A survey on wearable devices used to assist the visual impaired user navigation in outdoor environments

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***Abstract*—In this paper we introduce a comprehensive survey of wearable systems designed to assist the visual impaired users navigation in everyday life outdoor scenarios. We focus on presenting the main advantages and limitations of each technique in effort to inform the scientific community about the progress in the area of assistive devices and also offer users a review about the capabilities of each system. Various performance parameters are introduced in order to classify different systems by giving qualitative and quantitative measures for evaluation. At the end of the study conclusions are presented along with some perspectives for future work and development.**

Keywords—wearable devices; blind and visually impaired users; assistive outdoor navigation

I. INTRODUCTION

According to the World Health Organization the total number of visually impaired people worldwide is 285 million, while 39 million are completely blind [1]. In this context, the elaboration of assistive devices for autonomous navigation dedicated to blind and visual impaired people is a challenge. Nowadays, the white cane and the walking dogs still represent the most popular tools used for obstacle detection. The cane is also the cheapest, the simplest and most reliable elements used as navigation aid. However, it is not able to provide additional information elements such as: the speed and type of object the user is encountering, the static or dynamic nature of the obstacle, the distance and time to collisions. This information is gathered for normal users by their eyes and it is absolutely necessary to have it in order to percept and control the locomotion during the navigation [2].

In its absence partially sighted/visual impaired (VI) users always try to memorize all locations they have been to in order to become familiar with. In a new, unfamiliar setting they completely depend on other humans to reach the desired destination [3]. The task of route planning in an unforeseen obstacle environment can severely impede the independent travel of VI and thus reduce their willingness to travel [4].

Since 1960s evolving technologies are selected by researchers in order to develop electronic assistive devices used for navigation. Any sensor is designed to detect and locate objects and to provide user with information that allows him to determine the dimension and height of the object, its position and direction of movement. The sensors allow the partially sighted user to receive directional information about the environment in which he travels (*e.g.* the physical structure, detection and identification of objects, time to collision based on acoustic feedback…).

The rest of this paper is organized as follows. Section II presents and analyzes the related work in the area of electronic travel aids. The focus is put on the main advantages and limitations of each technique in effort to inform the scientific community about the progress in the area of assistive devices and also offer users a review about the capabilities of each system. Finally, Section III presents the experimental results and concludes the paper.

II. ELECTRONIC TRAVEL AIDS SYSTEMS

The ETAs (Electronic Travel Aids) are defined as any device designed to replace the traditional vision system by sensors in order to acquire the environment information. In the following part we will briefly present the most important techniques existent in the technical literature. We will study these systems and give comparative results that answer the questions of how advanced, useful and desirable each system is. The focus is put on the feedback sent to a VI user.

A. vOICe

The vOICe system, designed to augment the human hearing perception is composed of a video camera and a computer that invertible transforms the image into a sound mapping [5]. The alerting messages are sent directly, without any filtering, to a pair of headphones using as main processing unit the human brain (Fig. 1a).

The system is light weighted, easy to wear, small and with a simple architecture. Its drawbacks are related to the use of regular headphones that block the user ears. Also, the visually impaired requires an extensive training phase to become familiar with the sound patterns.

B. University of Stuttgart System

In [6] the authors introduce an object identification system that assists the VI to orient themselves in indoor/outdoor environments. The prototype is designed to work in real time and it is composed of a processing computer and a sensor module with detachable cane (Fig. 1b). In order to increase the detection performance a virtual 3D model of the environment is build to match the data received from the sensor.

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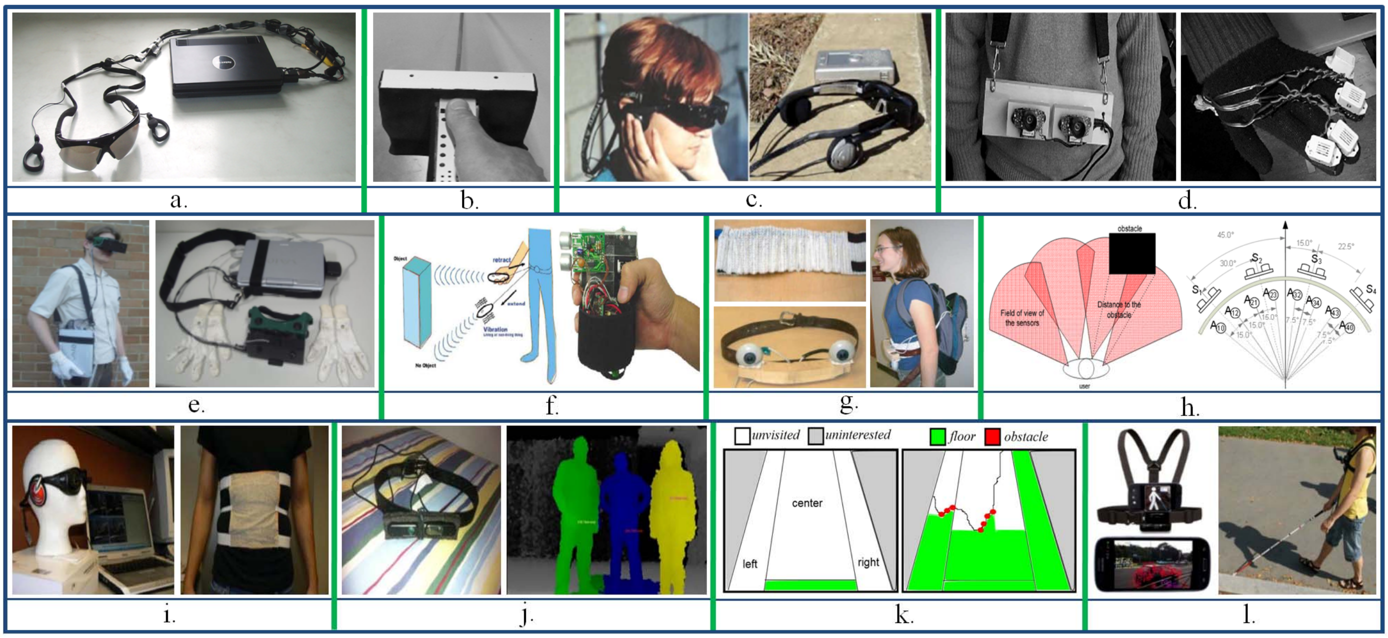

Fig. 1. Electronic travel aids prototypes: a. vOICe system; b. University of Stuttgart system; c. Virtual acoustic space; d. University of Guelph system; e. Electronic neural vision system; f. CyARM system; g. Tactile vision system; h. EPFL system; i. Tyflos system; j. KinDetect assistant; k. Curtin University; l. ALICE system.

The system is characterized by the sensor robustness. The negatives are that the prototype needs to be hand hold, is limited to a reduce number of objects and all the testing are performed in simulated environments.

C. Virtual Acoustic Space

The virtual acoustic space [7] creates a sound map of the environment so that the VI users can orient themselves by perceiving the space at the neuronal level. The system is composed by eyeglasses equipped with two color video cameras and headphones (Fig. 1c). The cameras, using stereoscopic vision, capture information of the surroundings by creating depth maps. The depth map is further used to determine the distance between the VI and the objects presented in the scene. Based on color, texture and depth information the system generates sounds regarding the obstacles situated on the user surroundings.

The systems can be characterized as small, while the eyeglasses are convenient and easy to wear. The major drawback is that it blocks the user hearing and was never tested in real environments or on actual VI users.

D. University of Guelph Project

The system introduced in [8] uses low price components to acquire stereographic images and transform depth information into tactile impulses. The prototype is composed of a stereo camera, a processing unit and a tactile glove with five piezoelectric buzzers on each finger (Fig. 1d).

On the left hand each finger corresponds to an obstacle map in a forward direction away from the user. The middle finger corresponds to straight ahead. The depth map is created and divided into five sections each corresponding to a vibration element. If an obstacle is situated in a specific area then the buzzer elements are activated to inform user about its presence on that direction [8].

The system is simple with a reduce power and cost. However, the stereovision algorithm returns low accurate depth maps and is sensitive to the intensity variation. Also, the hand free constraint imposed by the VI users is violated.

E. Electron Neural Vision System

The electronic neural vision system (ENVS) is designed to enable the VI users to achieve obstacle avoidance and assistance in navigation with the aid of visual sensors, GPS and electro-tactile stimulation [9]. The ENVS extracts depth maps from stereo cameras by measuring the disparity between images. The information is transmitted to the fingers via electro-neural simulation to indicate the range of objects existent in the scene. The system is completed with a digital compass and a portable computer with GPS capabilities and a database of landmarks (Fig. 1e).

As a major improvement, the system works in real time and does not block the user hearing. However, by using electrical nerve stimulation gloves, the human hands are always occupied. Moreover, the ground and overhead objects are not detected, while the walking path needs to be flat (*i.e.* no stairs).

F. CyARM

An electronic aid device denoted CyARM is introduced in [10] to be used in guiding orientation and locomotion of visually impaired users (Fig. 1f). The system detects obstacles existent in the scene and determines their distances from the VI user, based on an ultrasonic sensor. The alerting mechanism is composed of a tension wire attached to the VI through a vest or a belt. Low tension indicates longer distances to the obstacle and vice-versa. The prototype architecture is composed of a micro-controller to process information coming from sensors and a motor to control the wire tension.

The system major advantages are given by a high detection rate in the case of static obstacle and an easy to learn interface.

On the contrary, for the dynamic objects the tracking results are not so encouraging. Furthermore, the VI needs to hold the device when scanning the environment. The authors do not provide any real experimental results on VI users.

G. Tactile Vision System

The tactile vision system (TVS) introduced in [11] to improve the VI user navigation through obstacles avoidance, was developed as a compact, wearable device that converts the visual information into tactile signals. The prototype is composed of two webcams, a laptop computer, a servo control board and fourteen vibrating motors attached to flexible belt (Fig. 1g). The vibration frequency increases nonlinear for closer objects. The user is informed about the obstacle presence through vibration coming from the belt mounted directly on his/her skin.

The system works in real time and gives user free hands without blocking the hearing. Its major disadvantage is that it cannot differentiate overhead and ground obstacles. Also, no experiments on real visually impaired users were made.

H. EPFL System

The system introduced in [12] is a wearable device, designed to detect obstacles situated at the shoulder height by using stereoscopic sonar. At the hardware level, the prototype is composed of a microcontroller, sonar sensor, eight vibrators and a calibration console (Fig. 1h). The sonar returns the distance of the nearest obstacle in range which is translated into vibration based on the sensor position and actuators. The vibrators are mounted on the VI cloths. The calibration console communicates through bluetooth with the microcontroller and allows the dynamical adjustment of the calibration curve.

The experimental results are conducted only on indoor environments but, even so, they are remarkable since users manage to walk through corridors, distinguish obstacles and localize themselves. The cons are given by the use of sonar that cannot reliable represent the 3-D space. Another aspect that needs to the highlighted is that in some case the system detects as obstacle the user hands. Some tests on actual VI users need to be performed.

I. Tyflos

Tyflos navigation system was originally introduced in [13] and further extended in [14]. The prototype contains two cameras, an ear speaker, a microphone, 2-D vibration vest controlled by a microcomputer and laptop (Fig. 1i). Using the video cameras a depth map is generated. The dynamic objects are identified using motion detection and face recognition methodologies. The resulted image is represented as a 3-D space that is converted into vibrations depending on the object distance to the subject. The technique can detect obstacles situated at various height levels and does not block the user hearing. However, the system is quite invasive (the vibration jacket needs to be situated near the skin), and some tests on real users need to be performed.

J. KinDetect

The KinDetect navigation assistant introduced in [15] uses the depth information to recognize objects and other humans. The technique uses a Kinect, as a depth sensor, an acoustic feedback system and a computer in order to identify obstacles situated at head or foot level. The system firstly generates depth maps and RGB information. Than by incorporating a tracking strategy it detects moving objects, people and estimate in 3D space their distance and position relative to the VI user (Fig. 1j).

Incorporating a Kinect sensor limits the system to indoor applications. By using regular headphones to transmit warning messages the user ears are blocked and the ears-free condition is not accomplished. Also, the system has never been tested on actual VI user.

K. Curtin University System

In [16] a smartphone navigation assistant is introduced. The prototype is designed to detect any objects attached to the floor regardless of their height (Fig. 1k). For each frame of the video stream captured using a monocular camera low level descriptors such as: color histograms and edges are extracted. Then the image region of interest (*i.e.* obstacle position), initial histogram of safe region, and the safest path to follow are determined, by employing computer vision algorithms.

The system is reliable with a reduced acquisition cost returning high obstacle detection rates. However, it is evaluated solely in indoor scenarios and only on normal humans. In addition, the smartphone needs to be hand hold violating the hands-free requirements [17].

L. ALICE

Our navigation assistant, firstly introduced in [18], denoted ALICE is composed of a regular smartphone attached to a chest mounted harness (Fig. 1l). The system detects obstacles based on interest points tracking using the Lucas-Kanade algorithm, camera and background motion estimation and agglomerative clustering. Then the obstacles are classified by incorporating the HOG (histogram of oriented gradients) descriptor into the BoVW(Bag of Visual Word) retrieval framework.

The system can be described as a simple device, ready to use without any training, non-intrusive, satisfying the hands-free requirement imposed by VI users. The major drawback is given by the lack of alerting functionalities. On the other hand, a wider study with more blind users should be performed.

III. Discussions And Conclusions

From the systems presented above and after a set of discussions with several groups of VI users, software developers and researchers, we determined the most representative features an ETA should have (Table I).

For every feature (F_i) and for every system (*A–L*), we assigned a score based on the information we have for each method, got from the literature and our discussions with our groups of users and engineers that have tried each prototype in real-life scenarios. Thus for each system we have assigned a value between 1 and 5. The final score is computed as:

$$Score = \sum_{i=1}^{N} f_i / N \tag{1}$$

where f_i represents the feature value and N is the total number of characteristics considered for analysis (Table II).

TABLE I. STRUCTURAL AND OPERATIONAL FEATURES

	Features	Description
F1	**Real time**	The system should return warring messages fast enough so that the user should walk normally.
F2	**Wearable**	The device is attached to the user as a piece of clothing. The user ears and hands need to be free.
F3	**Portable**	The system has to be easy to mount, light weighted so it can be carried without effort for long distances, small, with a ergonomic shape.
F4	**Reliable**	The software should have high accuracy and recall rates, but also to correctly function in unexpected/hostile situations.
F5	**Low-cost**	The device should be affordable to all users.
F6	**Friendly**	The system should be intuitive, easy to learn, without an extensive and expensive training phase.
F7	**Robust**	The device should resist in difficult environmental conditions or in hard use.
F8	**Wireless/no connection**	The systems should connect wireless to a computer in order to exchange information.

TABLE II. SYSTEM EVALUATION USING THE STRUCTURAL AND OPERATIONAL FEATURES

Method	F1	F2	F3	F4	F5	F6	F7	F8	Score
A	3	4	4	4	4	1	2	0	**2.75**
B	4	0	4	3	3	4	3	5	**3.25**
C	3	4	4	3	4	2	2	0	**2.75**
D	3	4	4	2	3	3	2	0	**2.87**
E	4	4	4	3	3	4	3	5	**3.75**
F	4	0	4	2	4	4	2	0	**2.5**
G	5	4	4	3	3	4	3	5	**3.87**
H	4	5	5	3	5	4	2	0	**3.5**
I	3	4	4	3	2	5	2	0	**2.87**
J	5	4	4	2	3	3	4	0	**3.12**
K	3	5	5	1	4	3	2	5	**3.5**
L	4	5	5	3	3	3	3	5	**3.87**

From the results presented in Table II the following conclusion can be highlighted: no system incorporates all required features in a satisfactory degree. Every system offers something special over the others but it cannot meet all the needs, since an ideal technology should have all the features and functionalities. The difficulty is not developing a system that has all the "bells and whistles" and to alert user about any object present in the scene, but to conceive the technology that will last in time and is useful.

For the moment, the VI users can not be completely confident about the prototype robustness, reliability or overall performance. Any new technology should be designed not to replace the cane or the walking dog, but complement them by alerting the user of obstacles in a few meters, and provide guidance.

ACKNOWLEDGMENT

The work has been funded by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Ministry of European Funds through the Financial Agreement POSDRU/159/1.5/S/132395 (InnoRESEARCH).

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