Algorithm for Short Term Conflict Detection, Using Multi-Objective Optimization of the Decision Making Process

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Abstract: **This paper presents a review of short term conflict detection methods that are in use in current algorithms for conflict detection and gives some arguments using multi-objective optimization. Evaluation of different methods for multi-objective optimization and their applicability for making decision of effectiveness of conflict detection algorithm.**

Key words: **short term conflict ,multi-objective optimization, Pareto optimization, vector synthesis, function of parameters.**

I. INTRODUCTION

Taking into consideration safety and the increasing of the efficiency of ATC, the questions for conflict alerting in due time become a hot topic. The key element in the conflict prediction and uncertainty modeling, common for aircraft motion, because of the wind, commands of ATC, Navigation and control. This paper presents short –term conflict detection in the case of optimizing criteria for estimated value of the distance between two aircrafts in each moment of their flight. The probabilistic method is used for calculation of the estimate aircraft position taking into account all potential trajectories. In this method uncertainties are modeled to describe potential variations in the future trajectory of the aircraft. All situation are described by their “possibility of conflict”.

II.BASIC APPROACHES TO MULTI-OBJECTIVE OPTIMIZATION

A)Possibility of conflict

The “probabilistic drift” has a Gaussian density with increasing covariance matrix. The validity of the prediction decreasing during the time interval. That model has a lot of disadvantages, but a probabilistic approach provides an opportunity for a balance between relying on either a single-trajectory model or a set of worst- case maneuvers. Short-term conflicts are time limited up to 10 min.

Conflict detection uses current aircraft position to describe estimate future trajectory of the aircraft. The ordinary propagation of the trajectory is for 5-10 min. During that time the aircraft keeps its initial flight path especially straight forward.

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Conflicts are detected, by checking the distance ($\vec{R}(x,y,z,t)$) between the flight paths at time steps of Δ seconds.

Since the algorithm does not compute the actual time when the first loss of separation occurs, the choice of Δ is crucial.

(3) The major contributor to the uncertainty in the aircraft motion is wind, for which a consistent physical model is not available yet. However, since the prediction error can be modeled as the sum of a large number of independent random perturbations in disjoint time intervals, it is expected to be Gaussian. This hypothesis was indeed verified by empirical data, which also suggested that the uncertainty can be decomposed in to two components: an along track component whose variance grows with time, and a cross track component whose variance remains constant.

According to the minimum vertical and horizontal separation is designed a protected zone for each aircraft. Protected zone is a cylinder with 2000 ft or 4000ft height, depends on the flight level, and radius of the bases- 5 nm. In the center of that cylinder is situated the aircraft. The conflict probability is equal to the probability of intersecting of PZs of two aircrafts and for its calculation the predicted future positions of the two aircrafts must be used. If the conflict probability is divided in two components, the conflict will appear at every moment when any of the separations is broken.

$$P(C) = P(C)_{H.}\, P(C)_V \qquad (1)$$

Conflict detection as a process is similar to radar signal detection. The conflict detection algorithm has the following steps:

1)detection and processing with the data signal for ($\vec{R}(x,y,z,t)$)

2)calculation of the predicted value of ($\vec{R}(x,y,z,t)$)

3)comparison between the calculated value of R and the threshold. Making decision there is a conflict or not for given future period.

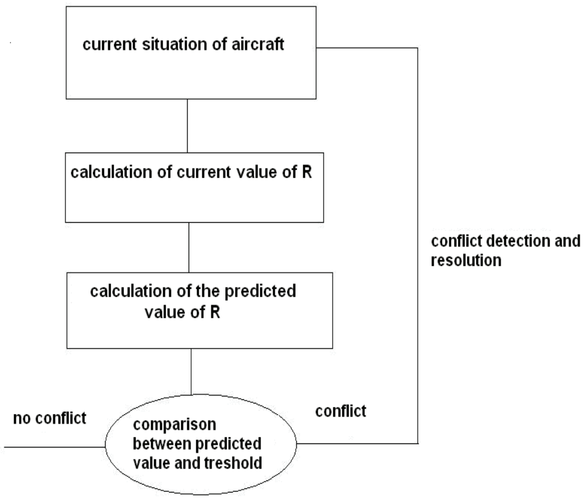

fig.1 Conflict detection algorithm

Conflict detection is entirely addressed to future moment of time- the correctness of the detection depends on the correctness of the prediction. Obviously, the existence of a conflict depends on the type and parameters of the chosen predicting algorithm. The conflict detection is a random process, determined by the probabilistic algorithm for prediction calculation. At the first step of the algorithm, the process of data receiving is also the random type process.

Analysis of the results of every type of error, provide the information about weight coefficient of evaluation, for each error. The optimization of conflict prediction algorithm is a multi-objective optimization.

Parameters of the optimization:

1)current value of R

2)time interval of the prediction

3)data innovation period (frequency of innovation)

4)measuring errors

- meteorological phenomena
- electro-magnetic environment

5)size of the Protected Zone

6)dynamic model of the aircraft

7)interference between the predicted position of the pair of aircrafts.

The quality of prediction of ($\vec{R}(x, y, z, t)$) affected by a lot of operators.

The aim of the present algorithm is to realize the most real estimation of R. For the given value of R, is it optimal or not, can be decided, according to the parameters, which determined the explicit situation. For every parameters is calculated the value of the target function and it must be maximum. By this way regarding the chosen parameter (criteria) the optimum is reached.

. f_i – local criteria

$f=(f_1,f_2,\dots,f_m)$ – vector criteria

when m=1 – one-object task

$m \geq 2$ – multi-objective task

each solution –x – determined entirely the vector - f(x)

$$Y = f(X) = \{ y \in E^m \,|\, y = f(x), x \in X \} \quad (2)$$

All methods for optimization used in the algorithms are Pareto methods. In the multi-objective tasks every solution

$x \in X$, is determined by its evaluation y=f(x), that's why the choice of the optimal solution is equal to the choice of a optimal evaluation, from the variety of all possible evaluations.

B)Probability state

Depending on the characteristics of criteria and the structures of varieties of possible solutions determined different types necessary and sufficient conditions for a specific solution to be optimal or not. All characteristics which prevent accurate conflict detection are called perturbation. In the context of the games theory "perturbations" are treated as enemies. The win of one player is a loss for other player. That type of game is antagonistic game with null sum.

$$H_{II}(s) = -H_I(s), s \in S$$
$$H_I(s) + H_{II}(s) = 0 \quad (3)$$

C) Min max method for game theory

The theorem of min max, declares that every antagonistic game has optimal strategy, called col point. The necessary and sufficient is:

$$\max_i \min_j a_{ij} = \min_j \max_i a_{ij} \quad (4)$$

Win function of the first player is mathematical estimation:

$$H(x.y) = \sum_{i=1}^{m} \sum_{j=1}^{n} a_{ij} x_i y_j \quad (5)$$

For determining the optimal strategies is used col point and the methods of domination and linear programming. Min max method gives solution in any case, but this solution is not always optimal according to Pareto rules. The availability of solution in any case is an advantage for the method, for the actual problem, where it is an important matter. But the method has one dangerous aspect, there is no guarantee that the particular solution is optimal.

D) Medium risk criterion

The medium risk criterion is an approach to the problem, which treats all factors by the same way. Analyzing and evaluating the distance between a pair of aircrafts(R) and comparing it with the threshold the method gives decision is there a conflict or not.

R_o (:R_{ox}, R_{oy}, R_{oz}.)

$R_{пр}$ =R+n(t)

The following situation are possible, as a result of the process:

1) When $R_o < R_{min}$ ($R_y < R_{ymin}$ or $R_x < R_{xmin}$ or $R_z < R_{zmin}$) -P(x_1)- conflict possibility

D(detect)- probability of successful detection.-D=P($R_o < R_{min}$)

P_1= P(x_1).D

M(miss)- probability of missed detection

M=P($R_0 > R_{min}$)

P_2 = P(x_1).M

2)When R_o >R_{min}(R_x>R_{xmin} and R_y>R_{ymin} and R_z>R_{zmin}) - $P(x_0)$-probability of no conflict
R(reject)- probability of right reject detection
$R=P(R_0>R_{min})$
$P_3= P(x_0).R$
F(false)- probability of unnecessary alert
$F=P(R_0<R_{min})$
$P_4= P(x_0).F$
$P(x_1).D + P(x_1).M + P(x_0).R+ P(x_0).F =1$
The conditional risk, when R is evaluated, is combination of the probabilities of missed detection and unnecessary alert. P(R) –priori distribution of the probability calculated estimate value of R_o to be exact.
If to situation is given a price for the error, depending on the risk, so that right solutions have null price and falt solutions-max.
The medium error price is a mathematical estimation:.

$$\overline{K} = k_1 D.P(x_1) + k_2 M.P(x_1) + k_3 R.P(x_0) + k_4 F.P(x_0) \quad (6)$$

When k_1 =0 and k_3 =0

$\overline{K} = k_2 M.P(x_1) + k_4 F.P(x_0)$ - medium risk is a sum of error probability.

The medium risk criterion is one of the most common criteria. The exceptions of these criteria are the criterion of the ideal observer, criterion of the posterior probability and etc. For the criterion is needed output data for the characteristics of perturbation. That data is not always available, because of that the criterion is not reliable and appropriate for the specific problem.

E)Criterion of the ideal observer

All errors lead to same results. $k_2 = k_4 = 1$

and $\overline{K} = k_2 M.P(x_1) + k_4 F.P(x_0) - \min$ -error probability

$\overline{K} = k_1 D.P(x_1) + k_3 R.P(x_0) - \max$ - probability for right evaluation

Optimal by the criterion of the ideal observer is that method of evaluation of R, which provide min probability for error and at the same time max probability of right decision. The solution of the problem can be simplified by refusing to take into consideration the different result of the errors.

F) Criterion of the maximum likelihood.

$P(x_1) = P(x_0)$ - conflict probability and probability of no conflict are equal

$P_{гр} = M + F - \min$

Disadvantages of these approaches are the same as the ones of medium risk.

G)Multi-target (vector) optimization.

In the process of searching the best solution there is need to have a chance to change some of parameters, describing the state of the object. The managing parameters must be changed independently and promote varieties of the problem solution. Mathematical model of the object join all the parameters by a system of functions.

$$Y_i = f_i(x^u), i = 1, 2, \ldots n \quad (7)$$

Input parameters $\mathbf{x^u}$ include: x- vector of managing parameters and $\mathbf{x}^{\mathbf{c}}$ – vector of constant parameters. Limitations of parameters form G_x – range from which the managing parameters can take values. Analysis of the obtained results –y, produce the selection of the optimal decision. Criterion of optimization is numerical presentation of estimate object state and it is used for comparing different states.

$$Q = Q(x) = Q(x_1, x_2, \ldots x_n) \quad (8)$$

Design and work of the conflict detection algorithm is appraised by a complex index.

$$Q_i (i = 1, 2, \ldots n1) \quad (9)$$

The optimal level of the index are achieved at different values of managing and design parameters. In general case, range of solutions- Q_i is open, but if some restrictions are made the range will become covered (closed) inside which will be situated the optimal solution. For every point in G_0- field, can be found better solution, except the points on the line. These kind of solutions is called Pareto- optimal (non-improvable). The final solution of a problem of multi-objective optimization is solution from Pareto- optimal solution. The main problem is which point is the optimal one. Some methods are proposed: scalarization of vector criterion, generalized loss function, utility, iterative approach and etc.

H)Compromise optimization using loss function.

Deciding to choose one or another Pareto – optimal point for a final solution will provide some loss of absolute extreme Q_i^* of the target function $Q_i(x)$.

$$\Delta Q_i(x) = \frac{Q_i^* - Q_i(x)}{Q_i^*}, i = 1, 2, \ldots m \quad \text{-relative loss} \quad (10)$$

Generalized target function:

$$\phi(x) = \sum_{i=1}^{m} [\Delta Q_i(x)]^2 W_i = \sum_{i=1}^{m} [\frac{Q_i^* - Q_i(x)}{Q_i^*}] W_i \to \min_{x \in G_x}, \sum_{i=1}^{m} W_i = 1 \quad (11)$$

The optimal solution by some criteria is that solution, optimal by Pareto, which has minimal value, according to minimizing criteria and maximal, according to maximizing. Giving the weight of the every criterion, ensure that there is one optimal solution, based on the given priorities.
It is acceptable and possible the chosen solution to be very close to the optimal, but not to be optimal.

$\Delta Q_i = Q_i^* - Q_i(x)$ -min – diversion of the chosen solution from the optimal

In order to minimize the diversion for all criteria it is necessary they to be normalized. When the criteria functions are transformed it must be taken into account, that the transformations have to be started from a common point and same order of priorities. The transformations must be monotonous and inside the $[0;1]$.

$$0 \le \omega_i(q_i(x)) \le 1 \quad (12)$$

Using consistent analysis approach each acceptable solution $x \in A$ and $0 < \omega_i(x) < 1$ there is a vector $\rho \in \Phi^+$ which covers:

$$\rho = \langle \rho_i \rangle \in \Phi^+ = \langle \rho_i : \rho_i > \forall i \in I, \sum_{i \in I} \rho_i = 1 \rangle \quad (13)$$

The transfromation of the vector type criteria into scalar type can be made by different ways: linear, minimizing, maximizing etc..

As a result of the review is presented the following optimizing algor4ithm of conflict detection process.

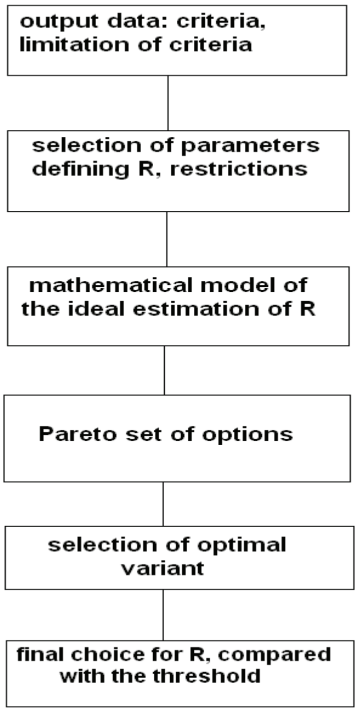

fig.2 Optimizing algorithm

Proposed algorithm uses:

$$q_{iн}(x) = \frac{q_i(x) - \min\limits_{x \in X} q_i(x)}{\max\limits_{x \in X} q_i(x) - \min\limits_{x \in X} q_i(x)}$$ - simple normalization. (14)

III. CONCLUSION

That survey is an attempt, analyzing some of the approaches for obtaining estimation of parameter (R), to find the best solution for the optimization of conflict detection process, taking into consideration the particularity of the problem. The proposed methods for optimization, which provide necessary and sufficient conditions for Pareto optimization, have a strong advantage. They are more effective, because of the performing the priorities better. Vector-valued optimizing criterion guaranteed bigger part of demanded requirements of criterion selection. Using of vector-valued criterion, which choose one solution from a variety of Pareto optimal solution, gives assurance that the final one is optimal and it is the closest one to the ideal solution. At the same time we can be sure that all the criteria are taken into account, because by this way can be processed all the available information. For our particular problem is very important to find just one solution and to be sure that it is the most non-shifted one from the real value (we compare calculated by the system R with real R in the air).

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