Advancements in Smart Navigation Systems : A Review for Visually Impaired and Elderly Individuals

Arya Titu Kurian[1*], *A.* Rajendran[4], *Girish* Balasubramanian[3] and *Senthil Arumugam* Muthukumaraswamy[2]

[1]Imperial College of London, Department of Computing, London, United Kingdom
[2,3]Heriot-Watt University, School of Engineering and Physical Sciences, Dubai, United Arab Emirates
[4]Karpagam College of Engineering, Coimbatore, India

Abstract. Navigation assistance is becoming increasingly important for visually impaired and the elderly, as traditional tools often lack sufficient feedback for safe, independent mobility. With recent advancements in assistive technology, particularly in smart canes, the internet of things (IoT) is integrated with artificial intelligence (AI) to enable real-time environmental awareness. This paper traces the evolution of simple white canes into advanced devices fitted with sensors and computer vision technology, guiding users through real-time audio and sensory feedback. Additionally, a comparative analysis of object detection models-Faster Regional Convolutional Neural Network (Faster R-CNN), You Only Look Once (YOLO), and Single Shot MultiBox Detector (SSD)-used in assistive devices is presented to aid visually impaired and elderly users in detecting hazards. The accuracy, processing time, and real-time feasibility of each model were evaluated. Simulation results indicated that YOLO-v8 outperformed Faster-RCNN and SSD, achieving the highest accuracy of 92.6% under the same testing conditions. In summary, the integration of IoT and AI has significantly enhanced the functionality of navigation assistance devices, improving safety, independence, and quality of life for the elderly and people with vision impairment.

1 Introduction

About 295 million people globally have moderate to severe visual impairments as of 2024, while an additional 43 million are blind [1]. About 1.1 billion individuals worldwide suffer from some kind of visual loss, according to the World Health Organization (WHO) [1, 2]. People who are visually handicapped have several social and emotional challenges. For older adults, tasks like avoiding obstacles, traveling through new areas, crossing roads safely, and accessing public transportation can significantly complicate daily activities [3].

* Corresponding author: atk2001@hw.ac.uk

Older and visually impaired individuals often face mobility issues, as well as reading written material and interacting with others [3]. The majority rely on adaptive methods and assistive technology that allows them to stay independent. This also highlights the importance of raising awareness in society and including accessible practices in city planning, transport, and technology design to better support their needs [3].

Navigation devices provide visually impaired persons more mobility and independence by offering them real-world information [3]. Users are able to travel through unfamiliar areas and discover new locations more confidently by using these systems [3].

A comparative review and analysis of various existing assistive navigation tools for visually impaired and elderly individuals are discussed. Although these systems have improved, challenges with accessibility, affordability, and lack of inclusive design still remain [3]. Addressing these barriers is essential for ensuring that future innovations more effectively meet the needs of these communities. Doing so could not only support greater independence but also help improve social inclusion. Continued research and innovation will be key to developing smarter, more intuitive solutions that can genuinely improve lives.

2 Assistive devices

A vast array of hardware and software tools are referred to as assistive navigation devices, and they are made to help people with impairments with their daily tasks [4, 5]. These technologies are vital for helping people maintain independence by improving how they engage with their environment and carry out everyday tasks. Through real-time analysis of their environment, assistive technology helps the visually impaired and elderly understand and navigate their surroundings in addition to identifying obstacles [4, 5]. These devices typically fall into two major categories, as depicted in Fig. 1, each providing different types of support to meet various needs.

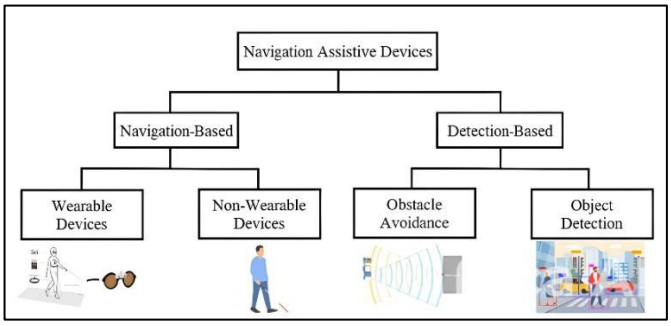


Fig. 1. Classification of Navigation Assistive Devices

2.1 Navigation-based assistive devices

Navigation-based assistive devices are extremely necessary in improving the mobility and autonomy of visually impaired and elderly users. These devices can generally be categorized into wearable and non-wearable, both aimed at helping users navigate effectively.

2.1.1 Wearable navigation systems

Wearable navigation systems utilize body sensors like magnetometers, accelerometers, gyroscopic sensors, and force sensors, placed on various parts of the body - the waist, knees, or feet. These sensors can be mounted on the clothing, shoes, and other accessories of the

user to capture a range of signals corresponding to human movement [4]. The measured signals are:

- Acceleration Signals from accelerometers detect the rate of velocity change and provide information on direction and speed of movement [6].
- Angular Velocity Signals from gyroscopic sensors measures how the body rotates and turns to calculate orientation changes and direction [6].
- Magnetic Field Signals from magnetometers works like a digital compass, using the Earth's magnetic field to determine direction of the device [6].
- Force Signals from force sensors measure the pressure exerted on different areas of the body while walking to examine gait and balance [6].
- Muscle Activity Signals from electromyography (EMG) picks up electrical activity of muscles, showing when and how intensely muscles are working during different activities [6].
- Positioning Signals from GPS and other positioning systems, provides user's location information that can enhance navigational capabilities [7].
- Vibration and Pressure Signals from sensors detect environmental changes and provide tactile feedback, helping users sense the environment [7].

Common wearable systems include smart glasses, haptic vests or belts, and other wearable sensors [5] are shown in Fig. 2 [8, 9]. Notably, smart glasses use ultrasonic sensors and a pi-camera for the object recognition devices which have become increasingly popular due to the ease of use, offering real-time monitoring and a variety of navigational cues.

Fig. 2. Wearable Navigation System Devices

2.1.2 Non-wearable navigation systems

Non-wearable devices represent a category of assistive technology that doesn't require users to wear any equipment, as depicted in Fig. 4 [10]. Instead, these systems rely on sensors and technologies built into the environment to aid navigation. They normally operate in controlled lab settings, where sensors are strategically placed to collect gait data from people walking along predefined paths [3].

Non-wearable systems are broadly grouped into two categories [3] as shown in Fig 3. By working in controlled settings, researchers can minimize other external factors, measure walking patterns more accurately, as well as ensure high consistency and repeatability in results [3].

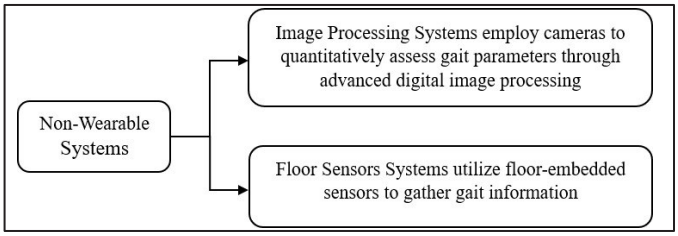


Fig. 3. Wearable Navigation System Devices

Fig. 4. Non-Wearable Navigation System Devices

2.2 Detection-based assistive devices

Detection-based assistive devices combine advanced IoT and AI technologies to locate obstacles, recognize objects, and deliver real-time guidance. This supports safer navigation and improves overall awareness of the environment. There are two main types of detection system: obstacle detection and object detection.

2.2.1 Obstacle detection

The most common approach for obstacle detection involves utilizing ultrasonic sensors paired with buzzers and speakers to provide audio alerts as feedback for users [3]. However, with advancements in sensor technology, more sophisticated systems such as Light Detection and Ranging (LiDAR) sensors, stereo cameras, and Red Green Blue-Depth (RGB-D) cameras have emerged [3]. These systems not only detect obstacles but also determine the distance and location, providing more comprehensive information about road profiles, and hazards such as holes and trenches [3].

2.2.2 Object Detection

Recent developments in computer vision have greatly improved the ability to identify, classify, and locate objects, while also planning optimal pathways. Machine learning, especially deep learning, has played a great role in this progression. Neural networks allow systems to make accurate autonomous decisions without humans' real-time intervention [11]. AI-based object recognition is used in many areas today – from robots and driverless cars to assistive tools and security systems [11, 12]. Due to real-time recognition of common objects, obstacles , and landmarks, these technologies are especially valuable for elderly and visually impaired users. Furthermore, such systems can continuously analyze and react to their surroundings, due to real-time scene analysis, which increases awareness and enables users to move with greater safety and confidence.

Popular deep learning architectures like YOLO (You Only Look Once), SSD (SingleShot MultiBox Detector), and Faster R-CNN (Faster Region-Convolutional Neural Network) are more commonly used in object detection, as they can process images in real time, making them suitable in dynamic environments. These models further take advantage of the strengths of continuous learning, whereby they can improve their accuracy and learn new objects with the passage of time [12].

3 Discussion on existing smart cane technologies

Over the years, assistive technologies have evolved significantly, enhancing the quality of life for those with disabilities to the extent that they can interact more efficiently with their environment. The history of support for the elderly and visually impaired goes back hundreds of years. It started with human reliance and developed into more advanced systems of independent navigation aids [5]. A major breakthrough was the invention of the white cane, which has since turned into sophisticated smart devices with sensors and real-time feedback mechanisms [5].

Majority of early systems used basic obstacle-detection techniques and audio cues. Electronics travel aids (ETAs) were developed from advancements like ultrasonic and infrared sensors, which over time began providing feedback through touch or sound [13]. The ETAs used these sensors to locate obstacles or produce sound signals, improving mobility for users [13]. The most common assistive technologies for visual impairment are listed in Table 1.

Access to assistive technologies remain a major challenge in low- and middle-income countries, where only 5 to 15% of those in need of assistive technologies can obtain them [14]. This is due to barriers such as high costs, low-quality local production, and a lack of trained personnel. WHO has addressed these issues by developing the Assistive Products List (APL), or priority list of assistive goods, which comprises 50 essential items chosen for their widespread use and impact on people's lives [15]. It is a model that may be adopted by governments to create country-specific lists of assistive products and technologies. It may also guide policies in service delivery, procurement, product development, and reimbursement. Similarly, the International Agency for Prevention of Blindness has developed a standard list of low-vision services to make it easier to source and obtain eye care products [16]. These initiatives are key to increasing the availability and affordability of assistive devices globally.

The development of smartphones also transformed navigation tools by providing GPS-based apps that makes use of various sensors to deliver precise, up-to-date location data [29, 30]. Machine learning and AI have enhanced the capability of the tools further in recent times by enabling sophisticated features like text-to-speech synthesis, object detection and recognition, and better display of contextual information. For visually impaired groups, new technologies such as augmented reality (AR) glasses and sensory replacement devices are expanding possibilities and redefining navigation, making the experience easier and more interactive [30, 31].

Much research has been done to close the accessibility and affordability barriers in addition to commercial solutions. An overview of studies and applications of smart navigation systems for people with visual impairments is shown in Table 2.

Table 1. Commercial Assistive Devices Designed for Visually Impaired

Name	Key Features	Benefits	Limitations	Review
UltraCane [17-19]	Dual-range ultrasonic obstacle detection, tactile feedback, compact design	Intuitive to use, builds spatial awareness, promotes confidence	Expensive (£621), requires battery, limited detection range, learning curve for new users	User testimonials highlight its user-friendliness, user-friendly interface, and obstacle detection capability. Drawbacks include high cost, learning requirements, limited scope of detection, battery reliance, and potential social misconceptions.
WeWALK [20-22]	Obstacle detection, smartphone integration, voice feedback, LED light	Navigation with real-time updates, easy smartphone control, AI mobility tracking	Expensive (£695), needs familiarity with smartphone, potential dependency on app updates	Users praise device for its navigation, obstacle alerting capabilities promoting independence and safety. However, concerns include a slippery handle, hand fatigue during extended use, difficulty hearing voice feedback in noisy environments, and lack of weatherproofing. Despite these limitations, it effectively improves mobility and confidence in users.
Envision Glasses [23-25]	Text-to-speech, object recognition, scene description, lightweight AI-powered design	Hands-free assistance for reading, identifying objects, and understanding surroundings	High cost (£1586.82), potential data privacy concerns, reliance on AI for accuracy	Users find Envision Glasses promising for hands-free use, precise text reading, and helpful object recognition. However, limitations such as delayed Describe Scene function, restricted object identification, and lack of multi-user support are noted. Despite these issues, glasses still increase independence, though some recommend waiting for further improvements.
JAWS [2628]	Screen reading, braille output, text analysis, web navigation	Increases productivity, supports professional tasks, accessible through keyboard shortcuts	Expensive license (£77.82/ year), steep learning curve for new users	Highly customizable and braille-friendly but has a steep learning curve and is memory-intensive, which some find off-putting. Still, its extensive features and support lead many to view it as a worthwhile investment.

Table 2. Overview of Research Studies and Smart Navigation System Implementations

Paper	Components	Features	Accuracy/Performance
"Ultrasonic Sensor-Based Smart Blind Stick" [32].	"Ultrasonic Sensors, Buzzer, PIC Microprocessor".	Obstacle detection using Ultrasonic Sensor; Buzzer makes sound upon obstacle detection.	100% accuracy for detection range: 5-35cm, however, as distance increases, accuracy decreases.
"Smart Blind Walking Stick with Integrated Sensor" [33].	"Arduino UNO, Infrared Sensor, Ultrasonic Sensor, Water Sensor, Buzzer, Switch".	Infrared sensor detects stairs, ultrasonic sensor detects obstacles, water sensor detects wet areas, buzzer alerts user.	Good accuracy for obstacles within 3m of the user's trajectory, however, cannot detect uneven ground surfaces.
"Smart Blind Stick Integrated with Ultrasonic Sensors and Communicati on Technologies for Visually Impaired" [34].	"Ultrasonic Sensors, Arduino Nano Microcontroller, GPS and GSM modules, Gas and Flame Sensors, Speaker, Vibration Motor, DFPlayer module".	Obstacle detection, Fire sensor for fire detection, vibration motor and speaker for alerting users, GPS and GSM modules for tracking location.	The product has achieved 98% accuracy with a detection range: 20-200cm from clubfoot.
"Smart Stick Navigation System for Visually Impaired Based on Machine Learning Algorithms Using Sensors Data" [35].	"Arduino Nano Microcontroller, GPS and GSM Module, Heart Rate, Ultrasonic and Moisture Sensor, Vibration Motor, Buzzer, ML algorithms."	Heart Rate Sensor checks user's vitals, obstacle detection, Vibration Motor and Buzzer for feedback, GPS and GSM module. Machine Learning (ML) to enhance alert accuracy	ML models like AdaBoost, Gradient Boosting, and Random Forest demonstrated superior performance, attaining 100% for both AUC and specificity and 99.9% accuracy.
"An IoT-Based Smart Stick for Visually Impaired Persons" [36].	"Raspberry-Pi, Pulse Sensor, GPS and GSM Module, Ultrasonic Sensor, Water Sensor, Heartbeat Sensor, Camera."	Object Detection using camera, Obstacle Recognition using Ultrasonic Sensor, detection of damp areas using Water Sensor, Pulse, Heartbeat Sensor for monitoring user's vitals, GPS and GSM module.	Overall accuracy of the system = 91.7%. Highest detection accuracy for person = 98.3%, Lowest detection accuracy for animals = 89% and for electronics = 90.9%.
"Integrated AI Based Smart Wearable Assistive Device for Visually and Hearing-Impaired People "[37].	"Sony's Spresense microcontroller, Ultrasonic Sensor, HD camera, Piezo Electric Transducer, GPS and GSM Module."	Ultrasonic Sensor with Piezo Electric Transducer for Bone Conduction System, GPS and GSM Module, HD camera for face recognition.	After 910 iterations, the AI model attained an accuracy of approximately 95.1%.
"DeepNAVI: A deep learning-based smartphone navigation assistant for people with visual impairments" [38].	"Smartphone, deep learning and ML algorithms (EfficientDet-Lite Model), bone conduction headset, Android Application."	Detects types of obstacles along with the location, distance, movement status, and scene context offered through audio cues.	87.7% Obstacle Detection Accuracy 85.0% Scene Recognition Accuracy Distance estimation = high accuracy for obstacles up to 5 meters Motion Detection and Position Estimation =

			high accuracy however few misinterpretations detected.
"Google Glass-Based Real-Time Scene Analysis for the Visually Impaired" [39].	"Google Glass, Camera, Smartphone, Bone Conduction Speaker."	Camera used for scene recognition processed by smartphone through Azure Vision API and communicated to user through bone conduction speaker.	Azure Vision API achieved a mAP of 29.33% on the MS COCO dataset and 73.1% accuracy on ImageNet. Enhanced scene description, boosting mAP from 63% to 84% with an IoU above 0.5.

Table 2 highlights how the performance and usefulness of smart blind sticks have been greatly improved by combining IoT systems and AI technologies. IoT by itself made basic obstacle detection and sensor-based communication easier, but it frequently failed to give users precise and prompt help. The devices' ability to adjust to different surroundings and user needs were limited because they relied on simple data processing. However, with the addition of AI, machine learning algorithms can process sensor data instantly, allowing the stick to detect obstacles and alert users more intelligently. With some devices reaching up to 99.9% accuracy in alert decision-making, this combination has enhanced accuracy and responsiveness. Furthermore, as AI gains knowledge from user interactions and environmental factors, the device's performance gets better and smarter. This leads to improved situational awareness and a more customized, user-friendly experience.

IoT and AI technologies combined to improve responsiveness and accuracy. They enable real-time navigation assistance and obstacle recognition. The potential of IoT facilitate seamless device connection improves the overall user experience. For instance, GPS and GSM modules can track location, provide emergency contact details, and support health monitoring. The devices can simultaneously analyze complex data more efficiently due to AI-driven analytics. This helps users make informed decisions by providing them with timely feedback on their environment.

Overall, this integration significantly enhances the performance, functionality, and user experience of smart blind sticks, empowering the visually impaired and elderly individuals with more effective tools for safer, self-directed travel.

4 Object detection simulation results

Object detection is the process of identifying and classifying objects in images or videos. It uses deep neural networks and ML algorithms that work together to recognize objects in real-time [40]. For visually impaired individuals, independent mobility can be challenging. Even on familiar routes, hazards can arise from obstacles, uneven terrain, or sudden changes in the environment. Object detection addresses these challenges by providing real-time information that improves safety and supports independent mobility [40]. Deep learning plays a pivotal role in object detection because it trains machines to use neural networks to make correct decisions independently, without human intervention [40].

Many object detection algorithms have been developed to improve both accuracy and efficiency in identifying and localizing objects. Some of the most well-known algorithms are Faster R-CNN, YOLO (You Only Look Once), and SSD (Single Shot Multibox Detector). A comparative analysis was performed by testing each of these algorithms on the MS COCO dataset [40, 41]. Fig 5 [41] below shows the ground truth image, and Table 3 presents the findings of this comparative analysis of the detection algorithms.

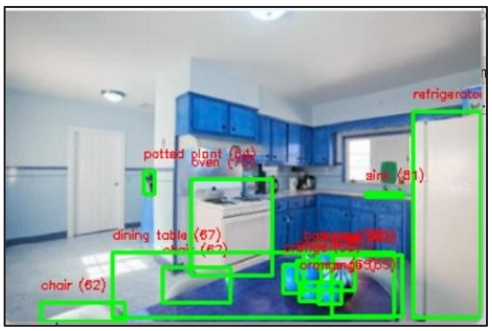
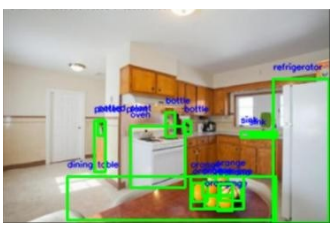


Fig. 5. Ground-truth Image

Intersection over Union (IoU) is the primary performance metric used to evaluate the performance and efficacy of object detection models on the MS COCO dataset [42]. It calculates how much the predicted bounding boxes overlap with the ground-truth boxes. A score near 0 indicates little to no overlap, and a score closer to 1 indicates perfect alignment [42]. Predictions with a confidence score below 0.5 are eliminated. The IoU metric offers a trustworthy and precise assessment of the model's object localization capabilities [42]. The model's overall performance can be measured by averaging IoU scores over all instances in the validation set [42].

Table 3. Comparative Analysis of Object Detection Algorithms.

Algorithm	Precision	Recall	Latency	Average IoU	Analysis
Faster R-CNN	0.750	0.857	3.796	0.918	
YOLO	0.917	0.846	1.238	0.797	
SSD	0.800	0.308	0.301	0.583	

Two further critical measures for evaluating object detection algorithms are precision and recall. Precision measures the proportion of correctly predicted objects to the total number of predictions produced by the model, whereas Recall evaluates the model's ability to identify all the real objects in an image. It indicates the proportion of actual objects (from ground-truth) that the model correctly identified [42, 43]. Equation (1) and (2) shows the calculation of precision and recall [43].

$$Precision = \frac{True\ Positives}{True\ Positives + False\ Positives} \quad (1)$$

$$Recall = \frac{True\ Positives}{True\ Positives + False\ Negatives} \quad (2)$$

Table 2 demonstrated YOLO's superior performance for real-time applications, achieving 91.7% precision with 1.24-second processing time. While Faster R-CNN excels in quality of detection, its slower inference time of 3.79574 seconds makes it less suitable for time-sensitive use cases. SSD, although the fastest, struggles with lower accuracy and recall, making it less reliable for safety-critical navigation tasks where missed obstacle detection poses hazards.

5 Conclusion

This paper provides an in-depth analysis of the current advancements in navigation assistive devices for visually impaired and elderly individuals. It explores the evolution of smart canes, from traditional aids to IoT-enabled smart devices with AI capabilities. Through comparative evaluation of object detection models, YOLO-v8 demonstrated superior performance with 92.6% accuracy in object detection. Their integration has made intelligent blind sticks better at detecting obstacles and guiding users in real-time. By providing immediate environmental feedback through haptic and audio interfaces, these devices enable greater navigational autonomy for users.

One of the most essential factors in designing effective assistive devices is the ease of interaction between the user and the device and the information provided to the user. Effective assistive devices need to be comfortable to use while still maximising sensor coverage. Current limitations include ultrasonic range in crowded environments, processing latency in systems running complex CNN models, and high costs of commercial tools. Future work should focus on improving small, low-power LiDAR units and making neural networks run faster on lightweight hardware. Continued research is important to further improve the usability, affordability, and accessibility of smart blind sticks. Improved sensor technology and more sophisticated algorithms are needed to improve accuracy and performance in the devices.

New innovations such as AR and sensory substitution could potentially further enhance navigation for visually impaired users. AR can provide spatial perception through auditory or haptic feedback, while energy efficiency would make devices more comfortable for users over the long term. Through user-centric design, cost-effectiveness, and accessibility, developers can create smart blind sticks that meets the needs of diverse users and support the continuous improvement of assistive navigation technology.

References

1. The International Agency for the Prevention of Blindness, Global Estimates of Vision Loss (The International Agency for the Prevention of Blindness). https://www.iapb.org/learn/vision-atlas/magnitude-and-projections/global/
2. World Health Organization, Blindness and vision impairment (World Health Organization, 2023). https://www.who.int/news-room/fact-sheets/detail/blindness-and- visual-impairment
3. M.H. Abidi, A.N. Siddiquee, H. Alkhalefah, V. Srivastava, A Comprehensive Review of Navigation Systems for Visually Impaired Individuals. Heliyon **10**, e31825 (2024). https://doi.org/10.1016/j.heliyon.2024.e31825
4. Hello Access, Assistive technology (2024). https://www.helloaccess.co/post/assistive-technology
5. M. Mashiata et al., Towards assisting visually impaired individuals: A review on current status and future prospects. Biosens. Bioelectron. X **12**, 100265 (2022). https://doi.org/10.1016/j.biosx.2022.100265
6. F. Porciuncula et al., Wearable Movement Sensors for Rehabilitation: A Focused Review of Technological and Clinical Advances. PM&R **10**, S220–S232 (2018). https://doi.org/10.1016/j.pmrj.2018.06.013
7. A.J. Ramadhan, Wearable Smart System for Visually Impaired People. Sensors **18**, 843 (2018). https://doi.org/10.3390/s18030843
8. ResearchGate, Spectrum of smart gadgets and healthcare services (2018). https://www.researchgate.net/figure/Spectrum-of-smart-gadgets-and-healthcare-services_fig1_328112213
9. Creative Commons, Creative Commons — CC BY-NC-ND 4.0 (2017). https://creativecommons.org/licenses/by-nc-nd/4.0/
10. J. Bai, Z. Liu, Y. Lin, Y. Li, S. Lian, D. Liu, Wearable travel aid for environment perception and navigation of visually impaired people. Electronics **8**, 697 (2019). https://doi.org/10.3390/electronics8060697
11. U. Vijetha, V. Geetha, Obs-tackle: an obstacle detection system to assist navigation of visually impaired using smartphones. Mach. Vision Appl. **35**, 27 (2024). https://doi.org/10.1007/s00138-023-01499-8
12. A. Ben Atitallah, Y. Said, M.A. Ben Atitallah, M. Albekairi, K. Kaaniche, S. Boubaker, An effective obstacle detection system using deep learning advantages to aid blind and visually impaired navigation. Ain Shams Eng. J. **15**, 102387 (2024). https://doi.org/10.1016/j.asej.2023.102387
13. W. Elmannai, K. Elleithy, Sensor-Based Assistive Devices for Visually-Impaired People: Current Status, Challenges, and Future Directions. Sensors **17**, 565 (2017). https://doi.org/10.3390/s17030565
14. C. Khasnabis et al., Assistive devices (World Health Organization, 2010). https://www.ncbi.nlm.nih.gov/books/NBK310951/
15. World Health Organization, Priority Assistive Products list. https://www.who.int/publications/i/item/priority-assistive-products-list
16. International Agency for the Prevention of Blindness, IAPB Essential List for Low Vision Services (2017). https://valuedsupplier.iapb.org/media/uploads/2021/03/IAPB- Essential-List-for-Low-Vision-Services-V1-March-2017.pdf

17. Ultracane, UltraCane.....putting the world at your fingertips (2019). https://www.ultracane.com/
18. Ultracane, About the UltraCane (2019). https://www.ultracane.com/about_the_ultracane
19. Ultracane, Testimonials (2025). https://www.ultracane.com/testimonials
20. WeWalk, Home (WeWALK Smart Cane, 2024). https://wewalk.io/en/
21. A. Marten, WeWalk Review (Rehabmart.com, 2022). https://www.rehabmart.com/post/wewalk-review
22. Open Sight, WeWalk App Review (2021). https://www.opensight.org.uk/wewalk-app- review
23. LetsEnvision, Top 5 Assistive Technology Devices for People who are Blind or have Low Vision [2023] (2023). https://www.letsenvision.com/blog/top-5-assistive- technology-devices-for-people-who-are-blind-or-have-low-vision-2023
24. G. Alexiou, Envision Smart Glasses – A Game-Changer In Helping Blind People Master Their Environment (Forbes, 2021). https://www.forbes.com/sites/gusalexiou/2021/01/28/envision-ai-glasses--a-game- changer-in-helping-blind-people-master-their-environment/
25. LetsEnvision, Envision Glasses | Reviews and recognition (2024). https://www.letsenvision.com/reviews
26. Freedom Scientific, JAWS® (2016). https://www.freedomscientific.com/products/software/jaws/
27. American Foundation for the Blind, Putting Words to Windows: A Review of JAWS for Windows and Window-Eyes (2024). https://afb.org/aw/1/2/16177
28. Perkins School for the Blind, Screenreader Comparisons. https://www.perkins.org/resource/screenreader-comparisons/
29. V. Isazade, Advancement in navigation technologies and their potential for the visually impaired: a comprehensive review. Spat. Inf. Res. (2023). https://doi.org/10.1007/s41324-023-00522-4
30. M.H. Abidi, A.N. Siddiquee, H. Alkhalefah, V. Srivastava, A Comprehensive Review of Navigation Systems for Visually Impaired Individuals. Heliyon **10**, e31825 (2024). https://doi.org/10.1016/j.heliyon 2024.e31825
31. Z.J. Muhsin, R. Qahwaji, F. Ghanchi, M.A. Al-Taee, Review of substitutive assistive tools and technologies for people with visual impairments: recent advancements and prospects. J. Multimodal User Interfaces **18**, 1–26 (2023). https://doi.org/10.1007/s12193-023-00427-4
32. N. Dey, A. Paul, P. Ghosh, C. Mukherjee, R. De, S. Dey, Ultrasonic Sensor Based Smart Blind Stick, in Proceedings of the 2018 International Conference on Current Trends towards Converging Technologies (ICCTCT) (2018). https://doi.org/10.1109/ICCTCT.2018.8551067
33. P. Akhil et al., Smart Blind Walking Stick with Integrated Sensor, in Proceedings of the 2nd International Conference on Innovative Research in Renewable Energy Technologies (IRRET 2022) (2022). https://doi.org/10.3390/materproc2022010012
34. L. Thuy, L.G. Phuong, Q.T. Le, H.T. Nguyen, Smart Blind Stick Integrated with Ultrasonic Sensors and Communication Technologies for Visually Impaired People (Studies in Computational Intelligence, 2023), pp. 121–134. https://doi.org/10.1007/978-3-031-29447-1_11

35. S.K. Gharghan, H.S. Kamel, A.A. Marir, L.A. Saleh, Smart Stick Navigation System for Visually Impaired Based on Machine Learning Algorithms Using Sensors Data. J. Sens. Actuator. Networks **13**, 43 (2024). https://doi.org/10.3390/jsan13040043
36. K. Jivrajani et al., AIoT-Based Smart Stick for Visually Impaired Person. IEEE Trans. Instrum. Meas. **72**, 1–11 (2023). https://doi.org/10.1109/TIM.2022.3227988
37. S. Rajeshkannan et al., Integrated AI Based Smart Wearable Assistive Device for Visually and Hearing-Impaired People (2023), pp. 51–59. https://doi.org/10.1109/icrtec56977.2023.10111863
38. B. Kuriakose, R. Shrestha, F.E. Sandnes, DeepNAVI: A deep learning based smartphone navigation assistant for people with visual impairments. Expert Syst. Appl. **212**, 118720 (2023). https://doi.org/10.1016/j.eswa.2022.118720
39. H. Ali A., S.U. Rao, S. Ranganath, T.S. Ashwin, G.R.M. Reddy, A Google Glass Based Real-Time Scene Analysis for the Visually Impaired. IEEE Access **9**, 166351– 166369 (2021). https://doi.org/10.1109/access.2021.3135024
40. P. Singh, S.A. Muthukumarswamy, The Implementation of Object Detection Using Deep Learning for Mobility Impaired People (Advances in Intelligent Systems and Computing, 2022), pp. 205–216. https://doi.org/10.1007/978-981-19-4182-5_17
41. COCO Consortium, Common Objects in Context. https://cocodataset.org/#download
42. J. Geng, How to Evaluate an Object Detection Model: Explain IoU, Precision, Recall and mAP with examples (Medium, 2022). https://zihaogeng.medium.com/how-to- evaluate-an-object-detection-model-iou-precision-recall-and-map-f7cc12e0dcf6
43. Labelf.ai, What is Accuracy, Precision, Recall and F1 Score?. https://www.labelf.ai/blog/what-is-accuracy-precision-recall-and-f1-score