600 square feet in the multi-floor old main building on the south campus. The department has 23 offices, seven laboratories, a conference room, a student lounge, a tutor room, two elevators, several bathrooms, and two staircases. Robotic guide was built on top of the Pioneer 2DX robotic platform from the Active Media Corporation.

Figure 9 Robotic guide

Robotic guide's navigation system includes a set of ultrasonic sensors used for local obstacle avoidance and radio frequency identification (RFID) reader and antenna that resided in a polyvinyl chloride (PVC) pipe structure mounted on top of the platform. The system consist a laptop which is connected to the platform's microcontroller. The antenna and RFID reader were used to detect small RFID tags that placed in the environment. These tags can be attached to objects either in the environment or worn on clothing/user's body and do not require any others external power source or direct line of sight to be detected by the RFID reader. The tags are activated by the spherical electromagnetic field generated by the RFID antenna which radius around 1.5 metres. There is a unique ID assigned for each tag programmatically. When detected, RFID tags enable and disable local navigation behaviours.

The original interface was based on automatic speech recognition. The user would wear a wireless microphone with one ear headphone. The user would speck a destination and the robot would take him or her to that destination. However, speech was later abandoned after unsuccessful trails with users with visual impairments (Kulyukin et al., 2004).

Another patented device, the taking cane, has the ability to give speech output. It is also named as laser orientation aid for visually impaired (LOAVI). The device is incorporated in a white cane, which has integrated laser transmitter and receiver. It works like optical radar. The environment around reflects the light emitted by the transmitter and the receiver receives it. The receiver is able to read the standard bar code indications, even at 10 to 15 metres away. As the light hits the sign, the device produces beep sound. On hearing the beep, the blind can press the button provided to listen to the pre-recorded speech, to indicate the user about doorways, traffic lights, exit signs, etc. even the laser light emitted by the device is mentioned as harmless for normal condition, but it is unsafe when it is pointed to the eye of a sighted human (Lofving, 1998; Duen, 1996).

Handheld Nottingham obstacle detector was redesigned in 1984 and it was named sonic pathfinder (Heyes et al., 1983; Heyes, 1983, 1984, 1985). The sensors and transmitters were mounted to a header instead of previous handheld devices, with the identical sensor is denoted by the music tones. It has three ultrasonic transmitters and two receivers. The main drawback of this system is the inaccuracies caused by the ultrasonic sensor due to secular reflections and cross talks. This is the general problem faced by all sonar devices.

MIMS infrared mobility aid uses emitters and receives built into spectacle frames to provide obstacle detection. The optical transmitter emits a train of 20 millisecond pulses at a rate of 120 Hz. One side of the spectacle frame contains the emitter and the other side contains the receiver. When an object is detected by the signals from the emitters, reflected signal is converted to an audible tone and it is heard through the user's earpiece. This is a secondary travel aid and should be used with a long cane or a guide dog (Smith-Kettlewell Institute, 2011).

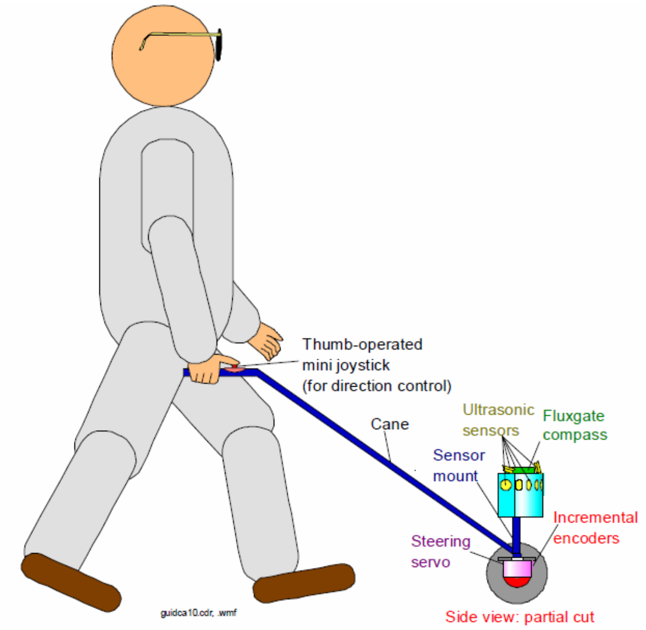
NavChair is a navigation system that is developed to provide mobility to individuals that find difficult to use a powered wheelchair due to cognitive, perceptual or motor impairments. The user will basically control the path of navigation and the wheelchair's motion along that path, and the NavChair restricts itself to ensure collision free travel. The prototype of NavChair is shown in Figure 10.

Figure 10 Prototype of NavChair assistive wheelchair navigation system

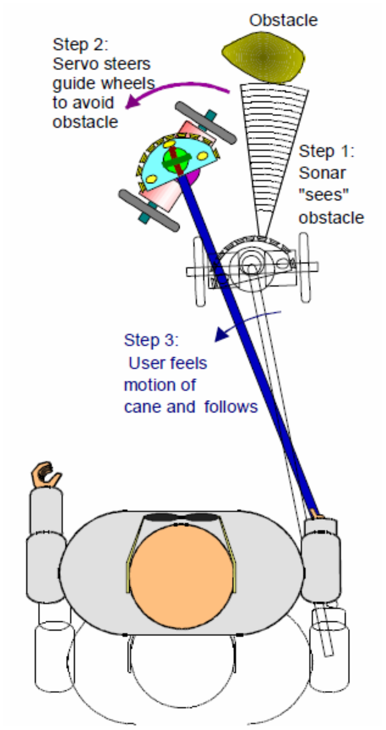
The NavChair currently offers several modes of operations to the user that is the general obstacle avoidance, door passage assistance, and close approach to an object.

This operating level works well with continuous input methods such as a joystick but is less suited to discrete methods such as voice control. A level requiring additional control from the NavChair system is appropriate when using voice to operate the NavChair (Figure 10) and the system must make some of the planning decisions (Levine et al., 1990, 1994).

Figure 11 (a) Schematic and (b) operation of the guide cane prototype



(a)



(b)

Guide cane is the second project by Shoval et al. (2003) and it serves as an update for Navbelt. Much like the white cane, the user holds the guide cane in front of him/herself while walking. The guide cane is considerably heavier than the white cane, but it rolls on wheels that support the guide cane's weight during regular operation and that guides the user by changing its direction when an obstacle is detected (Figure 11). The sketch of the prototype is shown in (a). A handle (cane) is connected to the main device. The main device has wheels, a steering mechanism, ultrasonic sensors and a computer.

During operation, the user pushes the guide cane forward. Similar to the NavBelt's directional-guidance mode, the user can prescribe a desired direction of motion the user moves the guide cane, 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 (a or b). The sensors can detect small obstacles at the ground and sideways obstacles like walls.

The guide cane does not block the users hearing with audio feedback and since the computer automatically analyses the situation and guides the user without requiring user to manually scan the area, there is no need for extensive training. The disadvantages are the limited scanning area since, small or overhanging objects like tables cannot be detected and that the prototype is bulky difficult to hold or carry when needed.

The ultrasonic sensors detect any obstacle around 1,200 wide sectors ahead of the user during travelling. The built-in computer with helping some specify software uses the sensor data to instantaneously determine an appropriate direction of travel. The obstacle-avoidance algorithm prescribes an alternative direction to circumnavigate the obstacle if an obstacle blocks the desired travel direction, and then resumes in the desired direction.

Smart shoe can detect an object a metre away by using an infrared sensor located on the shoe. A vibration will be given as an output with respect to the signal received once an object or obstacle is detected. The closer the user gets to the object, the faster the vibration of the motor. The motor which is attached at the shoe can vibrate at certain places on the shoe. This makes it easier for the user to change its direction if there is an obstacle in the way. Figure 12 shows a prototype of a smart shoe (Castle, 2003).

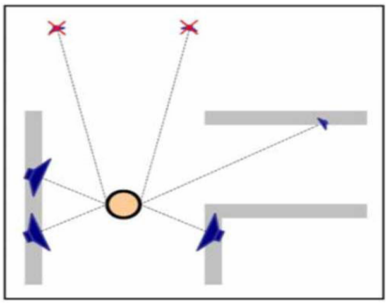
Figure 12 Smart shoes for blind

The shoe is being upgraded so that it is waterproof. This is done by embedding the circuitry system in the sole. Besides that, a system on detecting whether the user needs to go down a staircase is being developed for future implementation.

In Florida International University (FIU) developed of a prototype which is an obstacle detection system that uses 3D specialised sounds based on readings from a multidirectional sonar system. That prototype (Figure 13) has two subparts: the sonar and compass control unit, which consists of six sonic range sensors pointing in the six radial directions around the user and a microcontroller; and the 3D sound rendering engine consisting of headphones and a personal digital assistant (PDA) equipped with software capable of processing information from the sonar and compass control (Aguerrevere et al., 2004).

Figure 13 (a) FIU project prototype and (b) an example of its operation

(a)



(b)

The algorithm is used head-related transfer functions (HRTFs). It creates a 3D sound environment that represents the obstacles detected by sensing device. The user in that way creates a mental map of the layout of his/her surroundings so that obstacles can be avoided and open passages can be considered for path planning and navigation. A four blind-folded man was asked to navigate in a building. The results were promising where the navigation speed was slow. As seen in ‘Figure 13’, the system is small and wearable.

Future University-Hakodate, Kanazawa University, Ochanomizu University and Fuji Xerox Company Ltd. are developed CyARM in Japan. It is an aid for use in guiding orientation and locomotion, using a non-standard interface: ultrasonic sensors detect obstacles and calculate their distance from the user. The informed about the obstacle’s distance and size are sent via the tension of a wire that is attached on user (e.g., user’s belt): a lower tension indicates longer distance and high tension indicates close distance or the user can reach the obstacle by extending his hand (Ito et al., 2005). The handheld prototype has weight of 500 gm. The proposed prototype contains a microcontroller that main function is to processes the information from the sensors and operates a geared motor/reel/servo that controls the tension of the wire as a function of feedback of this system (Figure 14).

The efficiency in detecting obstacles, navigation through paths and target tracking were tested by doing some experiment in small-scale to evaluate CyARM’s performance. The results of those tests for the obstacle detection and navigation through tasks were promising since most of the times the subjects were able to detect the various types of obstacles placed in front of them as well as to judge if it is possible to navigate through two of them for stationary obstacles. Nevertheless, the moving target tracking results were not so encouraging. The major advantage of this system is easy-to-learn alternative interface for the user. However, the user needs to hold it and scan the environment continuously on his way and the lack of many experimental results with visually impaired users, which failed this device to fulfil its desired requirement.

From State University of New Jersey developed the tactile handle device by Bouzit et al. (2004) that will help blind people navigate in familiar and unfamiliar environments without any assistance. The size of the prototype is 5 cm × 5 cm × 20 cm. Besides, it is lightweight, ergonomic, low-power, about 80 hours autonomy handheld device. Foe actuation, it has a 4 × 4 tactile array microcontroller where each actuator matches one finger phalanx. Moreover, it has four sonar sensors, is used for detecting obstacles in the front, left, right, and bottom, respectively.

The sensors navigate the environment and send the terrain information around the user in an encoded form through actuator. The location of the feedback signal represents obstacle position or direction (Figure 15). The intensity of feedback signal represents different distance and the timing of the feedback makes the user feel more comfortable and helps user understand dynamic aspects of the environment. Simple experiments were performed in controllable indoor environments by blind-folded users. The results and performance indicate that training is necessary and the prototype can perform as an obstacle detection system for indoor or outdoor environment (Bouzit et al., 2004; Shah et al., 2006). The advantages of this project are mostly the development of low-power ergonomic and compact prototype actuators. Furthermore, the tactile actuation system does not block hearing. However, constantly scan and use one of user’s hand are always needed. Moreover, the results show that excessive training is required.

Figure 14 Prototype CyARM and the concept of operation

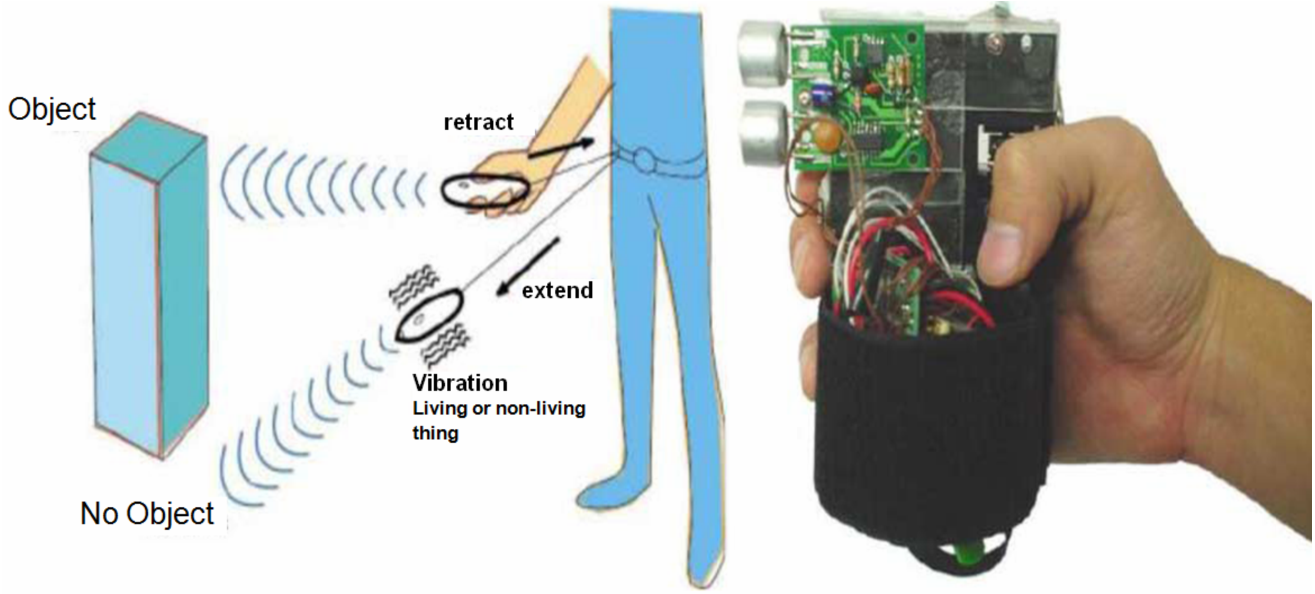


Figure 15 Tactile handle operation and navigation scenarios

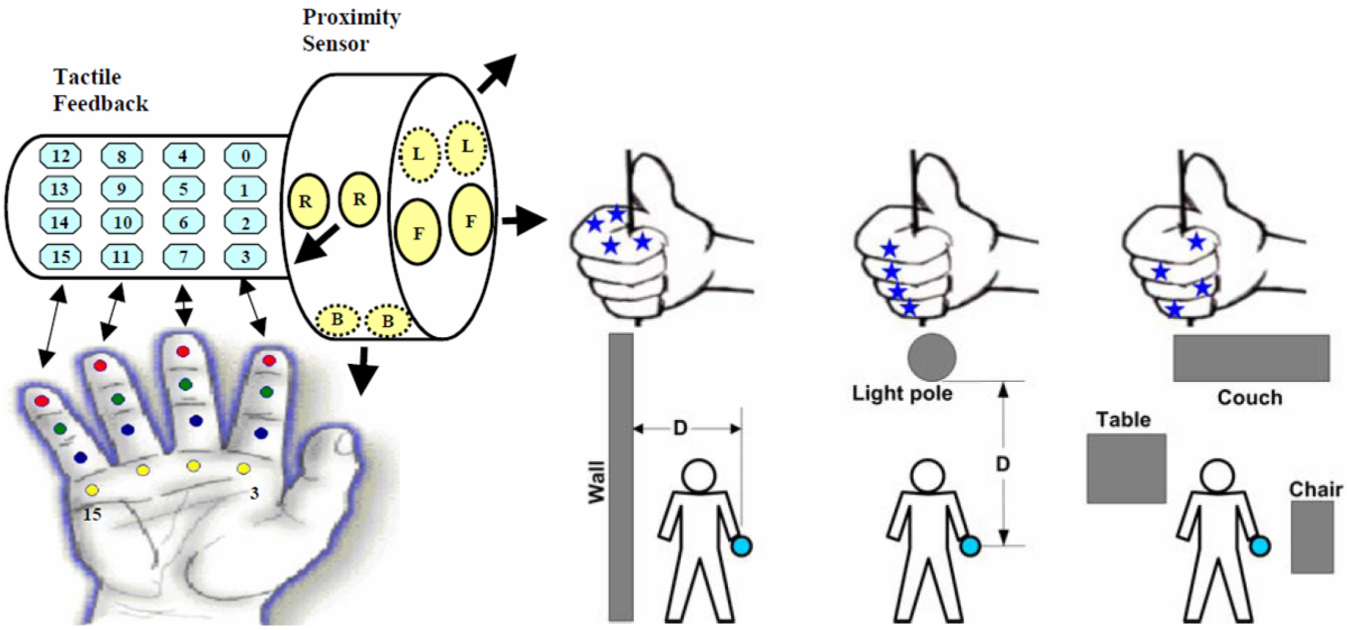


Figure 16 Hardware details of the EPFL prototype

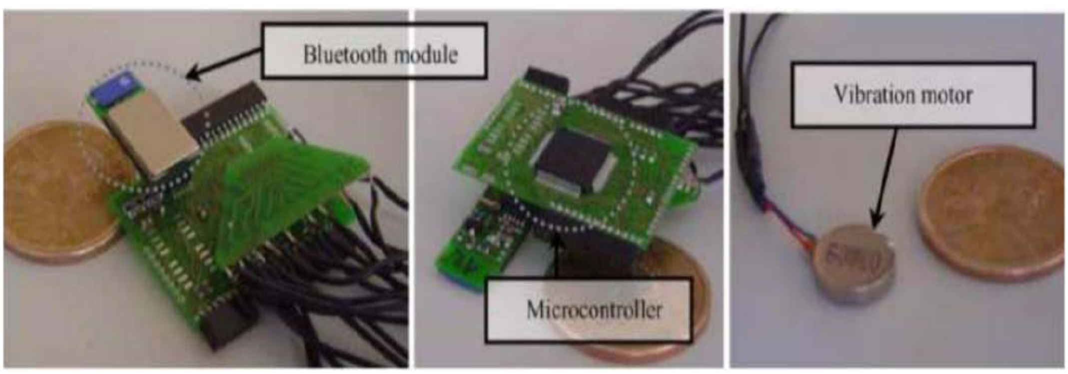
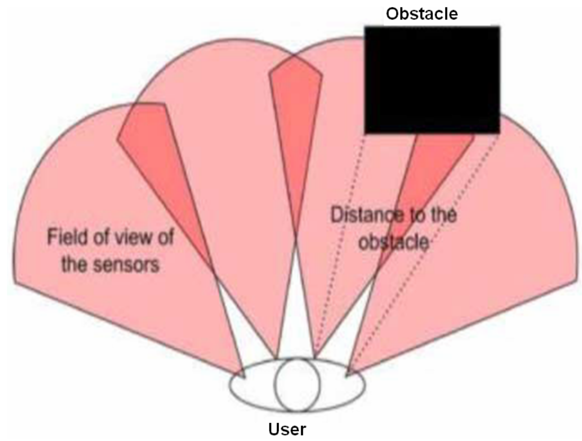
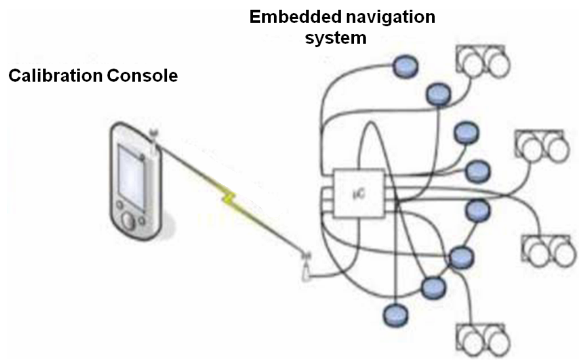


Figure 17 Operation and high-level design of the EPFL prototype





Cardin from Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland proposed and developed a wearable system that can detect obstacle that surrounds the user by using multi-sonar system and sending appropriate vibro-tactile feedback so that the mobility of visually impaired can be increased. It offers new sensing abilities that detects obstacles of shoulder height via a stereoscopic sonar system and sends back a vibro-tactile feedback to inform the user about its localisation. The prototype consists of ultrasonic sensors, a microcontroller, eight vibrators/motors, and a calibration console (PDA) (Cardin et al., 2007).

First, they determine from which direction the obstacles are coming from and then localised by feedback system. The microcontroller (Figure 16) gathers information from the sonar sensors (Figure 17) proportional to the distance of detected obstacles. It calculates the approximate distance of the obstacle using sound wave and then converts the distance to a pulse width modulation (PWM) signal that is redirected to the different vibration speeds of vibrator, so that the user can get information about the detected obstacles. The sonar sensors and the vibrators are mounted on the clothes/body of the user all-around the shoulder. Finally, Bluetooth is used to communicate with the microcontroller and allows dynamical modification of the calibration curve (real distance between object and sensor).

Experimental results have been obtained by passing the same tests on five different users as well as those were obtained by testing the device in a controlled indoor environment. The results show that the proposed system is quite intuitive and a reduction of 50% of the time to pass through the obstacles after a couple of minutes training with the system and localise themselves in the corridor. The advantages of this project are that it is a wearable, light, consumes low power, needs less training and costs less. The cons are that it is not tested on visually impaired people and that four sonar sensors cannot represent adequately 3D space as well as cannot detect different heighted obstacles. Moreover, it can detect hand as an obstacle in practical as mentioned by the authors and all experiments are conducted at indoor environment.

Figure 18 Smart cane on a user

The smart cane is developed by the IIT Computer Science Development. It is basically a walking stick that helps the blind users to commute with city buses, walking around the outdoor and also indoor. It is also equipped with avoidance system.

The smart cane (Figure 18) has the ability to navigate the knee level and also gauge any obstacle 3 metres ahead. With a user-triggered wireless identification system, vibration warning signal manager and a battery-driven speaker, the stick can send radio frequency to a passing public bus with a small electronic box at its entrance, to detect the route number and speak it out. The user wearing a mono-earplug will hear the number of a bus and get proper directions to reach its entrance and exit (IIT, Delhi, 2007).

From Table 1, we have summarised some projects of walking support system for blind where sensor is being used as a sensing device. Most of the researchers are interested on using of ultrasonic sensor for mapping the terrain and for feedback they used audio, vibration and tactile system. Those devices are usually either wearable or portable. However, we have noticed that some researchers used combination of some sensing systems and some actuation systems as well.

Table 1 Summarising the projects where only sensors are used for sensing

#	Project's name	Year	Type of sensor used	Actuation system	Feature of device
1	G5 obstacle detector	1984	Optical	Vibration	Portable
2	Superbat	1991	Ultrasonic	Sound image	Wearable
3	Navbelt	1992	Ultrasonic	Sound/earphone	Wearable
4	Robotic guide	1994	Ultrasonic	Head phone	Portable
5	LOAVA	1998	Laser	Speech	Portable
6	Sonic path finder	1999	Ultrasonic	Music tone	Portable
7	MIMS	1999	Optical	Audio sound	Portable
8	NavChair	2000	Ultrasonic	Voice	Portable/wearable
9	Guide cane	2001	Ultrasonic	Earphone	Portable
10	Smart shoe	2003	Infrared	Vibration	Wearable
11	FIU	2004	Ultrasonic	Head phone	Wearable
12	CyARM	2005	Ultrasonic	Tension of a wire	Wearable
13	SUNJ	2005	Ultrasonic	Vibro-tactile	Portable
14	EPLP	2007	Ultrasonic	Vibro-tactile	Portable
15	Smart cane	2007	Ultrasonic	Vibration/speaker	Portable

3.2 Camera used as a sensing device

Meijer (1992) started a project having the basic argument that human hearing system is quite capable of learning to process and interpret extremely complicated and rapidly changing sound patterns. The prototype shown in 'Figure 19' consists of a digital camera attached to conventional eyeglasses, headphones, and a portable computer.

Figure 19 Implementation of the vOIce – 'seeing with sound' system

Note: Glasses with attached camera, ear speakers, and portable computer.

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. Almost 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 cell phone, and thus the user can use the cell phone's camera and earphones. In addition, sonar extension is available for better representation of the environment and increased safety. Many researchers tried the system providing very responsible feedback, but they required extensive training because of the complicated sound patterns and it might increase the cost of the system (Meijer, 1992).

Adjouadi from Florida International University worked on a computer vision project in order to exploit, in an optimal fashion, the information acquired by cameras to yield useful descriptions of the viewed environment. Then, efficient and reliable cane cues can be sought in order to improve the mobility needs of individuals with visual impairments.

The system consists of digital cameras and a microcomputer, which is equipped with software for detection of depression or drop-offs, discrimination of upright objects from flat objects, identification of shadows, identification of special objects (staircase, crosswalk, doorway, etc.), planning of safety path/direction.

This project is not yet to be considered as an operational ETA, since issues as how the user will be informed during navigation are still open, but the algorithms are specially designed and implemented for navigation of blind and visually impaired. The author proposed audio verbal messages or tactile devices. As far as the software part, the strong points are that the algorithms were tested with good results since many special cases are considered (staircases, vertical edges, depressions, etc.) with the limitation that there are good-lightning conditions (Adjouadi, 1992).

Sonic eye (Reid, 1998) works with the concept of mapping of image to sound. It works by scanning the device's thin window over the object of interest from left to right. Features of the object in the top of the window are transferred to high pitch sound, while features in bottom are mapped to low pitch tones. It is used for two purposes, navigation and reading. While used for navigation, sonic eye can be hand to sweep the environment like torchlight or it can be head mounted. In reading mode, it is possible to read all alphabets with the mapped sound after adequate training; it is cited that by continuous practice the user can understand the continuous text. But users have to listen to each letters sound carefully to know the word, which requires a lot of patience and concentration. General problem of secular reflections in sonar also affects its accuracy.

Besides the technique presented above, there are multiple approaches for the vision assistance by non-wound methods. In the auditory interfaces realm, much process has been made since the new century. For presenting graphical scenes using non-speech sounds, we can utilise the physical tablet, the virtual-sonic grid, or the sound localisation system. For instance, Yoshihiro and his workgroup proposed a support system for visually impaired people using three-dimension virtual sound. Its user is informed of the locations and movements of objects around him by the 3D virtual acoustic display, which relies on HRTFs.

Kamel and Roth developed a GUESS system (graphics and user's exploration via simple sonics) that provides interrelational representation of objects in a non-visual environment. And the stereo-vision system of Zelek's (Audette et al., 2000) group is added a feedback component, which is used to relay visual information via tactile feedback through the user's fingers. Another experimental vision substitution system for the visually impaired people, SoundView, also provides haptic feedbacks, and its effect is quite excellent (van den Doel, 2003, 2004).

Some of the students from University of Guelph, in Canada, developed an inexpensive, built with off-the-shelf components, wearable and low power device. It will transform depth information into tactile or sound information for use by blind people during navigation. The prototype, shown in 'Figure 20' (top) consists of two stereo cameras, a tactile unit, and a portable computer. Each finger corresponds to a spatial direction (Figure 20). For instance, the middle finger corresponds to straight ahead. Using a standard stereovision algorithm, the depth map is created and then divided into five vertical sections, each one corresponding to a vibration element (Audette et al., 2000). If a pixel in an area corresponds to a threshold distance (here 3 ft) then the corresponding vibration element is activated, informing the user about a close obstacle in that direction. The low power and cost is the pros. However, the lack of sophisticated methodologies (e.g., the stereovision algorithm needs improvement) does not show better result or expected result.

Sainarayanan from University Malaysia Sabah developed an ETA to assist blind people for obstacle identification during navigation, by identifying objects that are in front of them. The prototype navigation assistance for visually impaired (NAVI) (Figure 21) consists with a digital video camera, headgear, stereo headphones, a single-board processing system (SBPS), rechargeable batteries, and a vest (Sainarayanan, 2002; Sainarayanan et al., 2001, 2007).

The human focuses on objects that are in front of the centre of vision. It is important to distinguish between background and obstacles for avoiding obstacles. The video camera captures greyscale video, which resembles to 32×32 resolution, besides there is option to change the resolution of it. Then using a fuzzy learning vector quantisation neural network, the pixels are classified to either background or object and then the object pixels are enhanced and the background suppressed. The last stage cut the pre-processed image into two parts, transform to sound that is sent to the user via the headphones or earphones.

A system that helps blind people orienting themselves in indoor environments was developed by researchers in University of Stuttgart in Germany. It has both wearable and portable feature. It consists of a sensor module with a detachable cane and a portable computer. The sensor (Figure 22) is equipped with two cameras, a keyboard, a digital compass, a 3D inclinator, and a loudspeaker. The working principal of this prototype like a flashlight and "by pressing designated keys, different sequence and loudness options can be chosen and inquiries concerning an object's features can be sent to the portable computer. After successful evaluation these inquiries are acoustically answered over a text-to-speech engine and the loudspeaker" (Hub et al., 2004).

Figure 20 Prototype from the University of Guelph and the hand spatial correspondence

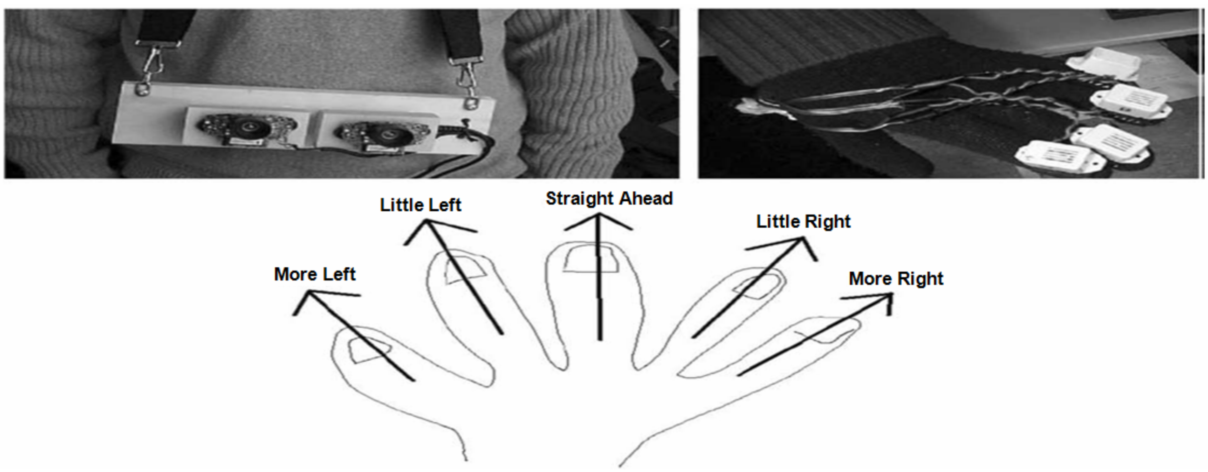


Figure 21 NAVI and its components

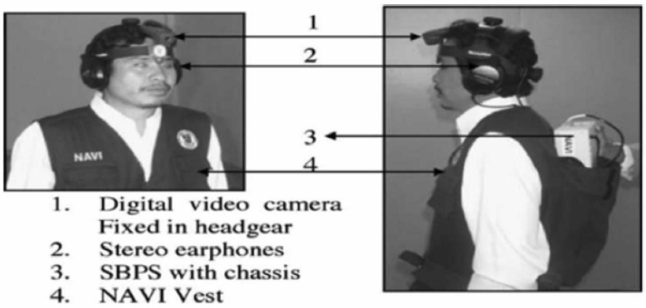
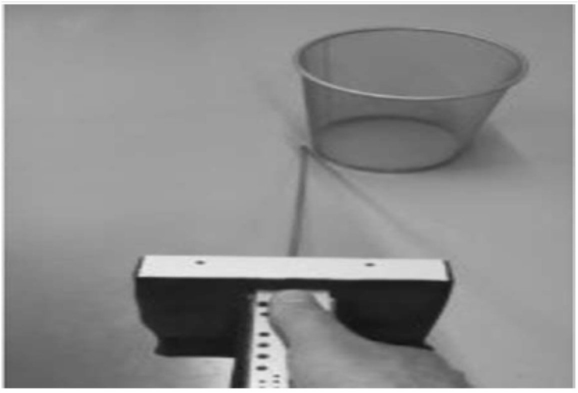


Figure 22 Sensor of the University of Stuttgart's project



The computer contains some specify software for detection of colour, distance and size of objects around the user; and wireless local area network (WLAN) capabilities and it works almost in real-time. For better performance of the system, a virtual 3D model of the environment was built. And the information from the sensor can be matched with the data stored in the 3D model. A matching algorithm for sensor information and 3D model's data and embedding the system to Nexus framework proposed as a future work.

Although the blind users attain the capacity of some objects identification like black patterns on a white background by the electro-tactile displays, they cannot get hold of any available 3D perception during the mobility period which is needed for object recognition, spatial localisation, target detection and obstacle avoidance. Due to these problems, a vision system for providing 3D perception of the environment via transcutaneous electro-neural stimulation was developed by Meers and Ward (2005a) which is called as ENVS (short for electro-neural vision system). Extracting depth information from the stereo cameras first and latter conveys this information to the fingers via electro-neural stimulation. For reading the range data, the user only imagine that his hands are being guided by fingers extended in the direction which is viewed by the cameras (Meers and Ward, 2004). The level of electro-neural stimulation felt by each finger indicates the distance of objects from finger and directed from that particular fingers (as shown in Figure 23).

Virtual acoustic space was developed by researchers in Instituto de Astrofísica de Canarias (IAC). The prototype (Figure 24) consists of two colour micro cameras attached to the frame of some conventional eyeglasses, a processor and headphones. The cameras capture information of the surroundings of the user by using stereoscopic vision. The processor, using HRTF, creates a depth map with attributes like distance, colour, or texture and then generates sounds corresponding to the situation in which sonorous sources exist in the surroundings. The experimental results on blind people showed that in most cases, individuals could detect objects and their distances and in small simple experimental rooms, it was possible for user to move freely and extract information from environment such as walls, table, window, and opened door (González-Mora et al., 2009). The main advantage of this proposed system is that the eyeglasses are convenient, very cheap and no need hold it and the size of the processor is small. This system is still not tested in real environments.

Figure 23 Electro-neural vision

Figure 24 Virtual acoustic space prototypes (cameras and headphones mounted on eyeglasses and microprocessor) (right)

The electron-neural vision system (ENVS) by Meers and Ward (2005b) from the University of Wollongong in Australia aims to achieve obstacle avoidance and navigation in outdoor environments with the aid of visual sensors, GPS, and electro-tactile simulation. The prototype (Figure 25) consists of a headset with two stereo cameras and digital compass, a portable computer with GPS capabilities and database of landmarks, the transcutaneous electrical nerve stimulation (TENS) unit (microcontroller), and the TENS gloves (Meers and Ward, 2010).

The basic concept behind the ENVS prototype is the stereo cameras, using stereoscopic vision, create a depth map of the environment and using the portable computer, information regarding the obstacles (from the depth map) or landmarks (from GPS) is transformed via TENS to electrical pulses that stimulate the nerves in the skin via electrodes located in the TENS data gloves. The ENVS uses a laptop to obtain a disparity depth map of the immediate environment from the head mounted stereo cameras. The user perceives the information if imagines that user's hands are positioned in front of abdomen with fingers extended. The amount of stimulation is directly proportional to the distance of the objects in the direction pointed by each finger.

To experiment blindness with sighted users the stereo camera headset was designed and fitted over the user's eyes so that no light whatsoever could enter his eyes. The prototype was tested with blindfolded users in outdoor campus environment, working in real-time (video of 15 frames/s). With a minimum training (1 hour) the users were able to report the location of obstacles, avoid them and arrive at a predefined destination. The system is one of the most complete in this survey because it is portable, real-time, it has GPS capabilities, it does not block user's hearing, and the experimental results are very promising. Some of the drawbacks are that the ground or overhanging objects are not detected, that a flat path is required (i.e., no stairs or drop-offs) and that the user is required to wear the TENS gloves. To calculate the disparity between the pixels, the stereo disparity algorithm requires automated detection of corresponding pixels in the two images, using feature recognition techniques. Consequently, featureless surfaces can create a problem for the disparity algorithm due to a lack of sophisticate features.

Figure 25 ENVS and its components

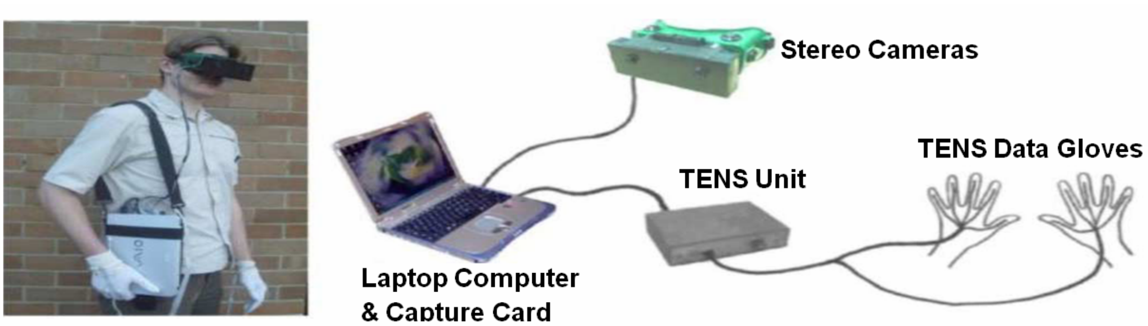


Figure 26 Schematic representation of the prototype

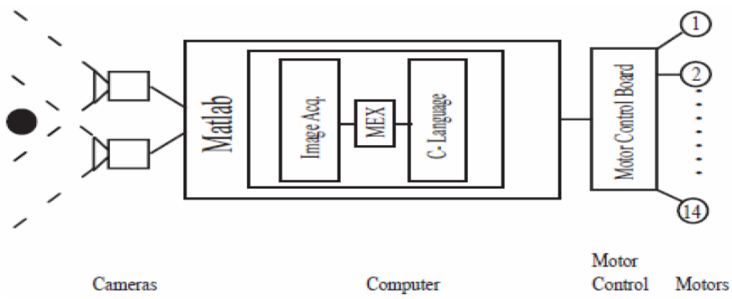


Table 2 Summarising the projects where only cameras are used for sensing

#	*Project's name*	*Year*	*Type of camera used*	*Actuation system*	*Features*
1	vOICe	1992	Cell phone	Earphones	Portable
2	FIU	1992	Digital	Verbal message/tactile	Wearable
3	Sonic eye	1998	Sonic	Sound	Portable
4	Yoshihiro	1998	Sonic	3D sound	Portable
5	GUESS system	2000	Sonic	Graphics'	Portable
6	University of Guelph	2000	Stereo	Tactile/Audio	Wearable
7	UMS, Malaysia	2002	Digital video	Sound	Wearable
8	University of Stuttgart in Germany	2004	Cell phone	Matched 3D model	Wearable/portable
9	Electro neural vision	2004	Conventional	Electro tactile	Wearable
10	Virtual acoustic apace	2004	Colour micro camera	Head phone	Wearable/portable
11	ENVS, Australia	2005	Stereo camera	Electro tactile	Wearable
12	University of Arizona	2006	Web camera	Tactile/vibration	Wearable

The objective of Johnson and Higgins from Department of Electrical and Computer Engineering, University of Arizona was describe a compact, wearable device that converts visual information into a tactile signal and to create a wearable device that converts visual information into tactile signal to help visually impaired people self-navigate through obstacle avoidance with commercially available parts. The prototype is named tactile vision system (TVS) (Figure 27) and consists of a tactile belt with 14 vibrator servo motors spaced laterally with Motor Control Board, a camera belt with two web cameras attached and a portable computer carried in a backpack with necessary software as shown in Figure 26 (Johnson and Higgins, 2006).

Two cameras capture images of obstacle and a 2D depth map is created using the images and then it is sliced in 14 vertical regions. Each vibrator motor (used as an actuation system) is assigned one region and the value of the closest object in each region is transformed to vibration (Figure 28). Vibration frequency and distance of object are non-linear and very far or very close objects are ignored. The signal given by the tactile belt is applied on the user flat and sensitive skin so that he/she can easily interpret tactile information. Video is captured with rate up to ten frames, which makes the system real-time for normal walking speeds.

The main advantages of TVS are that it is wearable first of all, it gives user free hands without blocking hearing, inexpensive webcams and it operates in real-time. However, it cannot differentiate between overhead and ground/flatted obstacles, requires huge power to operate and that no real experiments with visually impaired people have been performed.

Figure 27 TVS prototype

Figure 28 Example of TVS operation: image from the two cameras, disparity map, and the corresponding signals sent to the tactile belt

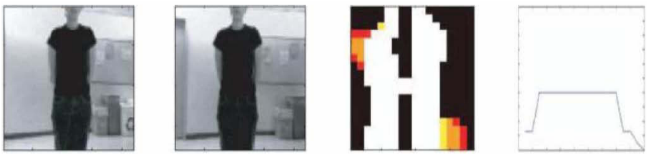


Table 2 shows the summarisation of some project where camera is being used as a sensing device. Researchers used various types of camera in their project such as cell phone camera, web camera, digital camera, video camera and so on. Nevertheless, the feedback systems and features are almost same as it was in our previous section. Using camera, they do have better sensing system but need to deal with a lot of complex algorithm as well as needs more battery power.

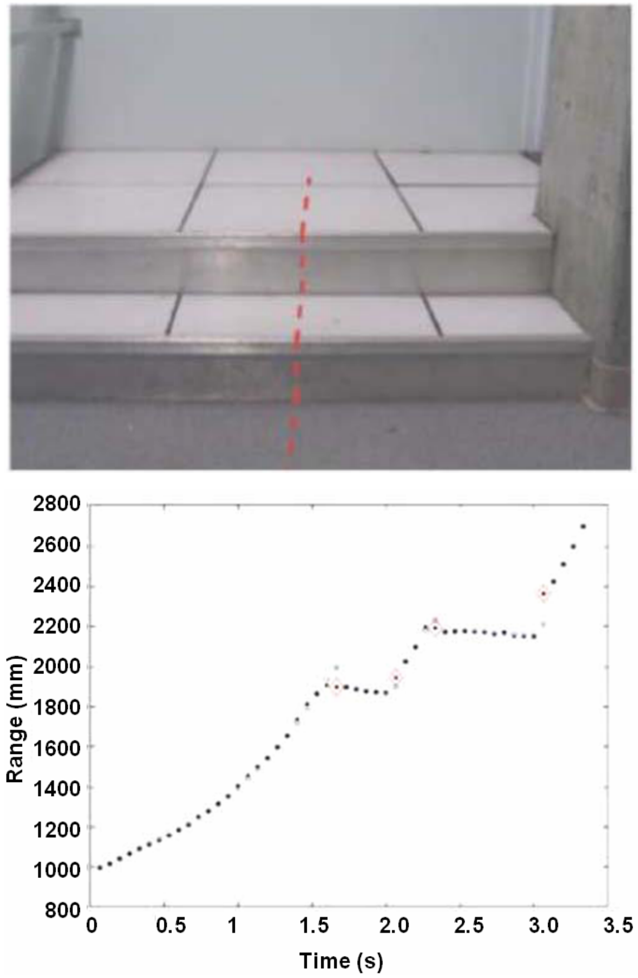
3.3 Both sensor and camera are being used as a sensing medium

Yuan and Manduchi from Department of Computer Engineering, University of California Santa Cruz (UCSC) developed a non-contact handheld tool for range sensing and environment discovery for the visually impaired people. The final device will be composed of a laser-based range sensor and of an onboard processor. As the user swings the handheld system around, user will receive local range information by means of a tactile interface. The basic principal of this prototype similar to white cane appears to be a natural procedure for environment discovery. Thus, the tool is handheld and as the user swings it around (vertical or horizontal) user will receive information by means of tactile devices (Yuan and Manduchi, 2004). The system deals only with single dimension data, which is computationally cheaper than computer vision or spatial sound techniques. The prototype consists of a laser range sensor (point laser matched with a matrix CCD), as seen in 'Figure 30', and a computer. The range sensor for our virtual white cane' should provide measurements between 0.5 m and 3–4 m, with a resolution of a few centimetres at the maximum distance. It is based on active triangulation. In addition, the time profile of the range is analysed by the computer to detect environmental features that are critical for mobility, such as curbs, steps, and drop-offs (Figure 31), by means of an extended Kalman filter tracker.

Figure 29 UCSC's handheld device equipped with laser range sensor

The advantages of this system are reliable for local range measurements and give promising environmental features detection. In addition, it is small and easy to carry although it is handheld. The cons are that it is not tested with visually impaired people, there is no interface between device and user and that it is constraint in the detection of only planar structures and objects near the ground. Moreover, it is designed for only indoor environment. The user of camera and sensor together make the system algorithm more complex and costly. The proposed future improvements by the authors are improvement of feature detection algorithms; replacement of point laser with laser striper; built in processor in the device instead of computer; tactile devices that will inform user about features detected as well.

Figure 30 Time profile of two steps acquired as the device was pivoted in an upward motion



The preservation and analysis of important image information needed for blind people for safe navigation in an indoor environment are presented in Wright State University, USA in Tyflos navigation system. It was conceived by Bourbakis, Kavraki and Dakopoulos (Bourbakis and Kavraki, 1996; Dakopoulos and Bourbakis, 2010; Dakopoulos et al., 2007) in the mid-1990s and various prototypes have been developed. The reader and the navigator (ETA) are two basic modules for Tyflos navigation system.

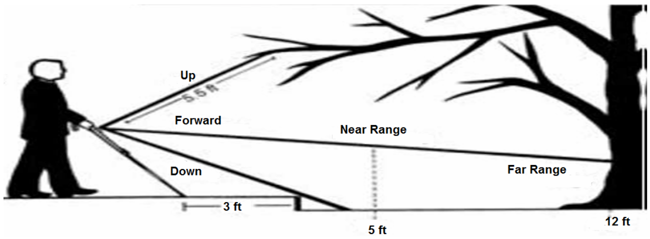
The Tyflos system consists of a wireless handheld computer, cameras, range sensors, GPS sensors, microphone, natural language processor, text-to-speech device, and a digital audio recorder. And methodologies consist of region-based segmentation, and range data conversion, fusion. The main goal for the Tyflos system is to integrate different navigation assistive technologies in order to offer to the blind more independence during navigation as well as reading. Here, the actuation systems are the audio-visual input devices and the audio-tactile, and the output of those devices can be worn for the user. Collected data from the various sensors are processed by the Tyflos' modules each specialised in one or more tasks. Besides, it interfaces with external GPS sensors, range sensors, as well as the user, facilitating focused and personalised content delivery (Dakopoulos and Bourbakis, 2008).

Figure 31 Commercial products, (a) K-sonar cane (b) mini-radar (c) Miniguide and (d) laser cane

(a)

(b)

(c)



(d)

The main role of the navigator is to capture the environmental data from various sensors and map the extracted and processed content onto available user interfaces in the most appropriate manner. Previous Tyflos prototypes are designed using many of the technologies mentioned above and tested yielding promising results. The latest Tyflos navigator system prototype developed in Ohio at 2008 is shown in 'Figure 32'. It consists of two cameras, an ear speaker, a microphone, a 2D vibration array vest, attached on the user's body, controlled by a microprocessor, and a portable computer/laptop, and it integrates various software and hardware components.

Figure 32 Tyflos' second prototype hardware components, (a) stereo cameras attached on dark eyeglasses, microphone, earphones, and portable computer (b) 2D vibration array vest attached on a user's abdomen

(a)

(b)

During navigation there are three basic elements that can appear on the scene (i.e., image/video captured by the cameras) such as obstacle, object and corridor. The stereo cameras create a depth map of the environment which can be verified by the range sensor's output. Resolution optimised by algorithm keeping necessary information for navigation such as safe navigation paths and objects of interest. This final 'image' is a representation of the 3D space, and it is converted into vibration sensing on a 2D vibration vest that is attached on the user's chest. The element of the array that vibrates represents the direction; where an object is detected and the different vibration levels represent the distance of the object (Figure 33). Optional audio feedback can inform the user for objects of interest.

Free-ear and the use of the 2D vibration array with the variable vibration frequencies that offer the user a more accurate representation of the 3D environment (including ground and head height obstacles) as well as information for distances are main advantages of Tyflos system. The disadvantages are that the system is not yet tested on blind users, which is an important step for receiving feedback for future hardware and software changes. Moreover, it was designed for indoor environment only and need to deal with a lot of complex algorithm.

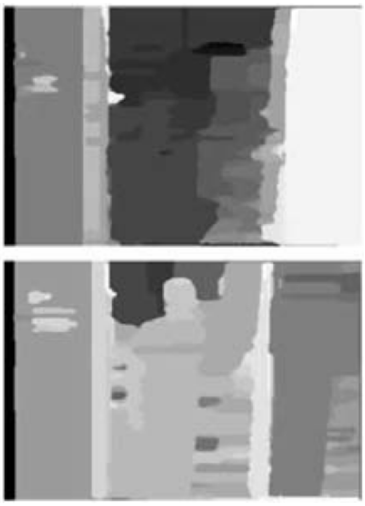
In last decade, researchers are most interested using both sensor and camera as a sensing device with various types of sensors as well as cameras (Table 3). Moreover, they do have more sophisticated actuation system for the users. However, to process those complex algorithms we need to have powerful processor and more power which lead the cost of those devices.

Table 3 Summarising the projects where both sensors and cameras are used for sensing

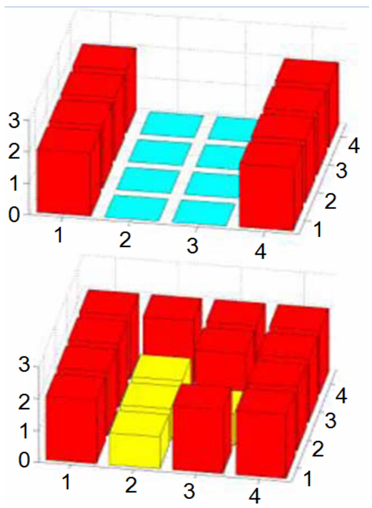
#	*Project's name*	*Year*	*Sensing devices*	*Actuation*	*Features*
1	Tyflos Navigation System	1995	Range, GPS sensor; stereo camera	Micro phone	Portable
2	UCSC	2004	Laser sensor; digital camera	Tactile	Wearable/portable
3	Advanced Tyflos Navigation System	2008	Range, GPS sensor; stereo camera	2D vibration array vest/audio	Portable

Figure 33 Operation of the Tyflos with two navigation scenarios (one in each row), (a) shows the images captured by the cameras (b) the depth maps (c) what the user senses via the 4 × 4 vibration array

(a)



(b)



(c)

4 Critical findings from the review

Besides, currently available walking support system cannot differentiate between animate and inanimate obstacles. So in further works it should consider this issue. Moreover, those devices are limited to standard pace of mobility of the user. It requires making more sophisticated system so that user can walk at a pace of a normal human. The used sensors sometimes are affected with temperature and humidity and also its accuracy and precision is not enough to get proper data. It is my recommendation that use more filter to eliminate all possible noise from the system. For complete walking support system, one should plan for more sensors to further enhance mapping capability of the system. In such case, it is expected number obstacle scenario will increase significantly, which would need alpha numeric brail representations. To train scenario information better, neuron network could be applied.

5 Conclusions

From the above survey, it becomes clear that, many researchers have worked for blind people to help them navigate their ways (Hossain, 2010). Some of them used ultrasonic sensor, laser sensor or infrared sensor at different locations of the body for detecting front obstacles only; none talks about hazardous obstacle like step, stair or hole. Most of those systems are costly as well as need the huge power to operate and neither wearable nor hands free. Cameras have also been tried by some researchers to replace ultrasonic and the like sensors. However, for image processing it needs a computer or more sophisticated processing system which involves more cost and operating power and heavy weight. For conveying information about the surrounding, different actuating systems like sound, vibration, tactile force are used. Nevertheless, the problem of the blind people navigation with minimal dependency still remains unresolved due to less concern of the researchers about cost, weight, and power consumption of the blind navigation related devices. So the topic of blind people navigation still needs attention for better solution.

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