Annotation

Dissertation research topic:
“Development of an information system using an artificial intelligence approach for the evaluation and prediction of the behavior of complex objects”

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1. Relevance of the topic and justification of the chosen direction

The modern stage of development of digital and intelligent technologies is accompanied by the complication of control objects, characterized by a high degree of uncertainty, nonlinearity of processes, a large volume of heterogeneous data, and the need for adaptation to external conditions. Against this background, intelligent information systems capable of independently analyzing complex situations and predicting the development of events are gaining increasing importance.

Such systems are of particular relevance in the field of remote sensing of the Earth (RS) using unmanned aerial vehicles (UAVs), where there is a need for automated interpretation of data, terrain modeling, object monitoring, and adaptive navigation. The development of an intelligent system combining GIS, UAVs, and AI methods corresponds to modern scientific priorities and the objectives of the “Digital Kazakhstan” program.

2. Purpose and objectives of the research

The purpose of the dissertation research is the development of an information system using an artificial intelligence approach for the evaluation and prediction of the behavior of complex objects.

The achievement of this goal envisages the creation of algorithms and models that ensure high prediction accuracy, adaptive control, and automated data processing under conditions of uncertainty and changing environmental factors.

To achieve the goal, the following objectives are formulated:

1. To conduct a system analysis of existing methods and models for predicting the behavior of complex dynamic objects, to identify their limitations and to determine directions for improvement using artificial intelligence.
2. To develop theoretical and methodological foundations for constructing an intelligent information system that ensures the integration of AI components and supports the processing of spatio-temporal data.
3. To form the architecture and algorithms for the functioning of the main modules of the information system - data collection, preprocessing, intelligent analysis, adaptive learning, and visualization of prediction results.

4. To implement a software prototype of an intelligent information system, to conduct experimental studies on UAV, remote sensing (RS), and GIS data, and also to evaluate the accuracy, adaptability, and computational efficiency of the proposed solutions in comparison with traditional approaches.

3. Methodology and applied methods

Within the framework of the research, the following scientific approaches were applied:

- System analysis - for decomposition and structuring of the behavior of complex objects;
- AI methods - neural networks (CNN, RNN), Group Method of Data Handling (GMDH), decision trees, regression algorithms;
- Machine learning and visual SLAM - for prediction, navigation, and image analysis;
- Data filtering methods - Kalman filter, RANSAC;
- Geoinformation technologies (GIS) - for constructing digital terrain models;
- Experimental methods - test flights, image processing, comparison of predictions with actual values;
- Mathematical modeling - for analysis of UAV technical characteristics and construction of predictive models.

4. Main provisions submitted for defense

1. A method for predicting the behavior of complex objects based on joint processing of spatial and temporal data using neural network models.
2. An approach to integrating heterogeneous data (UAV, remote sensing, and geoinformation systems) into a unified framework of analysis and prediction.
3. The architecture of an information system providing automated processing, synchronization, and analysis of telemetry, geospatial, and visual data.

5. Main results and scientific hypotheses

In the course of the dissertation research:

- A hardware-software system IIS-UAV integrating AI, image processing methods, and GIS has been developed;
- A prototype of an autonomous aerial survey complex with intelligent modules has been implemented;
- Terrain prediction algorithms enabling the creation of 3D terrain models have been developed;
- Software for processing IMU, GPS, and photogrammetric data has been created;
- Orthophotomaps, digital surface models (DSM), and 3D models of objects (“Sairan”, “Alatau”, “Dumps”, etc.) have been obtained;

– A comparison of efficiency has been carried out: the proposed methods outperform traditional ones in accuracy and adaptability;
– Implementation of results in scientific projects and educational courses has been carried out.

6. Scientific novelty

1. A method for predicting the behavior of complex objects based on joint processing of spatial and temporal data using neural network models is proposed, ensuring increased prediction accuracy under conditions of uncertainty.
2. An approach to integrating heterogeneous data (UAV, remote sensing, and geoinformation systems) into a unified framework of analysis and prediction is developed.
3. An information system architecture providing automated processing, synchronization, and analysis of telemetry, geospatial, and visual data is proposed.

7. Compliance with priority directions

The results correspond to:

– The goals and objectives of the State Program “Digital Kazakhstan”;
– Directions of development of space and geoinformation technologies; priorities of the scientific strategy of the Republic of Kazakhstan for 2020–2025;
– Requirements for the implementation of AI in industry and security;
– Directions of international Erasmus+ projects in the field of Smart Agriculture and Sustainable Systems (SAGRIS, 2020–2023).

8. Contribution of the doctoral student and approbation

The doctoral student personally:

– Performed forecasting algorithms and software modules;
– Developed and tested aerial survey complexes;
– Designed prototypes of data collection and processing systems;
– Prepared 33 publications (including Scopus, MES RK, patent, 6 author’s certificates).

The results were approbated in:

– Al-Farabi Kazakh National University,
– Kazakh National Agrarian Research University,
– Institute of Information and Computational Technologies,
– ITMO University (Russia),
– HFWU (Germany).

Contribution to publications: the doctoral student acted as the leading author on AI methods, modeling, and analysis, participated in the implementation of algorithms, testing, verification, and writing of sections of articles and manuals.

9. Practical significance

The developed solutions have been implemented in:

- JSC “National Center for Space Research and Technologies”;
- Satbayev University;
- Kazakh National Agrarian Research University (educational process).

The use of IIS made it possible to significantly reduce the time for processing aerial data, increase prediction accuracy, and automate UAV control under conditions of uncertainty.

10. Structure of the dissertation

The dissertation consists of:

- Introduction
- 4 chapters
- Conclusion
- References (82 sources)
- Appendices (A–E)

Total volume: 164 pages, 92 figures, 28 tables.