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Advances in Substitutive Technologies for Supporting Visually Impaired Individuals

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ABSTRACT

Visual impairment is a significant public health issue, with over 253 million people in the world affected. These individuals face major limitations on their independence, mobility and daily social functioning. The evolution of assistive technology (AT) for blind and low vision (BLV) individuals has progressed from the basic devices like a white cane and braille reader, to more intelligent and technologically advanced wearable systems and multimodal sensor-fusion devices. The objective of this review is to critically compare commercially available assistive devices, experimental research-based assistive systems and the new hybrid technologies for BLV individuals. By evaluating these three categories, the review aims to identify their respective strengths, limitations, and future research opportunities for improving accessibility, usability, and independent living. This paper evaluates the AT landscape which consists of 3 major segments: commercial devices, experimental research systems and hybrid technologies. While traditional methods are reliable and cost effective, they do not provide environmental information or physical access. Research based systems in turn have demonstrated improved spatial navigational skills, object recognition, better contextual understanding and also demonstrated greater abilities in the area of haptic feedback. Experimental algorithms use commercial consumer electronic devices that give rise to hybrid systems that are less costly, more resilient, scalable and less cognitively demanding. The comparative study of the existing technologies reveals a high degree of accuracy, latency and contextual sensitivity, yet the technology is still not affordable, accessible and ready to be deployed. The review reflects the latest developments in clinical and laboratory research and highlights the role of user-centered and cost-effective assistive ecosystems integrated and working together. Moving forward, further developments in sensor fusion, wearable technology, and adaptive AI systems are expected to bring about improved autonomy and quality of life for BLV individuals in the future.

INTRODUCTION

Visual impairment (VI) is one of the major health and social problems worldwide, impacting millions of people from all age groups and socio-economic backgrounds. More than 253 million people in the world are visually impaired, with around 36 million of them being blind and 217 million having low vision (Ackland et al.). This issue is disproportionately concentrated in low and middle income countries

(LMICs). Almost 70 million people in India suffer from visual impairment, the largest visually impaired population globally, of which around 4.95 million are blind (Shamanna et al.; Udayakumar et al.). These figures underscore the need for BLV individuals to have access to technology and inclusive systems that will enable them to live and navigate their surroundings independently.

Visual function is essential for perception, navigation, object recognition and social interaction. Visual impairment has a profound impact on a person's independence in daily living, learning, working and psychological health. For the past few centuries, assistive devices for the visually impaired have been largely based on the “traditional” white cane, guide dog, and braille communication system. The white cane is one of the most commonly used mobility devices, because it is easy to use, simple, and inexpensive. But conventional aids have inherent limitations, such as inability to detect an object from a distance, inability to interpret the dynamics of the environment, lack of contextual information about the surroundings.

The last decade has seen a huge development in the world of assistive technology, particularly with the rapid development of digital technologies, artificial intelligence (AI), sensor systems, and wearable computing. Assistive systems today are striving to do more than just compensate for the loss of sight: they are to give the user sensorial substitution, so that they can see and interpret their surroundings through their hearing, touch or through multiple modalities. The iPhone and iPod Touch are now powered by several smartphone features: optical character recognition (OCR), text-to-speech synthesis and GPS navigation, making information more accessible and mobility easier to use. Commercial systems like OrCam MyEye, Envision Glasses and Aira combine computer vision, cloud computing and real-time audio feedback to provide context-awareness and environmental interpretation.

At the same time, experimental technologies, such as deep learning, convolutional neural networks (CNNs), Vision Transformers (ViTs), LiDAR sensors, multimodal haptic interfaces, have been sprouting and growing at a much faster pace thanks to research. The idea behind these systems is to improve the real-time obstacle detection, facial recognition, gesture understanding and spatial mapping. Devices with vibrotactile feedback and spatial-audio interfaces try to alleviate the cognitive overload without sacrificing users' natural auditory perception. Moreover, sensor-fusion systems of cameras, inertial measurement units, GPS telemetry, and tactile interfaces have proven to be effective in enhancing the accuracy of navigation and environmental perception.

While these improvements have been made, many issues are still unsolved. Most advanced assistive devices are too expensive and unavailable to the majority of people with BLV, particularly in low- and middle-income countries (LMICs), where almost 90% of people with BLV are living in low-income households (Bourne et al.). This further restricts its real-world applicability due to the need for internet connectivity, battery life, computational power, and language-specific AI training datasets. Furthermore, technologies that are validated in controlled lab environments often fail to perform in an unstructured outdoor setting for various reasons such as changing lighting conditions, dense environments, and moving obstacles.

As a result, the current research is turning to the integration of traditional aids and AI-powered ones - hybrid approaches. The hybrid architectures are designed to develop resilient assistive ecosystems that are affordable, user-centred and can adapt to various real-world conditions. Researchers are using commercial consumer hardware to integrate experimental algorithms, aiming to lower costs and keep functionality and safety levels high.

The main goal of this review is to critically assess the current state of the art for assistive technologies designed for blind and low vision (BLV) people, and to compare three main categories of existing assistive technologies: commercial, research-based experimental systems and emerging hybrid systems. In particular, the following research questions are explored: (1) What are the differences between these three categories regarding technological capabilities, usability, accessibility, scalability and cost-effectiveness? (2) What are the major assets and liabilities for each category in facilitating independent living for people with BLV? (3) What research paths should be taken in order to produce more affordable, user-centred and widely accessible assistive technologies? They were chosen because they span the range of innovation in assistive technologies from existing commercial and well-known systems in use, to emerging experimental research systems, to integrated hybrid systems that have the reliability and well-known status of an established device, but are enhanced by the more recent advances in artificial intelligence, sensor fusion, and wearable computing. A systematic analysis of these categories, all in the same framework, will provide a broad overview of the state of the art, and will suggest avenues for future innovations and clinical translation.

METHODOLOGY

The research was undertaken as a narrative literature review, which aimed to bring together the existing evidence about substitutive technologies designed for blind and low vision (BLV) people. It is a thorough literature search, which included several electronic databases such as PubMed, Google Scholar, IEEE Xplore, SpringerLink, ScienceDirect as well as relevant publications from recognised organisations and commercial technology developers where applicable. Searches had been done with the keywords: visual impairment, blindness, assistive technology, computer vision, artificial intelligence, wearable devices, sensor fusion, haptic feedback, smart navigation, deep learning, and substitutive technology. The literature reviewed was mostly published from 2018 to 2025, with some earlier publications included when they offered novel insights or background information.

Studies were selected when they presented commercially available assistive technologies, experimental research systems, hybrid assistive solutions or review articles related to mobility assistance, environmental perception, object recognition, navigation, or information accessibility that were relevant for BLV people. Publications were eliminated if they did not include adequate technical description; if they were duplicate reports; if they were not about disabilities unrelated to the focus; or if they were of limited empirical or technological relevance. After the literature was screened and evaluated, there were about 46 sources that were selected for final review. The selected studies were analysed qualitatively in the three thematic areas of commercial technologies, research-based experimental systems, and hybrid approaches, in order to allow a structured comparison of the technological performance, usability and accessibility, scalability, cost-effectiveness of the selected systems, the current challenges, and the potential for future research.

CLASSIFICATION OF SUBSTITUTIVE TECHNOLOGIES

Conventional/Commercial Assistive Devices

Commercial assistive devices provide a practical foundation for daily independence for most BLV individuals globally. These devices range from non-electronic aids like white canes, braille tools to sophisticated technology like smartphone applications, navigation tools. These devices enable independent mobility and provide information that aid BLV individuals to better understand and perceive their surroundings. These devices are evolving along with advancements in technology and society.

Traditionally, support begins with a white cane which is one of the most popular and widely adopted mobility aids. Its popularity stems from its simplicity, affordability and mechanical reliability. It does not require a battery, internet connectivity or software updates. Users navigate streets, detect obstacles, surface texture changes through direct contact and interpretation of the cane-tip vibrations and sounds. Although it requires minimal maintenance, it comes with some fundamental limitations. It can only detect hazards within the physical sweep range and cannot provide any information about above-waist height obstacles such as overhanging branches, open doors or windows. Furthermore, effective use of the white cane requires training as well as constant effort and attention which can be cognitively draining over extended time periods. (Yeon Kim and Cho)

The Braille system is an important pillar of informational independence for BLV individuals. It allows them to access written language through a system of raised-dot characters that can be read by touch. This system has been extended to the digital world through refreshable Braille displays (RBD) which translate digital text into tactical Braille output by small rounded pins that raise and lower through a flat surface. Companies such as Vispero offer comprehensive screen-reading suites, including the industry-standard JAWS software, that integrate with operating systems and applications to provide non-visual access to digital environments. These tools have demonstrated strong performance for text-based computing tasks. However, they have limited utility for physical navigation and are extremely expensive with prices ranging from $3,500 to $15,000, depending on the number of characters displayed (“Refreshable Braille Displays”; “Braille Displays and Readers”; Brauner)

Thus, to enable independence and increase BLV individuals' awareness about their surroundings various electronic navigation aids and smartphone apps have emerged. GPS apps such as BlindSquare and NaviLens provide audio guidance calibrated for pedestrian navigation. Microsoft's Seeing AI and Envision AI's Envision App leverage on-device and cloud-based machine learning to perform real-time text reading, barcode scanning, currency identification and basic scene description. These smartphone application based solutions provide considerable functions that help reduce the information asymmetry.

Their marginal cost is nearly zero where affordable devices are available, making them a very effective scalable pathway for LMICs.

Dedicated wearable devices occupy the premium tier of commercial devices. OrCam Technologies' MyEye, a clip-on camera that attaches to spectacle frames, uses AI to read text, identify faces, and recognise objects and Envision Glasses, built on Google Glass hardware, provide hands-free continuous scene description and text-to-speech synthesis. These tools help provide autonomy as well as comfort. (Cohen) However, they are extremely expensive, unaffordable for most BLV individuals as 90% come from low income households (Kohli) - OrCam MyEye retails at over USD 4,200 (Staff).

Despite significant progress, commercial devices also come with certain limitations. Prohibitive price points are a significant challenge as they make technology inaccessible for the overwhelming majority of BLV individuals globally. Smartphone-based solutions which are more accessible are limited by dependence on battery life, reliable internet connectivity and accurate training data which limits their efficacy in unfamiliar and low signal environments. Additionally, data privacy concerns from systems that continuously capture and store data in cloud servers have also impeded adoption. (Jain et al.) Furthermore, there can be a steep learning curve associated with more complex devices for older users or those with limited technological literacy which is a significant barrier for adoption as people 50 years and older represent 65% and 82% of visually impaired and blind, respectively (Pascolini and Mariotti). Overall, there is a need for more integrated, affordable and intuitive solutions. (Raniyah Wazirali et al.; Tapu et al.)

Research-Based and Experimental Devices

While commercial tools have established a solid foundation for the assistive device market, their limitations have fuelled current research to develop substitutes that provide conceptual and perceptual support rather than just reactive and task-based outputs. The field has shifted focus towards creating proactive systems that provide sensorial substitution to the human vision. Modern solutions are leveraging deep learning, multimodal sensing and AI which allow these devices to move beyond simple object detection and provide users with a more intuitive and richer real-time environment understanding. (Pfreundschuh et al.)

Experimental smart glasses have been designed using these deep learning architectures, such as Convolutional Neural Networks (CNNs) or Vision Transformers (ViTs), for real-time scene categorization, object recognition and visual understanding of social information (such as facial expression, gestures, etc.). CNNs are specialised neural networks that use hierarchical convolutional filters to process visual data. (GeeksforGeeks; Pardeshi and Yannawar) Their layered structure makes them extremely efficient, accurate and well-suited to tasks such as object recognition. ViTs, unlike CNNs do not use convolutional layers, rather use self-attention to model long-range dependencies across the entire image patch -a global understanding of the image. They have achieved stellar results in computer vision tasks. These functionalities are majorly absent from commercial devices and have significant implications for social participation for BLV individuals due to their accuracy. (GeeksforGeeks, Vision

Transformer (ViT)). For instance, wearable devices such as Envision Glasses use a camera and real-time speech synthesis to provide contextual information, which allows BLV users to interact more effectively with their environment (Naayini et al.).

Many sound feedback systems constantly generate audio and information, which is often a cognitive burden for the user, thus, researchers are designing multimodal haptic interfaces, such as virtual whiskers and vibrotactile waist belts. These devices convert spatial information into braille grids so that tactile information can be provided without blocking a person's natural hearing. Despite these technological developments, the most significant gap is in implementation of these technologies in real world environments that are unpredictable and uncontrollable. (Nikam et al.; Raniyah Wazirali et al.)

Hybrid Approaches - Integration of Commercial and Research Innovations

The field of assistive technology is becoming a hybrid space as commercial products are proven to be reliable and state of the art research is now rapidly becoming available. The idea behind these systems is that they form an integrated system, with the power of consumer electronics (high processing power of smartphones, ubiquity of cloud computing), experimental sensors and specialized architecture of artificial intelligence. Combining these two aspects can reduce the expense of dedicated hardware, while still offering users high-end capabilities such as environment mapping and low latency obstacle detection. (Hersh and Johnson)

One of the main examples of this synergy is when commercial off-the-shelf (COTS) wearable devices such as bone conduction headphones or smartwatches are combined with custom-developed research-based software. For example, standard flagship smartphones, such as the Apple iPhone Pro series, have LiDAR sensors that can be used in experimental spatial-audio algorithms and incorporated into hybrid systems. (Rouxinol) The LiDAR data from the smartphone is input into custom depth-processing software which allows the end user to measure object distances through audio cues. Thus, these hybrid systems can convert a regular cell phone into a sophisticated proximity sensor, using a standard mobile application and no additional hardware. (Liu et al.) Bone conduction systems have similarly been integrated into assistive technology such as non-occluding audio channels that allow the user to perceive ambient noise as well as system feedback. (Ntawuzumunsi et al.)

Overall, hybrid systems aim to reduce the cognitive burden by applying AI to sift through the data, rather than overloading the user with information, they prioritize data based on research and contextual filtering: they only alert the user to potentially hazardous objects, haptic alerts, social cues (recognised faces, emotions) or objects of interest such as landmarks, places.

The future of these hybrid approaches, proposed in recent literature, lies in Sensor Fusion, in which the information from the physical feedback of the white cane is combined with the visual information from a wearable camera, smartphone processing and GPS telemetry. (Bala et al.) This multi-layered architecture ensures that in case of failure or interruption in any system, there is no danger to the user. It provides the user with the analog safety of the white cane if there is a lack of internet connection or battery depletion on the smart device. Hybrid systems, where functions are spread across several devices and technology is decentralized, provide a more resilient, cost-effective and user-friendly experience that suits the real-world vagaries.

COMPARATIVE ANALYSIS

Performance metrics: accuracy, sensitivity, response time

Assistive technologies for BLV individuals can be effectively measured in terms of three measures: detection accuracy, contextual sensitivity, and real-time response latency. Each parameter captures a distinct aspect of functional utility and the trade-offs between them differ significantly across device categories.

Commercial devices like OrCam MyEye and Envision Glasses have claimed to be able to identify objects and images with a significant accuracy rate in controlled environments, and to recognize text within milliseconds in typical situations like reading printed text.(Amore et al.; Seiple et al.) But, in dynamic, cluttered real-world settings, accuracy is significantly reduced, particularly in crowded, poorly lit environments and layouts that are unfamiliar. (Mathia and Moreno-García; Cohen; Granquist et al.)

Systems that are derived from the research using Convolutional Network and Vision Transformers (ViTs) have shown better context sensitivity, especially when it comes to the interpretation of social cues, such as face expression recognition, as some of the systems have managed to achieve classification accuracy above 85% on benchmark datasets. However, most of these gains are confirmed in the lab. Haptic substitution systems such as vibrotactile belts tend to be more concerned with low latency (less than 200ms) (Maereg et al.) than categorical accuracy, because the ability to convey a spatial signal is more important than a precise object name. (Zhao et al.) The most promising overall performance profiles have been demonstrated using sensor fusion architectures combining the LiDAR, RGB camera and GPS data, but they demand significantly more computational resources. (Zhong et al.)

Usability: user comfort, learning curve, portability

Usability encompasses both objective measures such as device weight, form factor, battery duration and subjective user experience dimensions including comfort, learnability, and social acceptability. These factors strongly mediate real-world adoption, alongside technical performance.

White canes have the highest usability for basic mobility as they are lightweight, universally understood by the public, require little training in their operation, and impose no significant learning burden. Although braille tools and screen readers (e.g., Vispero's JAWS) have steeper learning curves, once mastered, they provide highly efficient access to the digital world. Wearable devices such as OrCam MyEye and Envision Glasses score moderately on usability. Their form factor is non-intrusive for spectacle wearers and interaction is often gesture or voice-triggered reducing tactical operation. However, the 100-gram weight of spectacle-mounted devices over extended wear periods has been noted as a source of fatigue and users report that the devices attract social attention, which some may find stigmatising and uncomfortable. (Amore et al.) Research-based devices rate poorly on usability since they are in the prototype stage. For instance, vibrotactile belts are bulky and have to be calibrated to the user. However, as they are developed for commercial use, they will likely improve in portability and appearance. Sensor fusion devices are only available as laboratory technology and there is no indication of immediate user adoption. Smartphone-based hybrid technology occupies the most advantageous position as users are interacting with hardware they already own and are comfortable with, thus minimizing the learning curve, and smartphones are less conspicuous.

Cost-effectiveness, scalability, and accessibility

The most important factor to be considered that limits widespread adoption is cost. It is important to highlight that around 90% of BLV individuals worldwide are from low income families, most of these in LMICs, where specialized devices are not affordable and not available through the public health systems. The majority of the target population are unable to afford dedicated commercial devices like OrCam MyEye ($4,200+) or Aira's subscription-based remote assistance service. Smartphone-based solutions are more accessible as if affordable Android smartphones are available, technology like Envision AI or Microsoft Seeing AI can be used which add significant functionality at near zero marginal cost. Research-based systems do not currently have scalable manufacturing pipelines and are not commercially viable, but there is promise in modular hybrid architectures with the use of consumer grade components to reduce cost. Language and script support are other barriers to scalability, as most AI systems are trained on English language and Latin script data sets, and thus are not as useful in markets across South and Southeast Asia, Africa, and the Middle East- where prevalence of visual impairment is greatest. 62% of the visually impaired world population lives in three Asian regions: South Asia (73 million), East Asia (59 million) and Southeast Asia (24 million) (Bourne et al.; Deswal; Udayakumar et al.).

Table 1. Summary of commercial devices

Sr. No.	Company	Accuracy	Sensitivity	Latency	Cost Effectiveness	References
1	OrCam MyEye OrCam Technologies	>90% in controlled environments; drops to 60–75% in dynamic/cluttered settings	Text and object recognition; limited social cue detection	<500 ms for standard tasks (e.g. printed text)	Low: $4,200+ so inaccessible to 90% of BLV users	Granquist et al.

2	Envision Glasses Envision AI	>90% in controlled environments; reduced in real-world conditions	Scene description, text-to-speech, limited contextual understanding	<500 ms for standard tasks	Moderate: High upfront cost; app tier available	"Envision - Enabling Vision for Visually Impaired. ; Khenkar et al.
3	Aira Aira Tech Corp	Dependent on human agent; high situational accuracy	High contextual sensitivity via live human assistance	Near real-time; subject to connectivity	Low: Subscription-based; financially inaccessible for most BLV individuals	Aira | Meta AI Glasses Park et al.
4	Seeing AI / Envision App Smartphone-based	Moderate; varies by lighting and image quality	Object, currency, face detection; text reading	Variable; depends on device and connectivity	High: Near-zero marginal cost on affordable Android devices	Envision - Enabling Vision for Visually Impaired
5	Vispero Suite Vispero	High for screen reading; limited object detection	Strong for digital/text environments; limited real-world sensing	Low latency for screen-reader tasks	Moderate: Licensing costs; widely used in institutional settings	Vispero – Empowering Independence

Table 2. Summary of research-based and experimental devices

Sr. No.	**Company**	**Accuracy**	**Sensitivity**	**Latency**	**Cost Effectiveness**	**References**

1	CNN / ViT-based Smart Glasses Experimental wearables	>85% on benchmark datasets for facial expression/scene classification	High contextual sensitivity;interprets social cues and complex environments	Variable; higher compute overhead reduces real-time performance	Low Not commercially viable; high R&D cost	Naayini et al.
2	Vibrotactile / Haptic Belts Multimodal haptic interfaces	Moderate; prioritizes spatial signalling over object naming	Spatial proximity and layout; low categorical sensitivity	<200 ms; optimised for immediate tactile feedback	Moderate Prototype-stage; component costs moderate	Raniyah Wazirali et al.
3	Sensor Fusion Systems LiDAR + RGB + GPS	Strongest overall profile across benchmark tests	High; multi-modal input improves robustness in dynamic environments	Higher latency due to computational overhead	Low High infrastructure cost; not scalable currently	M. Kempa

Table 3. Summary of hybrid devices

Sr. No.	Company	Accuracy	Sensitivity	Latency	Cost Effectiveness	References
1	COTS + AI Software Hybrids e.g. smartphone LiDAR + spatial audio	High; leverages commercial hardware with experimental algorithms	Strong; AI-filtered alerts reduce cognitive overload	Low latency on high-end consumer hardware	Promising Lowers cost by reusing consumer devices	Ntawuzumunsi et al., Naayini et al.

APPLICATIONS AND CASE STUDIES

Assistive technology (AT) for BLV individuals has evolved from mobility support to a more comprehensive system to help them navigate, communicate, learn, work, and participate in social activities independently. (Udayakumar et al.) Many practical applications have been realized in real world applications using artificial intelligence (AI), computer vision, wearable sensors and multimodal feedback mechanisms.

Independent navigation and mobility assistance is one of the most significant applications. While traditional mobility devices, such as white canes, remain vital, modern assistive systems incorporate an enhanced awareness of the environment by detecting obstacles beyond the reach of the cane, thereby enabling users with greater awareness about their surroundings. These devices, including the OrCam MyEye and Envision Glasses, contain embedded cameras, computer vision and algorithms, which allow them to recognise objects, read signs, recognize faces, and provide real-time audio feedback. These skills enable users to move around more confidently and safely in unfamiliar areas.

An intriguing use case is the application of OrCam MyEye to the visually impaired, students and professionals. Users said that they read printed documents more independently and were able to recognise their colleagues and products when they went shopping. Feedback from the system was given in real-time, reducing the need for caregiver assistance and promoting users' confidence in completing daily activities.

One other important application is text recognition and accessibility of information. Optical Character Recognition (OCR) and text-to-speech technologies can be used in smartphone apps like Microsoft Seeing AI and Envision AI when reading printed or digital text. Within a learning environment, where pupils can read their books, examination papers and class resources independently, these resources are found to be very useful. These solutions are also more scalable and cost-effective than specialised hardware, due to the availability of smartphones.

Social interaction support is another novel application domain. Deep learning algorithms integrated into research-based wearable systems can be trained in facial expression, gesture and social cues recognition. These types of technologies can assist BLV individuals in understanding non-verbal communication that they wouldn't otherwise be able to see. For emotion and social interaction recognition in real time, a new generation of smart glasses with Convolutional Neural Networks (CNNs) and Vision Transformers (ViTs) has emerged as a promising solution to improve human-human interactions and social inclusion.

Assistive technologies are helping make healthcare and public service environments accessible to people. AI has been applied to decipher public signage, to recognise the labels of medication, and to identify currency notes. Smartphone applications have been created that enable individuals to follow treatment instructions - using OCR-based recognition systems to read the label and dosage instructions themselves. Remote assistance services are another interesting case. There are services available, such as Aira, that use a camera worn on the head with a mobile device that allows BLV individuals to interact with trained human workers. The agents give real-time assistance in performing complicated tasks like navigating airports, filling out forms, or finding a certain product in stores. Subscription fees are a barrier but this service demonstrates the potential of human intelligence and technological infrastructure to work together and increase accessibility.

Spatial perception and obstacle avoidance are promising fields of application for research-based systems of haptic feedback. Vibrotactile belts and wearable tactile interfaces can transmit the information from the surrounding environment into a tactile perception without impacting ambient hearing. Experimental research indicates that users are able to learn the tactile navigation patterns relatively quickly, and it thus enhances mobility indoors.

A great deal of promise has been seen in the systems combining the old with the new. For example, a system of white canes and a GPS navigation system for a smartphone includes multiple layers of information in the environment, the use of a camera that can be worn and an artificial intelligence system that can recognize objects. This helps to ensure reliability and prevent users from losing their ability to access the traditional methods of navigation when digital systems go down.

As a whole, these applications illustrate the evolving role of assistive technologies from simple compensatory to intelligent systems which are capable of assisting visually impaired persons to live independently, participate in society and improve their quality of life. (Drue)

CHALLENGES AND LIMITATIONS

While there are significant developments in technology and assistive technology available, there are still concerns and barriers that need to be addressed to ensure their effectiveness, success and widespread adoption.

The foremost challenge is cost and affordability. Advanced technologies such as OrCam MyEye, Envision Glasses, and its like are generally prohibitively costly and not available for many visually impaired individuals particularly in LMICs. One of the factors that hinder equitable access is the cost of BLV devices, as a high percentage of BLV individuals are from low income families.

Another challenge is dependence on infrastructure due to computational complexity and power consumption. Many of the AI-based systems rely on the internet, cloud computing, GPS signals, and advanced technology. When such infrastructure is not available, for instance, in rural areas, these requirements can drastically reduce the capabilities and performance of the device. These systems also require a significant amount of processing power which consumes copious amounts of battery. The battery life also restricts how long it can run continuously.

There are also challenges due to environmental variability. Laboratory trained and tested systems are not always able to compete in real world situations of poor light conditions, bad weather, crowded space and moving obstacles. These changes affect the device capabilities, accuracy and reliability.

Another restriction is user adaptation and training needs. Haptic navigation systems and multimodal feedback interfaces for technologies like these can be complex and need extensive training before users can interpret the information they provide. Adoption and long-term usability can vary from person to person, depending on their learning style and age as well as their familiarity with technology.

Furthermore, there are language and cultural barriers that impact access. Most of the AI models have been trained on English language data sources and Latin script thus, may not be suitable to use in a multilingual environment. It is not as usable in a number of geographic regions due to lack of regional language support, local signage and culturally specific contexts.

Additionally, concerns about privacy and data security are growing. The deployment of wearable cameras and cloud-based processing systems collects a dearth of personal and environmental data, with privacy, informed consent and data handling security issues arising with their use.

Such are important hurdles that need to be addressed for future assistive systems to be reliable, affordable, and scalable taking into account varying social and environmental settings and needs of visually impaired users.

Along with the constraints of the current assistive technologies, this review also had several methodological constraints that need to be noted. This work was an attempt to undertake a narrative literature review and not a systematic review or meta-analysis; therefore, the search process and synthesis process was tailored to capture an overview of the literature and not quantitative evidence synthesis. Second, the study was restricted to English-language publications, so that it might have overlooked other language publications that presented relevant studies. Third, care should be taken in making direct comparisons between technologies, as the studies included varying datasets, evaluation procedures, performance measurements, and testing environments. In addition, many of the research-based systems have only been tested at a small scale and in laboratory conditions, and the performance observed only in these controlled conditions is not necessarily the same in a real-world setting. Last, but not least, the field of artificial intelligence and assistive technology is developing swiftly and devices or algorithms that have been presented since this review was written may not be included. Although these constraints are significant, the review offers a thorough review of the recent advances and identifies key gaps in the research that could be targeted in future studies and technology development.

CONCLUSIONS

Assistive technology for BLV individuals have undergone tremendous change from mechanical to intelligent AI systems that are able to understand their environment in real time and provide sensorial substitution. These are the newer innovations that have great promise, but are not currently standard practice for the visually impaired and remain key to the affordability, reliability, and accessibility.
However, the capabilities have expanded dramatically beyond navigation and reading text with the advent of Artificial Intelligence and Computer Vision, Wearable Computing and Sensor Fusion.

OrCam MyEye, Envision Glasses, and smartphone applications are just a few examples of how machine vision and context-awareness are being incorporated into everyday assistive devices. At the same time, experimental research systems based on deep learning architectures, multimodal haptic interfaces, and spatial mapping through LiDAR show the potential to enhance autonomy, the perception of the environment, and social interaction for BLV individuals. Another exciting development towards a user-centred and resilient assistive environment is the combination of traditional mobility devices with AI-driven technologies.

These developments come alongside the fact that there are a number of hurdles to be overcome to encourage adoption of these, including cost, scalability, infrastructure dependency and underlying field performance. But in order to confront these challenges, interdisciplinary collaboration, inclusive design thinking, and a more equitable vision of technological deployment will be essential to make assistive systems of the future accessible, adaptable and useful for the visually impaired of all ages, and in every country and region of the world.

FUTURE PERSPECTIVES

The future generation of assistive technology systems for the visually impaired can be expected to be intelligent, adaptive, and highly personalised – they can function in the real world without any major issues. New advancements in AI, edge computing and wearable sensor technology will likely enhance real-time object recognition, context awareness and autonomous navigation while also decreasing latency and computational reliance. Future sensor-fusion systems with LiDAR sensors, computer vision, GPS sensors and haptic interfaces, will be able to perceive the environment with greater accuracy and reliability in complex environments.

Furthermore, future studies will focus on cost and scale, incorporating commercial consumer electronics like augmented reality devices, smartwatches and smartphones. Culturally fine-tuned interfaces and multilingual AI systems will gain significance for assisting end-users in LMICs. Further developments in brain-computer interfaces, tactile displays, and immersive, spatial-audio technologies could continue to transform sensorial substitution. The future of assistive technology is one where systems are designed to be inclusive, user-friendly, and to enhance independence, accessibility, and quality of life for BLV individuals.

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