Formation of Unmanned Aerial Vehicle Link Configuration in the Problem of Cargo Transportation Scenario Selection Using Geospatial Data

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Abstract

Nowadays, technologies capable of coping effectively with the assigned problems by automating the processes being carried out are actively developing. Among them, unmanned aerial vehicles (UAVs) deserve special attention, because they can handle almost any mission with a high level of data processing. However, as UAVs have evolved, so have society's needs, and UAV application scenarios have become increasingly complex. Problems are being solved with geodigital data: the different locations of both the UAVs themselves and the objects they interact with are taken into account. On the one hand, some of these problems require simultaneous control of a heterogeneous group of UAVs, but, on the other hand, there are also problems where the use of UAVs for a mission must be carried out in the form of links. A UAV link is a set of UAVs with common characteristics that perform one part of the mission. It becomes relevant to use UAV links and conduct geodigital-based simulations that allow both observation of mission conduct and analysis and achieve optimal drone control. This paper considers an algorithm capable of selecting UAVs with a certain set of technical and operational characteristics for a given route, taking into account the characteristics of the transported cargo, weather conditions, and threat distribution, as well as evaluating the effectiveness of the mission according to the optimization criterion. The study describes and groups the data required for the mathematical statement of the problem, and discusses the basic steps of the algorithm, which is part of the proposed algorithm. In addition, the paper considers the software package, which uses the proposed algorithm as the basis of its work. Based on the results of the experiments, the conclusion about the feasibility of using the proposed algorithmic software in the implementation of applied tools as an effective way to support decision-making when performing a scenario problem is made.

Keywords

Unmanned aerial vehicles, cargo transportation, geospatial data, scenario problem, optimization.

Introduction

Currently, there is an increased interest in the use of unmanned aircraft in a number of fields, including geodesy, geological exploration, aerial agricultural work, cargo transportation, etc. (Gadzhieva, Kurbanov, 2019; Zakharov, Zemenkova, 2018; Ivanova et al, 2014). There are examples of successful use of unmanned aerial vehicles for emergency prevention and response, in particular, for extinguishing forest fires (Ishbulatov, Galeev, 2018; Pashkov, 2020; Meshcheryakov et al, 2021a, 2021b; Zakharova, Podvesovskii 2018).

In this regard, the development of information technologies, mathematical and software for solving the problems of controlling unmanned aircraft systems in these fields is of particular relevance. For example, in the field of cargo transportation, one can note the relevance of creating mathematical models and software support tools for solving the following problems:

a) the problem of forming a plan for cargo transportation using unmanned aerial vehicles (UAVs), which includes the problems of building and updating the route network of UAVs, as well as the evaluation and selection of the optimal transportation plan;

b) The problem of distributing UAVs on routes, which includes the problems of selecting the configuration of UAV links with given characteristics and forming a plan for their loading.

In solving these problems, it is necessary to use data from a variety of sources, among which the key ones are geospatial data (Zak, 1999; Eremchenko et al, 2017).

In addition to the above problems, it is possible to distinguish the so-called scenario problems, in which different UAVs with different functional and technical characteristics participate to perform a common mission. One example of such a problem is the formation of a control scenario for UAVs to extinguish fires (Kartenichev, Panfilova, 2019; Meshcheryakov et al, 2020; Neto et al, 2012). In this case, the first part of the UAV searches and monitors the areas of interest, after which the second part flies to the found areas, where the load is dropped or retransmitted.

Complex scenario problems require development of special algorithms allowing to optimize work of UAV links (Zubkov, Sharov, 2010). This work systematizes the data describing the problem and presents the developed software, which demonstrates the implementation of an algorithm capable of selecting UAVs with a certain set of technical and operational characteristics for a given route, taking into account the characteristics of the transported cargo, weather conditions, threat distribution, as well as evaluate the effectiveness of the mission in accordance with the optimization criterion.

Description of the problem of forming the UAV link configuration

The solution of a scenario problem in the general case assumes the following actions:

1) Definition of the initial data, necessary for formation of alternative variants of scenarios.

2) Definition of criteria, i.e. indicators of an estimation and comparison of alternatives and a choice of the best alternative.

3) Definition of a mathematical method of the decision of an optimization problem.

As a particular example for the future algorithm, the scenario of cargo transportation to consumers using UAV links is considered. Examples of problems to be solved for this scenario are shown in Figure 1. Those that are covered by the proposed algorithm are highlighted in orange.

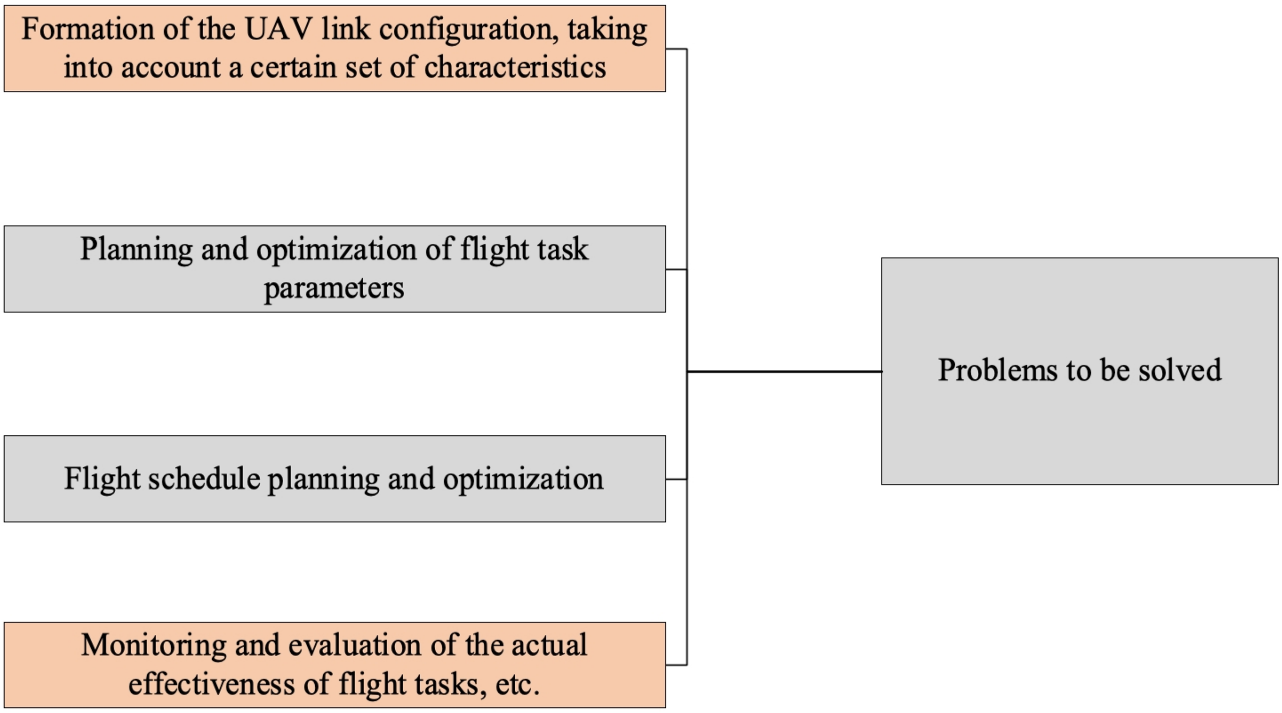

Fig. 1. Examples of problems solved for the transport scenario

Therefore, the alternatives are combinations of routes and UAV links, specified by means of some set of parameters. The parameters describing an individual link and external factors (e.g., weather conditions) are formed on the basis of the initial data, the scheme of which is shown in Figure 2 (Yang et al, 2016).

A number of indicators are defined to evaluate the effectiveness of UAV links, which can be divided into 4 groups: criteria for evaluating the vehicles; criteria for evaluating flight tasks; criteria for evaluating external factors; and criteria for determining cost-effectiveness. The indicators included in these groups are designed to assess how each function should be implemented and how each action should be performed to ensure that the requirements established for transporting cargo are met. Figure 3 shows examples of indicators included in the second and fourth groups.

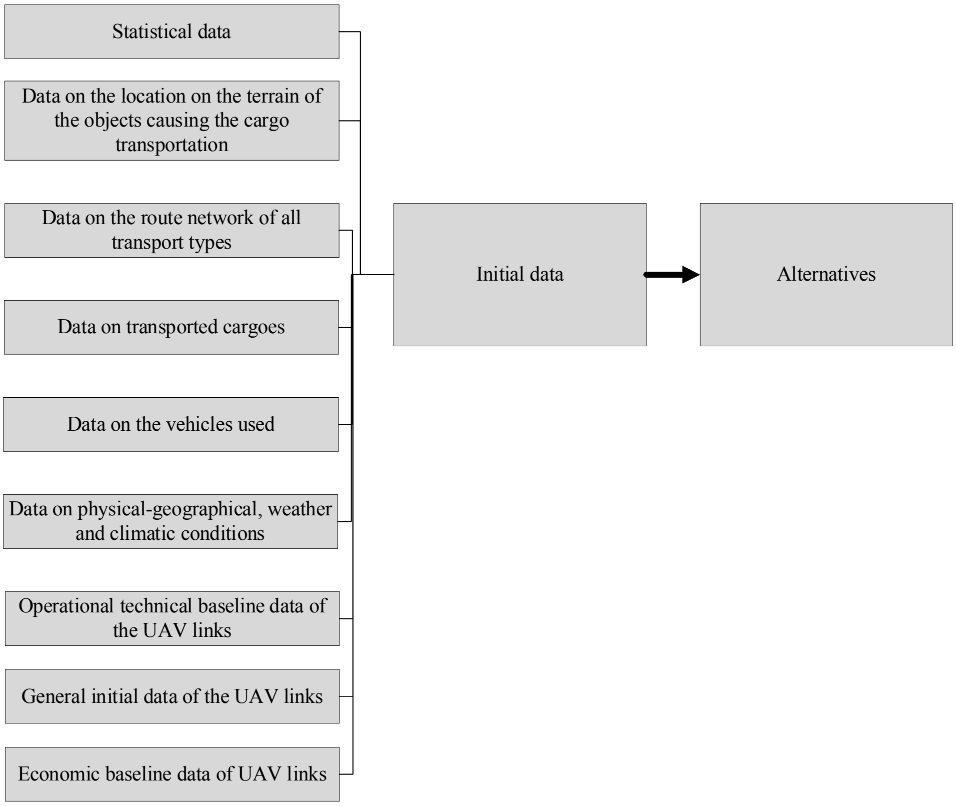

Fig. 2. Data describing UAV links and external factors

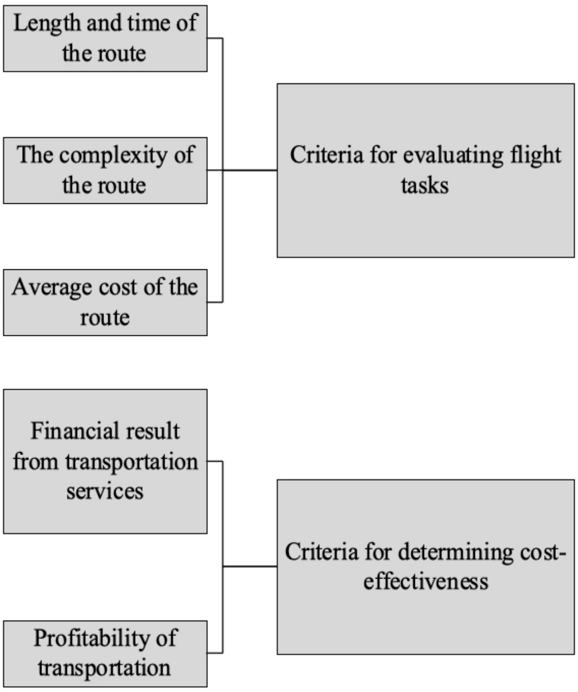

Fig. 3. Criteria for evaluating the effectiveness of UAV links

The scheme of the initial data required to build mathematical models for the formation of UAV link configuration and the software implementation of the corresponding algorithms is shown in Fig. 4 (Zvonarev, 2009; Korte, Figen, 2015). The indicators having a static character are marked with the symbol "c", the dynamic indicators - with the symbol "d". For each indicator y, the set of possible values is a subset of the area of acceptable values $D(y)$. For the static indicators the set of possible values is identical to the set of admissible values: $\{y^*\} = D(y)$. For dynamic indices the set of possible values is formed on the basis of the values constituting the most probable or most frequent range of admissible values $D(y)$: $\{y^*\} = \{y \mid y \in D(y), P(y) \quad p\}$.

Statistical
-Number, dislocation, and volume of cargo generation (s)
-Number, dislocation, volume, and frequency of cargo receipt (s)

The location on the terrain of the objects causing the cargo transportation
-Locations of suppliers and consumers (s)
-Locations of carriers (s)
-Locations of production, warehousing (s)
-Locations of order picking and sales (s)
-Locations of loading and unloading complexes (s)

The route network of all transport types
-Geospatial data (s)
-Length (s)
-Coverage factor (s)
-Transmittance (s)
-Organization of vehicle traffic (s)

Cargoes transported
-Mass (s)
-Overall size (c)
-Volume (s)
-Shape (s)
-View (s)
-Requirements for transport and storage conditions (s)
-Required method of loading/unloading (s)

Vehicles used
-Technical specifications: payload, cruising and maximum speed, range of altitude, practical and technical flight range, etc.(s)
-Technical economic characteristics: production cost, fuel and economic efficiency, etc. (s)

Physical-geographical, weather and climatic conditions
-Terrain types (s)
-Terrain relief (elevation matrix) (s)
-Air temperature (d)
-Air humidity (d)
-Atmospheric pressure (e)
-Precipitation (d)
-Locations of possible formation of dangerous weather phenomena (d)

Operational technical
-Throughput and carrying capacity (s)
-Regularity and safety of transportation (s + d)
-Speed and time of delivery (s + d)
-Level of cargo security (d)
-Mobility of transport (s)

Economic
-Transportation cost (s)
-Transport efficiency (s)
-Economic efficiency (d)
-Revenues, expenses, profitability, profit (s)

General
-Volume of cargo transportation (s)
-Cargo turnover (s)
-Distance of cargo transportation (s)
-Speed of delivery (s)
-Response time(s)
-Structure of the vehicle fleet (s)

Fig. 4. Data forming the information model of UAV link configuration formation

Mathematical model of cargo transportation plan formation

As an example of a mathematical model used in the process of forming the UAV link configuration, consider the model of cargo transportation plan formation.

Let the delivery of cargoes be carried out through several large intermediate (transit) points, which can be used both for storage and transshipment of delivered cargoes and for maintenance of UAVs (e.g., charging the batteries). The scheme of the corresponding transport network is shown in Figure 5.

Accordingly, let the transport network consist of m sources (A1, A2, …, Am), n stocks (B1, B2, …, Bn) и r intermediate points (C1, C2, …, Cr). Let us also assume that the cargo transported in this network is homogeneous or interchangeable. In this case the values of ai > 0 of cargo stock in sources Ai (i = 1, …, m), volumes of demands bj > 0 in cargo in stocks Bj (j = 1, …, n), and volumes of additional demands ct in cargo in intermediate points (in warehouses) Ct (t = 1, …, r) should be specified. At that, if ct > 0, it means that there is an actual need for cargo at the corresponding point (e.g. due to the need to make a reserve), and ct < 0 means that there is a cargo reverse (i.e. the negative value of the additional demand is associated with a surplus). In turn, ct = 0 means that this intermediate point is a transit point.

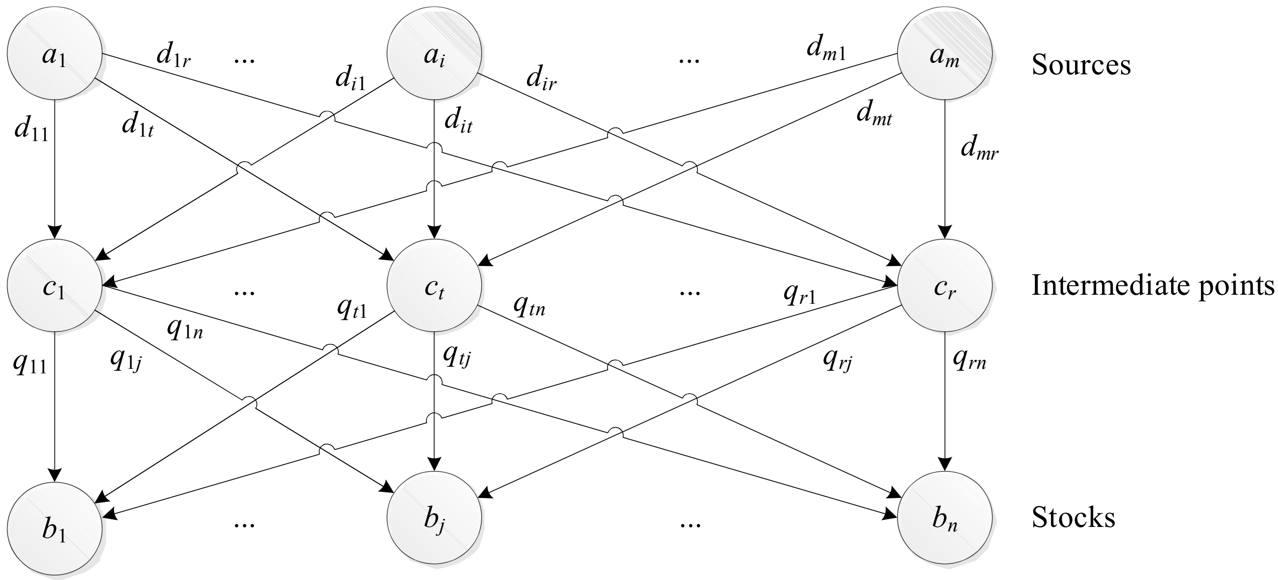

Fig. 5. Schematic representation of a transport network with one intermediate layer

Suppose one set the average cost d_{it} to transport a unit of cargo from the source A_i to the intermediate point C_t, and the average cost q_{tj} to transport a unit of cargo from the intermediate point C_t to the stock B_j.

If the task is to find a scenario that provides the minimum total cost of cargo transportation, then the corresponding optimization model has the form:

$$\sum_{i=1}^{m}\sum_{t=1}^{r} d_{it} x_{it} + \sum_{t=1}^{k}\sum_{j=1}^{r} q_{tj} y_{tj} \to min,$$

under the constraints

$$\begin{cases} \sum_{t=1}^{r} x_{it} = a_i (i=1,\ldots,m); \\ \sum_{t=1}^{r} y_{tj} = b_j (j=1,\ldots,n); \\ \sum_{i=1}^{m} x_{it} - \sum_{j=1}^{n} y_{tj} = c_t (t=1,\ldots,r); \\ x_{it} \geq 0 (i=1,\ldots,m; t=1,\ldots,r); \\ y_{tj} \geq 0 (t=1,\ldots,r; j=1,\ldots,n). \end{cases}$$

The variables there are x_{it} – the number of units of transported cargo from the source A_i to the intermediate point C_t, y_{tj} – the number of units of transported cargo from the intermediate point C_t to the stock B_j.

The obtained optimization model corresponds to the model of transport problem with intermediate points, for solvability of which it is necessary to meet the condition of equilibrium:

$$\sum_{i=1}^{m} a_i - \sum_{j=1}^{n} b_j = \sum_{t=1}^{r} c_t .$$

The example of building a software implementation of the transport mission model

The software implementation of the transportation mission model was performed in the GAMA environment (Taillandier et al, 2019a,b; Ban et al, 2020). Although GAMA does not have an off-the-shelf set of tools for process analytics, it is free and has a rich range of functionality similar to many other popular geocontext-aware programs.

Suppose there is an arbitrary number of UAVs of two links. There is an arbitrary number of homogeneous cargoes to be delivered. Each cargo can be delivered in two parts - large part of the cargo [10; 20] kg and small part of the cargo - up to 10 kg. There are also an arbitrary number of takeoff locations, landing locations, cargo delivery locations, or pickup locations. Any such type of location is considered to be another at the same time, that is, each takeoff location is also a landing location, a cargo delivery location, or a cargo pickup location. Cargo is initially located at separate takeoff and landing zones. One cargo is delivered by one UAV of some link to a certain location. Then at that point a small part of the cargo is intercepted by another UAV and delivered to another location. All UAVs, after delivery of their parts of cargo, return to their original takeoff zones.

In addition, a number of other characteristics are set in the program:

Coordinates of the takeoff and landing zones, etc.

- Geospatial data (area map).
- Mass, dimensions, volume, shape, delivery terms.
- Maximum payload, speed indicators (maximum takeoff, landing, cruising speed), production cost, available temperature conditions for flight, available air humidity, available precipitation, flight height, method of loading/unloading.
- Air temperature, air humidity, precipitation.

The criterion of efficiency is the time to complete the entire mission. Nevertheless, there can also be other criteria (there are variables for them, for example, the cost of transportation). In the course of solving the task the distribution of cargo delivery routes and UAV link configuration takes place, i.e. the selection of UAVs involved in the delivery. When the program finishes, the console displays the mission completion time and the notification that the mission is complete.

The program in GAMA allows the input and output of information in manual mode in three parts: the menu, the console and the experiment window.

The menu is a part of the program in which you can set parameter values for the initial data (Fig. 6).

The console outputs the desired data before and during the movement of the UAV links. An example of the output of a part of the initial data in the console may be as follows (Fig. 7).

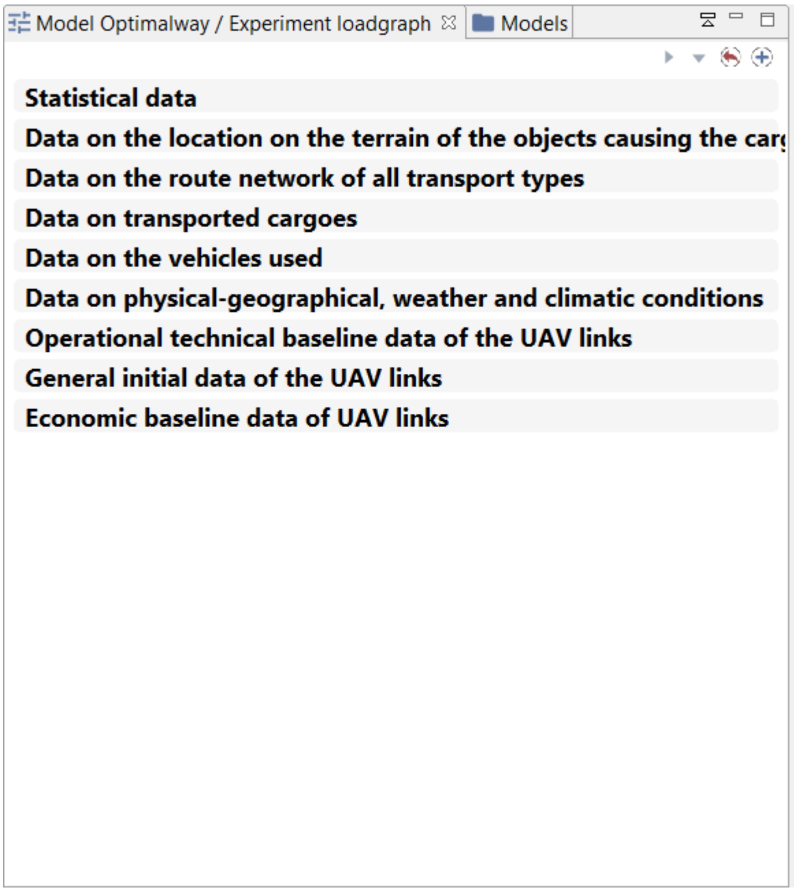

Fig. 6. The program menu

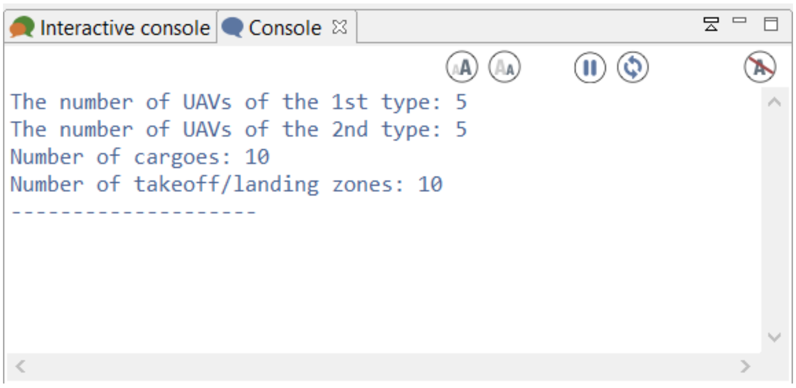

Fig. 7. The program console

Finally, the experiment window allows to monitor the execution of the problem being solved. Figure 8 shows some stage of the scenario problem.

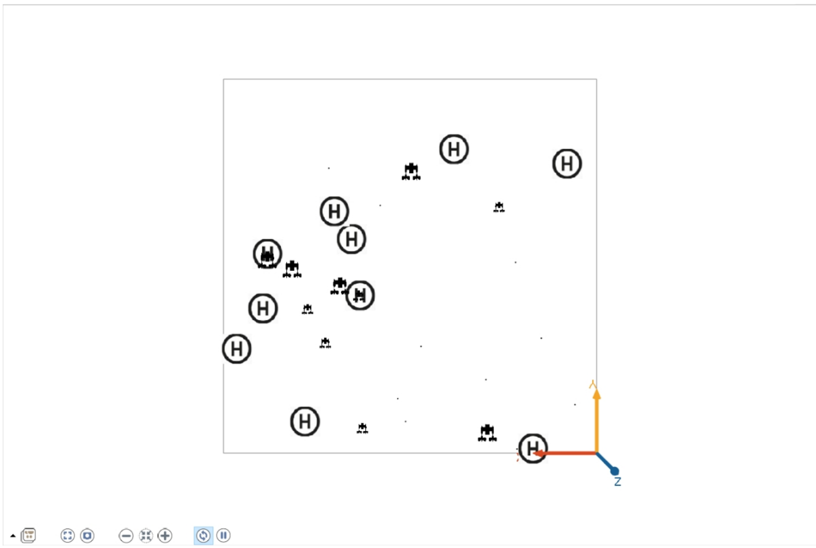

Fig. 8. The program experiment window

Thus, the proposed program makes it possible to monitor the execution of the transport mission at various given characteristics. It is worth noting that the testing and verification of the software implementation of the algorithm was carried out by experts. As a result, it was noted that the program successfully coped with the set scenario problems of cargo transportation, and the algorithm itself turned out to be workable.

Conclusions

In the course of the presented research, the algorithm was developed to optimize the performance of UAV links in a scenario problem. The data necessary to form the alternatives and criteria of the task were systematized. The step-by-step operation of the method capable of finding an optimal solution for the task of transporting cargo using multiple UAV links was presented. The program was also written based on the proposed algorithm. Experimental results confirmed that the algorithm is workable. In the future it is planned to expand the algorithm by increasing the number of input parameters that make up the marked groups of input data, by adding new groups of data (for example, data on the structure and architecture of the model of UAV links, data on the control system of UAV links), as well as to improve the accuracy and the running time of the method of selecting the UAV link configuration.

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