A Fuzzy Based Aircraft Collision Avoidance System

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Abstract— As new aircrafts are inducted into the fleets of commercial airliners the vast airspace is becoming congested on certain routes and commercial hubs. Midair collision risks are increasing with the growth in air traffic volume and therefore; for the sake of safety aircrafts must be technically adept of monitoring the airspace and divert from a predetermined route, when traffic or weather conditions so dictates. In this research a fuzzy based aircraft collision avoidance system is proposed which is capable of generating an alert of a potential midair collision. In addition, the proposed system is competent of protecting the aircraft by taking its control, if no preventive action is taken within specified time. The intension is that the collision avoidance scheme can be achieved by monitoring and avoiding the intersection of guarding spheres between aircrafts. The concepts of aircraft domain and advisory areas are used in the proposed system to compute a guarding sphere, radical axis and automatic control region for the collision avoidance system. The proposed system can be integrated with existing collision avoidance systems for enhanced air traffic security.

Keywords- airborne collision avoidance; fuzzy expert system; traffic surveillance

I. INTRODUCTION

The concept behind airborne collision avoidance is that a pilot should get sufficient information about a dangerous situation in order to take corrective action. Currently advanced aircraft collision avoidance systems provide the information to pilots at three different levels which are: Proximity Warning (PW), Traffic Advisories (TA) and Resolution Advisories (RA) [1]. Proximity warning is an alert for the presence of an aircraft in close vicinity; TA is the indication about a particular aircraft that is now a threat, while resolution instructions to avoid the specific intruder are known as RAs.

In the early 1950s, PW devices were used to alert for midair collision risks. However, as air traffic density has significantly increased the high air traffic volume and potential collision risks between airplanes has also risen. A number of airborne collision avoidance systems were proposed during 1950 to 1986. One of the earliest midair collision avoidance systems was a three range device, developed in 1950s for high speed aircrafts. The Bendix system [2] was proposed in early sixties which measured the time required to escape from a collision situation. Dr. John was the first researcher who used the concept of ‘Tau’, while developing the Bendix system. Tau is the time to the closest point of approach on a collision course.

Eliminate Range-Zero System (EROS) was another system that was proposed during this era [3]. EROS was using time frequency techniques for synchronization purpose where each aircraft broadcasts its altitude information at every second.

In 1981 the program of Traffic Alert and Collision Avoidance System (TCAS) was launched [4]. Today there are three different versions of the TCAS family, TCAS-I, TCAS -II and TCAS-III, in operation. TCAS-I is the least expensive member of the TCAS family and it can generate TA only. The two other versions can generate TA as well as RA. TCAS-II can generate RAs for vertical movement (climb or dive) while TCAS-III is designed to generate RAs for both vertical and lateral movements of aircrafts [5].

In TCAS models, multiple conflicts i.e. when there are more than two aircrafts on a collision course, the conflicts are resolved pair wise. In pair wise scheme the manifold of potential threats are de-conflicted successively in couples. Vertical escape maneuvers are allowed with optimized conflict resolution method [15, 16].

TCAS systems are widely accepted and used in commercial airliners [6] but these are complex and expensive systems for small aircrafts. Currently, TCAS-I and TCAS-II are used but these systems restrict collision avoidance by moving laterally and false alarms are common in areas of air traffic congestion. Furthermore, TCAS cannot generate advisories for those aircrafts which do not have mode S transponder [1] because Mode S transponder can send its current altitude information while Mode C can’t. Therefore, the selection of the range of surveillance area remains manual in these systems.

Automatic Aircraft Collision Avoidance System (auto ACAS) was a joint project of U.S. air force and Forsvaret
Auto ACAS has been developed specifically for collision avoidance in combat aircrafts. The idea behind auto ACAS algorithm was to use the optimal coordinated escape maneuvers to avoid an accident. This system was designed to take control from pilot at the last possible moment to avoid the collision and then return control to the pilot as soon as possible after ensuing collision avoidance.

Another class of collision avoidance systems is GPS based aircraft collision avoidance systems [1, 4, 8]. The concept behind GPS based systems is relatively simple: The three dimensional location of all the aircrafts having this system is tracked by using the GPS positioning system and this information is transmitted to the aircrafts within the surveillance area of 30 KM. This system is also used to manage the different aircrafts in surveillance area by using timing signal (one pulse per second). GPS based aircraft collision avoidance systems usually decrease the false alarm rate as well as late alarm rate.

In existing airborne collision avoidance systems, the range of surveillance area is either static e.g. GPS based system, or it can be dynamic to some extent, that the pilot can adjust the surveillance range based on surrounding information e.g. the TCAS. Furthermore, existing systems are alert systems which require the manual action from pilot to resolve the conflict. If the problem is not adequately addressed then a real risk for air collision exists. The intent is to address these issues in a proposed fuzzy based aircraft collision avoidance system (FACAS). The main concepts used in FACAS are as follows: (1) guarding sphere, (2) danger index or radical axis and (3) automatic control region. These three components are discussed below:

The proposed FACAS is based on a simple mathematical concept: the length of danger index grows as two spheres approach each other. This theory is used in FACAS to generate alerts in different levels i.e. Surveillance Area (SA), TA and RA, and if needed take control of the aircraft in Automatic Control Region (ACR). Automatic collision avoidance is achieved by monitoring and preventing the intruder from entering into the ACR at any time. If the pilot fails to execute the instructions for the RA then these advisories are executed automatically by the system at the last moments before the collision. Control of the aircraft is returned to pilot as soon as the minimum separation distance is achieved. The fuzzy inference system is developed in MATLAB and extensive simulations are used to determine the maturity and applicability of proposed system.

The remaining paper is organized in the following way: SECTION-II covers model of the proposed approach, results and discussions are presented in SECTION-III and concluding remarks with future directions are discussed in SECTION-IV.

II. MODEL OF THE PROPOSED SYSTEM

The proposed alert and automatic aircraft collision avoidance system, depicted in fig. 1, is based on three components i.e. fuzzy guarding spheres (SA and traffic advisories), danger index or radical axis of the overlapping spheres and ACR. These three components are discussed below:

![Proposed system block diagram](image)

A. Model of the Fuzzy Surveillance Area and Traffic Advisory

Since the discovery of fuzzy logic and fuzzy reasoning in 1965, fuzzy logic control is the most active research area in its applications. For the purpose of modelling system dynamics, fuzzy logic is usually adopted where linguistic terminology is applied to reduce the complexity of the problems [10]. Usually in existing aircraft collision avoidance systems an expert pilot defines the range of surveillance area in nautical miles (14-40 NM) by his experience or it can be up to 100 NM in new systems [6]. So the surveillance area of aircraft is a vague parameter which must be determined by considering the size, speed, weather and visibility, altitude of the aircraft and its location i.e. (terminal or non-terminal area).
In the proposed fuzzy system, aircraft size (S), speed (V) and altitude (H) together with weather and visibility (W&V) are used as linguistic variables. Each linguistic variable is a member of a fuzzy set to a certain degree e.g. size (S) is small to a degree of 0.35. Where small is a fuzzy set. The reader is encouraged to consult a standard textbook on fuzzy logic for a detailed explanation.

Fuzzy rules are constructed and then fuzzy multiple inputs multiple outputs (MIMO) rules are evaluated.

SA and Tau are two output variables of the fuzzy expert system. First output is SA which contains the boundaries of the aircraft proximity warning area. The second output is TA which is subset area of the SA. TA is used for the purpose of alerting the pilot whenever any intruder becomes a potential threat.

\[
f(x; a, b, c) = \begin{cases} 
0 & \text{for } x < a \\
\frac{x-a}{b-a} & \text{for } a \leq x < b \\
\frac{c-x}{c-b} & \text{for } b \leq x < c \\
0 & \text{for } x > c 
\end{cases}
\]

(3.1)

Fuzzy rules are used to capture the human knowledge. There are two ways to construct the fuzzy rules i.e. induction or deduction [13]. The induction technique is used to define rules as one rule for each possible combination of fuzzy sets. In deduction method we extract the rules only from experience. In this research fuzzy rules are constructed by decomposing the rules into two categories according to the outputs. ‘H’ has a basic relation with ‘Tau’ so there is one to one mapping of membership functions. In addition, induction method is used for remaining variables to construct the rules as \((3 \times 3 \times 2) = 18\). Hence the proposed model defines the rules that can be used by an expert navigator.

The MATLAB fuzzy logic tool box [14] was used to develop the fuzzy inference system (FIS), where the rules were encoded using the rule editor. Figure 4, 5 and 6 depicts various outputs of the FIS like SA and Tau versus various inputs i.e. size, location and visibility and altitude.

Where V is the speed of the aircraft
B. Model for Danger Index of Guarding Sphere

The concept of the danger index presented in [9] is used in this paper for the determination of collision risk. Radical axis or danger index is a line passing through the connection point of two overlapping guarding spheres or surveillance areas. This concept is illustrated in figure 7, where the line ‘ab’ is passing through the intersection points and whenever two spheres approaches each other, length of the line ‘ab’ (radical axis) increases which shows that potential threat level is increasing.

Mathematically according to Pythagorean Theorem when two circles come closer to each other their radical axis always increases. Length of danger index will decrease when one or both of the aircrafts approaching each other will deviate or reduce their speed because these factors have a direct impact on the domain of the aircraft.

C. Automatic Control Region

Currently installed systems for collision avoidance require explicit pilot action to avoid collision. In this research the ACR area is defined within the domain of RA, and constitutes an area of 75% of RA. In this region the proposed system takes control and automatically avoids the mid-air collision. Whenever the system identifies an intruder in its TA domain, it alerts the pilot that specific intruder is now becoming a potential threat. If pilot do not take preventive action in specified time limit and intruder enters into the RA region of the aircraft then system issues specific instruction to resolve the conflict. However, if pilot still do not execute these instructions within a predefined time interval i.e. 25% of RA time slot then the intruder penetrates into the ACR and at that moment the proposed system will take control from pilot and execute those pre-issued instructions automatically. Control is returned to pilot as soon as the intruder disappears from RA domain.

D. Conflicts and Resolution Instructions

A pseudo code for the conflict resolution is given below:

If (Head-On) Then
    Intercepted: Dive-Right
    Intercepting: Climb-Right
If (Head-On) AND (Altitude Difference) Then
    Upper: Climb-Right
    Lower: Dive-Right
If (Back-On) Then
    Intercepted: Dive-Right
    Intercepting: Climb-Left
If (Back-On) AND (Altitude Difference) Then
    Upper: Climb-Right
Lower: Dive-Left
If (Cross-each-Other) Then
   Left-One: Climb-Left
   Right-One: Dive-Right
If (Cross-each-Other) AND (Altitude Difference) Then
   If (Left = Upper) Then
      Left-One: Climb-Left
      Right-One: Dive-Right
   Otherwise
      Left-One: Dive-Left
      Right-One: Climb-Right

E. Resolution Maneuvers and Multiple-conflicts

There are three possible manoeuvres (1)-Lateral movement (2)-vertical and (3)-speed changes. In the proposed system we have used manoeuvres (1) and (2). Multiple conflicts can be resolved (1)-pair-wise: where multiple conflicts are resolved successively and (2) globally: in which the entire environment is taken as concurrent domain. The proposed fuzzy based ACAS is based on pair-wise form of multiple conflicts resolution.

III. RESULTS AND DISCUSSION

A. FACAS vs. GPS Based ACAS

In previous research [4, 8], there is a static 30 KM surveillance area around the aircraft having GPS based aircraft collision avoidance system. Therefore these systems have no impact of the factors like aircraft size and speed of the aircraft on its domain. However, in the results presented in figure 10-12 clearly show that in proposed system, surveillance area is varying according to the values of different factors like weather and visibility conditions, change in speed, size of the aircraft and current location i.e. terminal or non-terminal area. In addition, GPS based systems are alert systems which require pilot action to avoid the intruder while in proposed algorithm ACR is used to provide the automatic collision avoidance.

B. FACAS vs. TCAS

The proposed algorithm has the capability to take control at the last moment and avoid the intruder but the TCAS is a manual system. On the other hand we can compare our proposed system with TCAS in two different ways i.e. traffic advisory of FACAS vs. TCAS and SA of FACAS with TCAS surveillance area.

TCAS is the most widely installed system in aircrafts for collision avoidance. As per ICAO regulations the TA ranges between [20-48] seconds, in TCAS systems this range is subdivided in to sensitivity levels (SL) with respect to altitude. In figure 9 a comparison of the TAs of the TCAS and proposed system are illustrated.

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Figure 10: Dive and Climb manoeuvres for Black and White aircraft respectively

Figure 11: Automatic control descending
CONCLUSIONS AND FUTURE WORK

An alert and automatic conflict resolution system for aircrafts is proposed to monitor, predict and avoid potential airborne threats. This system calculates the time to closest point of approach for traffic advisories as well as range of surveillance area. Implementation of SA and TA model can be integrated with existing systems for the domain and TA calculations. Simulation results indicate that the system presented in this research meets the basic requirements for aircraft collision avoidance. It appears that the proposed system can provide a better protection to aircrafts by using automatic collision avoidance at the last possible moment. The proposed FIS can significantly improve the effectiveness of current airborne collision avoidance systems. This research can be enhanced further by extending it to avoid collisions, while at the same time maintaining an optimal travel route using evolutionary algorithms.

REFERENCES