ANNOTATION

dissertation for the degree "Doctor of Philosophy" (Ph.D) in

EP 8D6102- Machine Learning & Data Science

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"Development of a flight planning model for technically heterogeneous UAVs to solve precision farming problems”

In this thesis work, a flight planning model for technically heterogeneous UAVs was proposed in the context of precision agriculture. The difference of this work lies in an original approach to the optimization of trajectories for multiple UAVs combined with the use of a mobile ground station, where the application of a genetic algorithm aimed at minimizing the total cost of circling a field of a given size and configuration plays a key role. This approach allows to automate the planning process, making it more flexible and adaptive to the specifics of different agronomic tasks. The advantage of the model is: the possibility of planning the flight path of multiple heterogeneous UAVs to solve the problem of covering agricultural fields of different shapes; minimization of the total cost of the flight with a limited time of mission execution, with minimal operator intervention; automated selection of the required number of UAVs, taking into account the individual characteristics of each available vehicle; use of a ground mobile station as a launch and refueling point for UAVs.

Purpose of the work. To develop a flight planning model for multiple heterogeneous UAVs in precision agriculture using a ground mobile platform.

Objectives of the study.

In order to achieve the goal, the following objectives are set in the paper:

1) Analyzing the methods and models of UAV path planning in precision agriculture;

2) Developing a flight planning model that takes into account the following:

1. Parameters of the heterogeneous UAV fleet from which a group of UAVs can be selected to solve the overflight problem;

2. Availability of a ground mobile platform for refueling and collection of UAVs after the mission;

3. Labor of the personnel performing the overflight;

4. Costs associated with equipment wear and tear;

5. Penalty for extended (exceeding the threshold) flight time.

3) Development of a method of flight planning based on a genetic algorithm in which the cost function is based on the developed model;

4) Development of a software, total cost optimization system for the overflight process with a two-dimensional simulator for the path of UAV and ground mobile platform;

5) Conducting computational experiments to evaluate the quality of the developed method.

Relevance of the study. Modern agricultural production faces a number of challenges related to the need to increase productivity and optimize resource use while reducing environmental impact. In this context, precision farming acts as a promising direction offering intensive methods of agro-process management using advanced technologies.

Unmanned Aerial Vehicles (UAVs) have in recent years demonstrated their high potential as a tool to revolutionize many agricultural operations from monitoring soil and plant conditions to fertilizer and herbicide application. UAVs provide capabilities that were previously unavailable or uneconomical.

However, despite the many advantages, the use of UAVs in agriculture faces a number of technical and practical challenges. In this regard, optimization of flight planning is required, taking into account the heterogeneity of available equipment and the specificity of the tasks that UAVs have to perform during overflight.

Objects of the study. The process of application of UAVs in the field of precision agriculture.

Subject of the research. Methods and models of optimization of flight plans of a group of heterogeneous UAVs and a mobile ground station for refueling and collection of UAVs that have completed the mission.

Research Methods.

The following research methods are used in the dissertation work: Analysis of scientific literature, Adaptation of genetic algorithm, Creation of models and software prototyping, Computational experiments in virtual environment.

Scientific novelty:

1) A flight planning model is proposed that takes into account:

1. Parameters of the heterogeneous UAV fleet, from which a group of UAVs can be selected to solve the overflight problem;

2. Availability of a ground mobile platform for refueling and collection of UAVs after the mission;

3. Labor of the personnel performing the overflight;

4. Costs associated with equipment wear and tear;

5. Penalty for extended (exceeding the threshold) flight time.

2) A new method for solving the coverage problem using a mobile ground station for UAV control and intermediate maintenance is proposed.

3) A model that takes into account the complex price of overflight is developed. Under the conditions of computational experiments, the proposed model allowed (depending on the size and shape of the field) to minimize the complex cost of overflight from 10 to 30%.

The main results of the study: a model of coverage path planning has been developed, which takes into account: complex flight price with constraints; heterogeneity of the available UAV fleet; movement of the ground platform as a launch, control and recharging point.

The following practical conclusions and recommendations can be highlighted based on the study:

1. Assessment of the potential contribution of UAVs to agricultural processes. The main areas of potential application of UAVs and their role in improving agricultural processes were analyzed;
2. Analyzing existing solutions to the problem of coverage using UAVs in agriculture. The most common methods of solving the problem are identified and their disadvantages are revealed;
3. Study of methods and models of route planning for a set of UAVs. Models of existing methods are reviewed and a new approach using a ground mobile platform and a group of heterogeneous UAVs is proposed, providing optimization of the total cost of overflight;
4. A prototype software system for planning and visualizing the path of a group of UAVs and a ground mobile platform for refueling and collecting drones that have completed a mission based on Open Source solutions is developed;
5. Validation of the proposed methods: A series of computational experiments were conducted to verify the effectiveness of the proposed model in comparison with the random search algorithm.

The scientific results obtained in the course of the thesis work allowed us to propose a new method for optimizing the flight planning of technically heterogeneous UAVs in the context of precision agriculture. A model has been developed that takes into account field parameters, configuration of available UAVs, and personnel availability. Based on the model, a method is developed to determine the optimal set of UAVs for mission and ground platform movement based on a genetic algorithm. The method provides optimization of the total cost of overflights of a field of a given size and configuration.

As part of the research, a prototype of a software system for planning and visualizing the path of a group of UAVs and a ground mobile platform, providing refueling and collection of drones that have completed a mission based on Open Source solutions was developed.

Recommendations for application of the research results:

– For scientific researchers: The developed system can serve as a basis for further research in the field of automation of agricultural processes using UAVs;

– For agricultural enterprises and state bodies: The system can be integrated into existing agro-technological solutions to improve the efficiency and economy of agricultural production;

– For UAV manufacturers: The results of the research can be used to optimize the design and software of drones intended for operation in agriculture;

– For farmers and owners of agricultural enterprises: The proposed solutions can simplify the process of planning and controlling UAV flights, which in turn can lead to lower costs and higher yields.

In conclusion, the developed system represents a comprehensive solution to the problem of covering differently shaped fields using a mobile ground station and a heterogeneous fleet of available UAVs, which makes it relevant for a wide range of consumers in the field of precision agriculture. This system allows to automate the process of flight route planning, making it an indispensable tool for modern agricultural enterprises.

Provisions for defense:

1. A model of flight planning of a group of heterogeneous UAVs and the movement of a ground mobile complex to solve the problem of covering fields of a given size and configuration;

2. The method of planning the flights of a group of heterogeneous UAVs and the movement of a ground mobile complex to solve the problem of covering fields of different shapes on the basis of a genetic algorithm;

3. Results of computational experiments demonstrating the advantages of the developed method;

4. Software of the simulation environment, providing the execution and visualization of the method of flight planning of a group of technically heterogeneous UAVs and a mobile ground platform for solving the problems of precision agriculture.

Relationship of the topic to the plans of research programs. The presented results were obtained during the implementation of the project IIVT KN of the Ministry of Education and Science of the Republic of Kazakhstan (source of funding Committee of Science of the Ministry of Education and Science of the Republic of Kazakhstan): IRN: AP08856412, State registration number: 0120RK00298 "Разработка интеллектуальных моделей обработки данных и планирования полетов для решения задач точного земледелия с применением БПЛА" in 2020-2023 years.

Testing of research results. The main provisions and results of the study are published in the IEEE Access journal, which has an impact factor of 4.82.82 (Q1). A review article was also published in the journal Applied Sciences (Switzerland). The developed information system was implemented in the academic process at the University of Zilina, Slovakia as part of the project "Development of new methods for analyzing the reliability of complex systems" grant No. APVV-18-0027 (Appendix A of the Dissertation).

In total, 5 papers were published on the topic of the dissertation, of which 4 articles were published in journals included in the Scopus databases (1 article-Q1, 1 article-Q2, 2 articles - A report at a conference in Scopus without an assigned quartile). Certificate of entering information into the State Register of rights to objects protected by copyright No. 27918 dated June 21, 2022 (group of co - authors) "Information system for optimizing the flight plan of a field of arbitrary shape by a group of dissimilar unmanned aerial vehicles using a genetic algorithm", type of copyright object-computer program.

The main provisions and results of the study were presented at: Information Technologies and Management 2021, IDT (IEEE Czechoslovakia 2021,2023), Communications in Computer and Information Science 2020 and other conferences.

Publications.

1. Mukhamediev R.I., Symagulov A., Kuchin Y., Zaitseva E., Bekbotayeva A., Yakunin K., Assanov I., Levashenko V., Popova Y., Akzhalova A., Bastaubayeva S.,Tabynbaeva L. (2021). Review of some applications of unmanned aerial vehicle's technology in resource rich country // *Applied Sciences*. Switzerland. - Vol. 11, № 21.
2. Mukhamediev R.I., Yakunin K., Aubakirov M., Assanov I., Kuchin Y., Symagulov A., Levashenko V., Zaitseva Y., Sokolov D., Amirgaliyev Y. (2023). Coverage Path Planning Optimization of Heterogeneous UAVs Group for Precision Agriculture // *IEEE Access*. – Vol 11. PP. 5789-5803.
3. Mukhamediev R., Kuchin Y., Yakunin K., Symagulov A., Ospanova M., Assanov I., Yelis M. (2020). Intelligent unmanned aerial vehicle technology in urban environments // *Communications in Computer and Information Science*. – Vol 1242. PP. 345-359.
4. Mukhamediev R.I., Assanov I., Yelis M., Symagulov A., Kuchin Y., Yakunin K., Aubakirov M., Tabynbayeva L., Sedlacek P. (2021). Rapid bibliometric analysis in deep learning domain // *International Conference o Information and Digital Technologies*. -PP. 206-211.
5. Mukhamediev R.I., Yakunin K., Kuchin Y., Symagulov A., Murzakhmetov S., Ospanova M., Assanov I., Yelis M. (2020) Intelligent unmanned aerial vehicle technologies // *THE 18th INTERNATIONAL SCIENTIFIC CONFERENCE INFORMATION TECHNOLOGIES AND MANAGEMENT* 2021. 22-23.04.,2020.ISMA University of Applied Science. Riga, Latvia.-PP. 21-22.
6. Assanov I. (2021) Multi UAV simulator in Unity // *The 19h INTERNATIONAL SCIENTIFIC CONFERENCE INFORMATION TECHNOLOGIES AND MANAGEMENT* 2022. 22-23.04.2021. ISMA University of Applied Science. Riga, Latvia.-PP. 46-47.

Structure and scope of the dissertation. The paper consists of an introduction, four sections, a conclusion, a list of references with 167 titles and 5 appendices. The total volume of the dissertation is 113 pages and contains 20 figures, 9 tables.