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An Attack and Defense Decision Algorithm Based on GA-IPD

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Abstract. In order to solve the problem that exist in the process of pilot decision in the air-combat environment, it's proposed that the attack and defense decision model based on IPD uses the GA to find the optimal solution in this paper. Meanwhile, the attack and defense decision algorithm based on GA is presented and used to find the optimal strategies in air-combat. These methods make the process become effective, intelligent and easy, then the model using GA and IPD of game theory at the same time is used to simulate the process of decision. The results of simulation indicate that the GA and game theory is suitable for the process of decision in the air-combat environment.

Keywords: attack and defense decision, the iterated prisoner's dilemma, genetic algorithm, fitness function.

1. Introduction

With the extensive use of new information equipment, air combat has shown the characteristics of confrontation, timeliness and uncertainties. Pilots decision-making is more and more difficult due to the objective of combat. The PD (Prisoner's Dilemma) is a simple two-person game, well known in game theory (Axelrod 1984) [5]. If two players play prisoner's dilemma more than once continuously, the game can be called IPD (Iterated Prisoner's Dilemma). GA (Genetic Algorithm) is a computational model by simulating the biological evolution process of genetic mechanism and natural selection [9].

Over the years, the GA and IPD are studied all the way. Haider SA using GA to find strategy for PD [10]. According to Zeng's research in 2014 [4], coevolutionary algorithm are employed to find good strategies and observe IPD problem. Quek researched the Evolution and Incremental Learning in the Iterated Prisoner's Dilemma [8]. These researches are aimed at the problems in game theory and produce good results.

In this paper, an attack and defense decision Algorithm based on IPD is designed. Meanwhile, there are some effective changes made for GA. Firstly, a table is used to encode a strategy. This method can perform a strategy vividly. Then, by designing a tournament, the calculation process of the fitness of population becomes quiet easy. Finally, the attack and defense decision model considering the risk attitude of fighter pilots based on IPD and GA is proposed.

2. An Attack and Defense Decision Algorithm Based on GA-IPD

In this paper, the decision-making model is based on the air-combat process including two fighters and some simplification is made to make calculation as easier as possible. Firstly, assume that the fighters are placed in one-dimensional space, which is the fighter can only move forward and backward. Secondly, the distance of the fighters is initialized as a constant number at the start time, and the distance changes according to the step-length matrix (in 2.2). Moreover, the direction of velocity changes with the decision of Attack and Defense. Thirdly, take the ratio of the max attack distance of medium range missile and the

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distance of fighters as the current profit and loss. Finally, the terminating condition of this combat game is whether a fighter comes in the other fighter's attack area, and that means that the distance of fighters is less than the max attack distance of missile.

In this section, it's explained that the construction of Attack and Defense Decision model and how to design the Decision Algorithm using GA and the model above.

2.1. Fighter's Action Evaluation Function

In this part, the evaluating method of fighter's action will be introduced. Actually, this method is how to confirm the step length of attack and defense. Attack is attractive in the radical pilot's side. Similarly, the conservative pilot likes defense. Meanwhile, the effectiveness of fighter is also important.

When the concepts above are constructed, the evaluation method can be constructed. Firstly, the effectiveness of fighter is used to be base score. Then, the emotion parameters are used to calculate the attenuation coefficient that is reducing the base score above. A computational formula below is evaluating function of Fighter's action:

$$f(x) = \gamma \cdot base\_score$$

The effect of parameter γ is the pilot's emotion, and the parameter $base\_score$ is fighter's effectiveness. The $f(x)$ will be adjusted to between 1 and $base\_score$ in the end.

2.2. Attack and Defense Decision Method

In this paper, the combat is divided into some episodes, and the episode is the combat's basic unit. Moreover, the target of this model is maximizing the profit of pilot and minimizing the loss of pilot. It's proposed that the iterated game model based on the Game Theory. Assume that the parameters are set completely. Next, use an example to illustrate the Attack and Defense algorithm. For example, when one of pilots is radical, and the other of pilots is conservative, meanwhile assume that the combat effectiveness of fighters is similar to F-16 and Su-27, the step-length matrix can be expressed as:

Table 1: The step-length matrix

Step-Length	Player A	Player A
Attack	3	2
Defense	1	3

The table above is the step-length matrix in a single episode. Then, the profit and loss matrix will be stated below:

Table 2: The profit and loss matrix

	profit	loss
Pilot A	$R_{\max}^{A}/D$	$R_{\max}^{B}/D$
Pilot B	$R_{\max}^{B}/D$	$R_{\max}^{A}/D$

In the table above, the $R_{\max}^{A}$ and $R_{\max}^{B}$ are the max attack distance of fighter A and B, and the D is the distance of fighters. This matrix is similar to the payoff matrix in the Prisoner's Dilemma of game theory. At this moment, this air-combat process can be regarded as the iterated prisoner's dilemma.

According to the analysis above, the Attack and Defense decision method can be considered as a specific IPD. So the results of game theory can be used to solve this problem. In this method, GA is used to find the optimum solution.

2.3. Strategy Optimization Based on Genetic Algorithm

In this model, GA is used to search the optimum strategy of this model. How to encode the strategy and construct the fitness function is explained according to the air-combat environment in this section.

The approach to encode a strategy as a string is similar to construct a table including lots of state-action pairs. Considering that this problem is like the IPD, take "Tit for Tat" as an example to explain how to encode strategy. The cases of this kind of strategy is stated below:

Case 1: *DD* Case 2: *DA* Case 3: *AD* Case 4: *AA*

The A and D represents "Attack" and "Defense". Case 1 is when both pilots defended in the previous game; case 2 is when pilot A defended and pilot B attacked; and so on.

If cases are ordered in this canonical way, the strategy can be expressed as a table as follow:

Table 3: The table of tit for tat strategy

Bit	History	Move
0	First Move	D
1	DD	D
2	DA	A
3	AD	D
4	AA	A

Through this way of expression, the chromosome can be constructed. The TFT can be expressed as a string DDADA. After that the strategy is converted to a string, the string will be stored as a Bit-Set in computer as: 11010.

It's important for GA to construct Fitness Function truly. In the game theory, there is a native evaluation method. The payoff matrix can be used to evaluate the decisions of pilots. It's proposed that the strategy earning the highest payoff score is the fittest, while the lowest scoring strategy is the weakest. Therefore, the fitness of population can be evaluated by playing a tournament.

The tournament includes lots of games, and every game includes two fighters and two pilots. Moreover, consuming that the payoff is calculated in advance, every fighter of population fights with each other. And it's considered that a single game includes a number of battles. In a battle, pilots can only decide once. Therefore, an air-combat can be divided into some battles.

The detailed statement of the fitness function is shown below:

The process of calculating the fitness of population.

Initialize the *operational strategies list.*

For Pilot A in Population:

For Pilot B in Population – A:

Generating *operational process Plist* using A and B *strategies*.

Using evaluating method to calculate *ScoreA, ScoreB* according to *Plist*.

ScoreA, ScoreB = (profitA, lossA), (profitB, lossB)

Scores(A, B) = (scoreA, scoreB);

$Scores = Scores + Scores^T$; (The transposition of the Scores also need to change the order of the Score unit.)

Generating the *Pscores* N-list;

For Pilot in Population:

$$Pscores[Pilot] = \sum_{i=1\&i\neq Pilot}^{N} scores[i];$$

3. Simulations and Analysis

In this section, the simulations and analysis will be made about this problem. Firstly, some parameters of GA will be given, meanwhile the game parameters of the model can be also given. Next, the tournament will be held, and the results will be analyzed. Finally, the conclusion and analysis aimed at the results of GA will be stated.

3.1. Set the Initial Parameters

The parameters are mainly the genetic operators, the game counts, the iteration number of GA, the number of population, etc. It has a great import on the results of GA that the genetic operators change a bit. Actually, the genetic operators include crossover, mutation and selection in GA.

In Genetic Algorithm, crossover and mutation are genetic operators used to generate new population. In this simulation, the uniform crossover is used and the independent probability for bit is 0.5. The probability of crossing for each individual is 0.8. Moreover, the flip mutation is used and the independent probability for bit is 0.05. The probability of mutation for each individual is 0.2. After using these parameters, the convergence rate is quicker than simple. On the other hand, the number of iteration and the number of population is as bigger as possible in this study. The initial population is generated by random method.

3.2. Results and Analysis

After simulation, the algorithm solves the optimal results. Moreover, the results are converted to visualization after sorting out. The results are as follows:

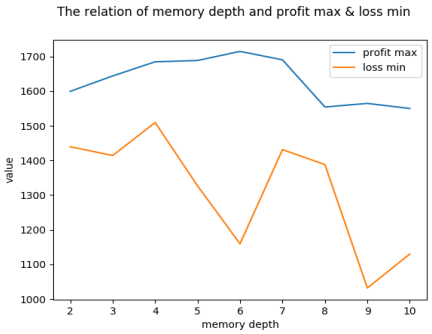

Fig. 1: The relation of memory depth and profit & loss.

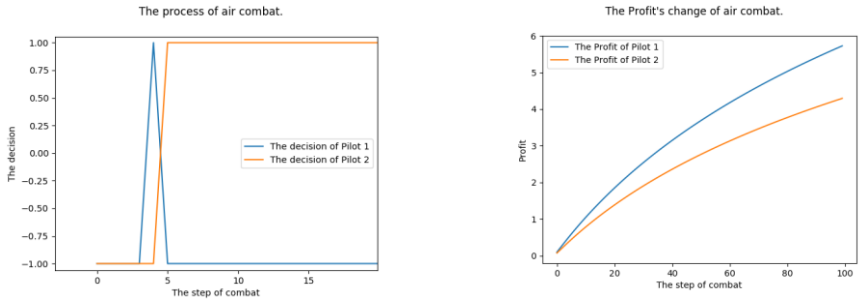

Fig. 2: The operational process.

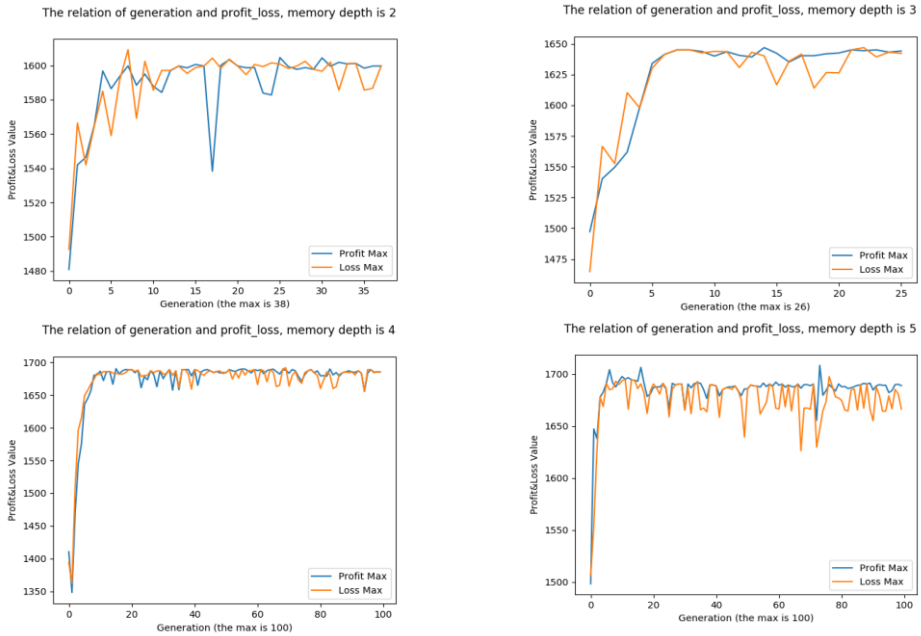

Fig. 3: The relation of memory depth and profit & loss.

From the figures above, it's considered that the model and the algorithm can work as expected.

Something can be considered from figure 1. The profit changes with memory depth. Moreover, the memory depth isn't the bigger the better. The best profit doesn't appear at the biggest memory depth. Because with the increase of depth, the policy space also becomes larger, causing noise increasing. Due to the disadvantages of GA, the strategy is never the best, only better. In addition, it's considered from figure 2 that the pilot standing on dominant side can accumulate advantages. The strategy of pilot 1 is better than the strategy of pilot 2. At the beginning of the process, the pilot 1 takes advantage after some operations. Finally, figure 3 shows that the changing of profit & loss is mostly tending to be gentle. However, sometimes the result doesn't converge to the optimal solution, because of the faults of GA and the defects of model. Because of the biological characteristics of GA, the initial population influences the results of GA. It causes the randomness of optimal results.

However, from the results above it's proposed that the results generated by this model are better than before. It's proved that the game theory such as IPD and evolutional algorithms such as GA are applicable to the decision process in air-combat environment.

4. Conclusion

In this paper, the problem that occurs in the process of pilot decision in the air-combat environment is solved. In the procedure of solving this problem, the attack and defense decision model is proposed and the corresponding algorithm is designed. Meanwhile, based on IPD of the game theory, the GA is changed to adapt to the algorithm designed in this study. Then, based on the process of air-combat, the simulation is constructed, and the results of simulation indicate that using GA and IPD at the same time can improve the effectiveness, intelligence and accuracy of the model proposed in this paper. The application of evolutional algorithms avoids falling into local optimum. Meanwhile, the combination of the game theory and air-combat creates a new method in the aviation decision field.

In a word, the evolutional algorithms and the methods of game theory are suitable for the field of aeronautical operations, and these methods can make a certain supplement to the traditional methods.

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