



Advancement in navigation technologies and their potential for the visually impaired: a comprehensive review

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Abstract

Improvements in technology and navigation tools are leading to more affordable and effective solutions to assist individuals with visual impairments. The progress made in navigation technology has the potential to increase inclusivity for the visually impaired in education, social, and workforce settings. After conducting a thorough review of the literature, we have identified key issues and concluded that collaboration among healthcare professionals, caregivers, programmers, engineers, and policymakers is essential for successfully developing navigation projects for the visually impaired. This study highlights different advances and relevant topics in the development of location-based applications for individuals with visual impairments. Our paper involved an extensive search of eight journal databases spanning from 1993 to 2021. We screened 4550 titles, analyzed 560 abstracts, and ultimately reviewed 35 full-text papers, resulting in the examination of 20 papers. Our findings indicate that the advancement of navigation technology can positively affect the quality of life of visually impaired individuals, particularly through assistive technology, mobile applications, and web services. Dot Waker, Nearby Explorer, Get There, and Google Maps are the most commonly used navigation systems by visually impaired individuals. Overall, our research suggests that continued development in navigation-assisted applications can significantly benefit the visually impaired community.

Keywords Navigation technology · Mobile applications · Visually impaired people · Location-based

1 Introduction

When encountering unfamiliar environments or pathways, perspective is deemed an essential component in mitigating visual hindrances that impede individual mobility. Consequently, a causal relationship between freedom and movement arises, whereby self-determination is enabled through absolute movement and spatial orientation [1]. The World Health Organization's (WHO) 2014 report revealed that there are 253 million individuals with visual impairments, with 36 million of them classified as blind and 217 million experiencing severe visual impairment (VI) [2]. This statistic primarily concerns developing countries, where 90% of the cases are concentrated, necessitating the development

of location-based aids for the visually impaired [3]. The white cane is the most important tool used by individuals with visual impairments; however, it can only detect near-ground obstacles, leaving obstacles below ground level or above knee level undetected [4]. Despite ongoing scientific research aimed at improving navigation for the visually impaired, assistive devices remain a viable means of facilitating mobility and object recognition [5]. The utilization of Geographic Information System (GIS) applications has the potential to increase the mobility of individuals with disabilities by analyzing various parameters. Navigation aids such as white canes, guide dogs, and trained guides have long been used by the visually impaired [6]. Studies show that individuals who become blind early in life rely on their vocal skills, including sound echoes, for navigation [7]. GIS technology can be employed to import map data, generate and prepare maps, and analyze networks for routing and directions. The use of tactile graphic images, such as the View-Plus IVEO-based map system, requires a separate braille printer, whereas audio descriptions can be collected on a touch screen using the paper-based method [8].

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Programs and aids developed for indoor and outdoor environments are particularly useful for individuals with visual impairments or legal blindness (VIB) and can facilitate the dissemination of ideas. Geographic technologies, including the white cane, are gaining interest. Technology and assistive devices can enhance independence in performing daily tasks and improve an individual's quality of life [9]. Visually-impaired individuals commonly require assistive technologies to access their phone or computer devices. Screen readers are a necessary form of assistive technology (AT) that transforms text and image content to speech or braille output [10]. Popular built-in screen readers include Apple's VoiceOver, Google's Talkback for Android, and ChromeVox for Chrome OS. Various research studies have been conducted utilizing different tools by visually-impaired or blind individuals.

Tapu et al. [11] conducted a study on a series of location-based tools for visually impaired people in external environments. Khan et al. [12] studied various methods to help the blind using positioning in the building environment. Fei et al. [13], about a variety of trip aides, particularly helping blind people identify directions using machine vision technology.

Hojjat [14] provided an outline of indoor location-based solutions for individuals with visual impairments, but systematic reviews of navigation systems that function both indoors and outdoors differ based on technological advancements.

Lin et al. [15] developed tactile maps that can be read with the finger, which enable individuals with visual impairments to encode information on the maps prior to arriving in the actual environment. Konstantinos et al. [16] studied the use of development navigation, including the use of technologies, tools, programs, and web services, in enhancing individuals' physical conditions.

However, most research has focused on improving the physical impairments of individuals, with fewer studies conducted on the use of developmental location-based for

individuals with visual impairments in academic studies. With the increasing volume of professional publications, it has become challenging to identify relevant research and integrate key concepts. In this paper, an integrated literature review was conducted using specific search strategies to address such issues during the identification phase. The main aim of this paper is to analyze the available investigation findings on the role of location-based tools in the lives of individuals with visual impairments and to identify their applications to make them accessible as discussed in the existing literature.

2 Method

The present study utilized specific keywords in a comprehensive database search to ensure the retrieval of relevant literature on visually impaired individuals (VI), development navigation, Geographic Information System (GIS), and location-based applications. Eight prominent journal databases were examined, and a cross-section of publications between 1993 and 2020 was included in the search results. After a primary screening of 4550 titles, 560 abstracts were reviewed, leading to the final selection of 35 full-text papers for analysis. Subsequently, a detailed evaluation of the 20 most relevant papers was conducted and their findings were synthesized (Table 1).

3 GIS systems for blind people

3.1 Apps, web services and tools

3.1.1 DotWalker

Dot Walker is an Android outdoor navigation application addressing the specific needs of sight-free trips. It is supposed that the Talkback screen reader will be used with this

Table 1 Search keywords and databases

Search Criteria	Keywords*					
	Field and Access**	Document Type	VI	Development Navigation	GIS	Location-based applications
Springer Link	All	Journal	350	752	70	421
Science Direct	All	Journal	350	831	60	721
Wiley Online Library	All	Journal	900	1245	82	767
IEEEXplore	All	Journal	100	503	50	239
PubMed	All	Journal	450	123	80	932
Taylor & Francis Online	All	All	350	82	0	892
Google Scholar	All	All	2050	1646	218	1251
Total			4550	5182	560	5223

Note: * A comprehensive search of papers was conducted through the use of relevant keywords covering the period between 1993 and 2021

** Papers were searched using every search criteria field with full text and restricted entry

application. On its own, Dot Walker uses straight speech output, sound alarms, vibrancy, and high-contrast text that can be enlarged as needed [17].

A GPS sensor should be switched on and a geomagnetic sensor is used for compass features and an accelerometer to trigger some user proceedings. (Fig. 1), the application is existing in two versions. The free version comes with restricted functionality, for example, management of up to 30 points and passive availability to web-relevant functions like navigation, maps, or place tracking. The paid version can be found as Dot Walker Pro [18].

3.1.2 Nearby Explorer

Nearby Explorer is an inclusive GPS-based application that has been specifically designed to accommodate the needs of blind and visually impaired individuals. This innovative software not only provides direction, but also employs

a range of techniques, including sign reading and route specifications, to create a rich, detailed description of the environment [19]. It uses internal maps, so there is no need to connect information. Still, if we have a map, Nearby Explorer complements the internal map information with locations collected from Google Places. Nearby Explorer Online d is a free version that fewer features and does not include internal maps. In contrast, it does include full maps of the USA and Canada, and internal maps are over 4GB in size [20]. If mobile data is connected, this program will increase the information with Google location data. Favorites can also be created, named, and shared on OpenStreet-Map so that others can use the places you mark and identify [21]. The app’s location and direction can also be used to obtain targets such as the movement of a vehicle and as a compass [21].

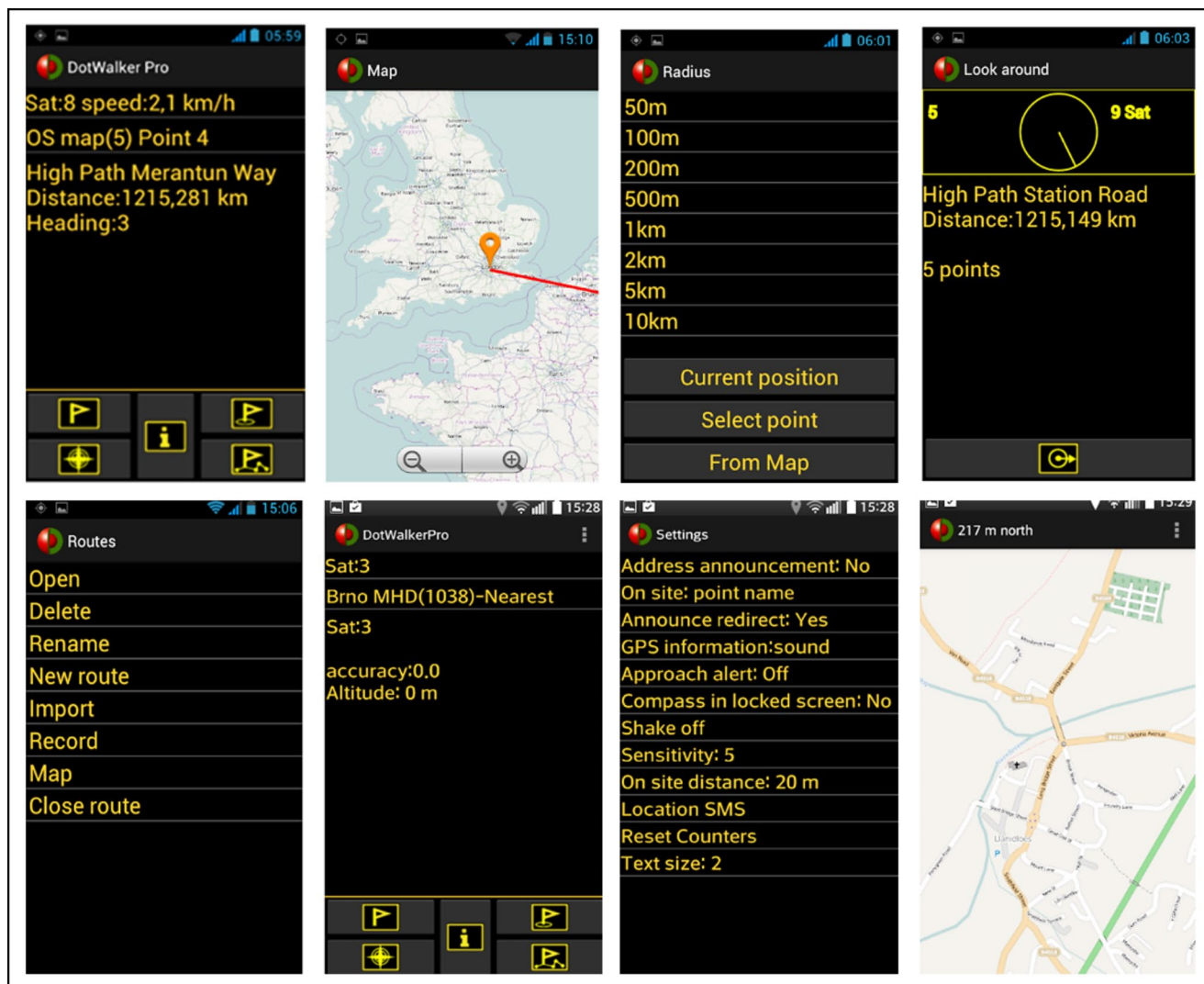


Fig. 1 Dot Walker Pro graphical user interface

3.1.3 Get there

The assistive technology Get There has been developed specifically for users with visual impairments, and is not an adaptation of technology designed for sighted individuals. The app works with Talkback, the standard Android screen reader, in such a way that the different messages do not vie with any other. Get There does not show a map but tells where you are and how to reach your destination. Navigational guidance automatically says to you before and after each junction. At every time, you can ask to Get There to say where you are, easily by shaking your mobile device. Get There find when you have gone off from the planned path, and says you where you went a mistake and what you require to do to get back on route.

If you are not navigating to a destination, Get There says you the street you are on, the next cross-streets, the interval to the next junction, and a full description of even unusually shaped intersections [22]. For partially sighted users, all menus are labelled with big bold kind, and the background colors are intermittent to form a corrugated pattern. Get There can be used anyplace in the world, subject to access to open-source map information in that region [22].

3.1.4 Google Maps

In October 2019, Google Maps launched a new application called Detailed Voice Guidance, which offers audio instructions for pedestrians to assist blind and visually impaired

individuals during walks. This feature represents a significant advancement in Google Maps' accessibility, particularly for individuals with visual impairments (Fig. 2).

However, in order to benefit from this feature, users must access their Google Maps settings and choose "Navigation." Subsequently, "Voice guidance" must be selected under the Options category located at the bottom of the list [23].

3.1.5 Blind square

The IOS smartphone possesses a GPS and compass feature that allows for user positioning and subsequent data collection regarding the website environment. This data is then processed using an algorithmic selection process to determine pertinent information communicated to the user through a synthesized voice, as per source [24].

3.1.6 LowViz Guide

This application, which is based on location services, enables users to navigate vast areas and determine the most direct route between two points (Fig. 3). Navigation will be available through the smartphone feature so the LowViz guide includes the following [25]:

- Indoor Location-based & presence detection.
- Navigation & pathing.
- places sharing.
- Location-based connection.

Fig. 2 Get Their graphical user interface

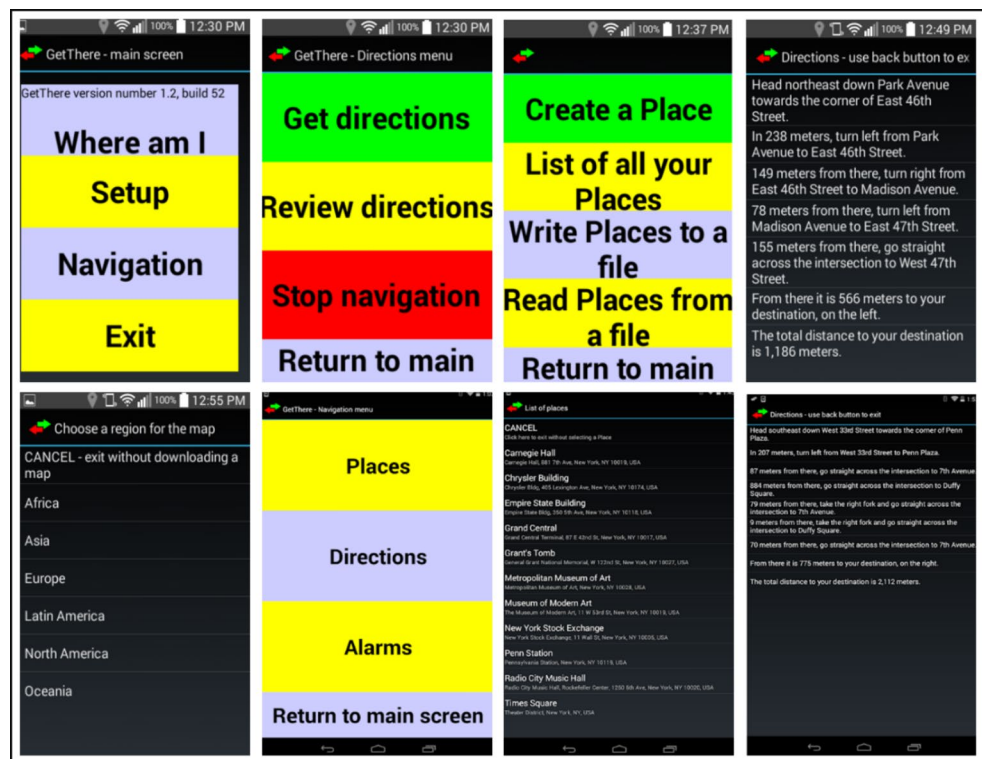


Fig. 3 LowViz Guide graphical user interface

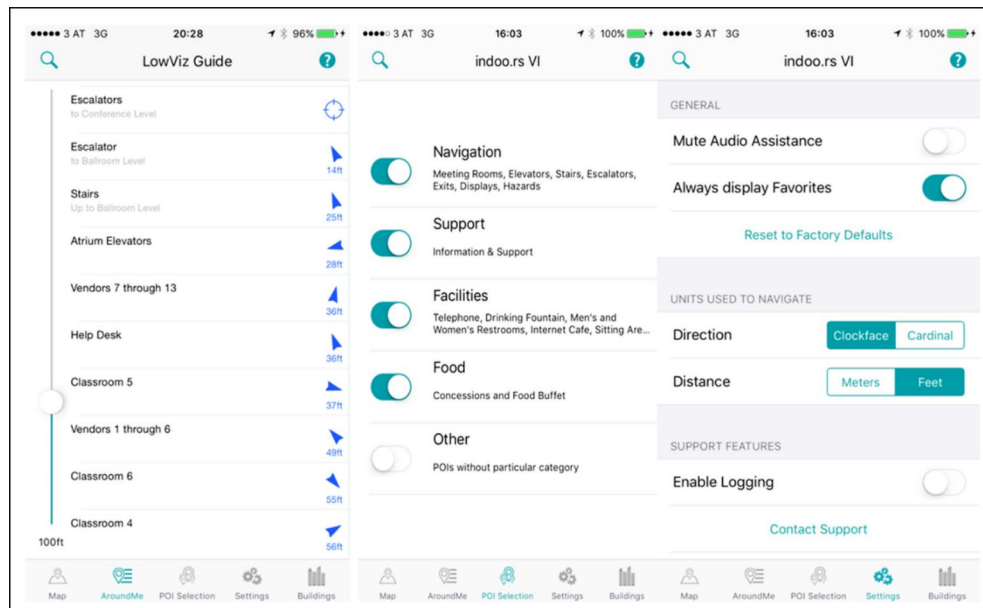


Fig. 4 3D tactile map made from OSM data

3.1.7 OSM for the blind

Open Street Map has initiated projects aimed at delivering OSM services specifically created for people who are blind or visually impaired (Fig. 4). These projects involve teams of experts who use a collection of approaches to design web-based instructions that are accessible to the blind and visually impaired through maps, as per the source [26]. One such initiative is the development of the web service <http://blindweb.org>, which offers tactile maps that can be produced or printed on microcapsule paper or 3D printers. This service includes shortcut options that allow users to

enlarge the maps, which feature typical landmarks, such as buildings and entrances. Another website, <http://hapticke.mapy.cz>, provides access to a range of maps of the Czech Republic that can be downloaded and published region. Finally, touch-mapper.org offers 3D touchable maps based on OSM information, including roads, buildings, railways, and water areas, to provide simplified navigation solutions for the blind, as per source [26].

Voluntary Geographical Information (VGI) is an essential component of Open Street Map (OSM), which supports of tailored solutions for the blind and visually impaired. Moreover, some people with color blindness have reported experiencing better usability of OSM compared to Google Maps. People with a red/green color combination have a stronger performance than red, and on the other hand, for a number of people, Open Street Map is more difficult to use than Google Maps [26].

3.1.8 Braille note GPS

The GPS receiver represents a critical location-based mapping tool, as it supplies location information necessary for independent travel among individuals who are blind or partially sighted [27]. This tool facilitates preparation for trips by enabling users to select any location worldwide and navigate to it either physically or virtually. Additionally, the GPS device can identify nearby destinations and announce them automatically [24].

Table 2 Summary of navigation methods

Ref. Paper	Target	Wireless Technology	Algorithm
Cecílio et al. [19]	Navigation	Bluetooth	Distributed Indoor Navigation
Li et al. [30]	Navigation	RFID	User positioning and Tags
Karchňák et al. [20]	Road planning and navigation	Wi-Fi	Wi-Fi-based positioning
Kanwal et al. [31]	Navigation	Infrared L.E.D.	Obstacle detection
Lim et al. [32]	Obstacle detection and navigation	Ultrasonic sensor	RISS-GPS-LKF

3.1.9 Approach of location-based systems based on ultrasonic sensors for blind people

Ultrasonic sensor-based technology utilizes ultrasound waves to calculate the interval between the sensor and the object by calculating the time of wave propagation and reflection. However, the short connection distance and line-of-sight (L.O.S) limitations caused by obstacles have been recognized as significant challenges of this technology [28]. In another study [29], an intelligent environment detection (SED) system established on wooden structures have been developed for the benefit of visually impaired and blind individuals.

The proposed system enhances spatial awareness, guides users, and provides an estimation of the users' status. The technology incorporates ultrasonic sensors, accelerometers, cameras, GPS, smartphones, and road protocols, which use the Linear Kalman Filter (L.K.F) algorithm within the Inertial Sensor System (R.I.S.S)-GPS for the following analysis.

The initial outcomes of this system have demonstrated success in helping blind individuals with walking, following, and recognizing traffic lights, actually for very short distances (Table 2). Furthermore, the study has explored various algorithms used in wireless technology to support the visually impaired.

3.1.10 Buzz clip

The Buzz clip is a compact and portable device that utilizes ultrasonic sound technology to detect potential obstructions that might obstruct the path of visually impaired individuals. This device notifies the user of obstacles in the path and also allows them to find their way again if they hit any objects around them [24].

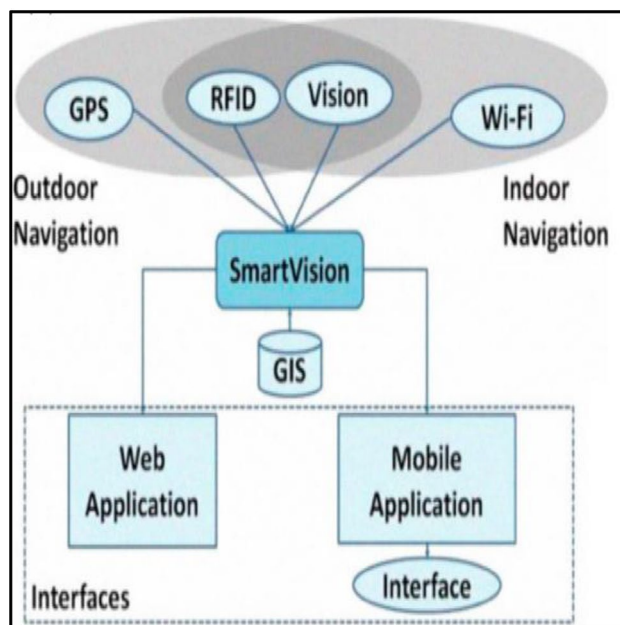


Fig. 5 Smart Vision navigation system

4 Scientific papers

4.1 Smart Vision: Navigation system

A Portuguese company introduced the “Smart Vision: Creating a Vision for the Blind” project (Fig. 5), which features a prototype indoor and outdoor navigation system comprising various modules that leverage GPS, Wi-Fi, and a GIS database. Additionally, the system incorporates a passive RFID tag system deployed on sidewalks that enhances visibility of routes and avoids obstacles [33].

The system's prototype incorporates global navigation capabilities by utilizing landmarks stored in a GIS database to optimize the route. Local navigation capabilities enable route recognition, which complements, but does not replace, the white cane system. The system also alerts visually impaired individuals to potential hazards [34].

The Smart Vision module utilizes GPS or Wi-Fi in indoor environments to provide regular and successive updates of the user's geographic coordinates via the geographic information system and navigation modules [35]. When GPS or Wi-Fi signals are unavailable, RFID tags and computer vision are employed as supplementary technologies. The second theme, which involves the detection of specific signs, is suitable in both indoor and outdoor environments [36].

Navigation modules interface with the Smart Vision module to retrieve and employ small GIS data. Following analysis of the retrieved data, the Smart Vision module stores the resulting navigation instructions, which are then executed

Fig. 6 Navigation system RFID

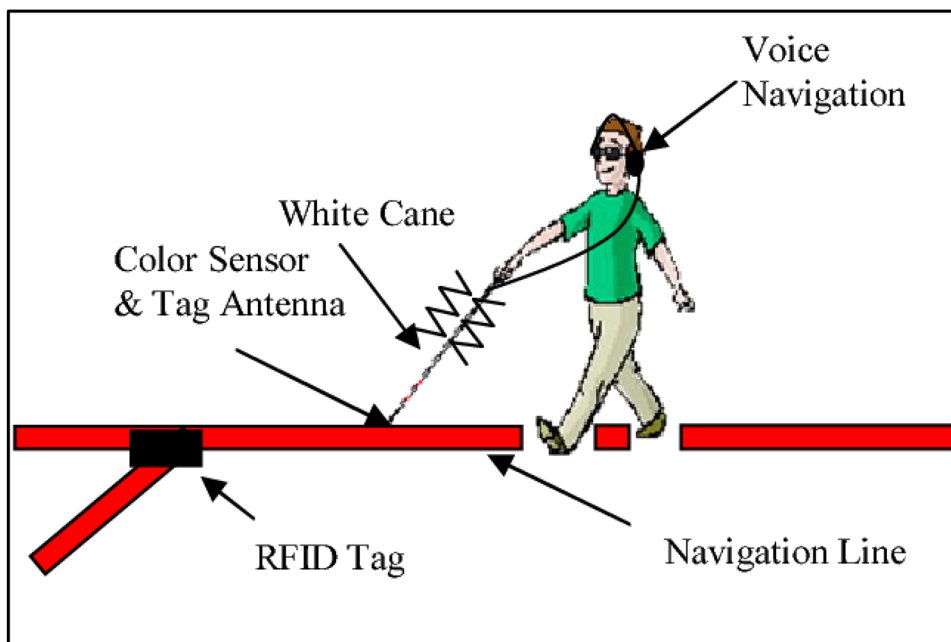


Table 3 Comparison of available technologies based on various technologies

Technology	Technique	Indoor	Outdoor	Necessity of Infrastructures
Straight Sensing	RFID	✓	✓	✓
	Bluetooth	✓	✓	✓
	I.R.R.	✓	-	✓
	Barcodes	✓	✓	✓
Dead Reckoning	IMU	✓	✓	-
	Triangulation	✓	✓	✓
From straight sensing	GNSS	-	✓	-
	Fingerprint	✓	✓	-
	Markers	✓	✓	-
Pattern Diagnosis	Natural Elements	✓	✓	-
	3D Sensing	✓	✓	-

using Dijkstra’s Shortest Route First (SRF) routing algorithm [36]. This algorithm efficiently calculates the shortest path between a start and an end point through a graph, and performs equally well using Wi-Fi signals (Fig. 6). The algorithm is particularly useful for indoor navigation where GPS signals are absent. The user’s location can be determined using the triangulation method based on signal strength, and a combination of the calibrated positions of Wi-Fi admission points (APs) with GIS data. The resulting positional accuracy ranges from 7 to 8 m [36]. Presents an analogy of current navigation development systems, allowing for a mental assessment of technologies based on user needs (Table 3).



Fig. 7 Components of the navigation system

4.2 Blavigator: navigation system

Blavigator (Blind navigator) is the successor of the Smart Vision project and intends to continue its work, improving and optimizing it. This system integrates a set of specialized modules, each one performing specific tasks (Fig. 7). The interface comprises three distinct elements: text-to-speech technology, a 4-button command pad, and vibratory outputs. Text-to-speech technology serves a dual purpose of conveying crucial information to the user and enabling menu

navigation. The user can also interface with the system by manipulating a 4-button command pad. The vibratory devices around his body will be triggered when the system wants to provide heading instructions like “turn to the left” or turn to the right. The approach for the GIS and Computer vision modules is similar to that of Smart Vision. Here we discuss the navigation module [37].

4.3 Kammoun et al.: Algorithm

Kammoun et al. devised a routing algorithm tailored to the requirements of visually impaired pedestrians, with the objective of identifying a more compatible route that links the starting and ending points, and simultaneously enhances the mental model of the travel route and surrounding environment for the blind [38]. This algorithm is a critical component of NAVIG (Navigation Assisted by Artificial Vision and GNSS), a multi-disciplinary project designed to enhance the navigational autonomy of individuals with visual impairment [39].

The NAVIG prototype is constructed using a GPS receptor, a stereoscopic camera, and a following tool installed on a helmet. Furthermore, a microphone and headphones have been incorporated into the prototype to facilitate speech and voice communication, while a notebook computer is housed within the backpack of the visually impaired individual. The prototype leverages Dijkstra’s algorithm to determine the optimal path [38].

4.4 Brock et al.: multi-model map

Brock and colleagues developed a tactile map system that utilized a single-touch screen with additional audio output, and explored the use of multi-touch displays to enhance interactivity with these maps. They identified the necessary

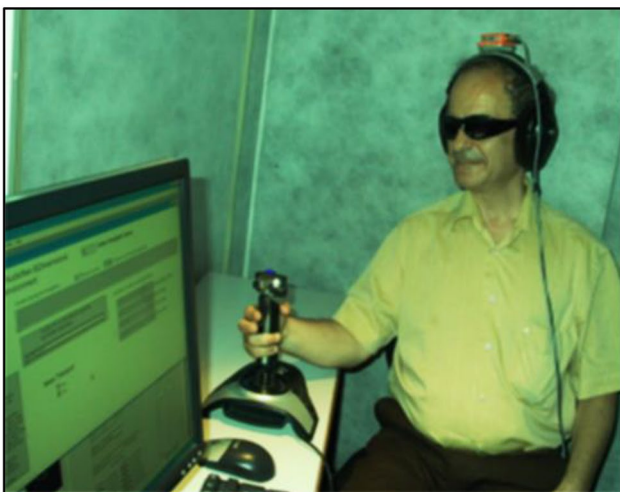


Fig. 8 Headphones equipped with orientation sensors

characteristics of an appropriate touch device and presented an early example of multimodal interactive maps. The prototype is formed of four interconnected modules that are linked by middleware. The first module is a driver that responds to user actions and screen events, and maps them to another software module in the SVG format. This module receives messages and utilizes touch location data to identify the touched map element and then sends a message with the corresponding ID. The third module is the Multimodal Interactive Map (MIM), which receives messages and data from both the driver and the touch module. To avoid unnecessary sound output, the MIM is less sensitive to touch alone, and the audio output is triggered only when the user clearly presses the map and not when they explore the map with their fingers. The MIM then sends a message with text output to the Text-to-Speech (TTS) module which converts it into voice output [40].

4.5 Audio-haptic map

Konstantinos et al. investigated whether the spatial science created after a person created an acoustic-haptic map with visual impairments could be used: (a) to move separately and efficiently in an area and also (b) to see specific points. Whether an area is represented on the desired map or not. In this study, a multimodal application was employed to present maps, which were analyzed using the Geomagic Touch, a tactile feedback device also referred to as the Phantom Omni. The study involved the participation of eleven adults who suffered from total blindness, with only light perception. The age of the participants ranged from 20 to 61 years. The findings indicated that the knowledge obtained through this study could be effectively utilized for orientation and mobility in urban settings [16].

4.6 Virtual reality

Picinali et al. conducted a study on aiding visually impaired individuals in navigating a new environment by training them to listen to sounds and their interactions with virtual reality events. Two learning methods were compared: in-situ movement and navigation in virtual architecture with audio information only (Fig. 8). Results from two groups of five participants indicated that interactive investigation of virtual sound room simulations could generate enough information to construct integrated spatial mental maps. Nonetheless, some differences were observed between the two environments tested, with topological and metric properties of mental images obtained through actual navigation [41].

4.7 Blind guide: Wireless sensor network

Pereira and colleagues proposed a novel approach for obstacle detection and warning using an ultrasound-based regional network, which can serve as an effective and comprehensive solution for visually impaired individuals while navigating through different locations. Through cost and time analyses, this method was found to be an adequate and practical solution for the blind community. Specifically, the proposed system involves a wireless sensor network consisting of ultrasound sensors located at strategic points on the human body to detect obstacles and avoid blind spots (Fig. 9) [42].

5 Discussions

Pal et al. [43] using blended-methods field research of smartphone assumption by 81 people with visual impairments in Bangalore, India, argue that these locations are dated in the instance of access where a non-similar population should adapt to technologies made for vision people. They found that more users switch to smartphones notwithstanding their understanding of significant availability challenges with smartphones. The authors suggest that assessing perceived usefulness and real usage of technology based on requirement-relevant social and economic functions is a critical step towards technology adoption for individuals with disabilities.

Cervenka et al. [44] developed a prototype on Mapy.cz that enables blind users to automatically convert maps into a tactile format that can be read through touch. This is accomplished by printing maps on microcapsule paper, which provides a new view of the use of tactile maps. Blind users



Fig. 9 Ultrasound sensors in different parts of the body to detect obstacles

can opt the desired region and extract a tactile map using this prototype. Calle-Jimenez and Luján-Mora [45] developed an accessible map visualization prototype based on WCAG2.0 that helps reduce visual barriers of online geographic maps. The prototype was tested in various browsers and assessed for accessibility by a series of tools. As a case study, the prototype displayed maps of Ecuador, and its degree of availability was assessed in a real environment.

Kanık [46] proposes that libraries and information centers should provide assistive technology for visually impaired individuals, as several Turkish libraries have already found it useful and beneficial. Kulyukin and Kutiyawala [47] found that while some devices help visually impaired individuals navigate stores and make purchases. Traveling for visually impaired individuals often requires extensive planning and dependence on others for information. Research in Malaysia has shown that user-friendly websites can be very beneficial for the travel of visually impaired individuals. Wong [48] used Hager Strand's Spatio-temporal frame to gain a new understanding of the daily movements of visually impaired people in the San Francisco Bay Region. The study analyzed data on sitting and mobile phone conversations and found that the space-time limitation of visually impaired individuals is closely related to the availability of vehicles, assistive technologies, and mobile devices. These findings provide opportunities for intervention to better the modality of life of visually impaired individuals. Isazade et al. [49] conducted research on the application of GIS-based location in modeling the spread of COVID-19 in Iran using geographic weighted regression models, hot and cold spots, and Moran's autocorrelation. The results showed that GIS can be used as a tool for modeling epidemiology in most parts of the world. Isazade et al. [50] integrated Moran's I, geographically weighted regression (GWR), and ordinary least squares (OLS) models in a spatial-temporal modeling of the spread of COVID-19 in Qom and Mazandaran provinces, Iran.

6 Conclusion

Advances in machine vision and robotics in the last decade have also improved blind navigation systems. The difficulty of location-based for individuals with visual impairments has been addressed by researchers from various perspectives, resulting in the introduction of several prototypes. However, the development of new navigation systems has been halted, leaving a gap in the market. A significant consideration in the implementation of these systems is the cost of equipping sidewalks with RFID tags, and whether the community is willing to invest in this for the benefit of a minority group.

Location-based applications have recently made significant strides in improving navigation for visually impaired and blind individuals who are unable to use traditional maps. These applications have the potential to enhance their understanding of their surroundings. However, the use of generic apps and programs, which are not designed specifically for visually impaired individuals, can present a range of challenges. Thus, designers should consider the needs of this community during the design phase.

This study highlights different advances and relevant topics in the development of location-based applications for individuals with visual impairments. However, it is difficult to provide conclusive advice that is applicable to all visually impaired communities, given the varied and constantly evolving social contexts in which they live. Society should recognize and embrace the expertise of visually impaired individuals who learn via computer-assisted technology in their respective countries. Therefore, available technologies can be a good starting point for further investigation to investigate the development and adoption of navigation technology among individuals with visual impairments in different countries.

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Declarations

Conflict of interest There are no conflicts of interest declared by the author.

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