Adaptive adjustment method of intelligent industrial product dimension accuracy

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Abstract: In order to overcome the problems of low precision and long time in the traditional method of adjusting the accuracy of external dimensions, this paper proposes an adaptive adjusting method for the accuracy of external dimensions of intelligent industrial products. The car model of industrial product dimension accuracy is constructed. After predicting and adjusting the parameters adaptively, the intelligent industrial product dimension error is detected, and the calculation process of dimension coefficient correction factor θ is determined. By describing the grinding process of industrial products, the residual vector in the adjustment process is determined to realise the adaptive adjustment of intelligent product dimension accuracy. The experimental results show that the adjustment time is only 1.5 s, and the relative error and absolute error are close to zero. The method in this paper can improve the accuracy and effect of dimension adjustment, and reduce the time consumption of industrial product dimension adjustment.

Keywords: CAR model; adjustment parameter; residual vector; correction factor.

Reference to this paper should be made as follows: Yang, K. (2022) 'Adaptive adjustment method of intelligent industrial product dimension accuracy', *Int. J. Product Development*, Vol. 26, Nos. 1/2/3/4, pp.25–38.

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1 Introduction

With the rapid development of science and technology, intelligent industrial product processing technology is widely used in modern industry. In particular, the aerospace industry, ordnance industry and other industries need more accurate workpieces. The dimensional error of each workpiece can have a serious impact on the spacecraft launch accuracy, trajectory, weapon range, target accuracy, etc., which is an important embodiment of the advanced productivity of each country (Naranjo et al., 2019; Dwivedi et al., 2020; Farzin et al., 2020). Therefore, it is of great significance to improve the overall dimension accuracy and reduce the relative error and absolute error of each workpiece to improve the product quality of the whole manufacturing industry. At present, both the workpiece measurement technology and the workpiece contour machining dimension need to be adjusted for accuracy (Macatangay et al., 2020; Avhad and Avhad, 2019). Relevant scholars have studied the adjustment method of dimension accuracy of industrial product contour processing, and made some progress.

In Zhi (2019), a method of adjusting the grinding dimension accuracy based on statistical learning is proposed. Through the active measurement method, the external dimension of industrial products is detected, and the grinding dimension prediction model is constructed. The statistical learning is used to optimise the grinding dimension accuracy and realise the grinding dimension accuracy adjustment. This method can effectively improve the dimensional accuracy of industrial products, but it takes a long time to adjust the dimensional accuracy of industrial products. In Liu (2020), a method of adjusting the dimension accuracy of industrial products based on machine vision is proposed. The image pre-processing technology is used to extract the dimension features of industrial products. The filtering method is used to eliminate the feature noise, and the local threshold segmentation method is used to segment the dimension features of industrial products. According to the Hough fitting algorithm, the optimisation of the dimension accuracy parameters of industrial products is realised, and the adjustment of the dimension accuracy of industrial products is realised. This method can effectively reduce the adjustment error of industrial product dimension accuracy, but the adjusted industrial product dimension accuracy is low. Kuang et al. (2019) propose a method for adjusting the accuracy of industrial product dimensions. By constructing the feature extraction model of product profiles, the defects of industrial product dimensions are obtained, and the dimension accuracy is adjusted according to the error compensation model of industrial product dimensions. This method can reduce the time of precision adjustment, but the dimension accuracy of adjusted industrial products is low.

In view of the problems existing in the above methods, a new adaptive adjustment method of intelligent industrial product dimension accuracy is proposed.

2 Intelligent industrial product dimension error detection

In order to achieve the effect of intelligent industrial product dimension error detection, firstly, the CAR model is constructed to obtain the random variable sequence of industrial product dimension, then the product dimension is predicted, and the adaptive adjustment parameters are adjusted to obtain the prediction error of product dimension processing; finally, the error detection of industrial product processing is realised by determining the dynamic parameters of grinding process.

2.1 Construction of mathematical model

In this paper, CAR model is used to realise the normal relationship between the actual dimension $d(t)$ and the required dimension $d(t)$ in the process of grinding

$$y(k) - \mathrm{a}_1 y(k-1) - \ldots - \mathrm{a}_n y(k-n) = b_1 u(k-1) + \ldots + b_n (k-m) + e(k) \tag{1}$$

$$A\left(q^{-1}\right) y(k) = B\left(q^{-1}\right) u(r) + e(k) \tag{2}$$

$$\begin{cases} A\left(q^{-1}\right) = 1 - a_1 q^{-1} - \cdots - a_n q^n \\ B\left(q^{-1}\right) = b_1 q^{-1} + b_2 q^{-2} + b_m q^{-m} \end{cases} \tag{3}$$

In the above formula, $A(q^{-1})$ is the prediction step timing of industrial product dimension setting, $B(q^{-1})$ is the actual step timing of industrial product dimension setting (Mahboubi et al., 2020), and the output $y(k)$ in car model is the sampling value of actual dimension $d(t)$ (Liu et al., 2019). The input $u(k)$ in car model represents the sampling value of required dimension $D(t)$ in car model. δ^2 represents the variance of car model, and $\{c(k)\}$ represents the sequence of independent normal distribution random variables of model residuals (Dey and Lee, 2019).

2.2 Prediction of adaptive adjustment parameters for industrial products

$y'(k+j/k)$ is used to represent the linear minimum variance prediction value of industrial product shape lead step for $y(k+j)$ by measuring value $y(k), y(k-1),\ldots,$ $u(h-1), u(h-2)\ldots$ and required dimension $u(k), u(k-1),\ldots, u(k+j-1)$ (Santos and Alves, 2019; Alves et al., 2019; Toca et al., 2020; Papazetis and Vosniakos, 2019). Then, the processing prediction error $\varepsilon(k+j)$ of industrial products is:

$$\varepsilon(k+j) = y(k+j) - y'(k+j/k) \tag{4}$$

Then, through the minimum variance prediction equation of product shape:

$$1 = E\left(q^{-1}\right)A\left(q^{-1}\right) + q^{-1}F\left(q^{-1}\right) \tag{5}$$

The minimum variance unique solution $E(q^{-1})$ of industrial products and the maximum variance unique solution $F(q^{-1})$ of industrial products are obtained by formula (5). According to formula (2) and formula (4), it can be concluded that:

$$y(k+j) = F\left(q^{-1}\right)y(k) + G\left(q^{-1}\right)u(k+j-1) + E\left(q^{-1}\right)e(k+j) \tag{6}$$

In formula (6), $G\left(q^{-1}\right) = E\left(q^{-1}\right)B\left(q^{-1}\right)$.

The index function of industrial product dimensions is obtained:

$$J = E\left\{\varepsilon^2(k+j)\right\} = E\left\{\left[y(k+j) - y'(k+j/k)\right]^2\right\} \tag{7}$$

Optimal prediction function for minimising the overall dimensions of industrial products (Kuo et al., 2021):

$$y'\left(k+\frac{j}{k}\right) = F\left(q^{-1}\right)y(k) + G\left(q^{-1}\right)u(k+j-1) \tag{8}$$

And the prediction error of industrial product dimensions:

$$\varepsilon(k+j) = E(q^{-1})e(k+j) \tag{9}$$

If the parameters of the model (2) are known, formulas (6) and (7) can be used to obtain the *j*-step-ahead prediction result of the shape of the industrial product.

2.3 Industrial product processing and grinding process inspection

The article expresses the industrial product processing and grinding process model by formula (l). At this time, the actual product shape and grinding process model is obtained by detection (Kui et al., 2019; Luo et al., 2019; Jiang et al., 2019; Yadeta et al., 2020). The least square structure is used to represent the grinding process model:

$$y(k) = \phi^r(k)\theta + e(k) \tag{10}$$

In formula (10):

$$\phi^1(k) = [-y(k-1), y(k-2), \ldots, y(k-n), u(k-1), .., u(k-m)] \tag{11}$$

$$\theta = [a_1, a_2, .., a_n, b_1, \ldots, b_m]^T \tag{12}$$

In the formula, θ represents the adjustment factor correction factor. Then, the process of analysing the processing and grinding of industrial products is:

First, obtain the estimated parameters a_i, b_j $(i = 1, 2, \ldots, n, j = 1, 2, \ldots, m)$ for the shape grinding of industrial products.

Second, calculate the structural parameters of the industrial product processing and grinding process model, that is, the order (n, m) value of the product processing and grinding process model, and the input delay b_j (that is, $b_1 = 0$, when $j < 1$).

Third, obtain the residual error $e(k)$ of the industrial product processing and grinding process model.

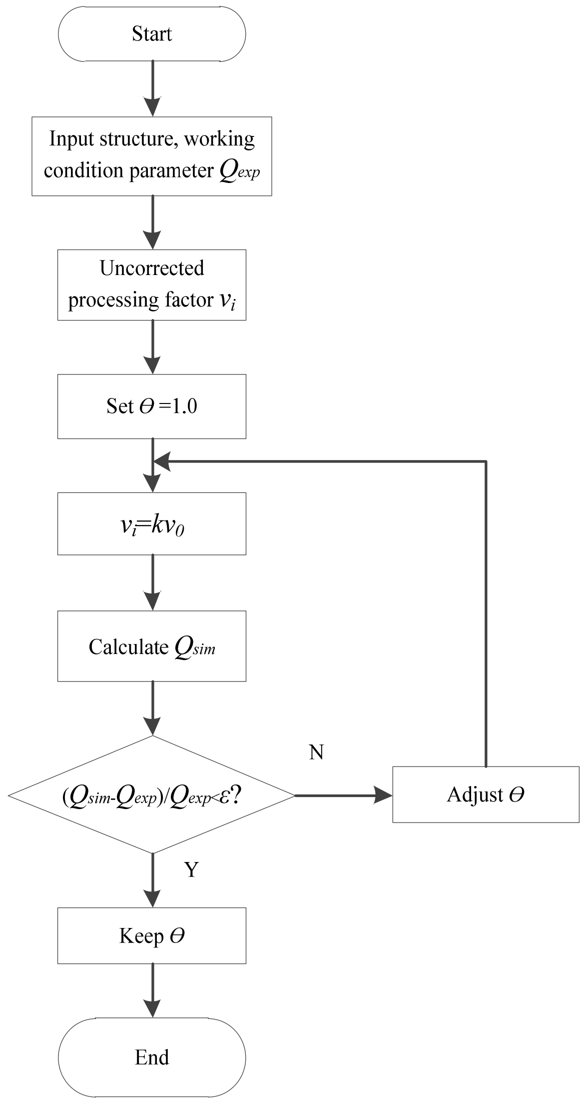
The first-order CAR model of the industrial product grinding process is:

$$y(k) = ay(k-1) + bu(k-1) + c(k) \tag{13}$$

According to the first-order CAR model, the industrial product processing and grinding process detection is realised. When the estimated parameters a and b of industrial product shape grinding are small, it can be called the dynamic parameter of industrial product shape size processing. According to the above process, the calculation process of the product shape adjustment coefficient correction factor θ is shown in Figure 1.

In Figure 1, ε represents the relative error of industrial product shape adjustment, Q_{exp} represents the actual energy consumption value of industrial product shape processing, and Q_{sim} represents the predicted energy consumption value of product processing. According to the above process, the product shape adjustment coefficient correction factor calculation is realised.

Figure 1 Calculation process of product shape adjustment coefficient correction factor θ



3 Self-adaptive adjustment method of industrial product outline dimension accuracy

There are two steps in the adaptive adjustment method of the shape and accuracy of intelligent industrial products. First, analyse the grinding process of the shape of industrial products to obtain the size and tolerance variation range of the industrial product after processing; second, determine the node displacement of the product shape error, Obtain the position deviation vector of the product shape, and determine the adjustment amount of the industrial product shape dimensional accuracy.

3.1 Analysis of grinding process of industrial product dimensions

In the CAR model, the target size $u(k)$ of the shape of the industrial product is added, and the accuracy change function of the shape of the product is obtained as:

$$u(k) = \begin{cases} y(0) - 2ks\, k \le k_1 \\ u(k_1) k_1 < k \le k_2 \end{cases} \tag{14}$$

In formula (14), $y(0)$ represents the sampling value of product workpiece size, s represents the sampling period of product workpiece processing, k_1 represents the start time of product grinding adjustment, and k_2 represents the completion time of industrial product adjustment. Use y_r and $y_r \pm \Delta$ to indicate the product grinding adjustment range, and j indicates the number of sampling steps for product shape adjustment.

3.2 Self-adaptive adjustment method of product dimension accuracy

On the basis of section 3.1, determine the node displacement of the k-th step of the product shape adjustment sampling, and construct a rectangular coordinate system O-xyz (see Figure 2) based on the ideal parabolic centre position. The z-axis method is the centre of the parabola. At this time, the ideal paraboloid equation of the product shape is:

$$x^2 + y^2 = 4fz \tag{15}$$

In order to obtain the target paraboloid after the adjustment of the dimensions of the industrial product, formula (15) is revised as:

$$x^2 + y^2 = 4f(z + h) \tag{16}$$

Among them, the offset of the parabola vertex along the z-axis is denoted by h, and the paraboloid of the shape of the industrial product obtained at this time is the best fitting parabola.

In order to obtain the adjustment amount of each node in the industrial product shape, the i ($i = 1, 2, \ldots, c$, where c is the number of nodes on the reflecting surface) node A on the reflecting surface of the product shape is set as $[x, y, z]^T$. During the shape adjustment of industrial products, the node mainly moves along the direction of target adjustment. The unit vector along this direction is recorded as $[p_x, p_y, p_z]^T$, and the intersection line is made from point A along the direction of adjustable cable to the best fit paraboloid, and the intersection line is at point C.

Let $AC = d$, then d is positive when node d is above the best fit paraboloid and negative when node A is below it, so that the coordinates of point C can be expressed as:

$$\begin{cases} x_0 = x + p_x d \\ y_0 = y + p_y d \\ z_0 = z + p_z d \end{cases} \tag{17}$$

Since point C is located on the best fit paraboloid, its coordinates satisfy the paraboloid equation (16):

$$\left(x+p_x d\right)^2+\left(y+p_y d\right)^2=4f\left(z+p_z d+h\right) \tag{18}$$

Because h and d are small quantities, we expand equation (17) and ignore the second order small quantity:

$$x^2+2xp_x d+2p_y d+y^2=4fz+4fp_z d+4fh \tag{19}$$

At this point:

$$d=-\frac{x^2+y^2-4fz}{2xp_x+2p_y-4fp_z}+\frac{4f}{2xp_x+2p_y-4fp_z}h \tag{20}$$

In this way, the deviation and direction of point A relative to the best fit paraboloid can be expressed in the form of vector:

$$d'=p\cdot d \tag{21}$$

It can be seen that the node deviation is only related to the node coordinates before adjustment and the correction h of the best fit paraboloid.

Let the number of nodes on the reflecting surface of industrial products be c, and these nodes should be located on the best fit paraboloid when adjusting. Note:

$$\Delta_c=\left[d_1^T,d_2^T,\ldots,d_c^T\right]^T \tag{22}$$

Where d_i is the position deviation vector of the i-th node. In this case, the corresponding root mean square error is:

$$\delta_c=\sqrt{\Delta_c^T\Delta_c/c} \tag{23}$$

The shape adjustment of industrial product shape reflecting surface is to minimise the root mean square error mentioned above, which can be obtained by minimising its square, even if the following formula takes the minimum value:

$$\delta_c^2=\frac{1}{c}\Delta_c^T\Delta_c=\frac{1}{c}\sum_{i=1}^{c}d_i^T d_i \tag{24}$$

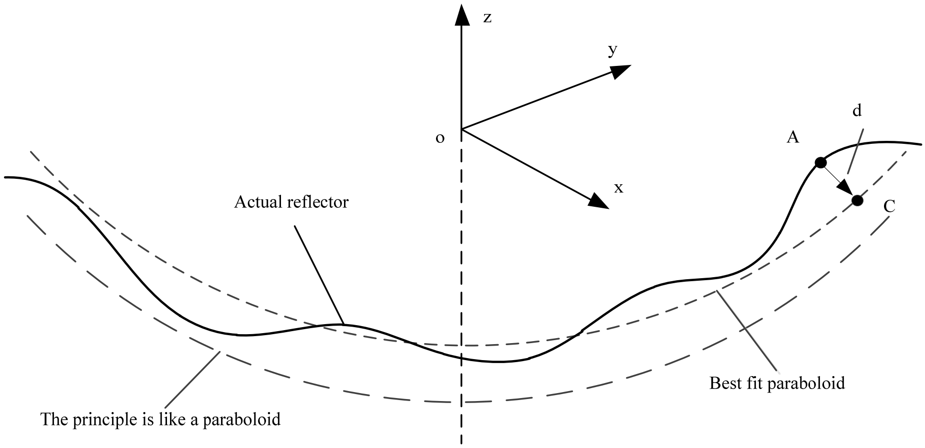
Since equation (24) contains only the variable h, the condition for taking the minimum value is as follows:

$$\frac{\partial\delta_c^2}{\partial h}=0 \tag{25}$$

From this, the paraboloid repair quantity h and the corresponding node displacement Δ_c can be obtained. The displacement Δ_c is the node displacement $\Delta X^{(k)}$ that needs to be generated during the adjustment.

According to this, the node displacement that needs to be adjusted for each node of the shape of the intelligent industrial product is obtained, and the adaptive adjustment of the product shape and size accuracy is realised.

Figure 2 The shape adjustment of industrial products best fits the paraboloid



4 Experiment

In order to verify the performance of the proposed adaptive adjustment method of intelligent industrial product dimension accuracy, comparative verification experiments are carried out. The experimental data comes from the product shape data of a large intelligent product processing enterprise, and the test sample size is 10 GB.

4.1 Experimental indicators

The proposed method is compared with Zhi (2019), Liu (2020) and Kuang et al. (2019). Based on the industrial product dimension adjustment accuracy, processing effect and adjustment time.

1 *The precision of the product after adjusting its dimensions*:

In order to obtain the accuracy of the adjustment of the dimensions of the industrial product, it is necessary to calculate the expected displacement $\Delta X^{(k)}$ of the reflection surface node of the industrial product. Because the physical reflection surface of the industrial product has a certain error in the model construction, the sensitivity matrix $\frac{\partial X}{\partial L_0}$ of the reflection surface of the industrial product and disturbance $\delta\frac{\partial X}{\partial L_0}$ to reflect surface of industrial product shape has the above relationship. At this time, the disturbance $\delta X^{(k)}$ caused by the measurement error of the external dimensions of the industrial product is equal to the accuracy after the adjustment of the external dimensions. Therefore, the accuracy calculation formula after the adjustment of the external dimensions of the intelligent industrial product is:

$$\frac{\partial X}{\partial L_0}\Delta L^{(k)} = \Delta X^{(k)} \tag{26}$$

The greater the accuracy after the adjustment of the outline size, the worse the adjustment effect, on the contrary, the smaller the accuracy after the adjustment of the outline size, the better the adjustment effect.

2 *Accuracy test results*:

The relative error value of industrial product dimension precision adjustment. The relative error of the machining accuracy of industrial product dimensions refers to the percentage of the difference between the machining accuracy and the actual requirements after adjusting the product dimensions, and the unit is%. The larger the relative error value is, the worse the adjustment effect of product dimension accuracy is. The smaller the relative error value is, the better the adjustment effect of product dimension accuracy is.

The absolute error value of product dimension machining accuracy. The absolute error of industrial product dimension precision processing refers to the difference between the actual requirements and adjusted by different methods. The absolute error values in this paper are all positive, and the unit is mm. The larger the absolute error is, the worse the adjustment effect is. On the contrary, the smaller the absolute error is, the better the adjustment effect is.

3 *Adjust time*:

The self-adaptability of this method is evaluated by the time taken to adjust the dimension accuracy of intelligent industrial products. The shorter the time taken to adjust the dimension accuracy of products, the stronger the self-adaptability is. The longer the time taken to adjust the dimension accuracy of products, the worse the self-adaptability is.

4.2 Accuracy of industrial products after adjustment

In order to verify the accuracy adjustment effect of industrial product dimension, the methods of Zhi (2019), Liu (2020), Kuang et al. (2019) and this paper are used to detect the change of intelligent industrial product dimension accuracy before and after adjustment, and the results are shown in Table 1.

Table 1 shows that for the 10 sets of test samples, different methods have different effects on the adjustment of the accuracy of the external dimensions of intelligent industrial products. In the first group of experiments, the accuracy of the intelligent industrial product before adjustment is 6.32 mm. After adjustment, the accuracy of the industrial product in Zhi (2019) method after adjustment is 3.85×10^{-8} mm, and Liu (2020) method industry The accuracy of the product size after adjustment is 5.66×10^{-7} mm, Kuang et al. (2019) method the accuracy of industrial product after adjustment is 6.68×10^{-8} mm, and the method of this article the accuracy of industrial product after adjustment is 8.43×10^{-10} mm. In the fifth group of experiments, the accuracy of the intelligent industrial product before adjustment was 5.76 mm. After adjustment, the accuracy of the industrial product in Zhi (2019) method after adjustment was 4.25×10^{-8} mm, and Liu (2020) method industry The accuracy of the product dimensions after adjustment is 3.98×10^{-8} mm, the accuracy of the industrial product after adjustment of Kuang et al. (2019) method is 4.22×10^{-8} mm, and the accuracy of the industrial product after adjustment of the method in this paper is 9.18×10^{-10} mm. The method in this paper has a higher accuracy after adjustment of the external dimensions of industrial products.

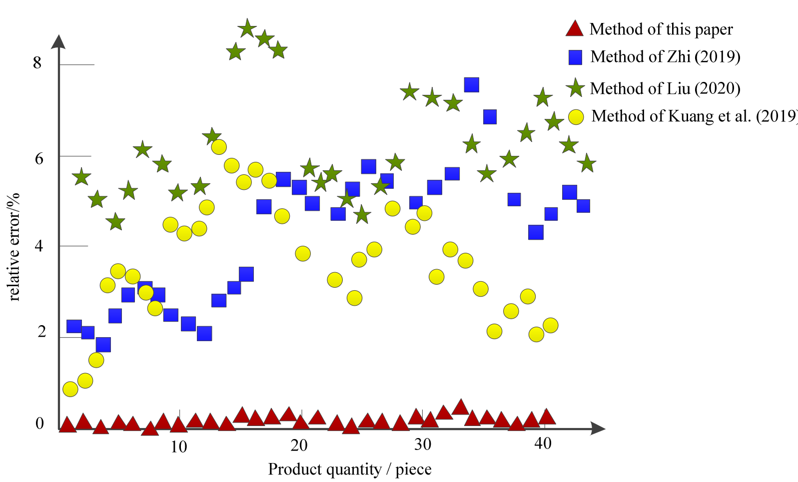
Table 1 Adjustment precision of industrial product dimension precision

Group number	*Accuracy before adjustment (mm)*	*The precision of industrial products after adjusting dimensions by different methods/(mm)*			
		Zhi (2019) method	*Liu (2020) method*	*Kuang et al. (2019) method*	*Method of this article*
1	6.32	3.85×10^{-8}	5.66×10^{-7}	6.68×10^{-8}	8.43×10^{-10}
2	6.26	4.32×10^{-8}	6.87×10^{-7}	6.22×10^{-8}	7.88×10^{-10}
3	5.98	3.67×10^{-8}	6.76×10^{-8}	5.65×10^{-8}	8.76×10^{-10}
4	6.21	3.89×10^{-7}	4.65×10^{-8}	7.12×10^{-8}	9.22×10^{-10}
5	5.76	4.25×10^{-8}	3.98×10^{-8}	4.22×10^{-8}	9.18×10^{-10}
6	6.56	5.12×10^{-8}	3.36×10^{-7}	3.89×10^{-8}	8.65×10^{-10}
7	6.33	3.98×10^{-7}	3.32×10^{-7}	4.32×10^{-7}	7.92×10^{-10}
8	5.98	3.67×10^{-8}	4.76×10^{-7}	5.76×10^{-7}	8.32×10^{-10}
9	6.18	5.76×10^{-8}	5.78×10^{-8}	4.86×10^{-7}	8.76×10^{-10}
10	6.86	5.88×10^{-7}	5.26×10^{-8}	3.88×10^{-7}	8.72×10^{-10}

4.3 Adjustment effect of industrial product dimension accuracy

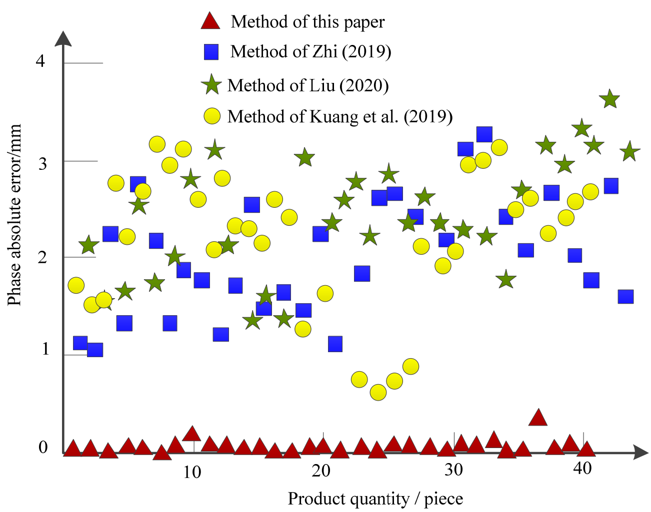
In order to be able to effectively verify the effect of adjusting the size accuracy of intelligent industrial products, the article uses 40 industrial products as experimental samples, and adjusts the product size accuracy according to the node displacement value of the industrial products, and calculates the relative and absolute errors of the dimensional accuracy processing. Through the two indicators of dimensional accuracy processing relative error and dimensional accuracy processing absolute error to verify, the adjustment effect of industrial product shape and size accuracy is shown in Figure 3 and Figure 4.

Figure 3 The relative error of industrial product dimension precision machining



Analysing Figure 3, it can be seen that different methods have different effects on the adjustment of the external dimension accuracy of intelligent industrial products. When the number of industrial products is 10, after the method of Zhi (2019) adjusts the size accuracy of intelligent industrial products, the relative processing error is 2.3%, and the method of Liu (2020) adjusts the size accuracy of intelligent industrial products. The relative error of processing is 5.5%. After the method of Kuang et al. (2019) adjusts the accuracy of the shape and size of intelligent industrial products, the relative error of processing is 4.3%. After the method of this article adjusts the shape and size of intelligent industrial products, the processing is relatively the error is almost zero, which can make the outline dimensions of industrial products conform to the best paraboloid, and effectively improve the processing accuracy of the outline dimensions of industrial products. From the analysis of the overall results, it can be seen that the method of Zhi (2019), the method of Liu (2020), and the method of Kuang et al. (2019) have much higher relative errors in the processing of industrial product outline dimensions than this method. The accuracy adjustment effect is better.

Figure 4 Absolute error of industrial product dimension precision machining



Analysing Figure 4, it can be seen that the absolute errors of industrial product outline dimensions processing under different methods are different. When the number of industrial products is 30 pieces, after the method of Zhi (2019) adjusts the accuracy of the shape and size of the intelligent industrial product, the absolute processing error is 2.4 mm, and the method of Liu (2020) adjusts the accuracy of the shape and size of the intelligent industrial product. The absolute processing error is 2.5 mm. After the method in Kuang et al. (2019) adjusts the precision of the shape and size of the intelligent industrial product, the absolute processing error is 2.1 mm. After the method in this article adjusts the shape and size of the intelligent industrial product, the absolute error is only 0.1 mm. When the number of industrial products is 40 pieces, after the method of Zhi (2019) adjusts the size of intelligent industrial products, the processing absolute error is 1.8 mm, and the method of Liu (2020) adjusts the size of intelligent industrial products. The processing absolute error is 3.4 mm, Kuang et al. (2019) method adjusts the shape and size of the intelligent industrial product, the processing absolute error is 2.6 mm, the method in this article adjusts the shape and size of the intelligent industrial product, the processing absolute error is almost zero.

Comprehensive analysis of Figures 3 and 4 shows that the adjustment effect of the method in this paper is obviously better than that of the method of Zhi (2019), Liu (2020), and Kuang et al. (2019). Because the three traditional methods do not calculate the adjustment of industrial product dimensions correction factor θ, and the method in this paper not only calculates the correction factor of industrial product shape size adjustment, but also constructs the CAR model of industrial product shape size accuracy. At the same time, it determines the residual vector during the adjustment process to realise intelligent product shape size accuracy adaptive adjustment. The method in this paper considers more comprehensively when adjusting the processing accuracy of industrial product dimensions.

4.4 Self adaptability verification of industrial product dimension precision adjustment

In order to verify the self-adaptability verification of industrial product dimension accuracy adjustment of this method, the methods of Zhi (2019), Liu (2020), Kuang et al. (2019) and this method are used to detect the time of intelligent industrial product dimension accuracy adjustment, and the results are shown in Table 2.

Table 2 Adjustment time of industrial product dimension precision

Product quantity/piece	*Adjustment time of industrial product dimensions under different methods/(s)*			
	Zhi (2019) method	*Liu (2020) method*	*Kuang et al. (2019) method*	*Method of this article*
100	8.2	13.5	23.9	0.1
200	12.3	14.6	20.8	0.02
300	16.9	12.1	22.0	0.5
400	21.3	19.7	25.7	0.8
500	18.9	20.5	22.7	1.2
600	27.5	22.8	17.6	1.5
700	22.6	23.7	18.9	0.9
800	17.6	31.8	16.2	0.8
900	15.8	32.0	15.2	1.5
1000	12.7	28.6	17.6	1.7

Analysing Table 2 shows that when the number of products is 300, the adjustment time of the industrial product dimensions of Zhi (2019) method is 16.9 s, the adjustment time of the industrial product dimensions of Liu (2020) method is 12.1 s, and the method of Kuang et al. (2019). It takes 22.0 s to adjust the dimensions of industrial products, and 0.5 s to adjust the dimensions of industrial products in this paper. When the number of products is 900, it takes 15.8 s to adjust the dimensions of industrial products in Zhi (2019) method, 32.0 s to adjust the dimensions of industrial products in Liu (2020), and the dimensions of industrial products in Kuang et al. (2019) method The adjustment time is 15.2 s, and the adjustment time of the industrial product's external dimensions in this paper is 1.5 s. The adjustment time of the industrial product dimensions of the method in this paper is much lower than that of the other three methods, which shows that the intelligent industrial products of the method in this paper are more adaptive in adjusting the dimensions of the intelligent industrial products.

5 Conclusion

The paper proposes an adaptive adjustment method for the shape accuracy of intelligent industrial products. By constructing the CAR model of the shape accuracy of industrial products; detecting the error of the shape of intelligent industrial products, determining the calculation process of the correction factor θ of the shape dimension coefficient; determining the adjustment process. The medium residual vector realises the self-adaptive adjustment of the size and accuracy of the intelligent product. In order to verify the effectiveness of the method in this paper, a comparative experiment on the accuracy, accuracy adjustment effect, and adjustment time of the design after size adjustment. The following conclusions are drawn through three experiments on the accuracy of the product shape after adjustment, the adjustment effect of the shape accuracy, and the verification of adjustment adaptability:

1 The industrial product of the method in this paper has a higher accuracy after adjustment of its external dimensions. In the fifth group of experiments, the accuracy of its industrial product after adjustment is 9.18×10^{-10} mm.

2 The method in this paper has a strong effect of adjusting the shape and size accuracy. After the method in this paper adjusts the shape and size of intelligent industrial products, the relative and absolute errors in processing are basically zero.

3 The method in this paper has high adaptability of the adjustment of the external dimension accuracy of intelligent industrial products. When the number of products is 900, the adjustment time of the industrial product external dimensions is only 1.5 s.

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