UDC 004.9 **doi:** https://doi.org/10.20998/2522-9052.2025.1.02

Vitalii Serdechnyi, Olesia Barkovska, Andriy Kovalenko, Vitalii Martovytskyi, Anton Havrashenko

Kharkiv National University of Radio Electronics, Kharkiv, Ukraine

KNOWLEDGE SYSTEMATIZATION ABOUT THE CHARACTERISTICS OF EXISTING TECHNOLOGICAL MEANS FOR ASSISTING PEOPLE WITH VISUAL IMPAIRMENTS

Abstract. The work is **devoted** to a detailed review of the main aspects of physical vulnerability for people with visual impairments, as well as technological means for navigation and adaptation to the surrounding environment, which can significantly enhance their sense of safety and security. The relevance of the topic is justified by its large social focus, because such systems help people with visual impairments to socialize more easily and ensure greater inclusion. This is particularly important in urban environments where insufficient attention is paid to inclusivity and the comfort of visually impaired individuals (e.g., lack of audible traffic lights, tactile paving, etc.). **The subject** of the article is the study of hardware components that ensure the functionality of support systems for people with visual impairments. **The goal** of this paper is to systematize knowledge about existing technological tools for people with visual impairments and to analyze the hardware characteristics of the components of such solutions. **The task** of this work is to examine the psychophysiological factors and aspects of physical vulnerability for people with visual impairments, review existing assistance systems for visually impaired individuals, identify the hardware base required for creating a “vision” system of the surrounding environment, and analyze the characteristics of sensors considering the external conditions in which visually impaired people may find themselves. The objectives are achieved through the use of **methods** such as comparative analysis, classification and categorization, and a systematic review of the literature in the relevant problem domain. **The results** of the work include a proposed classification of assistive devices for people with visual impairments, which encompasses the following classes: navigation applications and devices; sensory systems for obstacle and object detection; wearable devices with augmented reality (AR) features; “vision” systems for the surrounding environment; and text recognition systems. The evaluation and analysis of the advantages and disadvantages of devices in each of these classes demonstrate that a new solution should meet the criteria of compactness, wearability, energy efficiency, ease of use, and high accuracy in detecting environmental conditions, obstacles, and objects on the user's path. **Conclusions**. To ensure data complementarity in tasks of detecting moving objects in intelligent assistance systems for visually impaired individuals, the optimal approach is to combine multiple sensors using the Multisensor Fusion methodology. Specifically, this involves high-resolution cameras that provide detailed scene imaging and LiDARs that ensure precise distance measurement and 3D modeling of the environment. Such an approach compensates for the limitations of individual sensors and provides a more comprehensive understanding of the scene, improving data quality through the integration of diverse information sources. **Further research** will focus on conducting experimental research aimed at practically justifying the joint use of cameras, audio sensors, and LiDARs for obtaining heterogeneous data that provide the most comprehensive depiction of the environment surrounding visually impaired individuals.

Keywords: analysis; review; systems; assistance; LiDAR; camera; microphone; people with visual impairments; detection; dynamic objects.

Introduction

The sense of safety for a person is a subjective feeling of protection from physical, emotional, social, economic, or other threats. Fear of potential danger undermines an individual's sense of physical, emotional, and social stability. A review of available literature reveals a substantial body of research highlighting the relationship between physical disability and mental health problems [1].

Among the consequences of persistent fear in individuals are the following: chronic stress and deterioration of physical health, anxiety disorders, social isolation, reduced productivity and creativity, development of depressive behavior, depression, impaired decision-making, relationship issues, decreased quality of life, sleep disorders, and negative societal impacts, among others [2].

The feeling of insecurity from physical, emotional, social, and economic threats can affect the quality of life, hinder normal functioning, and lead to social isolation or avoidance of certain places.

The task addressed in this work is aimed at reducing the sense of physical insecurity for individuals with visual impairments, which may arise when they encounter unfamiliar environments. Potential risks faced by visually impaired individuals due to their limited ability to see include:

– difficulty in spatial orientation;
– difficulty identifying objects around them;
– difficulty detecting dangers in their surroundings.

Thus, fear of potential danger can significantly impact a person's life. However, an appropriate approach to overcoming this fear can improve the quality of life and enhance self-confidence. The main aspects of physical insecurity for people with visual impairments are presented in Table 1.

Physical insecurity can have a significant impact on the quality of life of a person with visual impairments. However, adherence to the approaches outlined in Fig. 1, including the development of technical means for navigation and adaptation to the surrounding environment, can substantially enhance the sense of safety and security for such individuals [3].

In the study [4], a model of a technological solution aimed at assisting people with visual impairments in everyday life to ensure greater inclusion is proposed. The study specifies that the first stage of the proposed system involves determining the environmental conditions, which is suggested to be implemented through a dedicated intelligent model called “Environment Conditions Detection.”

Table 1 – **Key Aspects of Physical Insecurity for People with Visual Impairments**

Aspects of Physical Insecurity	Description
Obstacles and hazards in the environment	• Obstacles on the path (uneven surfaces, stairs, uncovered manholes, curbs, objects on the road) can cause injuries; • Lack of accessible navigation aids; • Encounters with stray or wild animals.
Difficulties in mobility	• People with visual impairments often face challenges when crossing roads, using public transport, or even navigating familiar places due to the lack of clear understanding of their surroundings; • Absence of tactile markers or auditory signals.
Social interaction and risk of criminal offenses	• People with visual impairments may be vulnerable to fraud, theft, or physical assaults due to limited ability to identify threats or defend themselves; • Lack of the ability to quickly assess situations.
Transportation hazards	• Being outdoors or using transportation can be dangerous without adapted devices, such as audible traffic signals or notification systems in transport
Lack of access to information	• Absence of visual information or failure to consider the needs of people with visual impairments may lead to a lack of awareness about potential threats or dangers.
Dependence on external assistance	• In some cases, people with visual impairments have to rely on help from others, which may limit their independence and reinforce a sense of insecurity.

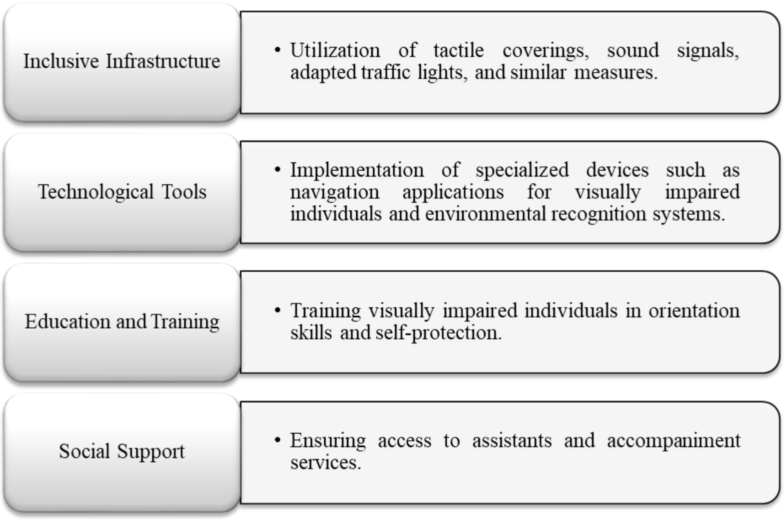

Fig. 1. Approaches to reducing physical insecurity for people with visual impairments

This model is designed to utilize various types of input data, namely video data, microphone data, and temperature sensor data.

The task of this model is to solve the classification problem and generate appropriate class labels that describe the environmental conditions for further informing the user about potential dangers along their path.

Aims and tasks

The aim of this work is to systematize knowledge about existing technological solutions for people with visual impairments and to analyze the hardware characteristics of the components of such systems.

To achieve this goal, the following tasks must be accomplished:

– review of psychophysiological factors and aspects of physical insecurity for people with visual impairments;

– overview of existing assistance systems for people with visual impairments;

– identification of the hardware base required for creating a "vision" system of the surrounding environment;

– analysis of the characteristics of sensors considering the external conditions in which people with visual impairments may find themselves.

State-of-the-art: review of existing assistance systems for people with visual impairments

An analysis of existing developments in the thematic area of this work revealed a significant number of solutions designed to assist people with visual impairments. However, these systems exhibit a wide range of shortcomings [5-10]. The generalization of these drawbacks, such as high cost (on average around $3000 USD), limited functionality, additional requirements for user skills, and the necessity of an Internet connection, underscores the need for an alternative device [11].

A proposed classification of existing technological solutions for people with visual impairments, aimed at improving their mobility, safety, and overall quality of life by compensating for limitations associated with vision loss through innovative solutions that provide navigation, orientation, and access to information [12], is presented in Fig. 2. Explanations for each class:

– navigation applications and devices provide real-time navigation for people with visual impairments using voice commands or audio signals. Examples of tasks solved by systems in this class include enabling independent movement within a city, warning about obstacles along the path, orienting in public spaces, and providing information about route changes or nearby points of interest [13];

– obstacle and object detection systems help people with visual impairments detect obstacles on their path and safely navigate around them using various types of sensors, such as ultrasonic sensors for obstacle detection and vibration sensors for alerting the user through vibrations;

– wearable devices with augmented reality (AR) [14] features deliver information about the surrounding world through voice or tactile prompts, utilizing augmented reality technologies;

– “vision” systems for the surrounding environment allow people with visual impairments to "see" their surroundings using specialized devices that analyze images or audio signals and provide relevant information. Examples of tasks addressed by systems in this class include real-time recognition and identification of objects, text, and people [15]; feedback on the environment to improve orientation; and access to information typically available visually (e.g., reading text, identifying colors);

– text recognition systems are designed to scan and convert text into audio or electronic formats for convenient perception by users. Examples of tasks solved by systems in this class include reading books, menus, and documents in any location, thereby increasing the accessibility of printed information for people with visual impairments [16].

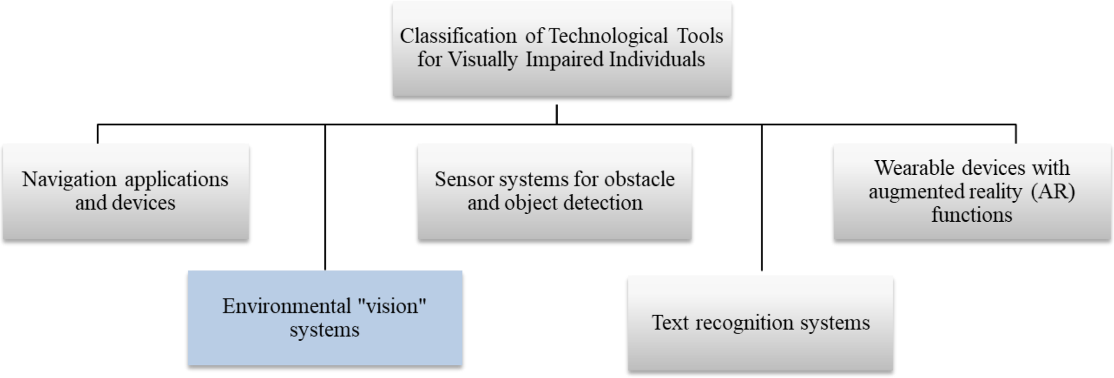

Fig. 2. Proposed classification of existing technological solutions for people with visual impairments

Existing assistance systems for people with visual impairments

The assistance systems for people with visual impairments listed below often incorporate the functionality of several classes described in Fig. 2.

The devices OrCam MyEye and Aira Glass share a similar form factor, utilizing a camera and artificial intelligence for recognizing text, objects, and faces. These devices attach to glasses (Fig. 3), are compact, lightweight, and easy to use. They can read text from any surface, recognize objects, and describe them to the user. Additionally, Aira Glass offers voice-guided navigation instructions. The cost of the OrCam MyEye device (USA) in Ukraine ranges from €3000 to €11000, depending on the configuration. The cost of the Aira Glass device (Israel) is approximately $1995 USD but is only available in the USA and Canada.

a b

Fig. 3. Devices: a – OrCam MyEye 3 Pro; b – Aira Glass

The NavVis devices utilize a camera, artificial intelligence, and GPS for navigation and providing information to the user (Fig. 4). NavVis is designed for indoor mapping and is not a personal navigation device specifically for people with visual impairments. The devices are user-friendly, support voice command control, can describe the surroundings to the user, recognize objects, and provide detailed descriptions. The cost of the NavVis device (Germany) ranges from €5000 to €7000, depending on the configuration. Officially, NavVis is not available in Ukraine.

Fig. 4. NavVis device

Among the limitations of hardware assistants focused on analyzing the visual scene for people with visual impairments, as described above, are high cost, a limited number of objects available for recognition, the inability to provide information about weather conditions, and the lack of tactile feedback. These shortcomings fail to ensure an adequate level of safety and comfort enhancement.

A distinctive device compared to the aforementioned is the WeWALK Smart Cane, whose functionality is not based on cameras and artificial intelligence for recognizing visual information.

Instead, it utilizes an ultrasonic sensor (to detect obstacles in front of the user, such as stairs, curbs, and other objects), a gyroscope (to determine the direction and speed of the user's movement), an accelerometer (to identify the user's position in space), and a compass (Fig. 5).

Fig. 5. WeWALK smart cane

The data collected by the sensors of the WeWALK Smart Cane is processed to create a map of the user's surroundings, determine the safest path, and guide the user by sending vibration signals to the cane's handle. These signals inform the user about obstacle locations and the direction to move. Additional features include GPS navigation and voice control. The cost of the WeWALK Smart Cane (Israel) is approximately 5500 UAH, and the device is available in Ukraine.

Among the limitations of the WeWALK Smart Cane are its short battery life due to dependency on its rechargeable battery, significant weight, and the relative complexity of using its functions.

Among software applications that can be considered for assisting people with visual impairments, Microsoft Seeing AI deserves attention. This free smartphone application uses the camera and artificial intelligence to recognize text, objects, and certain obstacles, detecting and describing them to the user. However, the drawbacks of such applications include requirements for high-performance smartphone cameras and reliable Internet connectivity. As a result, their functionality may be limited, particularly in low-light conditions.

One of the most innovative concepts in this field is robotic guide dogs (ROBODOGS), equipped with a wide array of sensors: cameras for visualizing their surroundings, LiDARs for obstacle detection and creating a 3D map of the environment, pressure sensors to detect contact with people and objects, and infrared sensors to identify obstacles in low-light conditions.

ROBODOGS utilize artificial intelligence for learning and adapting to new situations, as well as for leveraging their own experience to improve their skills over time (Fig. 6).

a b c

Fig. 6. Examples of robotic guide dogs: a – Unitree Robotics, b – ANYMAL Robotics, c – Aibo ERS-1000 by Sony

The term ROBODOGS refers to robotic guide dogs developed by various companies and research institutions, including Unitree Robotics (China) with the Laikabo model, ANYMAL Robotics (Switzerland) with the ANYmal robot, Sony (Japan) with the latest model Aibo ERS-1000, and Honda (Japan) with the robots Asimo and Sakura.

The cost of basic ROBODOGS models starts at approximately $25,000, making these devices inaccessible to a wide range of users.

One of the drawbacks is the low mobility of these devices, which can result in inconveniences when used in crowded areas or during transportation.

Based on the conducted review of existing solutions, it can be confidently stated that the development of an assisted guidance system for people with visual impairments meets social needs and has the potential to ensure greater inclusion for individuals with vision impairments.

Since "vision" systems for the surrounding environment address the largest number of potential risks faced by people due to their limited ability to see [17, 18], these systems effectively reduce the sense of physical insecurity for individuals with visual impairments.

Future in-depth reviews and functional analyses will focus specifically on this class of technological solutions.

Definition of the hardware base required for developing a “vision” system for the surrounding environment

The requirements for computer vision methods, considered essential and key in the operation of “vision” systems for the surrounding environment, include:

– efficiency (high accuracy in recognizing various objects within the scene at different distances from the user, including those moving at varying speeds);

– reliability (robustness and resistance to the influence of various factors, such as changes in lighting, weather conditions, obstacles, and Internet connectivity);

– flexibility (adaptability to individual user needs and changes in the environment);

– integrability (compatibility with assistive technologies, such as voice control systems);

– high performance (critical response speed in analyzing dynamic scenes to promptly warn users of danger, especially during offline operation with limited computational resources, such as when using a mobile phone as the processing unit).

The implementation of methods for determining environmental conditions as a module of an assistive system for people with visual impairments is intended to ensure the safety of visually impaired pedestrians in outdoor environments.

This can be achieved only by ensuring the complementarity of data to increase the accuracy of detection and tracking of both stationary and dynamic objects for subsequent trajectory and velocity prediction.

The complementarity of visual data can be achieved by utilizing a wide variety of sensors for visual object registration (Table 2), including:

Table 2 – **Devices for ensuring complementarity of visual data in tasks of recognizing moving objects in complex conditions, determining their distance, trajectory, and speed based on computer vision methods**

Device	Purpose / Tasks Solved
High-resolution cameras	Provide a high level of scene detail and enable timely detection of object movements [19].
Stereo cameras	Used to determine the distance to objects based on the principle of stereovision, mimicking the function of human eyes. Stereo cameras allow the creation of a 3D model of the environment, helping to evaluate the position and trajectories of moving objects.
LiDARs (Light Detection and Ranging)	LiDARs use laser beams to scan the surroundings and build a 3D model of the scene. They enable precise distance measurement to objects, as well as the determination of their shapes and sizes. LiDARs are particularly effective in challenging conditions such as fog or low light [20].
Radars	Radars can determine the distance, speed, and direction of object movement through the reflection of radio waves. They are effective in adverse weather conditions and low-light environments, making them ideal for detecting objects and measuring speed.
Thermal cameras	Used for detecting the thermal radiation of objects. Thermal cameras allow object recognition even in darkness, poor lighting conditions, or complex environments.
Time-of-Flight (ToF) cameras	Measure the time it takes for a light pulse to reach an object and return, enabling the creation of an accurate depth map of the scene. ToF cameras provide precise information about object distances and can be used for motion analysis.
Inertial Measurement Units (IMU)	Used for analyzing object movement, determining their acceleration and trajectory. IMUs can complement data from visual sensors, improving motion analysis accuracy.

– high-resolution cameras;
– stereo cameras;
– LiDARs (Light Detection and Ranging);
– radars;
– thermal cameras;
– Time-of-Flight (ToF) cameras;
– Inertial Measurement Units (IMUs).

To ensure data complementarity in the tasks of recognizing moving objects, the optimal approach is to combine multiple sensors — a Multisensor Fusion approach. This includes high-resolution cameras that provide detailed scene imagery and LiDARs that deliver precise distance measurements and construct three-dimensional models of the environment [21–23].

This approach compensates for the limitations of individual sensors, offering a more comprehensive understanding of the scene and enhancing data quality through the integration of diverse sources, leveraging artificial intelligence methods [24].

The scientific value of the planned research lies in investigating the joint use of heterogeneous data obtained from LiDAR sensors and cameras. This is expected to enable the recognition of low-contrast objects and those in low-light conditions, which may be invisible to the camera. By using LiDAR data, which is less sensitive to lighting changes and noise, the overall robustness of the intelligent assistance system for supporting people with visual impairments is anticipated to improve. It is predicted that data fusion will enhance object recognition in challenging conditions by considering both visual and spatial characteristics. The combined use of a camera and LiDAR offers significant scientific novelty, making the technology more flexible and versatile compared to the use of either sensor individually.

The rationale for extending the intelligent assistance system with a voice control module lies in ensuring psychological comfort and enabling users to interact with the system in natural language. This improves the ease of use and convenience of interaction with the assistant.

Enabling voice interaction with the assistant can be achieved using a wide variety of sensors for audio information registration (Table 3), including:
– high-sensitivity microphones;
– array microphones;
– noise-canceling microphones;
– wireless headsets;
– audio interfaces;
– voice activity detectors (VADs);
– sound processing systems (DSP processors).

Given that an assistive system for people with visual impairments should be lightweight, convenient, positioned close to the user's face, and capable of accurately responding to voice commands, the use of a large variety of sensors is not justified from the perspective of user comfort, energy efficiency, or prolonged operation time.

Guided by the principle of minimizing the number of sensors and conserving energy, the use of high-sensitivity microphones is proposed as a sufficient condition for accurate recognition of voice commands regardless of external conditions.

Analysis of the characteristics of recording devices considering the external conditions encountered by individuals with visual impairments

The development of an effective guidance system for people with visual impairments requires the use of various recording devices capable of providing accurate and rapid information about the surrounding environment.

Table 3 – **Devices for enabling user interaction with a voice assistant**

Device	Purpose / Tasks Solved
High-sensitivity microphones	Used for capturing the user's voice and identifying environmental conditions (e.g., detecting sounds of precipitation). They ensure accurate speech recognition by minimizing background noise and providing high-quality audio.
Array microphones	A group of microphones working together to determine the direction of sound, allowing more effective identification of the sound source and reducing the impact of ambient noise. Used to enhance voice recognition and ensure more natural interaction with the assistant.
Noise-canceling microphones	These microphones feature noise suppression functionality, enabling signal cleaning from extraneous noises and improving the quality of voice command recognition even in challenging acoustic environments.
Wireless headsets	Capture voice directly near the user's mouth, reducing the influence of background noise and improving the accuracy of interaction with the voice assistant.
Audio interfaces	Facilitate the connection of professional microphones to computer systems, processing, and converting audio signals for optimal interaction with voice systems.
Voice activity detectors (VADs)	Used for detecting voice activity within background sounds, allowing more precise identification of the start and end of commands.
Sound processing systems (DSP processors)	Used for processing audio signals, including noise reduction, improving sound quality, and preparing audio signals for further recognition.

A review of devices for ensuring the complementarity of visual data in the tasks of recognizing moving objects under challenging conditions, as well as devices for enabling user interaction with a voice assistant, has demonstrated the sufficiency of the following key components:

– high-resolution cameras;
– LiDARs;
– high-sensitivity microphones.

The listed devices possess unique characteristics that allow for the acquisition of complementary data about the environment and enable adaptation to various conditions the user may encounter. Only by considering these characteristics and diverse external conditions can a high level of data analysis accuracy and speed be achieved.

High-resolution cameras are one of the primary sources of visual information in artificial intelligence systems, navigation, and monitoring, particularly for ensuring the safety and support of people with visual impairments. Cameras can capture both static and moving objects, providing a detailed view of the environment.

Modern high-resolution cameras, despite having similar functionalities, differ in the following characteristics (Table 4):

– resolution;
– focal length;
– frame rate (FPS);
– field of View (FoV);
– light sensitivity (ISO);
– High Dynamic Range (HDR);
– sensor type (CMOS or CCD);
– noise reduction;
– device size and weight;
– compression;
– bitrate;
– weather resistance.

Table 4 – **Analysis of technical specifications of high-resolution cameras**

Characteristic	Description	Range of Values
Resolution	Defines the number of pixels in an image or video produced by the camera or display. Measured in pixels horizontally and vertically (e.g., 1920x1080, where 1920 pixels is the width and 1080 pixels is the height). Higher resolution provides more detail but requires higher network bandwidth and a powerful processor. However, under challenging conditions, such as fog or low lighting, resolution alone may be less effective unless supported by other features.	HD (720p), Full HD (1080p), 4K (2160p) or higher.
Focal Length (Fig. 7)	Adjustable focal length allows for camera field of view configuration: - Shorter focal length provides a wider field of view; - Longer focal length narrows the field and increases object magnification. This affects the ability to capture more details or cover a wider area, which is critical for spatial orientation.	Fixed (e.g., 35 mm) or variable (e.g., 18-55 mm).
Frame Rate (FPS)	Defines the number of frames a camera can capture or play back per second. Higher frame rates result in smoother motion and better ability to capture rapid changes in the environment. Cameras with high FPS may consume more energy, which is significant for wearable devices and autonomous systems, and may also increase data processing requirements.	30 FPS, 60 FPS, 120 FPS or higher.
Field of View	The extent of the scene or space the camera can capture.	60°–180°.

End of Table 4

Characteristic	Description	Range of Values
Light Sensitivity (ISO)	Determines the camera's ability to perceive light and affects image brightness. Higher ISO values allow capturing images in low-light conditions but are often accompanied by increased noise. High ISO values (1600 or more) make the camera very light-sensitive, suitable for low-light or nighttime photography without a flash. However, increased ISO may introduce "digital noise," degrading image quality.	ISO 100–51200 or higher.
High Dynamic Range (HDR)	Allows cameras to capture more details in high-contrast lighting conditions, making images richer and more realistic. HDR is especially effective in: - Bright sunlight (reduces overexposure while retaining detail in bright areas); - Dark conditions (improves detail visibility in dark areas without excessive noise).	Supported / Not supported.
Sensor Type	Determines how light hitting the camera's sensor is converted to an electrical signal: - CMOS sensors dominate the market due to affordability, speed, and energy efficiency, widely used in smartphones, DSLRs, and surveillance systems. - CCD sensors are often used in specialized cameras (scientific, astronomical, or high-end video cameras) where sensitivity and noise minimization are critical.	CMOS, CCD.
Noise Reduction	Noise can result from factors such as low lighting, high ISO, sensor temperature, hardware characteristics, etc.	3D Noise Reduction (3DNR), AI Noise Reduction, Contextual Noise Reduction.
Size and Weight	Determines the convenience of portability and integration into wearable devices.	Lightweight (under 30 g), Medium-weight (100–300 g).
Weather Resis-tance (IP Rating)	Indicates resistance to dust, moisture, and external conditions.	IP65, IP67, IP68.
Compression	Reduces video file size, facilitating storage and transmission. High compre-ssion can degrade image quality, especially during detailed processing.	H.264, H.265 (HEVC), VP9, etc.
Bitrate	Indicates the amount of data used to encode one video frame, which can be constant (CBR) or variable (VBR).	Constant (CBR), Variable (VBR); 1 Mbps or higher.

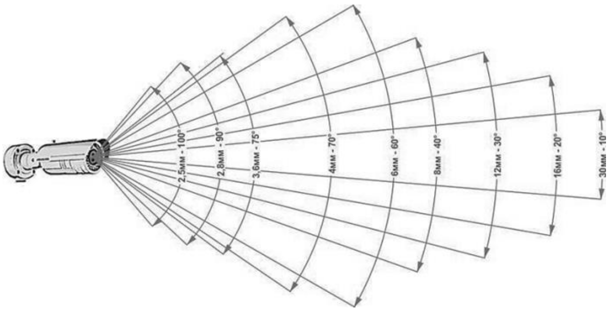

Fig. 7. Correlation Between Field of View and Focal Length

Considering the requirements for shooting under variable lighting conditions, the need to detect and detail moving objects, resilience to adverse conditions, wide scene coverage, and noise minimization, several camera models were selected that can be utilized in the proposed intelligent guidance system for people with visual impairments—Sony IMX378, OmniVision OV5647, OmniVision OV9281, Samsung S5K3L6, and Sony IMX586. LiDARs (Light Detection and Ranging) are used to create a three-dimensional map of the environment by measuring distances to objects using laser pulses. They provide precise determination of distances, shapes, and positions of objects, which is particularly important for real-time user orientation. LiDARs operate effectively even under challenging conditions such as fog, low light, or obstacles, ensuring an additional level of accuracy and safety.

Modern LiDAR models, despite having similar functionality, differ in the following characteristics (Table 5, [25]):

– measurement range (Range);
– accuracy;
– scan rate (Scan Rate);
– number of channels (Number of Channels);
– field of view (Field of View);
– frame rate (Frame Rate);
– scanning type (Rotary, Solid-State);
– angular resolution (Angular Resolution);
– laser wavelength.

As a conclusion, it can be stated that the factors influencing the range of a LIDAR sensor include weather conditions (fog, rain, snow, or dust can significantly reduce the effective range), the type and surface of the object (reflective properties, shape, and texture of the object can impact accuracy and range), and obstacles in the field of view (nearby objects or reflective surfaces can deflect signals and cause errors).

Considering the criteria of lightweight, compactness, easy integration into the overall wearable device construction, reliability with a long service life, and low power consumption to minimize battery impact, several solid-state LIDAR models were selected—STMicroelectronics VL53L1X, Terabee TeraRanger Evo Mini, and SparkFun Qwiic LIDAR-Lite v4 (Fig. 8).

High-sensitivity microphones complement visual sensors by ensuring high-quality recognition of sounds and voice commands.

They enable the assistive system to interact with the user through voice prompts and to detect environmental sounds, which is crucial for identifying potential hazards or engaging in interactions with others.

Table 5 – **Analysis of Technical Specifications of LIDAR Sensors**

Characteristic	Description	Range of Values
Measurement Range (Range)	Defines the maximum distance at which the device can accurately measure distances to objects using laser pulses. Environmental conditions can affect the range, such as rain or snow significantly reducing the effective distance. LIDAR performs best with objects that reflect light well. Dark or poorly reflective objects can reduce the effective range.	Short-range LIDARs (up to 10-50 meters) Medium-range LIDARs (up to 100-150 meters) Long-range LIDARs (up to 200-300 meters or more)
Accuracy	Determines the ability of the LIDAR to create accurate 3D models of the environment and detect objects. Surface reflectivity affects accuracy; glossy, metallic, or dark surfaces can distort signals or reduce precision.	Deviation from actual distance: High-precision LIDARs: ±1-2 cm Lower-precision LIDARs: ±10 cm or more
Scan Rate	Indicates the number of laser pulses or measurements the LIDAR performs per second. Higher scan rates enable faster and more detailed environmental mapping, allowing better tracking of moving objects in real-time.	Low scan rate (up to 10 kHz) Medium scan rate (10-50 kHz) High scan rate (50 kHz or more)
Number of Channels	Refers to the number of simultaneous beams or "laser lines" emitted and received by the device for distance measurement and 3D mapping. More channels improve detail and accuracy, allowing parallel scanning in multiple directions. Higher channel counts provide faster updates but increase energy consumption.	Low channel LIDARs (1-16 channels) Medium channel LIDARs (32 channels) High channel LIDARs (64, 128 channels or more)
Field of View (FoV)	Defines the range of angles within which the LIDAR can scan its surroundings.	Horizontal FoV: 90°-360° Vertical FoV: 10°-40°
Frame Rate	Defines how frequently the device can update environmental data per second. Crucial for real-time operation, especially when detecting moving objects or rapidly changing environments.	Low frame rate (1-10 Hz) Medium frame rate (10-30 Hz) High frame rate (30 Hz or more)
Scanning Type	Rotary LIDARs use rotating mechanisms to scan the environment in 360° horizontally. Laser beams rotate with mirrors or the LIDAR unit, providing circular coverage. These are prone to wear due to moving parts. Solid-State LIDARs lack moving parts, using electronic methods (e.g., phased arrays, MEMS mirrors, or lasers) for scanning, offering compact and lightweight designs suitable for portable or small devices.	Rotary or Solid-State LIDAR
Angular Resolution	Defines the minimum angular interval between two points that the device can distinguish. High angular resolution enhances the ability to differentiate closely spaced objects and provides more detailed object shapes.	High resolution: 0.1° - 0.5° Low resolution: greater than 2°
Laser Wavelength	LIDARs use different wavelengths (e.g., infrared or visible), impacting their accuracy under various conditions. Some wavelengths penetrate fog or dust better, reducing errors.	Infrared or visible spectrum
Power Consumption	Determines the amount of energy consumed by the device during operation. Affects the system's autonomy.	1-30 W
Dimensions and Weight	Affects the ease of integration into portable devices.	Solid-State LIDARs: tens to hundreds of grams Rotary LIDARs: 1 to several kilograms
Integration with Other Sensors	Compatibility with other sensors for constructing an environmental model.	Supports integration with cameras and other sensors

a b c

Fig. 8. Examples of LIDARs meeting the system's requirements:
a – STMicroelectronics VL53L1X,
b – Terabee TeraRanger Evo Mini,
c– SparkFun Qwiic LIDAR-Lite v4

Modern high-sensitivity microphone models, despite their common functionality, differ in the following characteristics:

– sensitivity (measured in millivolts per pascal (mV/Pa) or decibels (dB). Higher mV/Pa values or lower dB values indicate greater sensitivity. For example, a microphone with 25 mV/Pa sensitivity has a level of -32 dB, reflecting high sensitivity);

– directional pattern (determines the directions from which the microphone captures sound. It affects which sounds are recorded and which are filtered out);

– frequency response (defines how the microphone responds to various frequencies. A flat frequency response ensures natural sound without distortions);

– self-noise level (measured in dBA. A low self-noise level ensures a clean recording without additional interference);

– maximum sound pressure level (SPL) (indicates the loudest sound the microphone can handle without distortion. A high SPL is important for recording loud sound sources).

Considering the criteria of energy efficiency, seamless integration into a wearable device's overall structure, compactness, discretion, and lightweight design, several models of MEMS microphones with a cardioid directional pattern were selected for clear user voice recognition and background noise suppression: Knowles SPH0645LM4H-B, STMicroelectronics MP23AB02B, Infineon IM69D130, and TDK InvenSense ICS-40720.

Conclusion

The study presents a systematization of knowledge about existing technological tools for visually impaired people and an analysis of the hardware characteristics of such solutions.

The sense of insecurity from physical, emotional, social, and economic threats can significantly impact the quality of life, hinder normal functioning, lead to social isolation, and discourage individuals from visiting certain places. Physical insecurity can severely affect the quality of life of visually impaired individuals; however, the development of technical tools for navigation and environmental adaptation can substantially enhance their sense of safety and security.

The study proposes a classification of assistive devices for visually impaired individuals, including the following categories:

– navigation applications and devices;

– sensor systems for obstacle and object detection;

– wearable devices with augmented reality (AR) features;

– "vision" systems for environmental understanding;

– text recognition systems.

Devices within these categories aim to improve mobility, ensure safety, and enhance the overall quality of life for visually impaired individuals by compensating for the limitations caused by vision loss through innovative solutions that enable navigation, orientation, and access to information.

Based on the review of existing solutions, it is evident that the development of an assistive system for visually impaired individuals addresses societal needs and can foster greater inclusion.

To ensure data complementarity in recognizing moving objects, the optimal approach is to combine multiple sensors—a Multisensor Fusion approach—particularly high-resolution cameras, which provide detailed scene imagery, and LiDARs, which enable precise distance measurements and three-dimensional spatial modeling. This integration compensates for the limitations of individual sensors, providing a more comprehensive understanding of the scene and enhancing data quality through the fusion of diverse information sources.

In alignment with the principles of sensor minimization and energy efficiency, the use of high-sensitivity microphones is proposed as a sufficient condition for accurately recognizing voice commands regardless of external conditions.

Considering the criteria of lightness, compactness, seamless integration into a wearable device, reliability, long service life, and low power consumption, solid-state LiDAR models were selected, including STMicroelectronics VL53L1X, Terabee TeraRanger Evo Mini, and SparkFun Qwiic LIDAR-Lite v4.

Given the requirements for imaging under variable lighting conditions, the need for detecting and detailing moving objects, resistance to adverse conditions, wide scene coverage, and noise minimization, several camera models were chosen for use in the proposed intelligent assistance system for visually impaired individuals, including Sony IMX378, OmniVision OV5647, OmniVision OV9281, Samsung S5K3L6, and Sony IMX586.

In alignment with energy efficiency, seamless integration into the overall wearable device, compactness, and unobtrusiveness, several MEMS microphones with cardioid directional patterns were selected for clear voice recognition and background noise reduction, including Knowles SPH0645LM4H-B, STMicroelectronics MP23AB02B, Infineon IM69D130, and TDK InvenSense ICS-40720.

The development of an intelligent assistance system for visually impaired individuals is a socially beneficial and highly relevant endeavor, particularly in cities that lack sufficient attention to inclusivity and the comfort of visually impaired people (e.g., absence of audible traffic lights and tactile tiles). Its significance lies in:

– improving the quality of life by facilitating navigation in urban areas, avoiding obstacles, and optimizing routes to essential locations such as hospitals, stores, or public facilities;

– preserving independence and autonomy through assistance in movement, shopping, and route planning;

– enhancing user safety by identifying hazards or obstacles on the path, helping prevent injuries and accidents;

– promoting inclusion and equality for visually impaired individuals;

– advancing technological progress by integrating cutting-edge technologies into medical rehabilitation and social assistance, fostering innovation.

The next phase of this project involves conducting experimental research aimed at practically justifying the joint use of cameras, audio sensors, and LiDARs for obtaining heterogeneous data that provide the most comprehensive depiction of the environment surrounding visually impaired individuals. Based on these studies, a method for determining environmental conditions to ensure pedestrian safety will be proposed.

Acknowledgement

This work was partially supported under the grant ‘‘An assistant system that accompanies dynamic objects’’ (state registration number of the scientific and technical work: 0124U003837).

REFERENCES

1. Turner, R. J. and McLean, P. D. (1989), "Physical disability and psychological distress", *Rehabilitation Psychology*, vol. 34, no. 4, pp. 225–242, doi: https://doi.org/10.1037/h0091727
2. Turner, J. B. and Turner, R. J. (2004), "Physical Disability, Unemployment, and Mental Health", *Rehabilitation Psychology*, vol. 49, no. 3, pp. 241–249, doi: https://doi.org/10.1037/0090-5550.49.3.241
3. Stebnicki, M. A. and Marini, I. (2012), *The psychological and social impact of illness and disability*, Springer Publishing Company, available at: https://www.amazon.com/Psychological-Social-Illness-Disability-Seventh/dp/0826161618
4. Barkovska, O. and Serdechnyi, V. (2024), "Intelligent assistance system for people with visual impairments", *Innovative technologies and scientific solutions for industries*, vol. 2(28), pp. 6–16, doi: https://doi.org/10.30837/2522-9818.2024.28.006
5. Rahman, M. W., Tashfia, S. S., Islam, R., Hasan, M. M., Sultan, S. I., Mia, S. and Rahman, M. M. (2021), "The architectural design of smart blind assistant using IoT with deep learning paradigm", *Internet of Things*, vol. 13, no. 100344, doi: https://doi.org/10.1016/j.iot.2020.100344
6. Tahoun, N., Awad, A. and Bonny, T. (2019), "Smart assistant for blind and visually impaired people", *Proceedings of the 3rd International Conference on Advances in Artificial Intelligence*, pp. 227–231, doi: https://doi.org/10.1145/3369114.3369139
7. Liu ,Y., Stiles, N. R. B. and Meister, M. (2018), "Augmented reality powers a cognitive assistant for the blind", *ELife*, vol. 7, no. e37841, doi: https://doi.org/10.7554/eLife.37841
8. Tanveer, M. S. R., Hashem, M. M. A. and Hossain, M. K. (2015), "Android assistant EyeMate for blind and blind tracker", *2015 18th international conference on computer and information technology* (ICCIT), IEEE, pp. 266–271, doi: https://doi.org/10.1109/ICCITechn.2015.7488080
9. Sadi, M. S., Mahmud, S., Kamal, M. M., and Bayazid, A. I. (2014), "Automated walk-in assistant for the blinds", *2014 International Conference on Electrical Engineering and Information & Communication Technology*, doi: https://doi.org/10.1109/iceeict.2014.6919037
10. Kumar, K. and Mappoli, P. (2020), "An intelligent Assistant for the Visually Impaired & blind people using machine learning", *International Journal of Imaging and Robotics*, vol. 20, no. 3, available at: http://www.ceser.in/ceserp/index.php/iji/article/view/6521
11. Petrovska, I., Kuchuk, H. and Mozhaiev, M. (2022), "Features of the distribution of computing resources in cloud systems", *2022 IEEE 4th KhPI Week on Advanced Technology*, KhPI Week 2022 - Conference Proceedings, 03-07 October 2022, Code 183771, doi: https://doi.org/10.1109/KhPIWeek57572.2022.9916459
12. Hunko, M., Tkachov, V., Kuchuk, H. and Kovalenko, A. (2023), "Advantages of Fog Computing: A Comparative Analysis with Cloud Computing for Enhanced Edge Computing Capabilities", *2023 IEEE 4th KhPI Week on Advanced Technology, KhPI Week 2023 - Conference Proceedings*, Code 194480, doi: https://doi.org/10.1109/KhPIWeek61412.2023.10312948
13. Khan, S., Nazir, S. and Khan, H. U. (2021), "Analysis of Navigation Assistants for Blind and Visually Impaired People: A Systematic Review", *IEEE Access*, vol. 9, pp. 26712–26734, doi: https://doi.org/10.1109/ACCESS.2021.3052415
14. Kuchuk, H. and Kuliahin, A. (2024), "Hybrid Recommender For Virtual Art Compositions With Video Sentiments Analysis", *Advanced Information Systems*, vol. 8, no. 1, pp. 70–79, doi: https://doi.org/10.20998/2522-9052.2024.1.09
15. Kuchuk, H., Podorozhniak, A., Liubchenko, N. and Onischenko, D. (2021), "System of license plate recognition considering large camera shooting angles", *Radioelectronic and Computer Systems*, vol. 2021 (4), pp. 82–91, doi: https://doi.org/10.32620/REKS.2021.4.07
16. Sabab, S. A. and Ashmafee, M. H. (2016), "Blind reader: An intelligent assistant for blind", *2016 19th Int. Conference on Computer and Information Technology*, ICCIT, IEEE, pp. 229-234, doi: https://doi.org/10.1109/ICCITECHN.2016.7860200
17. Svyrydov, A., Kuchuk, H. and Tsiapa, O. (2018), "Improving efficienty of image recognition process: Approach and case study", *Proceedings of 2018 IEEE 9th International Conference on Dependable Systems, Services and Technologies*, DESSERT 2018, pp. 593–597, doi: https://doi.org/10.1109/DESSERT.2018.8409201
18. Kharchenko, V., Andrashov, A., Sklyar, V., Kovalenko, A. and Siora, O. (2012), "Gap-and-IMECA-based assessment of I&C systems cyber security", *Advances in Intelligent and Soft Computing*, 170 AISC, pp. 149–164, doi: https://doi.org/10.1007/978-3-642-30662-4-10
19. Cahyadi, W. A., Chung, Y. H., Ghassemlooy, Z. and Hassan, N. B. (2020), "Optical camera communications: Principles, modulations, potential and challenges", *Electronics*, vol. 9, no. 9, 1339, doi: https://doi.org/10.3390/electronics9091339
20. Raj, T., Hashim, F.H., Huddin, A.B., Ibrahim, M.F. and Hussain, A. (2020), "A Survey on LiDAR Scanning Mechanisms", *Electronics*, vol. 9, no. 741, doi: https://doi.org/10.3390/electronics9050741
21. Qu, Y., Yang, M., Zhang, J., Xie, W., Qiang, B. and Chen, J. (2021), "An Outline of Multi-Sensor Fusion Methods for Mobile Agents Indoor Navigation", *Sensors*, vol. 21, no. 1605, doi: https://doi.org/10.3390/s21051605
22. Chen, G., Liu, Z., Yu, G. and Liang, J. (2021), "A new view of multisensor data fusion: research on generalized fusion", *Mathematical Problems in Engineering*, vol. 2021, no. 5471242, pp. 1–21, doi: https://doi.org/10.1155/2021/5471242
23. Tsanousa, A., Bektsis, E., Kyriakopoulos, C., González, A.G., Leturiondo, U., Gialampoukidis, I., Karakostas, A., Vrochidis, S. and Kompatsiaris, I. (2022), "A Review of Multisensor Data Fusion Solutions in Smart Manufacturing: Systems and Trends", Sensors, vol. 22, no. 1734, doi: https://doi.org/10.3390/s22051734
24. Marsh, B.; Sadka, A.H. and Bahai, H. (2022), "A Critical Review of Deep Learning-Based Multi-Sensor Fusion Techniques", Sensors, vol. 22, no. 9364, doi: https://doi.org/10.3390/s22239364
25. Li, N., Ho, C. P., Xue, J., Lim, L. W., Chen, G., Fu, Y. H. and Lee, L. Y. T. (2022), "A progress review on solid-state LiDAR and nanophotonics-based LiDAR sensors", Laser & Photonics Reviews, vol. 16, doi: https://doi.org/10.1002/lpor.202100511

Received (Надійшла) 10.12.2024
Accepted for publication (Прийнята до друку) 05.02.2025

ABOUT THE AUTHORS / ВІДОМОСТІ ПРО АВТОРІВ

Сердечний Віталій Сергійович– аспірант кафедри електронних обчислювальних машин, Харківський національний університет радіоелектроніки, Харків, Україна;
Vitalii Serdechnyi – PhD student of Department of Electronic Computers, Kharkiv National University of Radio Electronics, Kharkiv, Ukraine;
e-mail: vitalii.serdechnyi@nure.ua; ORCID Author ID: http://orcid.org/0009-0007-8828-5803;
Scopus ID: https://www.scopus.com/authid/detail.uri?authorId=57210288841.

Барковська Олеся Юріївна – кандидат технічних наук, доцент, доцент кафедри електронних обчислювальних машин, Харківський національний університет радіоелектроніки, Харків, Україна;
Olesia Barkovska – Candidate of Technical Sciences, Associate Professor, Associate Professor of Department of Electronic Computers, Kharkiv National University of Radio Electronics, Kharkiv, Ukraine;
e-mail: olesia.barkovska@nure.ua; ORCID Author ID: http://orcid.org/0000-0001-7496-4353;
Scopus ID: https://www.scopus.com/authid/detail.uri?authorId=24482907700.

Коваленко Андрій Анатолійович – доктор технічних наук, професор, завідувач кафедри електронних обчислювальних машин, Харківський національний університет радіоелектроніки, Харків, Україна;
Andriy Kovalenko – Doctor of Technical Sciences, Professor, Head of the Department of Electronic Computers, Kharkiv National University of Radio Electronics, Kharkiv, Ukraine;
e-mail: andriy.kovalenko@nure.ua; ORCID ID: https://orcid.org/0000-0002-2817-9036;
Scopus ID: https://www.scopus.com/authid/detail.uri?authorId=56423229200.

Мартовицький Віталій Олександрович – кандидат технічних наук, доцент, доцент кафедри електронних обчислювальних машин, Харківський національний університет радіоелектроніки, Харків, Україна;
Vitalii Martovytskyi – Candidate of Technical Sciences, Associate Professor, Associate Professor of Department of Electronic Computers, Kharkiv National University of Radio Electronics, Kharkiv, Ukraine;
e-mail: vitalii.martovytskyi@nure.ua; ORCID Author ID: http://orcid.org/0000-0003-2349-0578;
Scopus ID: https://www.scopus.com/authid/detail.uri?authorId=57196940070.

Гаврашенко Антон Олегович – аспірант кафедри електронних обчислювальних машин, Харківський національний університет радіоелектроніки, Харків, Україна;
Anton Havrashenko – PhD student of Department of Electronic Computers, Kharkiv National University of Radio Electronics, Kharkiv, Ukraine;
e-mail: anton.havrashenko@nure.ua; ORCID Author ID: http://orcid.org/0000-0002-8802-0529;
Scopus ID: https://www.scopus.com/authid/detail.uri?authorId=58298107700.

Систематизація знань про характеристики існуючих технологічних засобів для супроводу людей із порушеннями зору

В. С. Сердечний, О. Ю. Барковська, А. А. Коваленко, В. О. Мартовицький, А. О. Гаврашенко

Анотація. Робота присвячена детальному огляду основних аспектів фізичної незахищеності для людей із порушеннями зору, а також технологічним засобам для навігації та адаптації людини до навколишнього середовища, які можуть значно підвищити відчуття безпеки та захищеність людини. Актуальність теми обґрунтовується великою соціальною направленістю, бо подібні системи допомагають людям із вадами зору легше проходити соціалізацію, забезпечувати більшу інклюзію, що є вкрай актуальним у містах, де приділяється мало уваги інклюзивності та комфорту незрячих людей (відсутні озвучені світлофори, тактильна плитка тощо). **Предметом** є вивчення апаратних компонентів, що забезпечують функціонування систем підтримки для людей з вадами зору. **Метою** статті є систематизація знань про існуючі технологічні засоби для людей із порушеннями зору, а також проаналізувати апаратні характеристики складових елементів подібних рішень. **Задачами роботи є** огляд психофізіологічних факторів та аспектів фізичної незахищеності для людей із порушеннями зору, існуючих систем асистування для людей з вадами зору, визначення апаратної бази, необхідної для створення системи «бачення» навколишнього середовища; проведення аналізу характеристик реєстраторів із урахуванням зовнішніх умов, в яких може опинитися людина із вадами зору. Виконання поставлених завдань є можливим завдяки використанню **методів** порівняльного аналізу, класифікації та категоризації, систематичного огляду літератури за тематикою проблемної області. **Результатами** роботи є запропонована класифікація допоміжних пристроїв для людей із порушеннями зору, яка включає наступні класи: навігаційні додатки та пристрої; сенсорні системи детектування перешкод і об'єктів; носимі пристрої з функціями доповненої реальності (AR); системи "бачення" навколишнього середовища; системи розпізнавання тексту. Визначення та аналіз переваг та недоліків пристроїв кожного із запропонованих класів показав, що нове рішення має задовольняти критеріям компактності, носибельності, енергоефективності, простоті використання, а також високій точності визначення умов навколишнього середовища, детектування перешкод і об'єктів на шляху користувача. **Висновки**. Для забезпечення комплементарності даних у задачах розпізнавання рухомих об'єктів системою інтелектуального асистування людям із вадами зору, оптимальним є поєднання декількох датчиків - Multisensor Fusion підхід, - зокрема камер з високою роздільною здатністю, які надають деталізоване зображення сцени, та лідарів, що забезпечують точне вимірювання відстані й побудову тривимірної моделі простору. Такий підхід дозволить компенсувати обмеження окремих сенсорів та надати повніше розуміння сцени, підвищуючи якість даних за рахунок інтеграції різних джерел інформації**. Подальші дослідження** будуть спрямовані на проведення експериментальних робіт, метою яких є практичне обгрунтування спільного використання камер, аудіодатчиків та лідарів для отримання гетерогенних даних, які забезпечують найбільш повне уявлення про середовище, що оточує людей із порушеннями зору.

Ключові слова: аналіз; огляд; системи; асистування; LIDAR; камера; мікрофон; люди із вадами зору; детектування; динамічні об'єкти.