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MINIMIZATION OF UNMANNED AERIAL VEHICLE TRAJECTORY DEVIATION DURING THE COMPLICATED OBSTACLES OVERFLY

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Abstract. *In the article the important problems of Unmanned Aerial Vehicle collision avoidance have been discussed. The model of Unmanned Aerial Vehicle movement was described. The principle of complicated form of the obstacle overfly trajectory creation has been represented. An overfly of the restricted area at the aeronautical chart was shown.*

Keywords: aeronautical chart, collision avoidance, obstacle, overfly, Unmanned Aerial Vehicle.

Introduction

The usage of Unmanned Aerial Vehicles (UAVs) has been increasing rapidly. Such aircraft are capable to plan their own trajectory in the transition between desired locations, and it can also avoid any obstacles in their path.

But if it is necessary to move the UAVs outside of the restricted areas into the areas of general use, it is necessary to take into account that UAV must be able not only to avoid fixed obstacles, but it can effectively deal with moving obstacles as well.

The change of the planning problem from the fixed obstacles to moving one changes the problem from a geometric (prohibition to enter the restricted area) to a dynamic one (prohibition to enter the restricted area at certain period of time taking into account the ability of UAV to change their location at time).

As far as conflict detection and resolution can be reliable that is to have the ability of the model to predict the future, the most concrete difference between modeling approaches involves the method by which the current states are projected into the future. There are three fundamental extrapolation methods such as Nominal, Worst-case and Probabilistic.

For the UAV's collision avoidance the following methods are used as well:

– Methods using dimensions of state information (vertical, horizontal, or three-dimensional);

– Conflict detection threshold;

– Conflict resolution method (prescribed, optimized, force field [1], or manual);

– Maneuvering dimensions [2] (speed change, lateral, vertical, or combined maneuvers);

– Management of multiple aircraft conflicts (pairwise or global).

Besides, regarding UAV's collision avoidance it is necessary to take into account the specific character which current states and metrics are used to make conflict detection and resolution decisions, how uncertainty is managed in the model, and the degree to which the model which assumes coordination between aircraft is involved in a conflict.

But all these methods do not take into account the exact shape of the obstacle specifying it by some geometrical figures i.e. circle or ellipse.

The purpose of the article is methodic development of trajectory choice of minimal deviation from the complicated form objects.
One of the possible UAV collision avoidance methods with obstacles is probabilistic method based on the UAV heading and turn rate changes. These methods give a set of UAV's trajectories for the change of its location in case of possible conflict situation.

Model of UAV movement

There are a lot of different models of UAV movement. Each of them is used for the particular tasks connected with UAV trajectory simulation. Besides, the choice of the model depends on the UAV type and its dynamic peculiarities. But all the models are characterized with maximal and minimal allowable parameters. To solve the navigation task of minimized deviation from flight plan trajectory the simplified model can be used. It is described by the following formulae:

$$X_i = X_{i-1} + \begin{pmatrix} V\sin(\psi) \\ V\cos(\psi) \end{pmatrix},$$

where X_i are coordinates of the location at the *i*th moment of time;

V is UAV velocity;

Ψ is UAV heading.

It is necessary to take into account that

$V_{\min} \le V \le V_{\max}$,

$\psi_{\min} \le \psi \le \psi_{\max}$.

At every moment of time it is possible to guide the UAV position by the change of its velocity and heading [3]. The possible ways of UAV trajectories with random change of velocity and heading in every time moment have the view of the tree. The example of the initial position (0, 0) modeling is shown in fig. 1.

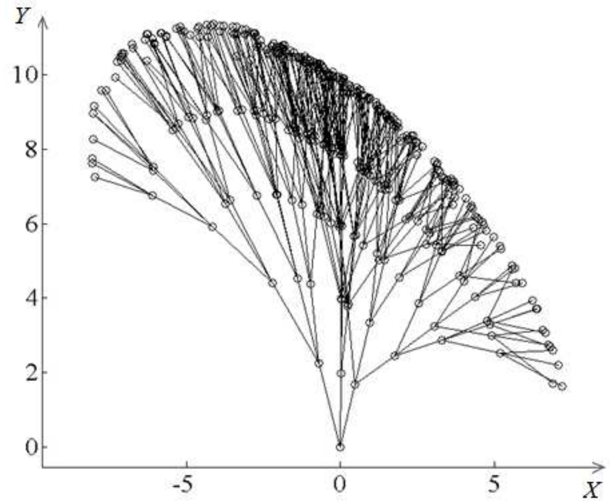

Fig.1. The possible ways of UAV trajectories for automatic conflict avoidance

Collision Avoidance Guidance

The task of UAV missions is based on the input of initial position and coordinates of the destination. Coordinates of the initial position can be determined, by the use of satellite navigation system or indoor navigation systems (Inertial Navigation System, whether they can be set by user in the local coordinate system). The coordinates of the destination point are set according to the mission task. The coordinates of the initial and destination positions are represented in matrix form:

$$XL = \begin{pmatrix} x_{01} \\ x_{02} \end{pmatrix},$$

$$YL = \begin{pmatrix} y_{01} \\ y_{02} \end{pmatrix},$$

where x_{01}, y_{01} are coordinates of the initial position;

x_{02}, y_{02} are coordinates of the destination.

Obtaining this data it is possible to determine the UAV trajectory that will be described with the help of line equation:

$$Ax + By + C = 0,$$

where *A*, *B*, *C* are line coefficients which are determined like:

$$A = \frac{1}{x_{02} - x_{01}},$$

$$B = \frac{-1}{y_{02} - y_{01}},$$

$$C = -Ax_{01} - By_{01}.$$

But the aviation safety requires the detection of obstacles at the planned flight trajectory.

The obstacle is determined by the vector-row of top coordinates

$$XO = (x_1, x_2, \ldots, x_n),$$

$$YO = (y_1, y_2, \ldots, y_n).$$

If there is a crossing of planned flight trajectory with any point of an obstacle it is necessary to overfly the obstacle with minimum deviation from the planned trajectory regarding the aerodynamic possibilities of the UAV.

For a new trajectory creation one should find the maximum coordinates of the obstacle tops from the both sides of the crossing.

To perform this operation it is necessary to find the distances matrix from the tops to the line of the trajectory (fig.2):

$$d = \frac{A \cdot XO + B \cdot YO + C}{\sqrt{A^2 + B^2}}.$$

The sign *d* informs about the location of the tops relatively to the line.

In such a way the tops are separated by the sides according to the line.

For a new trajectory creation it is necessary to choose the obstacle overfly direction. The choice will be prior to the side where the deviation will be minimal.

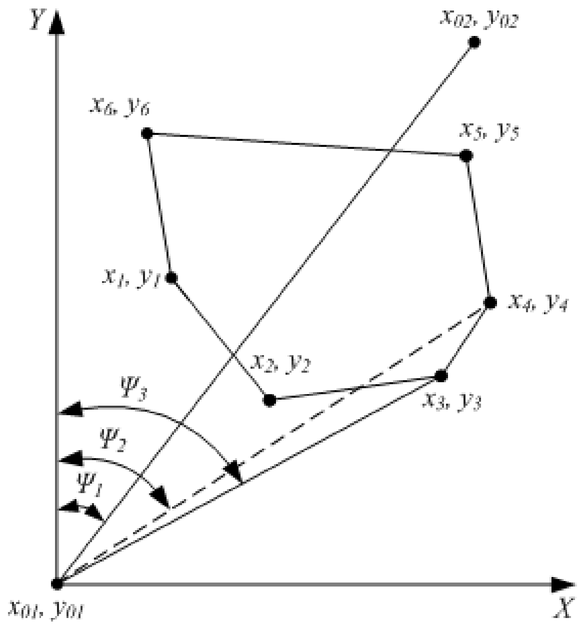

Fig. 2. Principle of obstacle overfly trajectory creation

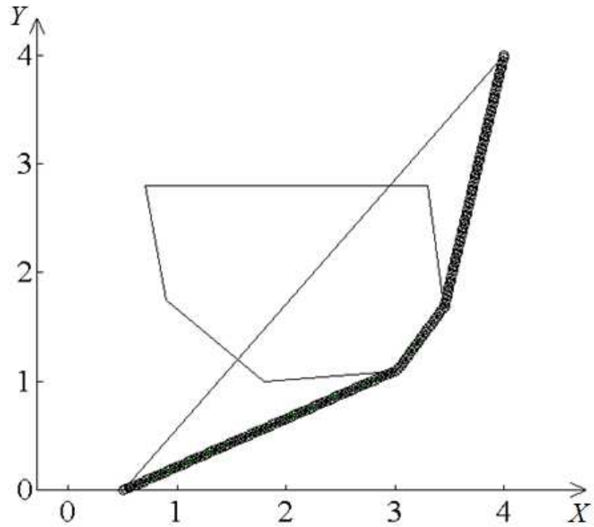

Fig. 3. The resultant overfly of complicated form obstacle

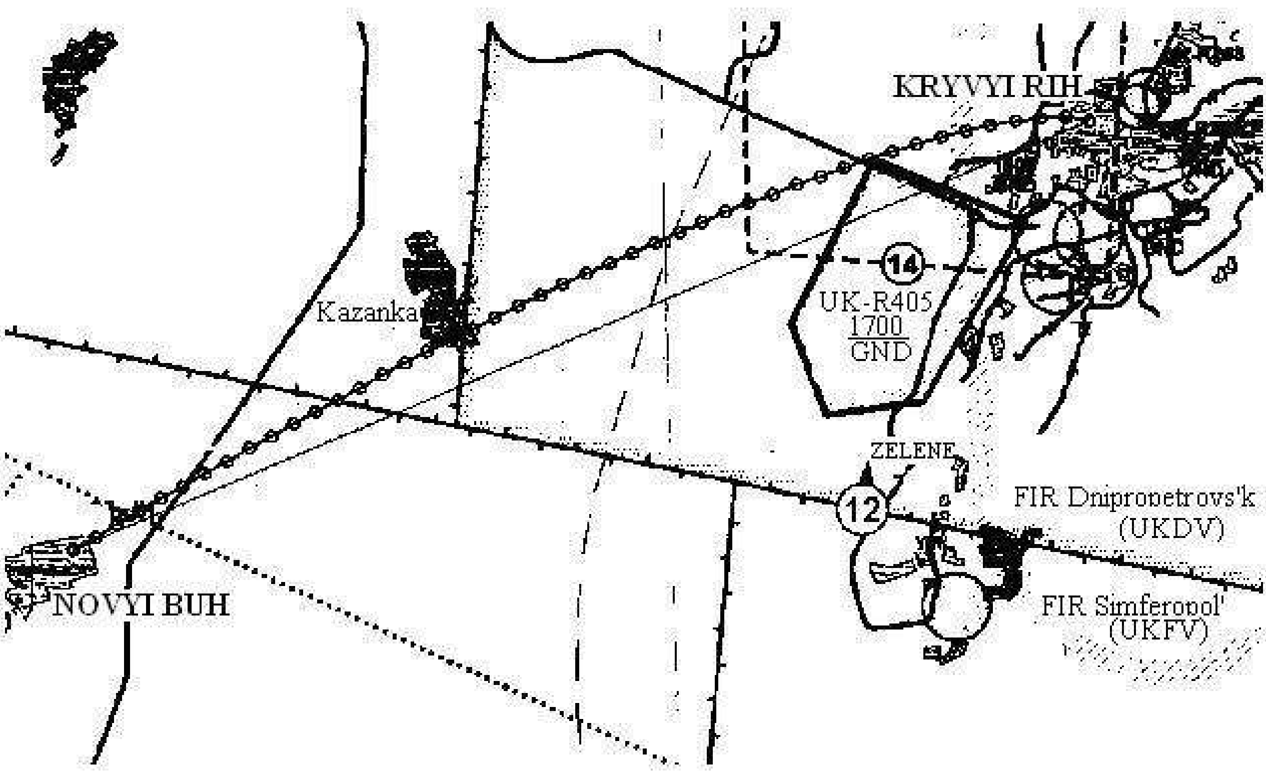

Fig.4. An overfly of the restricted area at the aeronautical chart

Thus, one should find the maximum deviation from the both sides of line and choose their minimum:

$$d_{\min} = \min\left(\left|\begin{pmatrix} \max(d) \\ \min(d) \end{pmatrix}\right|\right).$$

Using $d_{\min}$, the coordinates of the intermediate overfly point are defined.

The next step will be the heading change of the planned trajectory including the top at the next step of iteration.

But the obstacle has complicated form and the changed trajectory can also cross the shape of the obstacle.

Hence, the previous procedure should be done once more regarding the new trajectory with current position and the obstacle overfly point (fig. 2).

If any positive point is found, the destination will be changed prior to it.

As a result the first obstacle overfly point will be determined that will provide the heading change according to this point:

$$\psi_i = \mathrm{arctg}\left(\frac{-A_i}{B_i}\right),$$

where A_i and B_i are the line coefficients that links UAV and obstacle overfly point.

The procedure of heading choose is shown in the fig. 2.

Results of modeling

Performing this check for each point of the flight the resultant obstacle overfly is shown in the fig. 3.

The modeling can be applied to the aeronautical charts that are characterized by prohibited (P), dangerous (D) and restricted (R) areas.

Modeling of an overfly of the restricted area at the aeronautical chart of Ukraine is shown in the fig. 4. An initial position is Novyi Buh, destination is Kryvyi Rih. The obstacle at the planned trajectory is the restricted area under the number UK-R405.

Conclusions

UAVs can be used not only in civil aviation, but also provide other effective applications. Therefore UAV flight should be safety (omitting all the prohibited, dangerous and restricted areas), fast and with minimum consumption of the resources.

Hence, nowadays the trajectory choice of minimal deviation from the complicated form objects is an important challenge.

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