R. N. Kvetniy, Dc. Sc. (Eng.), Prof.; I. P. Borschova

COLLISION AVOIDANCE SYSTEM FOR UNMANNED AIRCRAFT ON THE BASIS OF RISK MINIMIZATION

This paper describes an approach for building a collision avoidance system for unmanned aircraft on the basis of risk minimization due to estimation of potential losses.

Key words: *unmanned aircraft, collision avoidance system, risk estimation.*

Introduction. Nowadays great worldwide attention is paid to the development of unmanned aircraft systems. By no means a new idea is to use UAVs (unmanned aerial vehicles) in search and rescue operations, information support during suppression of forest fires, for continuous air monitoring of main oil and gas pipelines, high-voltage transmission lines and other objects of the industry as well as for military purposes [1] . Their main purpose is removing people from the board of an aircraft in order to save the pilot's life in dangerous missions is. In addition, absense of people on board enables maneuvering with greater overloads, which cannot be achieved with manned vehicles.

Today's unmanned aircraft systems are complex functional systems. While designing them, the latest achievements in the fields of microelectronics, programming, high-performance small engines, composite materials and other complex technologies are used. However, analysis of global trends in the development of unmanned aircraft demonstrates increasing demands to ensure its security not only by improving the performance of UAVs, but also by the provision of flight resource increase through improving the intelligence of automatic control systems.

The analysis of previous studies. Air traffic safety in order to save human life is a prerequisite of designing any aircraft. An indicator of air traffic safety is the degree of risk of a collision between several aircraft in space. And the most important place in the decision-making system during air traffic control and management is occupied by identification of potential conflict situations [2].

Currently, there are many approaches and methods for identifying conflict situations designed for both on-board flight control systems and ground stations for air traffic control. There are probabilistic [3] and geometric methods for identifying conflicts. The most commonly used are probabilistic methods to identify conflicts since they allow using a collision probability distribution to assess the risk. The best known are the method of Reich and Reich's generalized method.

The best known and most common collision avoidance systems are TCAS (Traffic collision avoidance systems) and ADS-B systems (Automatic Dependent Surveillance - Broadcast).

TCAS is a system designed for preventing collisions between air vehicles in space. It is a combination of onboard devices that operate independently of ground-based air traffic control system and provide collision protection for a spectrum of different types of air vehicles.

ADS-B is a brand new technology that allows pilots and air traffic controllers "seeing" and operating the aircraft with greater accuracy over a much larger area of land than it was ever possible before. ADS-B enables determinination of the air transport location in space, using global navigation satellite systems, and periodical transmission of the signal.

However, existing collision avoidance systems for unmanned aircraft do not resolve the most pressing issues facing global aviation. They do not give accurate collision avoidance algorithms and cannot assess the risk of a collision. Therefore, a vital task is development of such collision avoidance tools which would enable solving the existing problems.

The aim of the work is to develop an effective approach to technology that is used to avoid collisions between UAVs and other air transport on the basis of risk minimization.

Materials and results of the research. Collision avoidance is not only a technical task. It is the task that involves safety of people. Collision avoidance system for unmanned aircraft must assume the risk of a collision in only one case in a billion. Therefore, since the main problem in the development of collision avoidance algorithms for unmanned aircraft is safety for other air vehicles, especially for manned aircraft and for passenger planes, the main task in the elaboration of such approaches is assessment of the risk [4].

For this case the risk of a collision with another aircraft in space is estimated by the formula:

$$R = L * P, \tag{1}$$

where L – potential losses, P – the probability of a collision.

Potential losses are calculated using the weight of the plane, moving towards the UAV (the bigger the weight, the greater losses in the event of a collision), the number of passengers on board the plane with which the collision takes place (more passengers – greater human cost), from the environment where there is a collision (if it is a city – greater losses, respectively, and so on) [5].

To do this, we construct tables of coefficients for the planes having different masses, different numbers of passengers on board and flying over different types of terrain.

Thus, L is a function of the coefficients of mass, the number of people and environment of the collision, which is mathematically written as follows:

$$L = f(M, N, E), \tag{2}$$

where M – a coefficient that depends on the mass of the plane that is moving towards the UAV, N – coefficient that depends on the number of passengers on board the plane with which it is likely to collide, E – a factor depending on the terrain over which a collision could take place.

Coefficients M, N, E are fuzzy parameters, the values of which are set by the ground control manager after analyzing the known values of the mass of the plane, the number of people on board, the environmental impact on the basis of the tables of coefficients for different types of aircraft. To calculate potential losses, the coefficients are fed to the input of the fuzzy controller. After that the resulting value of potential losses is formed according to fuzzy rules. In order to form inference on the basis of fuzzy rules, such system uses a fuzzy inference of Mamdani type.

Consider the probability of a collision of two aircraft in space. In order to use of the term "collision probability" introduction of a function, which characterizes the process of invasion into the forbidden zone, is required. This function is the probability of a collision of two aircraft depending on their coordinates in space. Mathematically this dependence can be written as follows:

$$P = f(\mathrm{x}, y, z), \tag{3}$$

where x, y, z – coordinates of the unmanned aircraft in space.

Since the aircraft position in space depends largely on the angle of its inclination to the planes, formed by the coordinate axes, then in order to solve the problem we pass to polar coordinates. Then relation (3) will be determined by the formula:

$$P = f(\mathrm{x}(\alpha, \beta), y(\alpha, \beta), z(\alpha, \beta)), \tag{4}$$

where α, β – the angles of the aircraft inclination to the planes XOY and YOZ; x, y, z – the UAV coordinates in space.

The probability of a collision depends on the direction of the aircraft motion: in the direction of flight the collision probability is the highest, on the left and on the right of the aircraft it would be accordingly lower. Behind the aircraft there is also a probability of a collision but it would be not so high as in the direction of flight.

Any aircraft that is moving in space has a family of surfaces describing the risk of a collision with another air vehicle in space. These surfaces are built taking into account potential losses at the time of collision.

Thus, taking into account formula 4 and coefficients M, N, E, we build surfaces that describe the risk of a collision of two air vehicles in space for the following set of parameters:

$N1 = 75,\ M1 = 10,\ E1 = 80,\ E2 = 80,\ M2 = 0,\ N2 = 50$. These surfaces are shown in fig.1.

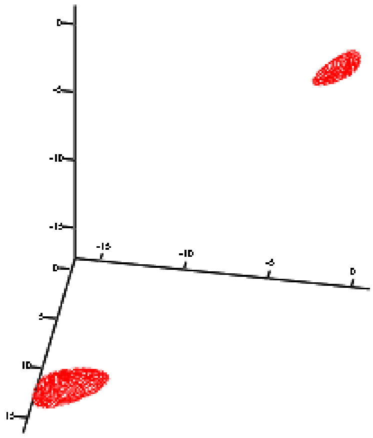

Fig. 1. The surfaces of risk for two air vehicles in space

The resulting risk for an unmanned aircraft depends both on its own risk and on the motion trajectory of the object flying towards it. Thus, the resulting risk will be written as:

$$P = f(\mathrm{x}(\alpha,\beta), y(\alpha,\beta), z(\alpha,\beta), z'(\alpha,\beta), x'(\alpha,\beta), y'(\alpha,\beta)), \qquad (5)$$

where α, β – angles of the aircraft inclination to the planes XOY and YOZ correspondingly; $\mathrm{x}, y, z, z', x', y'$ – coordinates of the UAV and coordinates of the aircraft moving towards it correspondingly.

The resulting surface of risk for the unmanned aircraft is presented in fig. 2.

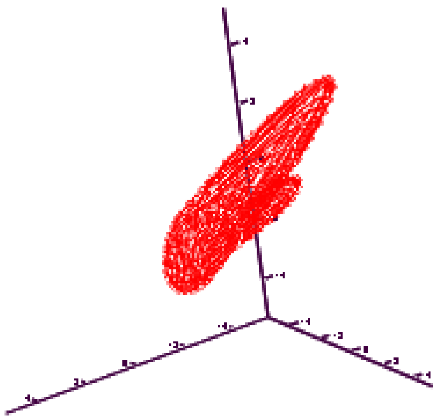

Fig. 2. The resulting surface of risk

The collision avoidance system is based on:

1. Standard modeling elements (tables of the coefficients of losses for a manned aircraft, for an unmanned aircraft, different classes of UAVs, collision probability values depending on the speed, distance, the aircraft mass).

2. Standard modeling structures (calculation and construction of the surfaces of risk depending on the collision probability values and potential losses).

3. Standard structures of risk evaluation using the "if – then" rule.

The algorithm of the collision avoidance system operation on the basis of risk minimization is represented by the sequence of the following actions:

1. The operator of the ground control station determines the values of fuzzy

coefficients M, N, E.

2. The system determines a fuzzy value of the coefficient of potential losses.

3. Defuzzification of this value of potential losses and its conversion into a numerical value.

4. Building a family of risk surfaces.

5. Determination of the most optimal route taking into account dynamic properties of the system.

Thus, after estimating the risk at all points of space, the UAV trajectory could be optimized in order to realize a collision avoidance maneuver with minimal risk. Hence, the proposed approach makes it possible to improve reliability of any collision avoidance system for unmanned aircraft.

Conclusions. This paper proposes an approach to the development of a new decision making support technology that is used to avoid a collision of unmanned aircraft. This approach provides the analysis of potential losses caused by a collision with another air vehicle by means of risk evaluation. This approach is oriented towards solving the main problem in the development of unmanned aircraft collision avoidance algorithms – to ensure safety of other air traffic means.

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Kvetniy Roman – Dc. Sc. (Eng.), Prof., Head of the Department of Automatics and Information Measuring Facilities.

Irina Borschova – Master's course student of the Department of Automatics and Information Measuring Facilities.

Vinnytsia National Technical University.