Aircraft Landing Scheduling in the Small Aircraft Transportation System

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***Abstract*—Aircraft Scheduling in terminal areas is the key technology for diminishing delay and cost. Especially in SATS(Small Aircraft Transportation System), without the guidance of ATC(Air Traffic Control), efficiency is hard to reach. Considering diversity of aircrafts in SATS, traditional approaches to solve these problems, such as CPS(Constraint Position Switch) is not available. Promote to sequence aircrafts based on flying ability, and improve genetic algorithm by introduce local fitness value, using it as optimize function. Also, take vortex and conflict-free as the constraint. A potential algorithm is introduced to de-conflict for its ability to cover all possible conflict scenarios involving multiple agents. As a dynamic system, the cost of resolve conflict during the approach will feed back to the system to rescheduling. Simulation shows, a conflict-free sequence with lower delay is reached. Besides, the improved algorithm is more directive and convergence quickly, accelerating solving process. It can meet the application's needs in real-time.**

Keywords-scheduling; landing; conflict; genetic algorithm; SATS

I. INTRODUCTION

With the rapid development of civil aviation in the past decades, air traffic flow increases heavily [1]. In some high-density areas, aviation transportation systems are almost reaching full capacity. Although enhancing air traffic control is an approach to alleviate this problem, it will not provide a long term solution, considering the space is limited. In 2003, there is a demand in the USA for "more people and goods to travel faster and farther, with fewer delays" as captured in NASA Strategic Plan [2]. It exploits the abundant small community airports across USA. Most small airports have no control towers and lie outside air traffic control radar coverage. SATS aims at take fully use of these small airports and realize free-flight in defined area called SCA, which is a region around non-controlled small airports. Within this airspace, pilots take responsible for separation and "one-in one-out/first-come-first-serve" procedure must be obeyed. In order to improve efficient, a new General Aviation (GA) concept called the Small Aircraft Transportation System, High-Volume Operations (SATS HVO) is designed, which support multi aircrafts operation in SCA during the same time. Scheduling and de-conflict should introduced to improve efficiency and assure safety. There are two ways to scheduling aircrafts, static case and dynamic case. In static scheduling the decision is made only once during the entire landing operation at a certain scheduling point. In dynamic scheduling aircrafts are rescheduled constantly during the complete landing operation due to changes in the dynamic operation environment [3]. For practical consideration, we choose dynamic cases to optimize the landing sequence.

Traditional approaches to scheduling take no consideration of aircrafts' differential flying ability in SATS. In this paper, promote to sequence aircrafts based on aircraft's velocity, improved genetic algorithm is introduced to optimize the result, which is more directive and convergence quickly. To the question of de-conflict, we use artificial potential algorithm, it can cover all possible conflict scenarios, although it's not always guaranteed to generate flyable trajectories, the obtained trajectories can serve as qualitative prototypes for coordination maneuvers between multiple aircrafts[4].

This paper is organized as follows. In Section 1, the sequencing problem is described. The details of conflict resolution based on artificial potential are described in Section 2. Section 3 introduces the experiment results with analysis.

II. SEQUENCING PROBLEM DESCRIPTION

The majority of SATS-type non-controlled airports have instrument approaches designed only for the primary runway, only few airports are capable of multiple runways [2]. So, only single runway is discussed in this paper.

Some variables are defined first:

i，j: the number of aircrafts，i,j=1,2,…,n;

E_i: the estimate time of arrival of plane i (ETA);

S_i: the schedule time of arrival of plane i（STA）;

α_i: the velocity changing ratio of plane i;

d_{ij}: the distance between plane i and plane j;

ds_{ij}: the safe distance between plane i and plane j;

D_{ij}: the vortex distance criterion between plane i and plane j, plane i is the leading plane;

P_i: the priority of plane i;

V_i: the velocity of plane i after optimize.

In SATS, aircraft intended to access SCA should get a clearance notified from AMM first, which is an Automatic Management Module. Then holding at IAF waiting for the opportunity to begin final approach. Fig. 1 shows the model of SATS Self Controlled Area.

978-0-7695-4501-1/11 $26.00 © 2011 IEEE
DOI 10.1109/ICCIS.2011.65

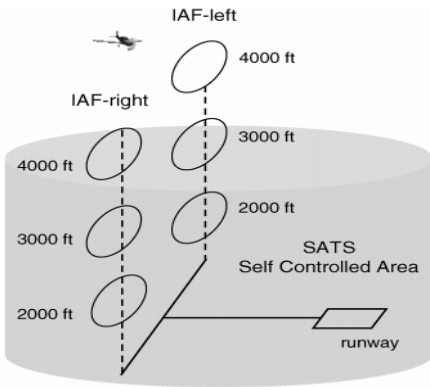

Figure 1. SATS SCA model.

As in two-dimension, we can simplify the model by the following figure.

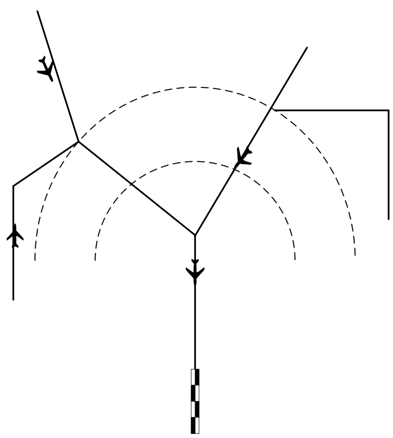

Figure 2. SATS SCA two-dimension model

The goal is optimizing each aircraft's velocity to get an efficiency sequence while maintain a safe separation. Whenever conflict is detected, ETA of involved aircraft will be update, it should be rescheduled.

After optimized the velocity of plane *i* should be:

$$V_i = V_i' \bullet (1+\alpha_i), \quad i = 1, 2, \cdots n \tag{1}$$

V_i' is the velocity of plane *i* before optimized. Constraining the velocity of plan can constrain aircraft's landing time window. In order to satisfy vortex separation, d_{ij} defines the vortex criteria. For simplicity, we classify multi aircrafts into three classes shown as bellow.

TABLE I. VORTEX SEPARATION CRITERIA

vortex criteria (nm)	Classes		
	heavy	*large*	*small*
Heavy	4	3	6
Large	3	3	4
Small	3	3	3

The result of scheduling is expected to reach a minimum time that all the aircrafts finish landing process, with each aircraft has a priority. Objective function can be obtained:

$$\sum_{i=0}^{n} P_i \bullet |\mathrm{E_i} - \mathrm{S_i}| \tag{2}$$

Improved genetic algorithm is introduced to optimize the result. A genetic algorithm (GA) is a search heuristic that mimics the process of natural evolution. This heuristic is routinely used to generate useful solutions to optimization and search problems.

To accelerate searching, introduce a local fitness function for each gene to direct cross and mutation. Local fitness values represent conflict between aircrafts, 0 indicates no conflicts exist, the larger the value is, the more serious the conflict is. Local fitness function of gene i is:

$$T_i = \sum_{i=1}^{n} F_i, i = 1, 2, \cdots n \tag{3}$$

$$F_i = \begin{cases} 0 & d_{ij} > ds_{ij} \\ ds_{ij} - d_{ij} & d_{ij} < ds_{ij} \end{cases}, j = 1, 2, \cdots n \tag{4}$$

n is the number of aircrafts. For calculation simply, ignore the distance caused during the acceleration. The algorithm is described in the following figure.

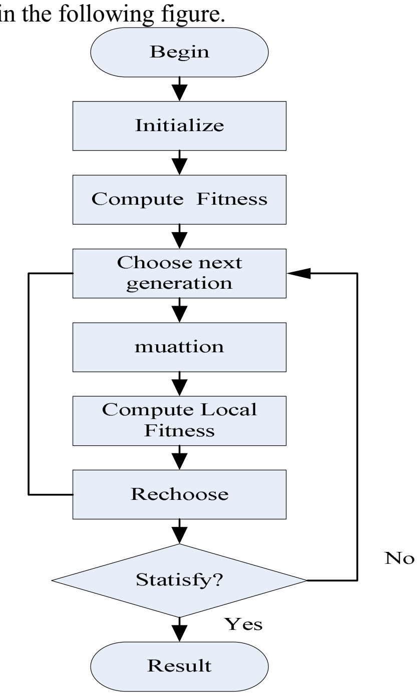

Figure 3. Improved-GA process

Cross and mutation depends on the local fitness value [5]. A1, A2 are parent gene, B1, B2 are child gene. $A1_i$ is the local fitness value of gene i.

Cross: If $A1_i$-$A2_i$>σ then $B1_i$=$B2_i$=$A2_i$. If $A1_i$-$A2_i$>σ, then $B1_i$=α$A1_i$+(1−α)$A2_i$, $B2_i$=α$A2_i$+(1−α)$A1_i$. σ∈(0,1), σ is a dynamic number, decrease with the increment of generation. This is shown below:

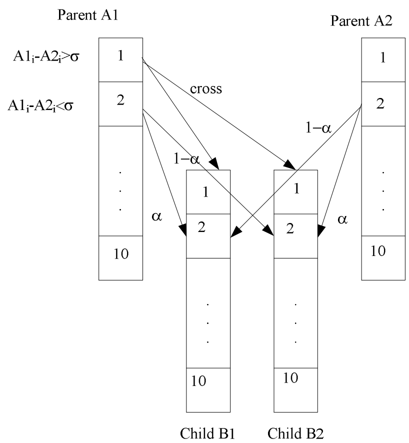

Figure 4. Cross

Mutation: If $B1_i > \varepsilon$, $B1_i$ mutate. ε is a dynamic number, decrease with the increment of generation, finally be 0. B2 is the same. This is shown below:

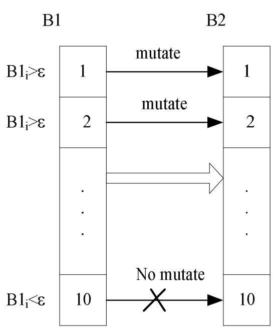

Figure 5. Mutation

III. CONFLICT RESOLUTION

As in SCA HVO, with multi-aircrafts and free flight, conflict resolution maneuvers must be adopted to avoid possible conflict with low cost. The purpose of this section is to extend CR maneuvers to cover all possible conflict scenarios involving multiple agents. An algorithm based on potential is introduced.

Define *i*th agent represented by a circle with r_i and its position denoted by (x_i,y_i), the destination of *i*th agent is denoted by (x_{di},y_{di}). Each agent is surrounded by attractive potential:

$$U_a(x_i,x_{di}) = \frac{1}{2}(x_{di},x_i)^2 \tag{5}$$

the attractive force is:

$$F_a = -\nabla U_a(x_i,x_{di}) = -(x_i - x_{di}) \tag{6}$$

When the distance between agent i and j is less than a defined value, repulsive field is associated with each agent to prevent collision. The repulsive field is:

$$U_r(x_i,x_j) = \begin{cases} -\frac{1}{2\delta_{ij}}(r_{ij} - (r_j + \delta_{rj}))^2 & \text{if } r_j \le r_{ij} \le r_j + \delta_{rj} \\ 0 & \text{otherwise} \end{cases} \tag{7}$$

$$r_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

the repulsive force is:

$$F_r(x_i,x_j) = \nabla U_r(x_i,x_j) = \frac{1}{\delta_{ij}}\left(\frac{r_j + \delta_{rj}}{r_{ij}} - 1\right)\begin{bmatrix} x_i - x_j \\ y_i - y_j \end{bmatrix} \tag{8}$$

The force on agent i is

$$F_i = F_r(x_i,x_j) + F_a \tag{9}$$

With the force, we can generate an ideal but not always guaranteed to be a flyable trajectory, but the obtained trajectories can serve as qualitative prototypes for coordination maneuvers between multiple aircraft. We can adjust the trajectories to make it flyable. Also, some optimize algorithm can be introduced to optimize the trajectory. With a pre-known trajectory, search space is diminished.

IV. EXPERIMENT RESULTS

Simulation is done under Microsoft VC++6.0. Ten aircrafts, single runway. The initial population is 50, $-0.6<\alpha_i<0.6$, i=1,2,…,*n*. P_i is 1 by default, maximum population is 200, after the 50th population, optimize function value is stable. Simulation result is following.

TABLE II. EXPERIMENT RESULTS

	Algorithm		
	FCFS	***GA***	***Impro-GA***
Objective function	2125	1880	1878
Max delay(s)	552	516	513

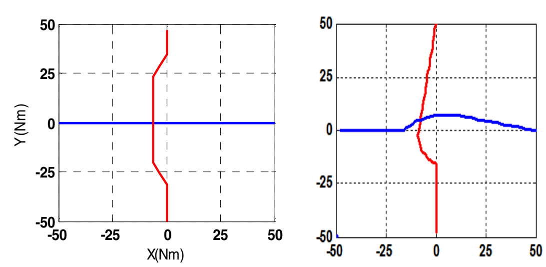

Figure 6. GA and potential algorithm

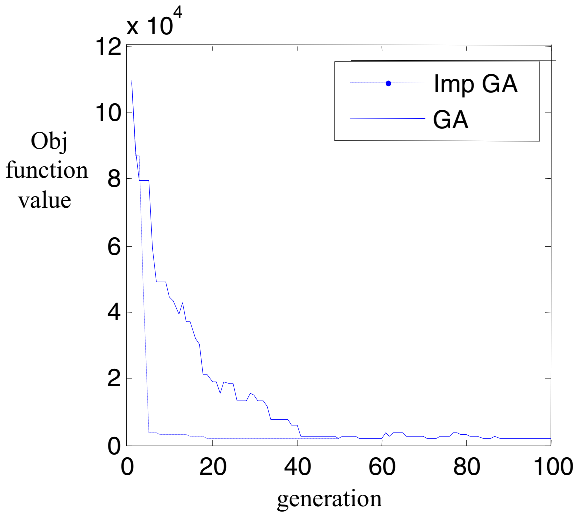

Figure 7. GA and improved GA

Table 2 shows, compared with FCFS, improved GA can reduce objective function value and aircraft's maximum delay. In Fig. 6, left figure shows the trajectory generated by GA algorithm in which aircraft could only turn 30 degrees left or right. The right figure shows trajectory generated by artificial potential algorithm, after modification to be flyable, a smooth trajectory can be reached, besides, the fly path to de-conflict is less than GA algorithm. Fig 7 shows the improved GA convergence at the 50th generation while traditional GA convergence at the 100th generation.

ACKNOWLEDGMENT

The authors would like to acknowledge the National Basic Research Program of China (Grant NO. 2011CB707000) and Specialized Research Fund for the Doctoral Program of Higher Education (Grant NO. 20101102110005) for supporting this work.

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