The Functionalities and Technologies Trends in Developing Electronic Travel Aids for the Blind or Visually Impaired People: A Review

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Abstract

In all parts of the community, basic autonomous navigation is essential. The capability to navigate complicated environments allows people to achieve a wide range of physical and mental objectives. With minimal non-visual infrastructure, indoor navigation is a complicated cognitive and perceptual activity, unlike Global Positioning System (GPS) infrastructure for outdoor navigation. Blind or visually impaired people (BVIP) require sophisticated technologies with inbuilt functionalities for obstacle detection and recognition and the identification of desired destinations like rooms, stairs, and elevators to better orient themselves and navigate in unfamiliar indoor environments. Electronic travel aids (ETAs) have developed and offered exceptional navigation support for the BVIP. ETAs increase opportunities for autonomous navigation by providing information regarding the surroundings in the indoor or outdoor environment, the user's present position, and navigational instructions about the route to a targeted destination. However, less focus has been found in the literature on integrating several functions in ETAs to have a more comprehensive system that supports indoor navigation activity of BVIP to facilitate the mobility of BVIP. This study provides a thorough review of previously developed ETAs using two main criteria: the used technologies and the fulfilled functions. Based on the review findings, this study suggests future research path of technological instrumentation for the BVIP' ETA solutions in indoor navigation.

Keywords
Electronic Travel Aids, Indoor Navigation System, Indoor Positioning, Obstacle Avoidance, Object Recognition.

1 Introduction
According to World Health Organization (WHO) factsheets issued in 2021, at least 2.2 billion individuals worldwide are visually impaired (*Blindness and Vision Impairment*, n.d.). One of the most important senses for engaging with the natural world is vision (Sreenivasulu et al., 2021). It is important in guiding people to their intended destination, finding the proper way in familiar/unfamiliar indoor environments, or navigating in both indoor and outdoor settings. However, blind or visually impaired people (BVIP) confront several difficulties concerning safe and effective navigation (Kuriakose et al., 2020).

Over decades, these people have utilized conventional navigational aids like a white cane and guide dogs, which are currently the most common navigational help (Fei et al., 2017). However, they are limited in delivering truly little navigation information. To overcome this constraint, there is a greater necessity for a supplement technique, system, or compact and portable technology. There has been a significant amount of work in creating visual assistive technologies (VATs) using electronic devices and the utilization of sensor functions during the past decade. VATs are classified as either visual enhancement, visual substitution, or visual replacement (Darabont et al., 2020).

A digital picture is captured, processed, and shown on the screen by visual enhancement equipment. On the other hand, vision replacement devices provide a processed signal to the brain's visual cortex. Visual substitution devices receive data from a range of sensors and provide information to the individual through non-visual modalities such as auditory and haptic (K. Patel & Parmar, 2020). Visual substitution is further classified into three major categories:

- Electronic Travel Aids (ETAs): assist the user in exploring their surroundings by converting information gained from vision as well as other sensors into information that can be heard (auditory sound feedback) or touched (tactile vibration feedback) (Fei et al., 2017).
- Electronic Orientation Aids (EOAs): determine the best direction to navigate the way into the environment. They might be a component of an ETA system (Azzopardi & Petkov, 2015).
- Position Locator Devices (PLDs): help in determining the location in the environment, such as the GPS (Azzopardi & Petkov, 2015).

Mobility refers to a person's ability to move from one location to another safely and efficiently (Kuriakose et al., 2020). With the advancement of science and technology, the number of developed ETAs has facilitated the mobility task for the BVIP (Fei et al., 2017). The ETA is typically the most vital component of a navigation system and usually linked to an EOA and a PLD (i.e., an ETA system). The ETA handles more critical system functions such as pathfinding computation and user guidance (Lim et al., 2017). Other essential functions of an ETA include a human-machine interface, navigation, obstacle detection, object recognition, mapping, perception, and locomotion control.

This study thoroughly reviews articles published in the field of ETAs and navigation solutions for the BVIP. This review considers the fulfilled functions implemented in major ETA solutions that were developed using various technologies. Review findings from this study identify that the ETAs and navigation systems developed for the BVIP lack some core functions that are critical for autonomous navigation. Most of the ETA systems created previously primarily concentrate on implementing the individual functions, such as navigation toward a particular point of interest, obstacle detection and avoidance, as well as communicating information about objects in the user's environment employing various technologies. This review study also found that no previous studies have addressed combining navigation functions with the tasks of obstacle detection and avoidance in one ETA for indoor environments. Considering this combination helps the BVIP to navigate efficiently and safely to the desired destination.

1.1 Objectives
This study reviews the most recent advances in the ETAs development for the BVIP and investigates trends in research and identifies gaps in the proposed field by answering the following research questions:

1. What are the most exploited technologies in the literature to develop ETAs that facilitate functional mobility for the BVIP?
2. What are the most fulfilled features in the previously developed ETAs?
3. What are the existing research gaps and future research recommendations for ETA development?

2. Background Information
One of the most significant barriers to the BVIP independence is safe and efficient navigation. The term "navigation" refers to tasks such as keeping track of the user's location, planning feasible routes and directing the user along those routes until they arrive at the requested point of interest (Kunhoth et al., 2020) in indoor and outdoor environments, which involve detecting obstacles along the way (Paiva & Gupta, 2020).

Different tools used to build an ETA that serves distinct functions (positioning and obstacle detection) are discussed in this section. The tools are divided into two groups based on the relationship between a system and a building: building-dependent and building-independent systems. The building-dependent system tools require installing devices in the building (new infrastructure) or utilizing the existing building infrastructure. While the building-independent system tools do not require installing a new building infrastructure or using existing devices in the building. The most used tools are as follows (other tools were not covered in this review paper):

1- building-dependent
- Radio-frequency Identification (RFID): Contains RFID tags affixed to the objects and RFID reader. Radio waves are used to read and acquire information from tags that can be read from a distance (Kathiravan, 2020).
- Near-field Communication (NFC) tags: A sticker or wristband containing tiny microchips with stored information that may be read by nearby mobile devices
- Wi-Fi: Wi-Fi access points are equipped with existing building infrastructure.
- Bluetooth Low Energy (BLE) beacons: Beacons are devices that employ BLE to periodically broadcast data.

- Ultra-wideband (UWB): Delivers many short-duration pulses to filter the signals reflected from the original signal
- Visible Light Communication (VLC): VLC-based systems make use of current LED or fluorescent lighting in buildings. Lamp light is detected via smartphone cameras or a separate photodetector (Kunhoth et al., 2020).

2- building-independent

- Vision-based technology (VBT): Single cameras, 3D cameras, or built-in smartphone cameras could be used to capture a scene and extract more specific information about the surroundings like the type, color, and shape of an object (Kunhoth et al., 2020). The camera could be employed in different Computer Vision (CV) techniques like Image Processing (IP), Machine Learning (ML), Convolution Neural Network (CNN), etc.
- Infrared sensor (IR): It has infrared transmitting and receiving sensors. The infrared LED transmits Infrared signals at a particular frequency and when an obstacle comes up in the infrared light path, it is reflected by the obstacle and detected by the receiver.
- Ultrasonic sensor (US): This sensor emits an ultrasonic wave that reflects after colliding with any object in front of it. It determines the distance to the item by measuring the duration between transmitting and receiving (Kathiravan, 2020).

While the core functions of ETAs that facilitate the mobility task are defined as follows:

- Obstacle detection and avoidance: This function detects the presence of an obstacle and locates its place so the person would know how to avoid it.
- Object recognition: This function detects the presence of an object and classifies its type, which helps the person to have a cognitive understanding of the surrounding environment and find objects of interest.
- Localization: This function makes the user aware of their indoor location.
- Navigation: the term in this paper considers navigation to be turn-by-turn user-solicited instructions. The directions, which are created either before the journey or during the preparation process, comprise a set of turns with details like turning direction, distance to turn, and context information at the turn. Considering the location of the user, the instructions are updated and/or recorrected and displayed to the users when they prompt the system. Localization in real-time is essential. Just like GPS, where the person specifies the destinations and then gets real-time instructions throughout the trip.

3. Methods

This review study was based on comprehensive searches of the literature for ETAs and indoor navigation systems with the combined keywords of “visually impaired”, “blind”, “electronic travel aid”, “assistive technology”, “mobility” and “indoor navigation”. This study was also primarily accomplished by examining articles from SCOPUS, SpringerLink, ScienceDirect, Google Scholar, IEEE Xplore, and ResearchGate databases for the topics over the last six years of research on this topic, where the time of 2017 till 2022 will cover five full years and half of 2022. The investigations were restricted to relevant research publications published exclusively in English. Other exclusion criteria for irrelevant articles were as follows:

- the publication was only a review purpose.
- the publication did not provide information on the implementation or hardware specifications of the device or system, and
- the developed device or system did not include one of the technologies mentioned in section 2,
- the device or system did not fulfill one of the functions mentioned in section 2 and
- the hardware was designed only for outdoors.

The initial literature scans using the keywords yielded 593 studies between the years 2017 and 2022, of which 232 were discarded as duplicates. The screening of titles and abstracts revealed that 142 articles were irrelevant. Out of the 219 remaining studies, 97 articles were finally selected after evaluating the full text. Figure 1 depicts the procedure of selecting research papers for inclusion in this review study.

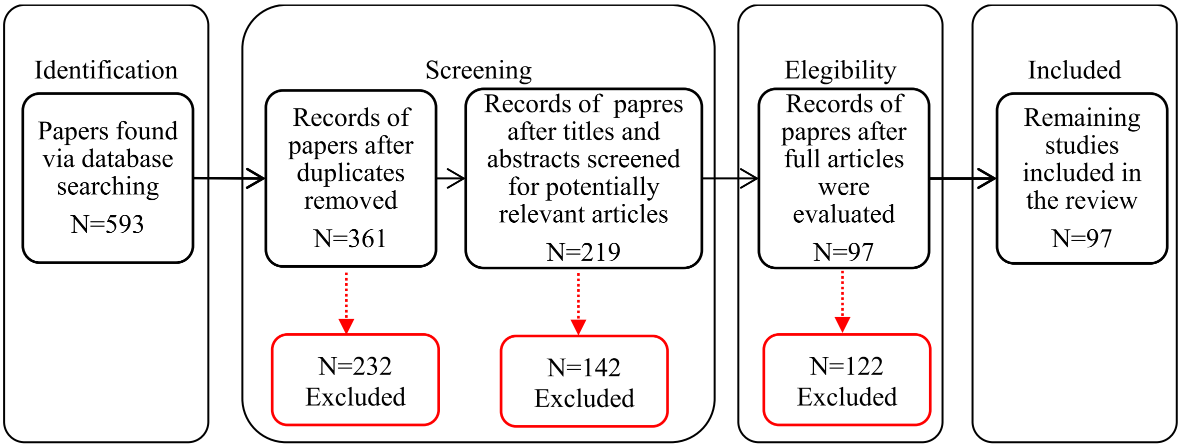

Figure 1. Flowchart of the selection process

4. Results and Discussion

Table 1 categorizes the reviewed papers by functionalities and used technologies, while Table 2 by the publication year. The notations ODA, OR, L, and N in Table 1 represent functionalities of obstacle detection and avoidance, object recognition, localization, and navigation, respectively. Figures 2 and 3 summarize the number of papers from each specified category in Tables 1 and 2, respectively. It is seen from Figure 3 that the peak of ETAs development was in 2020 with 23 published papers. On the other hand, the least number of publications was in 2022 with a total of 10 publications, noting that paper counting in 2022 is still not finalized.

Table 1. The reviewed papers by functionality and used technology

Studies	**Functionality**				**Used Technology**
	ODA	**OR**	**L**	**N**	
Barontini et al., 2021; Berenguel-Baeta et al., 2020; Davanthapuram et al., 2021; Fraga et al., 2022; Hoang et al., 2017; Jafri & Khan, 2018; Kundu, 2019; Macias-Garcia et al., 2022; Rihan & Seym, 2018; Saeteng et al., 2019; Tang et al., 2020; Vorapatratorn et al., 2021; Zhang & Ye, 2020.	✓				VBT
Abhigna et al., 2019.	✓				VBT & US
Vadwala et al., 2018.	✓				IR
Biswas et al., 2020; Islam et al., 2018; Jhonny et al., 2017; Koli et al., 2020; Manikanta et al., 2018; Manoj & Rohini, 2017; Meshram et al., 2019; Sendra et al., 2019; Tsuboi et al., 2019.	✓				US
Chandekar et al., 2017; Das et al., 2020; Rahman et al., 2020.	✓				US & IR
Afif et al., 2020; Aleixo, 2019; Ashiq et al., 2022; Bharti et al., 2019; Bhat et al., 2018; Bhole & Dhok, 2020; Calabrese et al., 2020; Chen et al., 2022; Gaikwad et al., 2021; Ghosh et al., 2020; Hasan et al., 2021; Hou et al., 2022; Joshi et al., 2020; Kim et al., 2018; Kuriakose et al., 2021; Kushnir et al., 2019; Megeshwari et al., 2021; Nasreen et al., 2019; Nemer, 2018; Nguyen et al., 2020; Ouali et al., 2020; Ramesh et al., 2018; Reddy et al., 2020; Sanchez-Galan et al., 2019; Shewale et al., 2021; Tahsin et al., 2019; Tomy et al., 2022; Zhang, 2020; Zhang et al., 2021.		✓			VBT
Endo et al., 2017; Li et al., 2019.	✓		✓		VBT
Vamsi Krishna & Aparna, 2018.	✓		✓		VBT & US
Yang et al., 2021.	✓		✓		RFID & US
Aralikatti et al., 2020; Baseer et al., 2021; Hussain et al., 2020; Khan & Prakash, 2017; Long et al., 2019; Zeng et al., 2017.	✓	✓			VBT

Joshi et al., 2020; Masud et al., 2022; Shahira et al., 2019; Silva & Wimalaratne, 2020; Suman et al., 2022; Yadav et al., 2020.	✓	✓			VBT & US
Al-Madani et al., 2019; Karabtcev et al., 2019; Leng et al., 2019; Meliones & Sampson, 2018; Murata et al., 2018, 2019; Nagarajan et al., 2020; Nair et al., 2022; Patel et al., 2020; Sato et al., 2017.				✓	BLE
Chumkamon et al., 2017; Lim et al., 2017.				✓	RFID
Chan et al., 2021; Kahraman & Turhan, 2021.				✓	RFID & BLE
Milici et al., 2018.				✓	UWB
Botre & Askhedkar, 2019; Mariya et al., 2019; Jadhav et al., 2018; Nikhil et al., 2019; Pravin & Sundararajan, 2018.				✓	VLC
Mahadevaswamy et al., 2021.				✓	WIFI
Narupiyakul et al., 2018.				✓	WIFI & BLE
Doush et al., 2017.				✓	WIFI, BLE & RFID
Gomes et al., 2018; Ou et al., 2022.				✓	WIFI & NFC

Table 2. The reviewed papers by year

Year	Studies	Count
2017	Chandekar et al., 2017; Chumkamon et al., 2017; Doush et al., 2017; Endo et al., 2017; Hoang et al., 2017; Jhonny et al., 2017; Khan & Prakash, 2017; Lim et al., 2017; Manoj & Rohini, 2017; Sato et al., 2017; Zeng et al., 2017.	11
2018	Bhat et al., 2018; Gomes et al., 2018; Islam et al., 2018; Jadhav et al., 2018; Jafri & Khan, 2018; Kim et al., 2018; Manikanta et al., 2018; Meliones & Sampson, 2018; Milici et al., 2018; Murata et al., 2018; Narupiyakul et al., 2018; Nemer, 2018; Pravin & Sundararajan, 2018; Ramesh et al., 2018; Rihan & Seym, 2018; Vadwala et al., 2018; Vamsi Krishna & Aparna, 2018.	17
2019	Abhigna et al., 2019; Al-Madani et al., 2019; Aleixo, 2019; Bharti et al., 2019; Botre & Askhedkar, 2019; Isabella Mariya et al., 2019; Karabtcev et al., 2019; Kundu, 2019; Kushnir et al., 2019; Leng et al., 2019; Li et al., 2019; Long et al., 2019; Meshram et al., 2019; Murata et al., 2019; Nasreen et al., 2019; Nikhil et al., 2019; Saeteng et al., 2019; Sanchez-Galan et al., 2019; Sendra et al., 2019; Shahira et al., 2019; Tahsin et al., 2019; Tsuboi et al., 2019.	22
2020	Afif et al., 2020; Aralikatti et al., 2020; Berenguel-Baeta et al., 2020; Bhole & Dhok, 2020; Biswas et al., 2020; Calabrese et al., 2020; Das et al., 2020; Ghosh et al., 2020; Hussain et al., 2020; R. Joshi et al., 2020; R. C. Joshi et al., 2020; Koli et al., 2020; Nagarajan et al., 2020; Nguyen et al., 2020; Ouali et al., 2020; S. Patel et al., 2020; Rahman et al., 2020; Reddy et al., 2020; Silva & Wimalaratne, 2020; Tang et al., 2020; Yadav et al., 2020; C. Zhang, 2020; H. Zhang & Ye, 2020.	23
2021	Barontini et al., 2021; Baseer et al., 2021; Chan et al., 2021; Davanthapuram et al., 2021; Gaikwad et al., 2021; Hasan et al., 2021; Kahraman & Turhan, 2021; Kuriakose et al., 2021; Mahadevaswamy et al., 2021; Megeshwari et al., 2021; Shewale et al., 2021; Surapol Vorapatratorn et al., 2021; Yang et al., 2021; Y. Zhang et al., 2021.	14
2022	Ashiq et al., 2022; Chen et al., 2022; Fraga et al., 2022; Hou et al., 2022; Macias-Garcia et al., 2022; Masud et al., 2022; Nair et al., 2022; Ou et al., 2022; Suman et al., 2022; Tomy et al., 2022.	10

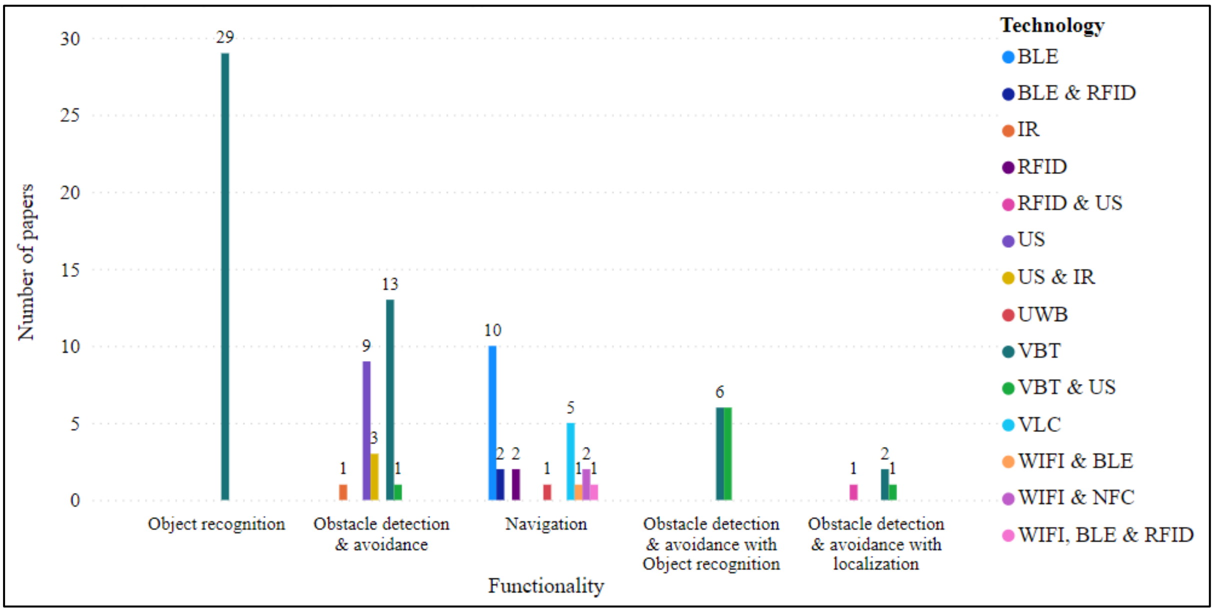

Figure 2. Number of papers by functionality and used technology

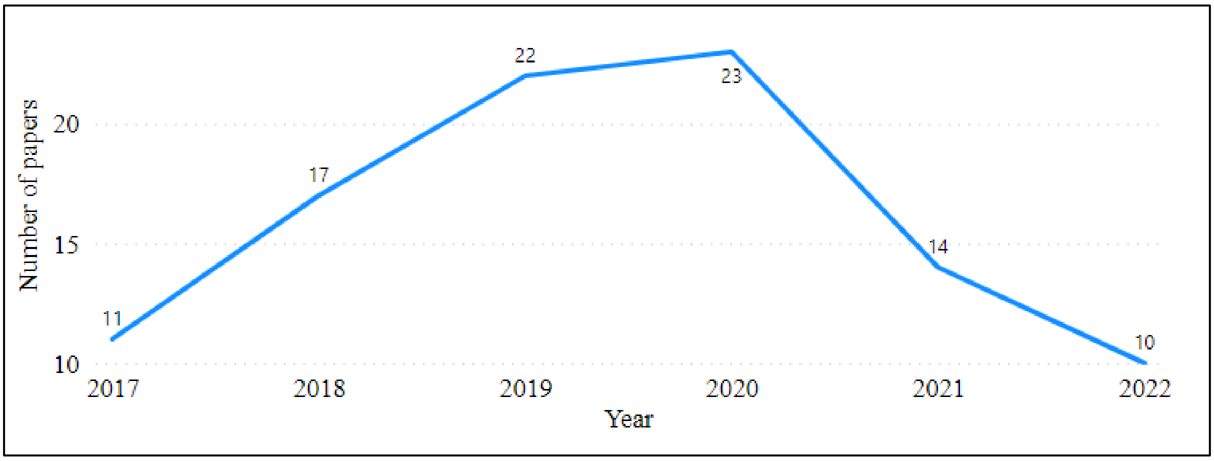

Figure 3. Number of papers by year

Based on the 97 selected research articles, the raised three critical questions on the developed ETAs for the BVIP are briefly discussed below:

1. What are the most exploited technologies in the literature to develop ETAs that facilitate functional mobility for the BVIP?

Over the past years, numerous ETAs have been developed using different technologies. Figure 4 shows a bar chart that compares the differences in the number of reviewed papers among the used technologies in the literature. As shown in Figure 4, the VBT (i.e., camera) was the most used among all other techniques, where 50 studies employed a camera to facilitate the mobility task for the BVIP. On the other hand, most of the least used technologies were the building-dependent ones (e.g., RFID, UWB, IR, and NFC). This might be because most of the building-dependent techniques require more effort and money to be implemented, where the system developer should install a specific infrastructure (e.g., UWB or RFID tags) in interest to employ these techniques, unlike the building-independent techniques where no prior building infrastructure is required. However, BLE technology received more attention than other building-dependent techniques. Moreover, a total of 18 studies combined two or more types of technologies (e.g., BLE with RFID) to take advantage of each type of technology.

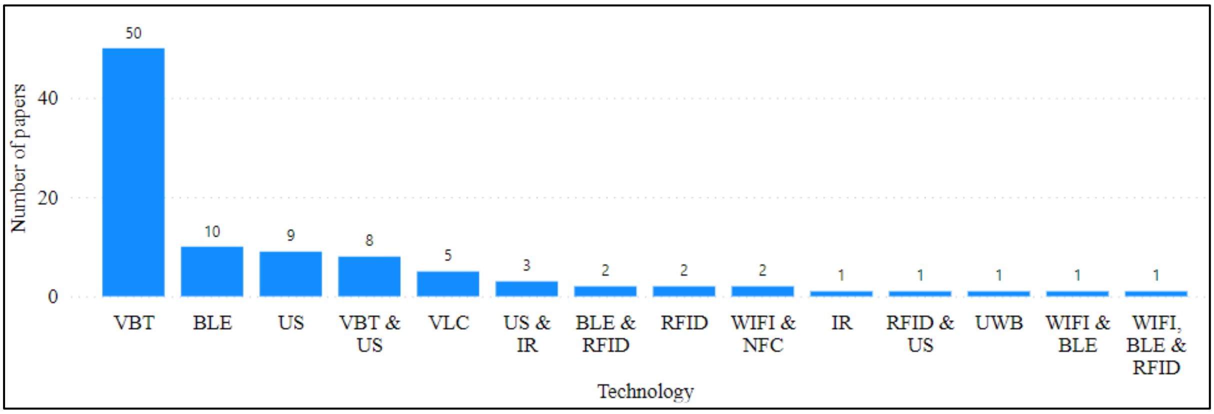

Figure 4. Number of papers by used technology

2. What are the most fulfilled features in the previously developed ETAs?

Several features were fulfilled by different ETAs. However, certain features received more attention in the literature. Most studies fulfilled the feature of object recognition. On the other hand, fewer studies focused on combining two features such as obstacle detection and avoidance with object recognition or obstacle detection and avoidance with localization. Figure 5 shows a pie chart that divides the reviewed papers on the implemented ETA functionality. It can be noticed that 83% of the reviewed papers addressed each of the functions individually.

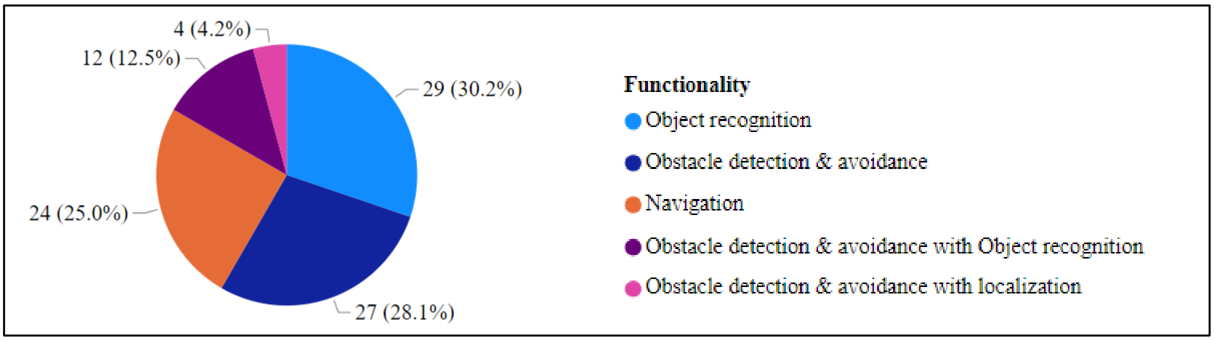

Figure 5. Number of papers by functionality

3. What are the existing research gaps and future research recommendations for ETA development?

To achieve effective and safe mobility, implementing one function alone in developing an ETA is not enough. Reaching the destination effectively and safely requires receiving turn-by-turn instructions along with receiving information about the surrounding obstacles to avoid. It is shown in Figure 5 that none of the reviewed studies combined the navigation feature with other features like obstacle detection and avoidance. Other combined features only included integrating obstacle detection and avoidance with object recognition or localization. Therefore, it is recommended to consider integrating the navigation function with obstacle detection and avoidance using diverse types of technologies (e.g., BLE with ultrasonic) to facilitate effective and safe mobility for the BVIP.

5. Conclusion

The development of ETAs for the BVIP had evolved to be a significant concern in the research field of VATs to facilitate their mobility. ETAs aid in independent mobility through obstacle detection and prevention, help in orientation and navigation and give extension for awareness of the surroundings beyond the reach of a fingertip, the end of a long cane, or the grip of a guiding dog's harness. This review study provides an overview of the trends of the technologies used to create ETA systems for the BVIP as well as the functions fulfilled by them. Mobility is a wide topic, and thus far, no ETA system or application has completely solved the mobility concerns experienced by the BVIP. Thus, this review study comes with some interesting findings. It is concluded that most of the current ETA systems focus on each of the mobility tasks individually, and none of the published studies combined the navigation function with another function. However, for future research, this review study suggests that linking the indoor navigation functions with other ones like obstacle detection and avoidance in one ETA system would help the BVIP to navigate further efficiently and safely to reach the desired destination.

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