Reliability Optimization of Complex Weapon System Using Particle Swarm Optimization Algorithm

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***Abstract*—To ensure the reliable use and to increase the ratio of cost to efficiency of the complex weapon system in the war, the reliability optimization of complex weapon system has received considerable study interest. Unfortunately, this kind of optimization problem usually belongs to the catalog of nonlinear optimization with multiple local extreme values. To make use of the global searching ability in optimization problem of this kind, Particle Swarm Optimization (PSO) is utilized in this paper to solve the complex weapon system reliability optimization problem. The general process of PSO algorithm is provided and implemented using advanced programming language. The simulation results show that PSO is an effective algorithm, and has obtained solution with the highest precision in solving the same problem as cited in the published literatures pertaining to optimizing complex weapon system reliability.**

Keywords-complex weapon system; reliability optimization; particle swarm optimization; global optimization; local best

ACRONYM

PSO	particle swarm optimization
I-NESA	improved nonequilibrium simulated annealing
LBEST	local best

I. INTRODUCTION

With the rapid development of modern high technology, especially the information technology, modern weapon system became more and more complex. To ensure the reliable use of the weapon system in the war and to increase the ratio of cost to efficiency of the complex weapon system, reliability optimization of complex weapon system has received considerable study interest from many researchers.

The optimization of this kind is a highly nonlinear optimization problem, and is rather difficult to solve because of its NP-hardness. Due to the nonlinearity combined with multiple local extreme values, traditional optimization techniques fail to arrive at the global or nearly global optimal solution. To achieve a better solution quality, modern meta-heuristics have been presented to solve complex network reliability optimization problems such as Artificial Neural Network (ANN) [1], Genetic Algorithms [2, 3, 4], Ant Colony Optimization [5, 6], and Tabu Search [7]. Particle Swarm Optimization (PSO) [8, 9] is utilized in this paper to further enhance the solution quality including precision and efficiency.

This paper is organized as follows. Section II put forwards the cost and reliability optimization problem of complex weapon system. Section III describes several key aspects involved in PSO algorithm. A numerical example is utilized in Section IV to demonstrate the effectiveness of this method. Conclusions are made in Section V with expectation of the future work.

II. OPTIMIZATION PROBLEM FORMULATION

A complex weapon system, as shown in Fig. 1, usually consists of several components connected to one another neither purely in series nor purely in parallel.

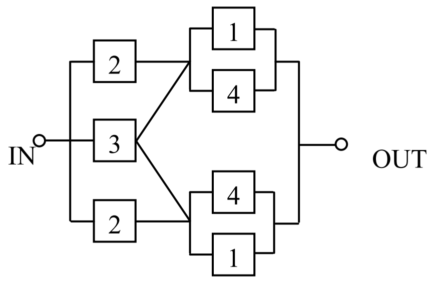

Figure 1. A complex weapon system.

It is very difficult to increase the reliability of the complex weapon system, and reduce the cost of the system at the same time. Hence, the complex weapon system reliability optimization problem trades between cost and reliability. In this paper, we consider one of the types where there is a need to reduce the cost under the reliability constraints.

Reliability of the system in Fig. 1 is as follows.

$$R_s = 1 - R_3(\bar{R}_1\bar{R}_4)^2 - \bar{R}_3[1 - R_2(1 - \bar{R}_1\bar{R}_4)]^2 \quad (1)$$

The optimization problem is to minimize the total system cost while the reliability constraints of the whole system and all the components in it are satisfied. That is:

$$\min\ C_S = \sum_{i=1}^{4} C_i = \sum_{i=1}^{4} X_i K_i R_i^{\alpha_i} \quad (2a)$$

$$\text{s. t. } R_{i,\min} \le R_i \le 1,\ i = 1,2,3,4 \quad (2b)$$

$$R_{S,\min} \le R_S \le 1 \quad (2c)$$

In which, R_i and C_i is the reliability and cost of component i respectively; R_S and C_S is the system reliability and cost respectively; X_i, being an integer and equal to or greater than 1, is the number of redundancies of component i; $R_{i,\min}$ and $R_{S,\min}$ is the lower bound on R_i and R_S, K_i and α_i are the multiple factor and power exponent of R_i respectively, i = 1, 2, 3, 4.

III. PSO Solution

A. Update Equation

The PSO algorithm updates the entire swarm at each time step by updating the velocity and position of each particle in every dimension by the following rules [8]:

$$v_{id} = wv_{id} + c_1\varepsilon_1(p_{id} - x_{id}) + c_2\varepsilon_2(p_{gd} - x_{id}) \quad (3)$$

$$x_{id} = x_{id} + v_{id} \quad (4)$$

B. Overall Algorithm

Particle Swarm Optimization algorithm is developed as in Algorithm 1. It is practically implemented in an iteration style. Initialization is done first, after which the population is evaluated and $\vec{p}_i$ is updated, which is a prerequisite to update $\vec{p}_g$ using LBEST Model. Updates of the velocity and position are followed to complete a generation of the optimization process. Terminating condition is checked to decide either to begin the next generation or to end the iteration. If terminating conditions are satisfied, R_i, C_i, R_S, C_S, and the elapsed time are output.

C. Fitness Function

For the complex weapon system reliability optimization problem as in (2), we recognize that the smaller the system cost and the less serious the violation of restrictions on the system and its components' reliabilities, the better the individual particle, therefore the fitness function can be chosen as followed.

$$eval(R_1, R_2, R_3, R_4) = C_S(1 + f_p) \quad (5)$$

In which, C_S is the system cost, and f_p is an additive penalty factor, which measures the degree of violation of the constraints in the optimization problem, and it can be obtained using the pseudo code 1 [10].

IV. Simulations

PSO algorithm is implemented using Matlab language to solve the optimization problem formulated in Section II. The parameters in (2) are set as such: X_1=2, X_2=2, X_3=1, X_4=2, K_1=100, K_2=100, K_3=200, K_4=150, $R_{S,\min}$=0.9, $R_{i,\min}$=0.5, and α_i=0.6 for all i, while the parameters for PSO algorithm are w=0.8, c_1=0.1, c_2=0.9, *popSize*=80, *maxGen*=1000.

Simulation code is run, and the results for the system, and the components' reliability and cost are shown in second column, Table I. For comparison, the reported solutions based on the Improved Nonequilibrium Simulated Annealing (I-NESA) [11] are also listed in columns three and four respectively. The solution from our method is superior to those either from GLFA or from I-NESA. From the data not given here, the coherence of the result is rather high. Of the 10 random runs, the optimal system cost 641.8236 is found 7 times, and the other costs are 641.8252, 641.8237, and 641.824, as shown in Table II. Fortunately, though all these three costs are suboptimal solution relative to the optimal system cost obtain in this paper, they are all superior to the solutions by others elsewhere [11,12]. Interestingly, it seems true that from vast amount of simulation runs we have executed the optimal solution to the optimization problem formulated in Section II can be reached at the boundaries of the reliabilities of components R_1, R_3, and R_4. If it is so, the four-dimension problem would be degraded to one-dimension problem, and the precision could be expected to be further enhanced. Numerical results show the high quality and the high efficiency of the PSO algorithm in optimizing the cost and reliability of complex weapon system under certain constraints. The optimization process of minimal system cost versus generation is shown in Fig. 2.

TABLE I. Global Optimal Solution of the Problem

	PSO	I-NESA	[12]
R_1	0.50000	0.50006	0.50001
R_2	0.83892	0.83887	0.84062
R_3	0.50000	0.50001	0.50000
R_4	0.50000	0.50002	0.50000
C_1	131.951	131.960	131.952
C_2	179.996	179.989	180.214
C_3	131.951	131.953	131.951
C_4	197.926	197.932	197.926
R_S	0.90000	0.90001	0.90050
C_S	641.8236	641.8332	642.04

TABLE II. PSO Solution of the Probblem

	#1	#2	#3
R_1	0.50006	0.50000	0.50001
R_2	0.83886	0.83892	0.83891
R_3	0.50000	0.50000	0.50000
R_4	0.50000	0.50000	0.50000
C_1	131.9597	131.9514	131.9525
C_2	179.9885	179.9954	179.9943
C_3	131.9508	131.9508	131.9508
C_4	197.9262	197.9262	197.9263
R_S	0.90000	0.90000	0.90000
C_S	641.8252	641.8237	641.8240

Algorithm 1 The PSO Process

```
initialize p_i
initialize p_g

for each particle i do
  for each dimension d do
    initialize x_id with random positions
    initialize v_id with random velocities
  end for
end for
for each time step t do
  for each particle i in the swarm do
    calculate particle fitness f(x_i)
    update p_i
  end for
  for each particle i in the swarm do
    update p_g using LBEST Model
    for each dimension d do
      update v_i & x_i using eqs 3 & 4
    end for
  end for
end for
```

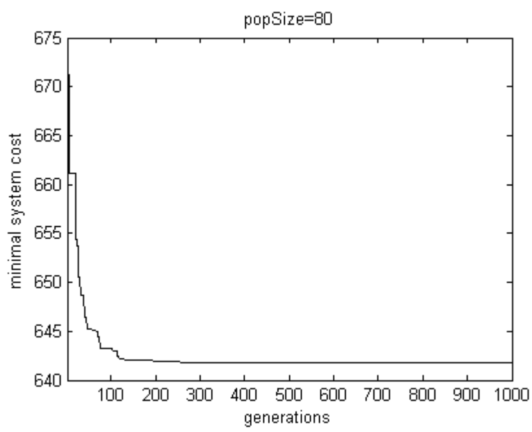

Figure 2. Optimization process of minimal system cost versus generation.

V. Conclusions

Reliability optimization of complex weapon system under certain constraints are formulated first, and then solved using PSO algorithm. Numerical results demonstrated that up to now, the PSO solution to the problem is superior to those published elsewhere [11, 12]. In the future study, we will focus on the one dimension degradation of this problem and incorporate genetic operator into the basic version of PSO algorithm implemented in this paper to further increase its precision and efficiency.

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