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A fuzzy modeling approach to optimize control and decision making in conflict management in air traffic control

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ABSTRACT

The intensification of air traffic worldwide has increased the complexity of the control operations and the search for alternatives to support decision-making in this sector. This paper presents two fuzzy models, structured according to Mamdani, for the control of conflict in the air traffic route, based on the manipulation of the longitudinal speed of the aircraft, considering the rules set out by the International Civil Aviation Organization (ICAO). Both fuzzy models work jointly following a dynamic approach. The first model proposes a metric to quantify the longitudinal conflict levels between two aircraft in the same direction (located in the same airway) and the second model provides the longitudinal acceleration of the aircraft based on the level of conflict detected. The results show that the proposed approach is able to detect and remove longitudinal conflicts in advance, providing a potential tool to support decision-making and to improve the safety and the optimized use of airspace.

1. Introduction

According to the data disclosed by the International Air Transport Association (IATA), demand in civil aviation is rising. More than seven billion passengers are predicted for 2035 (more than twice that of 2014), an average growth of 4.1% per year (IATA, 2015). This growing demand requires infrastructure growth in the sector which in turn should seek improvements in aspects related to safety and flight efficiency.

Currently, airspace is distributed which means communication, navigation and surveillance are maintained by control agencies responsible for their management. This often results in poor communication structures in certain areas of the airspace. Fig. 1 shows a view of the complexity level of the air traffic routes on a working day in the United States of America.

The tasks of the air traffic controller comprises the elimination (or reduction) of conflicts between aircraft on route through the longitudinal or vertical spacing adjustment, changes in speed and deviation from risk areas, among others. Cooperation in the execution of these activities, especially through control systems helps reduce the workload of the air traffic controllers and improve safety during flights. Air traffic systems are still being developed or improved worldwide. In the United States and Europe government agencies are working to define the next generation of these systems (Landry, 2011). Support for decision-making represents a meaningful breakthrough in air traffic control considering that the growing demand leads to higher levels of complexity in the choice of alternatives, increases the processing feedback and the workload of the controllers (Lehouillier, Soumis, Omer, & Allignol, 2016). Moon, Yoo, and Choi (2011) presents the results of experiments that show the connection between the level of complexity in air traffic and the mistakes in the decision process caused by controllers, suggesting the need to increase the number of controllers and improvements in control systems. Furthermore, Fothergill and Neal (2008) analyze the impact of air traffic controllers' workload while trying to solve conflicts between two aircraft on route.

Work involving air traffic control (or the reduction of conflicts) uses several approaches such as expert systems, dynamic programming, reinforcement learning, path planning techniques, resilience engineering and metaheuristics (Dougui, Delahaye, Puechmorel, & Mongeau, 2013; Evans, Vaze, & Barnhart, 2016; Souza, Weigang, Crespo, & Celestino, 2009; Timoszczuk, Pizzo, Staniscia, & Siewerdt, 2009; Vismari & Camargo Junior, 2011; Woltjer, Pinska-Chauvin, Laursen, & Josefsson, 2015). Cafieri and Durand (2014) present a model-based optimization to perform the speed control of aircraft in order to eliminate conflicts. The change in the airway is the most traditional alternative used by air traffic controllers (Cafieri & Durand, 2014; Rantanen & Wickens, 2012) while the benefits of speed control are often not highlighted (Cafieri & Durand, 2014). Alonso-Ayuso, Escudero, and Martín-Campo (2014) present a mixed integer programming approach that alters flight levels of aircraft in order to avoid collisions. An integer programming model is

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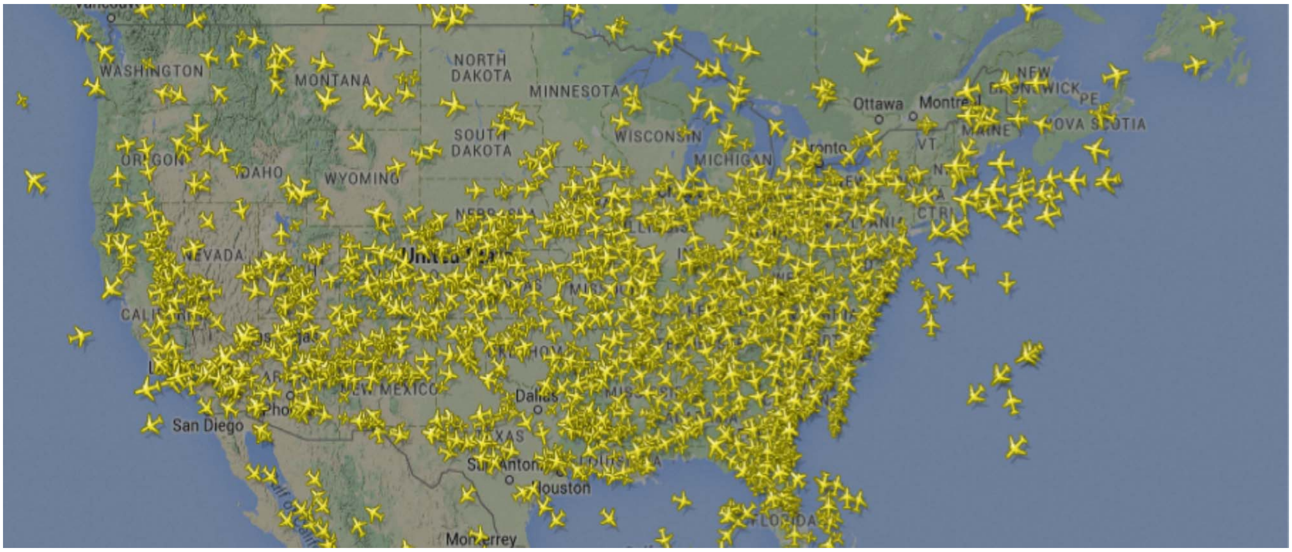

Fig. 1. Aircraft traffic route - working day (USA) (Flightradar24, 2015).

presented by Ozgur and Cavcar (2014) and Crespo, Weigang, and Barros (2012) to provide the best times for aircraft takeoff in order to avoid conflicts in the air traffic route, balancing capacity and demand at airports. Ozgur and Cavcar (2008) present an approach based on decision tree to support decision-making in the resolution of conflict. Peyronne, Conn, Mongeau, and Delahaye (2015) present a model which is able to find trajectories free of conflicts, and Boysen and Fliedner (2011) present a novel class of objective functions for ALP (Aircraft Landing Problem), which is designed to balance the workload of ground staff at airports. A recent work (Furini, Persiani, & Toth, 2016) presents an approach to optimize the route planning of a drone so as to minimize the total operational cost related to the air traffic and prevention of conflicts. Alonso-Ayuso, Escudero, Martín-Campo, and Mladenović (2015) tackle aircraft conflict and problem resolution by means of angle changes in aircraft directions based on the Variable Neighborhood Search metaheuristic framework.

Applications involving Artificial Intelligence (AI) to support the decision-making in the air traffic control is relatively recent. The works usually make use of multi-agent-based models that represent tasks to be performed or physical means (control centers, airports, lanes, among others) used in air traffic control. Gorodetskii, Karsayev, Samoylov, and Serebryakov (2010) apply multi-agents to the control of air traffic and classify the agents according to the tasks attributed to each human (pilot and controller). Pechoucek, Sislak, and Pavlicek (2006) propose agents represented by a set of aircraft joined by a cooperative system to avoid conflicts during the flight, where the behavior of agents is described by rule-based approach and A^* algorithm. Agogino and Tumer (2012) present each agent as a waypoint responsible for three functions: ensuring separation between aircraft; ordering delays on the ground; and changing the routes of aircraft. A multiagent algorithm where agents use reinforcement learning is explored. Callantine (2003) provides an architecture with a central agent and other ones representing control centers. The central agent provides additional information (and data) related to the environment surrounding each center. Other works adopt different approaches to the classification and definition of agents (Alam, Abbass, & Barlow, 2008; Cruciol, Weigang, de Barros, & Koendjbiharie, 2015; Nikumbh, Nathaman, & Vartak, 2011; Sislak et al., 2008; Turner & Agogino, 2009).

Air traffic control presents an intrinsic level of uncertainty usually related to the type of data, such as weather information, and to the decision-making carried out by the traffic controller. Fuzzy set theory enables the inclusion of heuristic behavior inherent to air traffic control. Some works involve the use of fuzzy logic (types I or II) as a tool to support decision-making in different problems related to air traffic control, such as exchange of flight levels and speed control (Lovato, Araujo, & Silva, 2006; Lovato & Oliveira, 2010), takeoff and landing (Lima, Fontes, & Schnitman, 2010), setting flight routes (Shafahi, Masouleh, & Masouleh, 2010; Sun, Cai, Yang, & Shen, 2015) and altitude control (Rahim & Malaek, 2011). Stula, Stipanicev, and Bodrozic (2010) combine a multi-agent approach with fuzzy cognitive maps to support decisions in air traffic control. Other works are related to Air Traffic Management (ATM), including evaluation of the planning and resource allocation and landing sequencing of unmanned aircraft, risk analysis and safety performance, and compartmentalization and control division of airspace (Kumar, 2014; Lower, Magott, & Skorupski, 2016; Nie, Zhao, & Dai, 2009; Oren & Kocyigit, 2016; Skorupski, 2016). The uncertainties associated with the weather conditions pose difficulties for ATM and often result in unused airspace capacity (Clarke, Solak, Ren, & Vela, 2013).

A common dynamic problem is the exposure of aircraft to conflict and this requires taking effective action in real time (changes in speed, direction or flight level) (Lehouillier et al., 2016). Some works propose action to be taken when minimum safety spacings between aircraft or security rules are violated, following binary (or crisp) logic. Pechoucek et al. (2006) employ spherical areas of safety, enabling cooperative action between agents even before the detection of the conflict. Chen, Landry, and Nof (2011) present a structure based on a decision tree and support the air traffic controller in spacing aircraft. Although these approaches are based on the existence or absence of conflict (DECEA, 2016; ICAO, 2007), the actions of the controller to avoid or eliminate the conflict are affected by their workload, the number of aircraft controlled simultaneously and restrictions associated with the operation of air traffic.

This paper presents a control strategy based on the manipulation of the longitudinal speed of a given aircraft during the flight on route, without changing the airway. The approach comprises the use of two fuzzy models (based on Mamdani structure) arranged in series. The first one represents a metric to quantify the level of longitudinal conflict between two aircraft and the second provides the acceleration to be applied in one of these aircraft in order to reduce or eliminate the level of conflict. This approach represents a feasible and comprehensive strategy for the identification and quantification of conflicts and an effective alternative for the control and monitoring of air traffic route. Both models were simulated and tested in normal airspace subject to the rules and restrictions set by ICAO (International Civil Aviation Organization). The results were compared with the standard procedure

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