Methodologies and evaluation of electronic travel aids for the visually impaired people: a review

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ABSTRACT

Technological advancements have widely contributed to navigation aids. However, their large-scale adaptation for navigation solutions for visually impaired people haven’t been realized yet. Less participation of the visually impaired subject produces a designer-oriented navigation system which overshadows consumer necessity. The outcome results in trust and safety issues, hindering the navigation aids from really contribute to the safety of the targeted end user. This study categorizes electronic travel aids (ETAs) based on experimental evaluations, highlights the designer-centred development of navigation aids with insufficient participation of the visual impaired community. First the research breaks down the methodologies to achieve navigation, followed by categorization of the test and experimentation done to evaluate the systems and ranks it by maturity order. From 70 selected research articles, 51.4% accounts for simulation evaluation, 24.3% involve blindfolded-sighted humans, 22.9% involve visually impaired people and only 1.4% makes it into production and commercialization. Our systematic review offers a bird’s eye view on ETA development and evaluation and contributes to construction of navigational aids which really impact the target group of visually impaired people.

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1. INTRODUCTION

For visually impaired people, the most common navigation aid is white canes. While this gives an excellent solution for a near ground obstacle, obstacles which are lower than ground or higher than knee level remain undetected. Difficult circumstances such as crowd disasters [1], road holes and hanging tree branches might also cause problems to blind people. Therefore, researchers are keen to explore scientific advancements which could help the visually impaired community with self-navigating. Mobility aids for visually impaired people known as electronic travel aids (ETAs) are equipped with measurement systems to detect objects and avoid collision [2]. Some of the objectives and challenges of ETA includes detection of obstacle, information on the travel surface, location of landmarks, identification information, self-familiarization and mapping of the surrounding [3]. Through solid ETA construction, the visually impaired people can be more self-independent, less likely to be involved in accidents, improve their reachability and finally improve the living lifestyle. The objective would be to enable the visually impaired people to travel in a safe and secure condition.

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A. Types of electronic aids

Figure 1 shows the types of ETAs that have been proposed by different researchers. Categorically, ETAs can be grouped into robotic navigation aids (RNA), smartphone-based systems and wearable attachments. RNA is a type of machinery that carries itself [4]. Usually in the form of wheeled robot, it possesses simpler mechanical and dynamics requirements [5]. An active RNA moves on its own, decreasing the burden and preventing the user from exhaustion. Another type of assistive system for the visually impaired is smartphone-based, with image and video processing capability. Wearable attachment systems come in various designs, targeting different body parts for device fitting. Eyeglass, headgear which connected with EEG (electro encephalography) [6]-[8] are some examples of wearable attachment used for navigation. There are pros and cons of each type of ETA. Therefore, it is important to highlight the advantages and disadvantages of different types of ETAs as shown in Table 1.

![Diagram of ETAs](image)

**Figure 1. Type of ETAs**

| Type of ETAs                        | Implementation                      | Advantages                                                                 | Disadvantages                                                                 | Ref   |
|-----------------------------------|--------------------------------------|-----------------------------------------------------------------------------|-------------------------------------------------------------------------------|-------|
| Robotic Navigation Aids           | Smart cane                           | – Offers portability can be used as a normal white cane should the electronics cease to function. | – Needs to be compact and lightweight                                         | [4]   |
|                                   | Robotic guide dog/mobile robot        | – The system gives room for larger hardware, as it does not require a user to carry it | – Complicated mechanicals while manoeuvring through stairs and terrain          | [4]   |
|                                   | Robotic wheelchair                   | – Suitable for the elderly and people who have a physical limitation provides navigation and mobility assistance for elderly visually impaired who cannot walk on their own, multi-handicapped, or people who have more than one disabling condition | – Safety remains an issue as user mobility fully depends on the robotic wheelchair navigation, road-crossing and stair climbing are difficult circumstances where the reliability of the wheelchair is of extreme necessity | [9]   |
| Smartphone-Based System           | Android apps                         | – Mobility/portability                                                     | – The system depends on sensors available on the smartphone                   | [10]  |
|                                   | Maps Image Processing                | – No load or invasive factor as the only device is the smartphone          | – May communicate with an outer sensor such as beacon or external server but then it limits the usage for indoor requires certain orientation for image processing or internet signal for online maps |       |
| Wearable attachment               | Eyeglass                             | – Gives a natural appearance to the visually impaired user when navigating outdoors | – Too much attention is required, thus giving a cognitive load to the user these devices are intrusive as they cover ears and involve the use of hands users are burdened with the system’s weight. | [4], [11] |
|                                   | Glove Belt Headgear Backpack         |                                                                              | – Requires a long period of training.                                         |       |
As there are pros and cons of each types of ETA, it is up to the designer’s approach to choose and build according to their set objectives and requirements. An RNA provides large room for designer’s hardware compartment and could provide additional functionality, a smartphone-based system offers mobility and ease of usage for consumers and wearable attachment gives a more natural appearance for users of the visually impaired community.

To form a comprehensive review on ETAs, we investigate the fundamental aspect of ETA build with the methodologies to achieve navigation, and a common ground for ETA’s evaluation. This review article investigates the contemporary and current designs of ETA’s methodology of achieving navigation and its fraction leading to mobility, then evaluate and classifies the system into a more consumer-centered perspective rather than the commonly designer-oriented innovation, which in results provide in depth insight on how far does the advancement of ETA really impact the core-targeted consumer of the visually impaired community. The rest of the paper is organized as follows: Section 2 describes the work of ETAs on navigation, while section 3 discusses the test and experiment conducted for evaluation. Section 4 provides a discussion on difficulties and challenges faced in ETAs and finally, section 5 concludes the review article and makes recommendations for future researchers. Figure 2 shows the flow chart of the review article from the types of ETA, navigation modules, experiments conducted and finally classifications of the system.

2. NAVIGATION

There are many integral functions which makes up an ETA. Human-machine interface, machine-human interface, object detection, object recognition, mapping, perception and control of locomotion are some of it just to name a few [3]. However, amongst all functionality, navigation remains as one of the most necessary and fundamental requirement of an ETA system for visual impairment [12].

Navigation is the process of updating one's position and orientation along with a preselected route leading to a destination [13]. Factors such as position tracking, wayfinding and orientation are integral aspects of navigation. The proposed taxonomy chart which classifies the navigation system is shown in Figure 3.

Figure 2. Flowchart of the review article

Figure 3. Taxonomy chart of a navigation system
2.1. Wayfinding
Wayfinding deals with the capability to select the correct route from a network of routes starting from an initial point to a destination [13]. It answers the question of “where do I go?” from the visually impaired person’s point of view. Other than moving towards destination, wayfinding also includes the action of evacuation [14].

2.1.1. Crowd sourcing
One of the methods to achieve wayfinding is through crowdsourcing. An example of crowdsourcing is shown by in [15], where they designed a smartphone application to navigate from point A to B through reliable directions from the online community. A web app of Google App Engine is developed where a sighted user can log on and provide instructions.

2.1.2. Geodatabase
Geodatabase, which consists of paths designed for the pedestrian, land-use map, actual video recordings, filed survey and community reports are used in [1], [16], [17]. This key information is then accumulated and amalgamated to form a representation of crossings, sidewalk and real topology of a pedestrian network for users with visual disabilities.

2.1.3. Geographic information system
Geographic information system (GIS) with visual landmarks for GIS/vision based localization is discussed in [18]. A camera with a small portable computer such as a netbook is used as its hardware. Incorporation of GPS and GIS for determination of position and orientation for navigation of the visually impaired have also been done. Other implementations of GIS in wayfinding systems include [19], [20]. GIS system may face some difficulties as nature environmental conditions are extremely difficult to measure [21].

2.2. Orientation
Orientation is an ability to be aware of one’s body position and heading in relation to surrounding objects, cardinal directions and one’s location in the followed path [13]. Usually related to rotation of the person’s body, it helps in making turns around a corner and keeping the body centre in the pathway. Different types of sensors used to accomplish orientation are discussed in this section.

2.2.1. Magnetometer
First, we examine the sensor of magnetometer which are used to estimate heading, measure roll and pitch angles [22]. Salonikidou et al. [23] proposed a system which makes use of a magnetometer for orientation purposes. It determines the heading angle with coordinates stored in GPS as a reference before giving direction command to the user.

2.2.3. Compass
A compass is another sensor that can enable orientation awareness. For instance, Skulimowski et al. [24] suggested the point of interest (PoI) explorer mobile application. Making use of an accelerometer and electronic compass within the smartphone, it calculates the angle and orientation of the user relative to the current position and gives direction to the target point. Nonetheless, the system does require a considerable amount of time for utilization, set to be 15 seconds for each complete scan.

2.2.4. Gyroscope/IMU
Zheng et al. [25] have estimated the orientation by making use of the gyroscope featured in a smartphone. By solely using a gyroscope, an accurate angle is achieved; with average error of 2.73 within 6% error rate. Correct altitude is tracked within a short period of 10s. Another sample of navigation assisted by IMU can be seen in [26], [27]. Other than wayfinding, gyroscope sensor is also associated with the ability of balancing and angle determination.

2.3. Position tracking
Position tracking or piloting is associated with sensing positional information and using it to determine one’s location [28]. One can use an external map or cognitive map to locate oneself relative to the destination. Often referred to by the term localization, it answers the question of “where am I?” for the visually impaired. A well-known predicament, the localization cases are a necessity both within indoor and outdoor situations.
2.3.1. Beacon
First, we examine the use of a beacon to achieve position tracking. Cheragi et al. [29] proposed using low-cost, Bluetooth-based beacon for indoor localization named as GuideBeacon. The GuideBeacon implements received signal strength indicators (RSSI) to estimate user proximity from the sensor. In an experimental phase, the system showed reduced navigation time compared to cane users.

2.3.2. GPS
Global positioning system (GPS) is the most commonly used technique for outdoor localization [30]. Chaccour & Badr [31] have proposed a computer vision-based technique to guide the visually impaired on navigation aspects by making use of the GPS technology and Google maps.

2.3.3. RFID
Another method to accomplish position tracking is by using radio-frequency identification (RFID). Costa et al. [32] suggest RFID and computer vision for detection of landmarks placed on the ground. The hardware is equipped with a RFID reader connected via Bluetooth.

2.4. Discussion on navigation techniques
Table 2 shows summarizes the navigation techniques of ETAs development with criteria and references. Most commonly devices to achieve navigation purposes are GPS, off-the-shelf smartphone sensors and camera-based system. GPS can be used to attain both wayfinding and path tracking information [33]–[35]. IMU, gyroscope, compass and magnetometer are commonly found in smartphone devices [25], [24]. Camera based wayfinding techniques include SLAM [36], Microsoft Kinect [37]–[39], novel liquid sound navigation [40] and FL2-0352 camera [41]. Machine learning methods which are getting numerous attention for researchers nowadays [42], [43] such as particle swarm optimization (PSO) [44] have also been implemented for navigation purposes.

| Category            | Wayfinding                              | Orientation                          | Position Tracking                      |
|---------------------|-----------------------------------------|--------------------------------------|----------------------------------------|
| Sensors/Method      | GPS & Crowd Sourcing                    | Magnetometer                         | Beacon & GPS                           |
|                     | GPS                                     | Gyroscope                             | GPS                                    |
|                     | GIS & Geodatabase                       | IMU                                  | RFID                                   |
|                     | GIS & GPS                               | Compass                               |                                        |
|                     | Camera [SLAM]                           | Compass                               |                                        |
|                     | Camera [Liquid Sound]                   |                                      |                                        |
| Hardware Spec       | Smartphone sensors- camera, compass, GPS|                                      |                                        |
|                     | and accelerometer                       | Ultrasonic sensor (HC-SR04),         |                                        |
|                     |                                         | (GPSUBLoX-NEO-6M-00) and             |                                        |
|                     |                                         | (Honeywell HMC5883L) magnetometer     |                                        |
|                     |                                         | Mobile phone’s gyroscope,            |                                        |
|                     |                                         | microphone speaker                   |                                        |
|                     |                                         | Geodatabase from phone (Nokia 6120)  |                                        |
|                     |                                         | Stereoscopic camera, GPS & IMU       |                                        |
|                     |                                         | Smartphone Android 4.2,              |                                        |
|                     |                                         | accelerometer, compass               |                                        |
|                     | 3D camera (SwissRanger SR4000)          |                                      |                                        |
|                     | Camera                                  |                                      |                                        |
|                     |                                        | Haptic device (SensAble Technologies,|                                        |
|                     |                                        | PHANToM OMNI), Laptop PC (Dell,      |                                        |
|                     |                                        | Precision M6300) and a GPS receiver  |                                        |
|                     |                                        | (GARMIN, eTrex Vista)                |                                        |
|                     |                                        | Geodatabase from phone (Nokia 6120)  |                                        |
|                     |                                        | Stereoscopic camera, GPS and IMU     |                                        |
|                     |                                        | 3D camera (SwissRanger SR4000)       |                                        |
|                     |                                        | Camera                               |                                        |
|                     |                                        | Haptic device (SensAble Technologies,|                                        |
|                     |                                        | Phantom Omni)                        |                                        |
|                     |                                        | Phone speaker                        |                                        |
|                     |                                        | Headphones                           |                                        |
|                     |                                        | Tablet speaker (HP Stream 7)         |                                        |
|                     |                                        | Headphone (AKG K612 Pro)             |                                        |
| Test Subject        | 8 Blindfolded people                    | NA                                   | 2 Visually impaired people             |
|                     | Blindfolded people                      | 6 Blindfolded people                 | 2 Visually impaired people             |
|                     | 16 VIP                                  | 21 VIP                               | Simulation                             |
|                     | 21 VIP                                  | 20 VIP                               | Simulation                             |
|                     | 7 Blindfolded people                    |                                     |                                        |
|                     | 14 Blindfolded People                   |                                     |                                        |
| Distance            | NA                                      | 25 m to 30 m                         | 2 Visually impaired people             |
| Travelled           | NA                                      |                                     | 2 Visually impaired people             |
|                     | 670 m                                   |                                     | Simulation                             |
|                     | Within 110 m x 40 m                     |                                     | Simulation                             |
|                     | 45 m                                    |                                     |                                        |
|                     | NA                                      |                                     |                                        |
Table 2. Summary of navigation methods of ETAs development for visually impaired people (continue)

| Category | Way finding | Orientation | Position Tracking |
|----------|-------------|-------------|-------------------|
| Area     | Indoor      | Outdoor     | Indoor & outdoor  |
|          | Outdoor     | Indoor & outdoor | Indoor & outdoor  |
|          | Indoor & outdoor | Indoor d outdoor | Indoor & outdoor  |
| Test Route | 1 initial room | 7 location around campus | Straight path with 3 beacons along the way |
|          | 1 U-turn shaped hallway | Indoor; hanging TV & stone wall. | Object distance from 45cm to 325 cm |
|          | 1 destination room | Outdoor; glass wall | |
| From starting point around a building to destination | 12 segments | Toulouse University campus, and district in Toulouse center | Set of different images were taken on UTAD campus |
|          | 13 decision points | 4 pedestrian crossings | |
| Toulouse University campus, and district in Toulouse center | 7 Points of Interest (PoI) | Area with 100 Point of Interest, segmented into smaller section | |
|          | 2 or 3 obstacles | | |
| Evaluation Criteria | Contact with wall | Arrival to predetermined destination | User location evaluation test |
|          | Completion time | – Distance measurement accuracy | – Calculate position of user |
|          | Comparison between concave and convex haptic representation of the objects. | – Wall detection accuracy | Object distance error percentage |
| Error rate | – Completion time | – User travel | Trajectory tracking |
|          | – User evaluation on safety, efficiency & comfort | – Positioning from GPS | |
|          | – User travel | – Positioning from the system | |
|          | – Positioning from GPS | – Distance to POI | |
|          | – Positioning from the system | – Direction of POI, with orientation relative to user and destination | |
|          | – Reach to PoI | | |
|          | – Reach to destination | | |
|          | – Average time | | |
|          | – Collisions with obstacle | | |
|          | – No of subject leaving test area | | |
|          | – Completion time | | |
| Result | Time completion: 67.1 s | Correction from 224° degrees to 280° degrees | Accuracy: 90% |
|          | Average contact: 0.25 | Error rate: 6% | Average distance error: 0.47m Distance error: 0.1m or 0.2m Low severity (neglected error) for the navigation system. |
| Based on user evaluation. | | Average angle error: 2.73° | Absolute error: 3.8% ~ 1.72%. Error minimal when the distance to the object is 3 m |
| Comfortability: 33% agreed | | Better positioning given by the system compared to GPS and improved user navigation | The trajectory correction is computed, and output is given to blind target |
| Efficiency: 50% agreed | | | |
| Safety: 33% agreed | | | |
| Better positioning given by the system compared to GPS only and improved user navigation | | Time of application: 15 s | |
| System identify PoI: 95% | | System accuracy decrease with higher number of POI | |
| Percentage of users arrive at destination: 81% End Point Position Error Norm (EPEN): 0.29 m | | | |
| Percentage of completed scene: 76% | | | |
| Ref | [15], [16], [27], [36], [40], [45] | [24], [25], [27], [46] | [30], [32], [33] |

3. TESTS AND EXPERIMENT

Test and experiment are done on ETAs to evaluate the system, acting as a benchmark for the prototype’s real-life usage. We categorised test and experiments done on ETAs into 3 categories; simulation based, blindfolded-sighted people and visually impaired person.

3.1. Simulation

Initially, experiments to evaluate ETAs are done by simulation. One of the early simulation tests for visually impaired technology with stereo vision-based aid is presented in [47]. They tested the ground plane
obstacle detection (GPOD) algorithm using a pair of cameras to simulate an image sequence of the real outdoor scene. Meanwhile, Karacs et al. [48] established a database for training and testing algorithms develop for bionic eyeglass; cell phone and camera-based image recognition system. A database of 200 videos with lengths of 10 to 90 seconds of indoor and outdoor recordings are taken from visually impaired persons. Nandini & Seeja [49] tested an algorithm for path planning within a supermarket environment with C++ simulation. A supermarket layout with numbered corners and section as point of interest (PoI) is mapped out on the system. Desired destination and current situation are given as the input from the user.

3.2. Blindfolded-sighted people

The second way of experiment is by having the ETA tested by blindfolded subjects. Several tests require the examinee to walk down a set of routes which resemble a real-life scenario, including walking within a pre-arranged pathway around indoor environment or outdoor surroundings. Table 3 shows some of the evaluation with a blindfolded examinee with varying numbers of the test subject, test route surroundings and evaluation criteria. The method of experiment using a blindfolded-sighted human subject can be considered as an intermediate technique in between simulation and using a real visually impaired people for testing. It is a more realistic way of experiment when compared to simulation-based testing but is less effective to really grasp the feeling and opinion of a visually impaired subject. In terms of difficulty, it is also in between simulation and using visually impaired as it involves human subject but depreciate of the necessity of the safety precautions and issues required of involving a real blind people subject.

| Ref | Distance | Indoor/Outdoor | Route/Obstacle | Evaluation criteria | Test Subject (blind-folded) |
|-----|----------|---------------|----------------|---------------------|-----------------------------|
| [50] | na       | Indoor        | 4 cycle around a trail | Time taken/No of contact on obstacle | 49 |
| [40] | na       | Indoor        | 2 or 3 obstacles | Collisions with obstacle/Number of leaving testing area/Completion time | 14 |
| [31] | na       | Indoor        | 1 kitchen/1 living room/1 bedroom/1 initial room/1 U-turn shaped hallway/1 destination room 4 doorways/4 hallways/2 downward stairways | Object search ability/Ability to provide path navigation | 8 |
| [15] | na       | Indoor        | | Contact with wall/Completion time | 8 |
| [51] | na       | Indoor        | | Object recognition accuracy | 7 |
| [36] | 45 m     | Indoor        | 7 Points of Interest (PoI) Indoor; chairs and ventilators. Outdoor; bicycles, cars, bushes and pedestrians Indoor; hanging TV & stone wall. Outdoor; glass wall | Reach to PoI/Reach to destination/Average time | 7 |
| [52] | na       | Indoor & outdoor | Mental demand/Physical demand/Temporal demand/Performance/Effort/Frustration | 6 |
| [25] | na       | Indoor & outdoor | Distance measurement accuracy/Wall detection accuracy | 6 |
| [9]  | 20 m–40 m Indoor | Looped trajectory | Final position error/Error reduction/Dead reckoning/Object recognition | 5 |
| [53] | 32 m     | Indoor        | office room to a stair 5 obstacles along the way | Walking errors/Travelling time | 4 |
| [54] | 10 m     | Indoor        | | Travel speed/Cleared obstacle | 3 |

3.3. Visually impaired person

The third method of evaluating ETA is by testing the device with visually impaired people. Having visually impaired as an experimental subject requires more safety measures and requirements. A clinical or ethical approval to run the test is compulsory before attempting to recruit a visually impaired person examinee. Table 4 shows the ETAs development which has been tested or evaluated by visually impaired people.

| Ref | Distance | Indoor/Outdoor | Route Surrounding | Evaluation criteria | Test Subject |
|-----|----------|---------------|-------------------|---------------------|--------------|
| [55] | 33.4 m   | Outdoor       | 3 turning point/3 pedestrian overpasses/2 tress obstruction/2 parked motorcycle/1 side door/1 plant terrace/1 cardboard box | Finishing time/Collision frequency Most collided obstacle/Parts of the body in contact | 15 5 |

Table 3. ETAs development tested by blindfolded sighted human subject

Table 4. ETAs evaluation test with the visually impaired people
Table 4. ETAs evaluation test with the visually impaired people (continue)

| Ref   | Distance | Indoor/Outdoor | Route Surrounding | Evaluation criteria                                    | Test Subject |
|-------|----------|----------------|-------------------|-------------------------------------------------------|--------------|
| [56]  | 1.2 m – 3.5 m | Indoor         | 3 persons in front of user to be recognized | Face recognition accuracy/User evaluation             | 5 9          |
| [10]  | 5 m × 7 m | Indoor         | 4 room/1 entrance/1 exit | Exploration time/Navigate/Layout recognition & representation | 5 20         |
| [23]  | 10 m × 7 m | Indoor         | 3 obstacles along the way | Navigation time/User evaluation on familiarity       | 5 11         |
| [57]  | na       | Indoor         | Sunroom/smoking room/dining room/main entrance | Time completion/Force on handlebar/Number of collisions | 2 -          |
| [16]  | 670 m    | Outdoor        | 12 segments/13 decision points/4 pedestrian crossings | Error rate/Completion time/User evaluation on safety, efficiency and comfort | 16 -         |
| [29]  | 50-300 steps | Indoor      | beacon 7 to 0 situated on upper floor, northwest from entrance | Exploration time/User evaluation | 7 1          |
| [58]  | 4.6 miles | Outdoor        | 10 metro stations/2 different metro network lines | Choosing metro station/Changing between metro lines/Arrival to destination | 10 -         |

4. DIFFICULTIES AND CHALLENGES IN ETAS BUILDUP

Figure 4 shows the maturity level inherent on the development of ETAs, categorically classified from simulation, tested on blindfolded subject, test on visually impaired. The final goal would be production and commercialization for end users. Table 5 shows the maturity level of ETAs development in selected reviewed research papers. Out of 70 related research articles only one exceptional product was successfully commercialized. The development of GUIDO, a smart walker for the blind [57] has seen success in preproduction unit sales to the U.S. Department of Veterans Affairs. There is an obvious trend of ETA constructions to be abbreviated the further they progress through the maturity stages. Therefore, it is of monumental importance to study the factors which hinder the progress of ETAs.

The first key factor which challenges the commercialization of ETAs is the market acceptance of new technology. Safety issues and concern remains an issue for the visually impaired community. However, with significant effort the sceptical mindset towards robotic machinery which hinders the progress of navigation technology can be eliminated. Researchers also claim that the user is not resistant towards adaptation of robotic technology if it can deliver benefits in their daily living [57].

Figure 4. Maturity level of ETAs

| Maturity Level of ETA Development | No of research articles | Percentage % (out of 70 research articles) |
|----------------------------------|-------------------------|------------------------------------------|
| Simulation                       | 36                      | 51.4 %                                   |
| Blindfolded Subject              | 17                      | 24.3 %                                   |
| Visually Impaired Subject        | 16                      | 22.9 %                                   |
| Production & Commercialization   | 1                       | 1.4 %                                    |

Table 5. Maturity level of ETAs development
The second obstruction to ETA’s commercialization lies within the complex production and testing systems. Ethical approval, and recognition by clinical bodies and organizations are a must, such as the food and drug administration (FDA) in the United States. And in order to acquire clinical validity, large and well defined patient groups are needed as evidence of safety aspects of the development [59]. Therefore, more involvement and participation from each contributing party is necessary, including designers (engineers), authorities (doctors and clinicians) and the end users (visually impaired community).

The third factor are designed methodologies which lack user-centred philosophy and requirements. There are many cases where sophisticated innovations of the designer’s concept overshadow consumer necessity. Therefore, an intensive effort must be made to see more collaboration between engineering designers, medical clinicians and visually impaired users to make the product more consumer-oriented and user-centred. There should also be a clear-cut objective which is to prioritize the needs of the visually impaired people at all costs.

5. CONCLUSION & FUTURE WORKS

This review paper has thoroughly discussed the fundamentals of ETA construction with the main objective of navigation and its components of wayfinding, orientation and position tracking. The evaluation stages of simulation, human subject tests and commercialization have been presented to assess the technology readiness level. This review article has presented the layout of advantages and disadvantages of each types of ETA, the methodologies of achieving the ETA’s most fundamental functionality namely the process of navigation, capacity and capability of varieties of sensors to achieve fractions of navigation in orientation, wayfinding and position tracking. test and experiments done on evaluating the ETA’s designed and finally classification of current ETA’s level of maturity. We perceive that such purposefully set objectives could give future researchers a benchmark for experimentation, and act as a blueprint of future ETA evaluation. In a nutshell, the highlights of our review paper are:

- Breakdown of types of ETA and its advantages and disadvantages. The navigation techniques of ETA are then divided into position tracking, wayfinding and orientation methodology, with further study on its sensor’s selection, and finally assessment on its capacity and capability of moving the visually impaired towards its destination.
- Results of ETA test and experiment, comparison on its level of readiness and overview of fraction of methods of evaluation; namely simulation, experiment done on sighted blindfolded subject and experiment done with real visually impaired subject.
- Classification of current ETA’s development into levels of maturity, providing an eagle eye view of impacts of ETA towards the targeted subject of the visually impaired community as a whole.

For future work, it would be interesting to see further investigation done from experts of the medical field or clinicians to assess ETAs. This would open the doors to consumer-centred concepts and diminish designer-oriented designs that we have at the present time. The core ideas assimilated in this research could serve as a benchmark for future research projects relevant to ETA evaluation. Through this review, we perceived that the future developers would be encouraged to have a better communication with physicians and the medical side of the system’s requirement, and to have a better understanding of the visually impaired people as the intended consumer of the developed product.

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REFERENCES

[1] A. M. Ibrahim, I. Venkat, and P. De Wilde, “The Impact of Potential Crowd Behaviours on Emergency Evacuation: An Evolutionary Game-Theoretic Approach,” Journal of Artificial Societies and Social Simulation (JASS), vol. 22, no. 1, pp. 1-15, 2019, doi: 10.18564/jass.3837.
[2] U. Rüjezon, M. Prellwitz, D. I. Ahlmark, J. van Deventer, G. Nikolakopoulos, and K. Hyypää, “A Haptic Navigation Aid for Individuals with Visual Impairments: Indoor and Outdoor Feasibility Evaluations of the LaserNavigator,” Journal of Visual Impairment & Blindness, vol. 113, no. 2, pp. 194-201, 2019, doi: 10.1177/0145482x19842491.
[3] E. Cardillo and A. Caddemi, “Insight on Electronic Travel Aids for Visually Impaired People: A Review on the Electromagnetic Technology,” Electronics, vol. 8, no. 11, 2019, Art. no. 1281, doi: 10.3390/electronics8111281.
[4] H. Ogawa, K. Tobita, K. Sagayama, and M. Tomizuka, “A Guidance Robot for the Visually Impaired: System Description and Velocity Reference Generation,” 2014 IEEE Symposium on Computational Intelligence in Robotic Rehabilitation and Assistive Technologies (CIR2AT), 2014, pp. 9-15, doi: 10.1109/CIRAT.2014.7099735.

[5] M. R. M. Romlay, M. I. Azhar, S. F. Toha, and M. M. Rashid, “Two-wheel Balancing Robot; Review on Control Methods and Experiment,” International Journal of Recent Technology and Engineering (IJRTE), vol. 7, no. 6S, pp. 106-112, 2017.

[6] K. R. Sravanth, A. Peddi, G. S. Sagar, B. Gupta, and C. Chakraborty, “Comparison of Attention and Meditation based mobile applications by using EEG signals,” 2018 Global Wireless Summit (GWS), 2018, pp. 260-265, doi: 10.1109/GWS.2018.8686634.

[7] M. Sameer, A. K. Gupta, C. Chakraborty, and B. Gupta, “Epileptical Seizure Detection : Performance analysis of gamma band in EEG signal Using Short-Time Fourier Transform,” 2019 22nd International Symposium on Wireless Personal MultiMedia Communications (WPMC), 2019, vol. 22, pp. 1-6, doi: 10.1109/WPIMC48795.2019.9096119.

[8] S. K. Ramakuri, C. Chakraborty, S. Ghosh, and B. Gupta, “Performance Analysis of Eye-State Characterization through Single Electrode EEG Device for Medical Application,” 2017 Global Wireless Summit (GWS), 2017, pp. 1-6, doi: 10.1109/GWS.2017.8300494.

[9] C. Ye, S. Hong, X. Qian, and W. Wu, “A New Robotic Navigation Aid for the Visually Impaired,” IEEE Systems, Man & Cybernetics Magazine, vol. 2, no. 2, pp. 33-42, 2016, doi: 10.1109/SMC.2015.2501167.

[10] J. F. Pissaloux, R. Velázquez, and F. Mangreaud, “A New Framework for Cognitive Mobility of Visually Impaired Users in Using Tactile Device,” IEEE Transactions on Human-Machine Systems, vol. 47, no. 6, pp. 1040-1051, 2017, doi: 10.1109/THMS.2017.7236888.

[11] S. K. Bahadir, V. Koncar, and F. Kalaoglu, “Wearable Obstacle Detection System Fully Integrated to Textile Structures for Visually Impaired People,” Sensors and Actuators, A: Physical, vol. 179, pp. 297-311, 2012, doi: 10.1016/j.sna.2012.02.027.

[12] M. Bousbia-Salah, M. Bettayeb, and A. Larbi, “A Navigation Aid for Blind People,” Journal of Intelligent & Robotic Systems, vol. 64, no. 3-4, pp. 387-400, 2011, doi: 10.1007/s10861-011-9555-7.

[13] P. Strumillo, “Electronic Interfaces Aiding the Visually Impaired in Environmental Access, Mobility and Navigation,” 3rd International Conference on Human System Interaction, 2010, pp. 17-24, doi:10.1109/HSI.2010.5514595.

[14] A. M. Ibrahim, M. Saiufullah, M. R. M. Romlay, I. Venkat, and I. Ibrahim, “Hybrid Social Force-Fuzzy Logic Evacuation Simulation Model For Multiple Evacuees,” 2019 7th International Conference on Mechatronics Engineering (ICOM), 2019, no. 7th, pp. 1-5, doi: 10.1109/ICOM47790.2019.8952063.

[15] G. Olsmschenk, C. Yang, Z. Zhu, H. Tong, and W. H. Seiple, “Mobile Crowd Assisted Navigation for The Visually Impaired,” 2015 IEEE 12th Intl Conf on Ubiquitous Intelligence and Computing and 2015 IEEE 12th Intl Conf on Autonomic and Trusted Computing and 2015 IEEE 15th Intl Conf on Scalable Computing and Communications and Its Associated Workshops (UIC-ATC-ScalCom), 2015, pp. 324-327, doi:10.1109/UIC-ATC-ScalCom-CBDCom-LoP.2015.69.

[16] J. Balata, Z. Mikovec, P. Bures, and E. Mulickova, “Automatically Generated Landmark-enhanced Navigation Instructions for Blind Pedestrians,” 2016 Federated Conference on Computer Science and Information Systems (FedCSIS), 2016, vol. 8, pp. 1605-1612, doi: 10.15439/2016F135.

[17] A. M. Ibrahim, I. Venkat, and P. De Wilde, “Uncertainty in a Spatial Evacuation Model,” Physica A: Statistical Mechanics and its Applications, vol. 479, pp. 485-497, 2017, doi: 10.1016/j.physa.2017.03.024.

[18] M. Serrão, J. M. F. Rodrigues, J. I. Rodrigues, and J. M. H. Du Buf, “Indoor Localization and Navigation for Blind Persons Using Visual Landmarks and a GIS,” Procedia Computer Science, vol. 14, pp. 65-73, 2012, doi: 10.1016/j.procs.2012.10.008.

[19] W. Dong, T. Qin, H. Liao, Y. Liu, and J. Liu, “Comparing the roles of landmark visual salience and semantic salience in visual guidance during indoor wayfinding,” Cartography and Geographic Information Science, vol. 47, no. 3, pp. 229-243, 2020, doi: 10.1080/15230406.2019.1699765.

[20] H. Itikhar, P. Shah, and Y. Luximon, “Human wayfinding behaviour and metrics in complex environments: a systematic literature review,” Architectural Science Review, pp. 1-12, 2020, doi: 10.1080/00038628.2020.1777386.

[21] M. M. Rashid, M. R. M. Romlay, and M. M. Ferdaus, “Development of Electronic Rain Gauge System,” International Journal of Electronics and Electrical Engineering (IJEEE), vol. 3, no. 4, pp. 245-249, 2015, doi: 10.12720/ijeee.c.3.4.245-249.

[22] P. Taylor, V. Renaudin, M. H. Afilal, and G. Lachapelle, “Magnetic Perturbations Detection and Heading Estimation Using Magnetometers,” Journal of Location Based Services, vol. 6, no. 3, pp. 161-185, 2012, doi: 10.1002/jlbs.2012.698109.

[23] B. Salomikidou, D. Savvas, G. Diamantis, and A. Astaras, “Development and Evaluation of an Open Source Wearable Navigation Aid for Visually Impaired Users (CYCLOPS),” 2012 IEEE 12th International Conference on Bioinformatics & Bioengineering (BIBE), 2012, pp. 115-120, doi: 10.1109/BIBE.2012.6399659.

[24] P. Skulimowski, P. Korbel, and P. Wawrzyniak, “POI explorer A Sonified Mobile Application Aiding the Visually Impaired in Urban Navigation,” 2014 Federated Conference on Computer Science and Information Systems, 2014, vol. 2, pp. 969-976, doi: 10.15439/2014F293.

[25] Z. Zheng, W. Liu, R. Ruby, Y. Zou, and K. Wu, “ABAid: Navigation Aid for Blind People Using Acoustic Signal,” 2017 IEEE 14th International Conference on Mobile Ad Hoc and Sensor Systems (MASS), 2017, pp. 333-337, doi: 10.1109/MASS.2017.37.
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[51] C. Ye and X. Qian, “3-D Object Recognition of a Robotic Navigation Aid for the Visually Impaired,” *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 26, no. 2, pp. 441-450, 2018, doi: 10.1109/TNSRE.2017.2748419.

[52] M. Martinez, A. Roitberg, D. Koester, R. Stiefelhagen, and B. Schauerte, “Using Technology Developed for Autonomous Cars to Help Navigate Blind People,” *2017 IEEE International Conference on Computer Vision Workshops (ICCVW)*, 2018, pp. 1424-1432, doi: 10.1109/ICCVW.2017.169.

[53] B. Li, J. Pablo Muñoz, X. Rong et al., “Vision-based Mobile Indoor Assistive Navigation Aid for Blind People,” *IEEE Transactions on Mobile Computing*, vol. 18, no. 3, pp. 702-714, 2019, doi: 10.1109/TMC.2018.2842751.

[54] A. Kumar, R. Patra, M. Manjunatha, J. Mukhopadhyay, and A. K. Majumdar, “An Electronic Travel Aid for Navigation of Visually Impaired Persons,” *2011 Third International Conference on Communication Systems and Networks (COMSNETS 2011)*, 2011, pp. 1-5, DOI: 10.1109/COMSNETS.2011.5716517.

[55] C. L. Lee, C. Y. Chen, P. C. Sung, and S. Y. Lu, “Assessment of a Simple Obstacle Detection Device for the Visually Impaired,” *Applied Ergonomics*, vol. 45, no. 4, pp. 817-824, 2014, doi: 10.1016/j.apergo.2013.10.012.

[56] L. B. Neto, F. Grijalva, V. R. Margareth Lima Maiké et al., “A Kinect-Based Wearable Face Recognition System to Aid Visually Impaired Users,” *IEEE Transactions on Human-Machine Systems*, vol. 47, no. 1, pp. 52-64, 2017, doi: 10.1109/THMS.2016.2604367.

[57] D. Rodriguez-losada and G. J. Lacey, “The Evolution of Guido; A Smart Walker for the Blind,” *IEEE Robotics & Automation Magazine*, vol. 15, no. 4, pp. 75-83, 2008, doi: 10.1109/MRA.2008.929924.

[58] J. Sánchez and M. Sáenz, “Metro Navigation for the Blind,” *Computers and Education*, vol. 55, no. 3, pp. 970-981, 2010, doi: 10.1016/j.compedu.2010.04.008.

[59] H. Moshtael, T. Aslam, I. Underwood, and B. Dillon, “High Tech Aids Low Vision: A Review of Image Processing for the Visually Impaired,” *Translational Vision Science & Technology*, vol. 4, no. 4, pp. 1-10, 2015, Art. no. 6, doi: 10.1167/tvst.4.4.6.

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