Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2014, 6(4):543-552

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

An intelligent approach for remote handling maintenance sequence planning in radiation environment

Guo Jian-Wen[1]*, Wang Song[2], Chen Hai-Bin[1], Sun Zhen-Zhong[1] and Zhang Zhi-Cong[1]

[1]School of Mechanical Engineering, Dong Guan University of Technology, China
[2]College of Mechanical & Automotive Engineering, South China University of Technology, Wushan Road, Tianhe District, Guangzhou, China

---

ABSTRACT

In order to improve the level of remote handling maintenance sequence planning for radiation equipment, a remote handling maintenance sequence planning algorithm based on adaptive mutation particle swarm optimization (AMPSO) was proposed. In view of the discreteness characteristic of the sequences planning, on the basis of the basic particle swarm optimization algorithm, the particle position, velocity and their update operation were redefined; the mutation operator of genetic algorithm was introduced to improve the ability to jump out of local optimum. The simulation experimental results show that compared with genetic algorithm and basic particle swarm algorithm, the proposed algorithm has high convergence speed and accuracy, can effectively improve the quality and efficiency of sequences planning.

Key words: nuclear safety, radiation equipment, remote handling maintenance, sequence planning, intelligent computation, adaptive mutation particle swarm optimization (AMPSO)

INTRODUCTION

The radiation installation (such as nuclear power station, high energy physics research institute etc.) generally possess the characteristics of large scale, high speed, heavy load, the continuous running as well as the complicated structures, and specially the facilities themselves and their working environments have the radioactivity. The characteristics of radiation installation can affect lifetime of the key installation so seriously that they may break down frequently. The malfunctions of core equipments will affect the experiment results and unplanned shutdown of the whole installation, and even bring about serious nuclear pollution and nuclear catastrophe causing huge losses to society. Therefore, during the installation lifetime all equipments that provide the base functions of the installation must be inspected and maintained.

The maintenance works include repairing or replacing the aging or faulty components of equipment component to ensure safe operation of the installations [1].Because most maintenance works should be done in the radiation environment in which man is unsuitable to work on site, these operations will be carried out by means of remote handling maintenance (RHM).Because of the complex construction of radiation equipment, it is difficult to carry out the RHM operations including the cutting, assembly, and disassembly and so on. The maintenance procedure should be planned in advance to ensure the reliability and security of the remote handling maintenance [2]. The remote handling maintenance planning (RHMP), which plan an optimal solution about the sequence, route, and used fixture and so on, is very important for the RHM during the early stages of radiation installation design. The virtual maintenance is introduced to overcome the shortcomings of tradition empirical design and physical verification mode. In virtual maintenance environment, the maintenance process of radioactive par can be simulated, and then the RHMP can be carried out by the virtual mode.

Remote handling maintenance sequence planning (RHMSP) including the assembly sequence planning (ASP) and disassembly sequence planning (DSP) is the core content of RHMP, which is to generate a sequence of operations to replace the aging or faulty components under certain constraint condition such as time, cost and reliability etc.. The complexity of this problem is proportional to the number of parts in the equipment. The number of feasible remote handling maintenance sequences can be increased with the complexity of maintained equipment. When the number of parts is large, combination explosion may occur and the optimal solution may be omitted. The RHMSP can be shown to be NP-complete.

Through the self-organization mechanism imitation of nature biology community and the adaptive ability formed by evolution, intelligent computation has provided new solutions for various complex optimization questions. In recent years, the intelligent optimization algorithms such as genetic algorithm [3], particle swarm algorithm [4], artificial bee colony algorithm [5] etc. have been studied in NP-complete. However, some defects still exist in genetic algorithm such as slow convergence, ineffective annealing algorithm, artificial neural networks lacking of global searching ability, and ant group algorithm which may stagnate in the later search etc. Compared with other algorithms, particle swarm algorithm may be more suitable to solve the RHMSP problem.

This paper proposes a self-adaptive variation particle swarm algorithm for remote handling maintenance sequence planning. The algorithm re-defines the particle's position and velocity and the refreshed operation of particle's position and velocity and introduces a mutation operator of genetic algorithm to avoid the precocious convergence. Finally simulation experiment of the algorithm is carried out on some radiation equipment, and the experimental result indicates that algorithm's precocious convergence can be greatly improved, and it can effectively improve the efficiency and quality of the RHMSP.

RELATED WORKS

At present, the remote handling maintenance for nuclear radiation equipment has achieved some progress; moreover it has been applied to nuclear power plants and nuclear science installments [1, 2]. The virtual maintenance technology has obtained some applications in the RHM. Ben et al. [6] figured out the demanding of remote handling maintenance for the virtual reality and simulation; Nobukazu et al. [7] developed a virtual reality simulator to support the ITER's Blanket simulation of remote handling maintenance process; Heemskerka et al. [8. 9] on the basis of ITER remote handling maintenance simulator, studied the dynamics of simulation process, and established a set of visualized master-slave mechanical arm handling platform for the ITER project; Salvador et al. [10] completed the digital simulation model of ITER separator; Shuff et al. [11] developed a set of discrete event simulation tool for remote operating process planning of ITER hot cabinet; Edward et al. [12] realized a real-time and visualized track of remote operating process planning by using virtual reality and intelligent database. Hee et al. [13, 14] studied the visualization and simulation of nuclear facility disassembly process and established remote handling maintenance system for PRIDE.

The above researches of the remote handling maintenance planning primarily shifted from physical verification to the virtual verification and from empirical design to simulation design. However in the above maintenance planning process, maintenance sequence was generally obtained in the exploration way, lack of the guidance of optimized maintenance sequence. On one hand it was not efficient; on the other hand the optimal solution might be omitted. Lack of intelligent support, more feasible plans and constraint conditions may make it impossible to obtain the optimal solution. Therefore, how to use the intelligent planning technology to provide the feasible sequence for planning personnel is an important content to further enhance the virtual maintenance planning.

MODELING

According to the characteristic of RHM, evaluating factors will be designated in this paper as follows: the geometry feasibility of the remote handling maintenance operation, equipment stability, the frequency of tool change, the frequency of operation direction change and the frequency of spare part connection type change.

3.1 GEOMETRY FEASIBILITY

The geometry feasibility of remote handling maintenance is determined by the interference relationship. The interference matrix is to describe the random components interference relations with other components in the ±x, ±y and ±z direction. Through the matrix operation, the feasibility of ASP and DSP can be evaluated in the remote handling maintenance process. The interference matrix A can be represented as:

$$A=\begin{bmatrix} I_{11x}I_{11y}I_{11z} & I_{12x}I_{12y}I_{12z} & \cdots & I_{1nx}I_{1ny}I_{1nz} \\ I_{21x}I_{21y}I_{21z} & I_{22x}I_{22y}I_{22z} & \cdots & I_{2nx}I_{2ny}I_{2nz} \\ \vdots & \vdots & \vdots & \vdots \\ I_{n1x}I_{n1y}I_{n1z} & I_{n2x}I_{n2y}I_{n2z} & \cdots & I_{nnx}I_{nny}I_{nnz} \end{bmatrix} \quad (1)$$

The equipment to be maintained can be described as $\{P_1, P_2, \ldots, P_n\}$, where P_i is a part of the equipment. I_{ijx} in interference matrix A is interference situation of the component P_i moving along +x direction with component P_j, and the value of I_{ijx} is represented as:

$$I_{ijx}=\begin{cases} 0 & \text{If } P_i \text{ does not interfere with } P_j \text{ when moving alone } +x \\ 1 & \text{If } P_i \text{interferes with } P_j \text{ when moving alonne } +x \end{cases} \quad (2)$$

Likewise, element I_{ijy} and I_{ijz} in matrix A are respectively interference situations of the component P_i moving along +y and +z direction with component P_j, and their values are the same as Equation (2). The interference matrix in –x, -y and -z direction can be induced by the interference matrix in +x, +y and +z direction. For example, interference situation of components P_i assembly/disassembly with components P_j along–x direction is the same as interference situation of components P_i assembly/disassembly with components P_j along +x direction.

Taking ASP as an example, the sequence $AP=(P_1, P_2, \ldots, P_{i-1})$ is supposed to be assembled components sequence; P_i is the component to be assembled, then the feasible assembly direction of component P_i may be determined by equation (3) and (4):

$$+D = \sum_{j=1}^{i-1} I_{ijD} \quad (3)$$

$$+D = \sum_{j=1}^{i-1} I_{jiD} \quad (4)$$

Where, D may take value of x, y and z respectively, therefore, the above two equations may be divided into six judgment equations. If equation is 0, it means that components P_i may continue assembly in the original assembly sequence along this direction; if equation is not 0, the assembly sequence is not feasible.

3.2 STABILITY

The stability means the conditions that whether the components or part will happen to collapse or fall down when it is used in controlling remotely to leave the equipment at times under gravity function. Establishing enhancement adjacent matrix $C=(c_{ij})_{n\times n}$ and support matrix $S=(s_{ij})_{n\times n}$ of parts can quantify the remote handling maintenance technology stability. Element c_{ij} expresses the connection type between components P_i and components P_j. Stable connection means $c_{ij}=2$; contact connection means $c_{ij}=1$; non-contact connection means $c_{ij}=0$. Element s_{ij} expresses the support relationship between components P_i and components P_j. When stable support exists between components P_i and components P_j, it means $s_{ij}=1$; otherwise, it means $s_{ij}=0$.

Taking ASP as an example, the sequence $AP=(P_1, P_2, \ldots, P_{i-1})$ is supposed to be assembled components sequence and P_i is the component to be assembled. The stability of remote handling maintenance technology assembly can be judged according to the following rules:

IF $c_{ij}=2$ ($j\in[1,i-1]$)exists, **THEN** this operation is stable;
IF $c_{ij}=0$ ($j\in[1,i-1]$), **THEN** this operation is unstable;
IF $c_{ij}=0$ and $s_{ik}=2$ ($j\in[1,i-1]$;$k\in[1,i-1]$)exists, **THEN** this operation is stable;
IF $c_{ij}=0$ and $s_{ik}=2$ ($j\in[1,i-1]$; $k\in[1,i-1]$) does not exists, **THEN** this operation is unstable.

n_s expresses the stable operation frequency in some assembly sequence. The smaller n_s is, the better assembly sequence assembly stability will be.

3.3 TOOL CHANGING FREQUENCY

Tool Changing Frequency is expressed as n_t . Taking ASP as an example, the sequence $AP=(P_1, P_2, \ldots, P_n)$ is supposed to be assembled components sequence, P_i is the component to be assembled and feasible assembly tool $AT(P_i)$ may be obtained by the components assembly tool collection P_i. Whether the tool is needed to change can be judged as:

```
IF   ⋂_{i=1}^{k} AT(P_i) ≠ ∅ , THEN P_{k+1} does not change the tool;
ELSE IF  ⋂_{i=1}^{k} AT(P_i) ≠ ∅   AND ⋂_{i=1}^{k+1} AT(P_i) = ∅ , THEN P_{k+1} changes the tool.
END IF
```

3.4 DIRECTION CHANGING FREQUENCY

To reduce the direction changing frequency can reduce tool operation time and improve the operating efficiency. The direction changing frequency is expressed as n_d. Taking ASP as an example, the sequence $AP= (P_1, P_2,\ldots, P_n)$ is supposed to be assembled components sequence, the geometry feasibility of any component P_i may determine feasible assembly direction $AD (P_i)$. Whether the direction is needed to change can be judged as:

```
IF   ⋂_{i=1}^{k} P_i ≠ ∅ , THEN (P_1, P_2,… , P_k) does not change the direction;
ELSE IF  ⋂_{i=1}^{k} P_i ≠ ∅   AND ⋂_{i=1}^{k+1} P_i = ∅ , THEN P_{k+1} changes the direction.
END IF
```

3.5 CONNECTION TYPES CHANGING FREQUENCY

Different connections may differ with different components, which may be screw joints, riveted joint, welding joint etc. Operation time may change with different connection types as well. Therefore, a good technology sequence should make the connection type change frequency fewer as far as possible.

The information storage of connection type can be saved by one-dimensional matrix $AC(i)$. For better description, two kinds of connection types may be respectively recorded as C_1 and C_2. If the connection type of components P_i belongs to C_i, then the value of corresponding $AC (i)$ is 1, so, the information storage of connection type information can be completed. n_c expresses the connection type change frequency of a remote handling maintenance sequence, whose computation rule is as follows:

```
SET   n_c=0;
FOR   i=1 to n-1;
  IF   AC(i+1)≠ AC(i);
  THEN  n_c= n_c+ 1;
  END IF
END FOR
```

3.6 OBJECTIVE FUNCTION

According to the above established target, objective function can be defined as follows:

$$f = c_f n_f + c_s n_s + c_t n_t + c_d n_d + c_c n_c \quad (5)$$

c_f, c_s, c_t, c_d and c_c are weighting factors of each evaluating indicator; generally c_f is much bigger than other four coefficients.

AMPSO ALGORITHM

4.1 THE REDEFINITION OF BASIC PSO ALGORITHM

The basic PSO algorithm is mainly used to optimize continuous function. In order to make the PSO algorithm be applied to the discrete space as well, some partial revisions to the basic PSO algorithm are needed to be conducted. The position, speed and the renewal operation of the granule will be redefined in the sorting space.

Definition 1: Particle Position. The position vector of each particle corresponds to an assembly sequence. The ith position vector of particle expression is $P^i = \left(P_1^i, P_2^i, \cdots, P_n^i\right)$, indicating that the product assembly process defers to the order of components $P_1, P_2, \cdots, P_n$, in which n is the product component number.

***Definition 2*: Particle Speed.** In this paper replacement operator will be treated as speed variable of the particle, whose function is to adjust the components order in the assembly sequence recorded as VOS. The *ith* velocity vector of particle expression is $VOS^i = (VO_1^i, VO_2^i, \cdots, VO_{n-1}^i)$. The function of speed operator $VO(x, y)$ is to exchange the position of *xth* component with the *yth* component in the maintenance sequence to create a new sequence.

***Definition 3*: Addition of Position and Speed.** The position vector of a particle added by its velocity vector result is a new position vector, and its expression is $P^i \oplus VOS^i = P^{i+1}$. Here mark "$\oplus$" has a new meaning to express velocity vector in the remote handling maintenance sequence.

***Definition 4*: Subtraction between Positions.** Two position vector subtracted is a velocity vector. Suppose $P^i = (P_1^s, P_2^s, \cdots, P_n^s)$ and $P^k = (P_1^k, P_2^k, \cdots, P_i^k, \cdots, P_t^k, \cdots, P_n^k)$, the subtraction of the two expressions is $P^s \Theta P^k = VOS^{s,k}$, in which $VOS^{s,k} = (VO_1^{s,k}, VO_2^{s,k}, \cdots, VO_{n-1}^{s,k})$, $VOS^{s,k}$ takes value according to the following regular rules:

For i=1 to n-1;
IF $P_i^s = P_i^k$, **THEN** $VO_i^{s,k} = (0,0)$;
ELSE IF $P_i^s = P_t^k$, **THEN** $VO_i^{s,k} = (i,t)$ And $P^k = (P_1^k, P_2^k, \cdots, P_t^k, \cdots, P_i^k, \cdots, P_n^k)$
END IF
END FOR

For example, $P^1 = (1,2,3,4,5,6)$ and $P^2 = (5,3,1,4,6,2)$, then it is obtained as $P^2 \Theta P^1 = [(1,5),(2,3),(3,5),(0,0),(5,6)]$.

***Definition 5*: Speed Multiplication.** The velocity vector of a particle can be supposed as $VOS^1 = (VO_1^1, VO_2^1, \cdots, VO_{n-1}^1)$ and coefficient $C \in [0,1]$. The multiplication definition of velocity vector and coefficient number is $C \otimes VOS^1 = VOS^2$, in which $VOS^2 = (VO_1^2, VO_2^2, \cdots, VO_t^2, \cdots, VO_{n-1}^2)$. VOS^2 takes value according to the following regular rules:

FOR i=1 to n-1

$$VO_i^2 = \begin{cases} VO_i^2, r \geq c \\ 0, r < c \end{cases}$$

r is a random number of uniform distribution from 0 to 1.
END FOR

Definition 6: Speed Addition. Two velocity vector added together is a new velocity vector, for easier calculation, the velocity vector cannot be directly added together, but can be added successively and separately with particle position vector and subtraction of the new and old position vector are used to get the velocity vector. It may be expressed in the formula as:

$$P^1 \oplus VOS^1 \oplus VOS^2 = [(P^1 \oplus VOS^1) \oplus VOS^2] = P^2, VOS^1 \oplus VOS^2 = VOS^3 = P^2 \Theta P^1.$$

Through above redefinition of particle position, speed and the renewal operation, we may modify slightly the basic PSO algorithm of particle position, speed and renewal formula to make the solution suitable for discrete space model:

$$VOS^{k+1} = \omega \otimes VOS^k \oplus \left\{ [c_1 \otimes (gBest \Theta P^k)] \oplus [c_2 \otimes (pBest \Theta P^k)] \right\} (6)$$

$$P^{k+1} = P^k \oplus VOS^{k+1} (7)$$

4.2 THE ALGORITHM IMPROVEMENT AND IMPLEMENTATION STEPS

The self-adaptive variation particle swarm optimization algorithm (AMPSO), introduced with a variation operator, on one hand may enhance the algorithm's searching effect; on the other hand it may maintain the individual difference of the community to prevent the occurrence of precocious convergence phenomenon and help to get a globally optimal solution.

(1) Granule initialization.
The assembly/disassembly sequence question's solution is a feasible sequence matrix AS of remote handling maintenance, and simultaneously AS is composed by components sequence AP, direction sequence AD, tool sequence AT and connection type sequence AC, in which AC may be determined only directly by AP. The stochastic initialization creates the sequence AP to determine the most optimal sequence AD and AT.

(2) Initial sufficiency computation.
The formula (5) may directly calculate various function value of granules sufficiency, and determine the initial individual optimal sequence and the initial global optimal sequence.

(3) Inertia weight computation.
Inertia weight ω takes value according to the equation (8):

$$\omega = m \times C_{dt} + n \quad (8)$$

Where, $\omega \in [0,1]$, this paper takes m=0.6, n=0.3, C_{dt} is the object distance factor and takes value according to the equation (9):

$$C_{dt} = \begin{cases} 1, f_{gb} \geq f_d \\ \dfrac{\left| f_{gb} - f_d \right|}{f_d}, f_{gb} < f_d \end{cases} \quad (9)$$

Where, f_{gb} has been found the global optimal sufficiency function value of remote handling maintenance sequence, and f_d is sufficiency function expectation value of global optimal sequence.

(4) Particle renewal.
Components sequence AP renews according to the formula (6) and (7), but direction sequence AD, tool sequence AT and connection type sequence AC will renew after the renewal sequence AP. Sequence AD and AT are the optimal sequences after the renewal of sequence AP. AC can be determined only directly by AP.

(5) Sufficiency renewal.
Formula (5) renews the sufficiency value of a particle swarm, and renews the individual optimal sequence and the global optimal sequence of various particles.

(6) Multiple factor renewals.
Taking the standard variance σ of the population sufficiency value as indicators of population diversity according to the equation (10):

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(f_i - f_a)^2} \quad (10)$$

Where, n is the particle number of particle swarm; f_i is the ith granule sufficiency; f_a is average sufficiency of particle swarm:

$$f_a = \frac{\sum_{i=1}^{n} f_i}{n} \quad (11)$$

(7) Variation.
In order to avoid algorithm premature to be partially optimal, variation operator will be introduced to take variation to the global optimal components sequence *gBest* (i.e. to change stochastically operation successive order of several component remote handling maintenance). The formula of variation probability p_m is as follows:

$$p_m = \begin{cases} k, \sigma < \sigma_d, f_{db} > f_d, i \neq run \\ 0, otherwise \end{cases} \quad (12)$$

where, $k \in [0.1, 0.3]$, σ_d is population convergence critical standard deviation, whose value is related with actual problem and generally far smaller than the maximum value of σ ; f_d is the expectation optimal value; *i* is the current iterative frequency; *run* is the biggest iterative frequency.

(8) If $i < run$, change to step 3; otherwise turn to the step 9.

(9) Output optimal sequence gBest which has been found.

VERIFICATION

The radiation equipment to simulated is shown as in Figure 1. The equipment is composed of 29 parts with related information as shown in Table 1. In order to verify the algorithm validity in this paper, This paper have carried out the simulation of assembly and disassembly operation planning for the radiation equipment by the proposed algorithm, genetic algorithm (GA) and the basic particle swarm optimization algorithm (PSO), and compared the results to prove the superiority of the algorithm.

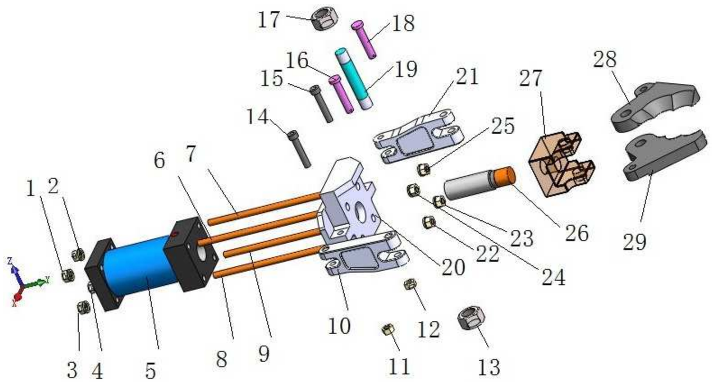

Fig. 1: Some radiation equipment

Simulation experiment environment: 2.0GHz PC, 2GB memory, Windows 7 systems, Matlab. Parameters of AMPSO: c_f=*10*, c_s=*0.2*, c_t=*0.3*,c_d=*0.3*,c_c=*0.2*,c_1=*0.5*, c_2=*0.5*,σ_d=*4*, *k=0.2*, *sizepop=150*, *run=800*. For assembly sequence planning, then optimal sufficiency expectation function value f_d=6; for disassembly sequence planning, f_d=*4.6*. Parameters of genetic algorithm and basic PSO: Overlapping probability of genetic algorithm takes 0.8; the variation probability takes 0.1; inertia weight ω of basic PSO algorithm takes 0.6; other parameters are the same as those of AMPSO. The repeat operation frequency is 20 to find the mean value of sufficiency function global situation extreme value and mean value of sufficiency function value standard. This example's AMPSO uses the variation operator to treat the global optimal particle which has been found at present as a stochastic particle.

Figure 2 and Figure 3 are the simulation results of ASP, and Figure 4 and 5 are the simulation results of DSP. Figure 2 and Figure 4 show the ability and convergence speed of the three algorithms to search the globally optimal solution. Figure 3 and 5 show the change tendency of population diversity along with the iterative frequency of the three algorithms.

Results of Figure 2 and 4 may represent: the convergence speed of genetic algorithm convergence is the slowest, and the precision is also the lowest; but basic PSO algorithm, although the convergence speed is quick, is easy to fall into the partial optimal solution; the AMPSO algorithm convergence speed, the same as basic PSO algorithm, can find the better globally optimal solution, moreover the precocious phenomenon is not easy to occur.

It can be concluded from Figure 3 and 5 that the population diversity of AMPSO algorithm always maintains certain level, which may guarantees that in the large iterative frequency situation a better globally optimal solution can be found in the algorithm. Through the above simulation results, it indicates: The AMPSO algorithm convergence speed is fast and precise, better than GA and the PSO algorithm in the performance of assembly sequence planning.

Table 1 Related information of assembly/disassembly optimization model

Component	Component name	Tool	Connection type
1-4	Nut washer assembly 1-4	T1	C1
5	Hydraulic cylinder	T4	C3
6-9	Pole 1-4	T3	C2
10	Strut 1	T4	C1
11-12	Nut 1-2	T1	C1
13	Nut 3	T1/T2	C1
14-15	Bolt 1-2	T1/T3	C2
16	Pin 1	T3	C2
17	Nut 4	T1/T2	C1
18	Pin 2	T3	C2
19	Central pin	T3	C2
20	Back plate	T4	C3
21	Strut 2	T4	C1
22-25	Nut washer assembly 5-8	T1	C1
26	Axis	T3	C2
27	Hydraulic pressure scissors	T4	C3
28-29	Hydraulic pressure shear blades 1-2	T5	C3

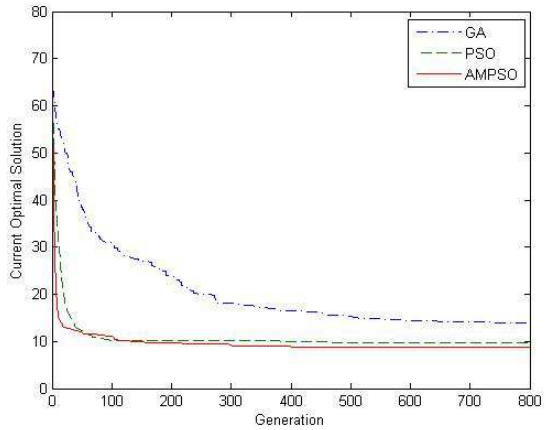

Fig. 2: Algorithm performance contrast – ASP

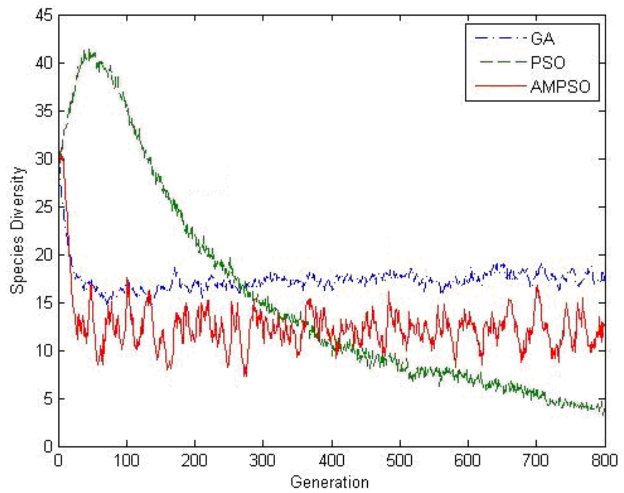

Fig. 3: Population diversity contrast – ASP

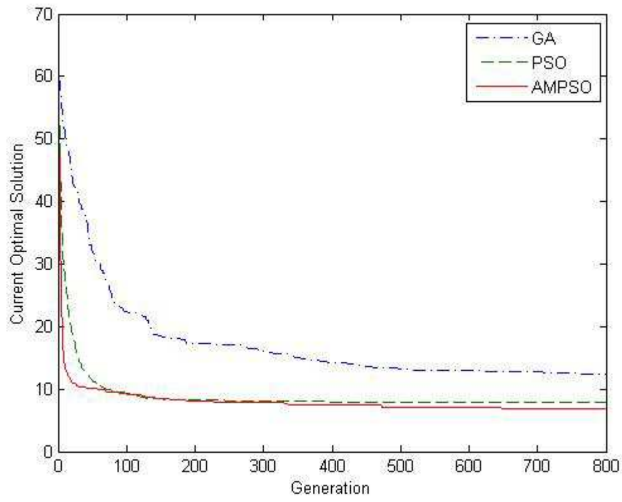

Fig. 4: Algorithm performance contrast – DSP

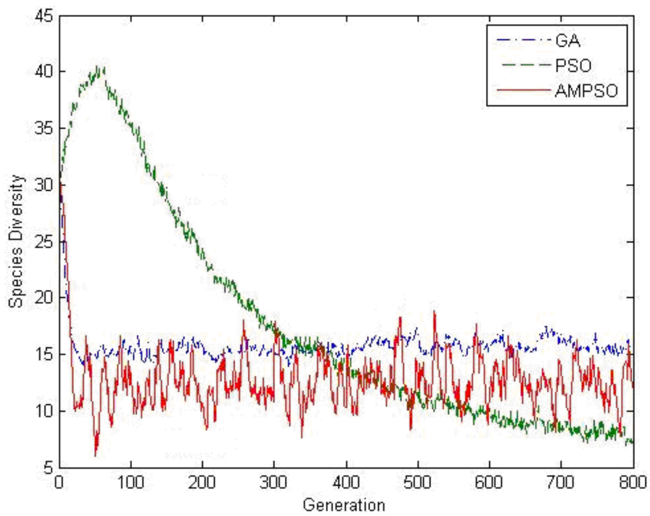

Fig 5: Population diversity contrast – DSP

CONCLUSION

On the basis of particle swarm algorithm, the particle position, speed, renewal operation of the particle velocity and the position are redefined in this paper. Moreover it enhances the algorithm through the introduction variation operator of genetic algorithm to jump out of the optimal solution. Furthermore it proposes an optimization algorithm of the product assembly sequence planning method based on a self-adaptive variation particle swarm. The simulation results show that compared with the genetic algorithm and the basic particle swarm algorithm contrast, this algorithm has advantages of fast convergence and high precision to improve the efficiency and quality of radiation equipment remote handling maintenance sequence planning.

Acknowledgment
The authors wish to thank the National Natural Science Foundation of China (Grant No.71201026), the Development Program for Excellent Young Teachers in Higher Education Institutions of Guangdong Province (No.Yq2013156), the Project of Department of Education of Guangdong Province (No. 2013KJCX0179), and the Research Starting Foundation from DongGuan University of Technology (ZJ120424).

REFERENCES

[1] Chang-Hwan C., Jim P., Carles C., et al.. *Fusion Engineering and Design*. **2011**, 86(9-11), 2025–2028.
[2] Isabel R., Carlo D., Alessandro T, et al.. *Fusion Engineering and Design*, **2011**, 86(9-10), 471–477.
[3] Lazzerini B., Marcelloni F.A.. *Artificial Intelligence in Engineering*, **2000**, 14(4), 319-329.
[4] Muhammad I., Rathiah H. & Noor E.A.K.. *Procedia Engineering*, **2013**, 253, 491-496.
[5] Mingxing D., Qiuhua T., Zhe L.. *International Review on Computers and Software*, **2011**, 6(7), 1307-1312.
[6] Ben E., Marco B., Rene C, et al.. *Fusion Engineering and Design*,**2009**, 84(2-6), 733–735.
[7] Nobukazu T, Satoshi K, Masataka N, et al.. *Fusion Engineering and Design*, **2008**, 83(10-12), 1837–1840.
[8] Heemskerka C.J.M., Baarb M.R., Boessenkoola H., et al.. *Fusion Engineering and Design*, **2011**, 86(9-11), 2082–2086.
[9] Elzendoornb B.S.Q, Magielsenc A.J., Magielsen A.J., et al.. *Fusion Engineering and Design*, **2011**, 86(9-11), 2064-2066.
[10] Salvador E., Jouni M., Mikko S., et al.. *Fusion Engineering and Design*, **2009**, 84(2-6), 752–756.
[11] Shuff R., Locke D., Roulet D. A.. *Fusion Engineering and Design*, **2011**, 86(9-11), 1950–1953.
[12] Edward R., Stephen S., Adrian W., Allan P.. *Fusion Engineering and Design*, **2009,** 84(7-11), 1628–1632.
[13] Hee S. P., Sung K.K., Kune W. L., et al.. *Journal of Nuclear Science and Technology*, **2007**, 44(4), 649-656.
[14] Hee S. P., Chang H. C., Sung H. K., et al.. *Annals of Nuclear Energy*, **2011**, 38(4), 767–774.