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DETERMINING THE UNMANNED AERIAL VEHICLE OPTIMAL FLIGHT ROUTE BASED ON THE ANT COLONY OPTIMIZATION

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ABSTRACT
The use of an Ant System to determine the flight routes of an unmanned aerial vehicle to reconnaissance (impact) objects is proposed. In the method, the solution is built in an iterative process by many agents (ants), which interact with each other through stems – by making changes in the environment, namely – the deposition of pheromones on the routes, and higher pheromone levels are deposited on the best routes. The results of research are generally positive and indicate the possibility of solving the problem using the Ant System. Laying of flight routes will be carried out taking into account the presence of obstacles on the route, "forbidden zones". The work of the MAX-MINI Ant System in the presence of such obstacles on possible flight routes has been studied. Depending on the chosen method of determining the accessibility of the section of the flight route, it either has to bypass the "restricted areas", or can pass through them, but the attractiveness of such a route decreases. The results of research are generally positive and indicate the possibility of solving the problem using the Ant System.
Keywords: Ant System, artificial intelligence, flight path, optimization, unmanned aerial vehicle

1. INTRODUCTION

The practice of modern hostilities in Syria, Libya, eastern Ukraine, between Azerbaijan and Armenia, etc. shows the widespread use of stealth aircraft objects [1–3]. Employing unmanned aerial vehicles has become one of the main components of hostilities between Armenia and Azerbaijan [1]. Thus, some Western commentators have dubbed these activities the "South Caucasus war of unmanned aerial vehicles" [4]. Despite the considerable interest in the development of theory and practice of creating and the use of unmanned aerial vehicles (UAV), the issue of planning their use using modern information technology remains incompletely explored.

2. ANALYSIS OF RESEARCH AND PUBLICATIONS

The tasks of flight route planning are traditionally reduced to various kinds of optimization statements [5]. The main methods are: complete search [5], dynamic programming [6, 7], genetic algorithms [8, 9], greedy algorithms [10], ascent method [11] and others [12-14].

A complete search [5] of all possible options is the simplest solution to this problem, the solution found is always optimal, but the time to solve the problem increases exponentially. The disadvantage of the method of dynamic programming is the mandatory linearity of the objective function [6, 7], does not provide sufficient speed and does not work in non-stationary systems. The advantages of the genetic method [8, 9] are almost complete independence from the characteristics of the search space, little dependence on the choice of the criterion of optimality. The disadvantage of this method is the complexity of implementation and the significant dependence on the choice of chromosome coding. The principle of operation of the greedy algorithm [10] is to find the optimal solution for each local problem. The advantages of the method are the simplicity of implementation, speed of work, known in advance the search time. The disadvantage of the method is that the solution of the global problem may not be optimal in the general case.

In [15-19] the construction and optimization of routes using optimization methods on graphs (solving the classical problem of a salesman) is considered. The construction of the flight route is reduced to the formation of the sequence of flight points, the location of which on the earth's surface is considered a priori specified. The length of the route acts as a minimizing criterion. At the same time, it should be noted that the procedure for substantiating the choice of points depending on the tasks of the UAV is not given in these works.

In [17, 20], optimization on graphs using the Little algorithm is proposed, which is highlighted as one of the exact solutions of the salesman problem. The disadvantage of the methods [17, 20] is not taking into account the specifics of the application and the possibilities of route optimization directly for the UAV. In [21, 22] methods of clustering the choice of routes with similar features are considered. The main approaches to their solution are analyzed, the advantages and disadvantages of different clustering methods are highlighted. But the methods [21, 22] do not take into account the peculiarities of flight route planning, namely altitude, flight speed and more.

In [23, 24] the authors refused to reduce the routing problem to variants of the salesman problem. In [23, 24] the method of linear Boolean programming is used. . The advantages of the method are the ability to take into account more factors associated with the use of UAVs. In [25], the optimal flight route of the UAV is subject to the limitation on the allowable flight duration. In [26], the inequality of points included in the route is additionally taken into account. But in [23-26] there are no cases when sudden obstacles ("forbidden zones" - zones of fire of anti-aircraft missile systems, zones of suppression by electronic warfare, areas with difficult meteorological conditions, etc) can be detected in the path of a given UAV movement. This requires rescheduling the flight of the UAV in automatic mode, which is a difficult task. The results of work [27, 28] require the creation of an appropriate method for determining the optimal flight route of the UAV, taking into account the presence of "forbidden zones" on the route.

3. PROBLEM STATEMENT AND PRESENTATION OF RESEARCH MATERIALS

In recent years, multiagent methods of artificial intelligence have been developing, which include the ant algorithm or the method of Ant System (AS), proposed by M. Dorigo in 1992 [29]. Initially, the algorithm was used to find the shortest path in graphs, further research [30-33], led to numerous modifications of the algorithm and demonstrated its versatility to solve a wide range of optimization problems. One of the important advantages of the algorithm is its high efficiency in optimizing distributed non-stationary systems [34]. When the studied system changes, the algorithm quickly adapts to these changes and finds a new optimal solution. The above, as well as other advantages of the algorithm (such as, for example, speed) make it relevant to conduct research on the possibility of using the ant algorithm and its varieties to determine the optimal flight path of the UAV.

Ant System are based on imitation of natural mechanisms of self-organization of an ant colony. A colony of ants is considered as a multiagent system in which each agent (ant) operates according to very simple rules. The self-organization of the system is ensured by low-level interaction of agents, with agents exchanging only local information, and any centralized management of the system aimed at achieving global goals is excluded. To transmit local information, agents use so-called stigmas - a time-spaced type of interaction where one agent changes some part of the environment and other agents observe these changes after a while when they are at the appropriate point in the environment and use the relevant information in their activities. Ants use stigmas by releasing a pheromone, a special secretion that is deposited by an ant on its route in the process of finding food and returning to the anthill with food. The next ant, which will be near the route of the first ant, perceives the pheromone and will most likely continue to move to the path of the first ant, in turn depositing the pheromone (increasing its concentration on the route). The higher the concentration of pheromone on the route, the higher the attractiveness of this route for subsequent ants, and the more ants choose this route. The distribution of the pheromone in the environment is like a dynamic memory system. Each ant at a certain point in time perceives and changes one bed of this memory - the level of pheromone in the vicinity of the point where the ant is located.

The concentration of pheromone deposited on the route is inversely proportional to its length. The shorter the route, the greater the concentration of pheromone on it, as a result, the shorter route will remain in the global memory of the anthill as more successful and more likely to be selected by subsequent ants.

Over time, the pheromone evaporates, providing feedback. Since, as mentioned above, the concentration of pheromone will gradually increase on successful routes, and the rate of evaporation of pheromone is constant, after a while the unsuccessful routes will disappear, and more and more ants will move only on successful routes. The use of feedback (evaporation) prevents premature convergence of solutions - the choice of ants of the same suboptimal route.

Consider the features of the application of the ant algorithm for the route of the UAV.

In the simplest case, the UAV flight route can be represented as a set of the following sections: take-off areas from the starting point of the route (SPR) and altitude, horizontal sections where the flight takes place, overcoming the air defense zone, access to the reconnaissance object (impact), descent area to the boundary of the task (BT) and the finish point of the route (FPR). Horizontal sections pass through turning points of the route (TPR), where there is a change of course, and in the general case, possibly the flight altitude (Fig. 1). In the future, we believe that the position of SPR, FPR and turning points of the route completely determines the flight route of the UAV.

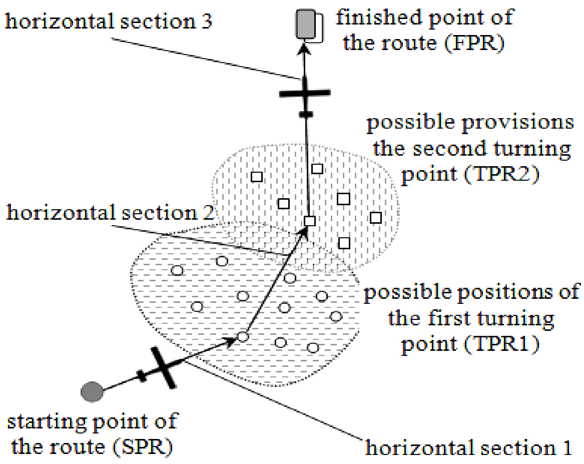

Fig. 1 Example of route representation

Flying on each section of the route, as well as supporting the maneuver in selected TPR, has certain dangers for UAVs and requires large expenditure resources that will lead to the benefits of one route over another. We will demonstrate how to pave the route using the Ant System.

In the Ant System, in each iteration of the iterative process, the m agents search for a solution and update the pheromones on the found route. Each k agent starts the path with SPR, sequentially passing the selected turn points of the route and turns the path in FPR. The choice of TPR from J possible is based on the probability rule that determines the probability of transition of the k-th agent in the i-th TPR, taking into account the availability of the i-th section of route L_i and the concentration of pheromones in this section F_i at time t as follows (expression (1)):

$$P_i^k(t) = \frac{F_i(t)^{\alpha} \cdot L_i^{\beta}}{\sum_{j=1}^{J} F_j(t)^{\alpha} \cdot L_j^{\beta}} \qquad (1)$$

where α and β – are the parameters that determine the weight of the pheromone and the availability of sites, respectively.

When α=0 agents at each step go to the nearest TPR and AS becomes a "greedy" algorithm of the classical optimization theory. When β=0, only the effect of pheromones is taken into account, which will quickly lead to a suboptimal solution. According to rule (1) are the probabilities of choosing a TPR. The choice is made on the principle of "roulette wheel". This can be realized, for example, by dividing the active segment of length S into J part by length proportional to P_i, generating a random number evenly distributed in the interval [0, S] and selecting TPR according to which random number falls on the ordinal number of the participant S.

The availability of the section of route L_i in the simplest case can be calculated by expression (2):

$$L_i = \frac{1}{D_i} \qquad (2)$$

where D_i is the length of the i-th section of the route.

In more complex cases, the value of L_i can be calculated depending on the presence of areas of detection and damage by air defense and other hazards in the flight area.

At the beginning of the iterative process, the amount of pheromone in the sections of the route is assumed to be equal to and equal to a small number of F_0. After each iteration, the concentration of pheromones in the selected agents is updated according to rule (3):

$$F_i(t+1) = (1-\rho)F_i(t) + \sum_{k=1}^{m} \Delta F_i^k , \qquad (3)$$

where ρ∊[0,1]– pheromone evaporation rate;

ΔF_i^k – the concentration of the pheromone in the i-th section of the route created by the passage of the k-th agent.

In that case, if in the current iteration of the site did not pass any of the agents, rule (3) becomes:

$$F_i(t+1) = (1-\rho)F_i(t) ,$$

that is, the renewal of the pheromone is its evaporation at a rate of ρ.

MAX-MINI Ant System (MMAS) [30] is a development of the original ant algorithm AS. Its characteristic features are that only the best agents increase the level of pheromone on their routes, and also that the level of pheromone on the routes is limited. Updating the pheromone level on the routes is carried out according to the rule:

$$F_i(t+1) = [(1-\rho)F_i(t) + \Delta F_i^{best}]_{F_{min}}^{F_{max}}$$

Where F_{max} and F_{min} – are the upper and lower limits of the pheromone level;

$[x]_b^a$ - operator, which is defined as:

$$[x]_b^a = \begin{cases} a, if \ \text{x > a} \\ b, if \ \text{x < b} \\ \text{x, in other cases} \end{cases},$$

and ΔF_i^{best} is defined as: the best route in iteration

$$\Delta F_i^{best} = \begin{cases} 1/L_{best}, \ \text{if i - the best route sn steration} \\ 0, \qquad \text{in other cases} \end{cases},$$

L_{best} - the length of the route of the best agent. This can be either the best route found in the current iteration, L_{ib}, or the best solution found since the algorithm started, L_{bi}.

In [30] it is shown that to solve problems similar to those considered in this article, it is more appropriate to use MMAS. We will show the results of the application of MMAS for the route of the UAV.

The validity of the MMAS algorithm was performed using the data of the control example. For clarity of presentation of results the rectangular coordinate system in which SPR, FPR and TPR are in one horizontal plane is applied. The availability of sections of the route was calculated by (2). Output data:

the amount of SPR – N_{SPR}=1;

the amount of FPR – N_{FPR}=1;

number of horizontal sections of the route – 3;

the number of possible first TPR (TPR1) – N_{TPR1}=20;

the number of possible first TPR (TPR2) – N_{TPR2}=20 (the provisions of SPR, FPR, TPR1 and TPR2 are shown in Fig.2);

"greed" of the algorithm – β=1;

weight of pheromones – α=2;

pheromone evaporation rate – ρ=0.001;

number of iterations of the algorithm – N=400;

the number of agents in the iteration – m=100;

initial amount of pheromone – F_0=0.01.

Obviously, for the conditions of the control example, the optimal route will be a straight line from SPR to FPR. In fig. 2 shows the operation of the algorithm after 40, 80, 200 and 400 iterations.

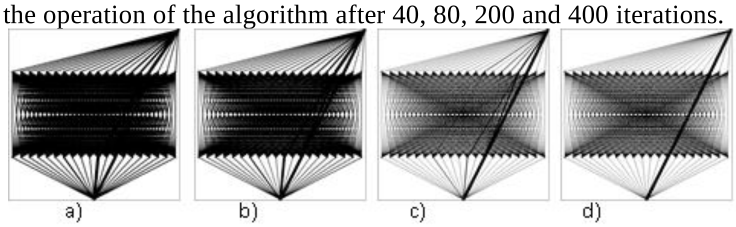

Fig. 2 The results of MMAS for the original data of the control example
(a - after 40, b - after 80, c - after 200,d - after 400 iterations)

After 40 iterations, the pheromone level on all routes is still slightly different from the initial F_0 level, but agents have already marked two routes with pheromones as the best (fatter lines). After 80 iterations, the level of pheromone on all routes, except the best, is significantly reduced due to evaporation (the corresponding lines have become thinner), clearly identified three best routes, between which in the future "there is a dispute". After 200 iterations, the best route is already clearly identified, although several routes are still trying to "debate", after 400 iterations, the best route (which is optimal) obviously dominates.

The following example tested the performance of the MMAS algorithm using the criterion "shortest route of those that bypass obstacles". Obstacles ("forbidden zones") were added to the route environment, and the accessibility of section L_i was calculated as:

$$L_i = \begin{cases} 1/D_i, \text{if the i route passes outside the "forbidden zones"} \\ 0, \text{in other cases} \end{cases}.$$

Also increased to 60 power sets TPR1 and TPR2.

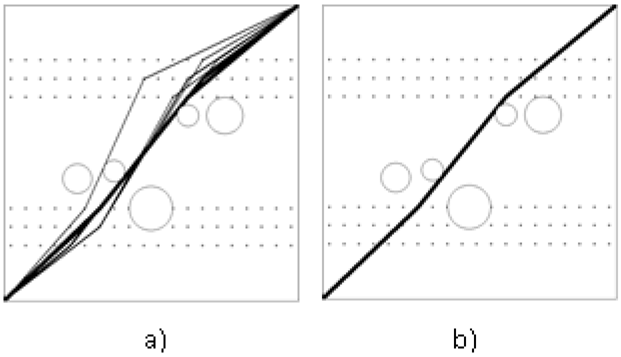

Fig. 3 MMAS operation in the presence of "forbidden zones"

a) after 100 iterations; b) after 300 iterations

The results of MMAS in the presence of "forbidden zones" are shown in Fig. 3. In all cases, the algorithm found the shortest route of those that do not pass through the "forbidden zones". It should be noted that Fig. 3 and the following do not show routes with pheromone levels below 5% of the maximum.

4. CONCLUSIONS

Thus, this paper considers the possibility of using the ant algorithm MMAS to determine the optimal flight paths of UAVs. The results of research are generally positive and indicate the possibility of solving the problem using the Ant System.

Laying of flight routes will be carried out taking into account the presence of obstacles on the route, "forbidden zones". The paper demonstrates the operation of the MMAS algorithm in the presence of such obstacles on possible flight routes. Depending on the chosen method of determining the availability of a section of the flight route, the route either has to bypass the "restricted areas", or may pass through them, but the attractiveness of such a route decreases. Further research can be aimed at implementing a three-dimensional search for UAV flight routes in geographical coordinates, taking into account the size of the turning points of the route where the UAV maneuvers, and the actual size and configuration of restricted areas and terrain. The practical implementation of the provisions set out in the article will also require justification of the boundaries of the possible positions of the turning points of the route and the step of their tabulation. The authors plan to implement a modification of the ant algorithm with a continuous medium, when the position and number of turning points of the route are not predetermined, and agents move in each iteration in a random direction and randomly select the moment of rotation. In this case, pheromones should be deposited not only along the route, but also in some of its surroundings. Relevant studies are conducted by the authors and will be published in future works.

REFERENCES

[1] *Armenia Azerbaijan: Reports of fresh shelling dent ceasefire hopes.* Available from: <https://www.bbc.com/news/world-europe-54488386>.

[2] *Civil War in Syria*. Available from: <https://www.cfr.org/global-conflict-tracker/conflict/civil-war-syria>.

[3] BANASIK, M. *Armed Forces As The Russian Federation's Strategic Tool*. Journal on Baltic Security, 2020, 5 (2), 29–40.

[4] ECKEL, M. *Drone Wars: In Nagorno-Karabakh, The Future Of Warfare Is Now*. Available from: <https://www.rferl.org/a/drone-wars-in-nagorno-karabakh-the-future-of-warfare-is-now/30885007.html>.

[5] RAIGORODSKY, A. *Extreme problems of graph theory and the Internet*: Moscow, 2012. 104 p.

[6] TARAN, I., TRISTAN, A. and PATALAKHA, V. *Methods for determining the rational flight route of an aircraft using dynamic programming*. Bulletin of the Military Institute of the National Guard of the Republic of Kazakhstan, 2015. No. 3 (17). pp. 34–42.

[7] NYGARD, K.E., CHANDLER, P.R., and PACHTER, M. *Dynamic network flow optimization models for air vehicle resource allocation*. In: Proc. of the the American Control Conference, Arlington, Texas, 2001. pp. 1853–1858.

[8] URUBKOV, A.R. and FEDOTOV, I.V. *Methods and models of optimization of management decisions*: Moscow, 2011. 240 p.

[9] DARRAH, M., NILAND, W. and STOLARIK, B. *UAV cooperative task assignments for a SEAD mission using genetic algorithms*. In: AIAA Guidance, Navigation, and Control Conference and Exhibit, AIAA-2006-6456. Keystone, Colorado, 2006.

[10] GUTINA, G., YEOB, A., and ZVEROVICHA, A. Traveling salesman should not be greedy: domination analysis of greedy-type heuristics for the TSP. *Discrete Applied Mathematics*, 2002, no.117, p. 81-86.
[11] SIGAL, I. and IVANOVA, A. *Introduction to applied discrete programming: models and computational algorithms*: Moscow, 2003.240p.
[12] MAKAROV, I.M., LOKHIN, V.M. and MANKO, S.V. Intelligent control systems for unmanned aerial veicles based on the integrated application of fuzzy logic technologies and associative memory. *Aerospace instrumentation*, 2002. no. 2. p. 29-36.
[13] MOISEEV, V.S. *Applied theory of control of unmanned aerial vehicles*: Kazan, 2013.768 p.
[14] NORSEEV, S.A. *Algorithms for pre-flight quasi-optimal determination of routes for a group of unmanned aerial vehicles* (Kovrov) [Research Report], 2016.182 p.
[15] MYKLUKHA, V. and KHIMCHYK, N. Optimization of the Flight Path of an Unmanned Aerial Vehicle. *Traektoria Nauki*, 2017, vol. 3, no. 9, p. 1009-1015.
[16] PULEKO, I., MYKLUKHA, V. and KHIMCHYK, N. Optimization trajectory of flight pilotless unmanned aerial vehicle is with the use theory of the graphs. *Innovative solutions in modern science*, 2017, no. 10 (19), p. 5-13.
[17] LEVCHENKO, A.Y., MOROZOV, and A.V. PANYSHEV, A.V. A mechanism for accelerating calculations in Little's method for solving problems of the traveling salesman class. *Piece intelekt*, 2012, no. 2, p. 95-110.
[18] CHERNOUSKO, F.L. and MELIKYAN, A.A. *Game control and search problems.* Moscow: Nauka, 1978. 270 p.
[19] ABCHUK, V.A. and SUZDAL, V.G. *Object search*. Moscow: Soviet radio, 1977. 336 p.
[20] MOROZOV, A.V., PANISHEV, A.V. and SKACHKOV, V.A. *Modification of Little's method for solving the ring problem of a rural postman*. Piece intelekt, 2010, no. 3, p. 103-115.
[21] ISAACS, J.T., and HESPANHA, J. P. Dubins Traveling Salesman Problem with Neighborhoods. A Graph-Based Approach. *Algorithms*, 2013, vol. 6, p. 84-99.
[22] GULYANYTSKY, L.F. and MULESA, O.Y. *Applied methods of combinatorial optimization.* Kyiv: Publishing and Printing Center "Kyiv University", 2016. 142 p.
[23] BEKHTI, M., ABDENNEBI, M., ACHIR, N. and BOUSSETTA, K. Path Planning of Unmanned Aerial Vehicles With Terrestrial Wireless Network Tracking. *Wireless Days*, Toulouse, 23-25 March 2016, p. 1-6.
[24] EFIMOV, A.V. *Planning of flight of the unmanned aerial vehicle at monitoring of a ground situation in the set region taking into account influence of a crosswind* (Moscow) [Research Report], 2012. 118 p.
[25] Moiseev, D.V. and CHIN, V.M. Flight routing of a light unmanned aerial vehicle in a constant wind field, taking into account the limitation on the duration of the flight. *Mechatronics, Automation, Control*, 2016, no 3, p. 206–210.
[26] MOISEEV, D.V., CHIN, V.M., MOISEEVA, S.G., and FAM, S.K. Routing of light unmanned aerial vehicle flying of unequal objects in the field of constant wind taking into account the limitation on the flight time along the route. *Aviation and astronautics: 14th International. Conference.* Moscow, 2015.
[27] SHCHYPANSKYI, P., SAVCHENKO, V., MARTYNIUK, O., and KOSTIUK, I. Air defense planning from an impact of a group of unmanned aerial vehicles based on multi-agent modeling. I*nternational Journal of Emerging Trends in Engineering Research,* 2020, no 8(4), p. 1302-1308.
[28] TYURIN, V., MARTYNIUK, O., MIRNENKO, V., OPEN'KO, P. and KORENIVSKA, I. General Approach to Counter Unmanned Aerial Vehicles, *IEEE 5th International Conference Actual Problems of Unmanned Aerial Vehicles Developments (APUAVD)*, Kiev, Ukraine, 2019, p. 75-78.
[29] DORIGO, M., MANIEZZO, V. and COLORNI A. Ant System: Optimization by a colony of cooperating agents. *IEEE Transactions on Systems, Man, and Cybernetics,* 1996,part B, vol. 26, no. 1, p. 29-41.
[30] STUTZLE, T. and HOOS, H. MAX–MIN Ant System. *Future Generation Computer Systems*, 2000, vol. 16, no. 8, p. 889-914.
[31] DORIGO, M. and SOCHA, K. *An Introduction to Ant Colony Optimization*. Technical Report TR/IRIDIA/2006-010, IRIDIA, Universite Libre de Bruxelles, 2006.
[32] SHTOVBA, S.D. Ant System. *Exponenta Pro: Mathematics in applications*, 2003, no 4, p. 70-75.
[33] SUBOTIN, S., OLIINYK, A. and OLIINYK, O. *Non-iterative, evolutionary and multiagent methods of synthesis of fuzzy logical and neural network models*. Zaporizhzhia, 2009. 375 p.
[34] CARO G. D., and DORIGO M. *Anet: a Mobile Agents Approach to Adaptive Routing.* Technical Report IRIDA 97-12. IRIDA, Universite Libre de Brusseles. Brussels, Belgium, 1997, 27 p.