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Research of effective UAV detection using smart sensors

ANNOTATION

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General characteristics of research. This work is aimed at research and development of an unmanned aerial vehicle (UAV) detection system based on smart sensors.

Relevance of the research topic. The best drone manufacturers on the market, like DJI, Parrot, and 3D Robotics, are constantly producing affordable and simple-to-use models of unmanned aerial vehicles (UAVs), also referred to as "drones," that can be used for a variety of legal commercial applications, including photography, first aid, agriculture, delivering packages, monitoring crowded places etc. However, the use of drones for illegal purposes, such as *smuggling* (transporting illegal substances at borders, in restricted areas, and prisons), *espionage* (illegal video surveillance of people, businesses, and government organizations), *collisions* with aircraft, drones loaded with explosives or chemicals, the use of drones for *attack* purposes [1] and other situations can cause serious problems for society. Prohibition of an unauthorized drone flight over the building of the Ministry of Defense of the Republic of Kazakhstan by the operational response group of the Military Police in March 31 of 2019 [2], confiscation of illegal transportation of the psychotropic drug “Tramadol” from the border of Kazakhstan to the border of Uzbekistan by Uzbek border guards in September 14, 2019 [3], for the first time in the history of the prison system of Kazakhstan transportation of prohibited items to the colony by an unmanned aerial vehicle (hereinafter UAV) in September 4 of 2020 [4], the arrest of a resident who launched an unregistered UAV over a military unit in Aktobe in June 13, 2022 [5] and other events that took place indicate that the careless or deliberate use of UAVs can pose a serious threat to the airspace of airports, power plants, civilians, organizations, and even the entire state.

The infrastructure may experience risky incidents such as information privacy violations, aircraft collisions, attacks on significant objects, allowing the transportation of illegal substances, etc. if the intrusion of drones into specially protected areas is not identified early on and stopped in time. In order to prevent such dangerous incidents, it is important to establish a reliable detection system that will detect drones in real time in the territory of important infrastructures.

Usually, conventional radar and radio frequency technologies are frequently utilized in the preparation of UAV target detection and tracking systems; however, the accuracy of these sensors reduces when the UAV flies in the area where the signal is obstructed or the received signal is blocked. Due to their accessibility and relative accuracy in object detection from a sufficient distance, optical camera sensors are useful in the development of effective detection systems that identify the UAV as soon as it approaches the specially protected area and present the visual output result (bounding box) to security personnel in real time.

In the field of communications, some possible UAV incidents may also occur, such as:

- Failure of telecommunication systems due to interference from drones;
- Violation of safety rules when using drones can lead to accidents that can damage telecommunications equipment, such as communication towers or cables, leading to communication interruptions and network failures, as well as damage to equipment and endanger the safety of personnel.
- Unauthorized use of drones to perform espionage operations or store classified information transmitted over communication networks.

Thus, the development of technologies for detecting and preventing the use of UAVs is becoming relevant due to the increase in the number of dangerous incidents associated with drones in various fields. The above situations require a deeper study of drone detection and avoidance systems, which leads to the development of this research field.

Research problem. The task of real-time UAV object detection in accordance with camera system requirements while maintaining a balance in accuracy and speed is challenging due to the territorial size and location of the specially protected area and the fact that UAVs are moving objects and move quickly in frames, which makes the detection task more difficult. In order to ensure effective detection, an important requirement is that the model must be able to identify the drone from a distance, as it approaches the area of a specially protected infrastructure, respectively, the dimensions of the drone in the images are very small in terms of pixels.

Research aim. Research and development of a real-time UAV detection system using smart camera sensors.

Research objectives. The following tasks must be completed in order to achieve research aim:

1. In-depth literary review of UAV detection methods based on smart sensors.
2. Choosing a camera sensor, taking into account the territory of the special protected area and the camera parameters, fixing the position of the camera sensor to detect the object with sufficient accuracy.
3. Data preparation and pre-processing, which allows the neural network to identify drones more accurately.

4. Theoretical description of the proposed detection system.

5. Research and development of a real-time and accurate drone detection system with a static background.

6. Research and development of a multiple sensor fusion system to avoid blind spots and reduce drone confusion with birds.

The object of research is UAV detection system.

The subject of research are primary visual data preparation and video signal processing methods, the structure and algorithms of neural networks used in object detection and classification, sensor fusion methods.

Research methods. To solve the research tasks the following methods were solved: Digital signal processing methods, machine learning theory, object detection methods, image classification methods, as well as sensor fusion techniques etc.

The scientific novelty of the work. The scientific novelty of the research lies in the development of a smart sensor fusion system using voting method for multi-angle detection of UAVs.

The following scientific statements are to be defined:

1. Data acquisition, processing and preparation methods.
2. Moving object detection methods and algorithms.
3. Moving object classification methods and algorithms.
4. Sensor fusion methods and algorithms.
5. Experiments, results and discussions.

The theoretical significance of the research results. This research can be used as a methodological guide for camera sensor selection, data collecting and preprocessing, neural network model selection, and training by anyone wishing to do visual camera sensor-based UAV detection.

The practical significance of the research results. The proposed sensor fusion-based unmanned aerial vehicle recognition model serves as the basis for the future work of the researcher under the Zhas Galym project AP14971031 «Research and implementation of a bimodal system for real-time detection of unmanned aerial vehicles» (priority direction «9. National security and defense»). That is, it is the basis for the development of a bimodal system that combines LiDAR sensors and cameras in real time to detect unauthorized penetration of flying objects into specially protected infrastructure (Appendix A).

Personal contribution of the author. The dissertation is the original work of the author, all the results of scientific research are obtained by the author herself. Approval of tasks to achieve the goal of the study, analysis of research methods and implementation of the proposed system, analysis of the results of scientific research were carried out by the author herself and under the guidance of a domestic supervisor and a foreign scientific consultant.

The validity and reliability of scientific provisions, conclusions and recommendations are confirmed by publications in journals included in the list of scientific publications recommended by the Committee for Control in Education

and Science of the Ministry of Education and Science of the Republic of Kazakhstan, and the Web of Science and Scopus database; approbation in a foreign international scientific and practical conference.

Approbation of research results. The main scientific results of the dissertation research outlined in the dissertation are presented at the international conference «The Fourth IEEE International Conference on Robotic Computing (IRC)», and the results are published in the IEEE Xplore proceedings:

1. Detection of loaded and unloaded UAV using deep neural network // 2020 Fourth IEEE International Conference on Robotic Computing (IRC), Taichung, Taiwan, 2020, pp. 490-494, DOI: 10.1109/IRC.2020.00093. Conference Paper.

2. Deep residual neural network-based classification of loaded and unloaded UAV images // 2020 Fourth IEEE International Conference on Robotic Computing (IRC), Taichung, Taiwan, 2020, pp. 465-469, DOI: 10.1109/IRC.2020.00088. Conference Paper.

Publications. Based on the main scientific results of the dissertation work, 6 publications were published, including 1 journal article in publications indexed in the Scopus and Web of Science databases, 3 articles in publications recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Science and higher education of the Republic of Kazakhstan and 2 papers in the proceedings of international conferences.

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Structure and scope of the dissertation. The thesis consists of 88 pages of typewritten text, including normative references, definitions, designations and abbreviations, an introduction, 5 primary chapters, a conclusion and the list of references. The primary chapters contain 63 figures and 10 tables, as well as 75 cited references. The work begins with an introduction part, where the author gives a general description of the work, the relevance of the study, the problems and provisions on defense.

In **Chapter 1**, UAV object detection technologies are explained in detail, and a huge number of literature reviews have been conducted on UAV detection based on visual data recognition.

Chapter 2 describes the steps for preparing UAV visual data including video signal acquisition and digital image processing techniques.

Chapter 3 describes moving object detection and classification methods using for visual UAV detection and classification tasks.

Chapter 4 presents the proposed real-time drone detection system in the scene with a static background.

Chapter 5 presents the developed model and algorithm of a smart sensor fusion system using voting method for multi-angle UAV detection and classification.

The conclusion discusses the analysis and outcomes of research work, its future directions.