Environmental monitoring using an unmanned aerial vehicle

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Abstract. The article discusses routing options for unmanned aerial vehicles during environmental monitoring to save battery power and minimize task execution time. It proposed an algorithm for environmental monitoring using an unmanned aerial vehicle. For its implementation, the authors developed and justified a network model of work. The article presents the results of network modelling for environmental monitoring in reconnaissance mode during the emergency case in the enterprise.

1. Introduction
Experts put forward more and more new ideas for the use of unmanned aerial vehicles (UAV) in various fields, including environmental monitoring (EM). Environmental experts widely use UAV equipped with various electro-optical sensors to monitor the condition and use of natural objects: poaching, illegal logging, detection of fires. There are projects for the use of specially equipped UAV for measuring environmental parameters: environmental control, patrolling at industrial enterprises in normal operation (mode 1) and reconnaissance, detection of sources of accidental emissions in emergency zones (mode 2) [1]. In these situations, UAV provides data collection from objects of different distances and dangers with minimal risk for laboratory staff.

For the science-based planning of the use of UAV during environmental monitoring (EM) in emergency zones, it is advisable to use network models (NM) [2, 3].

This planning method consists of a graphical representation of the total amount of work on EM and gives the following advantages:

- identify the necessary measures for the EM;
- identify the start and end time of the EM according to the standards for certain types of work and the results of calculations, draw up a schedule;
- identify a specific contractor for each EM event.

Analytical laboratories located on the AUV improve the level and quality of EM. Expanding the functional capabilities of UAV by equipping them with systems of radiation, chemical and biological control significantly increase their value as a means of remote analytical control. In addition to instrumentation, such UAVs have means of communication with a stationary computer for processing and storing the received information. Thus, the UAV sometimes has a significant instrumental load which imposes additional requirements on the battery of the UAV [4], its charge will be spent not only on the movement of the UAV itself but also on the operation of devices. Therefore, saving battery power by optimizing the route and runtime of the UAV task is relevant.
2. Theoretical part

To build the optimal route, it is necessary to ensure the movement of the UAV in a way that [5, 6]:

- the movement time was sufficient for the triggering of control sensors, but also minimal for increasing efficiency;
- without re-examination of the terrain and missed sites;
- the data collected was necessary and sufficient for making a managerial decision based on the results of the EM;
- eliminate the failure of the UAV due to the discharge of the battery.

Using modern management tools for the UAV group [7–9] allows achieving high efficiency of their application.

UAV in mode 1, patrol mode, has two possible route options (Fig. 1) depending on the location of environmental impact sources. In this case, the movement is a closed-circuit starting and ending at the starting point (SP) determined by the ground control point (GCP).

![Diagram](image)

**Figure 1. Route of the unmanned aerial vehicle in mode 1.**

The zigzag route (Fig. 1a) is most effective when the territory of the enterprise has a dense uniform development. In this case, the UAV moves in a zigzag so that the straight sections of motion (l) pass as far as possible through the maximum number of sources of environmental impact, and the UAV has a turning radius (r) over the free sections.

In this case, we determined the length of the UAV movement route (d) and the area of the examined territory (S) by the formulas:

\[ d = 8r + 2l(n + 1) + 2\pi r(2n + 1), \]  
\[ S = 16r^2 + 4lr(n + 1) + 4\pi r^2(2n + 1), \]  

where \( r \) is the turning radius of the UAV, m; \( l \) is the length of the straight section of the route, m; \( n \) is the number of curves of the route.

If sources of environmental impact are located along the perimeter of the enterprise territory (Fig. 1b), then a circular route is preferable, the parameters of which (d and S) are determined by the formulas:

\[ d = 2\pi r(n^2 + n + 1), \]  
\[ S = 4\pi r^2(n^2 + n + 1). \]
The UAV operating in mode 2, reconnaissance in the emergency zone, has also two possible routes of movement (Fig. 2) that depend on the configuration of the source of the damaging factor (DF).

![Diagram](image)

**Figure 2.** The Route of an unmanned aerial vehicle in mode 2.

The flight around a given point object is required during the environmental monitoring of specific objects (Fig. 2a). It is used in cases with known coordinates of the object that require clarification of its state. And the length of the optimal route consists of the path to the source and back (linear sections) and the survey route of a point object (circle):

\[
d = 2\pi r + 2 \cdot l. \quad (5)
\]

A fly-around of a linear object is necessary to control extended objects in conditions of their unambiguous position, for example, the state of pipelines (Fig. 2b).

When implementing this method, all UAV flight route from the starting point A to the ending point B separates into sections where the boundaries are coordinate points at the turning points of the linear object. Based on the task, at the B endpoint of flight, the UAV goes to the SP and the total route length is determined as

\[
d = 2 \cdot \sum_{i=1}^{k} l_i, \quad (6)
\]

where \(k\) is the number of individual sections of a linear object; \(l_i\) is the length of individual sections of a linear object.

Considering the manual introduction of the coordinates of the route points and the parameters of their overflights into the UAV information system, it is necessary to construct the route of the UAV movement in a way as to conserve battery power most economically (mode 1) or complete the task in the shortest time (mode 2).

The network planning and management system are based on an NM which is an informational dynamic model, of the relationships and results of all the work necessary to achieve the goal - to draw up a plan for the implementation of EM measures considering multivariate developments.

NM allows most rationally to build a plan of the EM, to establish the sequence and priority in the implementation of all actions. NM makes possible to determine the time limits of each event with sufficient accuracy and, therefore, the time to achieve the result, the final event; optimize the use of resources.

For EM, the authors propose to use specially equipped helicopter-type bi-directional aircraft with vertical take-off and landing, which will perform the following types of work:
• movement on a set route with a set speed;
• transmission of the detected information to the GCP;
• execution of the operator’s commands while moving.

NM are compiled at the initial stage of planning. Initially, the process planning requires separating
into several works, drawing up a list of works and events, thinking over their logical connections and
the sequence of execution, assigning work to responsible executors. It allows for evaluating the duration
of each work. Then it is possible to compile the NM. After that, specialists calculate the parameters of
events and activities, determine the time reserves and the critical path.

Then they analyse and optimize of the NM, and, if necessary, re-draws with a recount of the
parameters of events and works.

The event on the NM is represented by circles and activities by arrows demonstrating the relationship
between activities. Experts use natural numbers to indicate events and the codes of the initial and final
events for activities.

To analyse and monitor the implementation of both individual NM works and the entire set of
measures of the EM, it is necessary to determine the NM parameters: temporal characteristics of paths,
works and events.

The NM parameters include the average duration, the early and late dates of events beginning, the
reserves of time of events and works, road and work tension coefficient.

The average duration of work is determined by the formula [2]:

\[ t_{ij} = \frac{2t_{min} + 2t_{max}}{5}, \]

where \( t_{max} \) and \( t_{min} \) are the maximum and minimum estimates of the work duration.

Each NM event has two dates for completion: early \( t_{pi} \) and late \( t_{ni} \).

The early completion date of an event is the time required to complete all the work
preceding the
given event since this event will be after the completion of all work for which it is final and is determined
by the formula:

\[ t_{pj} = \max \left\{ t_{p1} + t_{ij}, t_{ps} + t_{sj}, t_{pm} + t_{mj} \right\} \]

(8)

The late date for the completion of an event is such a term exceeding which will delay the beginni
of the final NM event. Therefore, the late dates of events are calculated by the formula:

\[ t_{nj} = \min \left\{ t_{nl} - t_{ij}, t_{nk} - t_{ik}, t_{nf} - t_{if} \right\} \]

(9)

The time reserve of an event \( R_i \) is the period for a possible delay in the execution of this event without
violating the critical path:

\[ R_i = t_{ni} - t_{pi} \]

(10)

The full reserve of work time \( R_{nj} \) is the maximum period for increasing the duration of this work
without changing the critical path:

\[ R_{nj} = t_{nj} - t_{pi} - t_{ij} \]

(11)

An important property of this reserve is the possibility of its distribution between works lying on the
next path. It is the reserve of the entire subsequent path.

Free reserve of work time \( R_{et} \) is a period for the possible extension of the end of this work without
changing the early dates for the start of subsequent work
Reserves of work time allow manoeuvring the start and end dates of the work, setting the most favourable timelines for the work in terms of rational loading of resources allocated to achieve the goal. Work reserves also provide an opportunity to identify the critical path. Presenting a chain connection of works, it goes through works that do not have reserves.

One of the most important operations in the analysis of the calculated parameters of the NM is to determine the coefficients of work tension and the probability of the final event completion in a set period.

The tension coefficients of paths $K_L^H$ and works $R_{ij}^H$ allow identifying the critical zone of NM, along with time reserves.

The path tension coefficient $K_L^H$ is determined by the ratio of the durations of misplaced sections of the path $L$ and the critical path $L_{cr}$:

$$K_L^H = \frac{t(L) - t_{cr}(L)}{t(L_{cr}) - t_{cr}(L)} = 1 - \frac{R_L}{t_{cr} - t_{cr}(L)}$$

(13)

where $t$ is the duration of critical work on the path $L$, $T_{cr}$ is the duration of the critical path.

The work tension coefficient $K_{ij}^H$ is equal to the path tension coefficient of maximum duration passing through work $(i, j)$:

$$K_{ij}^H = \frac{L_{m}^H}{L_{m}^H} = \frac{t(l_m) - t_{cr}(l_m)}{t(l_{cr}) - t_{cr}(l_{cr})} = 1 - \frac{r_{ij}}{t_{cr} - t_{cr}(l_m)}$$

(14)

The magnitude of the tension coefficients lies within $0 < K^H \leq 1$, reaching one score only in critical works. The closer the tension coefficient is to 1, the more difficult it is to complete this work in a set period. The closer the tension coefficient is to 0, the greater the relative reserve the maximum path has through this work.

The calculated tension factors allow an additional classification of the work. Depending on the size, $K^H$ there are three categories of work: critical ($K^H > 0,8$); subcritical ($0,6 \leq K^H \leq 0,8$); reserve ($K^H < 0,6$).

If the total time reserves of the two jobs are equal, the one with the highest tension coefficient will have the greatest chance of becoming critical. To optimize the NM, first, it is necessary to use the reserves of work that have minimal tension factors.

3. Practical implementation

We examined the construction of NMs using the example of planning EM measures for emergencies at the local level with the destruction of buildings and structures and the spill of an emergency chemically hazardous substance (ECHS).

Our study considers local emergencies when the situation in a certain territory arose as a result of an accident in which DF did not go beyond the facility’s boundaries and can be eliminated by forces of emergency rescue teams, when no more than four people died, no more than 10 people were injured, living conditions of no more than 100 people were violated, direct material damage is not more than 1000 minimum wages on the day of emergencies [10].

For EM in the emergency zone, we identified four groups of activities in which it is advisable to use UAV (Table. 1).

The time for the EM event with UAV depends on the trajectory, the speed of the UAV and the response time of the instruments and equipment installed on it.
Table 1. Groups of activities to use UAV

| Work type | Preparatory activities                                                                 | Time to complete the work, min |
|-----------|---------------------------------------------------------------------------------------|-------------------------------|
| 1 - 2     | An emergency message arriving at the Unified Dispatch Duty Service                     | 5                             |
| 2 - 3     | Entering UAV flight parameters by GCP operator and launching UAV with special equipment| 5                             |
| 3 - 4     | The arrival of UAV to the border of the emergency zone                                   | 5                             |
| 4 - 5     | Initial data collection activities in various parts of the emergency zone               | \( t = \frac{d}{v} \)        |
| 5 - 6     | Flight around objects in the emergency zone in patrol mode to collect information       | 1                             |
| 5 - 7     | on warning emergency services about the state of objects: visible damage, ECHS spills  |                               |
|           | (mode 1)                                                                               |                               |
| 6 - 8     | Return to base                                                                         | 5                             |
| 8 - 9     | Transmission of coordinates of damaged UAV objects                                     | 1                             |
| 9 - 10    | UAV flight around the territory to search for DF sources at objects (mode 1)            | \( t = \frac{d}{v} \)        |
| 10 - 6    | Detection of DF sources at objects by UAV (mode 1)                                      | \( k \)                       |
| 10 - 7    | Exchange of information with the operator GCP                                          | 1                             |
|           | Return to base                                                                         | 5                             |
| 11 - 12   | Transmission of coordinates of DF sources by UAV                                       | 1                             |
|           | Monitoring of DF sources by UAV (mode 2)                                               | \( t = \frac{d}{v} \)        |
| 12 - 6    | Exchange of information with the operator GCP                                          | 1                             |
| 12 - 7    | Return to base                                                                         | 5                             |

Note: \( k \) is the number of DF sources that allows UAV using.

Not for all EM events, it is possible to calculate works time according to the methodology given in [2, 3]. First, it depends on the scale of the emergency, the affected area, the severity of the emergency consequences, the extent of the damage, the levels of DF, the response time of the devices installed on the UAV.

For the EM, it is preferable to use a cargo UAV, for example, the Versadrones Heavy Lift Octocopter brand which has the following tactical and technical characteristics: overall dimensions (in millimeters) - 1200 x 1200 x 400; UAV weight - 4000 grams; total lifting weight - 12000 grams; the maximum speed is 70 kilometers per hour [11].

The duration of the EM measures with UAV is calculated and optimized according to formulas (7) - (9) using data from [12].

Works 1, 2, 3 are the Preparatory activities and their duration is determined by the standard time of arrival of the first unit in the emergency zone and the operator’s ability to prepare and launch the UAV. At speeds of up to 70 kilometres per hour, the UAV will arrive in the work area in 5 to 10 minutes.

Works 4 and 5 are the Initial Information Collection Activities in various parts of the emergency zone. Given that UAV in video mode requires an optimal speed of 20 kilometres per hour, flying around an emergency zone along a zigzag or circular route will depend on its length and speed of the UAV considering the speed of the devices work and will take time \( t = \frac{d}{v} \).

The time required for exchanging information with the operator of the GCP depends on the conditions of reception and transmission in the emergency zone (work 5 - 6, 6 - 8, 10 - 6, 6 - 11 and 12 - 6).

Fig. 3 shows the network model built based on these calculations.
The algorithm for using UAV in EM begins with preparatory works 1, 2, 3 that consists in entering flight parameters and UAV starting with special equipment.

Works 4 and 5 are the collection of information necessary for the further operation of the UAV, clarification of the situation in the emergency zone and decision-making on the need and scope of the search activities related to the detection of objects with ECHS leak.

Based on this information, the UAV controls the concentrations of ECHS at the locations of depressurized objects. This information is the source for the rescuers to work to minimize the levels of DF at a given object of the emergency zone.

NM shows that UAVs perform some groups of measures sequentially, and some in parallel. Thus, the total time for search and rescue operations is reduced even further.

4. Conclusion

Thus, depending on the operating mode of the UAV, it is possible to set various driving routes for it which minimize the distance travelled, the time and resources spent on the UAV battery for the task.

For reconnaissance of the territory to find out the general situation in the emergency zone, transmitting a video signal, the EM for searching for DF sources, a zigzag flight path with rectilinear inserts (Fig. 1a) and a circular route is optimal for BVS (Fig. 1b).

The circular route is optimal for performing work on minimizing DF levels with known coordinates of the DF source. Moreover, depending on the parameters of the DF source (point or linear), it can consist of either straight-line segments and a semicircle (Figure 2a), or only linear sections (Figure 2b).

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