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Aircraft grouping based on improved divisive hierarchical clustering algorithm

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ABSTRACT

Because air traffic control efficiency can be largely increased by means of group, the aircraft grouping problem was studied based on improved divisive hierarchical clustering algorithm (DHCA). The concepts of position similarity, velocity similarity and heading similarity were defined and the merging rule about position matrix, velocity matrix and heading matrix was put forward. According to the definition of the most similar point and the neighbor set, the end condition of DHCA was brought forward. In order to increase the search efficiency, the neighbor set was saved by the open hash table. The flow of the improved DHCA was set up by binary tree and open hash table. The simulation results show that the improved DHCA can finish aircraft grouping, and moreover, the time complexity analysis proves that the improved DHCA has a better time efficiency than the bisection method.

1. Introduction

With the development of air transport, congestion and delay are becoming more and more serious, especially in terminal of hub airport and main route, and the operation cost of airline is greatly raised (Zhao and Yao, 2008). Because of congestion and delay, the workload of air traffic controller (ATC) is aggravated, moreover, flight safety is undermined. Therefore, it is important that traffic flow be accelerated and flight delays be reduced in order to improve efficiency of air traffic control.

In the military field, fighter aircraft usually combat by formation, and the formation is composed of one lead aircraft and several wing aircraft. The speed and heading of wing planes are consistent with lead aircraft, and the distance between each aircraft remains invariant (Lan and Yu, 2005). Formation can enhance airspace volume and bring convenience for command and control center to command the aircrafts. In addition, flying in formation can reduce air resistance and cut down oil consumption (Gabriele and Emilio, 2003; Ronald et al., 2002; Damien and Yuri, 2007). Deducing from the characteristics of fighter formation, civil aircraft can also fly in formation. ATC is responsible for grouping the aircraft and appointing lead aircraft and wing planes. The separation between aircraft in the same group can be automatically kept because each aircraft is equipped with TACAS, ADS-B, Inter-aircraft Datalink and Flight Crew Interface (Christine, 2004). Each group is considered as a control unit and ATC only needs to control lead aircraft, air traffic control efficiency and airspace volume are improved. Michael et al., (2005) and Christine, (2004) respectively summarized architecture of a military formation system (Fig. 1) and pointed out that civil formation can be implemented by the same mode as military formation. They did not further their research on how to group the aircraft. In China, the study of formation flight mostly concerned with formation combat, such as (Huo et al., 2006). The work of Peng et al. (2012) studied how to avoid collision by TCAS between each group of the large formation, but how to divide large formation into several groups was not carried out.

The mathematical model of grouping problem was set up by the definition of position similarity, velocity similarity and heading similarity. In order to increase time efficiency of DHCA, the DHCA was improved by binary tree and open hash table, and the aircraft grouping was solved by the improved DHCA.

2. Mathematical model of grouping

Grouping aims at simplifying airspace and increase efficiency by combining aircraft, according to position, velocity and heading. Grouping involves some concepts, such as target point, position similarity, velocity similarity and heading similarity (Guo et al., 2006).

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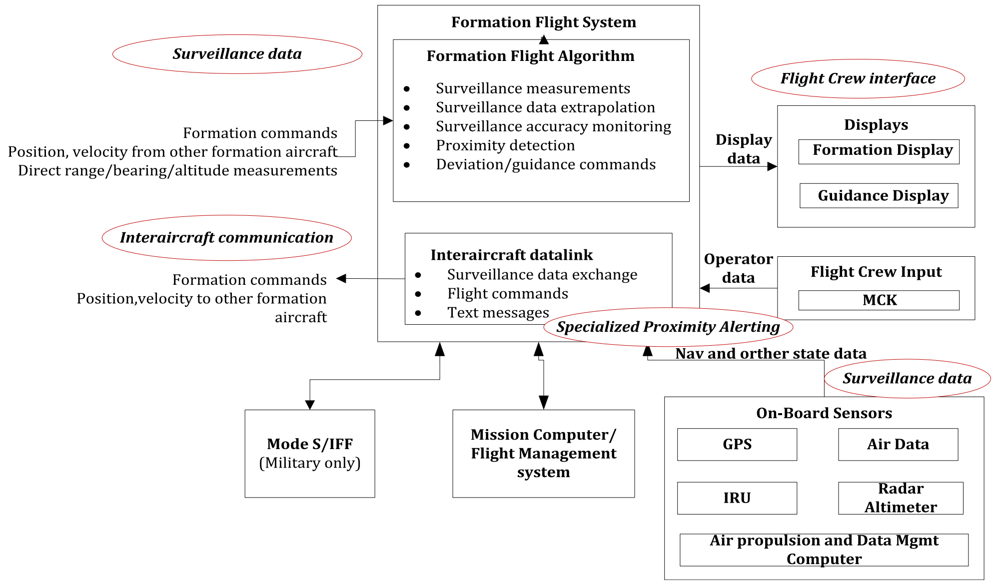

Fig. 1. Military formation flight system architecture.

Definition 1 Target point.

Aircraft in flight is called a target point, and its attribute set is $\{(x,y,z),v,\Psi\}$ where (x, y, z), v and ψ are coordinate, velocity and heading, respectively. Target swarm is made up of target points.

Definition 2 Position similarity.

Position similarity $C_P\,(T_1,T_2)$ indicates the jointing degree between target points T_1 and T_2. $C_P\,(T_1,T_2)$ can be calculated by the following formula.

$$C_P\left(T_1,\ T_2\right)=\begin{cases}1,\ |x_1-x_2|<\Delta x|,\ y_1-y_2|<\Delta y,\ |z_1-z_2|<\Delta z\\ e^{-k_1\left[(|x_1-x_2|-\Delta x)^2+(|y_1-y_2|-\Delta y)^2+(|z_1-z_2|-\Delta z)^2\right]/3},\ \text{else}\end{cases} \tag{1}$$

In this formula, Δx, Δy and Δz are the thresholds along axes of x, y and z and k_1 is the index of half normal distribution. The distance along axes of x, y and z between each pair of adjacent target points in the same group should be limited in a certain threshold. When the distance between two target points exceeds the threshold, the probability belonging to the same group will show half normal distribution.

Definition 3 Velocity similarity.

Velocity similarity $C_V(T_1,T_2)$ indicates the following degree between target points T_1 and T_2. $C_V(T_1,T_2)$ can be calculated by the following formula.

$$C_V\left(T_1,T_2\right)=\begin{cases}1, & |v_1-v_2|<\Delta v\\ e^{-k_2\left[(|v_1-v_2|-\Delta v)^2\right.}, & \text{else}\end{cases} \tag{2}$$

In this formula, Δv is the threshold of $|v_1-v_2|$ and k_2 is the index of half normal distribution. When $|v_1-v_2|$ exceeds the threshold, the probability belonging to the same group will show half normal distribution.

Definition 4 Heading similarity.

Heading similarity $C_D(T_1,T_2)$ of target points T_1 and T_2 can be calculated by paths angle ψ_1 and ψ_2 Heading similarity and velocity similarity collectively indicate the following degree between target points.$C_D(T_1,T_2)$ can be calculated by the following formula.

$$C_D\left(T_1,T_2\right)=\begin{cases}1, & |\Psi_1-\Psi_2|<\Delta\Psi\\ e^{-k_3\left[(|\Psi_1-\Psi_2|-\Delta\Psi v)^2\right.}, & \text{else}\end{cases} \tag{3}$$

In this formula, $\Delta\Psi$ is the threshold of $|\Psi_1-\Psi_2|$ and k_3 is the index of half normal distribution. When $|\Psi_1-\Psi_2|$ exceeds the threshold, the probability belonging to the same group will show half normal distribution.

Similarity matrices of position, velocity and heading among all target points can be calculated by formula (1) to (3). Every similarity matrix is a symmetric matrix, and the element value on diagonal line is 1. The target points belonging to the same group should satisfy corresponding threshold. Aircraft grouping can be implemented by merging these matrices. The merging rule of two similarity matrices is that elements in corresponding position are compared with each other and the minimum is the outcome. The merging rule can be expressed by formula (4).

$$C=C_P\wedge C_V\wedge C_D \tag{4}$$

In this formula, C is a target swarm similarity matrix, and the operator "$\wedge$" indicates that the element value in the corresponding position is minimum when two matrices are merged. The matrix C can be expressed as follows when there are n target points in swarm.