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Ocular Pathology and Functional Suitability of Assistive Technologies for the Visually Impaired

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ABSTRACT

Assistive technology for the visually impaired must be matched to the anatomical level of visual-system damage: some conditions leave the optic nerve and neural pathway usable, while others do not, and the practical usefulness of a given device follows directly from where the damage sits. This study combines a structured literature review of 15 papers (2020–2025), two illustrative field interviews with visually impaired individuals at the National Association for the Blind (NAB), Delhi, an ophthalmological consultation, and a market comparison of six commercial and assistive devices to examine how existing technologies align with different pathology levels. Across the reviewed literature, recurring limitations included insufficient user testing (12/15 papers), absent upper-body obstacle detection and limited OCR/document access (11/15 each), and lack of haptic feedback (10/15). Field interviews highlighted head-height hazards, offline document access, and alert fatigue as user-reported priorities. An exploratory Fast Fourier Transform (FFT) signal-processing investigation was also conducted to examine its potential relevance as an embedded preprocessing approach for future wearable devices. The findings suggest that image-enhancement and magnification devices remain useful only where sufficient retinal and neural capacity is preserved, while camera-based sensory substitution and mobility aids can remain functionally applicable across a broader range of pathology, including complete visual loss. This study is exploratory and limited by its small participant sample and conceptual (rather than measured) engineering analysis; it proposes design directions — including upper-body sensing, offline OCR, and context-aware alerting — for future assistive-device development.

Keywords: visual impairment, assistive technology, retinal pathology, sensory substitution, smart glasses, optical character recognition, Fast Fourier Transform, low vision rehabilitation.

INTRODUCTION

Assistive technology for the visually disabled should be matched to the anatomical level of visual-system damage. Emerging technologies have provided significant benefits for some. However, the functional perception through such devices is yet to reach a significant milestone. Non-treatable eye diseases may partially be addressed by assistive devices depending on the location of the damage within the visual system. For example, fundus disorders, which affect structures at the back of the eye including the retina, macula, and optic disc, such as age-related macular degeneration can substantially impair central vision

while leaving peripheral retina, retinal ganglion cells, and the optic nerve usable. In that setting, electronic image enhancement can exploit residual biological vision, while a retinal prosthetic approach is designed to stimulate surviving retinal circuitry after photoreceptor loss. By contrast, disease involving the inner retina, retinal nerve fiber layer, or optic nerve reduces the usefulness of technologies that depend on native retinal-to-brain transmission.

Recent technologies such as smart canes equipped with ultrasonic sensors, wearable cameras integrated into smart glasses, AI-based object detection systems, and navigation assistance platforms have sought to improve functional perception. Camera-based sensory substitution can shift the problem away from the damaged ocular pathway. SHG Smart Vision, Ray-Ban Meta Gen 2 and B by Lenskart convert visual information into spoken output and therefore can support tasks such as reading and face recognition without restoring vision itself. Ray-Ban Meta Gen 2 and B by Lenskart are consumer smart-glasses rather than dedicated assistive devices; they are included in this study as consumer technology benchmarks because they provide comparable camera, AI, audio, and voice-based functions. BrainPort converts camera images into electro tactile patterns on the tongue and can provide rudimentary spatial information even when the ocular visual pathway is severely compromised. The practical trade-off is information bandwidth: direct residual vision can provide rich, fast scene information, while audio and tactile substitution can remain useful across broader pathology but usually require interpretation and, for BrainPort, structured training. [16-17]

We initiated this research by synthesizing insights from multiple domains (a) extensive literature review, (b) direct consultations with visually impaired individuals (c) collaborative ophthalmological assessments (d) market and technology observation of commercially available assistive devices (e) gap analysis and (f) engineering research utilizing Fast Fourier Transform (FFT) applications, culminating in the identification of core requirements to guide future design solutions.

This study asks how assistive technologies can be matched to different anatomical levels of visual system damage, and what user-, clinical-, and engineering-informed design requirements emerge from this analysis.

The aim of this study was to investigate the functional suitability and limitations of existing assistive technologies in relation to different forms of visual system damage, while identifying user , clinical , and engineering informed requirements for future assistive-device design.

Biological function of an Eye: The retina is not a single functional layer. Photoreceptors and retinal pigment epithelium form the outer retinal interface that captures light, while bipolar, amacrine, ganglion-cell and retinal nerve-fiber layers form the downstream neural pathway. The optic nerve then carries retinal output to the brain. For assistive-device selection, this distinction is crucial: an enhanced image is valuable only if enough retinal and neural capacity remains to encode and transmit it.[18] (Figure 1)

Outer retinal or macular disease can leave portions of the peripheral retina and optic nerve functional. Devices that magnify or enhance the retinal image may therefore remain useful when sufficient residual vision is present. (Figure 2). However, few such devices exist beyond those that work through the eye's

own optical pathway — that is, those that rely on the cornea and lens to focus light onto the retina, where photoreceptors and downstream retinal circuitry process the visual signal. Where vision cannot be restored , creating an equivalent functional perception through other means remains challenging.

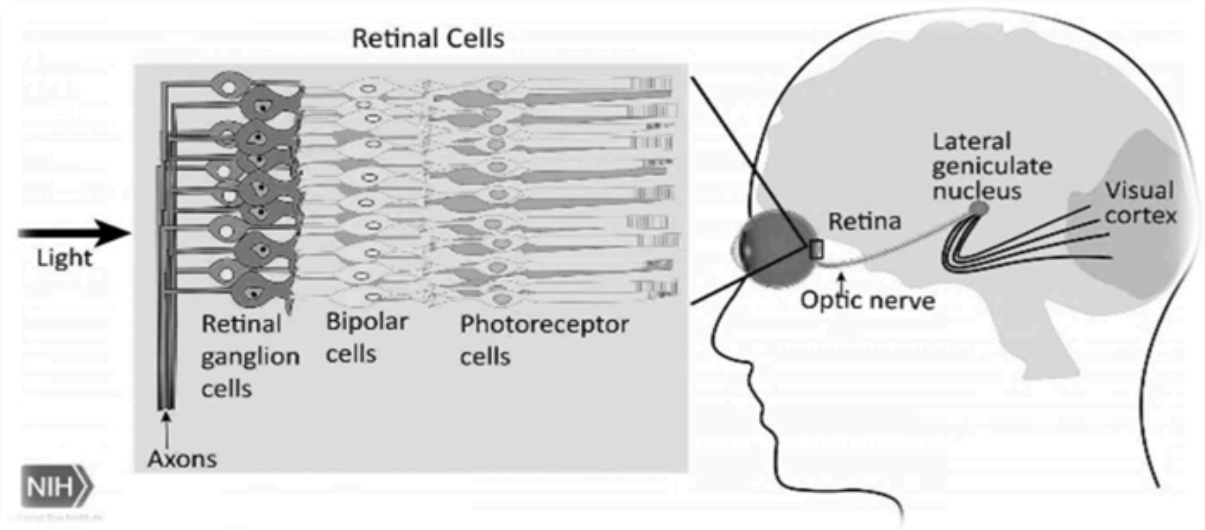


Figure 1: Normal visual pathway from retina to visual cortex ,Source: National Institutes of Health (NIH) records

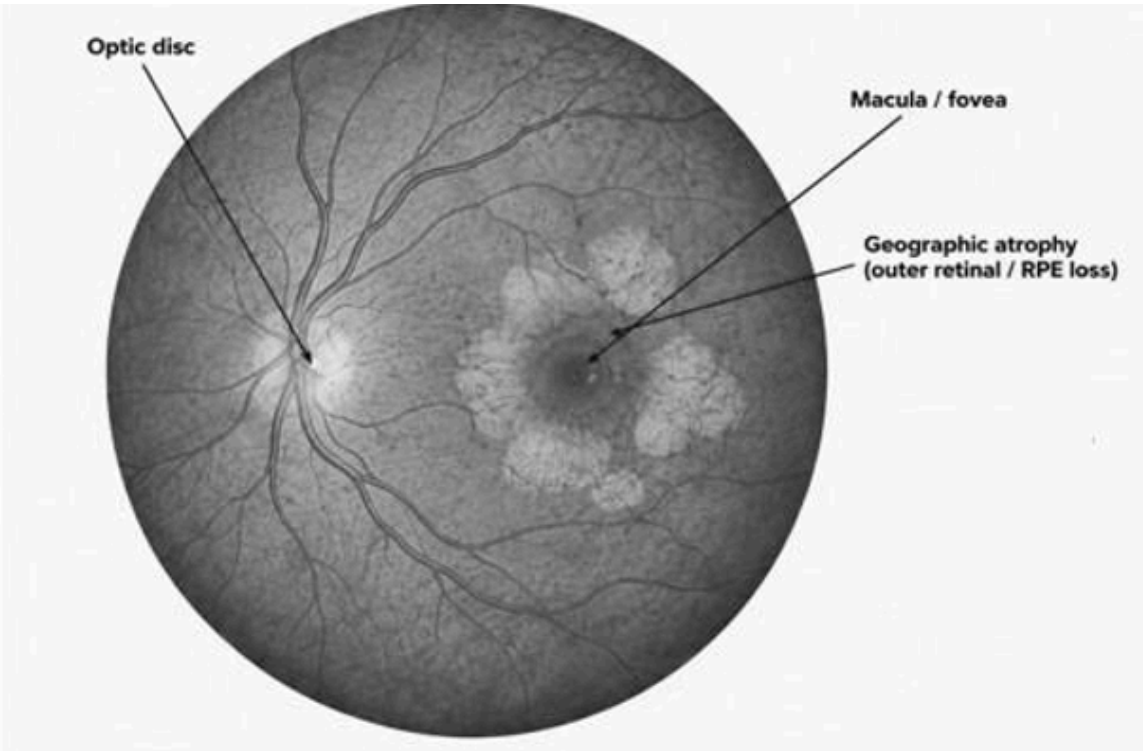


Figure 2: Fundus pathology example: geographic atrophy affecting central vision (Author created image)

METHODS

(1) Literature Search and Selection

A literature search was conducted using Google Scholar, IEEE Xplore, PubMed, SpringerLink, ScienceDirect, MDPI, and arXiv for publications from 2020 to 2025. Search terms included combinations of "visual impairment," "blindness," "assistive technology," "smart glasses," "smart cane," "obstacle detection," "OCR," "retinal imaging," and "visual perception."

Studies were included if they addressed assistive technologies for visual impairment and reported relevant functions, performance, benefits, or limitations. Studies unrelated to visual impairment or assistive technology, duplicate records, and publications outside 2020–2025 were excluded. More than 30 papers were initially identified, of which 15 were shortlisted for detailed analysis.

(2) Limitation Coding and Analysis

For each of the 15 shortlisted papers, limitations and functional gaps were identified from the findings, conclusions, and reported system characteristics of the respective study. These were grouped into technical and functional categories relevant to the research question. Where a limitation was not explicitly stated by the authors but was structurally precluded by the implemented device architecture, it was also coded as a limitation. The frequency of each category was then counted across the 15 papers. The coding and counting were conducted by the author, Soham Gandhi. The paper-level coding matrix used to derive the limitation frequencies is provided in Supplementary Table S1.

(3) User Interviews and Field Consultations

Two visually impaired participants with direct experience of assistive technologies were selected based on their professional and personal involvement with accessibility and assistive technology. Informed consent was obtained from both participants prior to the interviews. The field visit was conducted as an independent student research activity following an invitation from the National Association for the Blind, Delhi, and was not conducted under a formal institutional research or ethics-review protocol. The semi-structured interviews were documented through handwritten notes and video recording. The interviews were used to obtain illustrative user-reported needs and observations regarding assistive-device functionality. Given the small sample of two participants, these observations were treated as case insights and were not considered representative or generalizable to the wider visually impaired population.

(4) Ophthalmological Assessment and Clinical Interpretation

Clinical interpretation was informed by consultations with Dr. Savita Borkar and Dr. Navin Borkar, Mumbai, during which questions relating to visual-system pathology, functional vision, and the implications for assistive technologies were discussed. No formal clinical examination or diagnostic assessment of the two fieldwork participants was conducted as part of this study. The doctors' inputs were considered alongside the reviewed literature, technical specifications and functional characteristics of the assistive devices examined, and observations from the NAB, Delhi field visit to interpret how different forms and levels of visual-system impairment may affect functional perception and the suitability of different assistive technologies.

(5) Market and Technology Observation Procedure

A field visit to the National Association for the Blind (NAB), Delhi, was conducted to observe selected assistive and wearable technologies. Six technologies were examined through demonstrations and available product information. Observations focused on device form factor, primary interaction modality, sensing approach, battery life, major functions, and intended use. Where available, manufacturer specifications were used to document device characteristics. The observations were not treated as controlled head-to-head performance testing.

(6) FFT Signal Processing Experiment

An ESP32-S3 development board was used with a MAX30102 optical pulse oximeter and heart-rate sensor module. The MAX30102 measures heart rate (BPM) and blood oxygen saturation (SpO_2) and communicates with the ESP32-S3 using the I^2C interface. The sensor was used to acquire pulse-related data as the input signal for the FFT analysis.

The signal was sampled at 1 sample per second (1 Hz), with an FFT block size of 512 samples. The sampled digital signal was initially represented as a discrete signal and was then converted programmatically from a discrete representation to a continuous waveform representation using a C++ program. The resulting waveform was processed using a Fast Fourier Transform (FFT) to examine its frequency components and identify the dominant frequency associated with the pulse signal.

RESULTS AND ANALYSIS

a) Literature review

Table 1 synthesizes fifteen research papers published between 2020 and 2025. The papers were evaluated based on their publication year, system/authors, sensors employed, AI techniques, key strengths, and limitations. The limitation coding identified several recurring technical and functional issues across the reviewed studies (Figure 3). Insufficient user testing was identified in 12 of the 15 papers, followed by the absence of upper-body obstacle detection and limited OCR/document access, each identified in 11 papers. The lack of haptic feedback was identified in 10 papers. Other recurring limitations included limited AI accuracy (8/15), bulky hardware and short battery life (7/15 each), and narrow field of view (6/15). These findings highlight recurring areas for consideration in the design and evaluation of future assistive technologies. The underlying paper-level coding matrix and frequency calculations are provided in Supplementary Table S1.

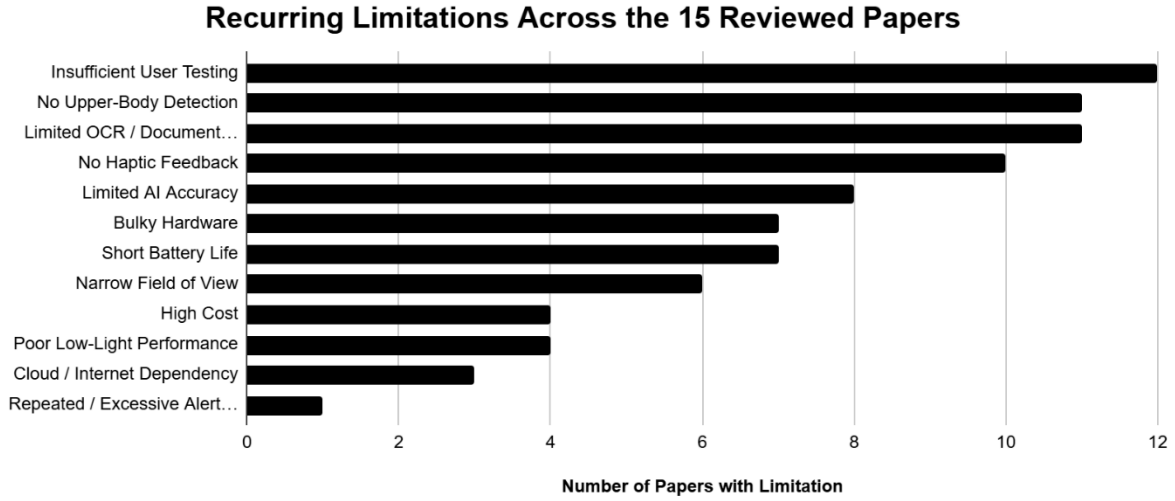


Figure 3: Recurring Limitations Across the 15 Reviewed Papers

Table 1. Comparative Analysis of 15 Reviewed Research Papers (2020–2025)

Year	System / Authors	Sensors	AI Technique	Key Strength	Limitation
2020	AI Visual Aid — Khan et al. [1]	Camera + Ultrasonic	SSDLite/MobileNet; OCR	60-user evaluation; integrated object recognition, navigation and reading assistance	Limited scene understanding; evaluation primarily in controlled environments
2021	V-Eye — Duh et al. [2]	Camera + GPS	VB-GPS; image segmentation; visual SLAM	Indoor–outdoor navigation; moving-obstacle detection; global localization	Communication delays and sensitivity to environmental/illumination changes
2021	Semantic Visual SLAM Wearable Device — Chen et al. [3]	RGB-D camera	Semantic segmentation + SLAM	Real-time semantic mapping and voice feedback on a wearable platform	Dependence on structured-light RGB-D sensing and environmental conditions
2022	LiDAR Navigation Assistance — Kuriakose et al. [4]	LiDAR	Obstacle detection and distance estimation	Contact-free obstacle detection and distance measurement	Hardware size/cost and sensing limitations in complex environments

2022	Crosswalk Navigation — Son & Weiland [5]	RGB-D camera + IMU + GPS	Computer vision / image segmentation + sensor fusion	Addresses a safety-critical crosswalk scenario	Prototype size/weight; limited handling of broader real-world conditions
2023	Wearable Tactile Assistive System — Chen, Shen & Sawada [6]	Stereo camera	Compressed deep learning + distance estimation	Converts obstacle location/distance into tactile feedback, preserving auditory attention	Tactile glove and sensing arrangement remain relatively specialized
2023	S-Cane — Ulfa et al. [7]	Ultrasonic sensors	Rule-based sensing	Low-cost smart-cane implementation	Limited sensing capability; primarily obstacle/proximity focused
2024	AIris — Brilli et al. [8]	Camera + microphone	Computer vision + NLP	Multimodal wearable assistance including object recognition, scene description and text reading	Server-based processing introduces connectivity and latency considerations
2024	Smart Cane — Mai et al. [9]	2D LiDAR + RGB-D + IMU + GPS	YOLOv5 + SLAM	Integrated navigation and obstacle recognition; real-time processing	2D LiDAR height limits vertical obstacle coverage; hardware
2024	Semantic SLAM Grasping System — Fei et al. [10]	RGB-D/depth camera + vibration array	ORB-SLAM2 + YOLOv5s	Combines semantic mapping with tactile guidance for grasping	Designed for tabletop grasping rather than general navigation
2024	LVLM Wearable Vision Assistance — Baig et al. [11]	Hat-mounted camera + distance sensor	Large Vision-Language Model	Context-rich object descriptions and recognition of new people/objects	Dependence on computationally intensive AI processing; prototype-level evaluation
2025	Sight Guide — Pfreundschuh et al. [12]	Multiple RGB + depth cameras	Classical robotics + learning-based perception	Integrated obstacle avoidance, object detection, OCR and multimodal	Prototype/competition-focused system; real-world applicability and

				feedback; 95.7% task success in testing	wearability require further development
2025	Smart Glasses for Visually Impaired Individuals — Ghuge et al. [13]	Camera	FaceNet + MobileNetV2-SSD + offline OCR	On-device face recognition, object detection and price-reading OCR	Limited to the evaluated recognition tasks and prototype environment
2025	IoT Wearable Assist Device — Lokesh et al. [14]	ESP32-CAM + ultrasonic sensor	SVM + ResNet-50 + YOLOv4	Integrated face recognition, object detection and obstacle sensing	Further extensive user validation is needed; prototype evaluation (Taylor & Francis Online)
2025	Low-Cost Smart Cane — Mungdee et al. [15]	Dual RGB cameras + ultrasonic sensor	YOLO-based models + PSTPD	Detects obstacles and pathway-surface transitions with distance/danger estimation	Future work required for cane-tilt compensation, larger datasets and power optimization (MDPI)

b) On-Field Research and Investigation

The primary research was conducted at the National Association of the Blind, Delhi (NAB – Delhi) through conversations with two visually impaired participants. Open-ended discussions were used rather than a fixed questionnaire so that participants could discuss the problems they personally found most important as shown in Table 2. these conversations, considered alongside the literature reviewed in Table 1, were used to identify illustrative user-reported needs and observations that informed the engineering considerations summarized in Table 3. Because the fieldwork involved only two participants, these observations are presented as case insights rather than generalizable themes.

Table 2. Participant Background Summary

Attribute	**Participant 1**	**Participant 2**
Background	Student	Visually impaired working professional
Primary challenges	Education access, mobility, affordable tech	Document handling, professional navigation, digital accessibility
Technologies used	White cane, screen readers, AI image apps	Smart cane, Optical Character Reader apps, screen readers
Key insight	Simple daily mobility remains unsafe at head height	Professional independence requires fast, offline document processing

Table 3. Key Recurring Issues : User Findings, Literature Alignment, and Engineering Implications

Recurring Issue	**User Evidence**	**Literature Alignment**	**Engineering Implications**
Upper-body detection	Both participants: tree branches, vehicle mirrors, scaffolding	11/15 papers	Design implication: upper-body sensing
Internet dependency	Both: failures in courts, rural areas, institutions	3/15 papers	Design implication: offline-capable operation
Affordability	Participant 1: commercial glasses financially inaccessible	4/15 papers	Design implication: cost-conscious design
Optical Character Reader (OCR)/ Document access	Participant 2: complex legal PDFs; Participant 1: printed materials	11/15 papers	Design implication: offline OCR and document access
Repeated / Excessive Alerts or Feedback	Both: repetitive warnings reduced trust	1/15 papers	Design implication: context-aware and selective alerting

Note: Participant evidence represents illustrative case insights from two participants and is not intended to establish population-level generalizability.

c) Ophthalmological Assessments

Engineering solutions for visually impaired individuals should be based on an understanding of their medical needs. We translated the medical observations to corresponding engineering design considerations and triangulated the participants' observations, medical observations, and Engineering requirements to narrow down the Technology solution as shown in Table 4.

Table 4. Triangulated Perspectives: User, Medical, and Engineering

Challenge	**User Perspective**	**Medical Perspective**	**Engineering Response**
Upper-body hazards	Tree branches, mirrors, scaffolding	Peripheral and full-field loss both affected	Head/chest-mounted sensing
Reading documents	Printed legal docs inaccessible	Macular degeneration: central vision lost	High-accuracy offline Optical Character Reader
Low-light navigation	Nighttime mobility dangerous	night blindness	Sensors effective in darkness (LiDAR, IR)
Repeated / Excessive Alerts or Feedback	Continuous warnings dismissed	Sensory overload concern noted	Context-aware selective alerting

d) Market and Technology Observation

A field visit to the National Association of the Blind (NAB) , Delhi was undertaken. Six assistive and wearable technologies (White Cane, Smart Cane, NeuroDrishti, SHG Smart Vision Glasses, Ray-Ban Meta Gen 2, and B by Lenskart) were observed. Data on their functionality, form factor, and user interface were collected from demonstrations and available product specifications.

For comparison, the observed technologies were also considered according to the level of the visual pathway on which their function depends. Technologies that rely on residual retinal vision are most relevant when usable retinal and neural function remains. In contrast, mobility aids and camera-based sensory-substitution systems do not require the conventional ocular visual pathway and may therefore remain functionally applicable when impairment involves the inner retina or optic nerve, and potentially in complete ocular visual loss. These classifications describe functional applicability rather than restoration of vision

Table 5. Comparison of selected assistive and wearable technologies. Sources: manufacturer product specifications and observations at NAB Delhi

Device	**Weight**	**Battery**	**Perception Driver**	**Functional basis**	**Pathology / Functional Applicability**	**Limitations**
White Cane	160-220 g[24]	No battery	Ground-level obstacle detection, tactile feedback	Simple and reliable baseline	Outer retinal; inner retinal/optic nerve; complete ocular visual loss	Upper-body obstacle limitations
Smart Cane	200-300 g [25]	Varies [25]	Electronic obstacle detection, GPS, audio/vibration	Adds sensing to traditional cane	Outer retinal; inner retinal/optic nerve; complete ocular visual loss	Upper body obstacle limitations
NeuroDrishti	34g[20]	12hr[20]	OCR, object detection, scene description, face recognition	Assistive smart glasses	Outer retinal; inner retinal/optic nerve; potentially complete ocular visual loss	Wi-Fi/Bluetooth connectivity required for connected features; audio performance may vary in noisy environments.

SHG Smart Vision	58g[21]	3hr[21]	OCR, object detection, obstacle detection, people and face recognition	Assistive smart glasses	Outer retinal; inner retinal/optic nerve; potentially complete ocular visual loss	Mobile-phone connectivity required for some functions; speaker output loses clarity in busy or high-noise settings
Ray-Ban Meta Gen 2	48g[22]	8hr[22]	AI, camera, audio, voice control	Consumer smart-glasses benchmark	Outer retinal; inner retinal/optic nerve; potentially complete ocular visual loss	Cellular data dependency, Cognitive load, and alert fatigue (constant audio warnings become distracting)
B by Lenskart	40g[23]	4hr[23]	AI, camera, translation, voice control	Indian consumer benchmark	Outer retinal; inner retinal/optic nerve; potentially complete ocular visual loss	One basic frame, relies on Gemini assistance, battery life varies with feature usage.

For comparison, the observed technologies were also considered according to the level of the visual pathway on which their function depends. Technologies that rely on residual retinal vision are most relevant when usable retinal and neural function remains. In contrast, mobility aids and camera-based sensory-substitution systems do not require the conventional ocular visual pathway and may therefore remain functionally applicable when impairment involves the inner retina or optic nerve, and potentially in complete ocular visual loss. These classifications describe functional applicability rather than restoration of vision.

e) Engineering gap in Functional Perception

The analysis identified a gap between the capabilities of existing assistive technologies and the functional information required by users with different levels of visual-system impairment. Addressing this gap may require improved sensing, signal processing, and methods of presenting information through visual, auditory, or tactile channels. The appropriate engineering approach depends on the location and extent of damage within the visual system. For individuals with residual visual function, image enhancement and

improved sensing may help make available visual information more accessible, whereas more extensive impairment may require alternative sensory channels such as audio or tactile feedback.

Signal-processing methods may provide an additional means of extracting or transforming information before it is presented to the user or processed by an AI system. Fast Fourier Transform (FFT) processing was therefore investigated in this study as an embedded signal-processing approach**.** The following section describes the FFT concept and its potential relevance to assistive-technology applications.

f) Fast Fourier Transform (FFT) to Retinal Imaging and Assistive Perception

Fast Fourier Transform (FFT) is not an assistive device by itself; it is a computational method that transforms a sampled signal from the time or spatial domain into the frequency domain. In retinal imaging, this is useful because slowly varying illumination occupies lower spatial frequencies, while fine vessel edges, text contours, and many structural boundaries contribute more strongly at higher spatial frequencies. Selected frequency bands can therefore be attenuated or amplified, followed by an inverse FFT to reconstruct an image that may be easier for a person with residual vision - or easier for a recognition algorithm - to interpret. Retinal-image restoration literature describes Fourier/transform-domain approaches as one route for correcting illumination, deblurring, and enhancing structural detail. [19]

Conceptual FFT pipeline: external-scene camera image or sampled signal → FFT → frequency-domain filtering or feature selection → inverse FFT or signal reconstruction → visual, audio, or tactile assistive output.

2-D image form: F(u,v) = FFT{f(x,y)}; enhanced image = IFFT{H(u,v) x F(u,v)}, where H(u,v) is a chosen frequency filter.

In this context, FFT-based processing of a fundus or retinal image refers to clinical image analysis and is distinct from processing an external scene captured by an assistive device. The latter may be relevant to assistive perception, whereas retinal-image enhancement is primarily a diagnostic image-processing application. FFT was investigated using C++ and Arduino-based systems to understand how sampled signals could be processed and analyzed. This investigation also explored how signal processing could be used before an AI model, potentially reducing the amount of raw data that needs to be processed by a small embedded system. FFT can therefore be useful for future wearable devices where processing power and battery life are limited. The FFT investigation was exploratory and was not intended to establish quantitative signal-processing accuracy or improvement in functional perception**.** However, FFT was not integrated into a complete wearable prototype during this research.

Table 6. Potential Applications of FFT in Assistive-Device Processing

FFT application	**What is processed**	**Relevance to pathology**	**Potential assistive-device effect**
Illumination correction	Low-frequency background variation in fundus/camera frames	Can make macular and peripheral retinal detail more uniform without assuming that pathology itself is low-frequency	Cleaner input for head mounted displays or computer-vision recognition; must avoid suppressing true broad lesions.
Edge / vessel / text enhancement	Mid- to high-spatial frequency components	May emphasize vessel borders, lesion margins, object edges, and text strokes that remain detectable through residual vision	Could increase functional contrast for low-vision visual enhancement or provide cleaner input for camera-based recognition and OCR systems.
Feature compression for sensory substitution	Dominant spatial-frequency or orientation components	Less dependent on the exact ocular lesion because the processed camera information is remapped to another sensory channel	A compact set of edges/orientations could be mapped to audio or tactile cues, reducing information load but not recreating normal vision.
Computational efficiency	FFT block size, filtering and inverse transform in a real-time pipeline	Applies to every pathology group	FFT-based processing has approximately O(N log N) complexity, however end-to-end processing time would require measurement in a complete device implementation

DISCUSSION

The findings suggest that the functional suitability of assistive technologies depends on the level of visual-system impairment. Technologies that enhance residual vision may be useful when retinal and neural function remains, while camera-based sensory substitution and mobility technologies may remain applicable when conventional visual pathways are substantially impaired.

For individuals with residual vision, assistive technologies may complement low-vision rehabilitation by enhancing usable visual information, while sensory-substitution approaches may provide alternative channels of information when conventional visual processing is substantially impaired. [16]

Across the 15 reviewed studies, recurring limitations included insufficient user testing (12/15), upper-body obstacle detection and limited OCR/document access (11/15 each), and lack of haptic feedback (10/15). The two participant interviews provided illustrative case insights involving head-height hazards, document access, affordability, offline operation, and repeated alerts. These observations were used to complement the literature and clinical interpretation, not to establish generalizable user requirements.

Together, these findings indicate that future assistive devices should consider pathology, sensing coverage, offline processing, document access, and selective feedback. The FFT investigation provides an exploratory signal-processing direction, but it was not designed to demonstrate quantitative improvement in functional perception or validated device performance.

LIMITATIONS

This study has several limitations. First, the fieldwork involved only two participants, so the observations are illustrative case insights and cannot be generalized to the wider visually impaired population. Second, the device comparison relied on available manufacturer specifications and field observations rather than controlled head-to-head testing; reported weight and battery-life values were therefore not independently verified. Third, the performance-related analysis, including the exploratory FFT investigation, was conceptual or exploratory rather than a quantitative measurement of end-to-end device performance. Finally, no complete assistive-device prototype incorporating the proposed engineering approaches was developed or tested.

Future work should expand the user study with a larger and more diverse participant group, verify device specifications through standardized measurements, and conduct controlled testing of response time, accuracy, and user performance. The FFT approach could then be integrated into a wearable prototype and evaluated using measured processing time and functional tasks. Further collaboration with ophthalmologists, rehabilitation specialists, engineers, and visually impaired users would help assess whether these approaches provide practical benefits across different levels of visual-system impairment.

CONCLUSION

The findings of this study suggest that the future of assistive technology for visual impairment lies not simply in developing devices with greater sensing or artificial-intelligence capabilities, but in designing technologies around the nature of the information a person can still access or needs to receive. A device that is highly capable in isolation may provide limited benefit if its method of perception does not correspond to the user's remaining visual function or daily requirements. This perspective places the individual and the functional consequences of visual-system damage at the centre of technology selection and design. Rather than seeking a single universal solution, assistive technology may therefore be better understood as a set of complementary approaches that restore, enhance, or substitute specific forms of environmental information.

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Supplementary Materials

Supplementary Table S1. Limitation coding matrix for the 15 reviewed research papers

Authors / Reference	Cloud / Internet Dependency	No Upper-Body Detection	High Cost	Bulky Hardware	Short Battery Life	Limited AI Accuracy	Narrow Field of View	No Haptic Feedback	Poor Low-Light Performance	Insufficient User Testing	Limited OCR / Document Access	Repeated / Excessive Alerts or Feedback	Row Total
Khan et al. 2020 [1]	1	0	0	0	1	1	1	1	1	0	0	0	6
Duh et al. 2021 [2]	0	0	0	0	n/a	1	0	1	1	0	1	0	4
Chen et al. 2021 [3]	0	0	0	1	1	1	1	1	0	1	1	0	7
Kuriakose et al. 2022 [4]	0	1	1	1	1	0	0	1	0	1	1	0	7
Son & Weiland 2022 [5]	0	1	0	1	n/a	1	1	0	0	1	1	1	7
Chen, Shen & Sawada 2023 [6]	0	1	1	1	1	1	1	0	0	1	1	0	8
Ulfa et al. (S-Cane) 2023 [7]	0	1	0	0	0	0	0	1	0	1	1	0	4

Brilli et al. (AIris) 2024 [8]	1	1	0	0	1	0	0	1	0	1	0	0	5
Mai et al. 2024 [9]	0	1	1	1	0	0	0	1	0	0	1	0	5
Fei et al. 2024 [10]	0	1	0	1	n/a	0	1	0	0	1	1	0	5
Baig et al. 2024 [11]	1	1	0	0	1	0	0	1	1	1	1	0	7
Pfreundschuh et al. 2025 [12]	0	0	1	1	1	0	0	0	0	1	0	0	4
Ghuge et al. 2025 [13]	0	1	0	0	n/a	1	0	1	0	1	0	0	4
Lokesh et al. 2025 [14]	0	1	0	0	n/a	1	0	0	0	1	1	0	4
Mungdee et al. 2025 [15]	0	1	0	0	0	1	1	1	1	1	1	0	7
Total:	**3**	**11**	**4**	**7**	**7**	**8**	**6**	**10**	**4**	**12**	**11**	**1**	**84**

Coding Key:
1 - Limitation explicitly reported by authors or structurally precluded by device architecture
0 - Limitation not evident in this paper/addressed by the system
n/a - Insufficient evidence not included in column totals