ABSTRACT

of the doctoral dissertation for the degree of Doctor of Philosophy (PhD) in the educational program 8D07101 – «Automation and Control»
Kaliyev Daniyar Issatayuly

OPTIMIZATION AND CONTROL OF FIRE EXPLORATION SYSTEMS USING ROBOTIC DEVICES

The relevance of the research. Nowadays, many countries of the world, including Kazakhstan, have adopted and are implementing national programs on the introduction of digitalization in various spheres of life of citizens. In Kazakhstan in 2017, the government approved the state program "Digital Kazakhstan", which is aimed at improving the quality of life of Kazakhstanis through the widespread introduction of digital technologies in their life activities. This research work corresponds to one of the priority directions of science development for 2024-2026 in Kazakhstan "Advanced Production, Digital and Space Technologies", namely, the development of new measures to combat fires. In particular, the development of a system of exploration and early detection of forest fires, will allow real-time identification of fire hotspots and promptly transfer information to authorized bodies. Research on this problem has been and remains very important, as fires are usually detected only when they have already spread over a large area, which makes stopping them difficult or even impossible at times.

An automated fire exploration system is necessary in Kazakhstan because of its vast territory and diverse ecosystems, which are difficult to cover manually. Frequent natural fires, especially in summer, cause significant damage to the ecology and economy and threaten the population's safety. The use of modern technologies, such as UAVs and machine vision techniques, allows rapid detection and response to fires, minimizing damage. The introduction of automated systems will increase the efficiency of natural resource management and population protection and reduce the economic costs of extinguishing and restoring the affected areas.

Considering the urgent need to fight fires, there is an urgent need for further development and optimization of modern automated fire exploration systems. This means that to solve the problems of detection and fire signs identification in real-time, it is necessary to develop new approaches, methods, and algorithms that utilize promising areas of modern science related to robotics, and information technologies such as machine vision.

This paper considers the need for further development of modern fire exploration systems, the development of new approaches, methods, and algorithms using promising areas of modern science related to information technology, such as machine vision, as well as the need to solve complex problems of fire detection and identification in real-time.

The research goal. Development of an automated fire exploration system using robotic devices and improvement of fire detection methods and algorithms.

The main idea of the research thesis is to develop and optimize methods of data processing and control of UAVs in fire exploration systems with the use of robotic devices to improve the efficiency of firefighting. The main emphasis is on the development of methods and algorithms for detecting fire signs from digital data, using advanced technologies such as machine vision and neural networks.

Research tasks:

− develop methods and algorithms for detecting fire signs using computer vision and machine learning technology;

− optimize methods of control and path planning of UAV (quadcopter) coverage path for fire exploration;

− implement the developed data processing methods using machine vision and neural network algorithms to improve the accuracy and speed of the system;

− design and construct a robotic device (quadcopter) to conduct experimental studies and field tests at facilities with high fire hazards.

The object of the research is fire exploration systems using robotic devices.

The subject of the research is the methods and algorithms of fire exploration systems using robotic devices.

The main research methods include automatic control theory, mathematical computer modeling, neural network theory, and testing of control algorithms in the program and on model objects.

Scientific provisions submitted for defense:

1) methods and algorithms for processing images acquired in real-time to detect fire signs from digital data on the chromatic, dynamic characteristic.

2) methods of quadcopter control, taking into account the applied forces and moments on the quadcopter and the method of UAV coverage path planning for effective exploration and monitoring of fires;

3) a set of results of approbation on the model and real data of the fire exploration and detection system with a new method based on the use of a convolutional neural network.

The scientific novelty of the work.

− new methods and algorithms for processing real-time images to detect fire signs from digital data using various criteria were developed;

− optimized methods of quadcopter control that take into account the applied forces and moments on the quadcopter during the exploration and monitoring of fires;

− the results of application on test and real video images of the developed methods of fire reconnaissance system with the use of advanced technologies, namely neural networks for recognizing the signs of fires in the exploration and early detection of fires with the use of UAV - quadcopter were obtained.

The reliability and validity. The validity of scientific provisions and conclusions are based on the analysis of scientific publications on the direction of the thesis, as well as on the application of a set of general scientific and special methods. The main obtained results were reported at international scientific conferences. The results of theoretical calculations, computer modeling, and

experimental studies show high comparability, which indicates the reliability of the presented results of the dissertation work.

Practical significance of the dissertation. The results obtained in the thesis are aimed at solving the urgent problem of early fire detection and monitoring using robotic devices. The results of the study can be applied in the systems of exploration and fire detection in industries with large territories and increased threat of fires, such as forestry, reserves, etc.

The results of the dissertation work are implemented in the educational process of East Kazakhstan Technical University named after D. Serikbayev in the educational program for training doctoral students in "Automation and control" for the discipline "Fuzzy algorithms and control".

In LLP "OHMK" received the act of production tests, where the effectiveness of the proposed system of exploration and fire detection with the use of a robotic device is confirmed.

It is proposed for implementation in practice: certificate of state registration for copyright object № 34830 dated April 18, 2023. Type of copyright object: computer program. Name of the object: "Program for detecting signs of fire from video/images".

Approbation of work. The main results of the dissertation work have been discussed and reported at international conferences:

1. 14th International Symposium on Applied Informatics and Related Areas (Székesfehérvár, Hungary, 2019).

2. 16th International Symposium on Applied Informatics and Related Areas (Székesfehérvár, Hungary, 2021).

3. ML-67 9th International Youth Scientific Conference "Youth and Knowledge - Guarantee of Success-2022", (Kursk, Russia, 2022).

4. Modern, relevant and popular research of world science. Proceedings of the II International Scientific and Practical Conference. (Tokyo, Japan, 2022).

5. 17th International Symposium on Applied Informatics and Related Areas (Székesfehérvár, Hungary, 2022).

Publications. On the subject of dissertation work published 11 scientific papers, including 2 articles in the journal indexed in the database Scopus, 3 articles in publications recommended by the Science and Higher Education Quality Assurance Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan, 1 publication in journals indexed by the database Russian Science Citation Index (RSCI), 5 papers in the collections of international conferences, including 4 articles in foreign countries publications.

The structure and scope of the dissertation. The thesis consists of an introduction, four main sections, a conclusion, and a reference list of 131 titles on 112 pages including 6 tables, 53 figures, and 4 appendices.