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Online four dimensional trajectory prediction method based on aircraft intent updating

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To facilitate decision support in the air traffic management domain, an online four dimensional trajectory prediction (4D-TP) method was proposed in this paper. First, this study outlined the processes of online 4D-TP. Second, four major components of offline 4D-TP were discussed and presented, such as computation model, aircraft intent, environmental conditions and performance parameters. Third, this paper came up with an approach of current trajectory updating by using ADS-B Receiver and the corresponding data processing algorithm. Furthermore, the strategies of aircraft horizontal and vertical intent updating were also put forward for online 4D-TP. And the aircraft intent should be updated while the deviation between the current and predicted trajectory exceeding the pre-defined threshold. Finally, two types of case studies were carried out to demonstrate the performance and effectiveness of the proposed online 4D-TP method. The results indicated that the proposed online 4D-TP method is able to increase the prediction accuracy by triggering 4D-TP while the position or speed deviation is beyond the pre-defined threshold.

1. Introduction

Currently, the Air Traffic Management (ATM) relies on a set of operational measures for air traffic to fulfill the missions of separating, metering and sequencing [1]. The ever continuous growth and still increasing demand of air transport are posing significant challenges to the civil aviation community; as such current paradigms of ATM will not ensure the target levels of safety, capacity, efficiency and environmental sustainability in the future. As a consequence, several renovation projects have been launched, such as the Single European Sky ATM Research (SESAR) in Europe, the Next Generation Air Transportation System (NextGen) in the United States, and the Aviation System Block Upgrades (ASBU) framework from International Civil Aviation Organization (ICAO), to enhance the levels of safety, capacity, efficiency and environmental sustainability. In the ATM domain, conflict detection and resolution [2], aircraft sequencing and scheduling [3], trajectory based operation [4] are the most promising novel concepts and advanced technologies of the above renovation projects. And these concepts and technologies could not be implemented without the accurate Four Dimensional Trajectory Prediction (4D-TP).

4D Trajectory Prediction is the process that estimates a future 4D trajectory (in three spatial dimensions, i.e., latitude, longitude and altitude, plus time dimension) of individual aircraft through computation [5] on the basis of current aircraft states, estimated pilot's and/or controller's intent, expected environmental conditions and computer models of aircraft performance and procedures. Besides the definition of 4D-TP, FAA/Eurocontrol Action Plan 16 (Common Trajectory Prediction Capabilities) also proposed varied performance requirements, like accuracy, uncertainty and response times. More specifically, an important conclusion was put forward in Action Plan 16 that the structure, process, function and performance requirements of 4D-TP were totally dependent on the application of 4D-TP, which was to say that 4D-TP for conflict detection, conflict resolution, aircraft sequencing, or flight planning had different concerns. However, the key issue of 4D-TP seems obvious that how to quickly and accurately predict 4D trajectory. Many researchers have devoted themselves to addressing this issue.

Trajectory prediction is the process of estimating a future trajectory for an individual aircraft, thus the optimal estimation is a reliable method for 4D-TP. Additionally, the aircraft movement involves both continuous dynamics and discrete modes switching, then trajectory prediction can be viewed as a hybrid estimation problem which may be tackled with multiple-model methods. And the Interacting Multiple Model (IMM) algorithm is a case in point [6]. In order to produce better mode and state estimates, Hwang

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[7] proposed a modified version of the IMM algorithm, called the Residual-Mean Interacting Multiple Model (RMIMM) algorithm, based on a new likelihood function. But the RMIMM algorithm still followed the assumption of residuals being zero mean, only considered the characteristics of single Kalman filter's residual and casually neglected the mixing process in the standard IMM algorithm. In view of these, Zhang [8] presented a new method for updating flight mode probabilities, which discarded the zero mean residual assumption and took the interacting influences into account. Furthermore, in the ATM domain, an aircraft always flies over the air routes, thereupon the transition probabilities of flight modes can be modeled as a state-dependent Markov process. As a result, Seah and Hwang [9] proposed the State-Dependent Transition Hybrid Estimation (SDTHE) algorithm for trajectory tracking and predicting to infer aircraft intent [10] and detect potential conflict [11]. Zhang [12] presented the SDTHE algorithm based on [8] to improve the accuracy of mode estimation and trajectory prediction.

Kinematic and kinetic modeling is another important method to implement trajectory prediction on the basis of current aircraft states, estimated aircraft intent, expected environmental conditions and aircraft performance parameters. In other words, this method consists of four distinctive parts: computation model, aircraft intent, environmental conditions and performance parameters. As to computation model, Total Energy Model (TEM) [13] and Point-Mass Model (PMM) [14] are most extensively applied. Zammit and Mangion [15] addressed the suitability of TEM for fast trajectory prediction during idle-thrust descents. PMM was utilized for trajectory optimization [16,17] by means of hybrid optimal control strategy. In terms of TEM, the energy sharing factor was a huge hurdle for trajectory prediction. As regards aircraft intent, the Aircraft Intent Description Language (AIDL) [18,19] was the most reliable way, which provided necessary elements to unambiguously formulate the aircraft intent. And the lateral, altitude and speed constraints could be extracted from the radar tracks, the procedures of airlines and the transfer agreements between different sectors. As for the environmental conditions, especially wind field, they can be obtained through meteorological observation and forecast [20], or local wind vector estimation with spatial and temporal variations [21]. With regard to the performance parameters, BADA [13] were widely used for the parameters of flight envelope, aerodynamics, engine thrust and fuel flow. The international Aircraft Noise and Performance database (ANP) [22] would be an alternative.

With the development of “Big Data” research in the ATM field, the machine learning method is an essential supplement to the trajectory prediction, especially for the flight time estimation field. On the one hand, it is dependent on the similarity of trajectories, while only taking past radar tracks into account. Hong and Lee [23] introduced a new framework for predicting arrival times by incorporating probabilistic information for the identified trajectory patterns. Tastambekov et al. [24] put forward an innovative approach for the trajectory prediction based on the local linear functional regression that considered data preprocessing, localizing and solving linear regression using wavelet decomposition. On the other hand, it is based on the reconstruction of input and output space. Leege [25] brought forward machine learning approach for the trajectory prediction based on the historic aircraft trajectory and meteorological data.

As discussed above, there exist three main methods for trajectory prediction: optimal estimation, kinematic and kinetic modeling and machine learning. And these methods have been widely used to predict the future trajectory, and moreover, to facilitate decision support in the ATM domain. So far, however, there has been little discussion about online trajectory prediction. With reference to this aspect of the research achievements, Alligier [26,27] made the best of the past observations to estimate mass and thrust parameters so as to improve the prediction accuracy. Nevertheless, such studies only focused on the proper updates of several parameters.

This paper aims at developing an online 4D-TP method. We firstly acquire the current surveillance messages of the aircraft through Automatic Dependent Surveillance-Broadcast (ADS-B) receiver. Secondly, we decode those surveillance messages to obtain the flight states of the aircraft and compare them with the predicted trajectory. Thirdly, if the deviation between current flight states and predicted trajectories beyond a threshold, then the aircraft horizontal intent and vertical intent updating methods are triggered. Finally, based on the updated aircraft intent and current states, we carry out the 4D-TP.

The novelty of the proposed online 4D-TP method is two-fold: First, the accessible current trajectory from ADS-B receiver could help to fulfill the function of trajectory conformance monitoring, which is served as a trigger for online 4D-TP. Second, the accessible current trajectory from ADS-B receiver is fully used to design the aircraft horizontal and vertical intent updating methods for online 4D-TP. Such proposed method might help to enhance the function and improve the accuracy of trajectory prediction to facilitate decision support in the ATM domain.

This paper is organized as follows: First, an online 4D-TP problem is addressed in Section 2. Subsequently, section 3 details the model and method of online 4D trajectory prediction. The simulation and validation results are presented and discussed in Section 4, before the conclusion in Section 5.

2. Problem formulation

As trajectory prediction is the process of estimating a future trajectory for an individual aircraft, online 4D-TP needs to update the future trajectory estimation in response to several events such as availability of new constraint information or deviation between actual and predicted trajectory exceeding a predefined threshold. Thereupon, our proposed online 4D-TP method is composed of three processes: preparation, computation and updating. The process flow chart of online 4D-TP is shown in Fig. 1, which is derived from Ref. [5].

Meteorological data, aircraft performance data and adaption data provide support function for the 4D-TP, in which adaption data consists of control airspace, control sectors, air routes, standard instrument departure (SID) and standard terminal arrival route (STAR).

Preparation process creates the initial version of flight intent based on flight plan and adaptation data. This process is activated at the beginning or when the trajectory prediction should be updated. Computation process constitutes the kernel function of 4D-TP, in which the aircraft intent contains a description of the way the aircraft will be operated, the trajectory predictor integrates aircraft intent information into 4D trajectory using the atmospheric conditions and the aircraft performance parameters, and estimated trajectory serves as the output of 4D-TP. For online 4D-TP, updating process plays an important role, which may result in the generation of new aircraft intent by triggering preparation process again and again. Conformance monitoring [28–30] in the updating process aims at determining whether the re-prediction is required or not. In this paper, conformance monitoring depends on the deviation between predicted trajectories and current states exceeds the pre-defined threshold whether or not.

The current trajectory offers a baseline for conformance monitoring to trigger the online 4D-TP whether or not. In this paper, the current trajectory was obtained through the ADS-B receiver (BAR6216 ADS-B 1090 MHz Receiver).

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