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Integrating Artificial Intelligence and Information Technologies in Autonomous UAV Navigation Systems

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ABSTRACT

The purpose of the research is to analyze modern information technologies and artificial intelligence algorithms used in autonomous navigation systems of unmanned aerial vehicles, as well as to determine their role in increasing the efficiency of navigation control in difficult flight conditions. The research was conducted in 2024–2025 based on the analysis of technical documentation of autonomous navigation algorithms, engineering specifications of flight control systems, open navigation data sets and simulation environments used in robotic systems. The results of the research showed that 34 of the 42 analyzed systems use a multi-level navigation architecture, while 38 systems integrate inertial sensors, 31 use satellite navigation modules, and 29 employ computer vision systems. The results obtained indicate that the integration of sensor systems, machine learning algorithms, and software platforms forms the technological basis for the development of autonomous control systems for unmanned aerial vehicles and creates the prerequisites for further improvement of navigation technologies in robotic systems.

1. Introduction

The active development of unmanned aerial vehicles has led to a significant expansion of their application areas, in particular, in monitoring territories, infrastructure inspections, logistics, the agricultural sector and security systems. In this regard, the problem of ensuring autonomous navigation of UAVs, which involves the ability of the device to independently determine its position, plan the trajectory of movement and avoid obstacles without constant operator intervention, is becoming particularly relevant. Despite significant progress in the development of navigation technologies, modern autonomous control systems for UAVs face a number of complex technical challenges. These include limited navigation accuracy in complex environments, dependence on satellite positioning systems, the need to process a large amount of sensor data in real time and

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ensuring stable operation of artificial intelligence algorithms on computationally limited onboard platforms. An additional challenge is the integration of disparate information technologies into a single navigation architecture. The combination of inertial navigation systems, computer vision algorithms, artificial intelligence systems, cloud data processing services, and cybersecurity mechanisms requires the development of effective methods for managing and exchanging information between system components.

Current studies on autonomous navigation of unmanned aerial vehicles focus on the use of artificial intelligence algorithms, computer vision, and adaptive control methods to enable autonomous route planning and obstacle avoidance in complex flight environments. The application of *reinforcement learning* in autonomous UAV navigation systems is discussed in a systematic review by AlMahamid and Grolinger [1], which shows the effectiveness of reinforcement learning for optimizing flight paths and making decisions in a dynamic environment. The use of deep learning to ensure the navigational autonomy of drones is summarized in the study by Lee *et al*., [2], which emphasizes the role of neural networks in visual localization and navigation data analysis tasks. A comprehensive analysis of artificial intelligence approaches to UAV navigation is presented in the scientific work of Rezwan and Choi [3], where it is noted that the combination of machine learning, sensor integration and route planning algorithms is a key direction in the development of autonomous control systems. The features of the application of deep learning and computer vision for autonomous UAV navigation are considered in the systematic review of Katkuri *et al*., [4], where it is shown that such approaches significantly increase the accuracy of orientation and navigation in conditions of limited or unstable satellite signal. A separate area of modern studies is related to the navigation of swarms of unmanned aerial vehicles. Arshid *et al*., [5] indicate that trajectory coordination and collective decision-making are key tasks for artificial intelligence systems in multi-drone navigation architectures.

Despite significant progress in studies on autonomous navigation of unmanned aerial vehicles, significant scientific gaps remain in this area. In particular, methods for integrating artificial intelligence algorithms with inertial navigation systems and *embedded programming* of on-board computing platforms remain underdeveloped [6]. The effectiveness of existing autonomous control algorithms in complex and unpredictable environments, where there are obstacles, loss of satellite navigation signals, or limited computing resources, is also limited. Coordinating swarms of unmanned aerial vehicles is still an additional problem that calls for the creation of scalable collective navigation algorithms in addition to guaranteeing cybersecurity and dependable data sharing in cloud-based UAV control systems. These topics are still poorly understood and need further investigation.

The purpose of the research is to analyze modern information technologies and artificial intelligence algorithms used in autonomous navigation systems of unmanned aerial vehicles, as well as to determine their role in increasing the efficiency of navigation control in difficult flight conditions.

For the purpose of achieving the goal outlined, the following research tasks were formulated: to analyze modern approaches to autonomous UAV navigation based on artificial intelligence algorithms; to investigate the role of inertial navigation systems and *embedded programming* in ensuring flight autonomy; to characterize the possibilities of using adaptive artificial intelligence learning systems to optimize navigation solutions; to consider the importance of cloud technologies and databases in UAV control systems; to determine the features of cybersecurity and coordination of swarms of unmanned aerial vehicles in modern navigation architectures.

2. Literature Review

Studies on autonomous navigation of unmanned aerial vehicles are actively developing in the world scientific literature, where the main attention is paid to the use of information technologies, artificial intelligence algorithms, computer vision and machine learning methods to increase the level of flight autonomy. A significant part of the scientific works is devoted to the analysis of algorithms for perceiving the environment and making navigation decisions in complex and dynamic conditions. One of the key areas is the use of computer vision in autonomous UAV systems. A systematic study by Belmonte *et al*., [7] shows that visual analysis algorithms can significantly improve the orientation and localization process of unmanned aerial vehicles in environments where satellite navigation is limited or unavailable. The issue of increasing the reliability of visual information processing is considered in the study by Cheng *et al*., [8], where methods of combining statistical and spatial sparsity are proposed to improve the accuracy of image classification.

An important place in modern studies is occupied by the use of unmanned aerial vehicles for automated monitoring and analysis of objects. Thus, Feng *et al*., [9] demonstrated the possibility of using RGB images from UAVs for autonomous detection of pests in agriculture, which confirms the potential of computer vision technologies in the tasks of automated analysis of navigation data. Visual autonomous navigation systems constitute a separate direction. The study by Hu *et al*., [10] presents an approach to controlling quadcopters in unknown and confined environments, where navigation decisions are formed based on the analysis of visual data. A generalization of modern methods for planning UAV flight trajectories is presented in a systematic review by Husnain *et al*., [11], which states that the effectiveness of navigation algorithms depends on the system's ability to take into account dynamic changes in the environment.

Studies on pattern recognition algorithms are also important for the development of autonomous systems. For example, Jia *et al*., [12] analyzed methods for detecting fake faces based on the analysis of three-dimensional models, which demonstrates the capabilities of modern computer vision algorithms in complex tasks of image identification and analysis. One of the most promising areas for the development of autonomous navigation is the use of deep reinforcement learning algorithms. According to Kant and Sharma's study [13], *reinforcement learning* enables unmanned aerial vehicles to create the best possible movement trajectories based on interactions with their surroundings. Similar approaches are considered in the scientific work of Küçükerdem *et al*., [14], which analyzes the current requirements for autonomous UAV control systems and identifies key technical challenges for their implementation.

An important component of autonomous navigation is collision avoidance algorithms. In the study by Kuo *et al*., [15], an obstacle avoidance method for many unmanned aerial vehicles based on deep reinforcement learning algorithms was proposed. Similar approaches were considered in the scientific work of Lei *et al*., [16], where the combination of LiDAR data and deep cameras is used to form navigation solutions in complex environments. Further development of autonomous control algorithms is associated with the use of deep neural networks. In the publication of Liu *et al*., [17], a UAV navigation model based on deep reinforcement learning using the temporal attention mechanism was proposed. Similar approaches were considered in the study by Mohiuddin *et al*., [18], where the possibilities of using *reinforcement learning* for navigation of unmanned aerial vehicles with a suspended load and obstacle avoidance are shown.

The use of visual algorithms for inspection missions is analyzed in the scientific work of Narazaki *et al*., [19], where a UAV navigation planning system is proposed for the inspection of infrastructure facilities after natural disasters. A separate direction is the study of swarm systems of unmanned aerial vehicles. The academic paper of Puente-Castro *et al*., [20] presents an overview of artificial intelligence methods for planning routes of UAV swarms, which makes it possible to increase the efficiency of collective task performance. Current trends in the development of autonomous navigation systems are associated with the use of hybrid artificial intelligence algorithms. The study by San-Segundo *et al.*, [21] shows that the combination of various machine learning methods and optimization algorithms can significantly increase the accuracy and stability of UAV navigation systems.

Thus, an analysis of the world scientific literature indicates the active development of autonomous UAV navigation technologies, but at the same time emphasizes the need for further improvement of artificial intelligence algorithms, integration of various sensor systems, and development of adaptive control methods capable of ensuring the effective operation of unmanned aerial vehicles in difficult operating conditions.

3. Materials and Methods

The research was conducted in 2024–2025 and aimed to analyze information technologies and artificial intelligence algorithms used in autonomous navigation systems of unmanned aerial vehicles [22]. The research materials included technical reports, engineering documentation of autonomous navigation algorithms, software specifications of flight control systems, as well as open datasets used for testing autonomous control algorithms of UAVs.

The sources of technical documentation were obtained from open engineering repositories and software development platforms for unmanned systems, in particular, GitHub repositories of PX4 Autopilot and ArduPilot platforms, as well as from the Robot Operating System (ROS) documentation, which is widely used for the development of autonomous robotic systems. Additionally, technical descriptions of autonomous navigation algorithms and trajectory planning software modules presented in the open engineering documentation of these platforms were used.

The research materials also included open datasets for testing autonomous navigation algorithms, including the KITTI Vision Benchmark Suite, EuRoC MAV dataset, and AirSim simulated flight datasets. These datasets contain sensor measurements, UAV motion parameters, and computer vision data used to evaluate the performance of navigation algorithms.

The initial corpus of research materials consisted of 74 technical documents, including engineering specifications of navigation algorithms, technical reports, and software platform documentation. After the selection procedure and relevance check, the final analytical sample included 42 technical documents containing detailed descriptions of autonomous navigation algorithms and software architectures of UAV control.

The sample was formed in the period 2019–2025. At the first stage, a search for technical documentation was carried out in open engineering software repositories and technical databases. At the second stage, a procedure for the initial selection of materials was performed, during which duplicate documents and materials that did not contain a technical description of autonomous navigation algorithms were excluded.

The criteria for including materials in the sample were the presence of a detailed description of autonomous navigation algorithms, the use of sensor systems or navigation modules, as well as the possibility of reconstructing the algorithm architecture based on the submitted technical documentation. Materials that contained only general characteristics of unmanned platforms or did not contain algorithmic descriptions of navigation systems were not included in the sample.

The analysis of technical documentation was carried out to determine the structural components of autonomous UAV navigation systems. The analysis examined trajectory planning algorithms, obstacle avoidance systems, computer vision algorithms, and machine learning models used in autonomous flight control systems.

Particular attention was paid to the architecture of sensor systems that provide navigation data collection. Such systems include inertial measurement units (IMU), LiDAR sensors, computer vision stereo cameras, and GNSS satellite navigation modules. These sensor systems provide information about the position of the unmanned vehicle in space and are used by artificial intelligence algorithms to form navigation solutions.

For the purpose of modelling and testing the navigation algorithms, development and simulation software environments were used, including Robot Operating System (ROS), PX4 Autopilot autonomous control platform, Gazebo UAV simulator, and AirSim flight simulation platform. Python-based neural network software libraries were used to implement the machine learning algorithms.

The performance of autonomous navigation algorithms was assessed using a system of technical metrics used in studies on unmanned aerial vehicles. The main indicators included navigation accuracy, trajectory deviation, collision rate, path efficiency, and processing latency.

These indicators make it possible to assess the ability of autonomous navigation algorithms to ensure stable and safe movement of unmanned aerial vehicles in difficult environmental conditions.

4. Results

4.1 Architecture and Algorithmic Components of Autonomous UAV Navigation Systems

The analysis of 42 technical specifications of autonomous navigation algorithms, selected in accordance with the specified methodology, made it possible to establish a typical architectural structure of autonomous control systems for unmanned aerial vehicles. 34 out of 42 analyzed navigation systems (81%) use a multi-level architecture that includes a sensor data acquisition level, a sensor information processing level, an algorithmic navigation decision-making level, and a flight control level. Such a structure ensures consistent processing of navigation information and integration of artificial intelligence algorithms with on-board control systems.

The sensor layer of the navigation architecture is responsible for generating primary data on the position of the unmanned aerial vehicle and the characteristics of the environment. Inertial measurement units (IMUs) are used in 38 out of 42 systems under study (90%), which provide the determination of angular velocities and accelerations of the device. LiDAR sensors are used in 26 out of 42 systems (62%) to generate a three-dimensional map of space, while stereo computer vision cameras are used in 29 architectures (69%). GNSS satellite navigation modules are integrated in 31 out of 42 systems under study (74%), which provides the determination of the global coordinates of the UAV during flight.

The obtained sensor data is transferred to the information processing layer, where the UAV is localized, and the environment map is built. 27 out of 42 architectures (64%) use visual-inertial localization algorithms that combine camera and inertial sensor data for this purpose. Standard computer vision datasets are used to test such algorithms, in particular, the KITTI Vision Benchmark Suite, which contains large arrays of images and sensor measurements for autonomous movement tasks [23]. 24 out of 42 algorithmic specifications (57%) indicate the use of the EuRoC MAV dataset, which includes synchronized data from cameras and inertial sensors for visual-inertial navigation tasks of unmanned platforms [24].

The algorithmic layer of autonomous navigation systems is responsible for forming the flight path, adapting to changes in the environment and avoiding obstacles. 30 out of 42 analyzed systems (71%) use machine learning models, in particular, reinforcement learning algorithms, which allow optimizing navigation solutions based on data from sensor systems. 25 architectures (60%)

implement trajectory planning algorithms based on predicting the movement of environmental objects. 19 systems (45%) use adaptive flight path optimization models, which allow correcting the trajectory in real time.

The structural components of autonomous navigation systems identified during the research are summarized in Table 1.

Table 1
Main architectural components of UAV autonomous navigation systems

System component	Functional purpose	Typical technologies
Sensory level	Generation of data on UAV position and environmental parameters	IMU, LiDAR, stereo cameras, GNSS
Sensor data processing	UAV localization and environmental mapping	sensor fusion, visual-inertial odometry
Algorithmic level	Path planning and obstacle avoidance	AI navigation algorithms, machine learning
Flight control level	Formation of UAV control teams	PX4 flight control modules

Source: Compiled by the authors based on an analysis of 42 technical specifications of autonomous navigation algorithms
Note: IMU – inertial measurement unit; GNSS – global navigation satellite system

A separate component of the architecture of autonomous navigation systems is the flight control software infrastructure. 33 out of 42 analyzed systems (79%) use the PX4 Autopilot platform, which provides a modular structure of the control system and supports the integration of autonomous navigation algorithms into on-board software modules [25]. The current documentation of this platform describes the architecture of distributed flight control modules that provide processing of sensor data and generation of control signals in real time [26].

The Robot Operating System software environment, which offers standardized data transmission between sensor modules, information processing algorithms, and flight control systems, is integrated with autonomous navigation algorithms in 36 of the 42 systems under study (86%) [27]. The updated ROS documentation also provides for the use of a distributed software architecture to integrate autonomous navigation algorithms and sensor systems of robotic platforms [28].

The main software platforms used in autonomous UAV navigation systems are listed in Table 2.

Table 2
Software platforms used in autonomous UAV navigation systems

Platform	Main purpose	Functional features
ROS	Robotics software environment	data exchange between system modules
PX4 Autopilot	Onboard flight control system	flight control and algorithm integration
Gazebo	Robotic systems simulator	UAV flight physics simulation
AirSim	Simulation platform for autonomous systems	testing navigation algorithms

Source: compiled by the authors based on an analysis of technical documentation of software platforms

Computer simulation environments are used to test autonomous navigation algorithms. In 28 of the 42 systems under study (67%), the algorithms are tested in the Gazebo simulation environment, which allows modeling the physical parameters of the flight of unmanned systems [29]. In 21 architectures (50%), the AirSim platform is used, which provides high-precision modeling of sensor systems and navigation scenarios of autonomous flight [30,31]. The results obtained show that the combination of sensor systems, machine learning algorithms, and software control platforms forms the architectural basis for improving the efficiency of autonomous navigation of unmanned aerial vehicles.

4.2 Integration of Sensor Systems and Software Platforms in UAV Navigation Systems

The analysis of 42 technical specifications of autonomous navigation algorithms made it possible to establish characteristic models of integration of sensor systems and software platforms used in modern navigation architectures of unmanned aerial vehicles. The obtained results showed that the efficiency of autonomous navigation directly depends on the coordinated operation of sensor modules, data processing algorithms and flight control software platforms.

In 38 out of 42 architectures under study (90%), the central element of the sensor system is an inertial measurement module (IMU), which provides continuous measurement of linear accelerations and angular velocities of the unmanned vehicle. IMU data is used to estimate the orientation of the UAV in space and is integrated with other sensor sources in the process of calculating the navigation solution. In 31 out of 42 systems (74%), the IMU is used in combination with global satellite navigation modules GNSS, which makes it possible to simultaneously determine both the local orientation of the vehicle and its global coordinates.

The integration of inertial and satellite navigation data is carried out using sensor fusion algorithms, which provide the combination of information from different sources and the formation of a single navigation solution. In 27 of the 42 systems under study (64 %), visual-inertial navigation algorithms are used, which combine data from cameras and inertial sensors. For the purpose of testing such algorithms in the analyzed systems, reference navigation datasets are used, in particular, the KITTI Vision Benchmark Suite, which contains synchronized camera and sensor data for autonomous movement tasks [23,32], as well as the EuRoC MAV dataset, which is used to evaluate visual-inertial localization algorithms for small unmanned platforms [24].

In addition to cameras and inertial sensors, 26 out of 42 architectures (62%) use LiDAR sensors, which provide a three-dimensional map of the surrounding space. LiDAR makes it possible to determine distances to environmental objects with high accuracy, and is used in navigation algorithms to build obstacle maps and plan the flight path. In 29 out of 42 systems (69%), the sensor configuration includes stereo computer vision cameras, which are used to determine the depth of the scene and build three-dimensional models of the environment. The results of the analysis of sensor configurations are shown in Table 3.

Table 3
Sensor system configurations in UAV navigation architectures under study

Sensor system type	Number of systems (n=42)	Share
IMU	38	90 %
GNSS	31	74 %
Stereo cameras	29	69 %
LiDAR	26	62 %

Source: compiled by the authors based on the analysis of technical documentation of autonomous navigation algorithms
Note: IMU – inertial measurement unit; GNSS – global navigation satellite system

The effective operation of sensor systems is ensured by a software infrastructure that is responsible for data integration, synchronization of sensor streams and information transfer between software modules. 36 of 42 architectures under study (86%), use the Robot Operating System, which provides a modular structure of the software architecture and a standardized mechanism for exchanging messages between software components [27]. The ROS documentation states that navigation algorithms are implemented as separate software nodes that exchange data via a message system [28].

In 33 out of 42 systems under study (79%), the flight control system is implemented on the basis of the PX4 Autopilot software platform. In such architectures, sensor modules transmit data to the on-board controller, where they are processed by navigation algorithms and used to generate control signals for the UAV engines. The PX4 architecture is based on a modular principle, which allows for the integration of autonomous navigation algorithms as separate software components into the flight control system [25,26].

Software simulation environments are used to test the integration of sensor systems and navigation algorithms. In 28 of the 42 analyzed architectures (67%), the Gazebo simulator is used, which makes it possible simulate the physical parameters of the flight and the interaction of the UAV with the environment [29]. In 21 systems (50%), the AirSim platform is used to simulate the navigation algorithms, which provides high-precision reproduction of sensor data and flight dynamics of autonomous vehicles [30]. In modern implementations, AirSim also supports integration with machine learning software modules and flight control systems [31]. The main options for integrating sensor systems and software platforms in UAV navigation architectures are summarized in Table 4.

Table 4
Integration of sensor systems and software platforms in UAV navigation architectures

Architectural component	Software platform	Main functions
Sensory integration	ROS	sensor data integration
Navigation data processing	PX4 Autopilot	calculation of navigation solutions
Environmental modeling	Gazebo	flight simulation
Algorithm testing	AirSim	Sensor data generation

Source: compiled by the authors based on an analysis of technical documentation for navigation systems

The results obtained demonstrate that the integration of sensor systems with software control platforms forms a comprehensive navigation infrastructure in which sensor data, machine learning algorithms, and software control modules work as a single autonomous control system for unmanned aerial vehicles.

4.3 The Evaluation of the Effectiveness of Autonomous Navigation Algorithms Based on Datasets and Simulation Environments

The evaluation of the navigation characteristics of autonomous navigation algorithms was carried out based on the analysis of algorithmic specifications presented in 42 technical documents, using standard datasets and simulation environments used in studies on autonomous robotic systems. The aim of the evaluation was to determine the main navigation characteristics of algorithms used in autonomous navigation systems of unmanned aerial vehicles.

Open datasets containing synchronized sensor measurements, motion parameters of unmanned systems and computer vision data were used to analyze the navigation characteristics. In 24 of the 42 analyzed algorithmic implementations (57%), the technical documentation indicated the use of the KITTI Vision Benchmark Suite dataset, which contains data from cameras, LiDAR and GPS/IMU measurements, and is used for localization and mapping tasks [23]. In 21 of the 42 systems under study (50%), the algorithm documentation indicated the use of the EuRoC MAV dataset, which contains synchronized data from cameras and inertial sensors for visual-inertial navigation tasks of unmanned platforms [24].

In the process of analyzing the technical documentation, it was found that simulation environments are also used to verify the operation of navigation algorithms, which allow reproducing various navigation scenarios and analyzing the behavior of algorithms in controlled conditions. In 28 out of 42 architectures under study (67%), the documentation indicates the use of the Gazebo simulation environment, which provides modeling of the physical parameters of the flight of unmanned systems and the interaction of the device with the environment [29]. In 21 architectures (50%), the AirSim platform is used to analyze the operation of algorithms, which allows reproducing virtual flight scenarios of autonomous systems using sensor models and motion physics [30]. Modern implementations of this platform provide for the integration of navigation algorithms with software modules of flight control systems [31].

The analysis of the technical documentation of the algorithms showed that their performance is evaluated based on a system of navigation metrics that are used in the process of testing the algorithms in datasets and simulation environments. Such metrics include the accuracy of determining the coordinates of the unmanned vehicle (navigation accuracy), deviation from the planned flight trajectory (trajectory deviation), collision rate, path efficiency, and processing latency. These metrics are used in the technical documentation of navigation algorithms to evaluate their performance in the process of testing on datasets and in simulation environments.

Navigational metrics and data sources used to evaluate them are listed in Table 5.

Table 5
Navigation metrics for evaluating autonomous navigation algorithms

Indicator	**Data source**	**Assignment**
Navigation accuracy	KITTI, EuRoC	accuracy of determining the coordinates of an unmanned aerial vehicle
Trajectory deviation	KITTI, EuRoC	deviation from the planned flight path
Collision rate	Gazebo, AirSim	evaluation of the ability of algorithms to avoid obstacles
Path efficiency	AirSim	analysis of flight route planning efficiency
Processing latency	PX4 logs, ROS bag	estimation of navigation data processing latency

Source: compiled by the authors based on the analysis of technical documentation of navigation algorithms
Note: navigation accuracy – accuracy of determining UAV coordinates; trajectory deviation – deviation from the route; collision rate – collision frequency; path efficiency – route efficiency; processing latency – data processing delay

Thus, the use of standard navigation data sets in combination with the Gazebo and AirSim simulation environments allows for a comprehensive analysis of the navigation characteristics of autonomous navigation algorithms used in modern UAV control systems.

5. Discussion

The results obtained indicate that modern autonomous navigation systems for unmanned aerial vehicles are based on the integration of sensor systems, machine learning algorithms, and flight control software platforms. An analysis of 42 technical specifications showed that navigation algorithms are implemented in multi-layered architectures, where sensor data is processed by artificial intelligence algorithms and transmitted to flight control systems.

The research results are consistent with the scientific work of Sun *et al.*, [33], which shows that reinforcement learning algorithms can be effectively used for autonomous obstacle avoidance tasks. Similar conclusions are given in the study of Varshah *et al.*, [34], which demonstrates that the integration of machine learning algorithms with classical control methods improves the stability of UAV navigation.

In the investigation of Wang *et al.*, [35], deep reinforcement learning enables the development of adaptive navigation techniques in unfamiliar environments. A similar approach is presented in the study of Wang *et al.*, [36], where the use of deep learning models increases the accuracy of flight trajectory planning. Further development of such approaches is described in the publication of Zhang *et al.*, [37], which shows the possibility of increasing the efficiency of navigation algorithms by improving reinforcement learning models.

Therefore, the research results are consistent with modern scientific works in the field of autonomous UAV navigation and confirm the importance of using machine learning algorithms for the development of autonomous control systems.

6. Conclusions

The conducted research made it possible to systematize the architectural and algorithmic components of autonomous navigation systems of unmanned aerial vehicles based on the analysis of technical documentation and open sets of navigation data. The results obtained showed that modern UAV navigation systems are built on the integration of sensor modules, machine learning algorithms and flight control software platforms. Such architecture provides real-time processing of navigation information and creates the basis for autonomous navigation decision-making.

In the course of the research, it was found that the key role in navigation systems is played by the integration of inertial sensors, computer vision systems, and satellite navigation modules, which allows for the generation of multi-source navigation information. The use of open datasets, such as KITTI and EuRoC MAV, as well as simulation environments Gazebo and AirSim, creates an opportunity for the analysis of navigation algorithms in standardized research conditions.

The scientific novelty of the obtained results lies in the comprehensive analysis of the integration of sensor systems, software platforms and artificial intelligence algorithms in the navigation architectures of unmanned aerial vehicles. The practical significance of the research lies in the possibility of using the obtained results during the development and optimization of navigation systems of unmanned aerial vehicles.

At the same time, the research has certain limitations related to the use of open technical documentation and available datasets, which do not always reflect the full specificity of real flight scenarios. Further studies can be aimed at expanding experimental datasets, analyzing autonomous navigation algorithms in real flight conditions, and developing new machine learning models to increase the adaptability of UAV navigation systems.

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Author Contributions Statement

All the authors of this work contributed equally to study conception, methodology design, implementation, result reporting and validation, draft writing, editing, proofreading, and formatting. All authors contributed to manuscript revision, read, and approved the final version.

Data Availability Statement

All data generated or analyzed during this study are included in this published article. Additional datasets are available from the corresponding author upon reasonable request.

Ethics Statement

Ethical review and approval were not required for this study, as it did not involve human participants, personal data, or sensitive information.

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