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Data-driven Conflict Detection Enhancement in Closest Point of Approach Problem

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Abstract—Closest Point of Approach (CPA) is one of the main problems in aircraft Conflict Detection (CD). It aims to find out the minimum distance and the associated time between two aircraft. Conventional CPA calculation algorithm generally assumes that the speed and heading of aircraft are constant. But the uncertainties in real operational scenarios lead to inaccuracy of CPA calculation. This project presents a novel data-driven CD framework with Machine Learning (ML) algorithms. The proposed framework provides a promising solution for improving the CPA prediction accuracy with the help of real trajectory data. It contributes to not only reduce the number of fault Short-mid term conflict alert for air traffic controllers, but also support the implementation of future free flight concept, so as to reduce fuel consumption and emission.

Keywords—Air Traffic Management, Conflict Detection, Closest Point of Approach, Data mining, Machine Learning

1. INTRODUCTION

Free flight concept is a crucial research topic in future Air Traffic Management (ATM). Nevertheless, the conflict between aircraft must be detected and resolved before achieving this goal. To ensure the safety and efficiency of free flight, automated aircraft Conflict Detection (CD) is of great significance.

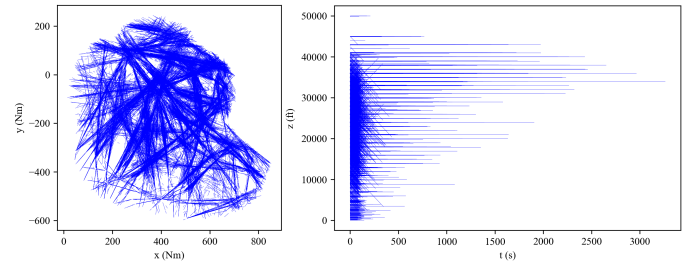
Closest Point of Approach (CPA) is a key concept in view of the algorithmic level for MTCD. It aims to determine the minimum distance and the associated time between two aircraft. However, theoretical CPA calculation is problematic in the actual MTCD application. It is assumed that each aircraft flies in a straight trajectory with a constant velocity vector. Actually, the aircraft may change or intend to change the heading and rate of climb throughout the flight. Besides, the ground speed is the sum of airspeed and wind speed vectors. These vector components both have high-level uncertainties, especially wind speed. Due to the stochastic climate change and the limitation of wind modelling strategy, the wind prediction bias is large and increases with time. Therefore, conventional CPA calculation algorithm frequently lacks accuracy in the real world with high rate of false alarms and missed detects. Thus, it is necessary to propose an optimal and effective CPA calculation framework.

2. DATASET

The data source is the mode-S observations covering France on January 20, 2012. This raw dataset contains 21,314 trajec-

tories with 11,214,216 records. The raw data needs to be pre-processed. Firstly, the Geographic Coordinate System (GCS) is transformed into Projection Coordinate System (PCS). Then, missing values are estimated using piecewise linear interpolation. The heading in the new PCS is also recalculated.

Then, in order to ensure the calculation of CPA and consider the uncertain factors in the real-world, trajectories are split into approximately straight segments. An effective way to achieve this is to split each trajectory respectively in the horizontal plane and the vertical plane, and keep the intersection of trajectory segments in two planes as the dataset. Figure 1 presents the trajectories in the dataset. To generate initial cases with more conflicts, we align the initial timestamps of all trajectories to 0.



(a) Projection of trajectories in the horizontal plane (b) Altitudes of trajectories that change over time

Figure 1: Illustration of trajectories in the dataset

3. CONVENTIONAL CPA CALCULATION ALGORITHM

A. In 2D airspace

In a horizontal plane with two aircraft, the protected zone of an aircraft is a circle, see Figure 2a. Given a lookahead time interval $[T_i, T_e]$, the time and distance of CPA is calculated as follows:

$$t_{CPA}(\mathbf{p}, \mathbf{v}) = \min \left(T_e, \max \left(T_i, -\frac{\mathbf{p} \cdot \mathbf{v}}{\|\mathbf{v}\|^2} \right) \right) \quad (1)$$

$$d_{CPA}(\mathbf{p}, \mathbf{v}) = \|\mathbf{t}_{CPA} \cdot \mathbf{v} + \mathbf{p}\| \quad (2)$$

where the vectors \mathbf{p} and \mathbf{v} are the relative position and velocity vector of 2 aircraft at the initial state.

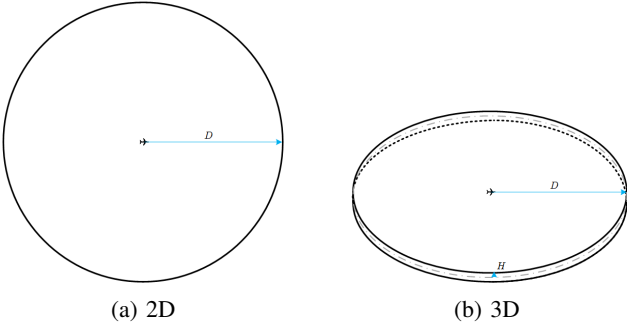


Figure 2: Protected zone

B. 3D

In a 3D airspace with two aircraft, the protected zone of an aircraft is a cylinder rather than a sphere, see Figure 2b. Therefore, the Euclidean distance is not suitable to calculate the time of CPA. A novel solution called cylindrical norm was proposed in [1]. Given a cylinder of radius D and half-height H , the cylindrical norm of a vector $\mathbf{w} \in \mathbb{R}^3$ is:

$$\|\mathbf{w}\|_{\text{cyl}} = \max \left(\frac{\|\mathbf{w}_z\|}{H}, \frac{\|\mathbf{w}_{(x,y)}\|}{D} \right) \quad (3)$$

The time of CPA can be derived by comparing T_i , T_e , the time that minimizes $\|\mathbf{w}\|_{\text{cyl}}$. The distance of CPA can be calculated according to (2).

4. METHODOLOGY

We propose a machine learning framework to predict the time and distance of CPA. The relative position, relative ground speed, wind speeds are basic features. For horizontal and 3D CPA prediction, the components of their CPA calculation formulas are respectively considered as additional features. In addition, because the variation of position and speeds may be stochastic in the real world, only the initial states of aircraft may not be suitable to represent all states along trajectories. For this purpose, we introduce a novel feature enrichment method called "convolution" to smooth speed and position features. It is not a real convolution operation, but borrows the idea. Given 2 vectors \mathbf{w}_i and \mathbf{w}_o , initial timestamp t , lookahead or lookbehind time K , then the "convolution" vector \mathbf{w}_{conv} is defined as follows:

$$\mathbf{w}_{\text{conv}} = \frac{1}{(2K)^2} \sum_{t_k=-K}^K (\mathbf{w}_i(t-t_k) - \mathbf{w}_o(t_k)) \quad (4)$$

The ML models applied to this study to predict time and distance of CPA are presented in Table I. Nested Cross Validation (CV) is introduced to select the hyperparameters and assess the model performance. random search algorithm is used for hyperparameter optimization in the inner CV.

In the horizontal plane, the outputs of models are time of CPA, distance of CPA. In 3D airspace, the output of models are time of CPA, horizontal and vertical distance of CPA. After evaluating the performance of ML models, the predicted distance of CPA is compared with the separation minimum to determine whether a conflict is likely to occur.

TABLE I: ML models used in this work

Type	Algorithm
Linear	Multiple Linear Regression (MLR)
Non-Linear	Support Vector Machine (SVM)
	Feed-Forward Neural Networks (FFNNs)
	K-Nearest Neighbors (KNN)
Ensemble	Gradient Boosting Machine (GBM)
	Random Forests (RF)

5. PRELIMINARY RESULTS

The preliminary results in the horizontal plane is published in [2]. ML models significantly outperforms conventional CPA calculation algorithm in terms of the prediction of time and distance of CPA. The MAE of the conventional model is reduced by 2.34 Nm (62.23%) and the RMSE is reduced by 5.18 Nm (64.67%) for the prediction of distance of CPA. Using the predicted distance and time of CPA, the conflict detection is performed. Compared to conventional CPA calculation algorithm, the best ML model contributes to 4.55% improvement in conflict case identification and 2.09% improvement in non-conflict case identification. These results prove that ML models are capable of improving the capability of conflict detection.

With less prediction error on distance of CPA, ATCO and pilots will obtain more precise information about the spatial severity of potential conflicts. Accurate predicted time of CPA will bring more reliable temporal information of crossing traffics. Reliable spatial and temporal severities result in the increase of situation awareness. Hereby, effective and exact conflict resolution instructions will be delivered by ATCO, which can avoid accidents.

6. NEXT STEPS

As next steps, prediction of time and distance of CPA in 3D airspace is now in progress. The proposed CPA prediction framework based on machine learning is still feasible in the 3D airspace. More data is collected to enrich the size of dataset. Because of the complexity of the airspace, more valuable additional features are explored to see if they could be used by machine learning models, such as aircraft information, meteorological information, etc.

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