Air traffic conflict resolution via B-splines and genetic algorithms

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1.   Introduction

From the beginning, the most critical point of Air Traffic Control was to ensure safety separation distance between airplanes. To achieve this goal, a safety standard separation has been defined : 5 Nm (Nautical miles) horizontally and 1000 feet vertically (*separation box*). Air traffic controllers are responsible for ensuring the respect of this separation rules.

However, air traffic has been constantly increasing and has already used all available ressources to increase airspace capacity. In the future, Air Traffic Management (ATM) will have to deal with a doubling of the air traffic while ensuring at least equivalent standards of safety [5]. The SESAR european project aims to find solutions to this problematic by automating the current system or by providing a decision support to the air traffic controllers in order to decrease their workload. Many works have been done on full automation, the most promising ones being Genetic Algorithm (GA) [1] and navigation function [2] methods. However, considering the technological advances on the airplane Flight Managment System (FMS) we will explore in this paper the possibility of a full automation generating continuous trajectories that new FMS can follow. In the first section, we detail the problem modeling (trajectory and optimization), in the second section we present our results and perspectives.

2.   Problem modeling

2.1   Trajectory model

We choose a continuous model for representing trajectories. Considering the new FMS abilities, In order to obtain FMS fliable trajectories, we use B-splines, the approximation tool which provides interesting properties for our concerns. The primary B-spline objective was to find a curve interpolating a set of points of R^2 called *control points*. This objective was later extended to approximation, thereby avoiding the undesirable oscillation inherent to interpolation. In our study, we shall focus on this use of splines to approximate a set of control points. The

control polygon, the linear curve linking the control points, completely defines the curve [3]. Indeed, the B-spline is to stay in the convex envelope of the control points.
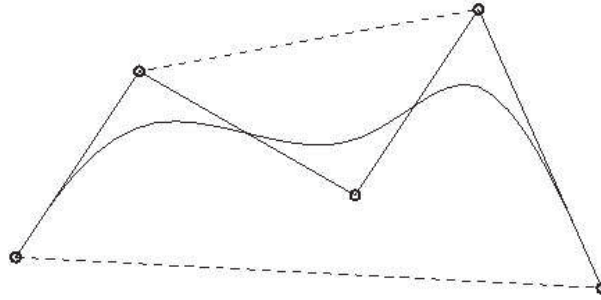

Figure 1.   Control points, control polygon and the resulting B-spline

Basically, B-splines are parametrized curves generalizing the Bezier curve concept. It is an efficient approximation tool which is constructed from polynomial pieces joined at certain parameter's values called *knots*, stored in a *knot vector*. In a very simplified way, if we consider a set of control points $(X_i, Y_i) = P_i \in R^2 (i = 0 : n)$, and a parameter u, we can define the B-spline as follows:

$$C(u) = (\sigma_x(u), \sigma_y(u)), u \in [a, b]$$

where $\sigma_x(u)$ and $\sigma_y(u)$ are the B-splines approximations of the couples $(i, X_i)_{i=0:n}$ and $(i, Y_i)_{i=0:n}$ for $u \in [a, b]$.

We choose to rely on B-splines modeling trajectories because it is a very efficient tool for curve approximation in terms of both approximation quality and computational time. Moreover, B-splines feature interesting properties such as $\mathcal{C}^2$-continuity (crucial for modeling smooth aircraft trajectories, robustness and flexibility and the use flexibility (if one control point is displaced, only a small part of the curve will be affected).

2.2   Optimization method : Genetic Algorithms (GA)

When several aircraft are involved in a conflict, the conflict resolution problem has been shown to be NP-hard [1]. Moreover, the optimization variables being the B-splines control-point location, we shall see that our objective function (1) is not differentible with respect to these variables. Consequently, we must rely on black box (direct) optimization to address our problem. In this paper, we choose to use stochastic global optimization method : genetic algorithms.

To guide the control points location, we use classical genetic algorithms [7]. First, a population of individuals is generated in the state space. For each individual, we calculate the objective function (the *fitness*). Then, we select the best individuals according to their fitness and we randomly apply genetic operators (mutation, crossover). From this operation, a new population is created and we apply the same process again. Evolution between two generations is shown in Figure 2.

Fitness evaluation : Conflict detection.

In order to evaluate each individual fitness, we decode it into N trajectory curves (one per aircraft) and we then evaluate two quantities. First, how many conflicts the situation creates and secondly what is the total extra distance engendered with respect to the direct routes. To calculate these quantities, we discretize the airspace into square cells of size half the standard separation. Our conflict detection is performed in two steps:

- First, for each airplane, we store the grid's cells through which the airplanes fly, the airplane number (its label), the entry and exit times in and out each of the stored cell
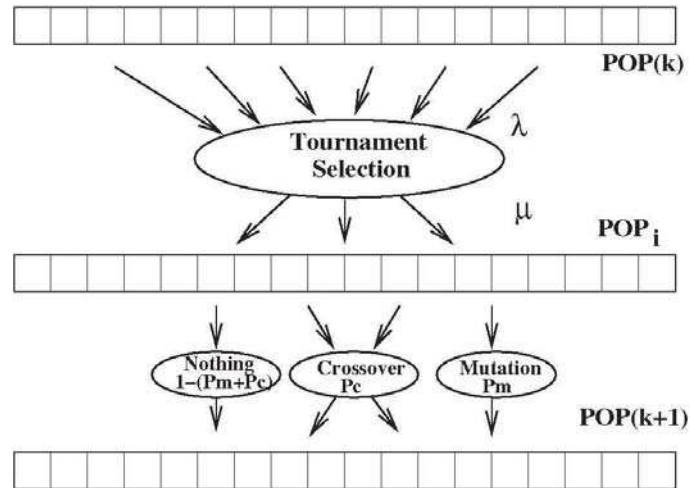
Figure 2. GA principle

- Then, we go through each stored cell and we check whether any other airplane goes through any of the eight neighbouring cells for other airplanes. If there are such airplanes, we check the time to see whether there is a conflict between these two airplanes. If so, we calculate the conflict duration.

Our conflict detection procedure send back the chromosome fitness to the evolutionary algorithm. Here is the formula we use to calculate the fitness:

$$f(X) = -(CN + (\frac{NR}{DR} - N)) \tag{1}$$

Where CN is the number of conflict, NR the length of the new route calcultated by the algorithm, DR the length of the direct route.and N the number of plane. High fitness correponds to good individuals. Indeed, the lower are the number of conflict and the route lengthening, the better is the chromosome.

3. Computational results

In this section, we present results we obtained on a roundabout test proble. This problem consists in making 16 planes equidistributed on a circle of $100Nm(= 185200m)$ radius fly to the diametrically opposed point at a common speed (each point on the circle has an outgoing and an incoming trajectory).

For this configuration, our method obtains a conflict-free situation displayed in Figure 3. When the fitness is in $]-1, 0]$ the situation is conflict-free (see (1)).

Although one can easily solve intuitively this academic problem due to its symetry, our implementation does not exploit any symetry here. This result, which we obtain automatically shows that our methodology is promising as the obtained conflict resolution is consistent with experts' advice.

4. Conclusion

We have shown in this paper that the combination of B-splines and genetic algorithms can be a promising methodology for automatic conflict resolution in air traffic control. More results are to come on different, various and more realistic situations. We also have in mind several developments to improve our approach like using the sharing (deals with equirepartition of
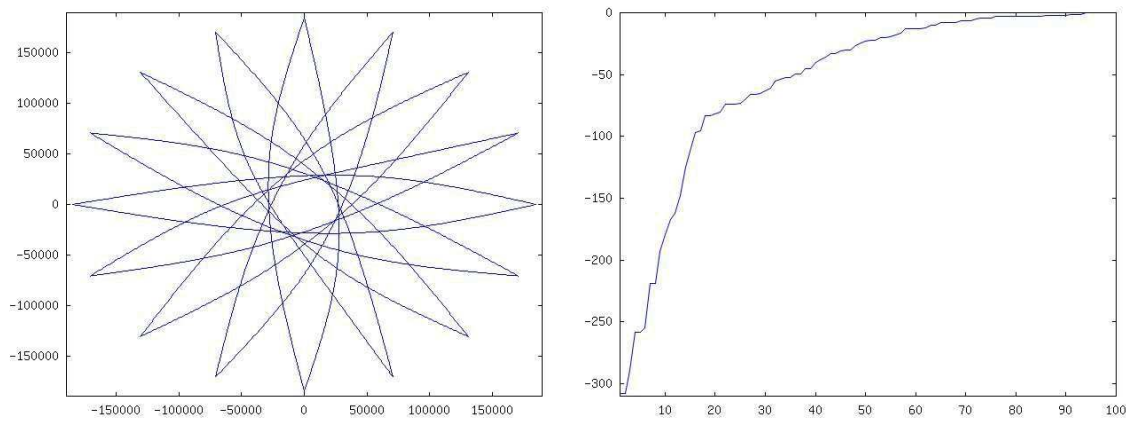
Figure 3.   The roundabout configuration after resolution and the fitness evolution with respect to the generation number

the population on the different maximums) in our GA or implementing a *self-adaptative* GA (every parameter in the chromosome such as bandwidth, control points' number, etc will be considered within the chromosome encoding, as proper optimization variables. Furthermore, we plan to exploit our B-spline model of trajectory to address the conflict resolution problem with deterministic derivative-free optimization methods [4]. Indeed, despite the local aspect of these methods, they can also be adapted to global optimization.

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