Test configuration method based on E-dominant NSGA2

Lin Yun
Naval Aviation University, Yantai, Shandong, China
e-mail: Yz@public.ytptt.sd.cn

Abstract: In order to solve the problems of the same target importance and too large solution set in the existing solutions, an E-dominant NSGA2 algorithm is proposed to solve the problem. In this paper, the mathematical model of the problem is established with the optimization objectives of test cost, test quantity and false alarm rate. The testability model under unreliable test condition is established by using Bayesian network. Then the E-dominated NSGA2 algorithm is used to solve the problem. After verification, the algorithm has good performance and practical value.

1. Introduction
Testability is a design feature that describes the degree of difficulty in monitoring and testing the health status of a system[1]. Since the 1970s, the importance of testability design has been widely recognized. An excellent testability design can greatly reduce the life cycle cost of equipment. Test configuration is an important part of testability design. Its purpose is to calculate the test set which can reduce the cost as much as possible under the premise of meeting the testability index assigned by the system[2].

After researching the predecessors[3-12], it can be found that the existing test optimization selection method has two defects. First, consider the problem as a single objective optimization problem for research. Secondly, when using multi-objective algorithms to solve problems, there are defects that the importance of the objectives is not considered and the solution set is huge.

In view of the defects of previous studies on this problem, this paper proposes a Test configuration method based on e-dominant NSGA-2 to solve the test selection problem under unreliable test conditions. Firstly, under the condition of unreliable testing, the paper takes the false alarm rate, test quantity and test cost as the optimization objectives, and takes the fault detection rate and fault isolation rate as the constraint conditions to establish the mathematical model of the Test configuration problem; secondly, in view of the test unreliable situation, the improved Bayesian network model is used as the tool for index calculation and scheme evaluation. After that, the improved NSGA-2 algorithm based on E-dominance theory is introduced, and the solution to the problem based on the algorithm is given. Finally, the method in this paper and the methods in literature [12] and [13] are used to carry out test optimization and selection for a certain system fault, and their results are compared, showing the advantages of the method, and verifying the effectiveness and practicability of the method.

2. Problem description and testability model

2.1 Test configuration
The main purpose of Test configuration is to give test configuration scheme, and then greatly improve the test ability on the basis of less cost investment. In testability design, the test configuration scheme of equipment is evaluated by various testability indexes, such as fault detection rate, fault isolation rate,
false alarm rate, missing detection rate. There is no obvious correlation between testability indexes, so it is unreasonable to evaluate test configuration scheme by single index. The analysis in the introduction points out that the Test configuration problem is a constrained multi-objective optimization problem. Its purpose is to provide one or several comprehensive optimal test configuration schemes for R & D personnel. In this paper, the fault detection rate and fault isolation rate are selected as constraints, and the average number of tests, the average test cost and the system false alarm rate are taken as the optimization indexes to solve the optimal test configuration scheme. The mathematical model of text
Test configuration is as follows:

\[
\begin{align*}
\min(FAR) \\
\min(D(x)) \\
\min(C(x))
\end{align*}
\] (1)

The constraints are as follows:

\[
\begin{align*}
FIR & \geq FIR' \\
FDR & \geq FDR'
\end{align*}
\] (2)

Where \(FIR', FDR'\) Indicates the minimum allowed \(FIR, FDR\) Value.

2.2 Bayesian network testability model
The main function of the model is to calculate testability index to evaluate the test selection scheme calculated by the algorithm. Bayesian network model is mainly composed of the following elements:
- Fault node set: \(F = \{f_1, f_2, \ldots, f_n\}\) In which \(f_i\)Represents the fault node and represents a fault mode;
- Test node set: \(T = \{t_1, t_2, \ldots, t_m\}\) In which \(t_i\)A test node represents a test;
- Directed edge: \(E\) Node correlation, fault correlation, test and connection;
- Conditional probability table: \(CPT\) The node parameters, i.e. uncertain information, are stored.

The Bayesian network model is shown in Figure 1.

![Fig. 1 Schematic diagram of Bayesian network](image)

The parameter information of each node in Bayesian network model is obtained by learning the parameters of fault test sample data and expert knowledge by using maximum likelihood estimation method. The principle of this method is not described here.

2.3 Calculation of testability index
The testability index is calculated as follows
- System to fault \(f_j\) The detection rate was as follows:

\[
FDR_j = 1 - p(\sum_{i=1}^{n} t_i = 0 | f_j)
\] (3)

System failure detection rate:

\[
FDR = 1 - \prod_{j=1}^{d} FDR_j
\] (4)

Fault isolation rate:
The false alarm rate of the system is as follows:

$$FAR = 1 - p(\sum_{j=1}^{n} f_j = 0 | \sum_{i=1}^{n} f_i)$$

(6)

### 3. E-dominance NSGA2 algorithm

#### 3.1 e dominance and related concepts

Before we talk about the algorithm, we need to understand the concept of e dominance. Firstly, the multi-objective function is assumed to be $G(x) = \{g_1(x), g_2(x), ..., g_m(x)\}$. Among $g(x)$ yes $G(x)$ The objective function, or index function, is included; $x_1, x_2, ..., x_m$ Denotes the decision variable, in this paper refers to the test selection scheme; $n$ is the number of objective functions.

**Definition $B, W, E$**

- $B(x_1, x_2)$ It refers to multi-objective functions $G(x_1)$ than $G(x_2)$ The number of good goals.
- $W(x_1, x_2)$ It refers to multi-objective functions $G(x_1)$ than $G(x_2)$ The number of poor targets.
- $E(x_1, x_2)$ It refers to multi-objective functions $G(x_1)$ And $G(x_2)$ The number of targets that represent the same.

Define decision variable evaluation matrix $P$

$$P = [g_{ij}]$$

(7)

Among them, \(g_{ij}\) Variable representation decision making \(x_j\) Target values.

Different target values have different dimensions and cannot be compared directly. Therefore, all target values need to be standardized.

In the Test configuration problem, there are two kinds of indicators: benefit index and cost index, so the standardization of the two kinds of indicators is not the same.

Benefit target: the larger the target value, the better, such as fault detection rate, fault isolation rate, which are processed by the following formula.

$$g_{ij} = \frac{\max_j \{g_{ij}\} - g_{ij}}{\max_j \{g_{ij}\} - \min_j \{g_{ij}\}}$$

(8)

Cost index: the smaller the target value, the better, such as false alarm rate, test cost, number of test points, which are processed by the following formula.

$$g_{ij} = \frac{g_{ij} - \min_j \{g_{ij}\}}{\max_j \{g_{ij}\} - \min_j \{g_{ij}\}}$$

(9)

Standardized scheme evaluation matrix $P'$

$$P' = [g_{ij}']$$

(10)

Define the concept of distance:

$$H(x) = \sqrt{\sum_{j=1}^{n} (g_{ij}'(x))^2}$$

(11)

Define bias coefficient $k$:

$$\sum_{j=1}^{n} k_j = 1$$

(12)

$k_j$ Represents the objective function $g_j(x)$ The bias coefficient of.
The concept of distance with bias coefficient is defined

\[ H(x) = \sqrt{\sum_{j=1}^{a}(k_j g_j(x))^2} \] (13)

E dominance: two decision variables \( x_1, x_2 \) if \( B - W > 0 \), and \( H(x_1) < H(x_2) \), then \( x_1 \) E is superior to E \( x_2 \), said \( x_1 \) control \( x_2 \) if \( x_1 \) is not dominated by any other solution \( x_2 \) It is a non dominated solution.

Non dominated sorting: find the non dominated solutions of the current solution set, store them in the set of dominating level 1, and delete them from the current solution set; continue the above steps in the remaining solutions to establish the set of dominating Level 2; continue to cycle the above steps until all solutions have corresponding support levels. The above is the non dominated sorting process.

Elitist retention strategy: using some index or sequence to reduce the population size, leaving the individuals with the highest index to form a new population. In this paper, the elite retention strategy is implemented according to two principles: (1) non dominated ranking level, the excellent level is reserved; (2) under the same level, the strategy is implemented according to the principle of distance priority \( H(x) \) Keep the small ones.

3.2 implementation of E-dominanceNSGA-2 algorithm

NSGA-2 algorithm is an improved genetic algorithm, which introduces non dominated sorting and elite strategy on the basis of genetic algorithm, and is widely used to solve multi-objective optimization problems. In general, NSGA-2 algorithm is based on Pareto dominance, but considering that in the Test configuration problem, indicators have different weights, that is, some indicators have higher importance, while others have lower importance, so different indexes need to be given different weights. Therefore, NSGA-2 algorithm in this paper is based on e dominance.

The basic idea of e-dominant NSGA-2 algorithm is as follows: (1) determine the population size \( n \), randomly generate the first generation of parent population, through crossover and mutation operators to get the first generation of offspring population; (2) mix the parent-child population and e-dominant sorting, and then execute the elite retention strategy to get the second-generation population with population size of \( N \); (3) repeat the above steps until the specified algebra is executed, and then jump out of the cycle.

4. example

Reference [12] and reference [13] share a case. In order to verify the effectiveness of the algorithm based on e dominance, this case is selected for comparison. There are 15 fault modes and 20 alternative tests in this case. The fault isolation rate is not less than 80%, and the fault detection rate is not less than 90%. Table 3 is the fault test matrix with uncertain information, table 4 is the failure rate, and table 5 is the test cost and false alarm probability information. Because of the layout restriction, the fault test correlation matrix is omitted. Here, it is considered that the uncertain parameter between fault tests is greater than 0.7, and there is a correlation between them. Therefore, the matrix in Table 3 can be transformed into the correlation matrix of fault test.

|       | \( t_1 \) | \( t_2 \) | \( t_3 \) | \( t_4 \) | \( t_5 \) | \( t_6 \) | \( t_7 \) | \( t_8 \) | \( t_9 \) | \( t_{10} \) |
|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| \( f_1 \) | 0.9518 | 0.9265 | 0.9472 | 0.9232 | 0.9532 | 0.9426 | 0.9422 | 0.9397 | 0.9612 | 0.9575 |
| \( f_2 \) | 0.8933 | 0.0000 | 0.9372 | 0.8691 | 0.8898 | 0.8968 | 0.8793 | 0.8583 | 0.9859 |
| \( f_3 \) | 0.9674 | 0.0000 | 0.0000 | 0.8742 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.9859 |
| \( f_4 \) | 0.9295 | 0.9123 | 0.9613 | 0.9872 | 0.8516 | 0.9157 | 0.9106 | 0.9032 | 0.9344 | 0.9886 |
| \( f_5 \) | 0.9019 | 0.0000 | 0.9842 | 0.8888 | 0.9751 | 0.8591 | 0.8816 | 0.9597 | 0.8573 | 0.9604 |
Table 4 failure rate

| f_1  | f_2  | f_3  | f_4  | f_5  | f_6  | f_7  | f_8  |
|------|------|------|------|------|------|------|------|
| 0.1% | 0.1% | 0.1% | 1%   | 1%   | 1%   | 1%   | 0.2% |
| f_9  | f_10 | f_11 | f_12 | f_13 | f_14 | f_15 |
| 0.1% | 1%   | 1%   | 0.25%| 0.15%| 1%   | 1%   |

Table 5 test cost and false alarm rate information

| test | t_1 | t_2 | t_3 | t_4 | t_5 | t_6 | t_7 | t_8 | t_9 | t_10 |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|      |     |     |     |     |     |     |     |     |     |      |
The NSGA-2 algorithm in reference [12], hbpsoga algorithm proposed in reference [13] and NSGA-2 algorithm in this paper are applied to solve the Test configuration problem of this example. The parameter setting of the algorithm in this paper is shown in Table 6, and the calculation results of the three algorithms are shown in Table 7.

Table 6 algorithm parameter setting

| parameter | numerical value | parameter | numerical value |
|-----------|-----------------|-----------|-----------------|
| Number of targets | 3 | Crossover probability | 0.7 |
| Number of decision variables | 20 | Mutation probability | 0.1 |
| Number of iterations | 100 | Population size | 50 |
| Cost weight | 0.5 | Missing rate weight | 0.3 |
| False alarm rate weight | 0.2 |

Table 7 calculation results of different algorithms

| method | Test configuration scheme | cost | Missing rate | False alarm rate |
|--------|---------------------------|------|--------------|------------------|
| E dominates NSGA2 | 1100100011110101010 | 390 | 0.98% | 1.51% |
| Literature [12] | 1110000011110101011 | 452 | 1.22% | 1.24% |
| Literature [12] | 1110010011110100011 | 567 | 0.12% | 0.27% |
| Literature [12] | 1110000011110100111 | 533 | 0.88% | 0.82% |
| Literature [13] | 1110000011110010101 | 503 | 1.25% | 0.99% |

By comparing the results of the table and the table, it can be found that the common NSGA-2 algorithm used in reference [12] has a large solution set, and each target has the same importance degree, so it is unable to carry out targeted optimization with weight. The e-dominant NSGA-2 algorithm proposed in this paper can balance all the objectives and focus on optimizing the indexes with higher weight. The test configuration scheme given to the decision maker is less, which avoids too many schemes affecting the decision-making. Moreover, the scheme optimizes the key indicators, which is more direct and reasonable. In addition, the relationship between test cost, false alarm rate, missed detection rate and iteration times is shown in the figure. It can be seen from the graph that the three target values tend to be stable when the population evolves to about 15 generations. The computation time of evolution 100 generation is 19 s, which shows that the convergence speed of the algorithm is fast and the calculation time is within the acceptable range.

Figure 2 Relationship among test cost, false alarm rate, missed detection rate and iteration times
5. Conclusion
In this paper, the Test configuration problem is reduced to a multi-objective optimization problem, and an e-dominant NSGA-2 algorithm is proposed to solve the problem, which overcomes the shortcomings of the traditional NSGA-2 multi-objective optimization algorithm, which has a large solution set and does not consider the important factors of the target. Finally, an example is given to show that the method can be used to optimize the test configuration according to the different requirements of the actual work, and the optimized test configuration scheme for a certain index can be calculated under the condition of balancing various indicators.

Firstly, the problem of Test configuration under unreliable test conditions is analyzed in depth, and it is pointed out that the problem is a typical multi-objective optimization problem. On this basis, the mathematical model of the problem is established with fault detection rate and isolation rate as constraints and test cost, test quantity and false alarm rate as optimization objectives;

Then, aiming at the defects of NSGA-2 algorithm, the E-dominance theory is used to improve the algorithm. A set of e-dominant optimal solutions can be obtained by using this method, from which the test configuration scheme can be determined;

Finally, taking the example in reference [12] as an example, this method is used to carry out Test configuration, and compared with other algorithms, it is proved that the algorithm has certain feasibility and effectiveness.

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