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INTELLIGENT ASSISTANCE SYSTEM FOR PEOPLE WITH VISUAL IMPAIRMENTS

Subject of the Research: The creation of an intelligent assistance system for people with visual impairments. Nowadays, the task of developing effective intelligent assistance systems that allow people with vision problems to achieve maximum independence is important and relevant, as existing systems have a number of drawbacks, such as limited autonomy, limited integration with other devices and systems, limited analysis of dynamic obstacles, and limited user feedback capabilities, which in most cases are restricted to voice guidance. **Objective:** The objective of this work is to create a generalized functional model of an intelligent assistance system for people with visual impairments, which has enhanced autonomy, integration with other devices and systems, the ability to analyze dynamic objects and predict their movement trajectory, and provide diverse feedback to the user. **Tasks:** To achieve the set objective, the following tasks were accomplished: a generalized functional model of the proposed intelligent assistance system for people with visual impairments was created; the functional dependencies of the components of the developed model were substantiated; a review of the basic modules of the proposed system model was conducted. **Methods:** The methods used include functional modeling methods and system analysis methods. **Results:** The following results were obtained: a functional model of an intelligent assistance system for people with visual impairments was proposed. This system surpasses existing analogs in a number of functional capabilities: detection of static and dynamic obstacles with prediction of dynamic obstacles' movement trajectory, the ability to operate in various conditions (indoors, outdoors, in light or dark, in different weather conditions), support for integration with other systems and devices, and a high level of autonomy. **Conclusions:** The developed system model has enhanced autonomy, integration with other devices and systems, the ability to analyze dynamic objects and predict their movement trajectory, and provides diverse feedback to the user.

Keywords: system; assistant; vision; LiDAR; video; trajectory; prediction; intelligent system; recognition; classification.

Introduction

According to the IAPB [1], in 2020 there were at least 1.1 billion people with visual impairment worldwide, of whom 43 million were completely blind. In 2023, the number of people with visual impairments increased to 2.2 billion, according to WHO [2]. Statistics show that the number of people who need help due to complete or partial lack of vision is growing every year.

In everyday life, these people face a number of challenges. As noted in the study [3], some of the key problems of people with visual impairments are a sense of burden and dependence (due to the need for help from others, especially with transportation), social interaction (such people often cannot perceive non-verbal signals, which makes social interaction difficult), and the use of aids (the use of things like a cane or guide dog marks a person as blind, which can lead to discrimination and lower self-esteem). In his article [4], author and disability rights activist Samiak Lalit also points out a number of problems that complicate the lives of people with visual impairments, including difficulty navigating in space, sorting clothes (most visually impaired people identify things by their shape and texture, and this makes organizing laundry a difficult task), gaining independence through modern devices (the author points out that the necessary equipment that can allow a blind person to live independently is not easily found in local stores or markets. Because of this, a person needs to make a lot of effort to get every device that can make them one step closer to independence).

People with vision problems are also more susceptible to serious life events. According to a study [8], the prevalence of serious life events for such people is higher than in the general population (60%, $p < 0.001$), especially in the case of fire or explosions, serious accidents, sexual violence, life-threatening illnesses or injuries, and severe human suffering.

Thus, it can be concluded that the task of creating effective intelligent assistance systems that will allow people with vision problems to gain maximum independence from other people, solve everyday problems more easily, and gain a higher level of life safety is currently important and relevant.

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Analysis of existing systems

To date, researchers have proposed a number of different intelligent systems to assist people with vision problems.

For example, in [5] (2018), a system called "A Smart Personal AI Assistant for Visually Impaired People" is proposed, which is based on Google's Cloud API platform and allows recognizing objects and textual information in photos (using the Cloud Vision API) and communicating with a chatbot to obtain the necessary information (using Dialogflow). The user can interact with the system through voice commands to his or her smartphone, and the system generates answers to questions or descriptions of objects and text recognized in the photos in audio format and plays them back for the user.

The article [6] (2019) describes a system called ANSVIP, whose main purpose is to assist in navigation for visually impaired people. The system uses the Google ARCore platform (specifically, the SLAM technology is used) running on a smartphone running on the Android OS. The use of SLAM technology allows the system to work indoors, unlike traditional GPS localization, which can work intermittently indoors. A field-based path planning method was created to keep a person away from various obstacles to prevent collisions during real-time path generation. In addition, the authors proposed a two-channel user feedback mechanism. The first channel is a classic voice guidance, and the second is tactile gloves. The left glove sets the direction of a person's movement, and the right glove warns of obstacles.

Article [9] (2020) describes an intelligent assistance system for the movement of visually impaired people that receives data from a video camera, performs object detection in video frames, and, if an obstacle is detected on the user's path, warns him or her with a corresponding voice message using the corresponding Text to Speech converter module.

The paper [10] (2023) shows a prototype of an assistance system for visually impaired people based on the Raspberry Pi module due to its low cost, small size, and ease of integration. The user's proximity to an obstacle is measured using a camera and ultrasonic sensors. Feedback to the user is realized through voice guidance. It is noted that the system can work both indoors and outdoors. In addition, the system proposed the introduction of a reading module and integration with a pulse oximeter, which allows the system to determine when a person is in danger and call the emergency number.

Paper [7] (2023) proposes a deep learning-based assistance system for visually impaired people called DeepNAVI. The main components of the system are a smartphone, a wireless bone headset, and six software modules: an obstacle detection module, a distance measurement module, a location measurement module, a motion detection module, and a scene recognition module. The system uses data from a smartphone's video camera and is able to detect 20 different types of obstacles and 20 different types of scenes. Interaction with the user takes place through voice guidance.

Analyzing these works, we can identify a number of common weaknesses of all the systems under consideration, which are listed in Table 1.

Table 2 shows the main areas for improving such systems.

Table 1. *The main disadvantages of the considered assistance systems*

Disadvantage	Description of the disadvantages
Limited autonomy	Most systems are dependent on external devices (smartphones, Raspberry Pi) or have limited functionality in offline mode. This makes them less useful in situations where there is no access to these devices.
Limited integration	None of the systems have full integration with other systems and devices. This makes it difficult to use them in conjunction with other assistive technologies, which could significantly expand their functionality.
Limited analysis of dynamic interference	Most systems can only detect static obstacles, which is not always enough for safe navigation in the real world. In addition, none of the systems can predict the trajectory of dynamic objects, which is also a significant limitation in the context of predicting a possible collision.
Limited feedback	Feedback is mostly limited to voice interaction, which may be insufficient for people with hearing impairments.

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Table 2. *Key areas for improving assistance systems*

Areas for improvement	Description
Increasing autonomy	Developing your own computing modules or using more energy-efficient components can reduce dependence on external devices and increase battery life.
Expanding integration	Integration with other systems, such as GPS, maps, public transportation, smart home, etc., can greatly expand the capabilities of systems and make them more useful in everyday life.
Improving the analysis of dynamic interference	The use of more advanced computer vision and machine learning algorithms can allow systems to better detect and analyze moving objects, which will increase user safety.
Development of various feedback channels	The introduction of haptic, vibration, or visual feedback can make systems more accessible to people with various disabilities.
Expanding the functionality	Adding new features, such as text, emotion, and gesture recognition, can make systems more adaptive to user needs.

These improvements will make systems for helping visually impaired people more efficient, versatile, and easy to use.

The theoretical foundations for the creation of such systems [5–7, 9, 10] are being actively developed and published in the following articles: [12] focuses on the fact that smartphones and wearable devices with built-in cameras are the main means of supporting the most advanced computer vision solutions that allow both positioning and controlling the area around the user; [13] substantiates the interdisciplinary importance and great social impact of such assistive technologies for visually impaired and blind people; [14] – a comparative review of wearable and portable assistive devices for visually impaired people to show the progress in assistive technologies for this group of people, highlighting the advantages and disadvantages of systems to further improve the level of safety, independence and mobility for visually impaired people.

Results and discussion

Assistance systems for visually impaired people (ASP) are complex systems with a large number of components that interact with each other. The components of the systems include modules for detecting the human environment in the form of audio or video data, modules for analyzing the environment near the person, modules for making decisions about the presence of danger, modules for feedback to the user, etc. Representation of such systems in the form of generalized models allows us to clearly define the components of the system, their functions and interaction between them, their influence on each other, identify weaknesses or potential problem areas in the system, plan and manage research aimed at improving systems, etc.

The article proposes an ASP model in the form of a generalized functional flowchart, as this will provide an opportunity to show the components of the system in more detail and provide a basis for applying a systematic approach to future research, which involves taking into account all the relationships and influences between the components. The above system model (Figure 1) will be used in the future to develop a prototype, conduct simulations and test the system, establish criteria for evaluating the effectiveness of the system and its components, which will contribute to a more objective analysis of the research results.

One of the main features of this system is that its practical implementation is envisaged by a separate module independent of the user, which moves alongside the user and performs all the necessary functions to accompany him or her and ensure his or her safety. In this case, the use of a smartphone is necessary only to ensure communication between the user and the assistant module.

In addition, the system uses data of high heterogeneity. The system works with input data of several types: video frames (data coming from video cameras), coordinates of points in space (data coming from LiDAR sensors), audio data (data coming from a microphone), and temperature sensor data. This approach is expected to improve the quality of object and scene detection, as well as environmental conditions.

The system functionality is provided by a number of modules, namely: Environment Conditions Detection, Video & LiDAR data merging, Objects Detection & Tracking, Trajectory Prediction, Trajectory Prediction Model Continuous Training, Generating an Assistance Decision, Generating an AI Assistant Module Control Signal, Assistance Decision Signal Conversion, Assistant Module Controller, External System & Sensors Data

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Processing. The modules are interconnected and interdependent, which can be seen in the proposed model of an intelligent assistance system for visually impaired people.

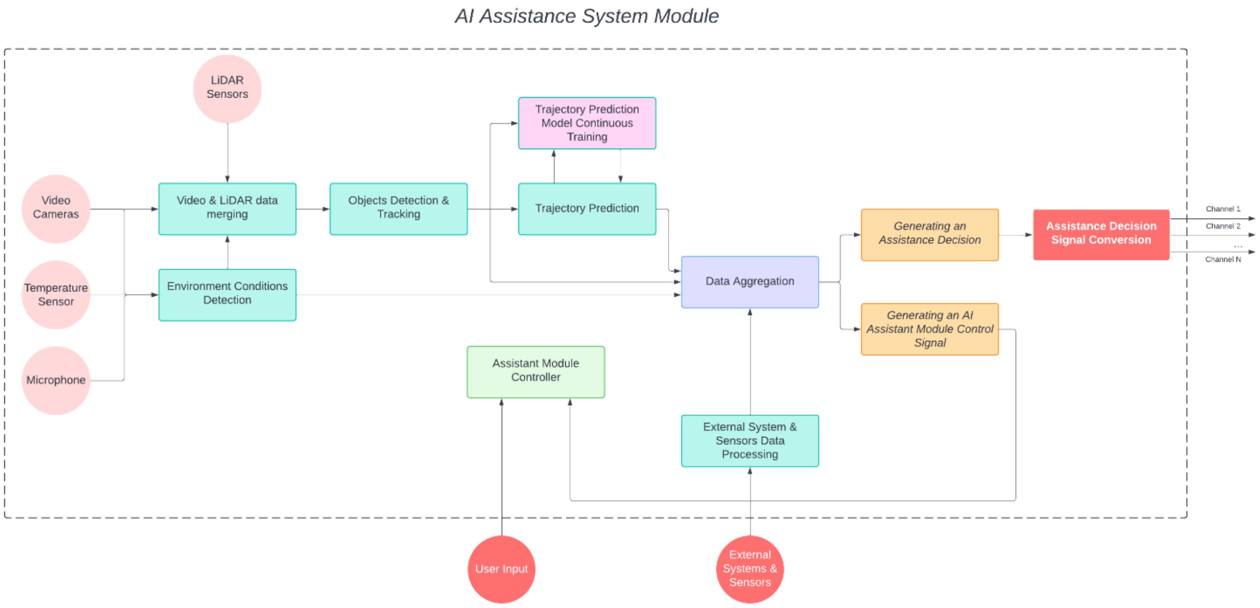

Fig. 1. Generalized functional model of an intelligent assistance system

Let us consider these modules and their functional interconnection in detail in the following subsections of the article.

Analysis of modules of the model of the system of assistance to visually impaired people

The first stage of the system's operation is the determination of environmental conditions, which is realized through a separate intelligent model called Environment Conditions Detection. This model uses different types of input data, namely video data, microphone data, and temperature sensor data. The task of this model is to solve the problem of classification and generate appropriate class labels that describe environmental conditions. Table 3 shows all the proposed class labels.

The stage of environmental conditions detection is necessary for two main purposes: taking these conditions into account for more accurate prediction of the trajectory of dynamic objects, notifying the user of weather conditions that require additional attention (for example, ice) and taking these conditions into account for applying the appropriate image preprocessing stack (for example, in the dark).

The labels of the defined classes are transferred to the Video & LiDAR data merging module, which contains an adaptive video frame pre-processing stack. The composition and parameters of this stack depend on the corresponding class labels, which are determined by the environmental detection module. The diagram of the Video & LiDAR data merging module is shown in Figure 2.

If, according to the environmental conditions, data pre-processing is not required, the Video Frames Preprocessing stage will be ignored and the video data will be directly transferred to the process of combining with LiDAR data.

The Objects Detection & Tracking module is designed to detect and track objects based on integrated video and LiDAR data. At this stage, the data on the identified objects are divided into static (stationary) and dynamic (moving). Data on dynamic objects are used separately to predict the trajectory of these objects and determine their possible coordinates after a certain period of time. Such prediction allows to assess the degree to which a moving object can be dangerous for a person. A diagram of this process is shown in Figure 3.

The first division is already the result of the work of an intelligent object detection model based on YOLO v9, the features and specifications of which are described in detail by the creators on the web resource [16].

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Table 3. *Classes of environmental conditions*

Group	Class label
Weather conditions	Sunny
	Cloudy
	Rain
	Snow
	Fog
	Wind
	Thunderstorm
	Ice
Lighting conditions	Bright sunlight
	Cloudy
	Twilight
	Darkness
	Artificial lighting
Acoustic conditions	Silence
	Noise of transport
	Rain noise
	Thunder
	Natural noise (birds, water, wind)
	Extraordinary car sounds (siren, car horn)
Temperature conditions	Low temperature (–30°C ÷ +5°C)
	Moderate temperature (+5°C ÷ +20°C)
	High temperature (+20°C ÷ +30°C)
	Heat (>+30°C)
Type of terrain	Urban environment
	Countryside
	Forest
	Beach
	Residential premises
	Office space
	Commercial premises
	Public premises
	Sports premises
	Industrial premises
Specific events	Repair work
	Fire
	Explosion
	Police operation
	Medical emergency
	Holiday (concert, parade, festival, wedding)

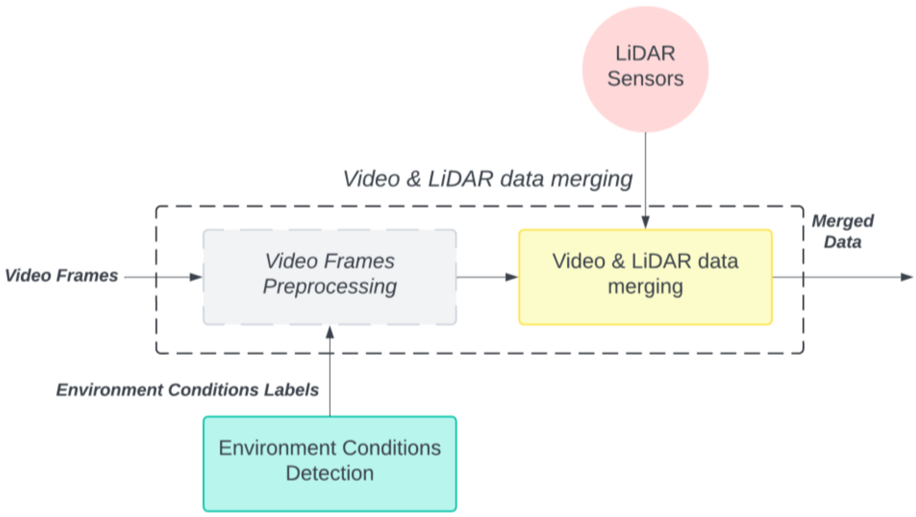

Fig. 2. Video & LiDAR data merging module

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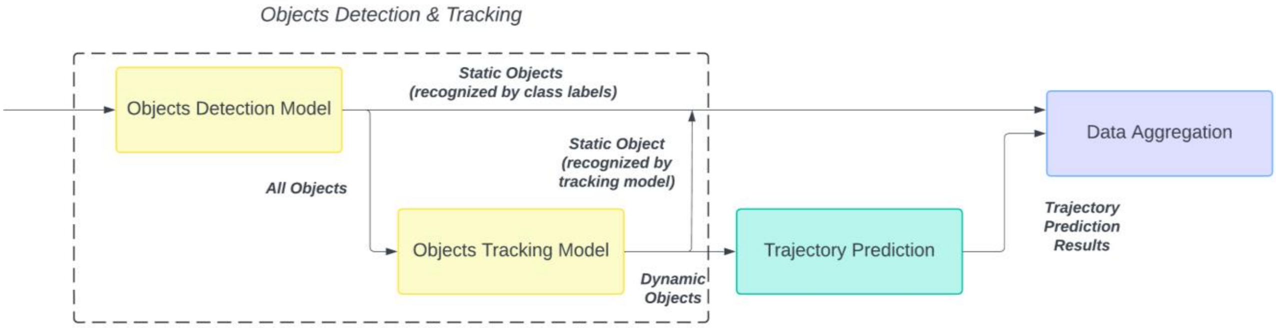

Fig. 3. The process of identifying static and dynamic objects with motion trajectory predictions

Objects are divided into static (e.g., house, bench, pole) and potentially dynamic (e.g., car, bus) according to the defined class labels. The location of potentially dynamic objects is recorded for a certain period of time to determine the presence of movement. Based on the results of such fixation, the objects are re-divided into static and dynamic. If no motion is detected (for example, a car is parked but not moving), such objects are transferred from the potentially dynamic category to the static category. If the motion is detected, such objects are defined as dynamic and their coordinates are passed on to the motion trajectory prediction model.

The task of the Trajectory Prediction module is to predict the trajectories of dynamic objects and their future coordinates in a certain period of time. To improve the accuracy of this module, it is proposed to create a mechanism for retraining this model in real time based on data on the real and predicted location of dynamic objects. The scheme of this mechanism is shown in Figure 4.

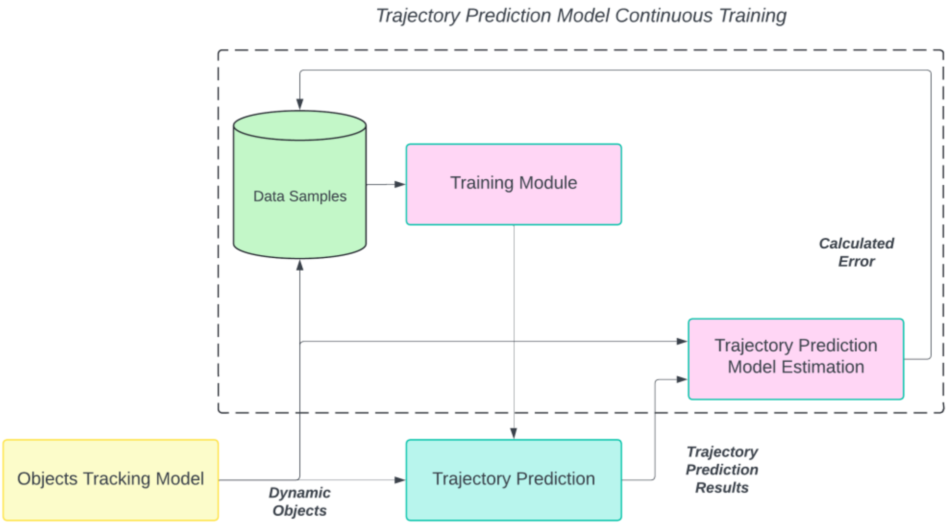

Fig. 4. A mechanism for retraining an intelligent model for predicting object trajectories

The system saves information about the movement of objects (their location at different time intervals) to a separate local database Data Samples to form training data. In addition, the accuracy of the system's predictions is calculated at a certain frequency (selected experimentally) by calculating the difference between the predicted location and the actual location of the object at the corresponding time. This approach allows you to evaluate the accuracy of the model during its operation and launch the retraining mechanism if necessary (if the prediction accuracy is satisfactory, then retraining is not required).

The following data is used to generate an assistant's decision in the Generating an Assistance Decision module:

– data of static and dynamic objects (types of objects, their current location);

– results of predicting the location of dynamic objects;

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– current environmental conditions;
– data from external systems and devices.

Items 1–3 are formed as a result of the operation of the system modules discussed earlier. Data from external systems and devices is data that the system receives from additional devices that can improve the safety and comfort of a visually impaired person. To work with such data, the system contains a separate module External System & Sensors Data Processing, which is designed to establish communication, receive and process data from external devices. Such devices can be: a pulse oximeter, a smartwatch or bracelet, an air quality sensor, smart home devices, etc. As a result of the Generating an Assistance Decision module, a label of the corresponding class and additional parameters (usually numerical) are generated. In fact, this intelligent model solves both classification and regression tasks. Examples of classes and their parameters are shown in Table 4.

The generated result is transferred to the Assistant Decision Signal Conversion module of the system. The task of this module is to convert the class label and additional parameters to the format of the corresponding user notification channel. The system model includes several feedback channels. They are shown in Figure 5.

Table 4. *Class labels and parameters that result from the Generating an Assistance Decision module*

Group	Class	Parameters
Navigation	Adjustment of the route	Number of steps and direction to adjust
	The need to stop	–
	Start of movement	–
	The need to turn around	Number of degrees and direction of rotation
	Appearance of an obstacle on the way	Distance to an obstacle and its type
	Description of the environment	Text description of objects and scenes along the route
Security (this group has a higher priority than the others)	Approaching vehicles	Distance to the vehicle, type (car, motorcycle, bicycle), direction of movement, speed
	Change of traffic light signal	Traffic light signal color (green, yellow, red), time until the signal changes
	Edge of the sidewalk/roadway	Distance to edge, type of edge (curb, steps), direction
	Falling objects	Distance to object, type of object (branch, glass, other), direction of fall
	Suspicious activity	Type of activity (person following the user, loud conversation, fight), distance to the source of activity, direction
Health	Heart rate deviation	Current heart rate, deviation from the norm (if any)
	Abnormal blood oxygen levels	Current SpO2 value, deviation from the norm (if any)
	Air quality abnormalities	Current values of pollutants (PM2.5, PM10, CO2, etc.), deviation from the norm (if any)
	Medication reminders	Name of medication, time of administration
	Determine the time	Current time
	Weather information	Temperature, precipitation, wind, other parameters
	Notifications from your smartphone	Notification text

Fig. 5. User notification channels

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There are two main channels of user notification: voice and tactile (via vibration). Voice commands can be transmitted by the assistant module to earbuds, a smartphone, or a portable Bluetooth speaker. Vibrations can be transmitted to a smartwatch, fitness bracelet, or specialized tactile gloves similar to those proposed in [6].

The system is positioned as a separate assistant module. This module can be made in the form of a ground, air, or combined (ground + air) drone. To control this module, it is proposed to introduce a separate Assistant Module Controller unit. The task of this unit is to autonomously control the physical module by transmitting appropriate signals to rotate the wheels, increase or decrease speed, stop the module, etc.

Table 5. *Class labels and parameters that result from the Assistant Module Controller module*

Group	Class	Parameters
Ground mode	Start of movement	–
	Stopping	–
	Increase speed	Speed increase
	Reduce speed	Reducing the speed
	Turn right	Turning angle
	Turn left	Turning angle
Air mode	Take off	Takeoff speed, Takeoff angle
	Landing	Landing speed, Landing angle
	Increase altitude	Climb rate
	Reduce altitude	Altitude decrease
	Turn right	Turning angle
	Turn left	Turning angle

A separate intelligent model is responsible for generating the corresponding signals, which is labeled Generating an AI Assistant Module Control Signal in Figure 1. This model, just like Generating an Assistance Decision, solves two tasks: classification and regression. As a result, this model generates a label of the corresponding class and additional parameters. Examples of classes and their parameters are shown in Table 5.

As a result of the work done, a model of an intelligent assistance system for visually impaired people has been developed. A modern system of intellectual assistance for visually impaired people should meet a number of functionalities, namely: real-time detection of static obstacles, real-time detection of dynamic obstacles and prediction of the trajectories of these obstacles (in order to timely notify the user of danger), recognition of objects (those that are not obstacles) and scenes (classification of the environment), localization and navigation, feedback (sound, tactile notification of the user, etc.), the ability to work in p

Table 6 shows the results of a comparative analysis of the developed model of an intelligent assistance system and its existing analogues.

Table 7 shows the results of the analysis of the compliance of the existing systems and the proposed system with the last five criteria.

Table 6. *Analysis of the compliance of the considered systems of intellectual assistance to visually impaired people with the first part of the specified functionalities*

Intelligent assistance system	Static interference detection	Detection and analysis of dynamic interference	Recognize objects and scenes	Localization and navigation	Feedback
A Smart Personal AI Assistant for Visually Impaired People [5]	No	No	Recognize objects in photos	No	Voice interaction
ANSVIP system [6]	Yes	No	Yes	Yes	Voice interaction, tactile interaction with gloves
The system proposed by Kushal Kumar [9]	Yes	No	Recognize objects (no scene analysis)	No	Voice interaction
System proposed by Surabhi Suresh [10]	Yes	No	Yes	No	Voice guidance and text reading
DeepNAVI system [7]	Yes	Partially (can distinguish moving objects from static ones)	Yes	Yes	Voice interaction
The proposed system	Yes	Yes	Yes	Yes (using external devices, for example, a smartphone with GPS)	Voice interaction, tactile interaction with gloves, smartwatch, fitness bracelet

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Table 7. *Analysis of the compliance of the considered systems of intellectual assistance to visually impaired people with the second part of the specified functionalities*

Intelligent assistance system	Ability to work in different conditions	Support for different work scenarios	Integration with other systems and devices	Autonomy	Reliability in critical situations
A Smart Personal AI Assistant for Visually Impaired People [5]	No	Yes (work in chatbot mode)	No	No	No
ANSVIP system [6]	No	No	No	Yes Yes (depends only on the availability of a smartphone)	No
The system proposed by Kushal Kumar [9]	No	No	No	No	No
System proposed by Surabhi Suresh [10]	Work indoors and outdoors (work in difficult weather conditions is not investigated)	Yes Yes (work in the mode of reading inscriptions)	No	Yes (depends only on the availability of the Raspberry Pi module)	Yes (includes a pulse oximeter and can notify emergency contacts if the user is in danger)
DeepNAVI system [7]	No	No	No	Yes Yes (depends only on the availability of a smartphone)	No
The proposed system	Yes	Yes	Yes	Yes	Yes (due to the integration of data from external devices)

Based on these data, we can see that the proposed system outperforms the analogs considered, offering a more versatile and effective solution in different conditions and scenarios.

Conclusion

In this article, we have proposed a generalized functional model of an intelligent assistance system for visually impaired people, which has increased autonomy, integration with other devices and systems, the ability to analyze dynamic objects and predict their trajectory, and provide various feedback to the user. This system outperforms existing analogs, providing a more versatile and effective solution in various conditions and scenarios. High autonomy is ensured by implementing the system as a separate independent module, has advanced integration with other devices, is able to analyze dynamic objects and provide user feedback through various channels.

The functional dependencies are substantiated and the basic components of the modules of the developed model presented in the article are reviewed.

One of the first large modules is the intelligent module "Environment Conditions Detection", whose task is to determine the environmental conditions. The module has two main goals: to take into account weather conditions to more accurately predict the trajectory of dynamic objects, to notify the user of weather conditions that require additional attention (e.g., ice), and to take these conditions into account when applying the appropriate image preprocessing stack (e.g., in the dark). The Objects Detection & Tracking module is designed to detect and track objects based on integrated video and LiDAR data. At this stage, the data on the identified objects is divided into static (stationary) and dynamic (moving). The task of the Dynamic Objects Trajectory Prediction module is to predict the trajectories of dynamic objects and their future coordinates over a certain period of time. The accuracy of the module is improved by the mechanism of retraining this model in real time based on data on the real and predicted location of dynamic objects. The result generated in the Generating an Assistance Decision module is transferred to the Assistant Decision Signal Conversion module of the system. The task of this module is to convert the class label and additional parameters to the format of the corresponding user notification channel. The system uses several feedback channels: voice and tactile (by means of vibration).

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The proposed system is focused more on assisting visually impaired people, but its functionality can be expanded for use in other areas, namely:

– autonomous driving of vehicles: the system can be used to develop autonomous driving systems that can safely and efficiently move on roads without human intervention;

– autonomous control of reconnaissance and strike drones and other robotic developments in the military industry: the system can be used to develop autonomous combat systems that can perform combat and reconnaissance missions without risking human life;

– automation of loading and unloading operations and cargo movement: the system can be used to automate processes at enterprises that require cargo movement, such as ports, transport hubs, postal and courier services, agricultural enterprises, retail warehouses, etc.

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УЗАГАЛЬНЕНА ФУНКЦІОНАЛЬНА МОДЕЛЬ СИСТЕМИ АСИСТУВАННЯ ЛЮДЯМ ІЗ ВАДАМИ ЗОРУ

Предметом дослідження є створення системи інтелектуального асистування для людей з вадами зору. У наш час завдання створення ефективних систем інтелектуального асистування, що дають змогу людям, які мають проблеми із зором, отримати максимальну незалежність, є важливою та актуальною, оскільки наявні системи мають низку недоліків, таких як обмежена автономність, обмежена інтеграція з іншими пристроями та системами, обмежений аналіз динамічних перешкод та обмежені можливості зворотного зв’язку з користувачем, які здебільшого зводяться лише до голосового супроводу. **Метою роботи** є створення узагальненої функціональної моделі системи інтелектуального асистування людям з вадами зору, яка має підвищену автономність, інтеграцію з іншими пристроями та системами, здатність аналізувати динамічні об’єкти та передбачувати траєкторію їхнього руху, забезпечувати різноманітний зворотний зв’язок з користувачем. Для досягнення поставленої мети були виконані такі **завдання**: створено узагальнену функціональну модель запропонованої системи інтелектуального асистування людям із вадами зору; обґрунтувано функціональні залежності складових модулів розробленої моделі; проаналізовано базові модулі запропонованої моделі системи. Упроваджені такі **методи**: функціональне моделювання, системний аналіз. Досягнуті **результати**: запропоновано функціональну модель системи інтелектуального асистування для людей з вадами. Ця система має переваги, якщо порівнювати з наявними аналогами за низкою функціональних можливостей: детектування статичних та динамічних перешкод із передбачення траєкторії руху динамічних перешкод, здатність роботи в різних умовах (у приміщенні, на вулиці, у світлий або темний час, за різних погодних умов), підтримка інтеграції інших систем та пристроїв, високий рівень автономності. **Висновки**: розробленій моделі системи властиві підвищена автономність, інтеграція з іншими пристроями та системами, здатність аналізувати динамічні об’єкти та передбачувати траєкторію їх руху, а також забезпечувати різноманітний зворотний зв’язок з користувачем.

Ключові слова: система; асистент; зір; LiDAR; відео; траєкторія; прогнозування; інтелектуальна система; розпізнавання; класифікація.

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