UNIVERSITY OF TECHNOLOGY SYDNEY

4-D Trajectory Prediction and Its Application in Air Traffic Management

by Zhiyuan Shi

Thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

under the supervision of Min Xu

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Declaration

I, Zhiyuan Shi, declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy in the Faculty of Engineering and Information Technology at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of the requirements for a degree at any other academic institution except as fully acknowledged within the text. This thesis is the result of a Collaborative Doctoral Research Degree program with Northwestern Polytechnical University.

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Abstract

Safety is assigned with the highest priority in Air Traffic Management. Trajectory prediction is the most crucial task in the increasing aviation activities. Situation of an aircraft can be assessed according to the predicted intention. Massive data contributes a lot for training a trajectory predictor, but cannot guarantee better decisions. While data visualization helps us understanding information well. Therefore, we carried out the following works in this thesis.

Points of interests play an important role in most land traffic prediction algorithms. Compared with land traffic, the sparse way-points and shared airways make it difficult for flight trajectory prediction. Practical information including landmarks, navigation facilities, and flight rules is fused and embedded in LSTM networks, namely the constraint LSTM network is proposed. Density-based Spatial Clustering of Applications with Noise and airports' locations segment the flight trajectories into climbing, cruising and descending/approaching phases. Linear Least Square fits the relationship of the constraint items. Sliding windows bridge the input sequences of LSTM network and help maintain the continuity of trajectory. Multiple ADS-B ground stations contribute to the historical flight trajectories for our experiment. The widely used LSTM network, Markov Model, weighted Markov Model, Support Vector Machine and Kalman Filter are used for comparison. Experimental results demonstrate that our trajectory predictor outperforms the above-mentioned state-of-the-arts models.

In addition to the trajectories, airports, pilots and geographical environment contribute a lot to stable and safe air traffic, especially during the climbing/descending phases. We increased of LSTM network to predict the flight trajectory in the climbing phase. Geographical environment, weather information, and dynamic performances of aircraft are modelled comprehensively in the proposed cubic A* search algorithm

for 3-D path planning when encountering an emergency. Real-time states of aircraft, including speed, altitude and track angle, are constructed as three threat factors, which are applied to assessment of the planned optimal path.

Finally, an auxiliary decision support system is developed based on ArcGIS 10.0, to graphically provide the intuitive and quick assistance for air traffic controllers. Multi-scale and multi-modal data is encoded as visual symbols and mapped on GIS to display geographical situations. Based on the predicted intention of an aircraft and scheduled flight plans, two cases are studied and analysed on our system, i.e., path planning for collision avoidance with mountains and rerouting suggestion for getting around the bush-fire, respectively. The system can provide timely auxiliary support for controllers to make decisions.

Publications

The contents of this thesis are based on the following papers that have been published, accepted, or submitted to peer-reviewed journals and conferences.

Journal Papers:

1. Zhiyuan Shi, Quan Pan, Min Xu. "LSTM-Cubic A*-based Auxiliary Decision Support System in Air Traffic Management," *Neurocomputing*, 2020. DOI: 10.1016/j.neucom.2019.12.062.

2. Zhiyuan Shi, Min Xu, Quan Pan. "4-D Flight Trajectory Prediction with Constrained LSTM Network," *IEEE Transactions on Intelligent Transportation Systems*. 2020. DOI: 10.1109/TITS.2020.3004807.

Conference Papers:

1. Zhiyuan Shi, Min Xu, Quan Pan, et al. "LSTM-based flight trajectory prediction", *2018 International Joint Conference on Neural Networks (IJCNN)*. July, 2018.

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