The application of artificial immune algorithm to earthquake relief route planning

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Abstract. After an extreme earthquake attacks an urban area with many mountains, the main objective of a search and rescue operation is to minimize the number of fatalities. Therefore the task of transportation rescue resources to operational areas is of great importance to disaster managers. This paper presents a quick path planning method based on Artificial Immune Algorithm (AIA) and helicopter operation performance in order to design an optimal path for an operational area. First, a simulation of an earthquake is implemented in environment only including terrain threat. Second, a more complex model contains terrain, weather, building and communication threats simulation is executed and the resulting performance measures are evaluated by considering the survival time and total value for taken out entrapped occupants in the disaster area. Additionally, the best parameters of planning path for dual helicopters to an operational area are determined. Further work will be dedicated to adding real 3D terrain model into the current threat model.

1. Introduction
Earthquake usually happened in mountainous areas with severe weather and communication condition. Due to its high-altitude plateau and hypoxia plagued environment, it is very difficult to timely supply relief and assesses. This paper mainly discusses and summarizes aircraft path planning for earthquake rescue. Hit remote areas of the sick and wounded are difficult to be transported out of treatment. Quickly open air channel should be without delay from around the country for transport persons and goods by air. But in front of flight is bad weather and complex terrain [1]: low visibility, complex terrain, thick cumulus clouds, fog, strong airflow and thunderstorms, the impact of seismic waves, lack of meteorological data, airdrop identification, and readily available flight routes, these will be great challenge for pilot on the fly, which is be prone to significant risk. This is an urgent need to come up with an optimal, safe and efficient three-dimensional flight path [2-4].

Artificial Immune Algorithm (AIA) mainly used for solving complex optimization problems has been paid more attention currently. Farmer et al. firstly proposed the conception of immune in the field engineering. Now AIA has been widely applied in the aspect of auto-control, fault diagnosis, pattern recognition, image recognition, optimization design, robot learning, and web safety. In the problem of optimization design, constrained seek optimization and traveling salesman problem have been studied by using AIA. Furthermore, robot path planning also been performed by AIA. However, it seldom used for aircraft path design. Biology immune functions are completed by participatory reaction cell and organize constitutive cells. Basic AIA is com-prised of immune recognition, immune study, immune memory and clone choice. Which studies antibody with natural characteristics inherent in adaptive immune system, AIA has more advantages over other methods in pattern recognition,
computer and network security, and dynamic task allocation. AIA has been widely used in robot path planning in [5-10], but rarely used in flight field. This paper focuses on verifying its application in flight route planning.

2. Methods and process
AIA has the characteristics of highly parallel processing, learning, memory and related repair capacity, as well as distribution and self-organization, so it has become a broad interest method on intelligent control and intelligent control system. So, AIA is used for flight path planning in complicate environment as earthquake-stricken area. In this method, optimal solution would be taken as antigen, solution of the problem as an antibody. Here basic AIA will be combined with airworthiness of aircraft (i.e. aircraft flight aerodynamics, mechanical, and acceleration capability) to design three-dimensional flight path shown in Figure 1, which shows the entire framework for helicopter to seek a safety path to destination and avoid been hampered by any of above threats. The path planning progress is divided into three parts: threat modelling, flight path searching, flyability and operation optimization.

![Figure 1 path planning progress by AIA](image)

1) Establishing Threat Model
Using the statistical data of airspace’s building, terrain and communication information, post-earthquake images were reference for threat modelling under the WGS-84 coordinate system. Building is modelled by cube, while altitude \( H(x, y) \) of mountain at \((x, y)\) position is simulated by following formula:

\[
H(x, y) = H_0 \times \exp\left(-\left(x - X_0\right)^2 / X_s^2 - \left(y - Y_0\right)^2 / Y_s^2\right)
\]

(1)

Here, \((X_0, Y_0, H_0)\) is coordination of peak, while \(X_s, Y_s\) express descending aspects along \(X\) and \(Y\) axis respectively.

![Figure 2 terrain and building threat: (a) cliff, (b) collapsed building, (c) highway bridge, (d) convex building and (e) landslide](image)

Complex building and terrain threats can be modelling by combination of cube and mountain, such as cliff, collapsed building, intact building, uphill and downhill road, concave building, and so on (see...
figure 2). Communication threat is modelled with hemisphere, which centre is located at transmission’s one, and radius is the range it covers.

2) Flight route planning by AIA

The main technology of flight route planning process involved by AIA is described as follows:

1) Initialization antibody as: randomly generated the track point coordinates \((x, y)\) within airspace, whose \(h\) is its corresponding ground elevation \(H(x, y)\) plus minimum safe flight altitude \(H_{\text{min}}\), i.e. \(h = H(x, y) + H_{\text{min}}\); (2) Roulette method is used for vaccines selection from parent generation antibody. Antibody choice is according to idea of “1:1” probability of selection. This paper uses 3 kinds of cross mode: (1) randomly selected parent antibodies and position to cross and recombine; (2) \(i\)th and \((\text{ATN} +1- j)\)th antibodies ordered by initiation’s serial number are chosen; (3) the \(i\)th and \((i + \text{ATN} / 2)\)th antibodies and their random position are determined; Here, \(\text{ATN}\) is the total number of antibodies. Vaccination modes have also 3 styles: (1) randomly selected antibodies; (2) each antibody; (3) the vaccination position of each antibody is randomly selected. (3) Antibody value is calculated by affinity function as by Eq. (2):

\[
A(l) = \sum_{j=1}^{\text{ATN}} \sqrt{(px(j+1) - px(j))^2 + (py(j+1) - py(j))^2} \quad n = 10, 1 \leq i \leq \text{ATN}
\]

Here, \(px, py\) express flight point \(x, y\) coordination.

3) Flyability and operation optimization

Compared the path designed by above process with actual helicopter performance, it is proved that the path is impractical. As a result, the flight path needs to re-adjustment for meeting the requirement of helicopter’s flyability and operation. The main performance parameters are taken into accounted in this paper including: climb angle, maximum and minimum cruise height, maximum voyage, maximum iteration number, turning angle or radium, maximum and minimum flight velocity and shortest flight path segment length.

3. Results and discussion

In following experiments, helicopter M-26 and its flight parameters: maximum velocity 295km/h, cruise velocity 255km/h, velocity range 60-77m/s, maximum altitude 5,500meter, voyage 500km, helicopter gravity acceleration -1g~2g. The area has 60 kmx60km including the threats of complex terrain, intact and collapsed building, communication disturb, post-earthquake images were reference for threat modelling under the WGS-84 coordinate system, starting point and target point are (0, 0) and (60, 60) respectively. In double aircrafts tests, starting point are (1, 8) and (10, 1), and target point (60, 60). Flying conditions: pitch angle \(-20^\circ ~ +20^\circ\); maximum turning angle of \(-60^\circ ~ +60^\circ\); minimum flight path segment length: 2km; flying speed: 61m/s ~ 77m/s. Experimental computer environment is Pentium (R) 2 CPU 2.2 GHz.

3.1. Results of flight path planning under complex terrain threats environment

| Table 1. Route planning’s parameters. | Table 2. Iterative number change effect on path planning. |
|-------------------------------------|---------------------------------------------|
| Test | Time(s) | AV (km) | TD (km) | Iteration | AN |
| 1 | 124.02 | 150.03 | 76.19 | 80 | 200 |
| 2 | 185.89 | 116.19 | 49.32 | 50 | 200 |
| 3 | 62.63 | 107.68 | 15.43 | 100 | 110 |
| 4 | 57.13 | 114.64 | 27.61 | 100 | 100 |
| 5 | 65.75 | 163.39 | 42.28 | 100 | 90 |
| Test | Time(s) | AP(km) | TD(km) | TP(10^3) | CM |
| 1 | 89.07 | 89.06 | 0.01 | 0.289 | 11 |
| 2 | 121.32 | 94.58 | 0.05 | 1.41 | 12 |
| 3 | 110.64 | 102.26 | 0.19 | 2.17 | 13 |
| 4 | 102.77 | 87.34 | 0.001 | 1.21 | 21 |
| 5 | 132.8 | 92.63 | 0.02 | 1.56 | 22 |
| 6 | 115.7 | 105.39 | 0.09 | 1.66 | 23 |
| 7 | 111.17 | 111.66 | 0.07 | 0.954 | 31 |
| 8 | 113.48 | 88.86 | 0.01 | 0.987 | 32 |
| 9 | 101.41 | 85.23 | 0.04 | 0.295 | 33 |
In this scenario, flight path from different direction transporting rescue materials to storage nearby earth-quake disaster is planned aim to arrive at destination at the same time, because they can be arranged in short time. To verify the feasibility of AIA path planning in a complex terrain environment, single and double flight path planning tests were designed (Figure 2). Figure 2 shows AIA can design save and short flight path(s) for either single or double aircrafts. Here, taken dual aircrafts path planning for example, we also analysed the impact of iterative and Antibody Number (AN for brief) on voyage and planning path(s) time (Table 1). Table 1 shows: two aircrafts’ Track length Difference and Average Voyage have the minimum value (107.68km) at antibody number of 110, and planning time (62.63s) approaches the shortest (57.13s) with 110 antibodies. So, it is possible to achieve optimal trajectory by various antibodies number (AN) and iteration from following experiments. Here, Tracks’ Difference—TD; Average Path—AP; Total Price—TP; Cross Mode—CM; Mutation Probability—MP; Antibody number—AN.

1) This test mainly analyses several factor’s influence on path value in terrain threat environment, such as number variation, iterative number, cross-way and mutation probability. This test considers the effect of number variation (range from 40 to 300) with fixed antibody iterative number 80 (Table 1). Figure 3 shows path planning time trending in plus proportion to antibody number; however, tracks’ difference decreased from 2.66km to 0.43km with antibody number increased from 40 to 60, and the reduce can be omitted (0.43 to 0.003km) when antibodies number is raised to 240, and there is little change on average range (114.06 to 89.33km), which has little effect on dual aircrafts’ tracks for they can arrive at the same time by speed adjustment. Therefore, following tests will focus on planning time and voyage. When the amount of antibody is 160, the average voyage is shortest and TD is smaller 0.16km with TP 0.669 × 109, which only inferior to the minimum cost 0.46 × 10⁹. As a result, antibodies number selects 160 in following tests.

![Figure 3 antibody number's change on flight path](image1)

![Figure 4 iterative change's impact on flight path](image2)

2) this test mainly studies iterative number's (range from 20 to 200) impacts on route planning with antibodies number being 160 (see Figure 4), and results show: when iterative number increased, planning time has slightly decreased (110.6 to 91.45s), while average voyage has some increased (88.87 to 108.08 km); TD has little change ranging from 0.002km to 0.24km; Total path value appears upward trend. When iterative number is 140, voyage takes the second shortest; track has smaller distance difference, but its planning time is longest. While iteration number is 120, planning time, average voyage, track deviation and consideration are optimal. As a result, the following tests’ iteration number select 120.

3) this test study cross-way’s influence on route planning when antibodies 120 and iteration generations 160 (shown in table 2). When twice crossing style chooses 3 and 2 respectively, it shows: track is mini-mum; average range is smaller, but planning time is longer; while twice cross pattern to be 1 and 1, it shows: planning time is least; tracks’ difference and average range are smaller with total cost being mini-mum, so test 4 fix cross style to 1 and 1.

4) In this test, route planning optimizes by antibody mutation probability’s increased from 0.1 to 0.99 with 160 iteration generation and 120 antibodies (Figure 5). With the mutation probability increased, TD, TP and time have shown a downward trend, indicating that increased mutation rate can decrease total cost and trajectory planning time, while average range’s minimum value is obtained at mutation probability 0.4. When mutation probability is 0.99, the path got optimal trajectory with the shortest planning time (110.59s) and average range is smaller; TD and TP get the shortest and
minimum values respectively. Paths planned by above optimal parameters for single and dual helicopters are shown in figure 6, which choose terrain avoid measure to decrease total flight value.

![Figure 5 mutation probability effect on path value](image1)  
**Figure 5** mutation probability effect on path value  

![Figure 6 3D single and dual path planning](image2)  
**Figure 6** 3D single and dual path planning

### 3.2. Results of flight path planning under complex threats environment

In this scenario, helicopter will take relief supplies to victim’s shelters and rescue injured people. In following experiments, threat environment is comprised of complex terrain, weather, intact building and communication disturb threats, which can more really reflect situation of earthquake disaster. Seven communication threat is same in following threat with threat radii 7~13 kilometres.

**Experiment 1** In this test, it aims at designing a safe flight path in short time with minimum total value: the total number of threats was 34 including 8 terrain with height of 200–900 meters, 19 building (15 of 200 meters and 4 of 500 meters in height) and 7 communication threat. There is a dam between two mountains in the way. Helicopter polite flies from start point (0, 0) to end point (60, 60), unit: km. The building and dam are expressed as cube, mountain by cone. Flight path points are depicted by white asterisks respectively which is shown in Figure 7 left. The designed path fills with many unnecessary turning points which not only increase voyage, but flying time. Therefore, Figure 7 right clearly shows optimal path. Total value, which is on behalf of the flight path’s safety, is 49.958, planning time 89.073 seconds with iterative number 193.

![Figure 7 path planning in Experiment 1](image3)  
**Figure 7** path planning in Experiment 1  

![Figure 8 path planning in Experiment 2](image4)  
**Figure 8** path planning in Experiment 2

**Experiment 2** this experiment increases buildings’ kinds and mountain’s number compared with experiment 1 (16 mountains of 200–1400 meters, 13 building with four 200 meters, five 400 meters and four 500 meters in height). Figure 8 shows that it is nearly total be blocked by mountain and buildings threat between 45 km and 50km at X-axis. Figure 8 right shows path smoothed by 3 orders B-spline over buildings. The planning result is that total value is 42.281, planning time 89.008 seconds and iterative number 193. The following two experiments add debris or collapsed buildings into the environment.

![Figure 9 path planning in Experiment 3](image5)  
**Figure 9** path planning in Experiment 3  

![Figure 10 path planning in Experiment 4](image6)  
**Figure 10** path planning in Experiment 4

**Experiment 3** The number of mountains is up to 18 with height of 200–1200 meters, and the buildings (four 200 meters and four of 500 meters in height) height kinds decreased without counting the number of collapsed buildings. In addition, Highway Bridge is also put into the environment. To the worse condition, there are some ruins near destination, to hamper helicopter finding ending point.
Figure 9 shows planned path is safe and shorter one. Planned path value takes time of 90.371 seconds, iterative number 156 and total value 37.678.

**Experiment 4** the experiment has improved the size of threat nearby the destination threat parameters being same as Experiment 3, so do the difficult of path planning. Some convex buildings, cliff and landslide are also modelled into the environments to simulate the real disaster situation. From Figure 10 it shows a safe path with value of 96.673 and iterative number 193 after 96.673 seconds. To testify the robust of AIA, flight path vary situation of distance and angle on level plane is studied. As the flight path on vertical plane can adjust by vertical angle limit. There is little difference among experiment 1, 2and 4, although the environment changed greatly. But path of experiment 3 has a slight longer than other three ones due to the mountain at lower left corner is high and steep which make flight path choose lower space to decrease voyage. Except flight point 2, the whole path keeps similar shape as others which means it is robust enough to deal with new threat appear suddenly by just adjust of the place changed.

4. Conclusions
The results of two simulations of the proposed method for a small region 360 km$^2$ under complicate environment indicate that safe flight path is able to designed in both scenarios. Most of the injured people die due to poor medical treatment condition, and many people are killed by lack of timely relief. In this paper, The results of the implemented two scenarios indicated the following: 1) Increasing the number of antibodies will improve the path planning time linearly; however, it has feeble impacted on average range;2) Increasing the number of iteration, flight path planning time will has slightly decreased; while average voyage is increased little;3) Varying cross style will influent path quality. With cross pattern picks 11, the result shows: smaller tracks’ difference and average range, least planning time and so do the total cost; 4) Increasing the mutation probability will improve the tracks’ difference, total price and path planning time; 5) With the amount and kinds of threats increased in comparison with the first scenario, path planning time and total value increased greatly, and it is difficult to get an optimal path. Thus, antibody and iterative number are increased accordingly.

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