R. N. Kvetnyi, Dr. Sc. (Eng), Prof.; I. P. Borshchova

COLLISION AVOIDANCE ALGORITHM FOR UNMANNED AERIAL VEHICLES

The paper considers the industries of unmanned equipment application. There had been analised the existing collision avoidance systems.On the base of the mathematical model of material point movement there had been suggested the algorithm for avoiding the collision of unmanned aerial vehicles. It may become the background for future developments and algorithms in this sphere.

***Key words**: algorythm, unmanned aerial vehicle, material point.*

Introduction. Now there is a considerable increase in interest to unmanned aerial vehicle (UAV). Absence of a man onboard allows to carry out manoeuvres, inaccessible for manned planes. UAVs were first employed extensively to make reconnaissance missions during the Vietnam War. Today's UAVs incorporate the latest technologies, including TV cameras, radars and infrared sensors. They range from small, remotely controlled drones resembling the model airplanes to glider-sized UAVs that can fly independently for hundreds of miles on preprogrammed missions [1-4].

Unmanned aerial vehicles are usually applied for the solution of tasks, the implementation of which can not be done by manned aircrafts. Such tasks are: monitoring of air space, earth and aquatic surfaces, ecological control, air traffic control, control of marine navigation, development of communication networks and other.

The main problem during disigning of unmanned aerial vehicle is the development of algorithms for avoidance of their collision.

Analysis of previous researches. Today there are hundreds of the UAVs of different types and classes - from miniature, size of which is a few tens of centimetres, to the big strategic vehicles. The most famous are the systems TCAS[5] and ADS-B[6].

TCAS is a tool designed to prevent midair collisions of aircrafts. Operational experience has demonstrated the utility and efficiency of TCAS. At the same time, operation of TCAS has identified areas in which its design and algorithms needs improvement or further increase in its efficiency and its interaction with controllers. TCAS also cannot prevent all the risks of collision and the system may involve an additional risk.

Special attention is payed today to the unmanned aerial vehicle which use the system of supervision-prognostication – Automatic dependent surveillance – broadcast (ADS - B). From other systems the ADS – B differs by the improved visual possibilities: possibility conducting the operations on the surface, possibility of conducting the operations under any weather conditions, diminishing of space for the eventual approaching.

However there are a lot of problems, which must be solved in the development of unmanned aerial vehicle, equipped by such a system. At first, the operators of unmanned aerial vehicle and controllers can not fully manage the flight, since they physically can not see all the motion round the pilotless system; secondly, the algorithms of collision avoidance are imperfect and do not allow to provide for collision avoidance with other flying vehicles totally and under any conditions. One more and also important issue duringf the design of flying vehicles equipped with ADS - B system is that not all the existing algorithms and approaches for collision avoidance are coordinated with the principles of ADS - B.

Therefore the task of development of the improved algorithms of unmanned aerial vehicle collision avoidance is a very urgent one.

The objective of the paper is to improve the collision avoidance systems for unmanned aerial vehicle using algorithm for collision avoidance based on mathematical model of a material point motion.

Materials and results of the research. A motion of the unmanned aerial vehicle consists of forward movement of its centre of mass which determines the trajectory of the flight, and the circulating movement round the centre of mass which determines the angular position of unmanned aerial vehicle in relation to the inertial space [7]. During the movement of unmanned aerial vehicle in the Earths' atmosphere, these two constituents of general motion are interconnected and must be considered together.

The basis of mathematical model for unmanned aerial vehicle motion is constituted by the nonlinear system of differential equation, which describes the motion of UAV in space.

Let's introduce some definitions. The vector of position is a vector, drawn from the beginning of chosen system of coordinates to the point of vehicles' location ($\bar{r}_1(t)$ and $\bar{r}_2(t)$ for both UAVs accordingly). A vector of position and speed of its change shall be written down in projections on axis of the chosen (cartesian or spherical) system of co-ordinates. A vector which is directed from one UAV to the other along the line of sight and on its value equals the distance between the centers of the masses of these UAVs is the vector of relative distance $\overline{D}$.

The unmanned aerial vehicle moves in space together with other flying device. To receive the equations of relative motion of these two aerial vehicles we use the known theses of theoretical mechanics. Using the above definitions, it is possible to assert that the position of vehicles is determined at every time by vectors $\bar{r}_1(t)$ and $\bar{r}_2(t)$.

Thus, vector of distance and relative velocity shall be written as:

$$\begin{cases} \overline{D}(t) = \bar{r}_1(t) - \bar{r}_2(t), \\ \overline{V} = \dot{\overline{D}}(t) = \dot{\bar{r}}_1(t) - \dot{\bar{r}}_2(t); \end{cases} \tag{1}$$

Vector equations of relative motion shall be written as:

$$\dot{\overline{V}} = \ddot{\overline{D}}(t) = \bar{a}_1(t) - \bar{a}_2(t); \tag{2}$$

where $\bar{a}_1(t), \bar{a}_2(t)$ - vectors of accelerations of both UAV accordingly.

Futheron we describe the relative motion of flying vehicles in the connected co-ordinates system which moves relatively to the inertial co-ordinate system. In this case a transition from the absolute vectors' derivative to local one is carried out according the known formulas:

$$\begin{cases} \dfrac{d^2\bar{r}}{dt^2} = \ddot{\bar{r}} + 2[\bar{\varpi}\dot{\bar{r}}] + [\bar{\varpi}[\bar{\varpi}\bar{r}]] + [\dot{\bar{\varpi}}\bar{r}], \\ \dfrac{d\bar{r}}{dt} = \dot{\bar{r}} + [\bar{\varpi}\bar{r}]; \end{cases} \tag{3}$$

Absolute motion of the unmanned aerial vehicle that is approaching to it in the related to the flying vehicle system will be determined by expressions:

$$\begin{cases} \overline{V}_1 = \overline{V}_2 + \dot{\overline{D}} + [\bar{\varpi}\overline{D}], \\ \bar{a}_1 = \bar{a}_2 + \ddot{\overline{D}} + [\bar{\varpi}[\bar{\varpi}\overline{D}]] + [\bar{\varepsilon}\overline{D}] + [2\bar{\varpi}\dot{\overline{D}}]; \end{cases} \tag{4}$$

Kinematic and dynamic vector equations of relative motion of the two UAVs in the connected co-ordinate system we get from (4):

$$\begin{cases} \dot{\overline{D}} = \overline{V}_1 - \overline{V}_2 - [\bar{\varpi}\overline{D}], \\ \ddot{\overline{D}} = \bar{a}_1 - \bar{a}_2 - [\bar{\varpi}[\bar{\varpi}\overline{D}]] - [\bar{\varepsilon}\overline{D}] - [2\bar{\varpi}\dot{\overline{D}}]; \end{cases} \tag{5}$$

Thus, the equation of relative motion of two flying vehicles enables to calculate the distance they will cover in certain interval of time, the distance between them in certain interval of time, the co-ordinates they will accept in certain interval of time. The developed algorithm for collision avoidance at each step of calculation considers the motion of one flying device in relation to the other.

Let's assume that the given aircraft moves in a horizontal plane and must reach a certain target, remaining in the same plane.

Other flying device moves opposite to it. Permissible distance between flying devices must not be less than some number R. According to the equations of relative motion, we consider the robot plane as a material point which moves, and other flying object - as obstacle which stands not moving. Thus a task is to "go" round this obstacle in a short cut.

Let's project both flying devices on the XOY plane of three-dimensional net in a specific scale. A cell where the second flying vehicle was projected we designate as an obstacle, considering minimum possible distance between them. We also designate as an obstacle those squares of net, which are located round a flying vehicle and are in the range of impermissible distance between airs. Fig.1 shows the projection of the flyng objects on the XOY plane.

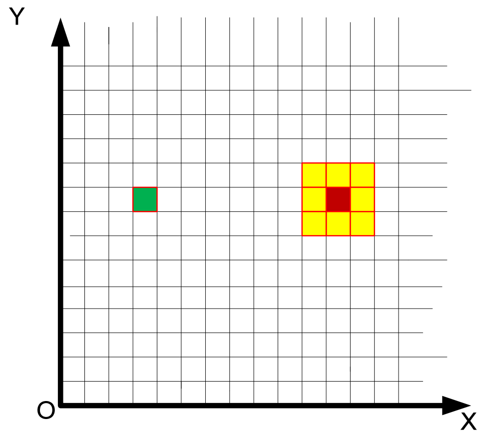

Fig 1. Projection of aircrafts on the plane of XOY

The developed algorithm is based on such principles:

1) We divide the three-dimensional space to a net. A specific square of net is a "cell" which may be occupied by UAV (as was mentioned above, we consider its motion as that of the material point).

2) The step of net equals the minimum relative motion of one airplane in relation to other after the interval of time chosen by us. Since the system is inertial and we calculate the relative motion of one flying vehicle in relation to other, we assume, that UAV moves with that speed which we determine as a relative, and the other flying vehicle doesn't move. Thus the algorithm of collision avoidance is considerably simplified.

3) If difference of coordinates $z_1 - z_2$ between these UAVs is bigger or equals the possible distance between flying vehicles, then the motion of UAV does not need to be corrected. If difference of coordinates $z_1 - z_2$ between UAVs is less than possible distance between them or equals zero, - it is then needed to search for the short cut for passing the obstacle.

Conclusion. Presently there is a considerable increase of interest to Unmanned Aerial Vehicles. In the systems of avoidance of collisions of Unmanned Aerial Vehicles a task of steering of one airplane from the initial point to the set area in a necessary moment of time, avoiding collisions with other flying vehicles, as well as with static obstacles is actual. A key question in the solution of this task is the development of collision avoidance algorithm. The suggetsted algorithm uses mathematical model of relative motion of two material points. This algorithm can be used for navigation systems, as well as for ADS - B system.

REFERENCES

1. Beylin M. System approach to weapons production in unmanned aviation systems / Beylin M., Burkovsky S. // Management systems, navigation and communication. – 2008. - № 6(2). – Pp. 60-61

2. Unmanned Aircraft Systems for the Navy [internet-resourse] / Shcherbakov V.–: http://www.uav.ru/articles/naval_uav.pdf

3. Best R. A. Intelligence Technology in the Post-Cold War Era, the Role of Unmanned Aerial Vehicles (UAVs): Report to Congress // Congressional Research Service , 1993. – Pp. 12-16.

4. Sterste-Perkins D. Military Unmanned Aerial Vehicles Report to Congress // Congressional Research Service , 1996. – Pp. 11-14.

5.Livadas C. High-Level Modeling and Analysis of TCAS [internet-resource] / Livadas C., Lygeros J., Lynch N. – Режим доступу: http://people.csail.mit.edu/clivadas/pubs/RTSS99.pdf.

6. Powell J.D Use of ADS-B and perspective displays to enhance airport capasity [internet-resource] / Powell J.D, Jennings Ch., Holforty W.-

Режим доступу: http://waas.stanford.edu/~wwu/papers/gps/PDF/PowellDASC05.pdf

7. Kumkov S.I. Informational Sets in a Problem of Observation of Aircraft Trajectory / Kumkov S.I., Patsko V.S., Pyatko S.G., Fedotov A.A. // Proceedings of the Steklov Institute of Mathematics.- 2000. - № 2

Kvetny Roman – Dr. Sc. (Eng)., Professor, Department of Automation and Information –Measuring Equipment.

Borshchova Irina – Student, Department of Automation and Information –Measuring Equipment.
Vinnytsia National Technical University.