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Environmental safety problems of swarm use of UAVs in precision agriculture

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Abstract. Digital technologies are an integral part of the functioning of many sectors of the state, which applies, in particular, to the agricultural sector, which plays a significant role in shaping the state's economy, ensuring food independence and export potential. One of the promising areas of digital transformation is the swarm use of unmanned aerial vehicles in precision agriculture, the use of which significantly increases productivity while reducing production costs. Analysis of the transport and technological cycles of UAVs allows us to identify a number of existing problems in the swarm use of UAVs that are associated with anthropogenic impact. The article examines the potential impact of unmanned aerial vehicles on the environment, analyzing such aspects as noise and vibration emissions, air and soil pollution, electromagnetic radiation, and the impact on biodiversity and ecosystems in general. The study is aimed at identifying key environmental problems, identifying ways to minimize and solve them. The authors offer recommendations for ensuring environmental safety and sustainable development of precision agriculture with the swarm use of unmanned systems.

1 Introduction

1.1 On the issue of digitalization

In accordance with the paradigm of post-industrial society, which meets the requirements of the concepts of the fourth and fifth industrial revolutions, which are being implemented and are at different stages of implementation in individual countries due to different levels of development of information infrastructures, digital technologies are an integral part of the functioning of many sectors of the state [1-3]. This applies, in particular, to the agricultural

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sector, which plays a significant role in shaping the country's economy, ensuring food independence and export potential. The development of the agro-industrial complex is directly related to the development of other industries, which together determine the plans, directions and resources necessary to ensure state leadership in the new conditions in the international arena. In a number of countries, the digital transformation of business processes, which consists in changing the quality of management of technological processes of information infrastructure, is enshrined in law and reflected in a number of system-forming strategic planning documents at the federal and regional levels. Digital transformation reflects the application of modern methods of lean and environmentally friendly production and the further use of information about the status and forecasting of possible changes in controlled elements and subsystems, as well as economic conditions in agriculture. World practice shows that the relevance of digitalization of business processes of agricultural enterprises is determined by the need to increase sustainable development, the efficiency of its functioning, as well as reduce the negative impact on the environment through changes through the technology stack of Industry 4.0 and 5.0. The above provisions make the research relevant in the context of modern challenges and requirements [4-6].

1.2 On the issue of using UAVs in precision agriculture

The stack of technologies used at agricultural enterprises and enshrined in the digital transformation strategy both at the federal and regional levels (in particular, in the strategy for digital transformation of the agricultural sector of the Krasnoyarsk Territory) includes unmanned aerial vehicles (abbreviated as UAVs, UAVs or drones), which are one of the most promising technologies. The relevance of the swarm use of UAVs in precision agriculture is determined by a number of advantages that arise as a result of the integration (and possible optimization) of UAV transport and technological cycles, expressed in the following provisions discussed below.

Traditional methods of organizing and managing production and transport-technological processes of agricultural enterprises are effective, but there are a number of problems and limitations to their use that reduce the efficiency, productivity and sustainability of agricultural methods. The most common problems and limitations include:

- dependence on manual labor;limited mechanization and automation;
- irrational use of resources;
- lack of adapted methods for optimizing UAV transport and technological cycles in the precision farming system;
- seasonal dependence and degradation of agricultural land.

Most of these problems are solved through the integration of modern technologies and innovative approaches.

Precision farming involves the use of methods and technologies based on working with data, which makes the issue of high-quality data processing and analytics relevant, because only qualitative characteristics of input data (completeness and volume, accuracy, validity, relevance, timeliness, variability and verifiability) can ensure the effective functioning of the technologies used. For processing, analysis and subsequent decision-making based on various spatial indicators and descriptive data about precision farming objects. Here, information sources are data on the state of agricultural crops (IoT, irrigation systems, VRT, RFID), cartographic materials (GPS, GIS, remote sensing and satellite and aerial photography), data from state statistical services and stationary measuring observation posts, crowdsourcing data, telematics data. Some of this data is characterized by continuity of processes and cyclical production of products, which follows from the analysis of transport and technological cycles of using UAVs. As a rule, applied technologies are used that specialize in working with spatial and descriptive information, which include UAVs.

In world practice, the swarm use of UAVs is used for environmental monitoring, inventory and protection of farmland, digitization (creation of electronic topographic maps of fields, relief models), compilation of digital yield maps, compilation of soil electrical conductivity maps, monitoring the condition of agricultural lands using remote sensing to assess germination and forecasting crop yields. Monitoring the condition of agricultural lands using remote sensing is important for tracking the normalized vegetation index and differentiated sowing, irrigation, tillage using soil maps, applying fertilizers, spraying crops with chemicals to combat pests and diseases. Optimization of transport and technological cycles is carried out using satellite monitoring of vehicles and parallel driving, assessing the volume of work and monitoring their implementation, in particular, with the aim of optimally constructing irrigation and land reclamation systems. The capabilities and flexibility of UAVs ensure their applicability in various regions, regardless of the initial conditions, facilitating the assessment of the effectiveness of existing technologies and methods of precision agriculture and the development of new ones [7-12].

2 Materials and methods

2.1 Terminological aspects

An unmanned aerial vehicle is an aircraft equipped with various sensors for collecting spatial indicators and descriptive data about precision farming objects, which in a universal configuration include:

- *Image sensors*: RGB cameras, multispectral and hyperspectral cameras are used for visual monitoring of objects (in particular, for inventory and protection of farmland), mapping and estimating the volume of agricultural work and monitoring its implementation. Thermal imaging cameras are used to monitor changes in environmental temperature and humidity to identify temperature anomalies that affect plant health and detect potential problems with crop yields (identifying pests and diseases), and optimize intelligent systems used to determine the normalized vegetation index and subsequent differentiated sowing, irrigation, tillage, fertilization, spraying crops with chemicals to combat pests and diseases.
- *LiDAR sensors* are used to create electronic topographic maps of fields and relief models, compile digital yield maps, soil electrical conductivity maps, monitor the condition of agricultural land, automatically control agricultural machinery and optimize intelligent systems for differentiated sowing, irrigation, tillage, fertilization, spraying crops with chemicals to combat pests and diseases.
- *GPS sensors* provide precise determination of the location, direction and speed of vehicles (in particular for parallel driving) and the coordinates of field areas where differentiated operations need to be carried out. GPS sensors are also used to determine the location of the drone.
- *Motion sensors to ensure UAV performance: IMU (accelerometer, gyroscope)* are used to determine the orientation of the UAV in space and compensate for errors that occur when using only GPS sensors, which increases positioning accuracy and improves the quality of the resulting spatial indicators and descriptive data. *The altimeter* determines the height of the UAV above the ground and adjusts the flight parameters depending on the terrain, which allows you to avoid collisions with obstacles and increase work efficiency when creating electronic field maps and terrain surveys.

- The *magnetometer* is rarely used, but helps identify magnetic anomalies to correct IMU data. *Wind sensors* measure wind speed and direction, which ensures safe flight of the UAV. *Rain sensors* are used to assess weather conditions during flight. *Battery and power monitoring systems* measure the UAV's battery charge level and monitor battery consumption to ensure safe and efficient flight. *Communication systems* provide data transmission to ground stations or remote servers. *RF scanners* read radio frequency signals to monitor radio communications equipment. *Microphones* are used to capture audio data.
- *Physical environmental monitoring sensors* are used to measure and monitor various soil parameters, crop conditions and weather conditions: *air quality detectors* are used to monitor air quality (air pollution levels, oxygen and carbon dioxide levels, and the presence of harmful substances such as carbon monoxide or ozone) in real time. *Rain sensors* are used to monitor rainfall in certain areas. *Sensors for water sampling* are used to determine soil moisture and the level of soil mineralization and acidity for the purpose of optimal construction of irrigation and reclamation systems [13-18].

The combination of sensors used makes it possible to collect extensive multidimensional spatial indicators and descriptive data about precision agriculture objects for analysis and subsequent decision-making.

3 Results and discussion

3.1 Potential environmental impact of UAVs

While sensors offer significant benefits in terms of efficiency, resource optimization, and decision-making based on various spatial metrics and descriptive data about precision agriculture assets, swarm applications of UAVs can pose certain environmental challenges.

One of the main environmental problems associated with the swarm use of UAVs is the possibility of *noise radiation* and *vibration effects.* Swarm use of unmanned aerial vehicles produces noise, manifested as sound waves and propagated during take-off, flight and landing, which has a cascading effect on biodiversity and natural ecosystems (especially in areas with sensitive ecosystems), disrupting the natural acoustic environment. Some mammals are vulnerable to sounds that are unfamiliar to them, which causes them to change their standard behavior, including feeding patterns, nesting habits, and migration routes, which affects population dynamics. Anxiety caused by flying can affect the well-being of farm animals, potentially leading to stress and reduced productivity. Noise pollution interferes with pollinators' natural behavior and navigation, potentially affecting pollination rates and therefore crop yields. In addition, noise can disrupt communication between animals, which can also negatively affect their survival and reproduction.

Air and soil polution. Drone propulsion systems, which typically run on fuel or rechargeable batteries, can contribute to air pollution. Emissions from UAVs, including carbon dioxide (CO2), particulate matter and other pollutants, can degrade air quality near agricultural areas. Long-term exposure to such pollutants poses a threat to animal health. In addition, dust raised during drone takeoff, flight, and landing contributes to soil contamination: fine particles thrown into the air may contain chemicals, pesticides, or other contaminants found on the ground. These particles settle on nearby crops or bodies of water, affecting soil fertility, water quality and threatening local flora and fauna.

Electromagnetic radiation. UAVs use advanced communication and sensing technologies that emit electromagnetic radiation. Radiation levels emitted by individual drones may be within acceptable limits, but the combined effects of multiple UAVs can interfere with existing communications systems, potentially disrupting wildlife activities that rely on certain frequencies for navigation and communication. Moreover, long-term exposure of ecosystems to elevated levels of electromagnetic radiation can have unpredictable consequences for the health and behavior of both flora and fauna.

Impact on biodiversity and ecosystems. UAVs may unintentionally contribute to habitat degradation. Repeated takeoffs and landings, as well as the possibility of collisions with flora, can lead to soil erosion and habitat fragmentation. Physical disturbances can create barriers to the movement and migration of wildlife, further threatening the resilience and resilience of ecosystems.

4 Conclusion

Drones are revolutionizing precision agriculture by offering efficient and optimized solutions for monitoring and managing agricultural assets. The ability of UAV sensors to collect spatial data and descriptive data about precision agriculture assets for decision making has significantly improved the productivity of agricultural operations. However, the growing use of swarm-based UAVs raises a number of environmental issues that require careful consideration. Noise and vibration pollution, air and soil pollution, electromagnetic radiation and impacts on biodiversity and ecosystems highlight the need for responsible and sustainable deployment.

To mitigate environmental concerns, it is important to develop and implement guidelines governing the use of UAVs in precision agriculture, including setting noise standards, promoting cleaner driving technologies, and establishing no-fly zones in environmentally sensitive areas. To solve problems associated with noise radiation and vibration, it is recommended to use noise-suppressing technologies when designing unmanned aerial vehicles, as well as to introduce restrictions on the time and frequency of their use. Developing and implementing standards and technologies that minimize pollutant emissions from drones (such as carbon dioxide and particulate matter) is a key solution to air and soil pollution. Additionally, using renewable energy to power drones can help reduce emissions. Increasing public awareness of the risks of electromagnetic radiation can help reduce its use. Implementing monitoring and management programs to control the impacts of drones on biodiversity can help reduce cascading impacts.

In addition, ongoing research into the long-term impacts of UAVs on biodiversity and ecosystems may contribute to a better understanding of their environmental impacts and the development of effective mitigation strategies. By carefully managing the environmental impact of UAV swarming, the agriculture industry can continue to benefit from the efficiency and precision offered by this technology while minimizing its negative impact on the environment.

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