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BSc THESIS

Electronic Smart Canes for Visually Impaired People

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ABSTRACT

The purpose of this paper is to present and describe existing devices and smart-stick technologies for blind and visually impaired people. This state-of-the-art review includes the most recent research results of international scientific literature (published in scientific journals, conferences, etc.), patents and commercially available products. These technologies are classified according to their basic characteristics and are then accompanied by of the research trials conducted (where reference is made to the respective sources) and their results.

In order to achieve this goal, after an extensive search in the international scientific literature, the most important and most recent technologies of smart sticks were selected and the operating principle of each of them was briefly described. Subsequently, the devices were classified according to the technologies they use and their basic characteristics, along with the additional information on the relative user trials and their results.

The positive and negative aspects of each device as well as whether it covers the needs and requirements of visually impaired people are easily distinguishable. The conclusion that accrues is that many of the blind-aid systems offer limited capabilities, and others can achieve the required precision in part. None of these, however, fulfills all the essential and fundamental features that would make the device ideal and satisfactory in its use. This work, therefore, shows the advancement of technology in this scientific field, aiming to indirectly highlight the improvements, advantages and disadvantages and to trigger the design of devices that fully ensure the safety and independence of the blind and the visually impaired people.

SUBJECT AREA: Human Computer Interaction

KEYWORDS: assistive technologies, smart cane/stick, visually impaired people, obstacle detection

ΠΕΡΙΛΗΨΗ

Σκοπός της παρούσας εργασίας είναι να παρουσιάσει και να περιγράψει υπάρχουσες συσκευές και τεχνολογίες «έξυπνων» μπαστουνιών για τυφλούς και άτομα με σοβαρά προβλήματα όρασης. Σε αυτή την ανασκόπηση της σύγχρονης τεχνολογίας (state-of-the-art) περιλαμβάνονται τα πιο πρόσφατα ερευνητικά αποτελέσματα της διεθνούς επιστημονικής βιβλιογραφίας (δημοσιευμένα σε επιστημονικά περιοδικά, συνέδρια, κ.α.), σχετικές πατέντες αλλά και τα εμπορικά διαθέσιμα προϊόντα. Κάθε μία από αυτές τις τεχνολογίες ταξινομείται ως προς τα βασικά χαρακτηριστικά της και στη συνέχεια συνοδεύεται (όπου αυτά αναφέρονται στις αντίστοιχες πηγές) με τα αποτελέσματα των ερευνητικών δοκιμών που διεξήχθησαν.

Για την επίτευξη αυτού του στόχου, αφού προηγήθηκε μια εκτενής αναζήτηση στη διεθνή επιστημονική βιβλιογραφία, επιλέχθηκαν οι σημαντικότερες και πιο πρόσφατες τεχνολογίες «έξυπνων» μπαστουνιών και για κάθε μία περιεγράφηκε περιληπτικά η αρχή λειτουργίας της. Στη συνέχεια, ταξινομήθηκαν οι συσκευές σύμφωνα με τις τεχνολογίες που χρησιμοποιούν και τα βασικά χαρακτηριστικά τους, ενώ παρουσιάζονται επιπλέον πληροφορίες σχετικά με τις σχετικές δοκιμασίες με χρήστες που πραγματοποιήθηκαν και τα αποτελέσματά τους.

Με την ολοκλήρωση όλων των παραπάνω, εύκολα διακρίνονται τα θετικά και τα αρνητικά της κάθε συσκευής και το κατά πόσο αυτή καλύπτει τις ανάγκες και τις απαιτήσεις των ατόμων με απώλεια όρασης. Το συμπέρασμα που προκύπτει είναι ότι πολλά από τα συστήματα υποβοήθησης των τυφλών προσφέρουν περιορισμένες δυνατότητες και άλλα μπορούν να επιτύχουν εν μέρει την απαιτούμενη ακρίβεια. Κανένα, όμως, από αυτά δεν πληροί όλα τα απαραίτητα και θεμελιώδη χαρακτηριστικά που θα καθιστούσαν κάποια συσκευή ιδανική και ικανοποιητική ως προς τη χρήση της. Αυτή η εργασία, λοιπόν, φανερώνει την πρόοδο της τεχνολογίας σε αυτό το επιστημονικό πεδίο σκοπεύοντας να τονίσει εμμέσως τις βελτιώσεις, τα πλεονεκτήματα και τα μειονεκτήματα και να αποτελέσει το έναυσμα για την σχεδίαση συσκευών που εξασφαλίζουν πλήρως την ασφάλεια και την ανεξαρτησία των τυφλών και των ατόμων με απώλεια όρασης.

ΘΕΜΑΤΙΚΗ ΠΕΡΙΟΧΗ: Επικοινωνία Ανθρώπου Μηχανής

ΛΕΞΕΙΣ ΚΛΕΙΔΙΑ: υποστηρικτικές τεχνολογίες, «έξυπνο» μπαστούνι, άτομα με απώλεια όρασης, ανίχνευση εμποδίων

Dedicated to Pantanassa and Theoktistos

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I would like to thank my supervisor, Associate Professor Georgios Kouroupetroglou, for the cooperation and his valuable support and contribution to the completion of this Thesis.

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PREFACE

In recent years, technology has entered every aspect of our everyday life. Technological development in almost every scientific field has brought significant enhancement in the quality of our lives improving everyday tasks from the simplest to the more complex and demanding. It is undeniable that the most important contribution of technology is the one to the health sector. The future of medicine and healthcare is closely connected to the empowerment of patients as well as individuals taking care of their health through devices and other technologies.

On the other hand, there are some healthcare sectors that are not as advanced as others, because, de facto, they are referring to small groups of the world population. One of these groups is the blind and visually impaired people. Many blind and partially sighted people of all ages are unable to lead independent lives because they have not the means that are necessary to help them overcome the problems that occur from sight loss. However, even though most of us are probably not aware, some very significant progress has been done from scientists and researchers who develop technological assistive-blind-aids, which are much more sophisticated and helpful than the well-known conventional long (white) cane.

For the elaboration of this thesis, I had to do an extensive research in scientific literature that includes different and many types of devices, patents and products for visually impaired people. So, studying the way such systems work provided to me a lot of information and knowledge about the previous and current technological paths in the development of electronic travel aids for blind and partially sighted people. Moreover and most importantly, perceiving where those systems focus and how they interact with the user in order to restore or replace, as much as possible, their sight, helped me understand more deeply the difficulties with which these individuals struggle with daily and how important it is that society, state and scientific community become sensitized and mobilized so that we all contribute in helping members of society with disabilities live their lives with as much normality as they can. And for that recognition, I would like to thank my supervisor, associate professor Georgios Kouroupetroglou for suggesting me to develop this subject for my Thesis.

1. INTRODUCTION

Out of all the five human senses, vision seems to be the most important. Humans are fairly unique in their reliance on sight as the dominant sense (Medium Corporation [US]), since 83% of information that human beings get from the environment, is via sight. The most recent statistics by the World Health Organization (WHO) estimates that there are 285 billion people in world with visual impairment. Among these individuals, there are 39 million who are totally blind and 246 with low vision.

People with visual impairment primarily rely on sighted guidance and/or traditional travel-navigation aids. Long (white) cane is the most popular and commonly used assistive device around the world. It increases the detection range to nearly one meter and provides information about the ground-level obstacles and the surfaces. However, there are many limitations of the white cane like uncertainty in discrimination and protection against drop-offs, limited preview range, danger of tripping pedestrians in crowded places and no protection of the upper part of the body from the hanging or protruding obstacles which do not have significant footprint on the ground. It is reported that walking without sight poses risk of head-level and fall accidents that often require medical attention. These accidents reduced the confidence and forced a substantial number of respondents to change their mobility habits.

The limitations of traditional assistive solutions led to the development of several electronic assistive travel aids and systems, for the purpose of detection of objects as well as guiding the user by providing the required orientation and navigation information. Such solutions would enhance the quality of VIPs' lives by improving the detection range of obstacles, objects, etc. which leads to better orientation in the environment and to less stressful, more independent, safe, comfortable, and simplified navigation task.

According to (Wiener et al, 2010), an assistive technology solution must try to address the following identified needs of visually impaired people:

- Detection of obstacles in the travel path from ground level to head height for the full body width.
- Travel surface information including textures and discontinuities.
- Detection of objects bordering the travel path for shore-lining and projection.
- Distant object and cardinal direction information for projection of a straight line.
- Landmark location and identification information.
- Information enabling self-familiarization and mental mapping of the environment.

1.1 Thesis content and the differences with other reviews

This thesis is a state-of-the-art review which presents some of the current assistive technology solutions for blind and visually impaired people, based on the relevant research results as they appear in the international scientific literature and commercially available smart stick products.

Among these research papers published in scientific journals or international scientific conferences, etc., six of these works – five review articles and one book – are worth mentioned in this section, to present the main differences between them and this thesis;

I. **Hossain et al, 2011** focus on electronic travel aids (ETAs). This state-of-the-art 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. The devices are chronologically divided in;
   a. Early ETAs
   b. Modern ETAs. For those there are three different tables;
      i. Table 1 summarizes the projects that only use sensors for sensing classifying them according to;
         1. Year
         2. Type of sensor used
         3. Actuation System
         4. Feature of device
      ii. Table 2 summarizes the projects that only use cameras for sensing classifying them according to;
         1. Year
         2. Type of camera used
         3. Actuation System
         4. Features
      iii. Table 3 summarizes the projects that use both sensors and cameras classifying them according to;
         1. Year
         2. Sensing device
         3. Actuation
         4. Features

II. **Elmannai et al, 2017** present a comparative survey of the wearable and portable assistive devices for visually-impaired people including a brief explanation of the systems' use and way of work. Their aim is to address and present most of the issues of these systems to pave the way for other researchers to design devices that ensure safety and independent mobility to visually-impaired people. They make a classification of the systems according to;
   a. Type of the sensors
   b. Accuracy
   c. Analysis Type (Online/Offline/Real-Time/Not-Real-Time)
   d. Coverage (Indoor/Outdoor)
   e. Measuring Angle
   f. Cost
   g. Limitation
   h. Day/Night
   i. Object Detection Range (Max/Min)
   j. Classification Objects (Dynamic/Static)
   k. Used Techniques for Detection, Recognition or Localization

III. **Chanana et al, 2017** review the assistive technology solutions for pedestrians with visual impairment and reveal that most of the existing solutions address a specific part of the travel problem. They separate the systems in two different categories;
   a. Obstacle detection systems. The commercially available of them are classified according to;
      i. Type (handled/cane mountable)
      ii. Information conveyed
      iii. Sensor technology
      iv. User interface
      v. Price

        vi. Special features
    b. Navigation systems.

Later, they present some technologies that are generally found in this kind of devices, without specifying which of them are used in each of the presented aids.

IV. **Ganguli et al, 2016** is a paper that reviews all the considered-significant previous work that has been done for the development of an electronic walking stick for blinds. It deals with all the finalized and implemented work done in this field rather than the developmental and theoretical part. It is very short and it doesn't give enough information about the devices' characteristics. There is a timeline table which classifies the devices according to;
    a. YEAR (when they were presented)
    b. MANUFACTURER
    c. USE

V. **Bujacz et al, 2016** is a review that contains an authored classification of various sonification schemes implemented in the most widely known ETAs. The review covers both those commercially available and those in various stages of research. The systems are separated in two different categories;
    a. Obstacle detectors. A table present their characteristics;
        i. Device input and description
        ii. Sonification summary
        iii. Description (reference)
    b. Environmental imagers.

The structure of this article is similar to that of Chanana et al, 2017.

VI. **Motta et al, 2018** is a chapter of a book about the mobility of visually impaired people. In this chapter the state-of-the-art of ETAs is presented by focusing on their functionalities, hardware architectures, and integration of Information and Communication Technologies (ICT) such as Cloud computing, IoT, and smartphone. The electronic devices are separated in three categories;
    a. Single-Input-Single-Output (SISO) ETAs
    b. Multiple-Input-Single-Output (MISO) ETAs
    c. Multiple -Input- Multiple -Output (MIMO) ETAs

It focuses on the MIMO ETAs making a description of a new concept of such tool, the eETA, with the description of its desired functionalities: obstacle detection, navigation and guidance, and support to environment perception. The third section exposes the current state of the implementation of an eETA, its architecture, and related experimentations. In the last section, its specifications, functions, and implementation are described.

The systems presented here are not classified according to their characteristics. Generally, the form of this chapter makes the paper a little difficult for the reader to distinguish the devices and the characteristics that differentiate or assimilate them.

The main difference between the six review papers and this thesis is that they all present many different kinds of ETAs; wearable or portable, but in this paper we exclusively focus on blind sticks and canes. As mentioned before, the traditional white cane is the most commonly used assistive device from blind and short-sighted people worldwide and thus, this work choose to present only the electronic aids that are based on and use the walking stick. So, if a problem with the device occurs or if the user decides to by him-/herself, then he/she can still use the aid as a conventional white cane. However, other kinds of devices will be rendered useless in case of a problem.

Moreover, this thesis tried to make a better classification of the devices using two tables (one for patents and one for products) with many of the systems' characteristics, while the other reviews make a poor classification or may not make some at all.

Another important difference is that this paper also created a third table which includes all the information about systems' tests and their conclusions, wherever they are mentioned in the corresponding bibliography. Test references were not made in any of the other reviews.

Finally, in this thesis the devices and systems that are presented are the most recent work in scientific literature. Most of them were announced in the last 5 years, while overall we use systems of the last decade. However, the review articles above mention some devices more than two or even three decades old.

To conclude, the main part of the current work consists of an extensive list with the most important and latest blind – cane-based – aid systems. A brief summary for each device is included explaining the operating principle, the well-known techniques and the technologies that being used, as well as the prototype of the system. The characteristics tables and the tests-results table are following to complete the thesis.

2. THE MOST SIGNIFICANT SMART STICKS FOR VISUALLY IMPAIRED PEOPLE PRESENTED IN THE INTERNATIONAL SCIENTIFIC LITERATURE

2.1 Smart Cane (Wahab et al, 2011)

Wahab et al. studied the development of the Smart Cane for detecting the objects and produce accurate instructions for navigation. The Smart Cane was presented originally by Central Michigan University's students. The design of the Smart Cane is shown in Figure 1. It is a portable device that is equipped with a sensor system. The system consists of ultrasonic sensors, microcontroller, vibrator, buzzer, and water detector in order to guide visually-impaired people. It uses servo motors, ultrasonic sensors, and fuzzy controller to detect the obstacles in front of the user and then provide instructions through voice messages or hand vibration.

The servo motors are used to give a precise position feedback. Ultrasonic sensors are used for detecting the obstacles. Hence, the fuzzy controller is able to give the accurate decisions based on the information received from the servo motors and ultrasonic sensors to navigate the user.

The output of the Smart Cane depends on gathering the above information to produce audio messages through the speaker to the user. In addition, hearing impaired people have special vibrator gloves that are provided with the Smart Cane. There is a specific vibration for each finger, and each one has a specific meaning.

Three different voice messages are utilized to alert the user:

No	Voice Message	Distance
1	No object in 4 feet in front of you	Far
2	Objects are between 3 to 4 feet in front of you	Medium
3	An object is right in front of you	Close

The Smart Cane has achieved its goals in detecting the objects and obstacles, producing the needed feedback. As shown in Figure 1, the Smart Cane is easily carried and easily bent. In addition, the water sensor will not detect the water unless it is 0.5 cm or deeper and the buzzer of water detector will not stop before it is dried or wiped. The authors of the paper have some recommendations for the tested system. They stated that in order to monitor the power status, it would better to have a power supply meter being installed. The authors recommended adding a buzzer timer to specify the period to solve the buzzer's issue as well.

Figure 1: The Smart Cane (Wahab et al, 2011) prototype

2.2 RFIWS (Saaid et al, 2009)

A Radio Frequency Identification Walking Stick (RFIWS) was designed by Saaid et al. in order to help blind people navigating on their sidewalk. This system helps in detecting and calculating the approximate distance between the sidewalk border and the blind person. A Radio Frequency Identification (RFID) is used to transfer and receive information through radio wave medium. RFID tag, reader, and middle are the main components of RFID technology.

A number of RFID tags are placed in the middle of the sidewalk with consideration of an equal and specific distance between each other and RFID reader. The RFID will be connected to the stick in order to detect and process received signals. Sounds and vibrations will be produced to notify the user with the distance between the border of the sidewalk and himself/herself. Louder sounds will be generated as the user gets closer to the border. Figure 2 shows the distance of frequency detection (Y) and width of sidewalk (X). Each tag needs to be tested separately due to different ranges of detection.

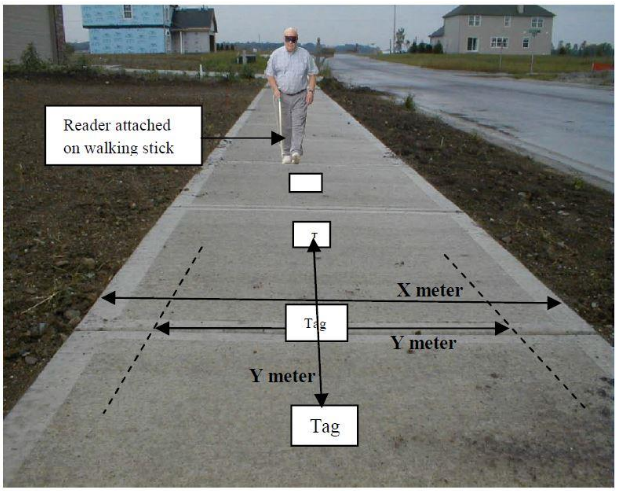


Figure 2: Distance of the RFID detection

RFID technology has a perfect reading function between the tags and readers that makes the device reliable in the level of detection. However, each tag needs a specific range which requires a lot of individual testing, that leads to scope limitation. Also, the system can be easily stopped from working in case of wrapping or covering the tags which prevents those tags from receiving the radio waves.

2.3 ELC (García et al, 2011)

The proposed electronic long cane (ELC) is based on haptics technology which was presented by A.R. Garcia et al. for the mobility aid to the blind people. ELC is a development of the traditional cane in order to provide an accurate detection of the objects that are around the user. A small grip of the cane shown in Figure 3 consists of an embedded electronic circuit that includes an ultrasonic sensor for detection process, micro-motor actuator as the feedback interface, and a 9 V battery as a power supplier. This grip is able to detect the obstacles above the waistline of the blind person. A tactile feedback through a vibration will be produced as warning to a close obstacle. The frequency of the feedback will be increased as the blind person gets closer to the obstacle. Figure 4 shows how the ELC could help the blind people in detecting the obstacle above his waistline, which is considered as one of the reasons to a serious injury for those who are visually-impaired or completely blind.

Figure 3: The prototype of grip

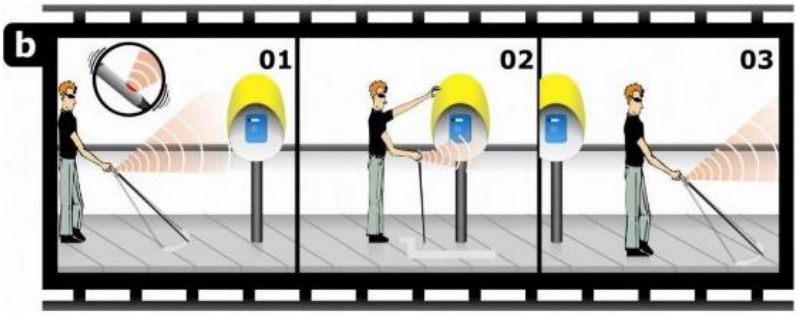


Figure 4: Spatial sensitivity of the proposed device

The ELC were tested on eight of voluntarily blind people. Physical obstacle, information obstacles, cultural obstacles are the main tested categories for the obstacles classification. The results were classified based on a taken quiz by the blind people who used the device. The results showed the efficiency of the device for physical obstacles detection above the waistline of the blind person. However, the device helps a blind person just in detecting obstacles but not in the orientation function. So, the blind person still needs to identify his path himself and relies on the tradition cane for the navigation as shown in Figure 4.

2.4 Ultrasonic Cane as a Navigation Aid (Ultra Cane) (Kumar et al, 2014)

Development to C-5 laser cane (Benjamin, 1973), Krishna Kumar et al. deployed an ultrasonic based cane to aid the blind people. The aim of this work is to replace the laser with the ultrasonic sensors to avoid the risk of the laser. This cane is able to detect the ground and aerial obstacles.

The prototype of this device as shown in Figure 5 is based on a light weight cane, three ultrasonic trans-receivers, X-bee-S1 trans-receiver module, two Arduino UNO microcontrollers, three LED panels, and pizeo buzzer. The target of the three ultrasonic sensors is to detect the ground and aerial obstacles in range of 5 cm to 150 cm. Figure 6 shows the process of the object detection within a specific distance. Once an ultrasonic wave is detected, a control signal is generated and it triggers the echo pin of the microcontroller. The microcontroller records the width of the time duration of the height of each pin and transforms it to a distance. The control signal will be wirelessly transferred by X-bee to the receiving unit which would be worn on the shoulders. The buzzer will be played to alert the user based on the obstacle's approach (high alert, normal alert, low alert and no alert).

Figure 5: The Ultra Cane prototype

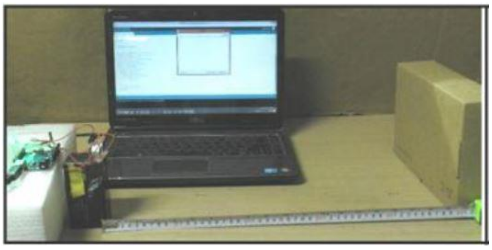


Figure 6: Object detection in range of 5 cm to 150 cm

The authors claimed that this device can be a navigational aid to the blind people. However, the results showed it is only an object detector within a small range. Also, detection of the dynamic object was not covered in this technique which may led to an accident. In order to improve this work, tele-instructions should be giving to the user for navigation aid as well as the integration of GPS which is needed to allocate the user's position.

2.5 A Design of the Blind-guide Crutch Based on Multi-sensors (DBG Crutch Based MSensors) (Yi et al, 2015)

Based on the ultrasonic distance measurement approach, a guidance system for blind people was proposed by Yi and Dong in 2015. The purpose of this system is to blind people in detecting and avoiding the obstacles in front, left front, and right front of the user as shown in Figure 7.

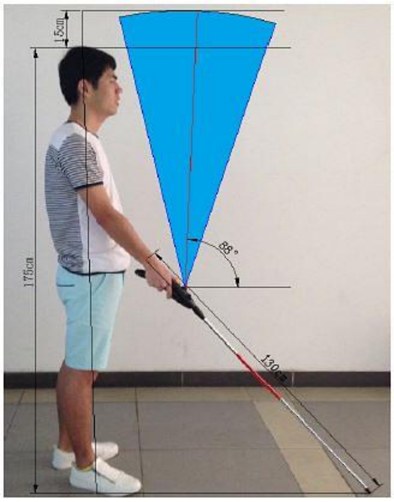


Figure 7: The proposed system and its detection range

Figure 8: The three ultrasonic sensors of the cane

Figure 8 displays the replacement of the three ultrasonic sensors on the cane. The function of these sensors is to collect the distance information from different ranges; the top sensor is used for detecting the overhead obstacle and the other two are used for detection front obstacles. In addition, ultrasonic transmitting and receiving modules, voice and vibration modules and the key to switch between the feedback modules are used in this system. The whole system is controlled by the STC15F2K60S2 microcontroller.

The STC15F2K60S2 MCU controls the signals between ultrasonic Transmit and Receive modules. The travelled times need to be recorded separately such as time1, time2 and time3 as the ultrasonic signal is emitted and the echo signals are detected. If the time counter is larger than the setup threshold, then there are no obstacles presented in that area. Based on the detected distance from the obstacle and the sensor, “the alarm decision making algorithm” produces the warning message either audio or vibration formation.

The system was successful in detecting the obstacle in four directions: front, left front, right front and overhead using three sensors. However, the detection range is small as the maximum range is 2m. Also, the system can be considered as obstacle avoidance system, but not a navigation system as it is claimed. The feedback of this system only consists of warning messages regarding the obstacle location and there were no given directions to proceed forward.

2.6 Smart Cane (Satpute et al, 2017)

The proposed device is used in conjunction with the white cane in order to guide individuals who are blind or partially sighted while, based on ultrasonic sensors, it provides voice alert to avoid obstacles. An emergency button and two switches are added to the system. It is also added a feature known as fall detection which detects the blind person’s status; after he/she gets fall the alert system sends an informational message via SMS to prespecified social contacts with blind person’s location, since that alert system can also track that person’s location. A common Android-based smart phone with an integrated triaxial accelerometer can be used so that the data from the accelerometer is evaluated with several threshold based algorithms and position data to determine a fall.

The system is GSM-GPS based so that it takes the advantage of the GSM network such as the popularity and cost-effectiveness. GSM-GPS module is used for navigation aids to guide visually impaired pedestrians and help VIPs to avoid obstacles and reach their destination. RFID is used in indoor to assist the blind people since GPS can be used efficiently only outdoor. Also, GSM is used to call relatives (switch one) and/or doctor (switch two) of that blind person if the VIP wants to talk and, in case of emergency and panic, to send the panic message with his/her location.

1. **Obstacle Detection:** When any obstacle is detected the system conveys the vocal message like obstacle detected at right, front, left.
2. **Fall Detection:** If the visually impaired person falls down with high velocity, the system sends fall detection message to relatives as well as family doctor.
3. **Panic Alerts:** In some situations he/she might feel that he/she is in an insecure environment. So, he/she can press the emergency button and automatically a message will be send to their relatives.
4. **Stair Detection:** When the person walks on straight road if he/she finds some difficulty or steps then the system automatically informs them vocally.
5. **Calling Switches:** We are providing two different kind of buttons. One button directly calls the family and the other one calls Doctor. If any problem comes then this feature is very beneficial.
    a. **Switch one:** When stick holder presses switch one then by using Android phone the system will help to call a family person which we save through our android application.
    b. **Switch two:** When stick holder presses switch two then by using Android phone the system help to call a family doctor which we save through our android application.
6. **Outdoor Navigation:** By using Google map, the device can provide the outdoor navigation to the stick holder. The directions are given to him/her vocally informing them where to turn or stop and when they’ve rich their destination.

2.7 Electronic Stick (Gurubaran et al, 2014)

In designing the electronic stick, there is used a GPS and GSM system and ultrasonic sensors with Bluetooth earpiece. These devices communicate with each other to provide enhanced security and safety for blind people.

The combination of GPS and GSM technologies might give an extra aid for the blinds. Whenever there is an emergency, the blind people need to press the trigger button which activates the GPS and GSM system. GPS identifies the location of the blind person immediately and is sent to GSM in the form of coordinates. An alert message will be sent along with the exact location of the blind person to the receiver.

For further aid, ultrasonic sensors with voice recognition are also used to detect obstacles. This gives information on the distance range of the obstacle moving across them. Finally for security purpose, thumb print scanner is used which activates the stick when the particular blind people access using their thumb prints. Thus this stick might not be misused by others except the authorized users.

2.8 Blind Stick (Meppurath et al, 2017)

Meppurath et al proposed a solution, represented in a smart stick with ultrasonic sensor to detect any obstacles in front, left and right of the user using ultrasonic waves. Moreover, another sensor is placed at the bottom of the stick for the sake of avoiding puddles. The vibration of motor is activated when any obstacle is detected. The blind stick is integrated with ultrasonic sensor along with GPS & GSM based Navigation/Tracking system. This proposed system uses the microcontroller ATmega 328 embedded system. The stick is capable of detecting all obstacles in the range 4 meter during 39 ms and gives a suitable respect message empowering blind to move twice his normal speed because she/he feels safe. The smart stick is of low cost, fast response, low power consumption, light weight.

On sensing obstacles, the sensor passes this data to the microcontroller which then processes this data and calculates if the obstacle is close enough. If the obstacle is not that close the circuit does nothing. If the obstacle is close the microcontroller then it sends a signal to vibrating motor. Microcontroller also detects Panic Switches Input (Emergency Help Switches) and sends SMS to user Family member with User's GPS location. The GSM module is used for sending the coordinates of blind person on mobile phone via message after GPS sends the coordinates continuously in form of string.

2.9 Voice Stick (Kumar et al, 2017)

The proposed voice stick is used to help VIPs cross the road and reach their destination without any support. It is introduced a new technique to read printed material using Android phone. It's low cost able to serve as a smart blind stick being more efficient and helpful than the conventional one. This will assist the blind people during the walk and provides an alarm if any hurdle is detected within the set range.

If any obstacle or any type of hazard conditions are detected the corresponding alarm alert the user. The proposed device works in both night and day and it is very reliable and effective. The proposed walking stick for the blind may be useful for control and monitoring using ad-hoc network where continuous safety is required. This will assist the blind persons during the walk and provides an alarm if any hurdle is detected within the set range.

There are five sensors namely ultrasonic, infrared, water, fire and light (LDR) which are used for sensing different conditions and depending upon which the processor will update its input and access the output devices as its response to the input. The system is having four different output devices i.e., speech instructor, vibrator, buzzer and flashlight which are accessed in different combinations depending upon different inputs state. If the person is holding this electronic intelligent voice stick while walking it will help him to protect himself from these hurdles such as human, animal or wall, pit or staircase, muddy surface, fire and many others. An easy path finding technology may be used in this device. A low cost microcontroller is useful for this design.

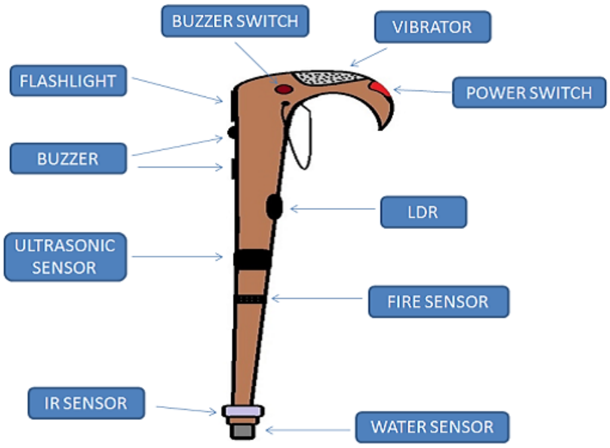


Figure 9: The proposed stick (Kumar et al, 2017) with the sensors' position

The design aim is to provide a low cost smart stick to the blind and partially sighted people. The system overview with its sensors is shown in Figure 9.

Large Obstacle Detection Methodology: Depending on distance of the obstacle from the person four zones are formed i.e., far (safe) zone, near zone, close zone and danger zone. If the detected object is found at far (safe) zone ($R \geq 4m$), the user will be informed through a voice instruction about presence of an obstacle at that distance. If the object is found at near zone ($2m \leq R < 4m$), a voice instruction along with vibrating alert signal will be send to the user. If the object is found close zone ($1m \leq R < 2m$), an emergency voice instruction along with vibrating alert will be send to user. And if object is detected at danger zone ($R < 1m$), a voice instruction to back step along with vibration alert is send to the user and at the same time a buzzer will also ring to let people around know that the person is blind and he needs help.

Small Obstacle Detection Methodology: Small-sized obstacles like pit, staircase or stone, etc. are detected by the IR sensor as it is located at the lower side of the stick. After detecting the small obstacles on ground, IR sensor will send the signal to the processor which will send a voice instruction for small obstacle available on ground and at the same time it will enable the first buzzer for informing the blind person about presence of obstacle on ground.

Muddy Surface Detection Methodology: In order to have precaution against the wet or muddy surface a Water sensor is located at the base of stick. When the Water sensor comes in contact of the wet surface its resistance changes and produced electrical signal which trigger the processor. Immediately, the processor will send a voice instruction for wet surface and at the same time it will enable the second buzzer for informing about presence of wet or muddy floor.

Fire Detection Methodology: In case of an ignited body that is radiating a lot of heat not sensed by the skin properly, a heat sensor is introduced in the stick which is very sensitive to the heat and can detect it from long distance. Also the direction from which heat is radiating can be identified by moving the stick in different direction. If the sensor detects the heat radiation it will send an electrical signal to controller and thus voice instruction will be send to person and at the same time vibrator and first buzzer also start alarming.

Smart Night Lamp: An LDR sensor is used in the Smart stick whose resistances change due to change of the light intensity. During night the LDR will have high resistive (Mohm) path and no current pass through it but through a LED connected parallel with it. Due to this **flow** of large current the LED connected in front of the stick illuminates brightly and acts as a Flashlight which can be easily noticed by others. It alerts the people around about the presence of blind person and thus provides him sufficient space to pass the way.

2.10 Smart Walking Stick (Ikbal et al, 2017)

The system was designed using an Arduino microcontroller board with three ultrasonic sensors and a water sensor. Two ultrasonic sensors were used to detect the front obstacle both on above waist and bottom. The calculated distance value is compared with the pre-defined value and determines whether the obstacle is present or not. By using the travel time, sensor calculates the distance between the sensor and the obstacle:

Distance = (Speed of light * Travel Time) / 2

Another ultrasonic sensor was used to detect manhole on the street or the gap between the stairs; it can detect the hole or the gap between the two stairs as an obstacle if the height of the gap is over 30 mm. Two metal electrodes were used as water sensor; the sensor will detect water on the street, if it's at least 9 mm in height. The stick was made by stillness steel. The shape of the stick was designed in such a way that the ultrasonic sensors can be mounted perfectly[1]. The complete prototype system is shown in Figure 10. The feedback of each sensor is connected to a designated buzzer which provides beep sound to alert the blind people about corresponding obstacle. The buzzer sound was closely monitored to take into account the misinterpretation about the obstacle.

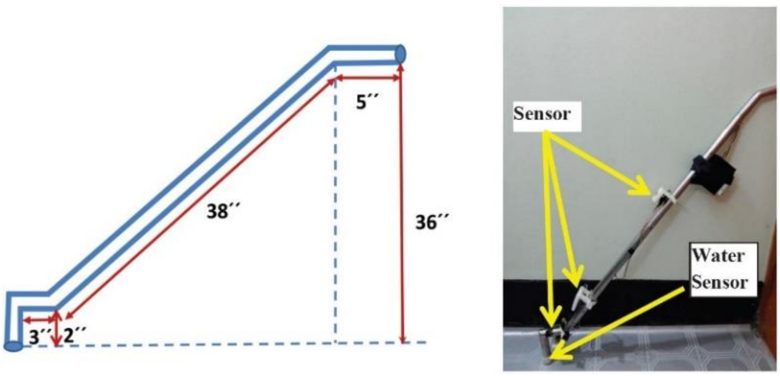


Figure 10: A sketch and a photo of the smart walking stick (Ikbal et al, 2017)

[1] The 3D CAD software was used to design the sensor holder and an Up-Mini 3D printer was used to print the sensor holders which were mounted on the walking stick. Therefore, the sensors were fixed in the right position.

In this system, two ultrasonic sensors were used for detecting front obstacle. One sensor was placed on the bottom of the stick for obstacle of the lower to the waist and another sensor was on the up of the stick for obstacle of upper waist. This is because to cover the total height of the people roughly 7 feet. In this way, a blind person can avoid any accident not only ground obstacle, but also upper obstacle such as door head.

2.11 Electronic White Cane (Niitsu et al, 2012)

A prototype system using ultrasonic ranging described in Niitsu et al. conveys information about the direction as well as distance of the detected obstacle. An ultra-sonic sensor, a gyro sensor, Bluetooth and control circuits are installed on a white cane. Distance between a user and an obstacle can be obtained from an ultra-sonic sensor and direction of an obstacle can be obtained from a compass. Direction of user's walk can be obtained from a compass in a Smartphone. Collected data from sensors are transferred to a Smartphone. Dangerous obstacles which are possible to collide with a user are informed through audio interface, via a bone-conduction headphone.

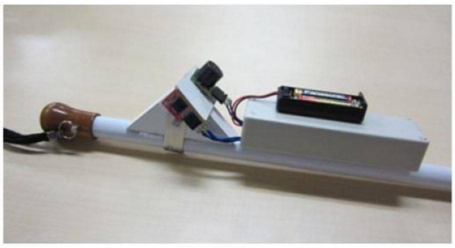


Figure 11: Manufactured Electronic White Cane

The proposed system's method is composed of two phases in order to differentiate motionless obstacles from the moving ones. The first phase decides obstacles in specified dangerous area (defined in detail in the first phase) which visually impaired persons collide with. The second phase discriminates moving obstacles from motionless obstacles among obstacles selected at the first phase. Moving objects are mostly vehicles, people, etc.; they can themselves alter their path to avoid collisions and therefore, the information about motionless obstacles is more crucial. It conveys information about moving objects only when they are at 1m from the user. The system is not capable of protecting upper body from high obstacles.

2.12 EYECane (Ju et al, 2009)

This system is composed of a white cane with embedding web camera and a notebook for processing online video streaming. While a user moving in an unfamiliar environment EYECane receives a live video streaming of 320×240 from web camera, which is processed and analyzed as shown in Figure 12. Firstly, the obstacles are extracted using online background estimation, thereafter occupancy maps sized at 32×24 are made where each cells is allocated at a walking area and it has the different gray levels according the occupancy of obstacles. These occupancy maps are given to path recommendation which estimates possible paths at current position. Here, for robustness to illuminations, weather condition and complex environments, the machine learning using neural network (NN) is used. The system notifies the recognized paths of a user by means of auditory information.

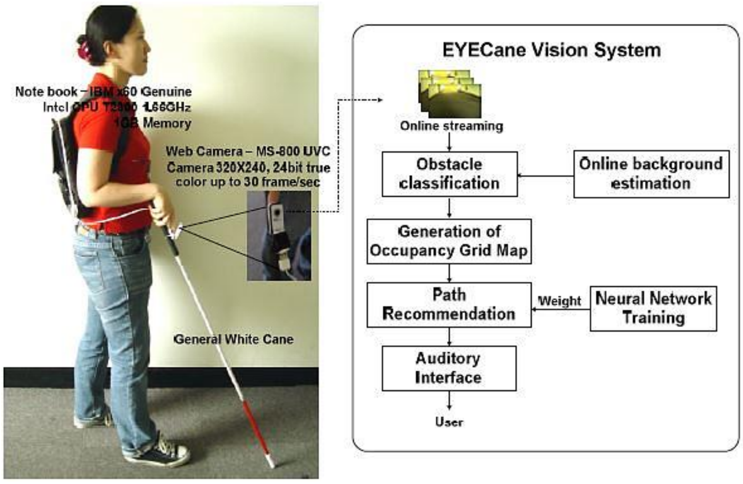


Figure 12: The EYECane (Ju et al, 2009) prototype

The advantages of EYECane include:

1. It is robust to a cluttered background and time-varying illumination, thus is operable in various indoor and outdoor environments
2. It support impaired people with safe mobility in unknown environments
3. It diminish the practice and effort in using.

2.13 MobiFree Cane (Lopes et al, 2012)

The developed cane is capable of detecting holes, drop-offs and steps, designed with the main purpose of improving the mobility of visually impaired individuals. Throughout this work, there was a great concern in the low-power consumption of the device, as well as the overall low cost of a hypothetically final product. The developed techniques for hole-detection rely on pulses of ultrasounds. Photovoltaic solar cells are used to keep the batteries charged so that the user does not need to worry about changing or charging any batteries on a regular basis. Another innovative feature of this cane is related with the increasing visibility and safety provided to the user under dark conditions, especially when crossing streets or in heavy traffic areas. The cane automatically detects the ambient light and decides to turn on or off an array of blinking LEDs along the body of the cane. This enables drivers to recognize the user earlier and better, in order to take the necessary precautions. The MobiFree Cane, when a hole is detected, informs the blind using vibration.

Figure 13: The MobiFree Cane device

2.14 3D Obstacle Detector (Zeng et al, 2012)

Zeng et al. used a 3-D Time of Flight (TOF) camera for detecting objects within a distance of 7m beyond the end of white cane. The system can be used in both indoor and outdoor environments. Camera is mounted on to the waist for capturing precise distance, orientation, and nature of obstacles using a density-based spatial clustering algorithm. This information is presented to the user on a refreshable display using abstract tactile symbols through a portable Braille display.

Two kind of haptic devices are employed to notify users about obstacles. In addition to the tactile display, a hand-held Wii remote controller equipped with a vibrator indicates whether there is an obstacle close-by immediately. To detect many more obstacles like holes and descending stairs, we set up the camera around a user's waist.

In the current system there were implemented two work modes; the first one is inspection mode, and triggered by users (press button "A" on Wiimote) to obtain and present the latest scene when users are at rest, and the other one is walking mode (press button "B" on Wiimote) to automatically monitor the environment for obstacles while walking. The users can change conveniently between both of them at any time. The walking mode will be interrupted and the Wiimote will be vibrating while some obstacles are closer than 2 meters, and then warn users by the Wiimote and the Braille display.

2.15 The Sesamonet System (Faggion et al, 2011)

The Sesamonet technology is based on a path constituted by passive low frequencies RFID transponders. The unique identification (UID) number of each transponder is stored in a database that links the user position to an acoustic informative message that helps the user to safely reach its destination. Along the journey an electronic customized stick reads the RFID transponders installed in the ground and transmits the received identification number to the PDA/Smartphone running the Sesamonet software. The application receives the transponder UID through a Bluetooth connection established with the electronic cane.

The software also manages the navigation logic and plays the audio messages on a Bluetooth (or wired) earphone in order to guide and inform the blind person along its journey. The information mainly describes the path and the eventual dangers that the user can incur into along his way but it also includes notions concerning the services and public utilities that can be found nearby.

The system can interact automatically with different electro-mechanisms available in an urban environment: for example it is possible to automatically call the green light at a pedestrian crossing or activate an automated gate such as the ones available in some subways or railways stations. It is also possible to interact with electronic public-transport timetables getting real-time information about transport services available in the area. These kind of communication and interactions between the automated services available in the cities and the Sesamonet system can be set on a Wi-Fi local network, a Bluetooth connection.

In case the portable device used by the blind person embeds a GPS receiver, it is possible to combine the navigation information provided by the Sesamonet system with the one given by the satellite geo-localization: in case the user moves too far away from any tag and cannot receive information from the Sesamonet system, the GPS can guide the person back to the transponders clear path.

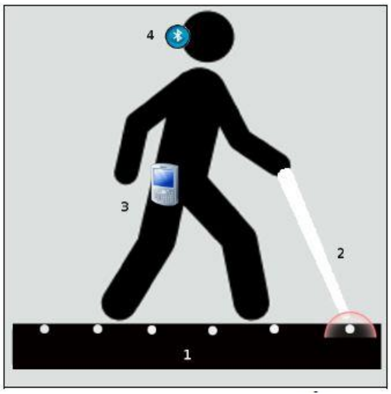


Figure 14: Sesamonet system components; 1. Low-frequency RFID passive transponders path, 2. Sesamonet electronic white cane, 3. Smartphone/PDA, 4. Bluetooth or wired earphone.

2.16 The EyeCane (Buchs et al, 2017)

The EyeCane can be used as a primary device, i.e. stand-alone, or as a secondary device, i.e. mounted on a white-cane.

It instantaneously (50 Hz) transforms distance information via sound and vibration, such that the closer an object is to the user, the stronger the vibration of the haptic actuator and the higher the frequency of the auditory cues. It was adapted to include two narrow infra-red (IR) sensors, a sensing range of 1.5 m, such that one of the sensors was directed straight ahead while the other was directed approximately 42 degrees up (Figure 19A). Each of the sensors conveyed its output via a unique modality, audio or haptic.

The EyeCane can be used either as a stand-alone device or mounted on a white-cane. In the condition where the EyeCane is mounted on the white-cane (Figure 19B), the tactile output reaches a wrist band through cables connected to the device; this was done to reduce confusion between the vibration of the EyeCane and that coming from the white-cane's contact with the floor. In both conditions, stand-alone and mounted, the audio information reached the left ear via bone-conductance headphones.

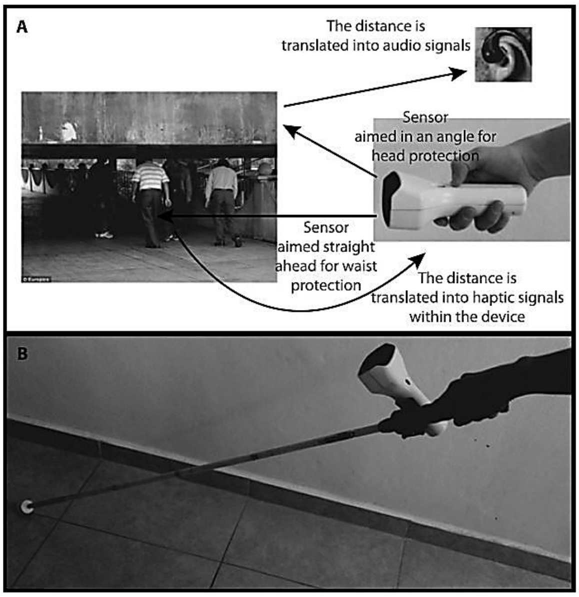


Figure 15: The EyeCane as: A. primary device and B. secondary device

2.17 White Guide (Agarwal et al, 2017)

This proposed smart product can be attached to white cane. White cane will help the user with obstacle detection, real time location tracking of the blind, support intimation in case of emergencies and some voice control features. It consists of various ultrasonic sensors to perceive the environment and give haptic feedbacks. The product connects with an Android application via Bluetooth. The device would not only cater features such as obstacle detection but would also help in case of emergencies and that would be fulfilled by the smart cane app.

The real-time location of the user can be mapped through the cane using the user's GPS system to give feeds to the support's mobile phone application. Real time location would be triggered in two cases, either when the user passes the SOS button on the cane or when the support tracks the user in the application itself.

Apart from SOS button, other peripherals such as Power Button and call button have their own functionalities. Power button switches the device On/Off. Call button on the other hand helps the user connect to the support in much less time and also helps the user connect or disconnect any incoming call.

A long-lasting battery would be installed in order to support all the embedded systems and their peripherals.

2.18 Smart Cane (Vineesha et al, 2016)

This smart cane for blind is a system which uses the biometric authentication such as face identification. The system is intended to provide an artificial vision to the user about the environment by identifying the friends and relatives in real time. If the cane recognizes the faces of known people, it will inform the blind about the person through voice signal. The face detection is done by Haar cascade classifier. The face recognition is performed by Principal Component Analysis (PCA).

The system works when the person is frontal with respect to the camera. The database contains certain images and once a face is recognized, the system informs the user through the voice signal.

The camera takes the images of the people in front of the blind. These images are then given to the Raspberry Pi module for further processing. The face detection module detects whether the image contains a face or not. If yes the image is undergone to the face recognition module. The recognition module performs PCA with the images stored in the database, if a match occurs it informs the blind who is the person is. Otherwise discard the image.

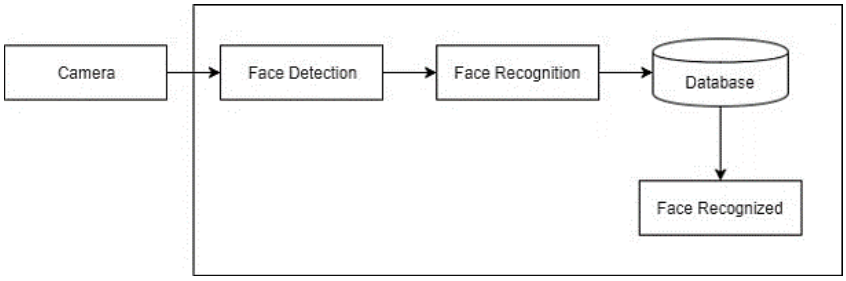


Figure 16: The block diagram of the Smart Cane (Vineesha et al, 2016)

2.19 Smart Cane (Tajimidi et al, 2013)

Tamjidi et al presents a 6-DoF[2] pose estimation method for a Portable Navigation Aid for the visually impaired. The navigation aid uses a single 3D camera – SwissRanger SR4000 – for both pose estimation and object/obstacle detection. The SR4000 produces both intensity and range images of the environment in its field of view. The range data is processed for object/obstacle detection; and both the range and intensity data are used by the Visual-Range Odometry (VRO) to determine incremental pose change and eventually the device pose in the world coordinate. Since the camera's y coordinate may be measured as the distance between the camera and the floor plane, it is used as an additional observation in this work. Experimental results indicate that the proposed pose estimation method results in accurate pose estimates for positioning the visually impaired in an indoor environment.

The proposed pose estimation method is used as an indoor GPS system for position estimation of the visually impaired. The pose estimates may also be used for 3D map-building to support obstacle/object detection and help the visually impair move around. The proposed method can also be used by a mobile robot for pose estimation.

In the Smart Cane, a handtop computer (worn by the user) is used for data acquisition and processing.

[2] **Six degrees of freedom (6DOF)** refers to the freedom of movement of a rigid body in three-dimensional space. Specifically, the body is free to change position as forward/backward (surge), up/down (heave), left/right (sway) translation in three perpendicular axes, combined with changes in orientation through rotation about three perpendicular axes, often termed yaw (normal axis), pitch (lateral axis), and roll (longitudinal axis).

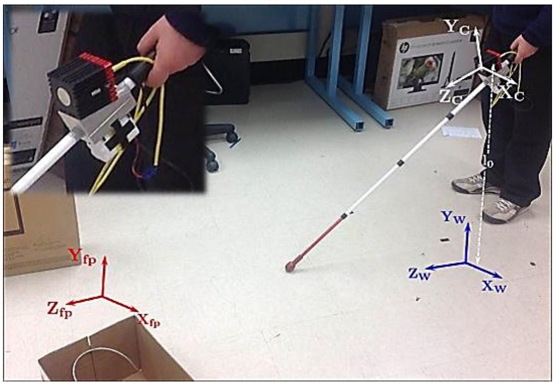


Figure 17: The Smart Cane prototype and its sensor installation and coordinate systems: the camera, floor plane and world coordinates are denoted by subscripts C, fp, and W, respectively.

2.20 Walking Stick (Selvanayagam et al, 2016)

This system will be able to detect the obstacle present in various directions with a single sensor. As alerting mechanism, two vibrator motors and a buzzer are used to let people know in which direction the object is present. One of the vibrator motors is placed on the arm and the other motor is to be worn on the fingers of the person as a ring.

The sensor reading is monitored regularly while the motor rotates, in a programed speed, for 180° to and fro. When an obstacle is detected, the motor is stopped immediately. The degree where the motor halts is noted, the range is considered, and accordingly, the corresponding vibrator is triggered. If the range attains a much lower value than the programed value, the buzzer is triggered. Until this point, the motor is made to be still, and after a provided delay time, the motor is switched on again. If the patient is in a closed environment, the sensor range need not be higher as the objects are nonmoving unlike an open environment where the objects are moving, and in some cases, they might be fast as well. Hence, this system is provided with two modes which can be swapped based on the environment. In one mode, the range is lower, and in the other, the range is programed to be higher.

The proposed system works efficiently when tested in various conditions. It is found to be cost-effective and the safety of the user is satisfactory. The system is reliable and fast with a minimized mechanism used. The two modes of the system assure more safety, which is very useful for the users to maneuver through any kind, both close and open environment.

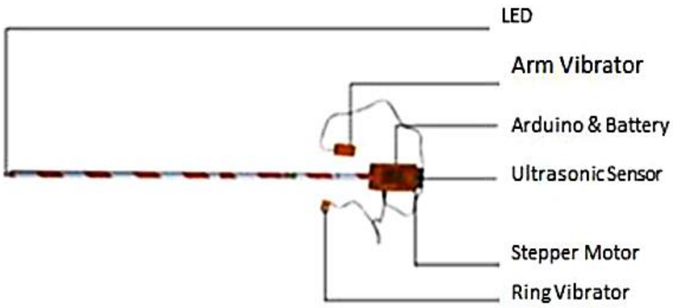


Figure 18: The design of the proposed walking stick

2.21 Clever Cane (Messenger Harry, 2016)

The CleverCane attempts to sense objects and detect gradients to provide an early warning, vibration-based communication mechanism to notify blind and partially sighted people of objects in advance of the traditional notification of the white-stick cane. It uses ultrasonic sensors and a Seeeduino v3 microcontroller.

The primary objective of the CleverCane project was to augment an existing white cane to sense obstacles. The secondary aims of this project were to provide additional functionality to the cane, dependent on the wishes of the users, to provide an early warning notification for detected obstacles and to provide a functional control system accessible to blind users of the cane.

The CleverCane connects with smart phone through Bluetooth. The user can change the band settings, by using the Phone App. The smart cane can also send notifications to the vibrating band, via the app. Finally, the app itself can configure and authorize with the servers, automatically.

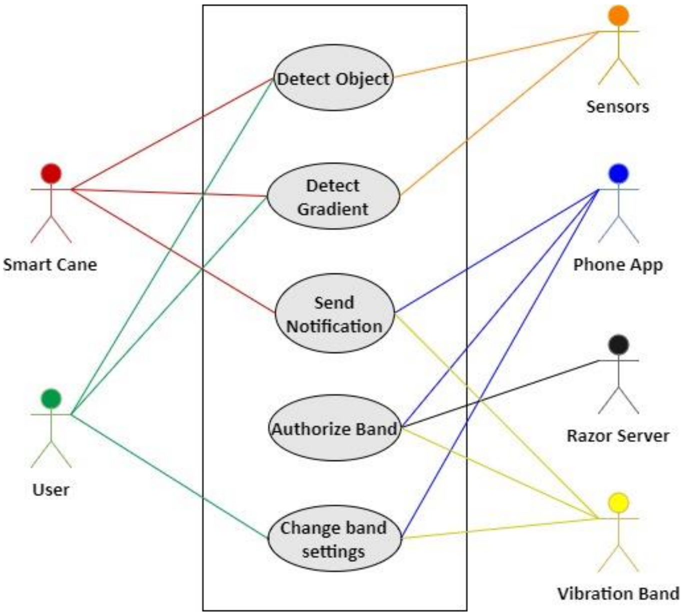


Figure 19: The Use Case diagram for the CleverCane system

The cane provides a tactile set of notifications via a wearable wristband. This alerts the user to early warnings of potential obstacles, as well as gradient changes. This wristband is composed of an existing watch and then three grove devices, two vibration motors and a switch, all mounted with elastic bands.

The CleverCane prototype is shown below. Highlighted are some of the main features of the cane.

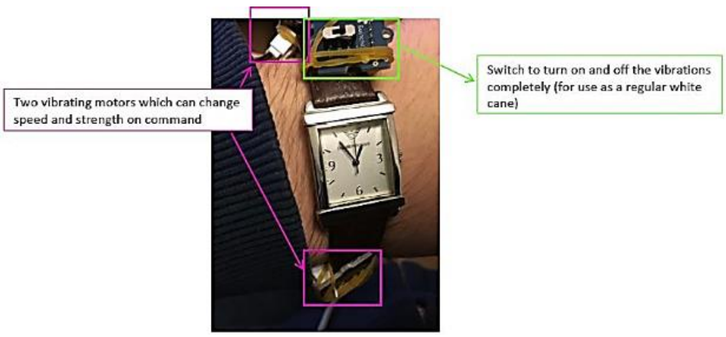


Figure 20: Picture of the Wristband

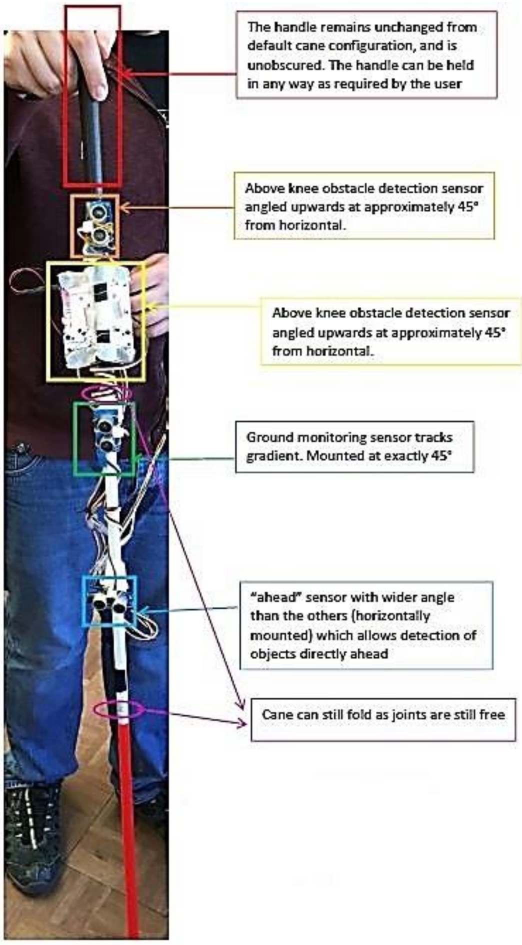


Figure 21: Picture of the CleverCane

2.22 AKSHI (Kaushalya et al, 2016)

The motivation of the system is to help blind people where they can move along without a dependent. AKSHI composes some unique features such as obstacle detection, pedestrian crossing identification, voice commands detection, outdoor navigation system and a tracking system with the use of Global Positioning system (GPS), Radio Frequency Identification (RFID), Android, and Global system for mobile communication (GSM) Technologies. This research has been developed by user friendly and cost-effective manner with the use of open source software and Hardware devices like Raspberry pi circuit, RFID Reader etc.

Once the device gets started it is capable of detecting obstacles, identifying pedestrian crossings, and if the user gives a place name, with the use of GSM module device communicates with the Google maps API and calculate the route from the current location and give the directions to the user. Location details are stored in a server and guardian can view the current location of the user with the use of AKSHI tracker mobile application.

Figure 22: AKSHI device model

Figure 26 shows the model of the AKSHI device which is combined with the circuit. At the bottom of the stick, RFID reader is placed which can detect pedestrian crossing through RFID tag and, below the circuit box, a sensor is placed in order to detect obstacles. There is a box placed in the stick which contains all the circuits including Raspberry pi, GSM, GPS Modules.

2.23 The Smartcane (Hussain et al, 2016)

The Smartcane is a smart white cane based on a micro-controller AT89C52. The system accompanied a portable unit that can easily be carried and operated by a visually impaired user. It could easily be incorporated into a walking cane. The salient features of the developed prototype are ultrasonic sensor for obstacle detection, water probe for mud and water detection, IR for ditch detection, GPS, GSM module, signal-to-speech module, speaker or headset, and portability (size and power).

“The Smartcane” functions like ordinary blind canes. The difference is that the Smartcane is equipped with ultrasonic sensor, water sensor, GPS and GSM modules as shown below. Also the cane is designed to be foldable so that it is easy for the user to keep and handle.

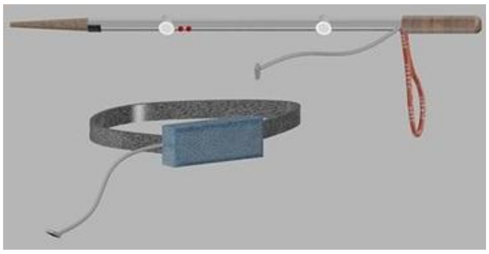


Figure 23: The Smartcane and belt modules

All the sensors are mounted on the stick and all the hardware circuitry are embedded in a belt pack that is clipped on the waist of the user. So the hardware design is then divided in two major parts; one is the stick and the other one is the belt pack.

1) **Stick:** The stick is 3’ft long, 0.75” inch diameter, carbon fiber body with ergonomic handle and a wire strap of rubber. There are three types of sensor mounted on the stick. First is ultrasonic sensor. Second is the Infrared (I.R.) sensor and the third one is the mud sensor. The ultrasonic sensor is placed on the height of 1 ft. and the I.R. sensor at height of 0.5ft and at the base of the stick is mud sensor.

2) **Belt Pack:** The belt pack contains all the circuitry that includes main controlling circuit, sensor circuits, GSM module, GPS module, Speech module and speaker along with headset. The circuitry and sensor are connected via connector.

2.24 Medico-Stick (Shrivastava et al, 2015)

The device includes a DTMF (Dual Tone Multi Frequency) device with ultrasonic, pulse and enlite sensor and a vibration motor. The whole system is designed on hollow steel rods with small sized buttons that works for specific set of sensors to be utilized by user. Whenever an individual using that stick meets with any critical situation from an accident to fluctuations in their blood-pressure rate, a subsequent alert will be sent to the concerned party also the inbuilt GPS within the stick will be activated enabling the location. An AT89S52 microcontroller is used.

The stick performance is judged in two aspects, firstly for the cases when a person is out of its home and secondly when he wants to perform a daily check-up of his body responses like Diabetes checkup or heart rate checkup in his home.

When the user is outside, the ultrasonic sensor, which will be continuously detecting any obstacle or vehicle under the range of 10m, will indicate the presence of any obstacle thus giving an interrupt which will initiate the vibrator motor that will warn the user. Also, after continuous check, the pulse sensor will be detecting the pulse of the user and after a particular threshold the sensor will generate an interrupt which will be further connected to DTMF module thus informing the relative of the user that he/she is in danger. When the device will be used indoors, the user can check his/her sugar ratio in the body as well as his/her heart rate which will be further connected to buzzer.

Shrivastava's et al work in this research has used the idea of piezo electric crystal, which converts the pressure generated at the end of stick to the electricity which latterly used for the recharge of the applied power supply.

2.25 Infra-Red Sensor Based Smart Stick (Nada et al, 2015)

This design represents the light-weight, cheap, user friendly, fast response and low power consumable blind stick based on the infra-red technology. A pair of infra-red sensors can detect stair-cases and other obstacle present on the path within the range of 2m and send data to a 16F877A microcontroller. The experiment results achieve good results and comparatively straight result. Though the battery life is comparatively poor-resulting in 4hrs of usage only, it focuses on every targeted problem and can be used indoors due to installation of IR sensors. It is connected to an earphone in order to alert the blind with speech warning message about the detected obstacles.

The horizontal sensor was able to detect high level obstacles, whereas the inclined sensor was able to detect the low level obstacles on floor and stairs case. Additionally, it can identify the type of the stairs (upward and downward) and appropriate message are played back through the earphone. The feedback from the real test was positive because all of obstacles can be detect although the avoidance accuracy was ranging from 75% to 90%.

2.26 Blind Walking Stick (Dhoot et al, 2016)

This cane is useful for navigation and obstacles such as fire, water i.e. slippery area detection, providing the solution of many problems that blind people face indoor as well as outdoor. There are also used GSM and GPS systems for finding the location and sending message to the relatives of blind people. The ultrasonic sensor is used for detection of obstacles which is coming in front of blind person using this stick, the fire sensor is used for detection of the fire and water sensor is used for detection of slippery area using two probes. GSM and GPS are used for the location detection and sending the message to the number which is already saved in programming. The Microcontroller used here, is the Atmega 328.

The main objective is to assist blind or visually impaired people to safely move among obstacles and other hurdles faced by them in their daily life. Using this guiding system, the blind people can travel in the unknown areas independently. Also less training time period is required to use this smart system. This solution is a low cost and user friendly navigational aid for the visually impaired and blind person.

2.27 Smart Electronic Travel Stick (Dhal et al, 2016)

The hardware of this Smart Electronic Stick for the visually impaired consists of a microcontroller integrated with Arduino Uno board, ultrasonic sensor, GPS module, GSM module, serial driver, buzzer and other additional equipment. The sensors used in this model provide information about the outside environment. GPS Technology is integrated with pre-programmed locations and it is sent to the desired number through GSM module when required. This presents a design and a system concept to provide smart electronic aid for blind people. The aim of the overall system is to produce an economic and productive navigation aid for the visually challenged which can give them a sense of artificial vision and object detection by providing information about the environmental scenario of static and dynamic objects around them. Ultrasonic sensors are used to detect obstacles from a distance so as to guide the blind person in the right path.

In the prototype that have been designed, the brain of the system is Arduino Uno. Modules like GSM Module, GPS module, ultrasonic sensor and water sensor are interfaced with the Arduino. 12 volts battery supply is provided. After getting the supply, the circuitry elements get on. The ultrasonic sensor triggers a SONAR wave within a distance of 3 meters. It continues its search for obstacles. At the same time, the GPS module continuously retrieves data regarding the location from the satellites. If an obstacle is detected, then the Arduino commands the buzzer unit to beep so as to alert the user. It beeps for 3 seconds. If the user is not concerned, then the codes are written in such a manner that the near person of the user will get a short message service. A water sensor is also present there that detects the presence of water on road and alerts the user by beeping the buzzer connected with it.

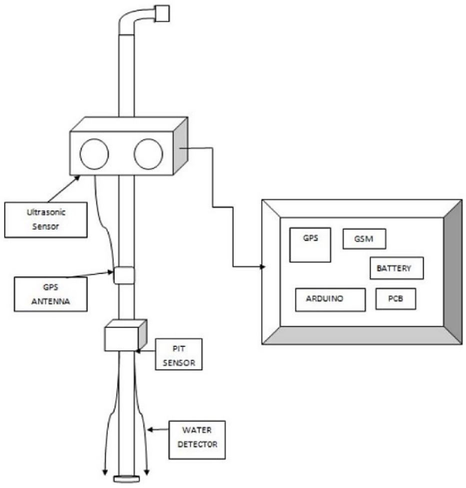


Figure 24: Sketch of the final Smart Electronic Travel Stick (Dhal et al, 2016)

2.28 Advanced Blind Walking Stick (Dabhade et al, 2016)

The system is intended to provide overall measures to detect the obstacles. The aim of the overall system is to provide an efficient navigation aid for blind which gives a sense of artificial vision by providing information about the environmental scenario of static and dynamic objects around them. All the sensors are used to detect the obstacles and to guide the user towards the available path. Output is in the form of voice which the blind person can hear through Head Phone. GPS is employed to find the position, velocity and time of user. By using GSM system an automatic message will be sent on the saved number when the user is in danger.

Four sensors are used in this system: ultrasonic sensor, water sensor, temperature sensor and light sensor for detecting various obstacles. The last two of them combined work as a fire sensor, too. Bluetooth technology is used for getting the stick in case it gets misplaced. A switch is given to the user by which he/she is able to find the stick. All the programming is inserted in the AT Mega 328 microcontroller.

The ultrasonic sensor is used to detect the obstacles in the path of the blind person. The obstacle may be vehicles, walls or anything which comes in front of ultrasonic sensor. The water sensor consists of two probes as a sensor. The fire sensor is used in combination with the LDR and IC LM35. The Light Dependent Resister (LDR) by itself is used to detect the light or darkness in the room. If an obstacle is detected by the sensors, then the controller sends a signal to the user through head phone.

2.29 Ultrasonic Blind Walking Stick (Bunnan et al, 2016)

This product is based on the distance measurement property of sensors. It will measure the distance and velocity of the obstacle in the way of the person and will alarm the person about any obstacle (moving/stationary). The stick will allow detection of obstacles on the ground, holes and pits, uneven surfaces, steps, and other typical obstacles in the path of the person. Since the device is incorporated with wireless module it will be very handy and will be much easier to use as compared to the similar products available in the market. The Ultrasonic Blind Walking Stick is fully automated, comfortable to use and cheap.

The stick is integrated with an ultrasonic sensor along with water (level sensor) and light sensor (LDR). The ultrasonic sensor detects the obstacles ahead with the help of the ultrasonic waves and passes the data to the microcontroller PIC18F4550. The microcontroller further processes the data and calculates the distance. When an obstacle is detected, it sends the signal to the buzzer to alarm the user. It also detects and buzzes a different alarm if the stick enters water. The blind is alerted with one more different buzzer if he enters a light or a dark room. This system also has an intriguing feature to help the blind user to find their stick, if it gets misplaced. A normal TV remote control is used for this purpose.

The features of the Ultrasonic Blind Walking Stick are briefly presented here:

1. Entirely automated.
2. Can be maintained & operated easily.
3. Very comfy to function.
4. Authentic & Durable.
5. Low power consumption.
6. The Microcontroller can be code protected.
7. Simplicity of the design makes it effective navigation assistant.
8. Wet or muddy or potentially slippery terrain can be detected by a pair of electrodes.
9. Overall manufacturing cost is low & parts are available in both local & international market.

2.30 The Eye-Cane (Maidenbaum et al, 2014)

The "Eye-Cane" is an ETA for the blind which translates point-distance information into auditory and tactile vibrations. The device provides the user distance information simultaneously from two different directions: directly ahead for long distance (5 m) perception of the environment and detection of waist height obstacles, and towards the ground at a 45◦ angle for detecting nearby ground level obstacles (1.5 m). This information is conveyed to the user using different auditory frequencies and different tactile actuators (in contact with the thumb for ground level obstacles and with the wrist for waist level obstacles).

Each of these directions is detected via a dedicated pair of infra-red (IR) emitters and sensors. The emitters emit narrow directional beams at different frequency ranges. The reflected signal is then detected by phototransistors sensitive to the emitted IR wavelengths. The signal is translated into sound frequencies and/or vibration amplitudes and frequencies, enabling instantaneous feedback to the user such that the closer an object is to the user the higher the frequency of the auditory cues and the stronger the vibration.

The multiple sensors, aimed in different directions and with different distance sensitivities, simultaneously enable both detection of near-ground-level obstacles and waist-level obstacles several meters ahead, thus providing upper body protection and a general perception of the upcoming five meters, such as locating open doors on the other side of a room.

These innovations join a series of design considerations, including decreased size (4×6×12 cm) and weight (<100 g) which enable it to be easily held and pointed at different targets while increasing battery life (>24 h of use).

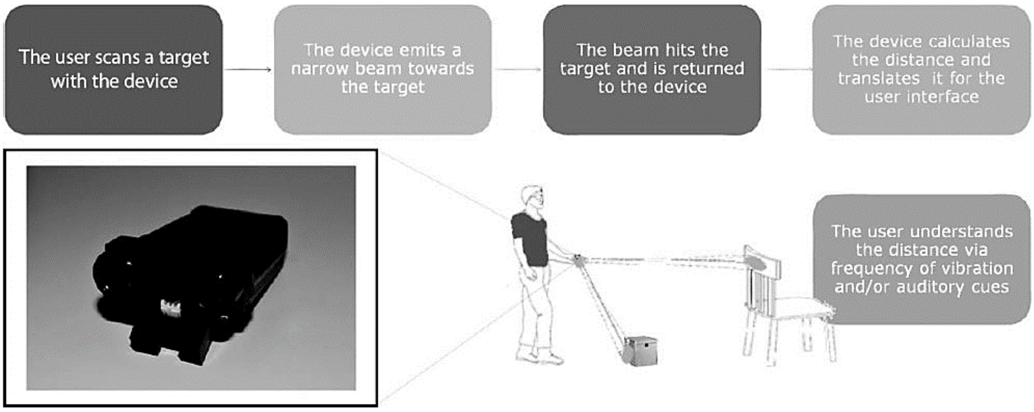


Figure 25: Picture of the Eye-Cane and a flow chart diagram of its use

3. COMMERCIALLY AVAILABLE SMART STICKS

3.1 The Ultra Cane (Sound Foresight Technology Ltd)

This device is modelled on the traditional long-white cane, and modifies the premise by adding two ultrasonic transducers to the handle of the device. The Ultra Cane detects obstacles within 2 or 4 meters (depending on which setting is used) and it does this by emitting ultrasonic waves from two sensors. It also detects up to 1.5m ahead at chest/head height, giving tactile feedback to the user through two vibrating buttons on the handle over which the user places their thumb. These buttons can vibrate at different frequencies and between this and the combination of the buttons allows an idea of distance and direction of the detected obstacles. The Ultra Cane is available on the mass-market in the UK and the EU, and distribution is handled through their own website, as well as through the blind society “Action for Blind”.

The main negative of the Ultra Cane is the price – costing £635.00 in the UK. This is vastly more expensive than other options abroad, but has an almost-monopoly on the very limited UK device market.

Figure 26: The Ultra Cane (Sound Foresight Ltd)

Figure 27: The cane handler of the Ultra Cane

3.2 The Smart Cane (The academia-NGO-industry partnership)

Smart Cane device is an electronic travel aid which fits as handle of the white cane. Smart Cane compliments its functionality by detecting obstacles from knee to head height. It also uses ultrasonic ranging for obstacle detection and distinct tactile vibratory patterns for conveying distance information. The vibrations can be felt on the entire grip that allows the user to conveniently grip the device. This device allows adjustment of the sensors at one of three positions according to height and gripping style of the user to ensure reliable detection of obstacles at different heights. Unlike most of the other devices, it comes with internal rechargeable battery and can be charged just like a mobile phone while it can be used in both indoor and outdoor navigation modes. It has been designed to accommodate varying types of user grips which are commonly used by visually challenged. Another high point of this technology is that it is extremely affordable. At present, there are nearly 10,000 users of this device in India.

Figure 28: The Smart Cane (The academia-NGO-industry partnership)

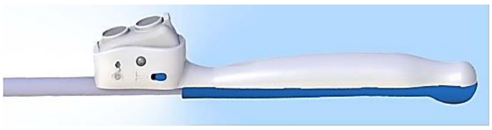


Figure 29: The cane handler of the Smart Cane

3.3 SmartCane Phoenix (Phoenix Medical Systems)

SmartCane is an electronic aid that fits on the top of a standard white cane and warns the user about the presence of obstacles between knee and head height. It uses ultrasonic sensors to detect obstacles within a distance of 3 meters and conveys information about the distance through distinct vibratory patterns.

SmartCane is easy to use. With basic training and orientation, any person with visual impairment who uses a white cane regularly, can use the SmartCane effectively.

Free self-learning resources for SmartCane are available in multiple regional and international languages, supplies along with the device but also found online. A Braille manual is available on request. Face-to-face training is provided by Saksham Trust and more than 50 partner organizations across India and many other countries.

Figure 30: The grip of the SmartCane

3.4 BAWA Cane (BAWA)

BAWA Cane is engineered to give reliability and safety in an assistive device, with the connection to mobile phones and wearable devices that enhance user's overall experience when moving around with a white cane.

This cane is scrupulously engineered to detect and alert the user of above knee level obstacles up to 1.2 meters above the waist, objects as small as 25.4 millimeters on the ground and steps or sudden drops as small as 25.4 millimeters. Battery level are conveyed to the user each time the BAWA Cane is turned on and alert warnings are given when battery level is low. It also sends alert signals when its orientation is wrong and, if it is dropped, it beeps till picked up.

BAWA Cane mobile app ensures the user will reach his/her destination safely with voice over navigation. An intact in-app integration to taxi services and ride sharing app is integrated to help the blind person reach his/her destinations beyond walking distance. As of now, BAWA Cane via the mobile app is integrated with Uber. In case of emergency, VIP's loved ones and medical assistance personnel will be informed with a click of a button or by voice command.

BAWA Cane band app empowers user with an easier access to the emergency alert button to immediately send SOS signals to relatives and medical assistance personnel. There is also haptic feedback on user's wrist.

Figure 31: The BAWA Cane

Figure 32: The BAWA Cane

Figure 33: The BAWA Cane with a mobile and the wearable device (wrist band)

3.5 Ultrasonic Blind Walking Stick (NevonProjects)

Blind stick is an innovative stick designed for visually disabled people for improved navigation. It is an advanced blind stick that allows visually challenged people to navigate with ease using advanced technology. The blind stick is integrated with ultrasonic sensor along with light and water sensing. The proposed project first uses ultrasonic sensors to detect obstacles ahead using ultrasonic waves. On sensing obstacles the sensor passes this data to the microcontroller. The microcontroller then processes this data and calculates if the obstacle is close enough. If the obstacle is not that close the circuit does nothing. If the obstacle is close the microcontroller sends a signal to sound a buzzer. It also detects and sounds a different buzzer if it detects water and alerts the blind. One more feature is that it allows the blind to detect if there is light or darkness in the room. The system has one more advanced feature integrated to help the blind find their stick if they forget where they kept it. A wireless rf based remote is used for this purpose. Pressing the remote button sounds a buzzer on the stick which helps the blind person to find their stick. Thus this system allows for obstacle detection as well as finding stick if misplaced by visually disabled people.

3.6 I-Cane Mobilo (I-Cane Social Technologies)

The I-Cane Mobilo is a white cane with advanced detection and navigation technology. It combines obstacle detection and GPS navigation and provides tactile feedback. To obtain a working unit, the user must also have an iOS (iPhone 4S and later, iOS 7.0 and later) or Android (version 4.2) smartphone with the app "GO I-Cane".

The I-Cane Mobilo has a stronger grip than an ordinary white cane. The grip contains the battery, the necessary electronics and a vibrating and rotating feel arrow. The vibrating and rotating feel arrow, at the height of the index finger, indicates the direction in which to run as a planned route were calculated by the app and warns the user of an obstacle. A kind of radar detector that can detect obstacles at shoulder level is integrated so that the user does not run against them.

If the user lost his orientation, the app via audio information can help them find where they are. It is also possible to send a help message with location coordinates via an emergency button to a healthcare provider or caregiver.

At the bottom of the pole there is a jumbo roll of 55 mm for scanning. The length of the pole is adjustable between 98 and 135 cm or between 110 and 164 cm and, in normal use, the battery lasts at least 8 hours.

4. THE CHARACTERISTICS OF THE DESCRIBED DEVICES AND PRODUCTS

In this section, table 1 and table 2 enlist the characteristics of the devices/patents and the commercially available smart sticks for visually impaired people respectively. The characteristics, according to which the canes are classified, are showing and explained below, as well as some of the tables' field values.

Explanation of the fields in the header row of the two characteristics tables:

h5-index: [Only in table 1] Journal h-index is a measure of the quality of a journal for articles published in the last 5 complete years and can be calculated using data from Web of Science, Scopus or Google Scholar. As with the impact factor, journal h-index does not take into account differing citation practices of fields and so is best used to compare journals within a field.

Journal IF: [Only in table 1] The Impact Factor (IF) of the journal where the article about the device was published. If the article was not published in a journal (e.g. conference, symposium, etc.) the field is filled with —.

Coverage: The device can be used Outdoor, Indoor or (both:) Outdoor/Indoor.

Time: The device can be used in Day, Night or (both:) Day/Night.

Range (meters): How far (in meters) in front can the obstacles be detected by the device.

Connection Type: The type of connection (Wi-Fi, Bluetooth, etc.) needed for the device. If not any connection is needed, the field is filled with —.

Cost: The cost of the device.

User Interface: How the user interacts with the device. It also includes the capability of sending messages to others through GSM technology, wherever it's possible.

Environment Interface: How the devices/technologies, used for obstacle detection, interact with the environment (e.g. ultrasonic/radio waves, IR spectrum, etc.)

Obstacle Detection: What kind of devices/technologies are used to detect objects (sensor/-s, camera, RFID, etc.).

Navigation & Tracking System: The kind of navigation-tracking system that is used. If there is such system but its kind is not specified, the field is filled with ✓. If no such system is used, the field is filled with —.

Sensors: What kind of sensors are used. If not any sensors are used, the field is filled with —.

Microcontroller: What kind of microcontroller is embedded to the device. If there is a microcontroller but it's not specified, the field is filled with ✓. If the device does not have a microcontroller, the field is filled with —.

Explanation of field values in the two characteristics tables:

N/A: Not mentioned / the information is not available.

—: Does not exist.

✓: Exists but is not specified.

Table 1: Characteristics of described devices / patents

Device	h5-index	Journal IF	Coverage	Time	Range (meters)	Connection Type	Cost	User Interface	Environment Interface	Obstacle Detection	Navigation & Tracking System	Sensors	Microcontroller
MobiFree Cane (Lopes et al, 2012)	39	—	Outdoor	Day / Night	Short R ≤ 1	Online	Low	Vibration LEDs (to indicate the VIP to others)	Ultrasonic Waves	Ultrasonic Sensors	—	Ultrasonic Sensors	TI low-power microcontroller MSP430
The EyeCane (Buchs et al, 2017)	27	2.526	Outdoor / Indoor	N/A	Medium R ≤ 1.5	Offline	N/A	Audio (bone-conductance headphones) Haptic (Vibration)	Light Wavelength in the Infra-Red (IR) spectrum	infra-red (IR) sensors	—	Infra-Red (IR) Sensors	—
The Eye-Cane (Maidenbaum et al, 2014)	27	2.526	N/A	N/A	Medium R ≤ 5	Offline	Low	Audio Tactile Vibrations	Light Wavelength in the Infra-Red (IR) spectrum	Infra-Red (IR) Sensors	—	Infra-Red (IR) Sensors	—
Smart Cane (Wahab et al, 2011)	24	—	Outdoor	Day	Medium 1 < R ≤ 5	Offline	High	Audio Messages Hand Vibration (through glove) Buzzer	Ultrasonic Waves	Servo Motors Water Sensor (Water >= 0.5cm) Ultrasonic Sensors	—	Ultrasonic Sensors Water Sensor	PIC Microcontroller
Blind Walking Stick (Dhoot et al, 2016)	22	—	Outdoor / Indoor	N/A	N/A	Offline	Low	Message (to relatives through GSM)	Ultrasonic Waves	Sensors	GPS	Ultrasonic Sensor Water Sensor (2 probes)	Atmega 328

Device	h5-index	Journal IF	Coverage	Time	Range (meters)	Connection Type	Cost	User Interface	Environment Interface	Obstacle Detection	Navigation & Tracking System	Sensors	Microcontroller
												Fire Sensor (LDR and LM35)	
Advanced Blind Walking Stick (Dabhade et al, 2016)	22	—	Outdoor / Indoor	Day / Night	N/A	Bluetooth	N/A	Message (to relatives through GSM) Voice (head phone)	Ultrasonic Waves	Sensors	GPS	Ultrasonic Sensor Fire Sensor (IC LM35 + LDR) Water Sensor (two probes) Temperature Sensor (IC LM35) Light Sensor (LDR)	AT Mega 328
DBG Crutch Based Msensors (Yi et al, 2015)	15	—	Outdoor	Day	Medium 1 < R ≤ 5	Offline	N/A	Voice Vibration	Ultrasonic Waves	Ultrasonic Sensors (overhead and front obstacles)	—	Ultrasonic Sensors	STC15F2K60S2
Walking Stick (Selvanayagam et al, 2016)	14	0.394	Outdoor / Indoor	N/A	N/A	Offline	Low	Vibrator Motors Buzzer	Ultrasonic Waves	Ultrasonic Sensor	—	Ultrasonic Sensor	✓

Device	h5-index	Journal IF	Coverage	Time	Range (meters)	Connection Type	Cost	User Interface	Environment Interface	Obstacle Detection	Navigation & Tracking System	Sensors	Microcontroller
The Sesamonet System (Faggion et al, 2011)	14	—	Outdoor / Indoor	N/A	Short $0.15 \le R \le 0.20$	Online (Wi-Fi / Bluetooth)	N/A	Acoustic Message (Bluetooth / wired earphone)	Bluetooth Radio Waves	RFID	RFID GPS	RFID sensor	—
Electronic White Cane (Niitsu et al, 2012)	13	—	Outdoor	N/A	Large $R \le 6.45$	Smartphone device needed (Android)	N/A	Audio Interface (Bone-conduction Headphone)	Ultrasonic Waves Compass Bluetooth	Ultrasonic Sensor	—	Ultrasonic Sensor	Arduino Pro Mini (Atmega328)
RFIWS (Saaid et al, 2009)	12	—	Outdoor	Day / Night	Medium $1 < R \le 5$	Offline	N/A	Vibration Sound	Radio Waves	Radio Frequency Identification (RFID)	—	RFID sensor	—
The Smartcane (Hussain et al, 2016)	12	—	Outdoor	N/A	N/A	N/A	$ 60.00	Speaker / Headset GSM	Ultrasonic Waves Light Wavelength in the Infra-Red (IR) spectrum	Sensors	GPS	Ultrasonic Sensor Infra-Red (IR) Sensor Mud Sensor	AT89C52
Medico-Stick (Shrivastava et al, 2015)	10	—	Outdoor / Indoor	N/A	Large $R \le 10$	N/A	N/A	Vibration Motor Buttons	Ultrasonic Waves	Sensors	GPS	Ultrasonic Sensors Heart Rate - Pulse Sensor	AT89S52

Device	h5-index	Journal IF	Coverage	Time	Range (meters)	Connection Type	Cost	User Interface	Environment Interface	Obstacle Detection	Navigation & Tracking System	Sensors	Microcontroller
								Alert Message (to relatives) (DTFM module)					
Ultra Cane (Kumar et al, 2014)	10	—	Indoor	Day / Night	Medium 1 < R ≤ 5	Offline	N/A	X-bee-S1 Trans-Receiver Module Buzzer	Ultrasonic Waves	Ultrasonic Sensors (ground and aerial obstacles)	—	Ultrasonic Sensors	Arduino UNO
Smart Cane (Vineesha et al, 2016)	9	—	N/A	N/A	N/A	Offline	N/A	Voice	Biometric Authentication (Face Identification)	Camera	—	—	—
Infra-Red Sensor Based Smart Stick (Nada et al, 2015)	9	—	Indoor	N/A	Medium R ≤ 2	Offline	Low	Audio Warning Message (through earphone)	Light Wavelength in the Infra-Red (IR) spectrum	Infra-Red (IR) Sensors	—	Infra-Red (IR) Sensors	16F877A
ELC (García et al, 2011)	6	—	Outdoor	Day / Night	Short R ≤ 1	Offline	N/A	Vibration	Ultrasonic Waves Micromotor Actuator	Ultrasonic Sensor (above waistline)	—	Ultrasonic Sensor	Atmel AVR
Smart Cane (Satpute et al, 2017)	4	—	Outdoor / Indoor	N/A	N/A	Online / Offline	Low	Voice Alert Emergency Button Switch1 (call family), Switch2 (call doctor) SMS Message (to Relatives/Doctor through GSM)	Ultrasonic Waves	Ultrasonic Sensors Triaxial Accelerometer (for fall detection)	GPS (Outdoor) RFID (Indoor)	Ultrasonic Sensors	✓

Device	h5-index	Journal IF	Coverage	Time	Range (meters)	Connection Type	Cost	User Interface	Environment Interface	Obstacle Detection	Navigation & Tracking System	Sensors	Microcontroller
3D Obstacle Detector (Zeng et al, 2012)	—	—	Outdoor / Indoor	N/A	Large $R > 7$	Offline	N/A	Tactile Symbols Wii Remote Controller	3-D TOF camera	3-D Time of Flight (TOF) camera Portable Computer	—	—	—
EYECane (Ju et al, 2009)	—	—	Outdoor / Indoor	Day / Night	N/A	Online	N/A	Acoustic Interface	Web Camera	Web Camera Portable Computer	— (Path Recommen-dation)	—	—
Smart Cane (Tamjidi et al, 2013)	—	—	Indoor	N/A	N/A	Offline	Low	N/A	3D camera (SwissRanger SR4000)	3D camera (SwissRanger SR4000) Handtop Computer	—	—	—
AKSHI (Kaushalya et al, 2016)	—	—	Outdoor	Day / Night	N/A	Online Smart Phone (Android)	≈ Rs. 20,000 (261.12 €)	Audio (Google Maps communication through GSM) GSM	Radio Waves Ultrasonic Waves	Radio Frequency Identification (RFID) (pedestrian crossing identification) Ultrasonic Sensor (obstacle detection)	GPS	Ultrasonic Sensor	N/A
Blind Stick (Meppurath et al, 2017)	—	—	Outdoor	N/A	Medium $R \leq 4$	N/A	Low	Vibration Emergency Help Switches	Ultrasonic Waves	Ultrasonic Sensors	GPS	Ultrasonic Sensors	Arduino Atmega 328

Device	h5-index	Journal IF	Coverage	Time	Range (meters)	Connection Type	Cost	User Interface	Environment Interface	Obstacle Detection	Navigation & Tracking System	Sensors	Microcontroller
								SMS Message (to family)					
Electronic Stick (Gurubaran et al, 2014)	—	—	Outdoor	N/A	N/A	Offline	Low	Bluetooth Earpiece Trigger Button Alert Message (to family/doctor through GSM) Voice Thumb Print Scanner	Ultrasonic Waves	Ultrasonic Sensors	GPS	Ultrasonic Sensors	✓
Smart Electronic Travel Stick (Dhal et al, 2016)	—	—	N/A	N/A	Medium R ≤ 3	Offline	N/A	Message (to relatives through GSM) Buzzer	Ultrasonic Waves	Sensors	GPS	Ultrasonic Sensor Water Sensor	Arduino Uno
Ultrasonic Blind Walking Stick (Bunnan et al, 2016)	—	—	N/A	Day / Night	N/A	N/A	Low	Buzzer TV Remote Control	Ultrasonic Waves	Sensors	—	Ultrasonic Sensor Light Sensor (LDR) Water Sensor (level sensor)	PIC18F4550

Device	h5-index	Journal IF	Coverage	Time	Range (meters)	Connection Type	Cost	User Interface	Environment Interface	Obstacle Detection	Navigation & Tracking System	Sensors	Microcontroller
Voice Stick (Kumar et al, 2017)	—	—	Outdoor	Day / Night	Medium R ≤ 4	ad-hoc Network	Low	Vibration Buzzers Speech Instructor Flashlight	Ultrasonic Waves Light Wavelength in the Infra-Red (IR) spectrum	Sensors	— “In future, GPS can be linked with the voice stick”	Water Sensor Fire Sensor Ultrasonic Sensor Infra-Red (IR) Sensor Light Sensor (LDR)	✓
White Guide (Agarwal et al, 2017)	—	—	Outdoor	N/A	N/A	Bluetooth	N/A	SOS Button Call Button Power Button Haptic Feedback	Ultrasonic Waves	Ultrasonic Sensors	GPS (through Smartphone application)	Ultrasonic Sensors	Arduino Nano
Smart Walking Stick (Ikbal et al, 2017)	—	—	N/A	N/A	Medium 1 < R ≤ 2	Offline	N/A	buzzer Sound Alert	Ultrasonic / Electromagnetic Waves	Sensors	—	Ultrasonic Sensors Water Sensor (surface ≥ 9mm)	Arduino Atmega 328

Device	h5-index	Journal IF	Coverage	Time	Range (meters)	Connection Type	Cost	User Interface	Environment Interface	Obstacle Detection	Navigation & Tracking System	Sensors	Microcontroller
CleverCane (Messenger Harry, 2016)	—	—	N/A	N/A	Medium $1 < R \leq 2.5$	Bluetooth Connection with Smart Phone	N/A (hardware manufacturer cost: ≈ £118.40 - £131.40)	Vibration (Wristband)	Ultrasonic Waves	Ultrasonic Sensors	—	Ultrasonic Sensors	Seeeduino v3

4.1 Main findings of Table 1: Characteristics of described devices / patents

ELC (García et al, 2011), **Ultra Cane** (Kumar et al, 2014), **DBG Crutch Based Msensors** (Yi et al, 2015), **Smart Cane** (Satpute et al, 2017), **Electronic Stick** (Gurubaran et al, 2014), **Blind Stick** (Meppurath et al, 2017), **Electronic White Cane** (Niitsu et al, 2012), **MobiFree Cane** (Lopes et al, 2012), **White Guide** (Agarwal et al, 2017), **Walking Stick** (Selvanayagam et al, 2016), **CleverCane** (Messenger Harry, 2016) and **AKSHI** (Kaushalya et al, 2016) use exclusively ultrasonic sensor/-s and the environment interface is achieved through ultrasonic waves. Some of them, though, apart from ultrasonic waves use other technologies too for the interface with the environment. More specifically, **ELC** (García et al, 2011) uses micromotor actuator, **Electronic White Cane** (Niitsu et al, 2012) uses compass and Bluetooth and **AKSHI** (Kaushalya et al, 2016) uses radio waves.

All of the systems which are mentioned below, use ultrasonic sensor/-s in combination with other sensors, too. **Smart Cane** (Wahab et al, 2011) uses a water sensor, **Voice Stick** (Kumar et al, 2017) uses a water, a fire, a light and an IR sensor, **Smart Walking Stick** (Ikbal et al, 2017) uses a water sensor, **The Smartcane** (Hussain et al, 2016) uses an IR and a mud sensor, **Medico-Stick** (Shrivastava et al, 2015) uses a heart rate-pulse sensor, **Blind Walking Stick** (Dhoot et al, 2016) uses a fire and a water sensor, **Smart Electronic Travel Stick** (Dhal et al, 2016) uses a water sensor, **Advanced Blind Walking Stick** (Dabhade et al, 2016) uses a water, a fire, a light and a temperature sensor and **Ultrasonic Blind Walking Stick** (Bunnan et al, 2016) uses a water and a light sensor. All these devices use ultrasonic waves. Some of them also use other technologies for the environment interface; **Voice Stick** (Kumar et al, 2017) and **The Smartcane** (Hussain et al, 2016) use light wavelength in IR spectrum and **Smart Walking Stick** (Ikbal et al, 2017) uses electromagnetic waves.

All the devices mentioned in the first two paragraphs of this section along with **Infra-Red Sensor Based Smart Stick** (Nada et al, 2015) are the only ones with embedded microcontroller apart from **AKSHI** (Kaushalya et al, 2016) for which it is not mention whether it has one or not.

RFIWS (Saaid et al, 2009) and **The Sesamonet System** (Faggion et al, 2011) use exclusively RFID sensor and RFID technology for the obstacle detection. Both of them use radio waves but the second one also uses Bluetooth for the environment interface.

The EyeCane (Buchs et al, 2017), **Infra-Red Sensor Based Smart Stick** (Nada et al, 2015) and **The Eye-Cane** (Maidenbaum et al, 2014) have exclusively Infra-Red sensors and use light wavelength in IR spectrum for the environment interface.

EYECane (Ju et al, 2009), **3D Obstacle Detector** (Zeng et al, 2012) and **Smart Cane** (Tamjidi et al, 2013) use a combination of a camera and a portable computer for obstacle detection and interface with the environment, while **Smart Cane** (Vineesha et al, 2016) has a only a camera.

The obstacle detection for the 26 systems (the 4 in the previous paragraph are excluded from the total of 30 devices/patents) is achieved though their sensors. **Smart Cane** (Wahab et al, 2011) also has servo motors, **Smart Cane** (Satpute et al, 2017) also has triaxial accelerometer and **AKSHI** (Kaushalya et al, 2016) also uses RFID technology.

The devices with a navigation and tracking system are the **Smart Cane** (Satpute et al, 2017), **Electronic Stick** (Gurubaran et al, 2014), **Blind Stick** (Meppurath et al, 2017), **The**

Sesamonet System (Faggion et al, 2011), **White Guide** (Agarwal et al, 2017), **AKSHI** (Kaushalya et al, 2016), **The Smartcane** (Hussain et al, 2016), **Medico-Stick** (Shrivastava et al, 2015), **Blind Walking Stick** (Dhoot et al, 2016), **Smart Electronic Travel Stick** (Dhal et al, 2016) and **Advanced Blind Walking Stick** (Dabhade et al, 2016).

As for the user interface, the devices that use haptic feedback or vibration through different mechanisms are **Smart Cane** (Wahab et al, 2011), **RFIWS** (Saaid et al, 2009), **ELC** (García et al, 2011), **DBG Crutch Based Msensors** (Yi et al, 2015), **Blind Stick** (Meppurath et al, 2017), **Voice Stick** (Kumar et al, 2017), **MobiFree Cane** (Lopes et al, 2012), **3D Obstacle Detector** (Zeng et al, 2012), **The EyeCane** (Buchs et al, 2017), **White Guide** (Agarwal et al, 2017), **Walking Stick** (Selvanayagam et al, 2016), **CleverCane** (Messenger Harry, 2016), **Medico-Stick** (Shrivastava et al, 2015) and **The Eye-Cane** (Maidenbaum et al, 2014).

The devices which provide any kind of acoustic interface, whether it's a voice or audio message, a buzzer, etc. are **Smart Cane** (Wahab et al, 2011), **RFIWS** (Saaid et al, 2009), **Ultra Cane** (Kumar et al, 2014), **DBG Crutch Based Msensors** (Yi et al, 2015), **Smart Cane** (Satpute et al, 2017), **Electronic Stick** (Gurubaran et al, 2014), **Voice Stick** (Kumar et al, 2017), **Smart Walking Stick** (Ikbal et al, 2017), **Electronic White Cane** (Niitsu et al, 2012), **The Sesamonet System** (Faggion et al, 2011), **The EyeCane** (Buchs et al, 2017), **Smart Cane** (Vineesha et al, 2016), **Walking Stick** (Selvanayagam et al, 2016), **AKSHI** (Kaushalya et al, 2016), **The Smartcane** (Hussain et al, 2016), **Infra-Red Sensor Based Smart Stick** (Nada et al, 2015), **Smart Electronic Travel Stick** (Dhal et al, 2016), **Advanced Blind Walking Stick** (Dabhade et al, 2016), **Ultrasonic Blind Walking Stick** (Bunnan et al, 2016) and **The Eye-Cane** (Maidenbaum et al, 2014).

The systems that send message to the user's relatives are **Smart Cane** (Satpute et al, 2017), **Electronic Stick** (Gurubaran et al, 2014), **Blind Stick** (Meppurath et al, 2017), **Medico-Stick** (Shrivastava et al, 2015), **Blind Walking Stick** (Dhoot et al, 2016), **Smart Electronic Travel Stick** (Dhal et al, 2016) and **Advanced Blind Walking Stick** (Dabhade et al, 2016). The first four of them along with **White Guide** (Agarwal et al, 2017) constitute the devices/patents which have buttons and/or switches for the user.

Some of the total technologies have some extra aids for the user interface. **Ultra Cane** (Kumar et al, 2014) has X-bee-s1 Trans-Receiver Module, **Electronic Stick** (Gurubaran et al, 2014) has Bluetooth earpiece and thumb print scanner, **Voice Stick** (Kumar et al, 2017) has a flashlight, **MobiFree Cane** (Lopes et al, 2012) has LEDs, **3D Obstacle Detector** (Zeng et al, 2012) has Wii remote controller, **AKSHI** (Kaushalya et al, 2016) and **The Smartcane** (Hussain et al, 2016) have GSM and **Ultrasonic Blind Walking Stick** (Bunnan et al, 2016) has a TV remote control.

The devices which are used only outdoors are **Smart Cane** (Wahab et al, 2011), **RFIWS** (Saaid et al, 2009), **ELC** (García et al, 2011), **DBG Crutch Based Msensors** (Yi et al, 2015), **Electronic Stick** (Gurubaran et al, 2014), **Blind Stick** (Meppurath et al, 2017), **Voice Stick** (Kumar et al, 2017), **Electronic White Cane** (Niitsu et al, 2012), **MobiFree Cane** (Lopes et al, 2012), **White Guide** (Agarwal et al, 2017), **AKSHI** (Kaushalya et al, 2016) and **The Smartcane** (Hussain et al, 2016).

The devices which are used only indoors are **Ultra Cane** (Kumar et al, 2014), **Smart Cane** (Tamjidi et al, 2013) and **Infra-Red Sensor Based Smart Stick** (Nada et al, 2015).

The devices that are used both outdoors and indoors are **Smart Cane** (Satpute et al, 2017), **EYECane** (Ju et al, 2009), **3D Obstacle Detector** (Zeng et al, 2012), **The Sesamonet System** (Faggion et al, 2011), **The EyeCane** (Buchs et al, 2017), **Walking Stick** (Selvanayagam et al, 2016), **Medico-Stick** (Shrivastava et al, 2015), **Blind Walking Stick** (Dhoot et al, 2016) and **Advanced Blind Walking Stick** (Dabhade et al, 2016).

There only two devices which can be used only in day; the **Smart Cane** (Wahab et al, 2011) and **DBG Crutch Based Msensors** (Yi et al, 2015). The other systems for which there is information can be used both in day and night and these are; **RFIWS** (Saaid et al, 2009), **ELC** (García et al, 2011), **Ultra Cane** (Kumar et al, 2014), **Voice Stick** (Kumar et al, 2017), **EYECane** (Ju et al, 2009), **MobiFree Cane** (Lopes et al, 2012), **AKSHI** (Kaushalya et al, 2016), **Advanced Blind Walking Stick** (Dabhade et al, 2016) and **Ultrasonic Blind Walking Stick** (Bunnan et al, 2016).

Smart Cane (Wahab et al, 2011), **RFIWS** (Saaid et al, 2009), **Ultra Cane** (Kumar et al, 2014), **DBG Crutch Based Msensors** (Yi et al, 2015), **Blind Stick** (Meppurath et al, 2017), **Voice Stick** (Kumar et al, 2017), **Smart Walking Stick** (Ikbal et al, 2017), **The EyeCane** (Buchs et al, 2017), **CleverCane** (Messenger Harry, 2016), **Infra-Red Sensor Based Smart Stick** (Nada et al, 2015), **Smart Electronic Travel Stick** (Dhal et al, 2016) and **The Eye-Cane** (Maidenbaum et al, 2014) have a medium range of obstacles detection.

ELC (García et al, 2011), **MobiFree Cane** (Lopes et al, 2012) and **The Sesamonet System** (Faggion et al, 2011) have a short range of obstacles detection, but **Electronic White Cane** (Niitsu et al, 2012), **3D Obstacle Detector** (Zeng et al, 2012) and **Medico-Stick** (Shrivastava et al, 2015) have a large range of obstacles detection.

The technologies that work <u>exclusively</u> offline are **Smart Cane** (Wahab et al, 2011), **RFIWS** (Saaid et al, 2009), **ELC** (García et al, 2011), **Ultra Cane** (Kumar et al, 2014), **DBG Crutch Based Msensors** (Yi et al, 2015), **Electronic Stick** (Gurubaran et al, 2014), **Smart Walking Stick** (Ikbal et al, 2017), **3D Obstacle Detector** (Zeng et al, 2012), **The EyeCane** (Buchs et al, 2017), **Smart Cane** (Vineesha et al, 2016), **Smart Cane** (Tamjidi et al, 2013), **Walking Stick** (Selvanayagam et al, 2016), **Infra-Red Sensor Based Smart Stick** (Nada et al, 2015), **Blind Walking Stick** (Dhoot et al, 2016), **Smart Electronic Travel Stick** (Dhal et al, 2016) and **The Eye-Cane** (Maidenbaum et al, 2014). The only technology mentioned that works both offline and online is **Smart Cane** (Satpute et al, 2017).

The technologies that work <u>exclusively</u> online or connected to a device such as a smart-phone are **Voice Stick** (Kumar et al, 2017), **Electronic White Cane** (Niitsu et al, 2012), **EYECane** (Ju et al, 2009), **MobiFree Cane** (Lopes et al, 2012), **The Sesamonet System** (Faggion et al, 2011), **White Guide** (Agarwal et al, 2017), **CleverCane** (Messenger Harry, 2016), **AKSHI** (Kaushalya et al, 2016) and **Advanced Blind Walking Stick** (Dabhade et al, 2016).

Finally, as far as it concerns the cost, the only device characterized as being high cost is **Smart Cane** (Wahab et al, 2011). **Smart Cane** (Satpute et al, 2017),), **Electronic Stick** (Gurubaran et al, 2014), **Blind Stick** (Meppurath et al, 2017), **Voice Stick** (Kumar et al, 2017), **MobiFree Cane** (Lopes et al, 2012), **Smart Cane** (Tamjidi et al, 2013), **Walking Stick** (Selvanayagam et al, 2016), **Infra-Red Sensor Based Smart Stick** (Nada et al, 2015), **Blind Walking Stick** (Dhoot et al, 2016), **Ultrasonic Blind Walking Stick** (Bunnan et al, 2016) and **The Eye-Cane** (Maidenbaum et al, 2014) are low cost. Specifically mentioned, **AKSHI** (Kaushalya et al, 2016) costs 261.12 € and **The Smartcane** (Hussain et al, 2016) costs $ 60.00.

Table 2: Characteristics of described commercially available smart sticks

Device	Coverage	Time	Range (meters)	Connection Type	Cost	User Interface	Environment Interface	Obstacle Detection	Navigation & Tracking System	Sensors	Microcontroller
The Ultra Cane (Sound Foresight Technology Ltd)	N/A	N/A	Medium R ≤ 4	Offline	£ 635.00	Vibrating Buttons	Ultrasonic Waves	Ultrasonic Sensors	—	Ultrasonic Sensors	N/A
The Smart Cane (The academia-NGO-industry partnership)	Outdoor / Indoor	N/A	Medium R ≤ 3 (outdoor) R ≤1.8 (indoor)	Offline	Rs. 3,500.00 (46.11 €)	Vibration	Ultrasonic Waves	Ultrasonic Sensors	—	Ultrasonic Sensors	N/A
SmartCane Phoenix (Phoenix Medical Systems)	Outdoor / Indoor	N/A	Medium R ≤ 3	Offline	$ 90.00	Vibratory Patterns	Ultrasonic Waves	Ultrasonic Sensors	—	Ultrasonic Sensors	✓
BAWA Cane (BAWA)	N/A	N/A	Small R ≤ 1.2	Bluetooth 4.2 wireless (connected with mobile phones and wearable devices through app)	$ 699.00	Alert Button (SOS signal to relatives) Voice (command by user to the device)	Ultrasonic Waves	Sensors	✓	Ultrasonic Sensor Accelero-meter	✓

Device	Coverage	Time	Range (meters)	Connection Type	Cost	User Interface	Environment Interface	Obstacle Detection	Navigation & Tracking System	Sensors	Microcontroller
						Haptic Feedback (on user's wrist)				Voltage / Battery level sensor	
Ultrasonic Blind Walking Stick (NevonProjects)	N/A	N/A	N/A	N/A	135.00 € / 151.00 € / 175.00 € (depends on the selected kit by buyer)	Buzzer Button	Ultrasonic Waves	Sensors	—	Ultrasonic Sensor Light Sensor Water Sensor	ATmega328
I-Cane Mobilo (I-Cane Social Technologies)	N/A	N/A	N/A	iOS / Android smart-phone App	1700.00 € – 1800.00 €	Vibrating and Rotating Feel Arrow Audio Emergency Button	N/A	N/A	GPS	N/A	N/A

4.2 Main findings of Table 2: Characteristics of described commercially available smart sticks

All the devices except for **I-Cane Mobilo** (I-Cane Social Technologies) – for which the corresponding information is not available – use ultrasonic sensors and microcontroller and the environment interface is achieved through ultrasonic waves. **BAWA cane** (BAWA) use an extra accelerometer sensor and a voltage/battery-level sensor. The **Ultrasonic Blind Walking stick** (NevonProjects) has a light and a water sensor, too. The obstacle detection for each of the six devices happens through the sensors they have.

As for the user interface, **The Ultra Cane** (Sound Foresight Technology Ltd), **The Smart Cane** (The academia-NGO-industry partnership), the **SmartCane Phoenix** (Phoenix Medical Systems) and the **I-Cane Mobilo** (I-Cane Social Technologies) use vibration. The last one mentioned also gives audio information to the user, while a person that uses the **BAWA cane** (BAWA) can give audio-voice commands to the device and receive haptic feedback to their wrist. **BAWA cane** (BAWA) and **I-Cane Mobilo** (I-Cane Social Technologies) have an emergency-alert button. The **Ultrasonic Blind Walking stick** (NevonProjects) has a button that when pressed a buzzer sounds to help the user find their stick.

The Smart Cane (The academia-NGO-industry partnership) and the **SmartCane Phoenix** (Phoenix Medical Systems) can be used indoors and outdoors – for the rest of the devices this information is not available. The two devices just mentioned and **The Ultra Cane** (Sound Foresight Technology Ltd) work offline and they detect obstacles in a medium range. The **BAWA cane** (BAWA) must be connected to a phone via Bluetooth and has a small detection range, while the **I-Cane Mobilo** (I-Cane Social Technologies) must be connected to an iOS or Android smart phone. The detection range of this and the **Ultrasonic Blind Walking stick** (NevonProjects) is not mentioned. Also, another characteristic that is not available for any of the six systems is whether they can be used in day, night or both.

Only the **BAWA cane** (BAWA) and **I-Cane Mobilo** (I-Cane Social Technologies) provide navigation and tracking service.

The most economically accessible canes are **The Smart Cane** (The academia-NGO-industry partnership), the **SmartCane Phoenix** (Phoenix Medical Systems) and the **Ultrasonic Blind Walking stick** (NevonProjects). **The Ultra Cane** (Sound Foresight Technology Ltd) and the **BAWA cane** (BAWA) are expensive enough, while the **I-Cane Mobilo** (I-Cane Social Technologies) transcends the amount of 1,700.00 €.

5. THE TESTING RESULTS OF THE DESCRIBED DEVICES

In this section, table 3 presents the results of the test experiments held by the creators to test the functionality and reliability of the devices/patents. In this table there is given information about the participants, but also description of each test and, certainly, their results.

It is important to emphasize here that, since the commercially available smart canes are already in the market, the products are, obviously, not accompanied by tests. Hence, in the test-results table, those devices are not included.

Below, the header row's fields are analyzed and some field values are explained as in the beginning of section 4.

Explanation of the fields in the header row of the test-results table:

Participants: Description of the participants (number and/or characteristics). If there were no participants during the experiment, the field is filled with —.

Testing Description and Results: Description of the testing and the results that followed. If there are no tests mentioned in the scientific literature, it is indicated.

Explanation of field values in the test-results table:

N/A: Not mentioned / the information is not available.

—: Does not exist.

Table 3: Test Results of described devices and/or patents

<table>
<tr><th>Device</th><th>Participants</th><th>Testing Description and Results</th></tr>
<tr><td>Smart Cane
(Wahab et al, 2011)</td><td>—</td><td>
<u>Voice warning</u>:
Three different voice messages are utilized to alert the user:
<table>
<tr><th>No</th><th>Voice Message</th><th>Distance</th></tr>
<tr><td>1</td><td>No object in 4 feet in front of you</td><td>Far</td></tr>
<tr><td>2</td><td>Objects are between 3 to 4 feet in front of you</td><td>Medium</td></tr>
<tr><td>3</td><td>An object is right in front of you</td><td>Close</td></tr>
</table>
In the testing, the Smart Cane was successfully addressing the three voice alerts. However, the first type of voice alert was found too misleading. Users feel confused with the voice alerts which are too repetitive.

<u>Result of Ultrasonic Sensor Analysis</u>:

The following table shows analysis of the ultrasonic sensor analog voltage value between the calculation value and measurement value.
<table>
<tr><th>No</th><th>Range (Inches)</th><th>Error %</th></tr>
<tr><td>1</td><td>0</td><td>0</td></tr>
<tr><td>2</td><td>5</td><td>16</td></tr>
<tr><td>3</td><td>10</td><td>6.0</td></tr>
<tr><td>4</td><td>15</td><td>5.3</td></tr>
<tr><td>5</td><td>20</td><td>3.5</td></tr>
<tr><td>6</td><td>25</td><td>2.0</td></tr>
<tr><td>7</td><td>30</td><td>1.3</td></tr>
<tr><td>8</td><td>35</td><td>1.1</td></tr>
<tr><td>9</td><td>40</td><td>1.0</td></tr>
</table>
<u>Result of analyzing the water sensor</u>:

There were few details that had been obtained when analyzing the water sensor as listed below:
1. The water sensor fully functions.
2. The water sensor can detect if only the water is over 0.5 cm deep.
3. The water sensor buzzer cannot be stopped unless the water sensor is dry, so it needs to be wiped to stop the buzzer.
</td></tr>
</table>

<table>
<tr><th>Device</th><th>Participants</th><th>Testing Description and Results</th></tr>
<tr><td>RFIWS
(Saaid et al, 2009)</td><td>—</td><td>Antenna Characteristic Test: The antenna characteristic that will be focusing for the experimental test is polarization. The polarization can be dividing in two types; linear-polarized antennas and circular-polarized antennas. In RFID application, the radio wave communication between tag and reader can be more efficient when the tag and reader antenna have the same polarization.

Tag Characteristic Test: Results from the final year project conclude that the detection range of RFID tag is not same as in literature. Also, each tag gives a different detection range and need to be tested individually.</td></tr>
<tr><td>ELC
(García et al, 2011)</td><td>Volunteers
(N/A information about them)</td><td>Volunteers had to complete several tasks based on the touch technique by using the ELC such as: to switch on-off correctly the device; to set properly the cane position; to stop the route when a tactile signal (vibration) into the grip alerts the presence of an obstacle; to identify, through exploratory touch, the shape characteristics of the physical barrier that has been identified and finally to bypass the obstacle after its recognition, following the original route.
<table>
<tr><th>No</th><th>Question</th><th>Qualitative Score (volunteers number)</th></tr>
<tr><td>1</td><td>Accuracy, related to detecting obstacles above the waistline</td><td>Positive (8)</td></tr>
<tr><td>2</td><td>Satisfaction related to the use of the device and their functions</td><td>Positive (8)</td></tr>
<tr><td>3</td><td>Satisfaction related to the ergonomics design</td><td>Positive (8)</td></tr>
<tr><td>4</td><td>Is easy to learn?</td><td>Yes (8)</td></tr>
<tr><td>5</td><td>Is it customizable?</td><td>Yes (8)</td></tr>
<tr><td>6</td><td>Could the cane be used for Mobility and Orientation programs?</td><td>Yes (8)</td></tr>
</table>
The table above summarizes quiz output data, starting from volunteers and professors information. It concerns about the spatial information quality provided by ELC. Score scale values were: Yes-No, Positive-Negative-Undefined. From the table can be concluded that barrier detection and secure mobility was properly evaluated in all cases.</td></tr>
<tr><td>Ultra Cane
(Kumar et al, 2014)</td><td>10 volunteers in the age group of 22-26 years</td><td>The volunteers were invited and trained on the developed device for 15 -30 min. Thereafter, they were blinded using a piece of cloth tied across their eyes and were subsequently asked to walk across a corridor where artificial obstacles were created. The volunteers were able to successfully detect the obstacles in the proposed range of the device.</td></tr>
<tr><td>DBG Crutch Based MSensors
(Yi et al, 2015)</td><td>—</td><td>No tests mentioned.</td></tr>
</table>

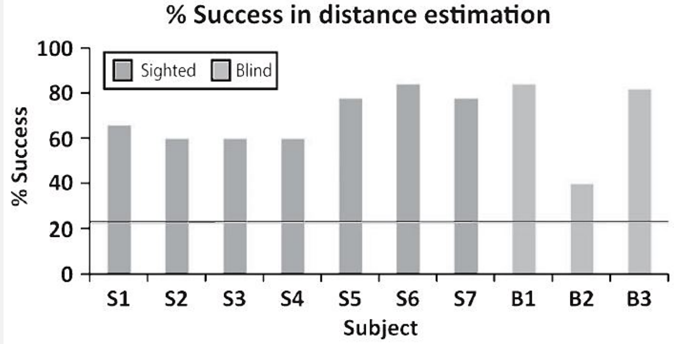
Device	Participants	Testing Description and Results
Smart Cane (Satpute et al, 2017)	—	No tests mentioned.
Electronic Stick (Gurubaran et al, 2014)	—	No tests mentioned.
Blind Stick (Meppurath et al, 2017)	—	No tests mentioned.
Voice Stick (Kumar et al, 2017)	—	No tests mentioned.
Smart Walking Stick (Ikbal et al, 2017)	—	After some experiments that were carried out, it is noticed here, that for the bottom sensor the minimum obstacle height was required at least 6cm from the ground surface. It means from ground surface (0 cm) to at least 6 cm, echo signal was not reflected. Although the sensor has the ability to detect the obstacle at about 200 cm but in the present study it was considered up to 100 cm. Because long distance will increase the greater angle which will make a problem of detection of obstacle for the user. As for the upper sensor, the result indicates that echo signal was not reflected between ground surface (0 cm) to 50 cm high which actually covered by the bottom sensor. In this way, approximately 175 cm high from the ground surface can be covered for detection of the obstacle using two front sensors which is enough for a blind person to overcome an unwanted accident to navigate in his way. The water sensor was working perfectly while testing.
Electronic White Cane (Niitsu et al, 2012)	—	It is considered that experimental results were strongly affected by swing speed or swing method of an electronic white cane, installed angle of sensors and accuracy of walking direction measured by a Smartphone. Especially in the discrimination method between a moving obstacle and a motionless obstacle, the length of period between 1st time measurement and 2nd time measurement is largely affected by swing speed of an electronic white cane. Direction error as well as fluctuating the length of period, makes it difficult to discriminate between a moving obstacle and motionless one. Response time from obstacle detection to user notification of a dangerous obstacle is less than 1 second. For practical use of this system, the response time is not so critical. However, much shorter response time is desirable in order to notify a user of a dangerous obstacle as soon as possible. To decrease the response time, synchronization of Arduino and Android command execution and improvement of sensing circuits' performance, etc. should be studied.

Device	Participants	Testing Description and Results
EYECane (Ju et al, 2009)	5 individuals (without visual impairment – using eye bandage)	To evaluate the performance of EYECane, it was compared with general white cane. The EYECane has the smaller navigation efforts than white cane, moreover it has the accuracy of 90%. The experiment results showed that the proposed EYECane was practical for visually impaired people.
MobiFree Cane (Lopes et al, 2012)	—	Field tests proved and validated the concept, allowing holes, drop-offs and steps to be detected flawlessly, and with only a very limited number of false detections occurring in very irregular surfaces. Nonetheless, all the holes were detected in every kind of surface, proving this is an efficient way of bringing a clear path to the visually impaired.
3D Obstacle Detector (Zeng et al, 2012)	6 blind individuals with average age of 33.7 years-old	Each participant spent about 2 hours to complete all of the tasks. During the training period, they learned the legends of symbols in a short time (3 minutes in average) and finished the test to identify the properties of 6 pre-selected symbols quickly (2.4 minutes in mean), and with a high mean accuracy of 87.8%. Errors mainly occurred when pointing out the width and height of symbols All of the subjects reported their strategies to use the proposed system as following; walked until were warned by the Wiimote cane, and stopped to touch the whole Braille display to find an open space. While touching the screen, they at first located the referenced grid to seek obstacles in 2 meters, and then explored the remaining space of the display. Besides the multiple and heavy equipment, they mentioned they were unable to walk fast due to the long updating period in one second, and suggested to improve the performance.
The Sesamonet System (Faggion et al, 2011)	—	No tests mentioned.
The EyeCane (Buchs et al, 2017)	A total of 16 blind participants participated in this study. 8 of them used it mounted on the white-cane (5 female, age 42±11.4, 5 congenital blind, 1 turned blind at the age of 1 and two turned blind at the age of 28).	Participants' success rates in the detection and avoidance of waist-up obstacles using the EyeCane were significantly higher than in the control with the white-cane alone. As expected, the detection rate was significantly higher than the avoidance rate, as avoiding obstacles required participants to use the perceived information to plan and execute the proper motor response to avoid the obstacles after their detection via the EyeCane. These findings demonstrate that the EyeCane can indeed increase upper-body protection over the current common methods. The success rates in both detection and avoidance of waist-up obstacles didn't vary in a significant manner between using the EyeCane as a stand-alone device or when mounted on a white-cane. These findings suggest that the EyeCane can be used both as a primary and as a secondary mobility aid, thus providing upper-body protection while enabling each user to choose their personally preferred setup in general, and for specific tasks and situations.

<table>
<tr><th>Device</th><th>Participants</th><th>Testing Description and Results</th></tr>
<tr><td>White Guide
(Agarwal et al, 2017)</td><td>—</td><td>No tests mentioned.</td></tr>
<tr><td>Smart Cane
(Vineesha et al, 2016)</td><td>—</td><td>No tests mentioned.</td></tr>
<tr><td>Smart Cane
(Tamjidi et al, 2013)</td><td>—</td><td>There mentioned 3 experiments carried out in indoor environments. The results show that the use of the y coordinate (the distance between the camera and the floor plane) observation greatly improves the pose estimation accuracy, since it reduced the average y error and the path-length error.</td></tr>
<tr><td>Walking Stick
(Selvanayagam et al, 2016)</td><td>—</td><td>The proposed system works efficiently when tested in various conditions. It is found to be cost-effective and the safety of the user is satisfactory. The system is reliable and fast.</td></tr>
<tr><td>CleverCane
(Messenger Harry, 2016)</td><td>—</td><td>
<table>
<tr><th>Type of test</th><th>Description of test</th><th>Description of goal result</th><th>Test Result</th><th>More Information</th></tr>
<tr><td>Above knee obstacle detection</td><td>Other sensors disabled. Object placed at random range between 1m – 2.5m</td><td>Variable strength vibration on wrist sensor according to operation instructions</td><td>PASS</td><td>With everything disabled achieved a 85% detection rate for single objects</td></tr>
<tr><td>Object ahead obstacle detection</td><td>Other sensors disabled. Object placed at random range between 1m – 2.5m</td><td>Variable strength vibration on wrist sensor according to operation instructions</td><td>PASS</td><td>As above, 85% (17/20) detected and correct vibration.</td></tr>
<tr><td>Gradient detection</td><td>Other sensors disabled. Angle of cane lowered by 30°</td><td>Gradient signal indicated on wristband according to operation instructions within 5 seconds</td><td>FAIL</td><td>Gradient detection change rate 60%, but average time taken 22 seconds</td></tr>
<tr><td>Sensitivity of vibration</td><td>Place object in front of sensor at 1.1m, 1.9m, 2.4m and check that the sensitivities are discernible</td><td>The user is able to know the difference between the sensor vibrations</td><td>PASS</td><td>I can discern the sensitivities at all ranges.</td></tr>
<tr><td>Weight</td><td>Cane weighted on scales</td><td>Cane weighs no more than 800gr</td><td>PASS</td><td>Cane weighs 720gr</td></tr>
<tr><td>Code functions</td><td>Input test data to the code functions with known outcomes</td><td>Result of speed of sound is 340m/s ± 1ms</td><td>PASS</td><td>Result is 340m/s</td></tr>
</table>
</td></tr>
</table>

<table>
<tr><th>Device</th><th>Participants</th><th>Testing Description and Results</th></tr>
<tr><td></td><td></td><td>There are two main issues picked out as solvable within the project timescale. The first was the gradient system. It appeared that the angle of change required was too big, and the time taken to register a change was far too long. For this case, the variables in the code should be altered to allow the gradient function to run more often (to speed up the delayed notification) and also slightly decrease the angle required to make this happen.
The second was the strength of the notifications. A small piece of padding will be added under the vibrating motor as well as the watch strap, in order to attempt to reduce the sensation.</td></tr>
<tr><td>AKSHI
(Kaushalya et al, 2016)</td><td>—</td><td>No tests mentioned.</td></tr>
<tr><td>The Smartcane
(Hussain et al, 2016)</td><td>▪ 10 visually impaired people (7 in between the age of 20 to 50, and 3 within the age of 10 years)
and
▪ 20 people who could see but have blindfolds on their eyes.</td><td>All the participants were tested by offering same pathway (200 meters length outdoor), containing obstacles of various types, to walk. They were evaluated on the basis of the rate of collision, walking speed and the usability on how they interact with the environment using the Smartcane and the ordinary white stick.
The system is capable of providing smart assistance to the blind person in a manner that it can detect any obstacle, any uneven surface and provide aid in the case of emergency. This system is practically tested on blind persons as well as blindfolded persons and as a result they feel very comfortable in operating the system.
<table>
<tr><th colspan="7">Average collision rate (%) with obstacles after 200 meters outdoor walk</th></tr>
<tr><th colspan="3">Performance test on 10 blind people</th><th></th><th colspan="3">Performance test on 20 blindfolded people</th></tr>
<tr><th>Obstacle</th><th>The Smartcane</th><th>Ordinary White Stick</th><th></th><th>Obstacle</th><th>The Smartcane</th><th>Ordinary White Stick</th></tr>
<tr><td>Above chest</td><td>98</td><td>100</td><td></td><td>Above chest</td><td>90</td><td>100</td></tr>
<tr><td>Average chest height</td><td>85</td><td>98</td><td></td><td>Average chest height</td><td>88</td><td>100</td></tr>
<tr><td>Above waist and below chest</td><td>25</td><td>50</td><td></td><td>Above waist and below chest</td><td>30</td><td>65</td></tr>
<tr><td>Below waist</td><td>1</td><td>15</td><td></td><td>Below waist</td><td>7</td><td>24</td></tr>
<tr><td>Mud Detection</td><td>10</td><td>100</td><td></td><td>Mud Detection</td><td>8</td><td>100</td></tr>
<tr><td>Wet garbage</td><td>40</td><td>90</td><td></td><td>Wet garbage</td><td>42</td><td>95</td></tr>
<tr><td>Dry garbage</td><td>70</td><td>70</td><td></td><td>Dry garbage</td><td>80</td><td>85</td></tr>
<tr><td>Wet surfaces</td><td>10</td><td>90</td><td></td><td>Wet surfaces</td><td>25</td><td>95</td></tr>
<tr><td>Uneven surface</td><td>8</td><td>25</td><td></td><td>Uneven surface</td><td>10</td><td>40</td></tr>
</table>
</td></tr>
</table>

Device	Participants	Testing Description and Results
Medico-Stick (Shrivastava et al, 2015)	—	No tests mentioned.
Infra-Red Sensor Based Smart Stick (Nada et al, 2015)	6 blind people	Real experiment was held by a group of six blind people to test the obstacles detection using the stick. Eight obstacles with different heights were placed in their walking path. Most of obstacles were detected and the appropriate messages were heard by them as they reported although some were not taking enough space away from the obstacle. Therefore, they sometimes touched the obstacle edge so these instances were considered as unintended error. The feedback from the real test was positive because all of obstacles can be detect although the avoidance accuracy was ranging from 75% to 90%.
Blind Walking Stick (Dhoot et al, 2016)	—	No tests mentioned.
Smart Electronic Travel Stick (Dhal et al, 2016)	—	No tests mentioned.
Advanced Blind Walking Stick (Dabhade et al, 2016)	—	No tests mentioned.
Ultrasonic Blind Walking Stick (Bunnan et al, 2016)	—	No tests mentioned.
The Eye-Cane (Maidenbaum et al, 2014)	10 participants took part in this experiment: ▪ 7 sighted blindfolded participants (4 male, all right-handed)	**Distance estimation experiment:** This experiment tested participants' ability to accurately estimate distances after less than 5 minutes of training. Participants were asked to report vocally the distance of a sheet of cardboard that was placed in front of them at 1, 1.5, 2, 2.5 and 3 meters. Participants were aware that the sheet would be placed at one of these five distances on every trial.

Device	Participants	Testing Description and Results
	▪ 3 blind (1 male, all right-handed).	
	▪ Thirteen participants (11 sighted, 5 male, aged 24 (21–54), 9 right-handed). ▪ An additional group of 11 blindfolded sighted participants took part in control experiment 1 (matched by gender and age to the 11 sighted participants), and ▪ 9 additional blindfolded-sighted participants participated in control experiment 2 (fitted with a White-Cane for their height).	**<u>Navigation experiment</u>:** Scores for the blind participants were similar to those of the sighted, and were therefore grouped with them for these comparisons. Nearly all participants succeeded in navigating to the end of the corridor on all trials, with a gradual reduction in the number of collisions. Control group 2 using the White Cane had a somewhat lower success rate although it did not differ significantly from the experimental group. On the first trial, participants a lot less collisions than control group 1 who attempted to walk down the same corridor for the first time blindfolded without any device. This was also significantly better than control group 2, who were using a White Cane. This difference remained significant on the 4th trial as well. Participants improved significantly between the first and fourth trial. By the end of the 4th trial all participants were easily able to draw and describe the corridor they had walked down.

Device	Participants	Testing Description and Results
	▪ As in Navigation experiment, except for one sighted participant who did not take part in this experiment. ▪ Control group 2, using the White Cane, performed this experiment as well.	**<u>Obstacle Avoidance</u>:** All participants were able to successfully navigate to the end of the corridor without returning to the starting point on all trials, gradually reducing the number of collisions. The number of collisions per trial dropped significantly between the first and fourth trials of the experiment. The introduction of obstacles in the experiment caused a significant increase in the number of collisions, but in the following trials the participants returned to their previous levels. Participants' performance during the control trial in which they were not using the Eye-Cane was significantly worse both compared to the first and fourth trials, indicating that the Eye-Cane significantly helped the participants avoid collisions even on their first attempt. Participants who used the White Cane had a significantly lower success rate and more collisions both on their first and last trial.

6. CONCLUSIONS

Nowadays, technology has made huge advances in many different areas, shaping our everyday lives and contributing to the progress of humanity. One of the fields that has been influenced by this technological development – although not such advanced – is the electronic health aids for impaired people and more specifically the blind and visually impaired ones. A lot of research has happened around this scientific area and many devices/patents have been created along with some commercially available products, so that VIPs will be able to move and navigate more easily and safely.

The purpose of the current thesis was to present in the best possible way the most contemporary and significant smart walking sticks for VIPs. To achieve that, after a research in the scientific bibliography, the technologies that are considered to be more efficient and/or promising were chosen to be included in this state-of-the-art review paper accompanied by their prototype and a brief summary of their operating principle. Apart from that information, it is very essential that the readers of this work will be able to form a comprehensive view that will help them to draw their conclusions. For that reason, three different tables were created;

a. Two (one for patents, one for products) for the classification of the devices' main characteristics. The information of the characteristics tables is combined in the text that follows after each table, showing the main findings.

b. One for the concentration of all the available information about the experiments and the testing results.

So, drawing the resulting conclusions of this thesis it must be mentioned that, considering the special needs and requirements of visually impaired people, there are some basic features required in an ETA system to offer a fair performance. Table 4, based on a corresponding table in Elmannai et al, 2017, shows these features. They can be the key to measuring the efficiency and reliability of any electronic device that provides navigation and orientation services for visually impaired people. It is undeniable that they should be the basis in designing assistive-blind-aid devices such the smart sticks.

Table 4: The most important features that correspond to the user's needs

Feature	Description
Analysis Type	The system needs to provide a fast processing for the exchanged information between the user and sensors. For example, the system that detects an obstacle 2m in front of the user in 10s cannot be considered as real time system.
Coverage	The system needs to provide its services indoors and outdoors to serve the user anytime.
Time	The system should perform as well in day time as at night time.

Range	Ideal minimum distance between the user and the object is 0.5 m, whereas the maximum range should be more than 5m. Further distance is better.
Object Type	The system should avoid the sudden appearance objects, which means the system should detect the dynamic objects as the static objects.
Simplicity	Simple interface, ease of use and friendly operations can make the device approachable to the user.
Economical Accessibility	The device should be economically accessible for the users, so more people can afford it and enhance their quality of life.

After the analysis that was done in this paper and according to the information provided – especially from results of research tests –, it is concluded that none of the presented systems fulfills all of the above features and thus, it cannot be considered fully satisfactory and ideal. Even though each device/patent/product supports some or may have more features over the other, none of them supports all of the evaluated features. A user, in order to feel comfortable using a smart cane, should be provided with all the information about the surrounding environment anytime. That means that a system must be equipped with the basic fundamental features before extra characteristics are added. Otherwise, no matter the plethora of its abilities, its use will still be limited and the device will be incomplete.

However, although none of these smart canes conform to all the key-features, many of them are still in developing phase and they are very promising. Researchers aim to add features in their designs, hopefully to completely cover the most important features and the main needs or special requirements of blind and visually impaired people. Also, the technology is a scientific field that is in advance every day and as a result, lot of progress is expected to happen in the field of ETA (id est, smart canes) for VIPs, too. Besides, this thesis, such as other papers, makes an extensive presentation of similar devices and products, giving an overview of where technology is and where it is directed, while, at the same time, it can be a guideline and pave the way for scientists and researchers to design systems that enhance the quality of VIPs' life ensuring safety, comfort and independence.

TABLE OF TERMINOLOGY

Ξενόγλωσσος όρος	**Ελληνικός Όρος**
state-of-the-art (technology)	Τεχνολογία αιχμής

ABBREVIATIONS - ACRONYMS

3D	3-Dimensional
3D CAD	3-Dimensional Computer-Aided Design
6-DoF	6 Degrees of Freedom
API	Application Programming Interface
DBG	Design of Blind-Guide
DTMF	Dual Tone Multi Frequency
eETA	connected Electronic Travel Aid
ELC	Electronic Long Cane
ETA	Electronic Travel Aid
EU	Europe
GPS	Global Position System
GSM	Global System for Mobile communications
ICT	Information and Communication Technologies
IF	Impact Factor
IoT	Internet of Things
IR	Infra-Red
LDR	Light Dependent Resistor
LED	Light Emitted Diode
MIMO	Multiple-Input-Single-Output
MISO	Multiple-Input-Multiple-Output
NN	Neural Network
PCA	Principal Component Analysis
RFID	Radio Frequency Identification
RFIWS	Radio Frequency Identification Walking Stick
SISO	Single-Input-Single-Output
SMS	Short Message Service
TOF	Time Of Flight
UID	Unique Identification
UK	United Kingdom
US	United States
VIP(-s)	Visually Impaired Person (People)
VRO	Visual-Range Odometry
WHO	World Health Organization

ANNEX I

Six degrees of freedom (6DoF) refers to the freedom of movement of a rigid body in three-dimensional space. Specifically, the body is free to change position as forward/backward (surge), up/down (heave), left/right (sway) translation in three perpendicular axes, combined with changes in orientation through rotation about three perpendicular axes, often termed yaw (normal axis), pitch (lateral axis), and roll (longitudinal axis).

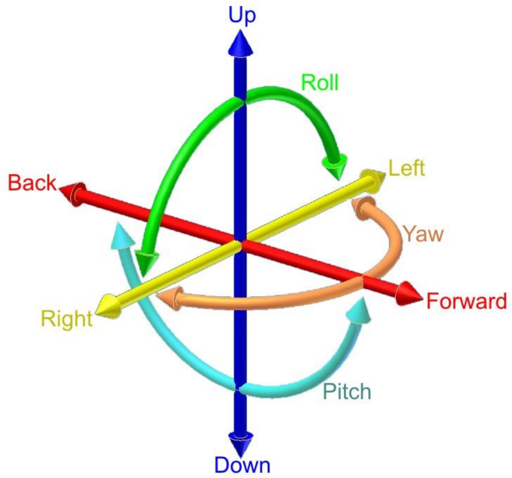


Figure 34: **The six degrees of freedom: forward/back, up/down, left/right, yaw, pitch, roll**

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