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Spatially-Temporal Interdependencies for the Aerial Ecosystem Identification

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Abstract

Present research in Air Traffic Management (ATM) is going towards improvement of airspace capacity, accessibility and efficiency while reducing the management costs and increasing the safety performance indicators. A 4D contract between an Airspace User (AU) and Air Traffic Control, in which aircraft should be located at a given time on a particular waypoint, opens a wide scope of applications for decision support tools (DSTs). This paper introduces a new modeling approach for a smooth safety nets transition within the high en-route airspace operations. The approach is based on a causal state space search as a response to some shortages in the collision avoidance events, resulted from a limited logic of Traffic alert and Collision Avoidance System (TCAS). It considers Enhanced TCAS (E-TCAS) that relies on an extended time horizon at the separation management level to define functionalities that will provide the most optimal resolution trajectories and remove the deadlock scenarios.

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Keywords: Ecosystem; State space analysis; Decision support tools; Intersection point; Look-ahead time; Deadlock

1. Introduction

At present, an upgraded Traffic Alert and Collision Avoidance System (TCAS II), has been designed for operations in the traffic densities of 0.3 aircraft per nautical mile. It demonstrates excellent performances for the pairwise encounters but, unfortunately, also shows some performance drawbacks in its logic due to well reported induced collisions in some traffic scenarios[1,2].

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Thus, there is a challenge to investigate and implement a new operational framework improving the TCAS functionalities to react at both tactical and operational level as a robust collision avoidance system for different traffic scenarios in which surrounding traffic should be considered with the real aircraft performances[3].

AGENT (Adaptive self-Governed aerial Ecosystem by Negotiated Traffic), as one of the SESAR[4] H2020 Exploratory Research projects, envisages a smooth transition from trajectory management, separation management to collision avoidance layers with an operational integration of seamless safety procedures in such a way that aircraft involved in a pair-wise encounter, together with the aircraft in the surrounding airspace behave as a stable conflict free “ecosystem”. The project defines the new operational framework though development of both the airborne and ground-based decision support tools (DSTs) that will generate the trajectory amendments for the ecosystem members taking into account the spatially-temporal interdependencies. The AGENT DSTs will work in line with the current and future SESAR requirements and fully capable to deal with the different levels of complex scenarios. The state space analysis tool is crucial for the ecosystem formation and the follow-up processes. A methodology for its successful implementation has been carefully developed and summarized in this research.

This paper illustrates the aircraft membership identification problem for potential ecosystem formation and explains the methodology used to verify the ecosystem based on both the space- and time-based parameters.

2. Problem identification and conceptual analysis

2.1. TCAS logic for pair-wise encounters

There are three common rules in the logic of TCAS for pair-wise encounters: (i) two Resolution Advisories (RAs) are opposite to each other, i.e. they advise an opposite sense for maneuver to the crew (for instance, “climb-descend” or “descend-climb”); it is defined as “reversal” TCAS logic; (ii) when RAs are issued, the aircraft at a lower altitude performs descending maneuver and the one at higher altitude climbing, without respect to the current flight configuration (cruising, climbing or descent); (iii) two aircraft after RAs activation form two spatial criteria: horizontal separation minima, called DMOD (Distance MODification, measured in nautical miles), and vertical separation minima, called ALIM (Altitude LIMitation, measured in feets), at the CPA. The third requirement is time separation, denoted with “tau” (measured in seconds) which is a contol factor for different Sensitivity Level (SL) index. This one-digit number features a strength sense of a TCAS command. Tau shows remaining time to reaching the CPA and measures an uncertainty level of the trajectory dynamics.

An induced pair-wise encounter event lies in fact that, after successfully resolved conflicts, the ″new″ conflict of two aircraft with their CPA cannot be easily predicted. Instead, surrounding traffic introduces a certain level of uncertainty in geometry of a pair-wise resolution trajectory and, thus, very tight spatio-temporal interdependencies between trajectories that could degenerate into collision are essential to be identified in order to define the conflict region itself[5]. Even if assumed that flight parameters, such as heading and closure rate, are progressively maintained, which also imply the constant time stamp updates, it is not possible to predict an induced CPA by analytical computational model. Naturally, this question opens many analytical aspects, but the main ones are definitely a limited TCAS logic based on the specific number of RAs, TCAS threshold requirements, and the feasible manoeuvers based on aircraft performances[6]. Table 1 gives the TCAS threshold values for different altitude ranges.

Table 1. TCAS threshold values.

Own Altitude (feet)	SL	TAU (seconds)		DMOD (nmi)		ZTHR (feet)		ALIM (feet)
		TA	RA	TA	RA	TA	RA	RA
1000 - 2350	3	25	15	0.33	0.20	850	600	300
2350 - 5000	4	30	20	0.48	0.35	850	600	300
5000 - 10000	5	40	25	0.75	0.55	850	600	350
10000 - 20000	6	45	30	1.00	0.80	850	600	400
20000 - 42000	7	48	35	1.30	1.10	850	700	600
> 42000	7	48	35	1.30	1.10	1200	800	700