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Advanced Technologies of Indoor Navigation for Visually Challenged Persons

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ABSTRACT
Indoor navigation in unfamiliar surroundings has been a tough task for visually challenged persons. Electronic travelling aids (ETA) embedded with different features such as obstacle detection and recognition towards the desired destination whether it is staircase, lifts or some room can help the visually challenged person for navigation. GPS technology has limitation in indoor navigation due to very low accuracy. This paper presents a comprehensive review on recent advances in indoor navigation technologies and aids for facilitating the visually challenged person movement. Based on the studied researches this paper gives some recommendation for the future scope of work in this direction has been enumerated.
Keywords—Indoor navigation, Blind, Visually Challenged, technology

1. Introduction

Navigation is a crucial part of every individual's life. Vision plays an important role in navigation since it eases the movement from one place to another. In familiar places it is easy to navigate even without vision such as in our room, office. However, it is very difficult to navigate in unfamiliar environment. Globally, according to World Health Organisation (WHO) 2.2 billion people are visually impaired in 2021[1].The major reasons of vision impairments are uncorrected refractive errors, cataract, age-related macular degeneration, glaucoma, diabetic retinopathy, corneal opacity, trachoma etc. [1].Blind navigation system is categorised into three categories that are Electronic Orientation Aids (EOAs), Position Locator Devices (PLDs) and Electronic Travel Aids (ETAs) [2]. Electronic Orientation Aids (EOAs) are developed to guide the navigating path for visually challenged or blind person. Basically, EOAs are used for outdoor navigation which consist of different types of sensors and a camera that detect obstacle in the path [3,4]. Global Positioning System (GPS) and Geographic Information System (GIS) are the technologies that are in used in Position Locator Devices (PLDs).This combination of GPS and GIS is used for the navigation of user from present location to destination. However, Lin et.al [5] claims that the grouping of GIS and GPS will not help visually challenged and blind person as this technology is not able to detect obstacle in the path. The limitation of this system is that it can only be used for outdoor navigation not for indoor navigation. Electronic Travel Aids (ETAs) gives better orientation and navigation to blind person.it is also helpful in detecting obstacles in the path [6]. The major use of ETA is obstacle detection and navigation [7,8].ETA has been implemented more or less successfully with GPS for outdoor navigation [9].ETAs consist of sensing unit and receiving unit. Sensing unit senses the input and gives single or multiple feedback modalities to give information as output to user which help user to navigate. GPS has limitation because of attenuation of signals due to physical barriers such as walls, roofs and other objects [10].

2. INDOOR NAVIGATION TECHNOLOGIES

After reviewing different publications indoor navigation technology has been distinguished into two categories namely visual perception based technology, non-visual perception based and hybrid technology. Different type of technologies can be used to build non visual perception based navigation system and visual perception based navigation system as shown in figure 1.

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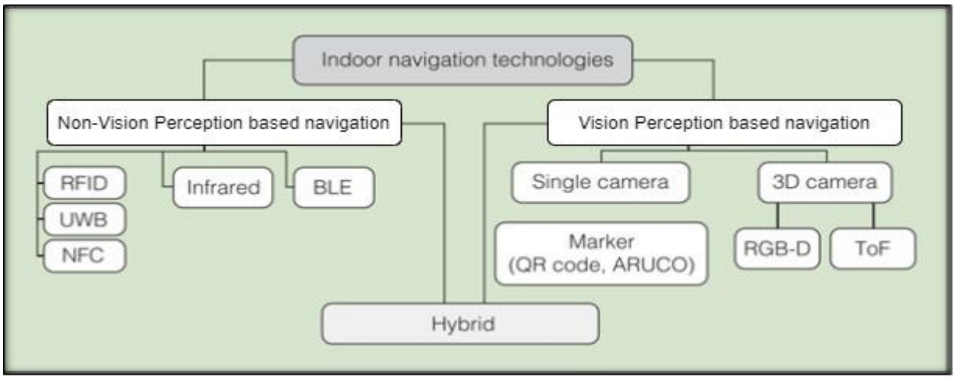

Fig 1. Types of Indoor Navigation Technologies

2.1 Non Visual perception based Technology

There are numerous technologies that can be employed to build up non-visual perception based system. These technologies mostly used for the solution of localisation problem. These technologies are not the stand alone technologies, these require additional sensory components to build a sensor based navigation tool. On the basis of accuracy, operating range, energy consumption, execution cost the comparison among these five technologies has been done in figure2.

Non-Visual Perception Based Navigation Technologies

Evaluation Criteria	RFID	NFC	BLE	UWB	IR
Accuracy	Moderate Low	Very High	Low (1-2 m)	High (+/-0.15 m)	Very High (0.04m)
Operating Range	0.5-1000 m	<0.2m	<75m	90 m	0.2-14 m
Energy Consumption	Very High	Low	Moderate	Low	Moderate
Execution Cost	Very High	Moderate	Moderate High	Low (non direct sight)	Moderate (direct sight)

Fig 2. Types of Non Visual Perception based Technologies

2.1.1 RFID

Radio Frequency Identification (RFID) navigation system is the first non-visual perception. Digital data can be encoded in tags or smart labels and captured by a reader via radio waves in this technology. The system mainly suffers from signal disturbances, signal accuracy because of fluctuation, slow read rates, reader and tag crash, etc. Moreover, the user is required to bear in mind the RFID reader location in a navigation framework. [11].Radio frequency is used for identify the object in RFID technology. Distance-dependable positioning problems could be solved depending on the type of (active, operation range ≤ 40 m to ≤ 1 km [44] or passive, operation range ≤ 0.5 m to ≤ 10 m) [45].

2.1.2 UWB

Ultra-wideband (UWB) is just like a bluetooth device which is a wireless communication device used for short range. UWB radio waves operates at very high frequencies (GHz) and it can capture highly accurate spatial and directional data. Ultra-wideband (UWB) is comparatively accurate (it can determine the position of the user within ±0.15 m, 95% CI) and doesn't require direct visibility between the tags and the sensors. UWB signals are commonly used for positioning and orientation. This technology has been used to create a SUGAR [13] system that helps visually impaired people navigate indoors. UWB sensors have an operating range of 90 m in low data-transfer mode, making the technology ideal for deployment in large buildings.Since UWB is a short-range radio technology that transmits short pulses (<1ns) over a large bandwidth, it is less sensitive to multipath effects and offers high precision. Localization systems based on UWB technology achieve an accuracy of

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centimetres (<30cm) that is considerably better than BLE or Wi-Fi. The NLOS (NON-Line-of-sight) signal significantly reduces the accuracy of localization. ML techniques have been gaining a lot of research attention in the literature to distinguish and mitigate the NLOS effect [40].The authors in [41], have proposed an UWB system for positioning in harsh environment that does not require any apriori knowledge. The root mean square (RMS) of absolute range errors after NLOS mitigation was reduced from the original 1.3 meter to 0.651 meter in their experiment in a real office environment.

2.1.3 NFC

Near Field Communication (NFC) is a standards-based short-range wireless connectivity technology that makes life easier and more convenient for consumers around the world by making it simpler to make transactions, exchange digital content, and connect electronic devices with a touch. NFC is compatible with hundreds of millions of contactless cards and readers already deployed worldwide [14].NFC isn't some radically new technology. It's simply an evolution of RFID (radio frequency identification) technology that has already been around for decades. If you've ever used a key card to access an office building or hotel room, you're already familiar with how it works. Both RFID and NFC operate on the principle of inductive coupling, at least for short-range implementations. This essentially involves the reader device generating a magnetic field by passing an electric current through a coil. When a tag (with its own coil) is brought nearby, the field induces an electric current within the tag — sans any wires or even physical contact. Then, once the initial handshake is complete, any stored data on the tag is wirelessly transmitted to the reader. The key distinction between RFID and NFC lies in their transmission ranges — the former is often used over longer distances. For example, some regions automatically collect road tolls through RFID. Tags are usually affixed to vehicle windshields and you simply have to drive through the toll booth. Communication can take place over even longer distances (think a hundred feet or more) if the RFID tag is equipped with a power source. NFC, however, only has a maximum range of a few centimetres, at most. And in most smartphone-related applications, you'll find that the software will only initiate communication if there's physical contact. This is to prevent accidental triggers — especially important now that the technology is used for transferring sensitive data. Another noteworthy point is that NFC devices can act as either a reader or tag. This bidirectional capability allows you to use one piece of hardware — such as your smartphone — for all kinds of different applications [15].

2.1.4 Infrared

One of the first and most widely recognized infrared (IR) (two papers) indoor positioning systems is the "Active Badge" system [16] for finding people in a room. The users wear "Active Badges" that emit short IR pulses containing unique identifiers at a frequency of 0.07 Hz. IR receivers signals is collected by a network which is used for localisation inside a building. Following this principle, Islam et al. [17] built a grid of 16 IR transmitters that continuously monitored user position and deployed it in an indoor environment. The authors also presented an algorithm for calculating the position of a receiver-wearing user within the grid.the proposed algorithm does not scale well due to the memory required for computing several paths simultaneously in larger grids. The distance of object/obstacles can be measured by IR sensor for indoor navigation [18]. 0.2-14m is the operating range of IR sensor. For instance, time-of-flight (ToF) IR sensors measure distance through emitting pulses of eye-secure infrared rays and recording the time it takes for the light to go back to the sensor [19]. The sensors measures distances up to 14 m with zero 0.005 m decision and 0.04 m accuracy. IR systems require direct visibility between the sensors. A short operating distance makes IR sensor-based positioning systems complex and inefficient in comparison to other technologies. Contrary to expectations, our systematic survey did not find any Wi-Fi applications in this research field. However, this methodology is becoming increasingly popular because it is easy to install a Wi-Fi positioning system using access points that already exist in many buildings.

2.1.5 BLE

Bluetooth Low Energy (BLE) is another technology (one paper) that could be used for creating a network of navigational tags [20]. Systems using Bluetooth beacons were reported in literature

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multiple times [47–49].Nair et al. [50] proposed a hybrid positioning and navigation solution that combines both Bluetooth Low Energy (BLE) beacons and Google Tango to tap into their strengths while minimizing their weaknesses. In the Guide Beacon system [51], a smartphone was used to interact with Bluetooth-based beacons placed in the different indoor locations which can assist the users in giving navigation directions. Some of the improvements needed in the proposed system are with the user interface and navigation modules. In comparison to NFC, it has a wider operating range (up to 75 m) and requires fewer tags to cover a given area. It reaches an accuracy of 1–2 m, depending on the signal spread pattern. BLE-based systems can be useful because indoor way finding for visually impaired persons does not require continually monitoring the user's location; rather, it is more important to locate the user accurately at significant points (e.g., stairs, elevators, office doors) [20]. Beacon is an active RFID as it does not depend upon RFID reader for energy generation. Beacons continuously transmit data packets of Bluetooth Low Energy signals (BLE) at regular interval of time. Mobile application, pre-installed services on smartphones used for the detection of data packets. BLE consumes less power as compared to other navigation devices as it transmit little data over a small range. The main disadvantage of Beacon is the maintenance cost, as the transmitter and receiver installed all over the ceiling.

2.2 Visual perception based Technology

Vision-perception based navigation systems are generally superior to non-vision-based systems. Vision-perception based systems are used for navigation as well as for object detection and recognition. The main advantages and limitations of four vision-based technologies are evaluated and compared in Fig. 4.

Visual Perception Based Navigation Technologies

Evaluation Criteria	Single Camera	Single Camera with Markers	3-D camera RGB-D	3D Camera ToF
Accuracy	Moderate Low	High	0.2m	Very High (=0.01m)
Operating Range	20 m (depends on resolution)	<2-10m (depends on markers resolution)	<10m	<5 m
Energy Consumption	Moderate	Low	Moderate Low	Moderate Low
Execution Cost	Low Moderate	Moderate-High	Low	Low

Fig 3. Types of Visual Perception based NavigationTechnologies

2.2.1 **Single Camera**

Depending on the type of camera sensor, the input can be divided into the following categories: single camera (CCD or CMOS sensor [21]) and 3D camera. In single-camera systems [22]–[25] (four papers), cameras without depth sensors are used. Building on the ideas from non-vision based systems, the use of fiducial markers (Aruco, QR codes) is suggested [23], [24] as an alternative to computationally intensive video analysis. Markers simplify complex video processing to a recognition of a finite set of markers integrated in the environment. Recognition of QR codes presented by Idrees et al. [23] were tested under varying light conditions, size and blurriness of the markers. QR codes were easily detected under low light conditions and up to 60% of blurriness ratio.

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Manlises et al. [25] demonstrated the feasibility of obstacle and shortest route detection and using a single web camera without compute-intensive hardware. The efficiency of such system reaches 80%by implementing CAMShift [26] and D* [27] algorithms. It was proven after testing of the system and from the post-survey results of visually impaired persons.

2.2.2 3D Camera

In the case of 3D cameras, indoor navigation systems could be divided in ToF camera and RGB-D camera methods. Both types are able to detect objects/obstacles and estimate distance to them. The Intelligent situational awareness and navigation aid (ISANA) [52] was an electronic SmartCane proto-type that uses the Google Tango [53] tablet as its mobile computing platform. Using the onboard RGB-D camera, efficient obstacle detection and avoidance approach Localization of the user's position in the room is estimated by visual odometry using RGB-D or ToF cameras. In ToF cameras [28]–[30] (three papers), IR ToF sensors are used. The camera illuminates the environment with modulated IR light and measures distances up to 5 m with accuracy ±0.01 m. For pose estimation, the 3D range data of the ToF camera are registered to form a large 3D point cloud map. H. Zhang and C. Ye [28] proposed a new indoor localization method using a ToF camera that outperformed the benchmarks. It shows that it is capable of obtaining a more accurate pose with less time than the state-of-the-art plane-based SLAM methods. Meanwhile Ye et al. [29] propose a system with a ToF camera used for both pose estimation and object recognition in an unknown indoor environment. This type of system performs object recognition by a Gaussian mixture model (GMM) based method and works with success rate over 86.7%. By the way, the pose graph algorithm used for pose estimation works with much smaller final position errors than dead reckoning methods. In Jeon et al. [30], a ToF camera is employed as the main sensor in the proposed system since it has a small size and requires relatively low computational complexity. To explore an unknown environment during robot navigation, Tai et al. [22] proposed a Deep Q-Network (DQN) based learning model where Convolutional Network was used to extract features from an RGB-D sensor. A depth camera provides ranging information. Among depth camera recognition systems, Microsoft Kinect [46] is usually used as the primary recognition hardware in depth based vision analysis systems.

3 Computer Vision Based Approaches

Recent advancements in computer vision and smartphone devices open up new opportunities, which should motivate the academic community to find novel solutions that combine these evolving technologies to enhance the mobility and general quality of life of VI people. Unfortunately, we have found that this prospective research niche has not yet been well covered in review papers. Unfortunately, we have determined that this potential studies area of interest has now not but been well protected in evaluate papers. The only reviews we could identify were several that focused on existing mobile applications for the blind [31], [32]. These findings suggest that Electronic travelling aids, navigation aid modules, and textual content-to-speech applications, in addition to that virtual audio shows which integrate audio with haptic channels, are becoming included into standard mobile devices. Increasingly, user-friendly interfaces and new modes of interaction have opened a variety of novel possibilities for the VI [34], [33].

Machine Learning algorithms can effectively solve many of the limitations of the conventional techniques used for localization in indoor environments. Conventional methods often lack scalability; therefore, cannot perform well in the large scale IPS such as airports, shopping malls and multi-storey buildings with large training data sets. Furthermore, traditional IPS methods are not very flexible in adapting well to dynamically changing environments and in the presence of multi-dimensional and heterogeneous data applications [35]. Machine Learning has demonstrated as an effective manner to fuse multi-dimensional data accumulated from more than one positioning sensors, technology and techniques. For example, both supervised and unsupervised learning have been applied for fusion weight generation in [36]–[37]. However, unsupervised ML fusion technique is superior since it calculates the weights in real-time without offline training [38]. Furthermore, transfer learning has been applied in fingerprint-based localization to enhance system scalability without excessive site surveys and without sacrificing accuracy when there is a lack of labelled data [39]. An Indoor Positioning System (IPS) is a GPS free system that estimates the position of the objects or people in a confined environment (e.g. buildings, tunnels) in a continuous manner. Typically, it has two phases that are the distance measurement phase and the position estimation phase [42].

4 Recommendations

a) **Proper Selection of Real Time Object Detection Solutions** : Recently there is much improvisation in the deep learning –based objection detection solutions and also in this solution time needed to do required taskn is being reduced [54,55].

b) **Multiple Feedback Mechanism Modalities**: Single feedback mode is available in utmost devices. But availability of multiple feedback solutions can bre more useful in different instances. Some people depends upon vibratory mode and some on auditory mode. There can be a situation in which both the solutions rely on each other depending on the environment .Therefore, if there is availability of multiple feedback solutions, then it will make the system more flexible in varying environments.The multimode system can be implemented on the basis of user preference ,it would be useful for the user even though it has complexities in the implementation [56,57].

c) **Reliability of personal and private information** : Proper management of personal and private information of user must be considered while designing the devices for visually – challenged and blind people[58,59].Futhermore ,there should be a customised setting mode in navigation devices while designing for blind and visually challenged .The settings can be executed as per the preferences of the user.

d) **Portability of Device** : Presently the navigation devices have more weight and heavy [60].Portability of such kind of navigating tool is an important factor[61].Many of the systems are integrated with mobile phone however still, it is not user –friendly.Design of system should be like it is easier to operate and handle by user.

e) **Reduction in extreme learning time** : Navigation systems must be user –friendly so that the user can learn how to operate device with ease and rapidly.Mitigation in learning time of new devices should be considered as user-centric factor.[97] Further the navigating system should be design in such a way so that the user do not feel difficulty in learning or using a new system.

f)

CONCLUSION

This paper gives a comprehensive and comparative review of recent advancements in indoor navigation system. The assistive indoor and outdoor navigational tools are categorized in to two categories, one is based on visual perception based and other on non-visual perception based. A comparative analysis is also been presented in this paper. The paper presents the recommendation based on the analysis of literature review for further development of effective system.

Many navigational systems got limitations concerned with portability and reliability of navigation systems. Design and development of assistive technologies is an active and challenging area of research. Recommendations for the navigating system has been discussed in this paper. In future the navigational aids for blind can be make more efficient by adding some features like precisely detecting path holes, fire, wet surface, indoor-outdoor staircase , traffic lights crossing etc.

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