3D Aircraft Path Planning for Hostage Rescue by Artificial Immunity Algorithm

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Abstract. The goal of aviation route planning for hostage rescue is to quickly design a safe and concealed path for aircraft hijacking under complex and unfamiliar circumstance. In this article, basic Artificial Immunity Algorithm (AIA) is improved by consideration of helicopter flyability and time restriction. And a threat model has been proposed through an appropriate simplification operation in in-time environment. Threat models are varied with different complicate environments designed. AIA can successfully plan safe paths by the models, which verify the method’s validity. Under more complex environment, the method can calculate a new path by performing the operation of local flight segment adjustment or re-planning the whole flight path. When the threat models being in dynamically updating state, AIA should be run with negotiation between safe degree and time remained, which allows it to play an active rather a passive role. This would help to enhance the ability of response ability to emergent incidents integrated plan time, aircraft safety, flyability and manoeuvrability in rescue.

1. Introduction

In the past decade, many Hostage hijacking events has taken placed every year worldwide, which caused many casualties need to be cured. For enhancing mission success rate of hostage rescue, helicopter-based emergency medical service is used currently in rescue responding system as an effective response measure for large or complex emergency incidents such as structure fires, wildland fires and Hostage hijacking events. Currently helicopter has been widely used in developed countries’ emergency rescue, but rarely in China; As a result, it is still urgent to expand its application range.

A routing model was established to help emergency rescues by introducing the influencing factors, such as road network and travel time reliability, which is combined with time variability of the traffic assignment on bi-level programming (Yang Z.S. et al., 2013). An algorithm is put forward by the contract net protocol of multi-agent theory on joint firefighting and rescue tasks and the establishment of the cooperation structure (Liu J. and Cheng H., 2014). Liu L. puts forward the concept of UAV positioning search system for field rescue by wireless communication technology and UAV flight platform (Liu L. et al., 2014). Wu T. proposed an adaptive adjustment method based on lead time judgment introduced the dynamic delay in transportation and information transmission of emergence rescue material inventory

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management problem from the perspective of system dynamics (Wu T.T. and Yu D.S., 2013). Wang Y. put forward the corresponding countermeasures and suggestions by analysis the fire fighting and rescues the risk factors that might influence the safety of fighting (Wang Y., 2013). There are many path planning methods studied mostly based on evolutionary algorithm and its improved algorithms. In our previous study we design flight path by AIA for forest fire rescue (Liu et al., 2012). Several classical AI algorithms, such as A*, have been applied to solve the path-planning problem (P. Muñoz et al., 2012). Francisco Geu Flores and Andrés Kecskeméthy decomposed the overall task into two cascaded main components: shaping the optimal geometry of the spatial path, and finding the time optimal one-dimensional motion of the system along this path in stead of parameterization the problem in configuration (joint) space. In case of probabilistic environment with static obstacles and obstacles with probability obstruct robot’s free passage, path planning problem is approached by the bacterial mimetic algorithm (J. Botzheim et al., 2012). A SAT solver to cooperative path-planning is presented to solve the whole instance but for optimizing the sigma-completeness of a sub-optimal solution (P. Surynek, 2012).

2. Threat environment model

Usually Hostage hijacking event takes place in complex environment, which is a great influential factor for path planning simulation. How to construct a comprehensive threat model including complicate terrain and building threats is studied in the paper; the model can vary with different threats condition to generate a safe path by Artificial Immune Algorithm; finally, this will provide a reference basis for directing air rescue and rescue personnel safety.

2.1. Environment’s generation

Real environments mainly include complex terrain, buildings and/or weather threats. More specifically, cliff threat, mountain threat, building threat and climate threats have been taken into consideration in this paper. Mountain threat model is expressed as formula (1):

$$H_i(x, y) = (x - x_{0i})^2 / x_{si}^2 + (y - y_{0i})^2 / y_{si}^2$$

Here, $H_i(x, y)$ is mountain’s height of $(x, y)$ point, and $(x_{0i}, y_{0i})$ is coordination of mountain center point. $x_{si}, y_{si}$ are descending direction along $x$ and $y$ axis respectively. Building threat is modeled as cube:

$$H_{bi}(x, y) = h(x, y) \quad \text{where } x_{\text{min}} < x < x_{\text{max}}, y_{\text{min}} < y < y_{\text{max}}$$

$H_{bi}(x, y)$ is building height at point $(x, y)$, $x_{\text{min}}, x_{\text{max}}$ are the minimum and maximum values of $x$ and $y$ value respectively.

Weather model is established by confining flight height to the range of $h_{\text{min}}$ and $h_{\text{max}}$. When the flight height is lower than $h_{\text{min}}$, it will be greatly increasing the probability of bump into ground. However, during it is greater than $h_{\text{max}}$, flight path will be extremely influenced by complicate weather condition.

$$H_{w}(x, y) = h_{w}(x, y) \quad \text{where } h_{\text{min}} < h_{w} < h_{\text{max}}$$

Here, $H_{w}(x, y)$ refers to flight height of point $(x, y)$.

The comprehensive threat model will integrate all the above threats together. That is, it is weighted sum of the three kinds of threats’ normalized value.

$$H_i = w_1H_i' + w_2H_{bi}' + w_3H_{w}' \quad w_1 + w_2 + w_3 = 1$$

Here, $H_i', H_{w}'$ and $H_{bi}'$ are the normalized values of $H_i$, $H_{w}$ and $H_{bi}$ respectively.

2.2. Aircraft performance requirements

In this paper, aircraft performance includes minimum turning radius, maximum flying speed, maximum rate of climb, minimum/maximum speed of level flight and maximum voyage.
3. Route planning process by Artificial Immune Algorithm

As a new artificial intelligence method, Artificial Immune Algorithm is widely used in robot path planning field. By combination with aircraft performance, the basic AIA is improved for application in aircraft path planning. Research and application of AIA has been involved in combinatorial optimization problems, such as Traveling Salesmen problem (TSP). However, there are still some problems in the algorithm such as lack of unified paradigm, bionic mechanism reference not deep enough, the deficiency of convergence and stability. In particular, the immune memory mechanism has not yet been fully utilized, so the efficiency of the algorithm has still room for further improvement.

The main steps of the route planning process: (1) Antibodies and parameters initialization; (2) Calculation of affinity value; (3) Safety and voyage requirements condition inspection. If yes, turn to (5); if not, turn to (4); (4) Crossover, mutation, inoculation operation; (5) Trajectory smoothing optimization; (6) Flyability requirements condition inspection. If yes, turn to (2); if not, turn to (7); (7) Program end.

4. Simulation tests

In this article, environment concludes three kinds of threats: terrain, building and weather threats. Airspace is set of 60 km × 60 km; the coordination of start point and end point are (0km, 0km, 0.1km) and (60km, 60km, 0.3km) respectively. Minimum flight path segment length: 2km; flight height less than 500m, flight speed in the range of 61m/s and 77m/s, unit is kilometer as following. For verifying the efficiency of AIA on complex environment, we design flight path experiments under different flight environment. The initial parameters of three tests and partial planning results show in table 1.

| Test No. | Iterative number | Antibody number | Cross style | Inoculation method | Mutation probability | Planning time | Total value |
|----------|------------------|-----------------|-------------|--------------------|----------------------|---------------|-------------|
| 1        | 138              | 3300            | 1           | 2                  | 0.999                | 69.88         | 39.15       |
| 2        | 187              | 600             | 2           | 2                  | 0.9                  | 9.58          | 54.15       |
| 3        | 164              | 900             | 1           | 3                  | 0.999                | 16.49         | 25.00       |

Figure 1. 3D route planning with building and iterative process.

4.1. Test one

The threat environment contains threat WX1 (16<x<30, 10<y<15), WX2 (26<x<38, 30<y<45) to simulate cliffs; WX1 and two peaks have hindered 82% initial route (Figure 1) in this test. The planned path’s turning corner respectively as: 48.54°, 19.73°, 7.46°, 10.32°, 3.87°, which are all less than maximum angle ±60°.

4.2. Test two

On the basis of Test one, the threat length in Y direction is increased, namely WX1 (21<x<24, 4<y<47), and 95% initial route is hindered (see Figure 2). Path planning turning corner (53.02°, 8.49°, 14.05°, 10.74°, 5.20°) are less than maximum angle 60°.
4.3. Test three
With the terrains unchanged in test one, a building WX1 is added (23<x<38, 2<y<35). There is only one flight path point x=1km left for designer at x-axis, which greatly hinder the generation of flight path shown in Figure 3. Path planning’s turning corner (-52.27 °, 5.85 °, 4.34 °, 3.87 °) were less than maximum angle 60 °.

**Figure 2.** 2D and 3D route planning of test two.  **Figure 3.** 2D and 3D route planning of test three.

5. conclusions
Artificial Immune Algorithm (AIA) is used for hostage relief route planning under various threat environments in this paper. Test results shows that AIA chose a safe flight path for hostage rescue under the coexistence of terrain threats, building threat and weather conditions threats, which provides a new method with a great effect for protecting people's lives and property safety. In our future study, more complicate task requirement, such as ground rescue combined with aviation, will be taken into consideration.

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