Ya. A. Kulyk, Cand. Sc. (Eng.), Assistant Professor; B. P. Knysh, Cand. Sc. (Eng.), Assistant Professor; V. M. Papinov, Cand. Sc. (Eng.), Professor

MODELING OF THE TERRITORY SURVEY BY MEANS OF THE UNMANNED AERIAL VEHICLES ON THE BASE OF THE ANT COLONY OPTIMIZATION ALGORITHM

The paper considers the problem of the optimal route length determination, that allows to perform the survey of the territory in the shortest possible time, that is very important for the monitoring of the forests, rivers, transport, buildings, agricultural lands, calculation of the objects, etc. For the solution of the given problem it is suggested to use the unmanned aerial vehicles and various methods of the route optimization, among which we can distinguish probabilistic methods of the solution searching with minimal time (MTS). Namely, heuristics, cross-entropic optimization, Bayesian optimization algorithm and genetic algorithms, methods of the swarm intelligence optimization on the base of the observations over the wild life (ants colonies optimization (ACO), artificial colonies of bees, flocks of bats, etc.).

It is suggested to use the algorithm of the ant colony optimization, as this enables to maintain the balance between various, namely computational parameters of the unmanned aerial vehicles and optimal length of its route. Experimental studies of the territory survey by means of the unmanned aerial vehicles at different amount of the iterations on the base of the ants colonies optimization algorithm applying modeling in WeBots and tsp-problem-ga-aco-comparisson environments have been carried out, these environments are the simulators of various devices, in particular, unmanned aerial vehicles, that compensates the impact of the external environment on the control of the flight of the unmanned aerial vehicle by means of the embedded programming tools for maintaining the current routing of the unmanned aerial vehicles.

It has been established that the usage of the ants colonies optimization algorithm enables to perform the survey of the territory during less time than the genetic algorithm, which is the standard algorithm of numerous control systems by default, finding the balance between the optimality of the route and computational resources.

Key words: *unmanned aerial vehicles, ant algorithms, optimization of the ant colony, survey of the territory, algorithm.*

Introduction

In recent years the remote devices and facilities are developed at a rapid pace. The application of the unmanned aerial vehicles (UAV), which perform various tasks, connected with the survey of the territory has become especially popular. The example of UAV application is the monitoring of the forests, rivers, transport facilities, buildings, agricultural lands, calculation of the objects, etc. [1]. As a rule, the task of the territory survey is formulated approximately. Operator of UAV solves this problem by introducing the sequences of the territory coordinates for the survey by means of UAV. To reduce the load on the operator the systems of the automatic calculation of the trajectory of the flight with the selection of the optimal route are used [2, 3]. However, the given systems do not operate very efficiently and use standard methods of motion, without taking into account the achievements in the sphere of optimization [4]. That is why, there appears the need to improve the efficiency of UAV motion in the process of the territory survey.

Flying time of UAV is limited by the accumulator capacity or fuel reserve, thus the territory survey must not exceed this time. Thus, there appears the need to compose the optimal plan of the UAV flight route passage.

For the determination of the optimal route, enabling to perform the territory survey during the shortest possible time, various methods of the optimization can be used. The probabilistic methods of the decision searching with minimal time (MTS) can be distinguished among them : heuristics, cross-entropic optimization, Bayesian optimization algorithm and genetic algorithms (GA) [5], group of the optimization methods of swarm intelligence on the base of the observation of the wild life: ants colonies optimization (ACO) [6], artificial bees colonies, flocks of bats, etc. [7].

Method of ant colonies optimization is suitable of the problems of various complexity, where the balance between different parameters must be maintained. In our case – these are computational resources of UAV and optimal length of its route. The problem of the territory survey, set by the group of the coordinates, is close to the travelling salesman problem [8], with which the method of ant colonies optimization, realized by means of the corresponding algorithm, copes well.

Aim of the research is the enhancement of the territory survey efficiency by means of UAV on the base of the ant colony optimization algorithm.

Algorithm of ant colony optimization for the territory survey by means of UAV

The ants colony optimization (ACO) – is metaheuristic algorithm on the base of the swarm, which simulates the behavior of the ant colonies in nature while food searching [9].

Artificial ants, unlike the biological ones, move across the discrete environment, determined by the nodes (vertices) and have memory, pheromones are secreted on the virtual pheromone map. Passing from one node to another, the ants leave the traces of the pheromones on the route between the nodes.

The traces of the pheromones attract other ants which secret more pheromones that leads to the accumulation of the pheromones traces. Negative feedback is used by the evaporation of the pheromones and restrain the ants from the same route and enables to search constantly better solutions.

Usage of the algorithm of the ants colony optimization for UAV will result that the most intensive pheromone routes will become the most probable route for UAV. The more optimal the route is, more probable is its usage by other ants, and, consequently, by other UAV.

UAV performs the survey of the territory, set by a group of coordinates, with minimal time losses, as the flying time is limited the capacity of the accumulator. The given task is close to the mathematical travelling salesman problem, namely, for the predefined set of the cites with the known distance between them it is necessary to find the shortest route, which allows to visit each city only once [8]. It can be presented in the form of the graph with N vertices, that represent cities and the set of E edges, which completely connect vertices N with the length d_{ij} ($(i; j) \in E$), which is the distance between cities i and j. For the solution of this problem it is necessary to find the Hamiltonian cycle of the graph $G = (N; E)$ for all $n = |N|$ vertices G, and its length is determined by the sum of the lengths of all edges it consists of. Optimal solution is the repositioning π of the vertices 1, 2, …, N so that the length $f(\pi)$ was minimal and determined as

$$f(\pi) = \sum_{i=1}^{N} d_{\pi(i)\pi(i+1)} + d_{\pi(n)\pi(1)}, \tag{1}$$

where $d_{\pi(i)\pi(i+1)}$ – is the length of the edge between the city i and city $i+1$ for all the combinations of the repositioning π from 1 to N; $d_{\pi(n)\pi(1)}$ – is the length of the edge between the city n and the city 1 for all combinations of the repositioning π from 1 to N.

Visibility of the vertex i relatively the vertex j is inversely proportional to the length:

$$\eta_{ij} = \frac{1}{d_{ij}}. \tag{2}$$

UAV performs the survey of the territory on the base of the algorithm of ant colony optimization, that generates the colony of the artificial ants, which move between the vertices in the search of optimal route. The algorithm consists of two basic stages, which are repeated: passage of the flight route and renewal of the pheromones (Fig. 1).

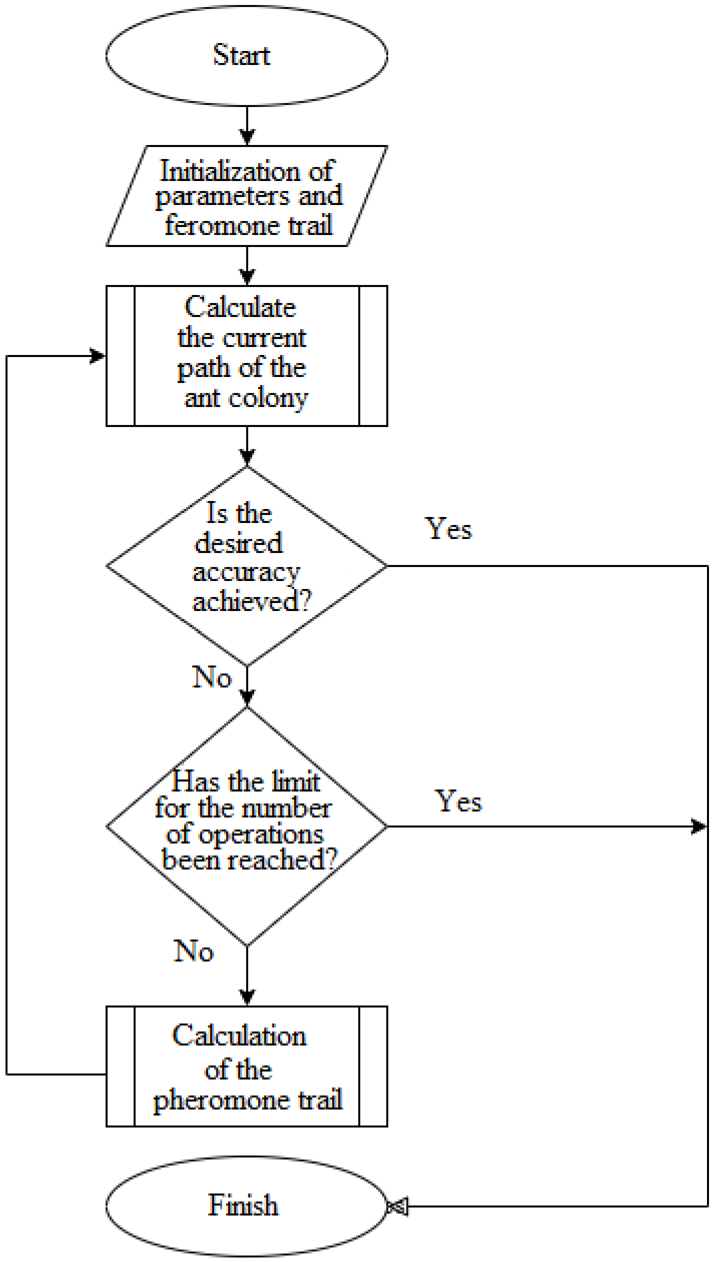

Fig. 1. Block-diagram of the algorithm of the ant colony optimization

At each step of the graph construction the artificial ant k uses the probabilistic rule of the action choice, called «rule of the roulette ». Each vertex is connected with a certain probability of being randomly chosen from the set of the vertices, which were not visited before.

Algorithm stops when the satisfactory solution is found or when maximum number of iterations is achieved [8].

Modeling of the territory survey with the help of UAV in WeBots environment

Modeling of the territory survey by means of UAV on the base of the algorithm of the ant colony optimization was performed in WeBots environment. The given environment enables to perform modeling of the programme control of the devices, in particular UAV. Control is simplified, i. e., the impact of the external environment is considered to be predictable, weather conditions – normal and suitable for the flight. WeBots, creates the conditions for modeling, when the impact of the external environment on the control of UAV flight is compensated by the built-in programming tools for maintaining the current route of the UAV.

Modeling allows to improve considerably the efficiency of the real system, detect faults, provide structural changes at the design stage and reveal strategic drawbacks, which are of long-lasting character.

In the modeling environment the test virtual world was created, where the simulation of the task of the territory survey by UAV was possible. The advantage of the virtual environment is the lack of risks of the material losses in case of the mistakes of UAV operator or the failure of the program, possibility of performing far more studies, simplified procedure of data collection and possibility of the time management in the environment.

For the experimental verification of the efficiency of the territory survey by means of UAV the environment on the base of the algorithm of the ant colonyoptimization is created in the form of the virtual world (Fig. 2), its impact on the UAV characteristic is not great.

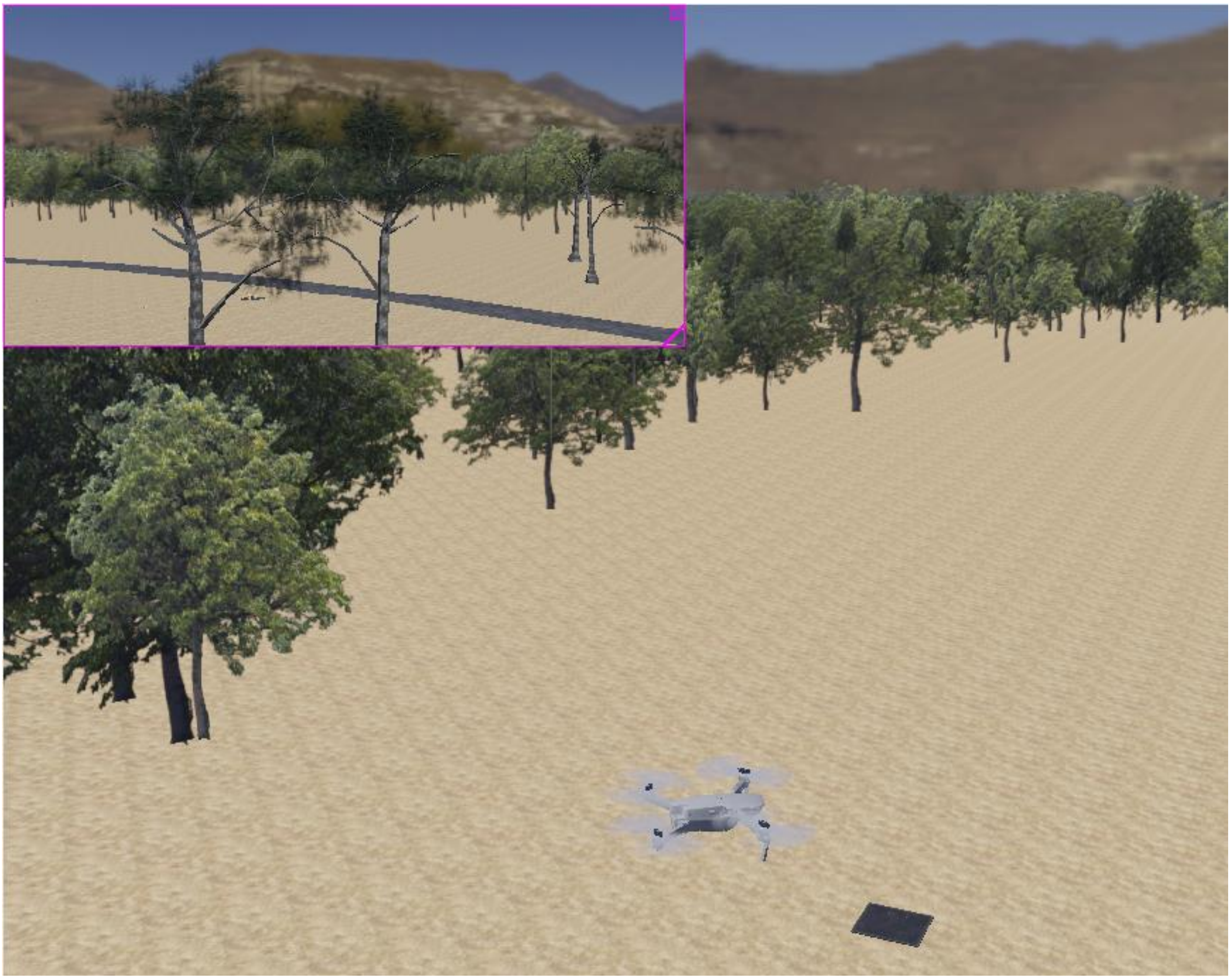

Fig. 2. Virtual world, created in WeBots environment for the experimental verification of the efficiency of the territory survey by means of UAV on the base of the algorithm of the ant colony optimization

Virtual world contains the territory with different landscape, trees and technogenic objects. As UAV model Mavic 2 Pro is chosen, this device has good system of video observation, bult-in collision prevention system, and maximum flying time 30 min. Section of the territory for the survey was assigned in the form of the set of the coordinates, which were the input data for UAV, performing the survey of this territory on the base of the flying control program that constructs the route after the optimization of the coordinates set by the algorithm of the ant colony optimization (Fig. 1), using the formulas (3 – 6).

Assessments of the territory survey efficiency by means of UAV on the base of the algorithm of the ant colony optimization

To obtain the characteristic which would serve as the assessment criterion for the efficiency of the system territory survey is not a trivial task and there is no unique and universal solution of this problem [10]. That is why, for the assessment of the efficiency of the given system we will take into account the fact that UAV operation time depends on the accumulator capacity (or petrol tank) and is one of the basic characteristics, that is difficult to change without considerable increase of the expenses or degradation of other characteristics. Thus, the possibility to perform the survey is determined by the time of the battery discharge, that is why, time is one of the main criteria of the efficiency.

Efficient survey of the territory by means of UAV requires the realization of the task, dealing with the planning of the UAV route, that provides the usage of the expenses function:

$$J_G = K \cdot \sum_{i=1}^{N+1} d_{ij} + C = K \cdot \sum_{i=1}^{N+1} d_{ij} + K1 \cdot \sum_{l=1}^{M} h_l + K2 , \quad (3)$$

where J_G – are flight expenses; d_{ij} – is the length of the route segments; C – is the value that combines the risk cost and flight stabilization cost; N – is the number of the coordinates for the territory survey; K –*is* expenses coefficient for a unit of the length during the flight; $K1$ – is a unit of the flight altitude change of UAV (consists of the fuel expenses or the electric energy of the battery of UAV); M – is a number of the altitude changes for UAV; h – is current altitude of the UAV during the flight; $K2$ – is the value that combines the cost of the risk during the flight and is calculated on the base of the statistical data of the UAV repair cost if damaged [11].

As it is seen from the formula (7) UAV performing the territory survey by the shortest route and, correspondingly, during the minimal time, will be least expensive.

Realization of the optimization of UAV covered route for the territory survey during the shortest time was performed by means of tsp-problem-ga-aco-comparisson software [12], it enables to generate the set of vertices and search for the ways of by-passing these vertices, using different methods, in particular, by means of the algorithm of ant colony optimization.

Fig. 3 presents the optimal routes of UAV, which performs the territory survey by means of the algorithm of the ant colony optimization by generated random 24 coordinates.

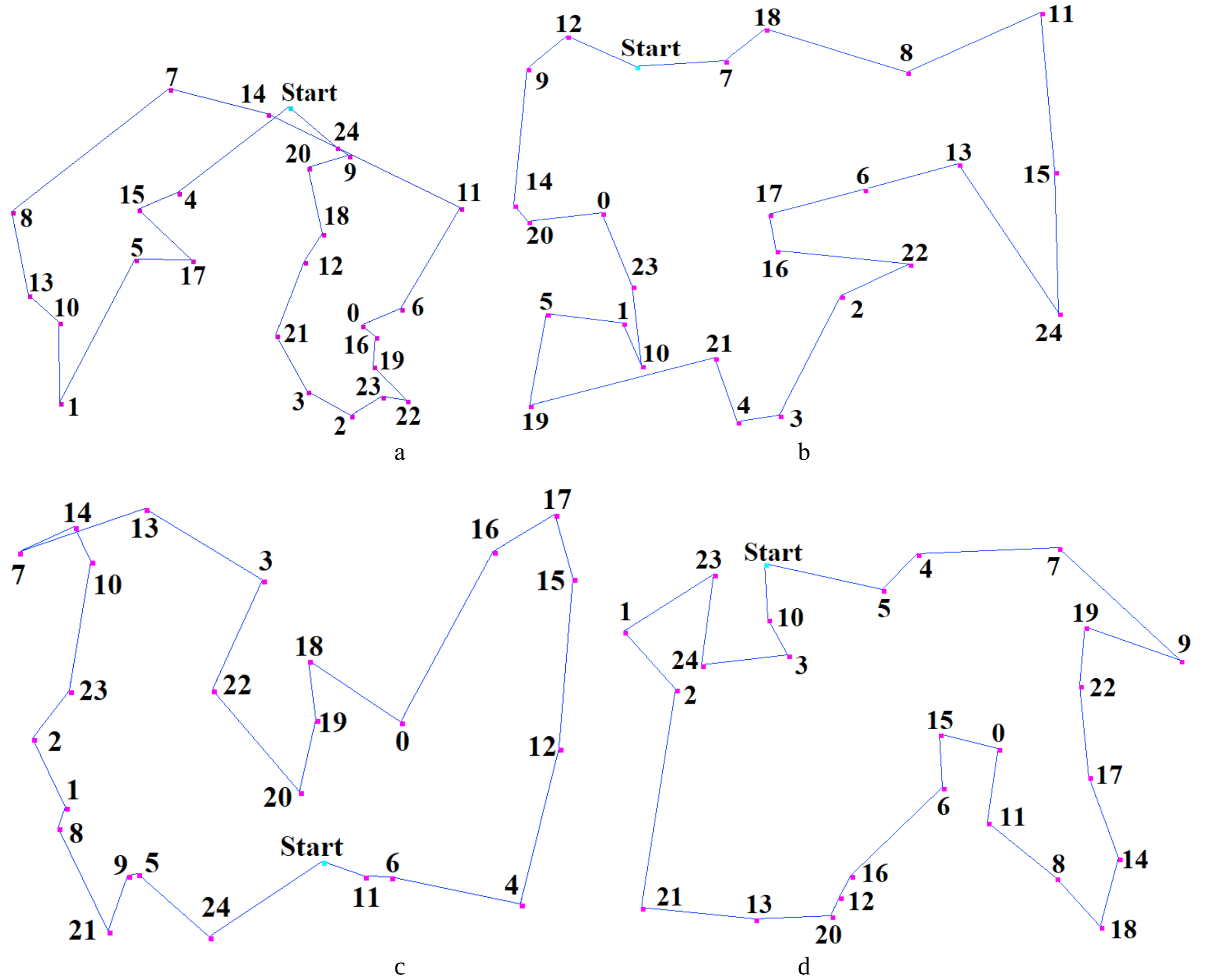

Fig. 3. Optimal routes of UAV relatively motion Start by generated random 24 coordinates: a – the first route; b – the second route; c – the third route; d – the fourth route

Figs. 4 – 7 present the graphs of the optimal route lengths, depending on the number of iterations on the base of the algorithm of the ants colony optimization, according to Fig. 3 and genetic algorithm. Comparison is performed namely with the genetic algorithm, as it is rather widely used for determining the optimal route.

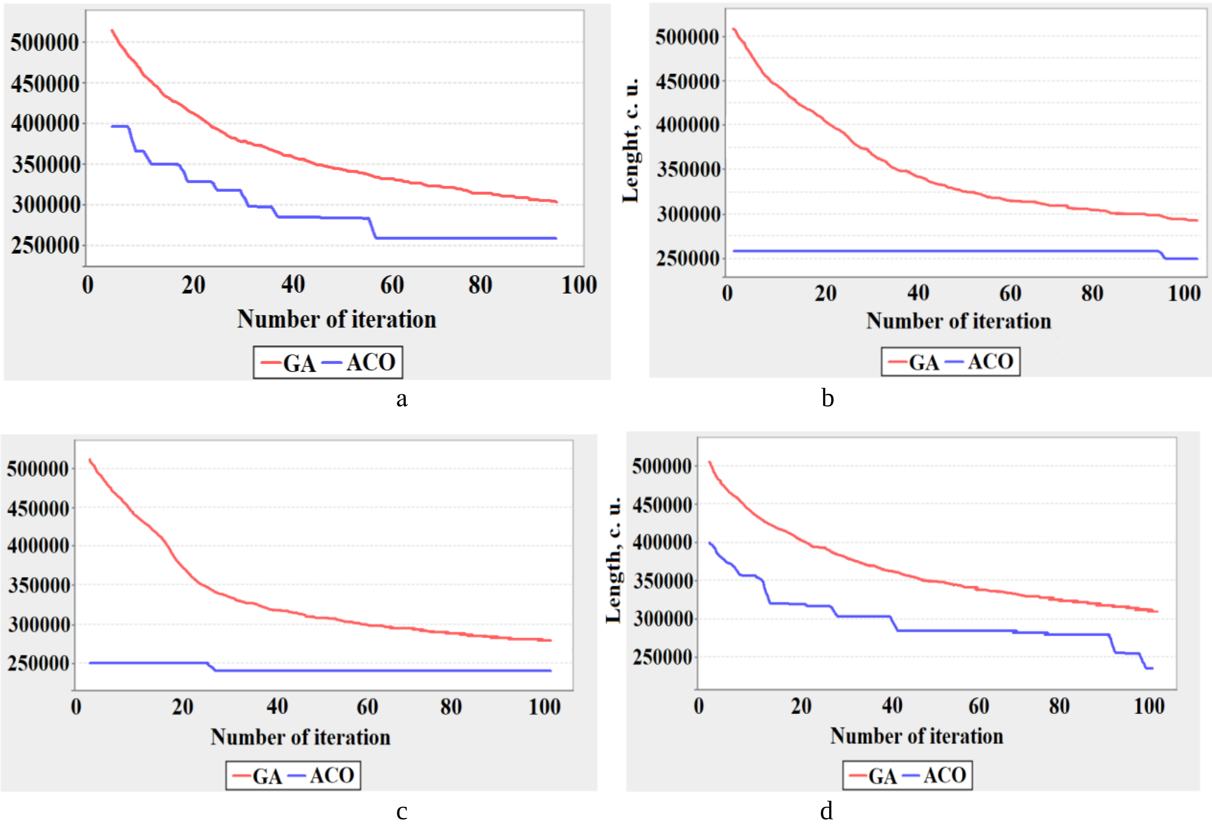

Fig. 4. Graphs of the length of the first optimal route, depending on the number of iterations on the base of the algorithm of ants colony optimization (ACO) and genetic algorithm (GA): a – the first route; b – the second route; c – the third route; d – the fourth route

Graphs in Fig. 4 are obtained at such parameters:

– number of ants in the colony m =50,
– speed of the pheromone evaporation ρ =0.1,
– intensity factor of pheromone α =0.1,
– visibility factor of pheromone β =0.8,
– visibility distance of pheromone – 2,
– number of points of the route (coordinates for visiting) – n =25,
– number of iterations (criterion of the calculation stop) – 100.

It is seen from Fig. 4 that ants colony optimization algorithm decreases the length of the optimal route with the increase of the number of iterations. Thus, for the first route the decrease occurs from 400 thousand c. u. at the iteration 5 to 260 thousand c.u. at the iteration 55; for the second route from 260 thousand c. u. at the iteration 3 to 250 thousand c.u. at the iteration 95; for the third route from 250 thousand c. u. at the iteration 3 to 240 thousand c. u. at the iteration 25; for the fourth route from 400 thousand c. u. at the iteration 3 to 240 thousand c. u. at the iteration 100. As it is seen, the greatest reduction of the length occurs at the initial iterations, whereas at the last iterations the reduction of the optimal length almost does not occur. That is why, to decrease the computational complexity of the method it is expedient to reduce the number of iterations.

Also, for the comparison, in Fig. 4 the graphs of the reduction of the optimal route on the base of the genetic algorithm are added. Thus, for the first route the decrease occurs from 510 thousand c. u. at the iteration 5 to 300 thousand c. u. at the iteration 95; for the second route – from 510 thousand c. u. at the iteration 3 to 290 thousand c. u. at the iteration 100; for the third route from 510 thousand c. u. at the iteration 3 to 275 thousand c. u. at the iteration 100; for the fourth – from 510 thousand c. u. at the iteration 3 to 310 thousand c. u. at the iteration 100. It is seen, that ant colony optimization algorithm enables to construct the shorter route, namely, for the first route – at

40 thousand c. u., for the second route – at 40 thousand c. u., for the third route – at 35 thousand c. u., for the fourth route – at 50 thousand c. u. Hence, ants colony optimization algorithm allows to perform the territory survey during less time and is more efficient.

Ants colony optimization algorithm finds the solution during suitable time, however it does not give the warranty that the determined solution is not suboptimal. It is possible to reduce the probability of finding the suboptimal solution by means of increasing the number of iterations, but even multiple increase of the iterations in greater part of cases will lead to minor reduction of the route length or does not lead at all.

Conclusions

The given research suggests to use the ants colony optimization algorithm for the calculation of the optimal route for the territory survey by means of UAV.

Experimental studies of the optimal route for the territory survey by means of modeling, using WeBots and tsp-problem-ga-aco-comparison environments were carried out. The studies showed that the usage of the algorithm of ants colony optimization allows to perform the survey of the territory during the less time, than using the genetic algorithm, maintaining the balance between the optimality of the route and computational resources. It is worth taking into account. that the found solution may be suboptimal.

REFERENCES

1. Knysh B. P. Assessment of the objects state by the unmanned aerial vehicles / B. P. Knysh, M. A. Alekseev// Bulletin of Vinnytsia Polytechnic Institute. - 2019. – № 2. – P. 58 – 65. (Ukr).

2. Classication of multi-UAV architectures. In Handbook of unmanned aerial vehicles / I. Maza, A. Ollero, E. Casado [et al.] // Springer. – 2015. – P. 953 – 975.

3. Modelling the one channel systems of a deliveryof goods provided by unmanned aerial vehicles / R. N. Kvetny, Y. A. Kulyk, B. P. Knysh [et al.] // INTL Journal of electronics and telecommunications. – 2020. – Volume 2020, № 3. – P. 487 – 492. – DOI: https://doi.org/10.24425/ijet.2020.134003.

4. Senanayake M. Search and tracking algorithms for swarms of robots: A survey / M. Senanayake, I. Senthooran, J. C. Barca // Robotics and Autonomous Systems. – 2016. – Volume 75. – P. 422 – 434.

5. Jones K. O. Comparison of ant colony optimization and differential evolution / K. O. Jones, A. Bouet // International conference on Computer systems and technologies (ACM). – 2007. – P. 25.

6. Carabaza S. P. Ant Colony Optimization for Multi-UAV Minimum Time Searching Uncertain Domains / S. P. Carabaza, E. Besada, J. A. Lopez-Orozco // Applied Soft Computing. – 2018. – Volume 62. – P. 789 – 806. – DOI: 10.1016/j.asoc.2017.09.009.

7. Cimino M. G. Combining stigmergic and flocking behaviors to coordinates warms of drones performing target search / M. G. Cimino, A. Lazzeri, G. Vaglini // In Information, Intelligence, Systems and Applications (IISA). – 2015. – P. 1 – 6.

8. Shtovba S. D. Ant Algorithms : Theory and Applications / S. D. Shtovba // Program Comput Soft. – 2005. – Volume 31. – P. 167 – 178. – DOI: https://doi.org/10.1007/s11086-005-0029-1.

9. Dorigo M. Ant Colony Optimization / M. Dorigo, T. Stützle // The MIT Press. – 2004. – P. 305. – DOI: http://dx.doi.org/10.1007/b99492.

10. Birdsey L. Identifying self-organization and adaptability in complex adaptive systems / L. Birdsey, C. Szabo, K. Falkner // In Self-Adaptive and Self-Organizing Systems (SASO). – 2017. – P. 131 – 140.

11. Lin N. A novel improved bat algorithm in UAV path planning / N. Lin, J. Tang, X. Li, L. Zhao // Computers, Materials & Continua. – 2019. – Volume 61, № 1. – P. 323 – 344. – https://doi.org/10.32604/cmc.2019.05674.

12. Yaseen M. Experimental Comparison between Genetic Algorithm and Ant Colony Optimization on Traveling Salesman Problem / M. Yaseen, J. Razia, Md. T. Rahman // International Journal of Scientific Research in Science, Engineering and Technology. – February 2021. – Volume 8, Issue 1. – P. 155 – 162. – DOI: https://doi.org/10.32628/IJSRSET218135.

Editorial office received the paper 18.09.2022.
The paper was reviewed 25.09.2022.

Kulyk Yaroslav – Candidate of Science (Engineering), Assistant Professor with the Department of automation and Intelligent Information Technologies.

Knysh Bohgan – Candidate of Science (Engineering), Assistant Professor with the Department of General Physics, tutmos-3@i.ua.

Papinov Volodymyr – Candidate of Science (Engineering), Professor with the Department of Automation and Intelligent Information Technologies.

Vinnytsia National Technical University.