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APPLICATION OF ARTIFICIAL INTELLIGENCE IN UNMANNED AERIAL VEHICLES: A CONCEPTUAL MODEL FOR ENSURING AUTONOMOUS NAVIGATION, TECHNICAL RELIABILITY, AND SAFETY

SHAYMIRZAYEV O'KTAM RO'ZIYEVICH
Major, Senior Instructor and Head of the UAV Control and Counter-UAV Operations Section, Department of Advanced Military Technologies, Faculty of the Central Military District, University of Military Security and Defense of the Republic of Uzbekistan

Abstract: This article examines how integrating unmanned aircraft systems (UAS) with artificial intelligence (AI) can support navigation, sensor-data analysis, and technical-condition monitoring. Based on an analysis of international guidance and four research methods, it proposes a five-stage conceptual model spanning risk identification to continuous monitoring. The model has not been empirically validated and is intended as a methodological basis for future testing.

Keywords: unmanned aircraft systems, artificial intelligence, autonomous navigation, sensors, flight safety, cybersecurity.

Introduction

Unmanned Aerial Vehicles (UAVs) are utilized in fields such as surveying, agriculture, infrastructure inspection, environmental monitoring, search and rescue operations, and scientific research. Onboard cameras, navigation equipment, and other sensors can collect vast amounts of data. Artificial intelligence (AI) techniques can assist in processing this data, identifying changes within images, and presenting information in a format that is easily understood by the operator.

However, the presence of AI does not, in itself, guarantee safe or fully autonomous flight. System performance can be affected by sensor errors, communication failures, software glitches, incorrect model inferences, adverse weather conditions, or cyber threats. Consequently, AI-driven functions must be considered in conjunction with clearly defined tasks, rigorous testing, human oversight, and adherence to relevant aviation regulations. This article focuses on secure data analysis, technical monitoring, and supervised control within civilian, scientific, and industrial contexts; it does not address weapon targeting or combat applications.

Scientific-Theoretical Foundations and International Approaches

UAV systems typically consist of an aerial platform, a flight control system, navigation tools, a communication link, a payload, and an operator interface. When AI is integrated into this architecture, it can perform supporting tasks such as analyzing sensor data, processing images, or detecting changes in technical status. Before implementing AI, the specific task, the consequences of potential errors, and the nature of human oversight must be clearly defined.

ICAO materials provide insight into safety and regulatory principles within international aviation. EASA's UAS regulations establish risk-based requirements for operations within Europe; their applicability depends on the type of operation and the relevant jurisdiction. Meanwhile, the NIST AI Risk Management Framework offers a comprehensive governance approach for addressing risks associated with AI systems throughout their design, deployment, use, and evaluation.

Research Methodology

The research is based on conceptual and documentary analysis. The selection of sources took into account their official status, their relevance to UAS (Unmanned Aircraft System) operations or the management of risks associated with AI (Artificial Intelligence), and the possibility of independent verification. Systematic analysis, comparative analysis, functional analysis, and generalization methods served as the primary methodological tools. The study of international documents and conceptual modeling functioned as supporting approaches.

1. Systematic Analysis Method

Systematic analysis was employed to examine the UAS not merely as a collection of individual devices, but as a system composed of interconnected technical and organizational components. In this analysis, the aerial platform, flight control system, navigation aids, sensors, communication channels, data processing, operator interface, cybersecurity, and safety controls were treated as interdependent elements.

This method helps determine how a failure in any single element might affect other components and the safety of the entire operation. For instance, a decline in the quality of sensor data can reduce the reliability of AI-based analysis, while a loss of communication impacts operator control and the system's transition into a safe mode. The scientific contribution of the systems analysis lies in integrating technical, informational, and organizational factors within a unified framework, as well as in substantiating the logical structure of the proposed five-stage model.

2. Comparative Analysis Method

A comparative analysis was employed to examine ICAO materials, EASA regulations on UAS (Unmanned Aircraft Systems), and NIST approaches to managing safety-critical (SC) risks, focusing on their respective objectives, scopes, and primary emphases. It should be noted that these sources are not treated as equivalent documents: ICAO materials address international aviation principles and the regulatory context; EASA regulations pertain to UAS operations within the relevant European jurisdiction; and the NIST framework provides a general methodological approach for managing SC risks.

The comparison identified common themes—such as safety, risk assessment, human oversight, and monitoring—while acknowledging differences in the legal status and scope of application of the respective documents. The scientific contribution of this method lies in demonstrating how principles from various sources can be synthesized to form a conceptual model, without conflating the distinct origins of these principles. In this article, the comparison serves to systematize the methodological foundations rather than to demonstrate quantitative effectiveness.

3. Functional Analysis Method

Functional analysis was employed to delineate the roles of the key components within the integration of unmanned aerial vehicles (UAVs) and artificial intelligence (AI). Sensors collect data regarding the environment and the status of the equipment; AI assists in analyzing patterns within images or technical indicators; the navigation system provides data on location and movement; communication channels facilitate the exchange of information; and the operator remains responsible for verifying results and making appropriate decisions. Cybersecurity measures are directed toward protecting data, software, and control channels.

This method allows for the distinction between the capabilities of AI functions and their inherent limitations. For instance, while AI may identify an anomalous change in technical indicators, this finding does not automatically constitute a definitive technical diagnosis; it must be validated through expert review and technical documentation. The scholarly contribution of this functional analysis lies in clarifying the function of each component, its

interdependencies with other components, and the specific points at which human oversight is required.

4. Generalization Method

The generalization method was used to synthesize the conclusions derived from documentary, systemic, comparative, and functional analyses. The general principles have been consolidated into the following stages: identifying needs and risks, assessing data and sensor infrastructure, integrating AI functions under controlled conditions, conducting safety testing, and performing ongoing monitoring during operation.

As a result of this synthesis, a five-stage conceptual model is proposed. It does not replace existing regulatory requirements, nor does it serve as a universal, ready-made solution for every type of unmanned aerial system (UAS) or jurisdiction. Its scientific contribution lies in organizing general principles—drawn from international sources—into a coherent sequence aligned with project planning and risk management processes.

Methodological limitation. This article does not present testing of a new UAS prototype; no flight experiments were conducted, and no statistical data were collected. Consequently, the proposed model should be viewed as a conceptual approach. Validating its effectiveness and practical viability would require controlled pilot tests, established criteria, and documented outcomes.

Applications of Artificial Intelligence in Unmanned Aerial Vehicle (UAV) Systems

Analysis of Imagery and Sensor Data

AI can assist in classifying objects within images, detecting changes in an area, and filtering data received from sensors. For instance, during infrastructure inspections, images can be prioritized for the operator, while in agriculture, visible changes in fields can undergo preliminary analysis. These results must be reviewed by a specialist, taking into account the possibility of misidentification.

Navigation and Flight Data Support

In certain systems, AI can help identify inconsistencies in navigation data or analyze post-flight data. Decisions affecting flight safety must align with established control mechanisms, fail-safe protocols, and operator oversight. AI outputs should not be treated as an infallible or sole source of information.

Technical Condition Monitoring and Preventive Maintenance

Data collected regarding the engine, battery, temperature, vibration, and other technical parameters helps in monitoring the condition of the equipment. AI can highlight unusual changes and assist in scheduling technical inspections. Such recommendations must be verified through technical documentation and an assessment by a qualified specialist.

Applications in Civil and Scientific Sectors

The integration of Unmanned Aerial Vehicles (UAVs) and Artificial Intelligence (AI) can be beneficial in fields such as geodesy, environmental monitoring, agriculture, the inspection of construction sites, the provision of information for search and rescue operations, and the collection of scientific data. For any given task, it is essential to adhere to requirements regarding data privacy, human safety, flight restrictions, and local legislation.

Key Challenges and Risks

Sensor Data and Model Errors

Poor lighting conditions, adverse weather, sensor contamination, calibration errors, or a lack of data can affect the output of an AI system. There is a risk that a model may produce errors when operating in conditions that differ from those under which it was trained. Testing procedures should encompass both routine scenarios and unexpected situations.

Flight Safety and Human Oversight

Errors involving UAS (Unmanned Aircraft Systems) can cause harm to people, property, and infrastructure. Therefore, prior to any operation, it is necessary to conduct a risk assessment, inspect the flight area, establish an emergency response plan, and define the operator's authority. AI-based recommendations must not be used to circumvent safety regulations.

Cybersecurity and Data Protection

UAS control software, communication channels, stored data, and update mechanisms are vulnerable to unauthorized access or compromise. Measures such as restricting access rights, implementing controlled software updates, ensuring data protection, maintaining audit trails, and establishing incident response procedures are essential.

Communication Loss and Infrastructure Dependency

In the event of degraded communication quality or satellite navigation issues, the system's behavior must default to pre-established, safe operating modes. Critical safety functions should not be entirely dependent on the continuous availability of external networks or cloud-based services.

Legal Requirements and Liability

Requirements for UAS operations vary depending on the country, the flight area, the type of equipment, and the specific mission. Before using the system, applicable permits, flight restrictions, privacy requirements, and the organization's internal policies must be reviewed. This article does not constitute legal advice or serve as authorization for any specific operation.

Evaluation Criteria and Practical Recommendations

When testing the model in a practical setting, performance indicators should be established before the project begins, and the results should be compared against the initial baseline. Recommended criteria include: (1) image classification quality and error rates; (2) stability of sensor and navigation data; (3) time required to detect technical malfunctions; (4) performance in safety tests; (5) transition to a safe mode in the event of a communication loss; (6) cybersecurity controls; and (7) operator training and decision-verification procedures.

It is advisable to begin practical implementation with a small-scale, controlled-risk pilot project; document operational conditions; conduct safety tests involving qualified specialists; and record the outcomes. Any decision to scale up the system must be based on empirical evidence, appropriate authorizations, and pre-established criteria.

Discussion

The application of AI in unmanned aerial vehicle (UAV) systems offers the potential to enhance data analysis and technical monitoring. However, technical capabilities cannot be decoupled from considerations regarding safety, cybersecurity, human oversight, and legal requirements. For every project, it is essential to pre-evaluate the benefits of AI integration, the potential consequences of errors, maintenance costs, and the scope of operator responsibility. The proposed model integrates general principles from international sources into practical implementation steps. A limitation of this model is that it has not yet been validated through actual flight tests or empirical measurements. Future work should involve pilot testing the model across various civil applications, while comparing safety metrics and operational costs.

Conclusion

The integration of artificial intelligence with unmanned aerial vehicles (UAVs) enhances capabilities in areas such as sensor data analysis, image processing, health monitoring, and decision-making support for operators. At the same time, the reliable

operation of the system depends on data quality, the condition of sensors, cybersecurity, flight safety, human oversight, and compliance with existing regulations.

The article proposes a five-stage conceptual model that integrates the identification of needs and risks, the assessment of sensor and data infrastructure, the controlled integration of AI functions, security testing, and continuous monitoring. Its scientific and practical contribution lies in offering a systematic approach and a set of criteria for the planning and evaluation of unmanned aviation (UA) projects. Future empirical research should determine the model's effectiveness, limitations, and costs across various conditions.

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