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An Inclusive Future for Assistive Technologies Supporting People with Visual Impairments: An Overview of Trends and Challenges*

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Abstract

This paper provides a comprehensive overview of current trends and persistent challenges related to the development of assistive technologies for people with visual impairments. The analysis focuses on the role of these technologies in increasing independence, digital accessibility and social participation. The motivation for addressing this topic is the dynamic development of digital innovations and the growing importance of inclusive design, which create both new opportunities and significant barriers for users with visual impairments. The paper is based on a review of scientific literature and institutional documents concerning the technological, social and ethical aspects of innovation in assistive technologies. The analysis highlights a consistent gap between research and practical implementation. Many solutions remain at the prototype stage, and their adoption is hindered by high costs, insufficient standardisation, limited training, and inadequate involvement of users in the development process. The findings demonstrate that the creation of an accessible ecosystem of assistive technologies requires interdisciplinary collaboration, supportive public policies, and the active participation of visually impaired people in co-design. The study concludes that the integration of technological innovation with social responsibility and coherent systemic support is essential for building an inclusive digital future. The results offer practical recommendations for designers, researchers, and policymakers who work towards improving digital accessibility at national and international levels.

Keywords: assistive technologies, visual impairments, accessibility, inclusive design

Introduction

Contemporary societies increasingly emphasize the role of assistive technologies in improving the quality of life of people with visual impairments. The dynamic development of digital innovations, mobile devices, and artificial intelligence enables the creation of tools that support independence, mobility, and social integration among people with visual impairments (Hersh, Johnson, 2008; World Health Organization [WHO], 2023). The growing availability of such technologies is not only a sign of technical progress, but also the realization of the idea of equal opportunities and social inclusion in accordance with the principles of universal design (Story, Mueller, Mace, 1998).

According to data from the WHO (WHO, 2023), more than 2.2 billion people worldwide experience some degree of visual impairment, of whom approximately 39 million are completely blind. This means that almost one in four people worldwide struggles with visual impairments, making this group one of the largest in terms of digital accessibility needs. However, it should be emphasized that not all diagnosed disorders qualify for the use of advanced assistive technologies. Therefore, it is crucial to distinguish between general visual impairments and severe visual impairments that require advanced devices. In Europe, according to the European Blind Union (EBU, 2023), the number of blind and visually impaired people exceeds 30 million. In Poland, according to data from the Central Statistical Office (GUS, 2024), the number of people with severe visual impairments reaches

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several hundred thousand, although it should be noted that precise data vary depending on the diagnostic criteria and sources of information used.

Technological advances in the field of vision assistance are closely linked to the development of the concept of digital accessibility and the Web Content Accessibility Guidelines (WCAG 2.1) developed by the World Wide Web Consortium (W3C, 2018). Their application contributes to the elimination of barriers to access to information, public services, and education for people with sensory disabilities (W3C, 2018; Lazar, Goldstein, & Taylor, 2015). These principles also form the basis for many EU initiatives on equal access to technology, including the European Accessibility Act (European Commission, 2019).

The development of assistive technologies for people with visual impairments includes both hardware solutions, such as mobile devices, sensors, navigation systems, and smart glasses, and applications based on artificial intelligence, image analysis, and speech synthesis (Zhang et al., 2024; Amore et al., 2023). The common denominator of these solutions is the aim to increase users' independence and improve their quality of life, as confirmed by research on the effectiveness of systems combining sound and haptic signals in spatial orientation (Paratore & Leporini, 2023).

However, it should be noted that access to modern assistive technologies remains uneven, both in terms of cost and limited awareness of their existence among potential users (Lynch, 2022; Shukla, Misra, 2022; Costa Marinho et al., 2024; Samaniego López, 2025). In addition, the implementation of such solutions in public spaces or organizations requires the integration of technological, social, and educational activities (Mashiata, 2022). It is therefore crucial to combine technological innovation with social responsibility, ethics, and an inclusive approach to design that considers the needs of all users (Barocas & Selbst, 2016; European Commission, 2019).

The aim of this article is to present the current state of development of technologies supporting people with visual impairments and to analyze their impact on the quality of life, social integration, and professional functioning. The article focuses on a review of scientific research and institutional documents discussing both technical aspects (e.g., wearable devices, mobile applications, artificial intelligence-based systems) and implementation, economic, and ethical challenges (Amore et al., 2023; Barocas & Selbst, 2016; WHO, 2022). The following chapters present the main research trends, technological limitations, and recommendations for the implementation of inclusive solutions in Poland and worldwide.

This article is a review based on a narrative scoping review. The analysis covered scientific publications, institutional reports, and strategic documents on assistive technologies for people with visual impairments published between 2018 and 2025. Sources were searched in the Scopus, SpringerLink, Web of Science, PubMed, ResearchGate, and IEEE Xplore databases. The inclusion criteria were: reference to assistive technologies for people with visual impairments, implementation or ethical aspects, as well as empirical or conceptual foundations of the analyzed solutions. This selection of literature enabled a synthetic overview of trends, barriers, and prospects for further development (Gurari et al., 2020; Nikanfar et al., 2025). This approach was chosen due to the multidisciplinary nature of the topic, requiring synthesis of diverse technological, social and regulatory perspectives.

The limitations of this review stem from its narrative nature. No formal quantitative analysis or meta-analysis was conducted. The time frame and language restrictions may have resulted in the omission of some of the most recent studies published in languages other than English and Polish. Despite these limitations, the selection of sources provides a representative picture of the most important trends and challenges in the development of technologies for people with visual impairments.

The development of assistive technologies for people with visual impairments: a review of research and challenges

The development of assistive technologies for people with visual impairments is a multidimensional process combining achievements in engineering, research on human-computer interaction, public policy, and social practice. Contemporary solutions range from traditional tools, such as white canes, Braille, and speech synthesizers to advanced systems based on image recognition, machine learning, and wearable devices that interpret and communicate spatial context to the user in real time (Zallio & Ohashi, 2022; Okolo, Althobaiti, Ramzan, 2024). This evolutionary transition from compensatory tools to integrated assistive systems has a significant impact on the independence, sense of agency, and participation in public life of people with visual impairments (Amore et al., 2023).

Universal design is a key concept for understanding this transformation. Story, Mueller and Mace (1998) formulated a framework that shifts the emphasis from creating “special” solutions to designing for accessibility for the widest possible group of users. In the digital environment, this role is fulfilled by the W3C (Web Content Accessibility Guidelines) the application of WCAG significantly reduces communication and information

barriers, while enabling organizations implementing these standards to achieve economic and educational benefits (W3C, 2018; Krok, 2024).

The actual implementation of universal design principles requires the use of user-centered practices, such as involving people with disabilities in the creation process, iterative testing, and the local adaptation of solutions (Ortiz-Escobar et al., 2023). The effectiveness of inclusive design depends on its practical application at all stages, from user research to prototype testing, as confirmed by examples of collaboration in projects such as Microsoft's Seeing AI. This project, carried out with the active participation of people with visual impairments, is highly usable and accepted, combining technological and ethical aspects that align with the principles of universal design (Avila et al., 2016; Ortiz-Escobar et al., 2023; Story, Mueller, Mace, 1998; W3C, 2018).

Contemporary research also emphasizes the importance of digital literacy education for people with visual impairments, as even the best-designed solution may not be fully utilized without adequate user training (Omar & Ali, 2022). The integration of training in the use of new technologies and inclusive practices in schools and support institutions is crucial for real accessibility (Amore et al., 2023).

The category of assistive technologies is very broad today. Systems based on image recognition and image captioning enable users to obtain information about objects, texts, or scenes. An example is research on automatic captioning of photos taken by blind people (Gurari et al., 2020). Such solutions are often combined with crowdsourcing mechanisms (e.g., VizWiz) or applications that connect the user remotely with a volunteer (Be My Eyes), resulting in a hybrid strategy: rapid human support plus automation where possible (Bigham et al., 2010; Avila et al., 2016). Research and implementation show that this approach improves access to information and reduces isolation, but at the same time requires adequate privacy and service quality safeguards (Avila et al., 2016; Gurari et al., 2020).

It is worth noting that traditional assistive technologies, such as Braille, screen readers (e.g., NVDA), and classic canes with ultrasonic sensors, continue to play an important role in the daily lives of people with visual impairments (NV Access, n.d.; Hersh & Johnson, 2008). Although bibliometric studies indicate the dominance of artificial intelligence and wearable devices, this does not mean that classic solutions are being marginalized, on the contrary, they are being integrated with new technologies, which increases the effectiveness of user support (Omar & Ali, 2022).

Commercial devices such as OrCam MyEye demonstrate the practical value of integrating cameras, text recognition (OCR), and speech synthesis multicenter studies indicate increased user satisfaction and improved functioning in daily tasks thanks to such systems (Amore et al., 2023). However, an analysis of costs and availability indicates that the high prices of commercial products may limit their widespread adoption, raising the issue of economic accessibility and the need for subsidy policies or public support (WHO, 2022). Hence, there is a call to promote open-source solutions and financing models that reduce the barrier to entry for users (Hajduk, 2023; Krok, 2024).

The integration of artificial intelligence brings promising benefits in terms of personalization and adaptability of interfaces. Modern systems can learn user preferences, predict needs in specific contexts, and tailor the way information is presented (Yao, Zhou, Hu, 2025; Zhang et al., 2024). Such capabilities are particularly important in the areas of indoor navigation, scene recognition, and visual information management. At the same time, however, the development of artificial intelligence carries the risk of misclassification and algorithmic bias, which can negatively affect user safety and trust (Barocas & Selbst, 2016). This requires transparency in the process of creating models and testing them with the participation of people with visual impairments, as emphasized by Ortiz-Escobar et al. (2023). Only such an approach allows for a reliable assessment of the usability and safety of assistive systems. In the European context, the Artificial Intelligence Act, which is currently being developed, is also of particular importance. It aims to regulate the use of high-risk systems, including assistive technologies, in a manner consistent with the principle of human rights protection (European Commission, 2023).

We are seeing rapid technological progress in the field of mobile applications and wearable solutions. Research and reviews show growing interest in the integration of sensors (e.g., ultrasonic, lidar), haptic feedback interfaces (vibration, force), and contextual connectivity (Okolo, Althobaiti, Ramzan, 2024; Nikanfar et al., 2025). Such systems, combined with cloud services and semantic scene analysis, can provide more accurate information about the environment and predict potential threats. In this context, edge computing is increasingly being used, which allows image and sound analysis without the need to transfer data to external servers, thus increasing privacy and system speed. Examples from the literature show that the combination of sound and haptics improve spatial orientation and reduces collisions in urban environments, which has a direct impact on user safety (Paratore & Leporini, 2023; Yao, Zhou, Hu, 2025).

Recent studies indicate a growing potential in integrating multimodal feedback with AI-based environmental recognition systems. For example, Soltani et al. (2025) found that users strongly prefer hybrid sensory systems

using both haptic and audio cues, as these combinations increase navigation efficiency and reliability compared to single-mode solutions. This indicates that future development should focus not only on hardware improvements, but also on optimizing multimodal interaction patterns (Soltani et al., 2025).

The consequences of implementing assistive technologies include economic and organizational dimensions. Organizations that invest in digital accessibility and assistive technologies report benefits in the form of broader access to talent, higher employee engagement, and improved image (Krok, 2024). However, bibliometric studies and literature reviews (Omar & Ali, 2022; Manirajee, Shariff, Mohd Rashid, 2024) identify a gap between research and practice: many projects remain at the prototype stage, and implementation at the level of SMEs (Small and Medium Enterprises) or public institutions faces financial, competence, and organizational barriers. Bibliometric reviews indicate that between 2020 and 2025, the dominant trend in publications is the exploration of AI and Internet of Things (IoT) applications in assistive technologies, while classic solutions (e.g., Braille, canes) are increasingly less frequently the subject of research. This points to the need for public policies that combine funding, standards, and education programs to increase the scale and effectiveness of implementations (WHO, 2022; Horizon Europe, 2023–2025).

Educational issues are crucial: simply implementing technology will not be effective without training users and educational staff. The literature emphasizes the need to integrate skills in using assistive tools into educational and training programs and to conduct information campaigns targeting potential users and caregivers (Hajduk, 2023; Manirajee, Shariff, Mohd Rashid, 2024). These programs should include training in the use of wearable devices, mobile applications, data security principles, and the basics of interacting with AI systems. The synergy effect technology + training + social support is a prerequisite for the sustainable and safe adoption of solutions.

From a regulatory and financial perspective, instruments such as the European Accessibility Act (European Commission, 2019), directives, and research programs (Horizon Europe) create a framework conducive to the development of inclusive technologies. These programs fund research, pilot projects, and implementations, promoting cross-sector cooperation between science, industry, and non-governmental organizations, which is essential for achieving scale (European Commission, Horizon Europe, 2023–2025). At the same time, the WHO report (2022) reminds us that scaling up solutions requires taking into account geographical and economic diversity: global standards and guidelines are important, but their implementation must take into account local capabilities and constraints.

Ethical and privacy considerations require special attention, especially when assistive systems analyze scenes and recognize people in the environment. Clear policies on the collection, storage, and processing of visual data are necessary, as are mechanisms for obtaining consent and user control over data (Barocas & Selbst, 2016; Ortiz-Escobar et al., 2023). In practice, this means designing solutions that minimize the transmission of sensitive data, use edge computing where possible, and provide transparent information to the user about how the system works.

The study is a narrative review and does not include empirical research involving users of assistive technologies. Although the selection of sources is broad and includes recognized databases, it may not fully reflect all available research, especially publications in languages other than English and Polish, as well as reports not indexed in international databases. In addition, the rapid pace of technological development means that some of the solutions described may become outdated in a short period of time. The narrative review method used, while allowing for the synthesis of diverse perspectives, does not enable a quantitative assessment of the effectiveness of individual technologies. The results should therefore be interpreted as an in-depth analysis of the state of knowledge, providing a starting point for further empirical research and implementation activities in the field of assistive technologies for people with visual impairments.

Summary and conclusions

Assistive technologies for people with visual impairments are developing very rapidly. They include both classic compensatory tools and advanced solutions using artificial intelligence and user context analysis. The development of assistive technologies resulting from the combination of achievements in engineering, computer science, education, and social sciences directly improves the quality of life, increases independence, and promotes greater social integration of people with visual impairments.

A key factor in the effectiveness of assistive technologies is the active participation of users in their design. Co-creation, iterative testing, and consideration of the real needs of users allow for the development of tools that are functional, acceptable, and accessible in everyday use. Universal design principles and digital accessibility guidelines play an important role, providing the basis for creating solutions that do not exclude any group of users.

Technological progress brings with it organizational, economic, and ethical challenges. High costs, a lack of interoperable standards, and limited availability of professional training continue to hinder the widespread implementation of innovations. These phenomena underscore the need for systemic support, including appropriate

legal regulations, financing mechanisms, and educational programs. Only such an approach can ensure equal access to assistive technologies.

The dynamic development of artificial intelligence brings significant benefits, but also risks related to user privacy, classification errors, and algorithmic bias. The use of validation procedures, algorithm audits, and local data processing increases security and trust in new solutions.

It is also important to educate users and professionals involved in the implementation of technology. The mere availability of tools does not guarantee their effective use without proper training of the people who will be using them. Training programs, information campaigns, and the inclusion of digital skills in formal and informal education systems are the basis for the responsible and sustainable use of assistive technologies.

In Poland, there is growing interest in the implementation of assistive technologies in public and educational institutions. Unfortunately, the pace of this process still depends on the availability of funding and the awareness of decision-makers. Initiatives such as the Accessibility Plus program (Ministry of Funds and Regional Policy, 2024) are an important step towards social inclusion and represent an attempt at a systemic approach. However, these attempts and initiatives require further evaluation in terms of their effectiveness and long-term impact. Compared to countries that are leaders in accessibility, such as the United States and Scandinavian countries, Poland is at an early stage of development.

To fully exploit the potential of assistive technologies, technical innovation must be combined with social, ethical, and organizational reflection. Such a comprehensive approach will enable the creation of solutions that truly support the independence and rights of people with visual impairments. Long-term progress depends on cooperation between designers, researchers, public institutions, and users.

Future research should include empirical evaluations of the effectiveness of technology in real-world conditions, taking into account cultural and economic diversity. The integration of scientific research, design practice, and coherent public policies will lay the foundation for sustainable, accessible, and ethically responsible technologies that support the independence and full participation of people with visual impairments.

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