Fuzzy Reliability Modeling of Mechanical Meta-action Assembly Accuracy

Hongyu Ge*, Baoqiang Liu, Chuanwei Zhang and Manzhi Yang

School of Mechanical Engineering, Xi’an University of Science and Technology, Shaanxi, China

Corresponding author: Hongyu Ge, Xi’an University of Science and Technology, No. 58 Yanta Middle Road, Xi’an City, Shaanxi 710054, China.

Email: 9203631@qq.com

Abstract. Meta-action assembly units are the basic units to ensure the reliability of mechanical function. For the problem that the reliability of meta-action assembly units are difficult to be finely modeled. Combined with the fuzziness of assembly process, this paper introduces fuzzy theory into the reliability analysis of meta-action assembly accuracy. By analyzing the structure of meta-action assembly units, it is concluded that meta-action assembly units are composed of support member, power source, transmission fastener and actuator. Then, an unified structural model of meta-action assembly units is established; according to the mechanism of assembly accuracy, the accuracy information of a meta-action assembly unit is mapped to each assembly item (assembly item is consisted of individual part feature and corresponding part feature). Combined with the fuzzy feature of assembly information, the concepts of assembly accuracy reliability and assembly accuracy fuzzy reliability are proposed. By analyzing the fuzzy characteristics of assembly accuracy of assembly items, membership function of assembly accuracy is determined. According to probability definition of the fuzzy events, a fuzzy reliability model of the meta-action assembly accuracy is established. In view of whether the assembly project of scientific research enterprise has faults, a large number of historical data are analyzed, and the overall 0-1 distribution of observation data is obtained. Precision test of fuzzy reliability model is got on by maximum likelihood estimation of the 0-1 distribution. The example shows that the reliability value obtained by using the model is different from the test result by 0.0029. The results indicate that the method has greater feasibility, simplicity and flexibility.

1. Introduction

With the development of complex products towards precision, opto-mechanical integration, and intelligence, the guarantee of assembly accuracy has become one of the difficult problems in the assembly of complex products [1]-[4]. Decomposing complex product assembly problems into meta-action units [5]-[7] assembly problems can greatly reduce the complexity of assembly problems. There are uncertain factors in the actual assembly process of parts, in addition to random uncertainties, there are also fuzzy uncertainties [8], most of the traditional assembly process analysis methods are based on probability assumptions and two-state assumptions. It can effectively solve the randomness problem in reliability engineering, but it is powerless to solve the ambiguity problem. Therefore, this paper carries out research on the ambiguity of the assembly process. Based on the traditional reliability theory, the fuzzy theory is used to deal with the fuzzy phenomena in the reliability analysis of the assembly process,
which lays the foundation for the reliability growth.

In terms of deterministic assembly accuracy, Bao Qianqian et al [9] derived the functions of assembly accuracy and operating force of the manipulator, and proposed an optimization method for assembly accuracy. Tang [10] et al. Studied the accumulation of errors between processes. Liu [11] et al. Proposed to establish a three-dimensional error transfer model using the state space method by considering various types of error factors in the multi-station assembly process. CAO [12] et al. Proposed a point-based error transfer model. LIN et al. [13] proposed an error transfer model to simulate the assembly errors of flexible assembly systems for large-sized parts. The above literature analyzes the assembly accuracy problem through error transfer accumulation, which is one of the effective methods to study the total assembly accuracy, but it is impossible to determine the degree of satisfaction of the assembly accuracy of each specific assembly item. Zhao Dongping [14] proposed an accuracy prediction method based on gap connectors and multidimensional vector loops. Su Chun et al [15] analyzed the composition of error and its calculation method for typical types of mating surfaces. This article provides inspiration for the idea of measuring assembly accuracy by studying the fitting and clearance or interference of each assembly item.

In terms of assembly accuracy prediction, The research results of GRANDJEAN et al. [16] show that if geometric errors are not taken into account, the prediction of assembly accuracy will be biased. Zhang Tingyu et al. [17] conducted an assembly precision prediction study on machining errors and fixture position errors as error sources. HONG et al. [18] used differential motion vectors to describe the error state of the assembly process, established a state space model of the assembly process of the precision machine tool, and realized the precision prediction of the precision machine tool assembly. Zhong Weiyu [19] et al. Proposed a product assembly accuracy model based on multicolor geometric theory. Predicting assembly accuracy and modeling is one of the theories of prior control, but accurate prediction of assembly accuracy is more difficult to achieve. Therefore, the introduction of fuzzy method modeling in this paper is more objective.

Regarding the reliability of assembly accuracy, Cheng Fenglan [20] studied the mapping relationship between machine tool function, machine tool structure and assembly process, and established the reliability evaluation index of machine tool assembly accuracy. This document determines the evaluation system by studying the assembly process, which provides a certain idea for the analysis of the assembly items of the assembly unit in this paper. However, in the assembly process, the influence of part errors on assembly accuracy is ambiguous. How to establish a fuzzy mathematical relationship and reliability model between machining errors and assembly accuracy from the perspective of probability theory requires further research. Yu Shunian [21] introduced fuzzy mathematics theory into the tolerance distribution of assembly dimension chain, and proposed the concept of assembly fuzzy reliability of assembly dimension chain. Ali [22] and others proposed to use intelligent simulation methods to solve the fuzzy uncertain problems in the manufacturing system; it provides a certain theoretical basis for the concept of assembly reliability fuzzy reliability in this paper.

Based on the above analysis, this paper intends to start with the analysis of mechanical element motion assembly. Under the support of the assembly accuracy data of each element, the fuzzy mathematics theory is used to establish the reliability membership function of assembly accuracy. Based on the transmission mechanism of assembly error, a fuzzy reliability model of assembly accuracy of mechanical element motion is established. The maximum likelihood estimation method is used to verify the accuracy of the model, thereby verifying the feasibility of the assembly accuracy reliability fuzzy model, and providing theoretical support for ensuring the accuracy of mechanical assembly.

2. Basic concepts

2.1. meta-action assembly unit
The mechanical meta-action unit is a basic unit in the machine tool motion system function. To ensure the reliability of the meta-action, the structure of the meta-action assembly unit must be clear, and the structural model of the unit must be established.
Define the mechanical meta-action assembly unit as follows:

Meta-action assembly unit: During the assembly process, an assembly that implements the meta-action is the core of the assembly. A group of parts can be assembled independently to meet the specified meta-action performance requirements, and an independent component that enables the meta-action to complete the specified function is called a meta-action assembly unit.

A typical meta-action assembly unit consists of supports, power sources, actuators, intermediate transmissions and fasteners. The structure model of the meta-action structure unit is shown in Figure 1.

![Fig.1 Element of the meta-action](image)

2.2. Reliability of assembly accuracy

Under the specified assembly conditions, the meta-action assembly unit, the ability of the actual assembly accuracy to meet the design requirements is the assembly accuracy reliability. The probability that the corresponding actual assembly accuracy meets the design requirements is called the reliability of the meta-action assembly accuracy.

Let an assembly item in the assembly unit be (the elements on a part in the assembly unit and the elements on the parts assembled with it are combined into the corresponding assembly item) The assembly accuracy and reliability of this assembly item are as follows:

\[
R_i = P(x_i) = P(x_{\min} < x_i < x_{\max})
\]

Among them, \(x_i\) is the assembly gap or interference of assembly item \(M_i\). \(x_{\min}\) is the minimum clearance or maximum interference. \(x_{\max}\) is the maximum clearance or minimum interference.

If the assembly unit has \(n\) assembly items, the assembly unit assembly accuracy reliability is as follows:

\[
R = R_1 \times R_2 \cdots \times R_n = \prod_{i=1}^{n} R_i
\]

Based on the analysis of assembly accuracy reliability, the fuzzy theory is introduced into assembly accuracy reliability analysis.

2.3. Fuzzy reliability of assembly accuracy

In the actual assembly process, the assembly accuracy is affected by factors such as the machining accuracy of the parts, the stiffness of the parts, the thermal deformation of the parts, the assembly method, and so on, and it presents fuzzy features.

The fuzzy reliability of assembly accuracy is now defined as follows:

The ability of the meta-action assembly unit to meet the requirements of the ideal state to a certain extent under the specified assembly conditions is called the fuzzy reliability of the meta-action assembly unit assembly accuracy. The probability that the corresponding actual assembly accuracy meets the requirements of the ideal state to a certain extent is called the assembly reliability fuzzy reliability.

Assembly accuracy \(x_i\) of an assembly item of the assembly unit, Consider the ambiguity of the meta-action assembly process behavior. The actual assembly accuracy meets the requirements of the ideal assembly accuracy to a certain extent is the fuzzy event \(\tilde{A_i}\). Then the fuzzy reliability of the assembly accuracy of the assembly item is recorded as \(\tilde{R} (\tilde{A_i})\), Abbreviated as \(\tilde{R}_i\), The fuzzy reliability of
assembly unit assembly accuracy is recorded as \( \tilde{R}_u = \prod_{i=1}^n \tilde{R}_i \)

3. Mathematical model

3.1. Basic model of fuzzy reliability of mechanical assembly accuracy

According to the definition of fuzzy event probability [23], the fuzzy reliability model of the assembly accuracy of a certain assembly item of the meta-action unit is established as follows:

\[
\tilde{R}_i = P(\tilde{A}_i) = \int \mu_{\tilde{A}_i}(x_i) f(x_i) dx
\]

Equation (1), \( \mu_{\tilde{A}_i}(x_i) \) represents the membership function of the assembly event fuzzy accuracy event \( \tilde{A}_i \) of the assembly item (which can be given based on experience, statistical methods, and expert authority). Since the assembly units are different, the membership functions of the assembly items may be different. Therefore, this paper will give a specific membership function expression method in the case analysis.

Assuming that the assembly accuracy sample data of each assembly item follows a normal distribution, then in equation (1):

\[
f(x_i) = \frac{1}{\sigma_i \sqrt{2\pi}} \exp \left( -\frac{(x_i - \mu_i)^2}{2\sigma_i^2} \right)
\]

Equation (2), \( \mu_{x_i} \) is the average value of the clearance or interference of the i-th assembly item in the assembly unit, which is expressed as follows:

\[
\mu_{x_i} = \frac{1}{m} \sum_{j=1}^m x_{ij}
\]

Equation (3): \( m \) represents the sample size of an assembly item, \( i \) represents an assembly item, and \( j \) represents a sample of an assembly item.

\( \sigma_{x_i} \) is the standard deviation of the gap or interference of an assembly item, which is expressed as follows:

\[
\sigma_{x_i} = \sqrt{\frac{1}{m} \sum_{j=1}^m (x_{ij} - \mu_{x_i})^2}
\]

Equation (4)

The assembly accuracy of the meta-action is guaranteed by the assembly accuracy of each assembly item. The assembly reliability fuzzy reliability consists of the fuzzy reliability of each assembly item connected in series.

\[
\tilde{R}_u = \prod_{i=1}^n \tilde{R}_i
\]

Next, the maximum likelihood estimation method is used to establish the accuracy verification model of the assembly accuracy reliability fuzzy model.

3.2. Accuracy verification of assembly reliability fuzzy reliability model

Use the project research enterprise to obtain historical data on whether an assembly item in the meta-action unit is faulty. The observation data can be set to obey the 0-1 distribution of the parameter \( p \), as follows:

\[
X = \begin{cases} 
1, & \text{Failure occurs} \\
0, & \text{Failure does not occur}
\end{cases}
\]

And \( P(X_i) = p \), the reliability of the assembly item is as follows:
\( R(X_i) = 1 - P(X_i) = 1 - p \)

Assuming that \( X_{i1}, X_{i2}, \ldots, X_{im} \) are a sample taken from population \( X_i \), the distribution law of each \( X_{ij} \) is as follows:

\[
P( X_{ij} = x_{ij}^* ) = p^{x_{ij}^*} (1 - p)^{1 - x_{ij}^*}, x_{ij}^* = 0, 1; \]

\( j = 1, 2, \ldots, m \)

Then the likelihood function is as follows [24]:

\[
L = L(x_{i1}^*, x_{i2}^*, \ldots, x_{im}^*; p) \\
= p^{\sum_{j=1}^{m} x_{ij}^*} (1 - p)^{m - \sum_{j=1}^{m} x_{ij}^*}
\]

The model log-likelihood function is as follows:

\[
\ln L = (\sum_{j=1}^{m} x_{ij}^*) \ln p + (m - \sum_{j=1}^{m} x_{ij}^*) \ln (1 - p)
\]

The log-likelihood function is zero for \( p \) partial derivatives, as follows:

\[
\frac{\partial \ln L}{\partial p} = (\sum_{j=1}^{m} x_{ij}^*) \frac{1}{p} - (m - \sum_{j=1}^{m} x_{ij}^*) \frac{1}{1 - p} = 0
\]

The maximum likelihood estimate of \( p \) is as follows:

\[
\hat{p}_L = \frac{1}{m} \sum_{j=1}^{m} x_{ij}^*
\]

The maximum likelihood estimate of the reliability of the assembly item is as follows:

\[
\hat{R}(X_i) = 1 - \hat{p}_L = 1 - \frac{1}{m} \sum_{j=1}^{m} x_{ij}^*
\]

Then the maximum likelihood estimate of the reliability of the meta-action is as follows:

\[
\hat{R}(X_x) = \prod_{i=1}^{n} \hat{R}(X_i) = \prod_{i=1}^{n} (1 - \hat{p}_L) \\
= \prod_{i=1}^{n} (1 - \frac{1}{m} \sum_{j=1}^{m} x_{ij}^*) \quad (6)
\]

It is a relatively new idea to introduce fuzzy theory into assembly accuracy reliability modeling. Using maximum likelihood estimation to verify the accuracy of the model, its feasibility can be checked.

4. case analysis

Now the reliability analysis of assembly accuracy is carried out by taking the worm rotating meta-action assembly unit in the NC turntable as an example.

4.1. Reliability membership function of assembly accuracy of worm rotating unit.

To use fuzzy theory to deal with mechanical assembly accuracy, we must first establish the membership function of the fuzzy event that the assembly accuracy meets the requirements of the ideal state. This function reflects the characteristics of the fuzzy concept, and the mathematical operations related to assembly accuracy can be realized through quantization. Therefore, the correct determination of the membership function [25] is the basis for establishing a fuzzy reliability model for assembly accuracy, and is also the key to solving the reliability problem of assembly accuracy using fuzzy methods.

According to the characteristics of the worm rotation meta-action assembly accuracy data (actual cooperation clearance or interference of each assembly item of the meta-motion unit) obtained from the research unit. The assembly accuracy of the general assembly item of the worm rotating element action
unit meets the performance requirements. The membership function of the fuzzy event can be approximated by the intermediate ridge distribution form as follows:

\[
\mu_i(x) = \begin{cases} 
1 + \frac{1}{2} \sin \frac{\pi}{a_i - x_{i \text{min}}} \left( x - \frac{x_{i \text{min}} + a_i}{2} \right), & x_{i \text{min}} \leq x \leq a_i \\
1, & a_i < x < a_2 \\
1 - \frac{1}{2} \sin \frac{\pi}{x_{i \text{max}} - a_2} \left( x - \frac{x_{i \text{max}} + a_2}{2} \right), & a_2 \leq x \leq x_{i \text{max}} 
\end{cases}
\] (7)

Equation (7), \( a_1 \) represents the value of the gap or interference that is determined to be higher after satisfying the ideal performance requirements of the meta-action after a large amount of assembly accuracy data analysis or empirical analysis.

\( a_2 \) represents the value of the gap or interference that cannot be satisfied with the ideal performance requirements of the meta-action after a large amount of assembly accuracy data analysis or empirical analysis. \( x_{i \text{min}} \) is the minimum clearance or maximum interference. \( x_{i \text{max}} \) is the maximum clearance or minimum interference.

Bringing equations (2) and (7) into equation (1) is as follows:

\[
\tilde{R}_i = \int_{x_{i \text{min}}}^{x_{i \text{max}}} \frac{1}{2} + \frac{1}{2} \sin \frac{\pi}{a_i - x_{i \text{min}}} \left( x - \frac{x_{i \text{min}} + a_i}{2} \right) \times \frac{1}{\sigma_i \sqrt{2\pi}} \exp\left[ -\frac{(x - \mu_i)^2}{2\sigma_i^2} \right] dx + \\
\int_{x_{i \text{min}}}^{a_i} \frac{1}{\sigma_i \sqrt{2\pi}} \exp\left[ -\frac{(x - \mu_i)^2}{2\sigma_i^2} \right] dx + \int_{a_i}^{x_{i \text{max}}} \frac{1}{\sigma_i \sqrt{2\pi}} \exp\left[ -\frac{(x - \mu_i)^2}{2\sigma_i^2} \right] dx + \\
\int_{x_{i \text{min}}}^{x_{i \text{max}}} \frac{1}{2} \sin \frac{\pi}{x_{i \text{max}} - a_2} \left( x - \frac{x_{i \text{max}} + a_2}{2} \right) \times \frac{1}{\sigma_i \sqrt{2\pi}} \exp\left[ -\frac{(x - \mu_i)^2}{2\sigma_i^2} \right] dx + \\
\int_{x_{i \text{min}}}^{a_2} \frac{1}{\sigma_i \sqrt{2\pi}} \exp\left[ -\frac{(x - \mu_i)^2}{2\sigma_i^2} \right] dx + \int_{a_2}^{x_{i \text{max}}} \frac{1}{\sigma_i \sqrt{2\pi}} \exp\left[ -\frac{(x - \mu_i)^2}{2\sigma_i^2} \right] dx.
\] (8)

4.2. Fuzzy reliability analysis of worm rotation assembly accuracy

The worm rotation meta-action assembly contains 10 parts and 9 coordinate. Now we will obtain the assembly accuracy information of each part of the worm rotating unit from a CNC machine tool company as shown in Table 1.

| Table 1 Information of each assembly item in the worm rotation assembly unit |
|--------------------------------|----------------|----------------|----------------|----------------|
| Fit   | Fit type     | fit geometry | fit parts     | basic dimensions and accuracy |
|-------|--------------|---------------|---------------|-----------------------------|
| Worm and left bearing | Left bearing outer circle line surface combination \( M_1 \) | Joint surface \( g_1 \) | Left bearing | \( \phi_{62}^{0.010} \) |
|       | Screw shaft hole fit of left bearing seat \( M_2 \) | Joint surface \( g_2 \) | Left bearing seat | \( \phi_{62}^{0.011} \) |
|       | Fitting of inner screw hole of left bearing \( M_3 \) | Screw shaft \( g_3 \) | Screws | \( \phi_{10}^{0.020} \) |
|       | Left nut shaft hole \( M_4 \) | Screw hole \( g_4 \) | Left bearing seat | \( \phi_{10}^{0.006} \) |
|       | Right bearing outer circle line surface | Mating hole \( g_5 \) | Left bearing | \( \phi_{30}^{0.018} \) |
|       |                | Mating shaft \( g_6 \) | Worm | \( \phi_{30}^{0.021} \) |
|       |                | Nut hole \( g_7 \) | Left nut | \( \phi_{30}^{0.018} \) |
|       |                | Mating shaft \( g_8 \) | Worm | \( \phi_{30}^{0.021} \) |
|       |                | Binding line \( g_9 \) | Right bearing | \( \phi_{65}^{0.018} \) |
|       |                | Joint surface \( g_{10} \) | Right bearing | \( \phi_{65}^{0.033} \) |
According to the information of each assembly item of the worm rotating assembly unit in Table 1, combined with the actual assembly accuracy (gap or interference) data of each assembly item of the multiple batches of assembly units measured by the actual survey, use formula (3) to solve the ith assembly of the worm rotating unit The actual gap or interference mean $\mu_i$ of the multi-sample corresponding elements in the item is shown in Table 2.

Table. 2 Average matching accuracy of each assembly item of the worm rotation unit

| $\mu_1$ | $\mu_2$ | $\mu_3$ | $\mu_4$ | $\mu_5$ | $\mu_6$ | $\mu_7$ | $\mu_8$ | $\mu_9$ |
|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| 0.038  | 0.112  | -0.012 | -0.014 | 0.025  | 0.110  | -0.015 | -0.011 | -0.013 |

According to the average assembly accuracy of each assembly item of the worm rotating unit in Table 2, combining the actual clearance or interference of the corresponding elements, use formula (4) to solve the standard deviation of the fitting accuracy of each assembly item as shown in Table 3.

Table. 3 Standard deviation of assembly accuracy of each assembly item of the worm rotating unit

| $\sigma_1$ | $\sigma_2$ | $\sigma_3$ | $\sigma_4$ | $\sigma_5$ | $\sigma_6$ | $\sigma_7$ | $\sigma_8$ | $\sigma_9$ |
|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| 0.004    | 0.007    | 0.004    | 0.003    | 0.005    | 0.006    | 0.004    | 0.004    | 0.005    |

According to the expert experience analysis of the corresponding assembly items in the survey data, the gap or interference value $a_1$ that begins to meet the higher performance requirements of the meta-action is determined. The gap or interference value $a_2$ that cannot meet the ideal performance requirements of the meta-action is higher, as shown in Table 4.

Table.4 The corresponding values for $a_1, a_2$ of the assembly items of the worm rotating unit

| $a_i$ | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| $a_1$ | 0.009 | 0.010 | -0.021 | -0.021 | 0.009 | 0.01 | -0.021 | -0.021 | -0.021 |
| $a_2$ | 0.041 | 0.122 | -0.004 | -0.004 | 0.041 | 0.122 | -0.004 | -0.004 | -0.004 |

The data in Table 1, Table 2, Table 3, and Table 4 are brought into formula (8) to obtain the fuzzy reliability of the assembly accuracy of each assembly item as shown in Table 5.

Table. 5 Fuzzy accuracy of assembly precision of each assembly item of worm rotating unit

| $R_i$ | $R_i$ | $R_i$ | $R_i$ | $R_i$ | $R_i$ | $R_i$ | $R_i$ | $R_i$ |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 0.8860 | 0.9327 | 0.9749 | 0.9942 | 0.9993 | 0.9810 | 0.9530 | 0.9648 | 0.9319 |
Bring the data in Table 5 into formula (5) to obtain the fuzzy reliability of the assembly accuracy of the worm rotating unit, as follows:

$$\tilde{R}_S = \prod_{i=1}^{n} \tilde{R}_i = 0.6728$$

The maximum likelihood estimation method of 0-1 distribution is now used to perform precision detection on the reliability data obtained from the examples.

Obtain the fault data information of each assembly item in the worm rotation element action unit in the past 5 years from the research unit (sample data of 300 assembly times). The failure occurrence of each assembly item is indicated by 1, and the failure occurrence is indicated by 0. Use formula (6) to calculate the reliability of the action unit of the worm rotation meta-action. The specific calculation data is shown in Table 6.

Tab. 6 Fault data sample information of each assembly item of the worm rotating unit in the past 5 years

| $X_{ij}$ | $i = 1$ | $i = 2$ | $i = 3$ | $i = 4$ | $i = 5$ | $i = 6$ | $i = 7$ | $i = 8$ | $i = 9$ |
|---------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| $j = 1$ | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      |
| $j = 2$ | 0      | 0      | 1      | 0      | 0      | 0      | 1      | 0      | 0      |
| $j = 3$ | 1      | 0      | 0      | 0      | 0      | 0      | 0      | 1      | 0      |

$R(X_i) = 0.6748$

The relative error of comparing the results of $\tilde{R}_S$ and $R(X_S)$ data is as follows:

$$\left| \frac{\tilde{R}_S - R(X)}{R(X)} \right| = 0.029$$

5. Conclusion and prospects

The fuzzy reliability model of assembly accuracy of the meta-action assembly unit is established, and the fuzzy phenomenon in the assembly process is integrated into the assembly accuracy reliability analysis. The membership function of the worm meta-action unit assembly item that meets the ideal performance requirements is determined.

The maximum likelihood estimation method was used to verify the accuracy of the proposed assembly reliability fuzzy reliability model (the relative error of the example verification was 0.0029), which provided theoretical support for the feasibility of the model.

Subsequent research on error transmission law can be conducted to further explore the mechanism of assembly error transmission.

6. postscript

| symbol | Symbolic meaning | Subscript and superscript meaning |
|--------|------------------|----------------------------------|
| $M_i$  | An assembly item composed of elements on a part in the assembly unit and the elements on the parts assembled with it | $i$ represents the $i$th assembly item in the meta-action assembly unit |
| $R_i$  | Assembly accuracy reliability of the $i$th assembly item | $i$ represents the $i$th assembly item in the meta-action assembly unit |
| $x_i$  | Assembly gap or interference of assembly item $M_i$ | $i$ represents the $i$th assembly item in the meta-action assembly unit |
| $x_{ij}$ | Assembly gap or interference of the $j$th sample of assembly item $M_i$ | $i$ represents the $i$th assembly item, $j$ represents the $j$th sample |
Failure status of the $j$th sample of assembly item $M_i$ (0 or 1)

Reliability of the entire assembly unit $R_i$

The $i$th assembly item assembly accuracy fuzzy reliability $\tilde{R}(A_i)$ represents the $i$th assembly item in the meta-action assembly unit

Membership function of fuzzy event $\tilde{A}_i$ for assembly accuracy of $i$th assembly item $\mu_{\tilde{A}_i}(x_i)$

Assembly reliability fuzzy reliability of the $i$th assembly item $\tilde{R}$ represents the $i$th assembly item in the meta-action assembly unit

The average value of multiple sample gaps or interferences of the $i$th assembly item $\mu_i$

The standard deviation of the gap or interference of the $i$th assembly item $\sigma_i$

Unreliability of assembly accuracy of $i$th assembly item $p$

7. Declaration of Conflicting Interests

The author(s) declare no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

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