# “Flight Map” Modelling Intellectual Geoinformation System for Urban Areas Cargo Delivery by Unmanned Aerial Vehicle

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Abstract: This article is dedicated to solving the problem of safe and secure cargo delivery in urban territory using unmanned aerial vehicles (multicopters) by modelling “flight map”, i.e. a system based on intellectual geoinformation system that develops an optimal and secure route for each UAV in the system and tracks all of them on electronic map online. The paper describes the results of algorithms analysis and assumes the algorithm showing higher test results.

## 1 INTRODUCTION

Today multicopters are highly sought and popular remote control Unmanned Aerial Vehicles (UAVs). Multi-rotor UAVs are equipped with special electronic sensors like accelerometers and gyroscopes allowing the UAV to stay stable and maneuver (Garcia et al., 2017). The multicopter can be used for performing various tasks including cargo delivery. UAV owners, logistics companies and carriers can benefit from using UAVs for cargo delivery purposes (Tkachev et al., 2015). Thereby, modelling “flight map” for UAVs using geoinformation system is absolutely necessary. “Flight map” modelling in this case means developing a transport network model, UAVs security control system (Bansal et al., 2017) providing UAVs flights safety in predetermined echelons and corridors, and online real-time UAVs tracking system. The automation system is based on geoinformation system, electronic vector map, transport network model and transport infrastructure objects database.

A step-by-step transition from autonomous route guidance to dynamic is a promising direction of route navigation development. In this case, the main task of information processing is optimal route selection and its dynamic correction during the flight (Iswanto et al., 2017). Dynamic route management presumes, first and foremost, the possibility to dynamically correct (recalculate) at any time and at any point of the route the optimal route taking into account any changes in the transport network (Stepanov, 2015) and also possible changes in route selection criteria (Antoniades et al., 2017).

## 2 TRANSPORT NETWORK MODEL

The paper provides *graph-based transport network model* for UAVs route development consisting of following entities:

- *area* – piece of transport network represented by a set of coordinate pairs, described as a set of physical parameters. The area is encoded by a polygon defined by its vertices coordinates;
- *node* – point where traffic flows are separated. The node is the vertex of the oriented graph, channeling traffic flows. It lies at the junction of two areas and indicates the possibility of moving from one area to another in the direction defined by the relevant arc. Two adjacent areas are assigned with two nodes. Node is encoded by a point;
- *arc* – element of the oriented graph that defines the direction of the traffic flow on the area. It contains relevant characteristics including arc length, traffic intensity, traffic density, etc. Two nodes are assigned with one arc defining the traffic direction, or two arcs defining the direction reverse area. Several arcs (traffic flows) can be included in one area but each arc can be included in only one area. Arc is a linear object.



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The “flight map” is meant for UAVs route development (from one landing platform to another) when performing cargo transportation from supplier to a consumer taking into account normal and abnormal situations. The “flight map” is characterized by a corridor (a range of possible UAV horizontal plane coordinates) and echelon (a conditional height, established intervals value distant from other heights).

This paper assumes that only 1 UAV is present in the arc or node at the same time. That means UAVs are canalizing in terms of time and space.

*Landing Platform (LP)* is designed for safe take-off and landing of UAVs in urban areas. All the LPs are deployed on the electronic map and included in UAV “flight map”. The LPs can be divided into groups according to its assignment: *sources* (take-off platforms), *outlets* (landing points), *charging points*, *service stations, emergency landing platfoms.*

# 3 ROUTE DEVELOPMENT ALGORITHMS

## 3.1 Graph Model Algorithms

Route development algorithms are based on UAVs “flight map” graph model and rely on Dijkstra’s algorithm and branch and bound method for various optimality criteria. In the context of dynamic route management an additional criterion appears: optimal path searching algorithm running time, which should be minimized (Hayat et al., 2017).

In fact, route development is one of the traveling salesman problem variations. All the optimal path searching algorithms operate with graphs, all vertices of which are included in the route (Vareldjan et al., 2015).

## 3.2 Little’s Algorithm

An algorithm for the traveling salesman problem by John D. C. Little is a particular case of the branch and bound method. In a best-case scenario its usage provides an opportunity to reduce the number of operations.

The algorithm is used for an optimal route search provided that an object (UAV) is returning to the starting point. As a result, Little’s algorithm provides a close loop (which may be not optimal) in less than $n$ steps. Calculation process complexity lies in the fact that at each step it is necessary to analyze the elements of the matrix and select zero elements (applicants for branching and evaluation). With regard to algorithm running time, with big $n$ values the optimal path may not be found at all due to the growth of the number of branches and bounds. Therefore, it is required to determine the optimal value for the algorithm.

## 3.3 Genetic Algorithm

Initialization, i.e. initial population formation is the random selection of a predetermined number of chromosomes represented by binary sequences of fixed length. For UAV “flight map” modelling the *id* number of the visited object is used as a gene. Route’s weighting coefficient is assumed as a chromosome fitness function (Silva Arantes et al., 2017).

## 3.4 Initial Data and Requirements

The algorithms were tested using the initial data shown in table 1 for single UAV involving. New graph is generated automatically after every test cycle.

Table 1: Test cycles initial data.

| № | № of areas | | | № of arcs |
|---|---|---|---|---|
| | T-shaped | X-shaped | I-shaped | |
| 1 | 5 | 20 | 3 | 275 |
| 2 | 10 | 40 | 6 | 550 |
| 3 | 20 | 80 | 12 | 1100 |
| 4 | 40 | 160 | 24 | 2200 |
| 5 | 80 | 320 | 48 | 4400 |
| 6 | 160 | 640 | 96 | 8800 |
| 7 | 320 | 1280 | 192 | 17600 |
| 8 | 640 | 2560 | 384 | 35200 |
| 9 | 1280 | 5120 | 768 | 70400 |
| 10 | 2560 | 10240 | 1536 | 140800 |
| 11 | 5120 | 20480 | 3072 | 281600 |
| 12 | 10240 | 40960 | 6144 | 563200 |

LP is an integral structure for UAV’s take-off and landing providing safe and accurate landing in urban areas. LP has to provide UAV’s wireless charging, UAV’s status, options, cargo information and other data transmission via WiFi / 4G / Ethernet networks. LP’s normal functioning should be ensured for supply voltage of 100-240 V, temperature of 5-45 C, wind speed up to 5 m/s and light precipitation.

Weight of transported cargo should not exceed 5 kg. Cargo has to be packed in a special container for transportation and should not be prohibited from transportation by Government regulations.

The UAV should be supplied with GPS / GLONASS navigation system, telemetry system, radio-beacon system, backup autonomous navigation system, navigation light and 3-axis magnetometer. The range of operating flight heights is from 300 m to 1200 m.

The analysis of each tested algorithm performance is presented in "Test Results" section.

## 4 SYSTEM DEVELOPMENT

System was based on intellectual geoinformation system ITSGIS. Figure 1 shows the UAV "flight map" implemented in ITSGIS (Golovnin et al., 2017).

The system offers the possibility to add and edit UAV "flight map" in multi-user mode, which determines the use of multitier system architecture. It is important to ensure data consistency and eliminate emerging conflicts. The system is developed using a three-tier architecture model (as shown in Figure 2). Communication between clients and the application server is based on Windows Communication Foundation (WCF) technology.

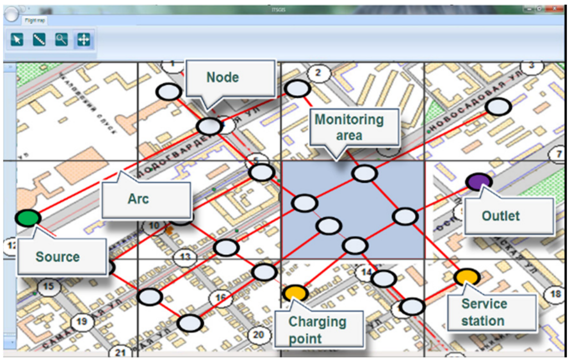


Figure 1: UAV "Flight map".

Figure 3 shows the diagram of system components.

Fundamental system components are:

- ITSGIS.exe – client's executable file;
- WCFServer.exe – server's executable file;
- DAO – database access layer;
- Services – system services; located on the server side and access the database through the database access layer;
- Managers – system managers; located on the client's side and access the services through the network channel.



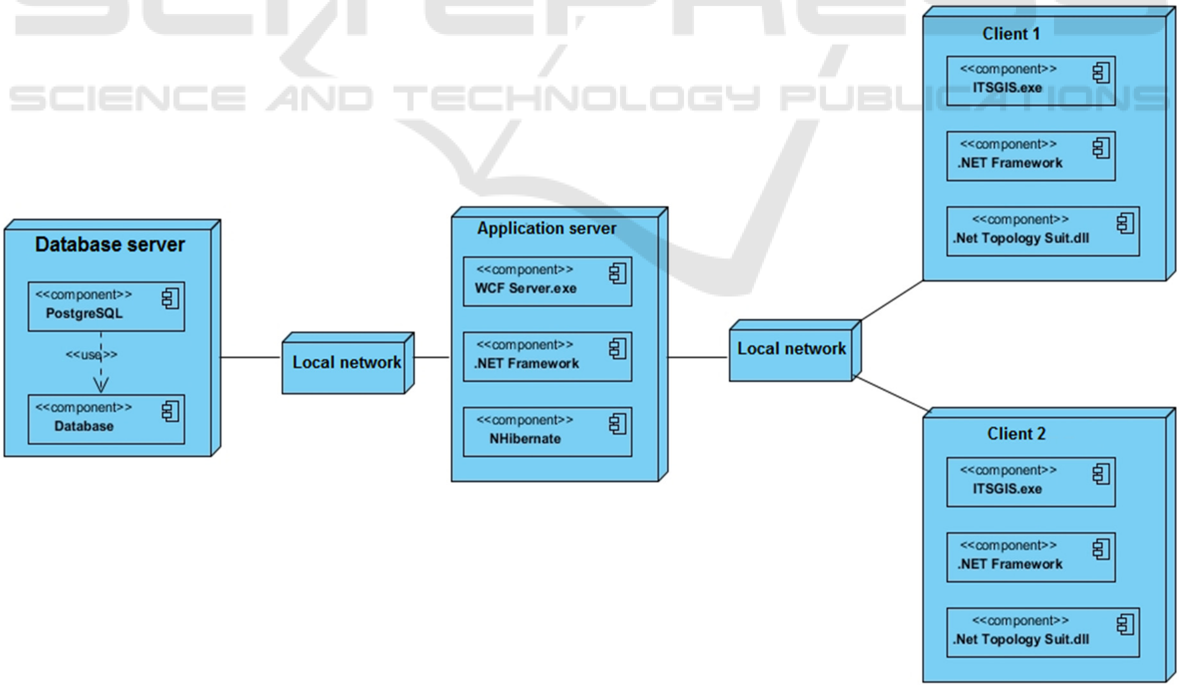


Figure 2: System architecture.

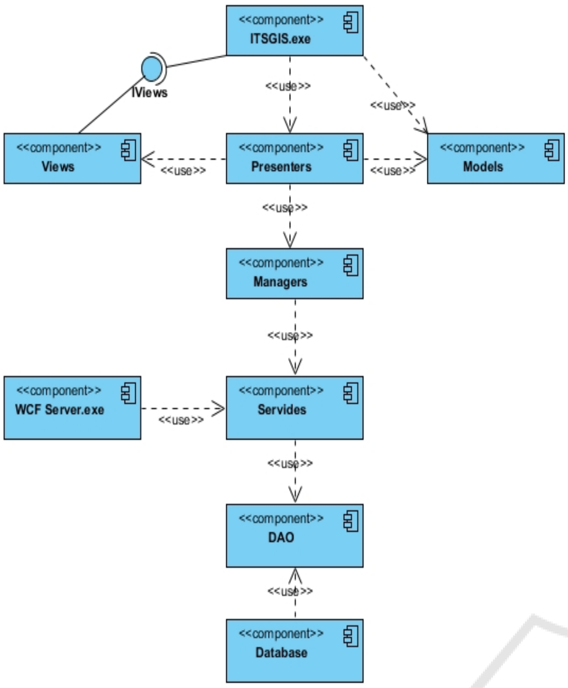


Figure 3: System components.

## 5 TEST RESULTS

Graphs of Figures 4 to 6 show the results of algorithm tests. All algorithm tests were conducted under the following testing conditions: CPU with 2 cores 2.8 GHz; 8 GB of RAM; Microsoft Windows 8; Microsoft .NET 4 and using the same test equipment.

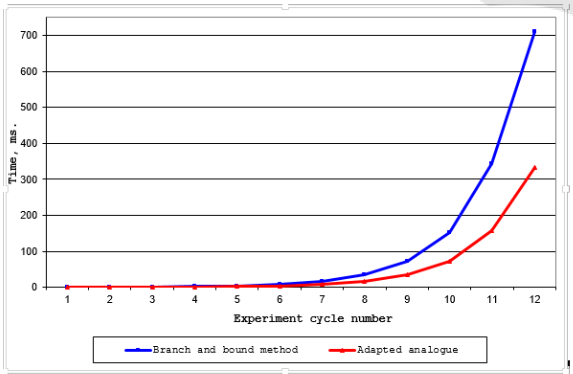


Figure 4: Branch and bound method and its adapted analogue comparison.

Figure 4 shows the comparison of branch and bound method and its adapted analogue according to its running time parameter.

The point of adapted branch and bound method is that it involves adding of an extra evaluation in order to find the best node to branch. Thereby, evaluation of every node in the tree is presented not only by the distance travelled to the current node but also by the distance left to travel to the final node.

In this case, the number of optimal path searching iterations increases in proportion to the length of the route.

Figure 5 shows the dependence of the optimal route searching time on the number of vertices of the graph containing about 35000 arcs.

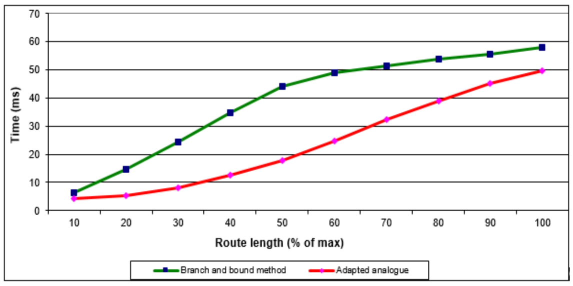


Figure 5: Dependence of the optimal route searching time on the number of vertices.

Figure 6 shows the comparison of branch and bound method and Dijkstra's algorithm. This test results show that with the number of nodes up to 30 000, Dijkstra's algorithm and branch and bound method have roughly the same running time. However, with the vertices number increasing, Dijkstra's algorithm is showing significantly lower results.

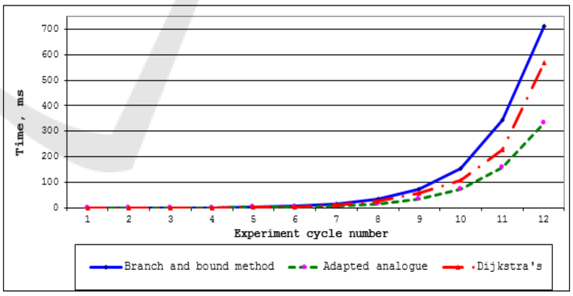


Figure 6: Dependence of the optimal route searching time on the model dimension.

Graph of Figure 7 shows the results of Little's algorithm running time analysis for various numbers of points.

For routes with the number of points more than 60 algorithm's running time increases significantly. Thereby, the optimal number of points to use that algorithm is ≈60.

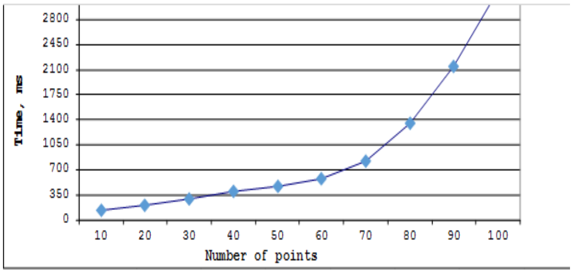


Figure 7: Little's algorithm running time analysis.

Graphs of Figures 8 to 10 show the genetic algorithm test results. An important parameter for mutation operator usage is a mutation probability $p_{mut.}$. Graph of Figure 8 shows the dependence of the route length on the algorithm running time for different mutation probabilities (0.3, 0.15, 0.05). The test was carried out for the 100 points graph.

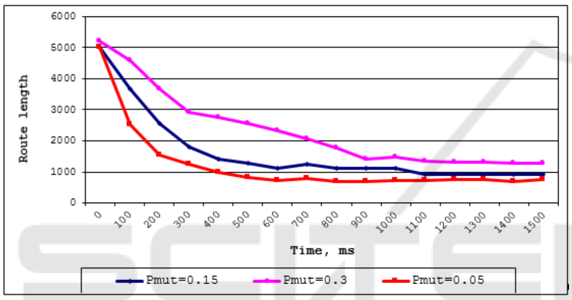


Figure 8: Dependence of the route length on mutation probability.

Algorithm's performance for 100 points graph various crossing over methods is shown in Figure 9.

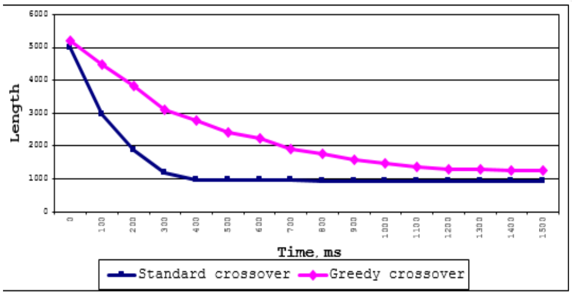


Figure 9: Dependence of the route length on crossingover.

The graph shows that standard crossing over method outputs a near-optimal result in less time than "greedy crossover". Convergence rate and accuracy depends on the number of individuals specified beforehand.

Figure 10 shows the genetic algorithm convergence analysis for 10, 100, 250 and 500 individuals. The analysis shows that an increase in the number of individuals leads to a more accurate result.

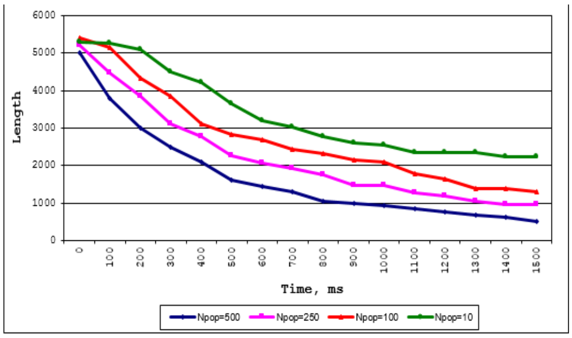


Figure 10: Dependence of the convergence rate on individuals number.

# 6 CONCLUSIONS

This paper suggests the concept of "flight map", developed for providing safe and secure unmanned aerial vehicles cargo delivery in urban areas.

The paper describes a graph-based transport network model for UAVs route development; requirements for unmanned aerial vehicles, landing platforms and cargo parameters; system architecture model and system components diagram.

The "Test Results" section presents the results of various algorithms performance analysis and its comparison depending on relevant parameters.

Proceeding from the results obtained the Little's algorithm is appropriate to use for optimal route searching in the cases of 60-70 vertices present. When performing the tests for the graphs of relatively small dimensions, all the examined algorithms show equal results on the average. For the cases with the mean distances in a graph the adapted algorithm has an advantage. And for the cases with maximum distances in a graph (from one graph's end to another) the benefits of adapted algorithm are decreasing.

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