International Journal of Innovative Computing, Information and Control
Volume 8, Number 4, April 2012
 ISSN 1349-4198
pp. 2803–2810

THE MULTI-TARGET FIRE DISTRIBUTION STRATEGY RESEARCH OF THE ANTI-AIR FIRE BASED ON THE GENETIC ALGORITHM

Chengsheng Pan[1,2], Yang Zhang[1,3], Li Yang[2,3] and Shaoming Qiu[1,3]

[1]Key Laboratory of Communications Network and Information Processing
[2]University Key Laboratory of Communication and Signal Processing
[3]Department of Information Engineering
Dalian University
No. 10, Xuefu Street, Economic Technological Development Zone, Dalian 116622, P. R. China
pcs@dlu.edu.cn

Received January 2011; revised May 2011

Abstract. *In view of the existing fire distribution algorithm without considering the coordination of firepower units and not giving the precise number of assigned, we proposed one multi-target fire distribution strategy based on improved genetic algorithm. We established the optimizing fire allocation model of air defense missile, designed its multi-target fire distribution strategy and performed a simulation research. Simulation shows the execution speed of this algorithm is high, that the global optimal efficiency is super, and that the problem of multi-target fire coordination distribution is solved. Meanwhile, the universality of this algorithm is good, which has a certain reference value to the direction.*
Keywords: Fire distribution, Genetic algorithm, Target optimization

1. **Introduction.** During modern battlefields, it is an important task for a commander to make a proper fire distribution for threat targets. The fire distribution problem is to find a distribution of firepower to threat targets, with the objective of maximizing the expected damage value to enemy-force assets effectively and quickly, as the battle is strict with the time. And among modern information-based anti-air warfare, air raids and counter measures become the hi-tech war style. Modern raid patterns are multi-batches, continuous attacks. And battlefield situation changes rapidly. So, it is strict to request the level of commanders' decision and commanding. It is important to send the target fire distribution to subordinates firepower unit on time, then to intercept and attack, which is to improve command efficiency. To strike the raid target, the ground-to-air firepower platform should act according to its own firepower characteristic as well as to raids the target destruction capability. This can result in timely and effective defensive firepower in order to achieve the best operational effect by a maximum extent to the raiding. As one important assistant function for making command and control decisions, the relationship between battle rules, strategy, plans and fire distribution is closely, and several variables and constants are in it. For the large-scale fire distribution problem, to get one superior plan in a short time to sharpen the direction combat automation ability as well as the enhance combat effect, it is still one important research question of command and control in nowadays during various countries. Fire distribution has been proved to be NP complete problem [1], and the number of solution space will be expanding by exponential form with the increasing number of firepower unit and raid targets. So, using the traditional linear programming method and complete enumeration method to get the optimal solution is not realistic. In view of this question, some new algorithms are presented. Kuttar proposed

sequence algorithm, fractional algorithm, but the convergence rate of these algorithms is very slow. Castanon proposed using misalignment network flow algorithm to get the accurate optimal solution, but the result has big error. Wacholker proposed one kind of neural network's algorithm which cannot obtain the stable solution. In recently years, people introduce heuristic algorithm to solve the fire distribution problem, for instance, using the ant colony algorithm [2,3], which program is difficult. Neural network's TSP algorithm [4], which relies on Hopfield net model, does not consider the coordination of platforms. Consider of artificial immunization algorithm [5], its actualizing is complex and constraint condition is strict. The genetic algorithm [6] imitates natural selection and the evolution in high-dimensional space may cannot find a best solution, but may find sub-optimal solution or satisfactory solution. It could solve the fire distribution of air defense well, which is significant to make commands and decisions in modern warfare. Genetic Algorithm has been widely used as search algorithms in various applications and has demonstrated good performance. Genetic Algorithm is based on the mechanism of natural selection to search for a solution that optimizes a given fitness function.

The paper is organized as follows. In Section 2, a mathematical formulation for fire distribution problems is introduced. Section 3 describes changed algorithm mechanisms. In Section 4, based on the consideration of optimal fire distribution overall targets and the real missile number of each firepower unit to the raid target, we design a simulation comparison between the presented algorithm and our method. The performance showed the superiority of the proposed algorithm. Finally, Section 5 concludes the paper.

2. **The Model of Air Defense Fire Distribution.** How to effectively assign firepower to destroy raid targets is the main concern of fire distribution problem. Nowadays, air defense weapon mostly based on the ground-to-air missile unit, which has the long range, high precision. The existing air defense model is established [7,8] for two kinds of situations: (1) The m batches of incoming targets detected by radar, n-fire platform centers belong to us, then design the algorithm, through the heredity operator, obtains goal function $F(x)$, as well as the mth batch incoming goal was shoot by the nth firepower platform. The drawback of this approach is only giving the goal batch of attack target, without considering one platform could hit the m batches of incoming targets, namely has not consider the coordination between multiple platforms, so it's failed to display the collaborative advantage of multi-weapon platforms; (2) Consideration the fully coordination superiority of multi-weapon platforms, established the superior goal function value $F(x)$, as well as the mth batch finally raids the goal to fire by the k $(1 \leqslant k \leqslant n)$ firepower units platform center. It increases the killing efficiency to raid targets. The drawback is not given the specifically firepower number of each platform center, so cannot provide detailed firepower reference for commanders.

Viewed the above shortcomings, presents a fire distribution model for target assignment. Before the fire distribution, each firepower unit's shooting advantageous degree and each batch of target threat degree already been assessed and sorted. The target assignment is not only to determine each launching platform attacks, but also to determine the number of each launching platform center against target with the condition of achieving maximum overall damage. The traditional methods, for instance, branch delimitation as well as linear programming, need long time to process the multi-dimensional and multi-objective problems. Existing intelligent algorithm such as artificial neural networks algorithm, it sharps the solution space at some extent when it has a stricter request to mathematical model's establishment. Regard the target and the firepower unit as two elements, then the mathematical model to this problem are as follows: set we have n different air missile launch platform center, m batch raid targets. There is n_i $(i = 1, 2, \ldots, n)$ pieces of surface to air missile in ith platform center, the threat degree of mth batch is w_j $(j = 1, 2, \ldots, m)$, the unit damage probability is r_{ij}. The weapon-target assignment of surface to air missile system can present by matrix X:

$$X_{n\times m} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \cdots & \cdots & x_{ij} & \cdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} \tag{1}$$

x_{ij} presents the firepower unit quantity of ith platform center to the jth batch target. The purpose of optimal allocation is to achieve the maximum damage extent, it defines by mathematic expectation. Usually, it presents as:

$$p_{ij} = 1 - \prod_{i=1}^{n} (1 - r_{ij})^{x_{ij}} \tag{2}$$

The damage mathematical expectation of raid target is:

$$E = \sum_{j=1}^{m} \left[1 - \prod_{i=1}^{n} (1 - r_{ij})^{x_{ij}} \right] \tag{3}$$

Therefore, may obtain the optimization target function is:

$$F = E \cdot \omega = \sum_{j=1}^{m} \left[1 - \prod_{i=1}^{n} (1 - r_{ij})^{x_{ij}} \right] \cdot \omega = \sum_{j=1}^{m} \omega \cdot \left[1 - \prod_{i=1}^{n} (1 - r_{ij})^{x_{ij}} \right] \tag{4}$$

Also satisfy the constraint conditions:

$$\text{s.t:} \quad \begin{cases} x_{ij} \geq 0, \\ x_{ij} \in I, \\ \sum\limits_{j=1}^{m} x_{ij} \leq m_i, \qquad i = 1, 2, \ldots, n; \\ i = 1, 2, \ldots, n; \quad j = 1, 2, \ldots, m; \end{cases} \tag{5}$$

The purpose of the target distribution is to obtain the maximum value, namely, max F. Objective function is nonlinear, but constraint conditions are linear. This is a nonlinear integer programming problem and the traditional algorithm is very tedious and time consuming especially when the target dimension is bigger.

3. **Fire Distribution Based on Genetic Algorithm of Multi-target.** The basic idea of genetic algorithm is imitating chromosomes string group evolution. Generate new group with good adaptability than previous ones, which through those strings with organized yet random information exchange. Its main feature is simple, universal, robust and better global search capability, is suitable to solve complex combinatorial optimization problem. So adopts genetic algorithm to settle the target of air defense missile fire distribution is reasonable. A complete fire distribution flow chart of genetic algorithm shown in Figure 1.

3.1. **Coding, generating initial population.** Genetic algorithm cannot be deal with the variables of solution space directly; it is necessary to present gene string by appropriate coding rules. Common coding method is binary coding [9], the digits width of coding can reflect the accuracy level and individual decision variable range. When targets and solutions is large, the length of binary coded string is long, it increases the number of search space with the explosive growth, subsequently duplication, crossover and mutation operations became more complex, which makes the search time longer, resulting in search

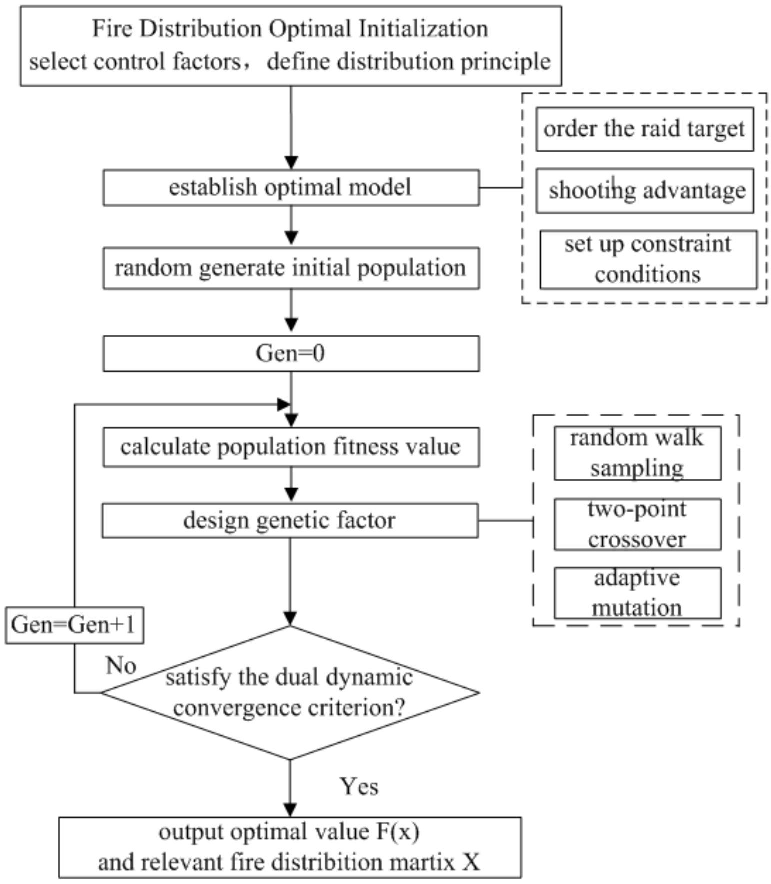

Figure 1. Fire distribution flow chart of genetic algorithm

efficiency is lower. Therefore, adopts decimal real number; each individual represents one fire distribution plan. And using random method to create initial population, which assure the richness of individual in it.

3.2. **Establishment fitness function and calculation fitness value.** Fitness function [10] used to judge the merits of the individual solutions group, the large individual fitness value is superior. Genetic algorithm is solving problem by seeking large fitness individual, so the fitness function should reflect the task of requirements. The aim of air defense is to maximize damage to raid targets [11] and the goal of optimal allocation is intended to provide the maximum overall combat effectiveness, so defines the combat benefits as fitness value, namely

$$F = \sum_{j=1}^{m} \omega_j \cdot \left[1 - \prod_{i=1}^{n} (1 - r_{ij})^{x_{ij}} \right]. \tag{6}$$

3.3. **Selection operator.** Some fine genetic individual are selected from the previous generation groups according to certain rules or methods by the fitness of each individual. Genetic algorithm adopts the idea of selecting to pursue the compatible strong individual as the next generation. Methods commonly used are roulette wheel method and random walk sampling method. Roulette wheel method can increase the survival of individual convergence easily. And random traversal sampling can increase the diversity of the population. While taking the optimal policy strategies, that is, if the maximum fitness value of individual in new generation groups is less than the maximum fitness value of previous ones, then the maximum fitness value of individual in previous ones replace the minimum fitness value in new groups. So as to make the best individual to participate in the evolutionary process, which to accelerate the convergence rate.

3.4. **Crossover operator.** Crossover operation simulates the evolution during the process of breed, each individual exchanges partial chromosome with crossover rate. Crossover operation is the most important genetic operation that produces new individual, the optimization of algorithm is also mainly depending on the crossover operator [12]. Adopt two-point crossover operation, which could exchange parent genes in wide range. It enables the next generation get the genetic information with higher fitness value from parent ones through the combination of two individuals to generate new varieties. Schematic diagram of two-point as follows: a pair of parent individuals A and B were selected for crossover operator, two crossover points generated randomly, will be recorded as an parent individual:

$A: (\cdots, a_{s-1}, a_s, a_{s+1}, \cdots, a_{t-1}, a_t, a_{t+1}, \cdots), \quad B: (\cdots, b_{s-1}, b_s, b_{s+1}, \cdots, b_{t-1}, b_t, b_{t+1}, \cdots).$

New individuals after crossing:

$A: (\cdots, a_{s-1}, a'_s, b_{s+1}, \cdots, b_{t-1}, a'_t, a_{t+1}, \cdots), \quad B: (\cdots, b_{s-1}, b'_s, a_{s+1}, \cdots, a_{t-1}, b'_t, b_{t+1}, \cdots).$

3.5. **Mutation operator.** According to genetic factors in the process of chance mutations in individuals with little probability with random, which change genetic value, the equivalent of a fine tuning the missile allocation. Mutation operation ensures groups with wider individuals, and will not make the search for local optimal value. When variation, a mutation probability pm given first, then chooses an individual from the group, and generates a random number at same time with rand. If rand $<$ pm, implement the mutation.

3.6. **The algorithm termination condition.** Adopt dual dynamic convergence criterion: (1) determine the basic genetic algebra G = 120, take a genetic algebra incremental G after arrival, then after G generations, if the average fitness improve is not significantly ($< 1\%$). (2) The result improved no longer in continual 10 generation of evolution process. Either is reached, terminate the algorithm, terminate algorithm, and select the largest fitness individual and its corresponding optimal solution as the original output.

4. **Simulations Analysis.** Based on the consideration of optimal fire distribution overall targets and the real missile number of each firepower unit to the raid target, design the following example simulation: Supposed we have eight fire platform centers, fire units of each platform are 6,8,6,6,8,5,6,7, ten batches of raid targets, target threat coefficients [13] and shooting advantageous degree already assessed, as Tables 1 and 2.

Table 1. Target threat coefficient

target	1	2	3	4	5	6	7	8	9	10	11	12
ω_j	0.47	0.97	0.76	0.48	0.22	0.77	0.83	0.80	0.54	0.85	0.55	0.67

As can be seen from Figure 2, the left one is adopted by previous presenting method, and the right one is adopted by changing genetic algorithm. The overall value damage of the right figure is bigger than left one. As well as, in the right figure, after 120 generations, the changing of solution and group is becoming steady, and the value of target damage is max. Namely, the bigger threaten target is, the more fire distribution, and it conforms to the actual combat principle "focus on threat biggest target to superior firepower".

And then chromosome is the best, to satisfy the corresponding optimal fire distribution plan, the fire distribution comparison of two algorithms shown in Table 3.

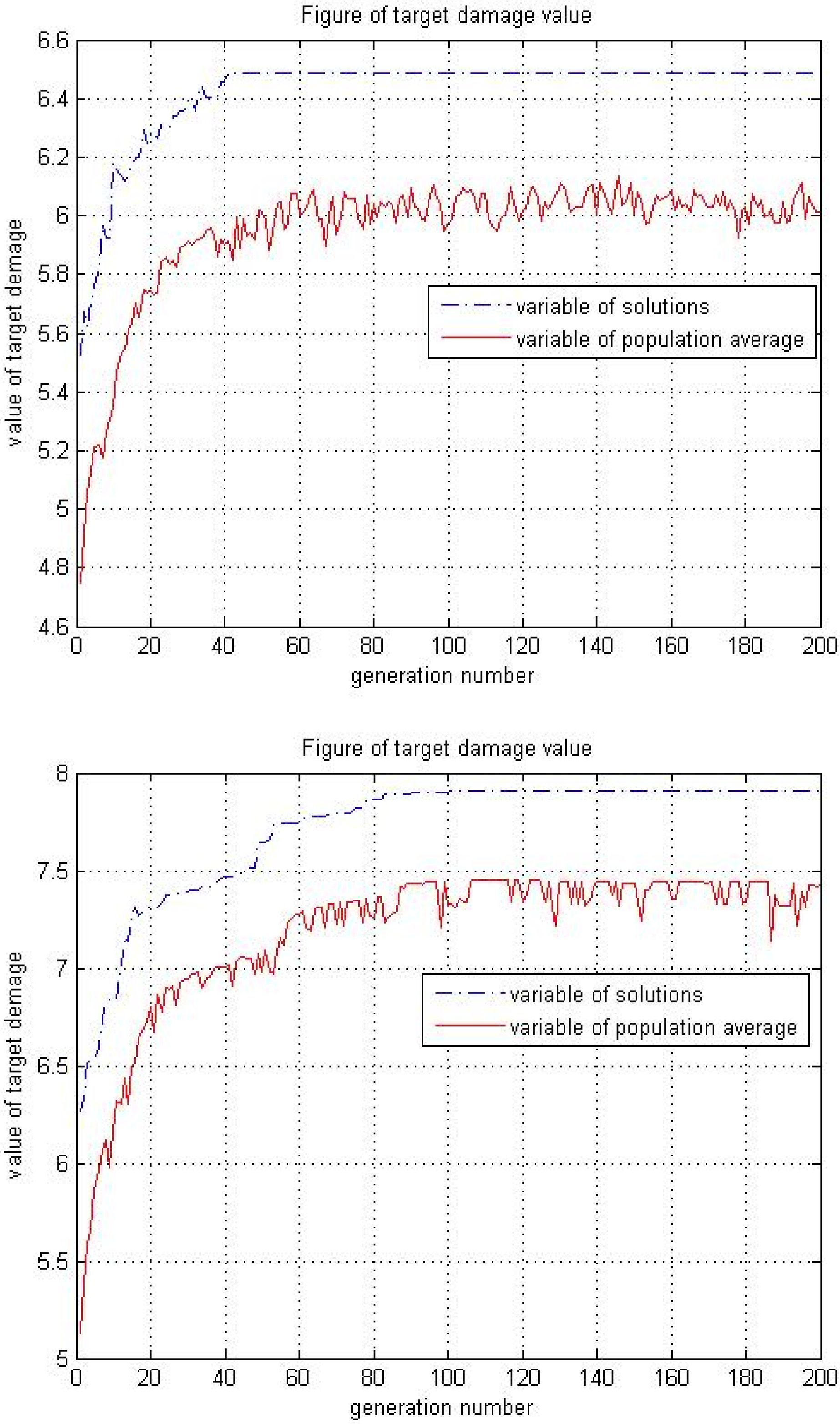

Figure 2. Figure of target damage value

Table 2. Damage probability of each firepower unit

	shooting advantageous degree r_{ij}											
	1	2	3	4	5	6	7	8	9	10	11	12
1	0.65	0.55	0.75	0.90	0.00	0.65	0.70	0.80	0.45	0.55	0.00	0.75
2	0.35	0.65	0.90	0.75	0.70	0.00	0.85	0.75	0.35	0.55	0.80	0.75
3	0.65	0.75	0.00	0.00	0.70	0.65	0.90	0.75	0.35	0.65	0.70	0.80
4	0.85	0.55	0.70	0.45	0.70	0.65	0.70	0.70	0.90	0.45	0.55	0.70
5	0.55	0.60	0.70	0.75	0.75	0.60	0.90	0.00	0.00	0.55	0.60	0.75
6	0.85	0.55	0.60	0.00	0.00	0.65	0.90	0.75	0.35	0.25	0.75	0.45
7	0.65	0.00	0.70	0.25	0.80	0.65	0.45	0.90	0.00	0.65	0.55	0.65
8	0.45	0.25	0.65	0.00	0.00	0.90	0.65	0.55	0.75	0.45	0.65	0.55

Table 3. Comparison of fire distribution

Comparison	Target	1	2	3	4	5	6	7	8	9	10	11	12
Existing Algorithm	1				√				√				
	2			√								√	
	3		√										√
	4									√			
	5							√					
	6	√											
	7					√					√		
	8						√						
Improved Genetic Algorithm	1	0	0	1	1	0	1	0	1	0	1	0	0
	2	0	1	1	0	0	0	1	0	0	0	1	1
	3	0	1	0	0	0	0	1	0	1	0	1	1
	4	1	0	0	0	0	0	0	1	2	1	0	0
	5	0	1	0	1	1	0	1	0	0	1	0	0
	6	1	0	0	0	0	1	1	0	0	1	0	0
	7	0	0	1	0	1	0	0	2	0	1	0	0
	8	0	0	1	0	0	1	0	0	1	2	0	0

As can be seen from Table 3, the existing fire distribution algorithm is given only for incoming targets hit by any one platform, not giving a detailed reference. However, each platform is given one raid target and detailed fire distribution reference, such as the first incoming target is striking by first firepower unit of fourth and sixth platforms, the missile number of each unit is 1,1; the second incoming target is striking by the second firepower unit of the second, third and sixth platforms, the missile number of each unit all 1,1,1; the three incoming target is striking by the unit of third of first, second, seventh, eighth platform, the number of each unit is 1,1,1,1; and so on.

5. **Conclusions.** Put forward one scheme based on genetic algorithm to solve air defense problem of multi-platform to multi-objective, it's ideal to settle the integer constraints. Finally, addressed one complex simulation example by MATLAB, confirmed the feasibility of the algorithm. Simulation proves that genetic algorithm is effective to this problem. Its global search optimal efficiency is higher, it has a certain reference value to making directions and decisions for the command.

Acknowledgment. This work was supported by a grant from the National High Technology Research and Development Program of China (863 Program No. 2010AAXX04), Program for Innovative Research Team of Liaoning Province Educational Committee (No. LT2010007).

REFERENCES

[1] Z. Wang and X. Yan, Simulation-based solution to weapon-target assignment, *Journal of System Simulation*, vol.21, no.20, pp.6597-6599, 2009.

[2] Z. L. Lee and W. L. Lee, A hybrid search algorithm of ant colony optimization and genetic algorithm applied to weapon-target assignment problems, *Computer Science*, no.9, pp.278-285, 2003.

[3] S. Gao, Ant colony algorithm for weapon-target assignment problem, *Computer Engineering and Application*, vol.39, no.3, pp.78-79, 2003.

[4] X. Wang, Z. Liu and C. Hou, Modeling and decision-making of multi-target optimization assignment for aerial defence weapon, *Acta. Armamentarii*, vol.28, no.2, pp.228-231, 2007.

[5] M. Ruan, Q. Li and T. Liu, Modeling and optimization on fleet antiaircraft firepower allocation, *Acta Armamentarii*, vol.31, no.11, pp.1525-1529, 2010.

[6] Y. Chen, Z. Fan and M. Xue, A hybid grouping genetic algorithm approach for constructing diverse review groups in group decision making, *ICIC Express Letters*, vol.4, no.2, pp.365-373, 2010.

[7] Y. Li, Y. Yang, L. Zhou and R. Zhu, Observations on using problem-specific genetic algorithm for multiprocessor real-time task scheduling, *International Journal of Innovative Computing, Information and Control*, vol.5, no.9, pp.2531-2540, 2009.

[8] X. Wang, C. Hou, J. Yan, F. Guo and H. Wei, Modeling and optimization method on antiaircraft firepower allocation, *Control and Decision*, vol.21, no.8, pp.913-917, 2006.

[9] X. Gao, S. J. Ovaskka and X. Wang, A GA-based negative selection algorithm, *International Journal of Innovative Computing, Information and Control*, vol.4, no.4, pp.971-979, 2008.

[10] J. Kushide, K. Oba and K. Kamei, Generation algorithm model for reducing the number of fitness evaluations on differential evolution, *ICIC Express Letters*, vol.4, no.6(A), pp.2089-2095, 2010.

[11] Z. Shen, W. Song and F. Tang, Research of optimal allocation of naval fleet underwater multi-objective defense based on genetic algorithm, *Journal of System Simulation*, vol.20, no.17, pp.4517-4549, 2008.

[12] W. Wang, C. Cheng and Z. Zang, Research on approach for a type of weapon target assignment problem solving by genetic algorithm, *Systems Engineering and Electronics*, vol.3, no.9, pp.1708-1711, 2008.

[13] L. Wang and Y. Fang, Allocation of firepower for multiple waves air-to-land attack based on advanced one-parent GA, *Journal of System Simulation*, vol.21, no.23, pp.7697-7702, 2009.