The Concept of Initial Air Traffic Situation Assessment as a Stage of Medium-Term Conflict Detection

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Abstract

Key decisions in the air traffic control system are supported by various technical systems. The most important include conflict detection and resolution (CD&R) systems. The main subject of this paper is a medium-term conflict detection system (MTCD). An excessive number of false alarms is one of the major functional problems of these systems in current implementations. They make the whole idea of CD&R systems less effective. The aim of this study is to present the concept of the system for the initial assessment of the overall level of complexity of the traffic situation. It should become the first stage of the MTCD system algorithm. The paper presents a general scheme of the model to assess the traffic situation based on fuzzy sets theory, and more specifically on the theory of fuzzy inference systems. Choosing this type of the model is justified by the lack of precise and well-defined relationships between the factors influencing the traffic situation complexity and its assessment, which is largely subjective. The paper discusses the input and output linguistic variables and briefly presents the results of simulation experiments conducted with the use of fuzzy inference system implemented in the SciLab environment. Experiments have confirmed the effectiveness of this solution and indicated the possibility of its inclusion in the MTCD system algorithm as a first stage. This will improve the MTCD software behavior with respect to alerting a controller about a detection of the conflict and supporting him/her by the development of proposals for its solution.

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1. Introduction

Air traffic control systems are complex sociotechnical systems. A human – an air traffic controller (ATCo) is supported by numerous technical systems. They include conflict detection and resolution (CD&R) systems. Their main task is detection of conflicts, which we define as events of loss of minimum separation between the aircraft. Another task is assisting the ATCo in finding the way of resolving a conflict situation. In this paper we deal only with the first of these tasks.

CD&R systems are created for different planning horizons. This paper is concerned with medium-term conflict detection (MTCD) systems, with planning horizon of about 15–20 minutes [1, 2]. Their general principle of operation is based on trajectory prediction according to one of several possible models, detection of possible collision points and alerting the ATCo.

Excessive number of false alarms is the fundamental functional problem of MTCD systems. A big difficulty in predicting the trajectory and future locations of the aircraft are the most common causes. The trajectory may be subject to deviations caused by the interaction of many factors of a random character.

Focusing controller’s attention on non-existent or negligible conflicts is the main negative effect of false alarms in MTCD systems. Negligible, because very often the ATCo is aware of the conflict, and there is still enough time to resolve the situation without any complications.

The aim of this paper is to create an outline of a method for initial overall assessment of the traffic situation, so that MTCD systems algorithms can be modified in order to reduce the number of false alarms. In our opinion, the response of the system when it detects a medium-term conflict between a pair of aircraft should depend on the overall assessment of the situation in the control sector. In the case of straightforward situation – a decision about warning the ATCo can be postponed, giving the ATCo a chance to notice and resolve the problem, possibly this may allow more reliable estimation of the future position of the aircraft. In case of a complex traffic situation – immediate ATCo warning is necessary, because a delay could lead to a safety hazard.

2. The principles of MTCD systems operation

Both the detection and methods of resolving conflicts are as reliable as accurate is the model for trajectory prediction. Prediction models differ from each other mainly by the way of determining the position of the aircraft. There are three main prediction models: nominal, worst-case and probabilistic [4].

Some CD&R systems, having discovered a conflict, propose the ways to resolve it. Kuchar & Yang [4] and ICAO [3] discuss in detail possible approaches. Broadly, they consist in performing one or more maneuvers of: a change of heading, a change of the flight level or a speed change. A situation when two aircraft trajectories intersect and it is predicted that collision is possible is an example of a situation where a change of heading can be used. In this case, one of the aircraft may change the course by a small angle. Another solution in such a situation may be changing the speed which causes the aircraft to reach the conflict point at different times. Also changing of the flight level is a very common way of resolving the conflict used by ATCos. It is necessary to consider various effects of maneuvers planned by MTCD systems, including the possibility of new, induced conflicts [7].

3. A fuzzy system for traffic situation assessment

3.1. General structure of fuzzy inference system

The idea behind the fuzzy set theory was to describe the phenomena and concepts having imprecise and approximate character. Methods based on classical set theory are not able to solve complex issues of this nature.

A fuzzy set will denote a set of pairs

\[ A = \{(x, \mu_A(x)) : x \in X\} \]  

(1)
where $\mu_A$ is the membership function of fuzzy set $A$ and $X$ is the universe of discourse of the fuzzy set. Each element $x \in X$ is assigned a degree of membership

$$\mu_A : X \rightarrow [0,1],$$

(2)

$\mu_A(x) = 1$ means that element $x$ fully belongs to fuzzy set $A$; $\mu_A(x) = 0$ means that element $x$ does not belong to fuzzy set $A$ at all; $\mu_A(x) < 1$ means that element $x$ partially belongs to fuzzy set $A$.

Fuzzy sets, described by their membership functions can be used to represent the so-called linguistic variables. These are variables expressed in natural language, describing the approximate values of the crisp variables. Replacing measurable, crisp input values with linguistic variables may be necessary when it is not possible to provide precise and exact output values for exact values of the input variables, but it is possible to determine them for the input values described by linguistic variables. Fuzzy inference rules are used for this purpose. They constitute the knowledge base used in the fuzzy inference system. Classic fuzzy inference system consisting of the fuzzification block, inference block, rules base and defuzzification block is shown in Fig. 1 [5].

Fig. 1. General structure of the fuzzy inference system.

Crisp values given as the input to the fuzzy inference system are subjected to the fuzzification operation. As a result, we obtain their representation as linguistic variables. They provide the input to the inference block. The inference is carried out on the basis of the knowledge contained in the rules base. The essence of inference is choosing and application of rules corresponding to membership functions of input linguistic variables. As a result we obtain the output fuzzy set, which is the aggregation of sets created in the inference process. As the last stage defuzzification is implemented, this produces a crisp output value.

A general diagram of interactions in the fuzzy model used to assess the traffic situation complexity in MTCD systems is shown in Fig. 2. The output variable Traffic situation assessment $z_e$ is dependent on the five input variables. These are: Number of aircraft $x_{ac}$, Distances between aircraft $x_d$, Number of collision trajectories $x_{ct}$, Time to conflict $x_m$ and Airspace availability $y_{av}$, which is the output of the local fuzzy inference model with two inputs: Airspace structure $x_{st}$ and Meteorological conditions $x_m$. Details on defining membership functions of linguistic variables are presented in Section 3.2.

Fig. 2. Diagram of the Traffic situation assessment fuzzy model.
3.2. Input and output linguistic variables

The number of aircraft in the control sector is a parameter used in the current operational work. It is used to determine the volume of the traffic in the sector as well as the ATCo workload. To determine the membership function of the linguistic variable *Number of aircraft* we have used the term of sector capacity, describing the maximum number of flight operations that can be performed in one hour. It was assumed that this variable will have three values: *small*, *medium* and *large*.

Depending on whether the aircraft are concentrated in a small area or are distributed in the whole area of the control sector, there is a significant difference in the complexity of the traffic situation. Due to the presence of many aircraft in the air traffic control sector, the linguistic variable *Distances between aircraft* is defined on the basis of aggregate indicator characterizing the averaged distance between aircraft. When determining this indicator we use the distances between the pairs of aircraft taking into account the minimum horizontal radar separation that is applied in the sector.

The ATCo has to resolve conflicts when the expected distance between the aircraft is less than the minimum separation. Such a situation is possible only if the planes are moving by exactly the same trajectory and catching up, and also in the case where the trajectories of the two planes intersect. Therefore, as one of the input variables we used a linguistic variable describing the number of intersections of the planned aircraft flight paths. The number of trajectories points of intersection increases with the number of aircraft in the sector. The greater the number of trajectories intersections, the situation becomes more complicated. Linguistic variable *Number of collision trajectories* will accept values: *low*, *average* or *high*.

The way of determining the linguistic variable *Time to conflict* is similar to the way used to represent the distances between aircraft. Important here is the fact that a special attention is paid to the conflict situations that may occur in a short time while the even larger number of conflict situations, but distant in time are less important. Therefore, the basis for the adoption of the form of membership functions of linguistic variable *Time to conflict* is an aggregate indicator characterizing the average time to potential conflicts between aircraft in the sector. This linguistic variable will take the value of *short*, *medium* and *long*.

When assessing complexity of the traffic situation in the context of CD&R support systems, a very important issue is the availability of the airspace. Restrictions on airspace availability come from two different sources. The first of these is the activity of so-called restriction areas. The second source of reduced availability of the airspace is the presence of atmospheric phenomena that hinder the air traffic. Both sources of restrictions have been taken into account in the form of linguistic variable *Airspace availability*, which can take three values: *poor*, *average* and *good*.

The result of applying the fuzzy inference system is a conclusion in the form of a value of output linguistic variable *Traffic situation assessment*. The proposed scale of this variable takes into account the objective of creating a fuzzy inference system described in this paper. It is the assessment of the traffic situation complexity. The final result is the basis to make a decision whether the MTCD system is to inform the ATCo about the detected conflict. Thanks to its use we obtain (after the defuzzification) an evaluation in the form of real numbers in the range [0.2].

3.3. Knowledge base in the fuzzy inference system

Knowledge base in the fuzzy inference system consists of a set of fuzzy inference rules. These rules have the form: IF P THEN Q ELSE S. Local fuzzy inference system *Airspace availability* contains 9 fuzzy inference rules. The rule base for the main fuzzy inference system *Traffic situation assessment* contains 39 rules. In both cases, the rules were created on the basis of group of experts’ knowledge. Such rules usually contain some inconsistencies. They were resolved with the use of the method described in [6].

4. Computer implementation and simulation experiments

Fuzzy inference system was built according to the model described in Section 3 and implemented in a SciLab 5.4 environment with the Fuzzy Logic Toolbox 0.4.6 package. To verify and validate the method, a number of
simulations were carried out using several examples of traffic situations. They have been chosen so that the situations depicted closest to the real ones. We analyzed four scenarios:

Scenario 1 – refers to situations with little traffic, typical, for example, for the night time. The result of the assessment of the traffic situation complexity is equal to 0.78 in the adopted scale, which corresponds to low complexity. In this case, low sensitivity strategy should be adopted, that is the MTCD system should alert the controller a little later or at a higher level of threat detected.

Scenario 2 – refers to the situation of average traffic volume in the sector. In this experiment, evaluation of the traffic situation complexity changes to the value of 0.9, which corresponds to average complexity. Additionally, the existence of areas inaccessible to traffic, that is reducing the sector availability, causes a further change of the evaluation to more complex. In these cases, the MTCD system algorithm should adopt a neutral strategy.

Scenario 3 – refers to situations in which traffic increases significantly. When it is well distributed, the traffic situation complexity assessment moves to 1.09, but it still remains at the level of average. In such circumstances the MTCD system should still take the neutral strategy, but with a tendency to increase the sensitivity of the reaction to a detected conflict along with the increase of the traffic volume.

Scenario 4 – examines the influence of the time to conflict on the assessment of the complexity of the traffic situation. The results show that the complexity of the situation is much higher when the time to conflict is short, with the assessment at the value of 1.67, which corresponds to high complexity. The key factor responsible for high complexity evaluation is a large number of situations in which the intersecting trajectories have a short time to the conflict. The MTCD system should accept the strategy of high sensitivity at such traffic situations. This means that is should alert and support the ATCo as soon as it detects any conflict situation. Even at the expense of a possible false alarm.

5. Summary and conclusions

The paper presents the concept of the method to assess the complexity of the traffic situation for the medium-term conflict detection system. The theory of fuzzy sets has been used and the fuzzy inference system has been developed which allows carrying out simulations for parameters reflecting the actual conditions of air traffic. The system was implemented in the SciLab environment using Fuzzy Logic Toolbox package.

As shown by experiments, preliminary assessment of the traffic complexity with the use of a fuzzy inference system may allow a reduction of false alarms which is now an important problem. This system, basing on a subjective expert knowledge, allows one to determine how complex the situation is, which can be an important input parameter for the MTCD system. Its algorithm could be based on this parameter to adopt a more liberal (less sensitive) or a more restrictive (more sensitive) strategy with regard to the decision whether the detected conflict situation (with an unknown probability of actual occurrence) should be presented to ATCo.

References