Chinese Journal of Aeronautics, (2014),27(1): 93–101

Chinese Society of Aeronautics and Astronautics
& Beihang University

Chinese Journal of Aeronautics

cja@buaa.edu.cn
www.sciencedirect.com

A strategic flight conflict avoidance approach based on a memetic algorithm

Guan Xiangmin [a,b], Zhang Xuejun [a,b,*], Han Dong [a,b], Zhu Yanbo [a,b,c], Lv Ji [a,b], Su Jing [a,b]

[a] School of Electronic and Information Engineering, Beihang University, Beijing 100191, China
[b] National Key Laboratory of CNS/ATM, Beihang University, Beijing 100191, China
[c] Aviation Data Communication Corporation, Beijing 100191, China

Received 14 January 2013; revised 7 May 2013; accepted 9 July 2013
Available online 8 December 2013

KEYWORDS

Air traffic control;
Combinatorial optimization;
Conflict avoidance;
Genetic algorithm;
Memetic algorithm

Abstract Conflict avoidance (CA) plays a crucial role in guaranteeing the airspace safety. The current approaches, mostly focusing on a short-term situation which eliminates conflicts via local adjustment, cannot provide a global solution. Recently, long-term conflict avoidance approaches, which are proposed to provide solutions via strategically planning traffic flow from a global view, have attracted more attentions. With consideration of the situation in China, there are thousands of flights per day and the air route network is large and complex, which makes the long-term problem to be a large-scale combinatorial optimization problem with complex constraints. To minimize the risk of premature convergence being faced by current approaches and obtain higher quality solutions, in this work, we present an effective strategic framework based on a memetic algorithm (MA), which can markedly improve search capability via a combination of population-based global search and local improvements made by individuals. In addition, a specially designed local search operator and an adaptive local search frequency strategy are proposed to improve the solution quality. Furthermore, a fast genetic algorithm (GA) is presented as the global optimization method. Empirical studies using real traffic data of the Chinese air route network and daily flight plans show that our approach outperformed the existing approaches including the GA based approach and the cooperative coevolution based approach as well as some well-known memetic algorithm based approaches.

1. Introduction

Airspace has become more and more crowded because of the rapid increase of Chinese air traffic. As the density of flights in airspace jumps to a high level, it is difficult to keep safe separation among flights. Consequently, the probability of flight conflicts could increase, which threatens airspace operational safety.[1,2] Moreover, it has resulted in other problems, such as delays, fuel waste, and pollution, which cost the airline

* Corresponding author. Tel.: +86 10 82338626.
E-mail addresses: guanxiangmin@ee.buaa.edu.cn (X. Guan), zhxj@buaa.edu.cn (X. Zhang).

Peer review under responsibility of Editorial Committee of CJA.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.cja.2013.12.002

industry billions of dollars every year. Conflict avoidance (CA), which provides effective solutions for flights to eliminate conflicts, is a key technique to ensure safety among aircraft. It has drawn much attention of researchers during the last several decades.[3]

The current approaches are mainly focused on short-term situations which need to solve conflicts happening in very short time.[4,5] In the last decade, many approaches have emerged,[6,7] which can be mainly categorized into: rule-based methods,[3] game theory methods,[4,8] field methods,[9] geometric methods,[5] numerical optimization methods,[1,10–13] and multi-agent methods.[14–16]

Short-term approaches require the fastest respond to handle emergencies on the way, which will be within several minutes or even shorter. Hence, local trajectories adjustments are usually implemented, such as instant velocity change and/or instant heading angle change.[1,3] However, the reactive and passive way to provide solutions in real time cannot consider the overall situation, and cannot give a feasible global solution.[14]

On the contrary, long-term approaches can take advantage of full knowledge to plan traffic flow strategically and provide solutions from a global view.[17] Therefore, strategic conflict avoidance (SCA) approaches via optimizing all flight plans to reduce conflicts have become a research tendency.

SCA is a large-scale combinatorial optimization problem with complicated constraints, which is hard to be handled by classical approaches. Some researchers introduced evolutionary algorithms (EAs) to manage it.

Durand used a genetic algorithm (GA) to solve it. Considering the problem is too large and complex, a sliding forecast time window was introduced to reduce the dimension of the problem to get feasible solutions.[18] However, it cannot get a global optimum solution, and it may overstock amount of flights in later time windows which causes high difficulty for the GA-based approach to solve. Recently, cooperative coevolution was successfully applied to deal with the problem.[19] It used a divide-and-conquer strategy to decompose the large-scale problem into several sub-problems which can be solved by adopting an EA for each one. However, the searching space of the sub-problems is still huge, and the variables and the constraints are tightly coupled, which cause the cooperative coevolution (CC) with a random grouping strategy to get into local optimum easily.[20] The two global optimization approaches both suffer from premature convergence in the SCA problem because of their limited search capabilities in a huge solution space with large amounts of variables and constraints.

Memetic algorithms (MAs), one of the recently growing areas in EA research, are population-based meta-heuristic search methods inspired by Darwinian's principles of natural evolution and Dawkins' notion of a meme defined as a unit of cultural evolution that is capable of local refinements.[21] They can be regarded as a bridge between a population-based global search and the local improvement made by each of the individuals.[22] They have shown to speed up the search process, attaining higher quality solutions on complex design problems compared with their conventional counterparts.[23]

In this work, with the aim to minimize the risk of premature convergence and yet to get high quality solutions, we propose an effective strategic conflict avoidance framework based on a MA. In addition, a specially designed local search operator and an adaptive local search frequency strategy are proposed to improve the solution quality. Furthermore, a fast GA is presented as the global optimization method. Empirical studies using the real traffic data of the Chinese air route network and daily flight plans show that our approach outperforms the existing approaches including the GA based approach and the cooperative coevolution based approach as well as some well-known memetic algorithm based approaches.

2. Problem formulation

Taking Chinese air route network in Fig. 1 for example, suppose that there are s air routes (A_1, A_2,..., A_s) with l waypoints (W_1, W_2,..., W_l) in the air route network involved in the problem, and there are n flights (F_1, F_2,..., F_n) with specific flight plans. Many conflicts may occur in the air route network because of separations broken among flights at some waypoints. In addition, suppose that there are only two flight levels on one air route segment, and the flights with opposite directions would fly on the two levels, respectively. Therefore, a conflict between two flights on the opposite directions along the same segment will be avoided while it will not along different segments.

Fig. 2 describes the conflict vividly. Aircraft i and j are separately flying from Xilinhot airport to Ulanhot airport and from Hailar airport to Tongliao airport. Black points denote waypoints in the routes. From the picture, we can see that

Fig. 1 Air waypoint network of China.

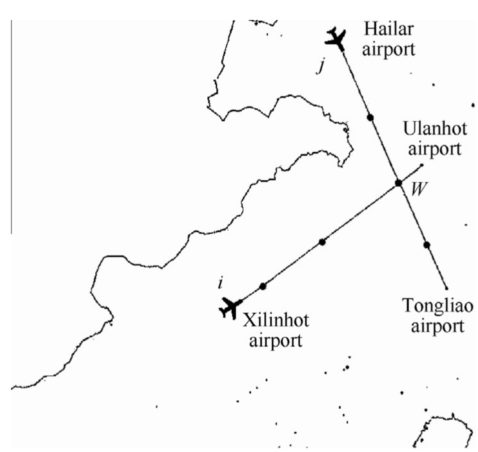

Fig. 2 Conflict description.