***Information and analytical system for UAV routing***

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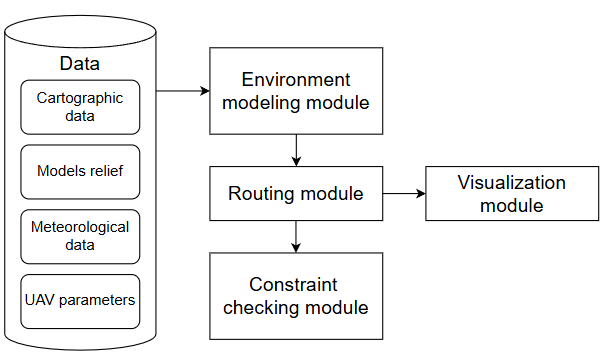
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*Abstract.* This article discusses the concept of an information and analytical system for UAV routing, focused on ecological monitoring of forest areas. The system automatically generates the optimal flight route based on geospatial, topographic, meteorological data and drone characteristics. A hybrid method combining a territory coverage algorithm and a modified ant colony algorithm is applied. A convenient interface is provided for mission configuration and visualization.

Keywords: UAV routing, environmental monitoring, territory coverage, ant algorithm, information system, decision-making methods.

# Introduction

In today's environment, when climate change is spreading, forests are degrading, and forest fires are becoming more frequent, ecological monitoring of forests is becoming a matter of paramount importance. Unmanned aerial vehicles (UAVs) are highly effective in monitoring the state of natural ecosystems, as they allow obtaining high-precision images and sensor data from hard-to-reach areas with minimal time and resources. However, the effective use of UAVs directly depends on the quality of the route planning along which the territory is flown.



1. Block diagram of the system

The process of planning flights for such tasks should take into account a whole range of factors: the spatial structure of the terrain, the presence of flight restriction zones, battery life, weather conditions, and the need for complete coverage of a given area. In the practice of environmental monitoring, the need to systematically fly over large areas without gaps causes particular difficulties, which requires optimization of the route by criteria, mission time, and flight safety. Some of the first works on coverage path planning rely on heuristics, which are simple rules of thumb that can work well, but lack evidence-based guarantees that guarantee the success of the coverage operation [1].

In view of this, it is important to create an information and analytical system that will ensure the automated generation of UAV routes, taking into account all technical, geographical and environmental constraints. Such a system should not only generate efficient routes, but also provide the user with a convenient interface for selecting the overflight area, setting flight parameters, viewing the generated route, and further processing the data obtained.

This paper proposes the concept of such a system, which is based on a combination of the classical Coverage Path Planning approach with metaheuristic optimization methods, in particular, the ant algorithm. Hybridization allows not only to guarantee full coverage of the territory, but also to minimize the time and energy consumption for overflights, which is critical when monitoring large or hard-to-reach forest areas.

# System Architecture

The information-analytical system for routing unmanned aerial vehicles for environmental monitoring of forests has a modular architecture that provides flexibility, scalability, and ease of adaptation to different types of missions. The system is based on the processing of cartographic, terrain and meteorological data, followed by the construction of an optimal flight route, taking into account all constraints. The block diagram of the system is shown in Fig. 1.

The system consists of several functional modules. In the first stage, the data collection module receives basic information from open sources such as OpenStreetMap, digital elevation models (SRTM), and meteorological services via API. OpenStreetMap was created by a community of cartographers who add and maintain data on roads, trails, cafes, train stations, and many other objects around the world [2]. The received data is processed by the environment modeling module, which forms an internal graphical model of the terrain, dividing the territory into coverage areas, taking into account terrain features, natural and regulatory restrictions.

The next stage involves the routing module, which implements a hybrid algorithm that combines the classical method of territory coverage with a modified ant optimization algorithm. Ant algorithms have proven to be a very effective approach for routing problems, for example, in telecommunication networks, where system properties, such as channel usage cost or node availability, change over time [3]. First, full coverage of the area is ensured, and then the order of overflight of the areas is optimized to minimize energy consumption and flight time. When building a route, the system takes into account flight time restrictions, maximum safe altitudes, weather conditions, and restricted areas.

After the route is built, the constraint checker automatically validates the route according to the technical characteristics of the selected UAV and applicable regulatory standards. The visualization module then allows the user to view the overflight area and route on an interactive map, edit the route manually if necessary, and evaluate the overall mission performance.

# Problems

The use of unmanned aerial vehicles (UAVs) for environmental monitoring of forests is accompanied by a number of technical and organizational challenges that make it difficult to plan routes effectively.

One of the key issues is the need to ensure complete coverage of a given area without gaps and unnecessary duplication. Standard terrain scanning strategies do not always take into account the complexity of the actual terrain or other areas, as well as the presence of natural and anthropogenic obstacles, which leads to the formation of “dead zones” or excessive resource costs for repeated overflights.

An additional challenge is the limited resources of UAVs, in particular, the autonomous flight time due to battery capacity and payload weight characteristics. This necessitates optimization of routes in such a way as to ensure full coverage of the territory within the available energy reserve of the vehicle.

The task is also complicated by natural conditions, such as significant altitude differences, difficult terrain, dense forests, and the presence of water bodies or gorges. In such conditions, there is a need for dynamic flight altitude planning, avoidance of risk zones, and route adaptation to the changing landscape. In turn, weather factors such as wind loads, precipitation, and temperature changes directly affect energy consumption, flight stability, and data collection quality, which requires the integration of weather data into the routing process.

Regulatory restrictions, which include bans on flights over certain objects, flight altitude restrictions, and the need to obtain special permits, pose a separate problem. When building routes, such restrictions should be taken into account automatically to avoid violating the law. Another important requirement is the scalability and adaptability of the system: it must work effectively both in small areas and large areas, and provide the ability to use several UAVs to monitor the territory simultaneously.

# Overview Of Existing Solutions

Currently, there are a number of systems designed for flight planning and routing of unmanned aerial vehicles (UAVs) in various applications, but most of them have limitations in terms of adaptation to the specific conditions of environmental monitoring of large natural areas.

Mission Planner is an open source flight planning platform compatible with many autopilots, such as ArduPilot and PX4 [4]. It provides route creation using predefined waypoints and supports 3D terrain visualization. The main advantages are its free of charge, active community, and customization, but it has a complex interface for an unprepared user and limited automatic route optimization algorithms.

QGroundControl is a cross-platform, open-source flight planning solution that supports various types of drones [5]. It has functions for automatic route planning with obstacle avoidance. The advantages of the system include free and open source, wide customization options, support for various operating systems, compactness and efficiency. The disadvantages are a less developed user interface compared to commercial systems, limited analytical capabilities, and the need for technical knowledge to make full use of the system.

DJI FlightHub 2 is a corporate platform designed to manage a fleet of drones with the functions of remote route planning, real-time flight monitoring, and data processing [6]. The platform is well suited for centralized management of large groups of UAVs, but has limited flexibility in planning complex routes with full coverage of natural areas.

SkyGrid is a cloud-based solution designed for automated drone mission planning using artificial intelligence [7]. It is suitable for tasks where adaptability to environmental changes is critical, but requires high-quality input data and significant computing resources.

Most existing solutions either focus on basic planning through point routes without full coverage of the territory or are focused on centralized management of groups of drones in corporate applications. Problems for environmental monitoring include the lack of automatic generation of full coverage routes, insufficient consideration of terrain and relief features, limitations in optimizing routes based on time and energy consumption, as well as the high cost of commercial licenses or closed systems.

# Solution Method

The problem of UAV routing for environmental monitoring of forest areas belongs to the category of Coverage Path Planning (CPP) problems with multiple constraints. In contrast to the tasks of navigation between individual points, in CPP, it is necessary to ensure full coverage of the entire observation area with minimal loss of time, energy, and taking into account the terrain and obstacles. Basic CPP methods, such as zigzag or spiral trajectories, are simple to implement but have significant drawbacks. They do not provide a non-ergo-optimal order of traversing the coverage areas, do not take into account changes in altitude or weather conditions, and are poorly scalable for complex object geometry or a large monitoring area [8].

To solve the problem of routing unmanned aerial vehicles in the process of environmental monitoring of forest areas, a hybrid approach is proposed that combines the method of full coverage of the territory with a modified ant optimization algorithm (Ant Colony Optimization, ACO). This approach makes it possible to ensure the completeness of the overflight of a given area while minimizing energy consumption and mission duration.

*Stage 1. Construction of the monitoring area breakdown.*

The monitoring area is divided into sub-areas of coverage. Let  be a given monitoring area, the breakdown is as follows:

 

where the monitoring area is divided into  non-overlapping cells . Each cell  is considered a separate route segment that must be visited at least once. The division is performed taking into account the resolution of the UAV's sensors, the complexity of the terrain and possible obstacles. Sub-zones are formed to ensure complete coverage of the territory without gaps and minimize the number of required turns and flights.

*Stage 2. Building a graph of transitions between subzones.*

At this stage, the graph  (2) is constructed, and the weight of the edge between the vertices is determined by the combined cost metric using formula (3):

 2

where  is the set of vertices that correspond to the centers of the cells in partitioning (1);  is the set of edges.

 3

where  is the weight of the edge between vertices  and , ;

 — is the Euclidean distance between the centers of cells  and ;

 — is the height difference between the cells  and ;

 — is an indicator of the risk of transition between  and  cells;

 — weighting coefficients of the importance of the relevant factors;

Each node of the graph corresponds to a separate subzone, and the weights of the edges between the nodes are determined based on heuristic indicators such as the distance between the centers of the subzones, the difference in terrain heights, and the expected energy consumption for the flight.

*Stage 3. Building a route.*

After the graph is built, a modified ant optimization algorithm is applied. The task is to find a route that minimizes the total cost of transitions and is calculated using the formula (4)

 4

where  is the set of all possible routes that cover all cells without gaps. Each ant builds a route by sequentially selecting the next cell, taking into account the pheromone trail and heuristic attractiveness according to formula (5)

 5

where  is the set of vertices not yet visited;

 is the probability that ant , being in vertex , will choose vertex  as the next one;

 is the pheromone intensity on the edge between vertices  and ;

 is the heuristic attractiveness of the transition, which is given as ;

 - pheromone exposure parameter;

 is the heuristic influence parameter.

Virtual “agents” imitate the natural process of finding optimal routes to cover the territory. Based on pheromone traces and local heuristics, the order of bypassing subzones is determined, which minimizes the total route length and energy consumption [9]. In the process of iterations, pheromones are amplified on those paths that have shown the best results according to mission quality criteria. After each iteration, the routes update the pheromones on the edges using the formula (6)

 6

where is the amount of pheromone left by an ant on an edge after completing its route in one iteration of the algorithm, calculated by formula (7)

 7

where  is the pheromone intensity,  is the length of the ant's route , and  is the evaporation coefficient. Also, if the edge  is included in the route , then the ant uses this transition as part of the route, otherwise it does not use it.

After determining the optimal sequence of subzone traversal, a local coverage path is generated for each subzone separately. Within the sub-zones, a classical scanning route planning method is applied to fully survey the entire sub-zone area.

At the final stage, the routes are optimized using local improvement methods, such as the 2-opt algorithm, which allows changing individual trajectory segments to further reduce the path length without losing coverage. At the same time, the system checks whether the built route complies with the UAV's technical characteristics, such as maximum flight time, power reserve, flight altitude limitations, and weather conditions.

The result of the algorithm is a complete route consisting of an ordered sequence of points with reference to the flight altitude.

##### System Functionality

The functionality of the system includes selecting a monitoring area through a map, setting technical parameters of the vehicle and mission restrictions, automatic route generation at the touch of a button, the ability to manually edit the route, as well as checking and visualizing the route before execution. Table 1 shows the main elements of the user interface of the developed information-analytical system for routing drones, their functional purpose, and the nature of interaction with the user:

Table 1

The Main Elements Of The User Interface

| Component | Functionality | Interaction |
| --- | --- | --- |
| Map | Displaying the territory | Selecting the monitoring area |
| Parameters panel | UAV settings | Entering technical characteristics |
| Route controller | Controlling the construction | Starting the algorithm,  editing |
| Information panel | Display of key route metrics | View time, route length, coverage area |
| Visualization panel | Show the finished route with point and trajectory labels | Switching map layers, zooming in |

The user interface of the system should be built taking into account the principles of simplicity, functional completeness and intuitive interaction. The basis of the interface is an interactive map that allows not only viewing geographic layers but also selecting the overflight area by drawing a polygon or uploading a ready-made file.

The UAV's parameter panel allows the user to flexibly customize flight characteristics, including time in the air, altitude, speed, and power consumption. Once the parameters are set, the route controller launches a hybrid route construction algorithm and, if necessary, manually corrects the resulting path. All changes are displayed in real time through the visualization panel, which shows a map with the route, control points, restriction zones, and predicted coverage.

For convenience, there is a dashboard that displays key flight metrics: route length, coverage area, and expected mission time.

##### Conclusions

The paper proposes the concept of an information-analytical system for routing unmanned aerial vehicles for environmental monitoring of forest areas. The system is based on a combination of the method of full coverage of the territory and the ant optimization algorithm, which allows to ensure full coverage of a given area while minimizing the mission time and energy consumption.

The proposed architecture provides a modular approach to building a system, including components for data acquisition, building a graphical model of the environment, route optimization, and visualization. The use of a hybrid method allows taking into account the technical limitations of UAVs, terrain features, weather conditions, and airspace restrictions.

The obtained results can be used to create practical systems for automated planning of UAV missions in environmental monitoring, forestry, control over the state of natural resources, as well as in other areas where systematic survey of large areas is required.

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