# Module Analysis and Reliability Optimum Distribution for Electronic Systems

Bumeng Liang, Yi Wan*

College of Physics and Electronic Information Engineering, Wenzhou University, Wenzhou, 325035, P.R.China
*Corresponding author E-mail: yiwan246@126.com

***Abstract* —With the increasing of integration level and complication of operating environment, the reliability of electronic products have been paid more and more attention, reliability distribution is a key issue for the reliability design of an electronic system, the fuzzy comprehensive evaluation and the support vector machine learning algorithm are applied to optimize reliability distribution modelling for electronic systems in this study, on basis of analysis for every module of an electronic system, the parameter collection of reliability levels and the weights of the parameters were determined and the membership degrees between every module of an electronic system and the parameters were obtained by the specialists' information and the support vector machine optimal clustering based on analyzing the influential characteristics of reliability distribution, optimum reliability indexes of an electronic system were distributed to every module. Furthermore, the comprehensive decision model was built based on the membership degrees of every parameter. The reliability of the whole electronic system are ensured and the electronic production cost and development period are reduced through the comprehensive algorithm.**

***Keywords - Electronic systems; Reliability optimum distribution, Module analysis, Fuzzy comprehensive evaluation***

## I. INTRODUCTION

In an electronic system, electronic devices and components are soldered directly in the PCB or ceramic substrate, the electrical and mechanical connection between the electronic component and circuit board is implemented through the solder joints. With the increasing of integration level and the complication of operating environment, the reliability of electronic products have been paid more and more attention [1-3].

The reliability design for electronic systems is an important research field. An electronic system consists of four modules, energy transformation and protection module, electronic control module, connection module, and signal transmission and transformation module. Because there is a difference in design and manufacturing cost, debugging repair cost, complexity degree and importance degree, reliability requirement for each module is different, basis on this, all parameters must be optimized in design and manufacture, the permissible levels of the failure probability are properly allocated to each module, and each module is able to be obtained optimum reliability [4-7].

The reliability distributions of an electronic system are the engineering optimal decision problems in nature, there are a great deal of parameters impacting on reliability distribution, these parameters include some uncertain fuzzy characteristics, and it is difficult to build specific mathematic model to optimize the reliability distribution [7-13]. Optimal integrative decision method based on fuzzy estimation is applied to the reliability distribution of electronic systems, and membership degrees of four module to each parameter were obtained through specialists' information and the support vector machine optimum clustering, the objective reliability index of an electronic system was properly distributed to each module of system, and reliability of the whole electronic system is guaranteed.

This paper is organized as follows. In section 2 we will present the method of building intelligent decision of membership degree. In section 3 we will introduce implementing step of reliability optimum distribution for electronic system based on fuzzy integrative decision, followed by the example analysis and evaluations on electronic system in section 4. The conclusions are given in section 5.

## II. INTELLIGENT DECISION OF MEMBERSHIP DEGREE

The membership degree represents the subject degree of a fuzzy relation among things. If there is a corresponding number $A(x) \in [0,1]$ for any an element x in the domain U, A(x) is a fuzzy set of U, A(x) is called the membership degree of x to A(x). The membership, A(x), is closer to 1, the level of x belong to A is higher. To obtain reasonably the membership degree between every module and importance, complexity, debugging and repair cost, development cost, optimal classification method is applied through support vectors machine, a fuzzy set is built for the member degree of every module to the same parameter:

$$MD = \{\text{smaller, small, large, larger}\}$$

Let smaller denotes 0.3, small denotes 0.5, large denotes 0.7 and larger is 0.9. MD will obtain the classified results by grouping, input variables are as follows:

{Operating frequency, component numbers, the debugging repair rate, development time, development cost}.

The implement principle of the machine learning algorithm is that input vectors are reflected to high dimensional characteristic space through the kernel functions [14, 15], the optimized classification super plane is built in the space, as is shown in Fig.1.

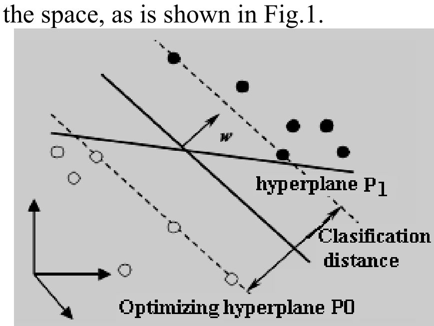


Fig.1 Optimizing Classification Hyperplane

Support vector is the closest sample points according to Eq. (1) for the support vector machine theory, and the distance from optimizing hyperplane $P_0$ for the same kind of support vectors is equal and the different kind of support vectors may be unequal.

$$OHP: (w \cdot x) + b = 0 \tag{1}$$

Assume m training samples are as follows:

$$(x_1, y_1), (x_2, y_2), \cdots, (x_m, y_m)$$

These training data need be on a classification hyperplane, and coefficient w and b are solved by Eq. (2).

$$y_i[(w \cdot x_i) + b] \geq 1, \quad (i = 1,2,\cdots,m), \quad \min_w \phi(w) = \|w\|^2 \tag{2}$$

To obtain the optimized classification hyperplane, Eq. (2) needs be transformed to a classical quadratic optimal model (3) by the Lagrange function:

$$\max W(\alpha) = \sum_{i=1}^{m} \alpha_i - \frac{1}{2} \sum_{i,j=1}^{m} \alpha_i \alpha_j y_i y_j K(x_i, y_j)$$

$$\sum_{i=1}^{m} \alpha_i y_i = 0, \alpha_i \geq 0, (i = 1,2,\cdots m) \tag{3}$$

$\alpha_i$ and $b_0$ are firstly solved , where

$$b_0 = \frac{1}{2}[K(w_0, x(1)) + K(w_0, x(-1))] \tag{4}$$

The optimized classification hyperplane is obtained through (5):

$$f(x) = sign\{\sum_{\alpha_i > 0} \alpha_i y_i K(x_j, x) - b_0\} \tag{5}$$

The sample points for $\alpha_i > 0$ are support vectors. The training samples for the support vector machine algorithm are obtained by the specialists' estimation in this study.

## III. RELIABILITY OPTIMAL DISTRIBUTION FOR ELECTRONIC SYSTEMS BASED ON FUZZY INTEGRATIVE DECISION

Integrative estimation is also called integrative decision, anything and objects have a lot of attributes, so every attribute must considered synthetically in estimating these objects, and the corresponding factors must synthetically consider to make an optimum decision. Fuzzy integrative estimation is that a compositive decision and judgment are made to an object based on fuzzy theory [16].

### *A. The alternative set and parameter set of fuzzy integrative estimation for an electronic system*

An alternative set A is constructed based on the four modules of an electronic system.

A = ($a_1$, $a_2$, $a_3$, $a_4$) = (energy transformation and protection module, electronic control module, connection module, signal transmission and transformation module).

Important parameters impacting on the reliability distribution of an electronic system include module complexity, module importance, development cost, and debugging repair cost. So parameter set P is formed basis on above analysis.

P = $p_i$ = ($p_1$, $p_2$, $p_3$, $p_4$) = (Importance, complexity, development cost, debugging repair cost).

The weight values denote influencing degree of every parameter to the reliability of an electronic system, they imply importance and function of every parameter in integrative decision, and they impact directly on decisive results. In general, they are counted through the statistical method according to several specialists' evaluation. The evaluation value of four parameters of $h^{th}$ specialist in k specialists by using a ten grading system is shown in table I, the mean value is obtained through (6):

$$P_i = \frac{\sum_{h=1}^{k} P_{ih}}{k}, \quad (i = 1,2,3,4) \tag{6}$$

where $P_i$ is the evaluation value of $i^{th}$ parameter, $P_{ih}$ is evaluation value of $h^{th}$ specialist to $i^{th}$ parameter, and the evaluation values are transformed by the normalization of (6):

$$a_i = \frac{P_i}{\sum_{i=1}^{4} P_i} \quad (i = 1,2,3,4) \tag{7}$$

Weight vector W is obtained:

$$W = (w_1, w_2, w_3, w_4)$$

Where $W_i$ is corresponding weight of $i^{th}$ parameter, $\sum_{i=1}^{4} w_i = 1$.

TABLE I. EVALUATİON VALUES OF FOUR PARAMETERS OF $H^{TH}$ SPECİALİST İN K SPECİALİSTS

| Parameters | Importance | Complexity | Development cost | Debugging cost |
|---|---|---|---|---|
| Evaluation value | $P_{1j}$ | $P_{2j}$ | $P_{3j}$ | $P_{4j}$ |

*B. The membership degrees of each module to all parameters and fuzzy integrative decision.*

The membership degrees are subjecting degrees of the fuzzy relation among things by the number between 0 and 1, their values are involved in the subjective judgment. To decide precisely the membership degrees between each module and importance, complexity, development cost and debugging repair cost, a fuzzy map of the alternative set to the parameter set is obtained by support vector machine intelligent classification.

$$a_i \mapsto [r_{i1} \quad r_{i2} \quad r_{i3} \quad r_{i4}]^T$$

The fuzzy relation matrix between A and P is structured through (8):

$$R = \begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} \\ r_{21} & r_{22} & r_{23} & r_{24} \\ \vdots & \vdots & \vdots & \vdots \\ r_{N1} & r_{N2} & \cdots & r_{N4} \end{bmatrix} \quad (8)$$

where the columns of the matrix are membership degrees of every module to importance, complexity, development cost and debugging repair cost respectively.

The fuzzy integrative decision is made based on the fuzzy mathematics theory [17], the three dimension space, (A, P, R), is transformed to fuzzy integrative evaluation model, the integrative fuzzy set E is obtained through (9).

$$E = W \circ R^T = (e_1, e_2, \cdots, e_N) =$$

$$(w_1, w_2, w_3, w_4) \circ \begin{bmatrix} r_{11} & r_{21} & \cdots & r_{N1} \\ r_{12} & r_{22} & \cdots & r_{N2} \\ r_{13} & r_{23} & \cdots & r_{N3} \\ r_{14} & r_{24} & \cdots & r_{N4} \end{bmatrix} \quad (9)$$

Where $\circ$ is a fuzzy operator:

$$M(\cdot,\oplus): b_j = \sum_{i=1}^{m} (a_i \cdot r_{ij})$$

The decision result E represents reliability optimum requirement of each module on the basis of comprehensive decision, so F implies high or low level of the relative failure rate for each module.

$$F = 1 - E = (f_1, f_2, \cdots, f_N) \quad (10)$$

WF is obtained by normalizing (10):

$$WF = (wf_1, wf_2, \cdots, wf_N) \quad (11)$$

$wf_1, wf_2, \cdots, wf_N$ represent the relative failure rate of each module. Because all modules of electronic system are a series system, the reliability of each module is optimized by the relative failure rate:

$$R_i = R_s^{wf_i}$$

Where $R_s$ is the reliability of the whole electronic system.

The changes of the reliability of the module with the relative failure rate in case of different reliability of the system are shown in Fig.2. It is clear that the reliability of the module changes slowly with the relative failure rate under the larger the reliability of the system.

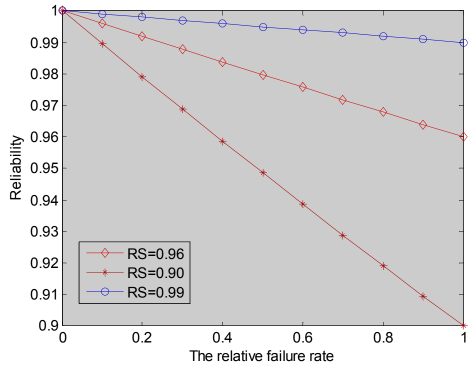


Fig.2 The Changes of the Reliability of the Module with the Relative Failure Rate

Each module includes lots of components for a specific electronic system, the failure rate of each component is different, a method based on the relative failure rate is applied to distribute properly the reliability to each component [18].

Assume the reliability of a module is $R_C$ , then the failure rate is obtained for each component:

$$F_{C_i} = \frac{F_i}{\sum_{i=1}^{n} F_i} F_C \approx \frac{\lambda_i}{\sum_{i=1}^{n} \lambda_i} F_C \quad (12)$$

The reliability is computed for each component:

$$R_{C_i} = 1 - F_{C_i} \quad (13)$$

## IV. AN EXAMPLE ANALYSIS ON AN ELECTRONIC SYSTEM

Reliability optimal distribution method for electronic systems based on the fuzzy integrative decision was applied to the electronic system of DC frequency conversion conditioning. The electronic system of DC frequency conversion conditioning includes eight circuits, it is a series system that consisted of four modules, energy transformation and protection module, electronic control module, connection module and signal transmission and transformation module, so the alternative set $A = (a_1, a_2, a_3, a_4)$ =(energy transformation and protection module, electronic control module, connection module, signal transmission and transformation module). The parameter set $P = p_i = (p_1, p_2, p_3, p_4) =$ (Importance, complexity, developing cost, debugging repair cost).

The weight values were evaluated by three specialists in the electronic field, evaluation values of the specialists on four parameters by 10 points system is shown in table II.

TABLE II. EVALUATİON VALUES OF THREE SPECİALİSTS ON FOUR PARAMETERS

| Parameters | I | C | D | DB |
|---|---|---|---|---|
| Evaluation Values | 5.2 | 1.9 | 1.9 | 1.0 |
| | 4.5 | 2.3 | 1.8 | 1.4 |
| | 4.3 | 2.1 | 2.0 | 1.6 |

*I denotes importance, C denotes complexity, D denotes development cost, DB denotes debugging cost.

The weight vector was obtained through (6) and (7):

$W = (w_1, w_2, w_3, w_4)$ =(0.467, 0.210, 0.190, 0.133).

Twenty groups of support vector machine learning samples were obtained using the specialists' evaluations. The membership degrees among every module and importance, complexity, debugging repair factor, development cost were decided by optimizing support vector machine classification. The membership degrees are shown in table III.

TABLE III. THE MEMBERSHİP DEGREES OF EACH MODULE TO PARAMETERS

| Parameters | Importance | complexity | Development cost | Debugging cost |
|---|---|---|---|---|
| A1 | 0.5 | 0.7 | 0.9 | 0.7 |
| A2 | 0.3 | 0.3 | 0.7 | 0.9 |
| A3 | 0.7 | 0.5 | 0.3 | 0.5 |
| A4 | 0.9 | 0.9 | 0.5 | 0.3 |

A fuzzy relation matrix was obtained by (8):

$$R = \begin{bmatrix} 0.5 & 0.3 & 0.7 & 0.9 \\ 0.7 & 0.3 & 0.5 & 0.9 \\ 0.9 & 0.7 & 0.3 & 0.5 \\ 0.7 & 0.9 & 0.5 & 0.3 \end{bmatrix}$$

The fuzzy integrative decision was made:

$E = W \circ R^T = (e_1, e_2, e_3, e_4) =$ (0.5495, 0.6049, 0.6909, 0.6509)

Then, $WF = (wf_1, wf_2, wf_3, wf_4)$ =(0.2201, 0.2423, 0.2768, 0.2608).

If the reliability, $R_S$, that whole electronic system requires is 0.96, the optimized reliability of energy transformation and protection module, electronic control module, connection module, and signal transmission and transformation module are 0.9911, 0.9902, 0.9888 and 0.9894 respectively. The objective reliability decided the electronic system requirements is satisfied through verification.

$R = R_{C_1} R_{C_2} R_{C_3} R_{C_4}$ =0.9601.

## V. CONCLUSIONS

We proposed an integrative method based on the support vector classification and the fuzzy decision to distribute optimally the reliability for electronic systems in this paper, Optimum reliability of each module in an electronic system is distributed through the fuzzy integrative decision according to the comprehensive analysis and evaluation on reliability parameters impacting on electronic systems, and the membership degrees of each module to each parameter are obtained by specialists' evaluations and support vector classification. A new method is provided for the optimum design of electronic systems in this study.

## CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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