# A Mechanical Part Sorting Method Based on Fast Template Matching

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*Abstract*—**In this paper, a method of part sorting based on fast template matching is proposed. This method accelerates the process of part recognition by improving the template matching method. Thus, the efficiency of the part sorting system based on machine vision is improved, and the effect is outstanding in the case of a wide variety of parts. First, the image of target parts is preprocessed and segmented into multiple sub images containing only one part. Then, a shape feature vector and a similarity measure function are defined to match the target part sub images with the template part images. Finally, the target parts are located and the path of the sorting is planned. The result of simulation experiment in MATLAB shows that the method proposed in this paper not only has high accuracy and stability, but also meets the requirements of rapidity.**

***Keywords-mechanical part sorting; template matching; path planning; machine vision***

## I. INTRODUCTION

Automatic sorting technology and sorting robots are indispensable in automatic production [1]. If the sorting robots work by means of teaching or off-line programming, there is a strict requirement for the type of the target parts. Another disadvantage of this kind of system is that the change of the position and posture of the target parts will lead to the failure of part grabbing. When the sorting system is combined with machine vision, the above problems are avoided, and the production line is more flexible and easier to adapt to different types of parts. Compared to artificial sorting, this method is faster and there is no leakage due to fatigue [2].

At present, most of the automatic parts sorting system based on machine vision use image template matching to recognize target parts. In template matching, a search window with the same size as the template image is covered on the image to be matched. By moving the search window, we compare the similarity of the image in search window and the target image to find the best matching position. This process is shown in Fig. 1.

Gray value and shape feature are commonly used features in template matching. The Absolute Balance Search (ABS) method proposed in [3] is a template matching method based on the feature of gray value. This method evaluates the similarity between the target image and the template image by the difference of the pixel gray value. A huge amount of gray value data involved in the calculation leads to the slow operation of this method. And it is not invariant to image rotation. In [4], a method of template matching based on the Hausdorff distance is proposed. The Hausdorff distance value can evaluate the similarity between the target image contour and the template image contour, and thus the matching result is obtained. The method proposed in [5] reduces the number of pixels involved in matching calculation by hierarchical search method. It pre-selects the possible matching points to reduce search scope of the search window. But this method can still not avoid traversing a large number of unrelated pixels while template matching.

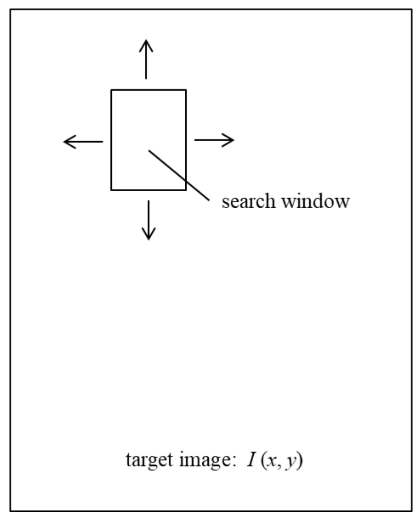


Figure 1. Image template matching.

In order to solve the problem above, a fast template matching method used in part sorting system is proposed in this paper. This method first segments the image of the target parts on the workbench into several sub images containing only one target part, and then it completes the template matching process through the shape features of the sub images. In this way, the image matching process is simplified and accelerated. The fast search algorithm is also used to further improve this method. In addition, after the target parts are recognized by template matching, this paper also expounds the method of parts positioning and sorting path planning. At the end of this paper, the simulation experiment of template matching process is conducted in MATLAB.

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## II. IMAGE PREPROCESSING AND FEATURE EXTRATION

### A. *Image Preprocessing*

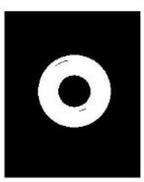
In this paper, the template matching process is based on the shape features of the target parts, so we need to get the binary image of the target to extract the features. Here, color image of targets and templates are first converted to gray images by weighted average method [6]. The relationship between the gray value of the gray image and the RGB value of the color image is shown as:

$$\text{Gray} = 0.3R + 0.59G + 0.11B \tag{1}$$

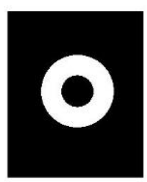
Then, a suitable threshold is selected through the gray histogram to further convert the gray image into a binary image [7]. In order to eliminate the small pores in the binary image and obtain a clear image edge, the morphological closing operation is used [8]. Color image, gray image, binary image and image after morphological closing operation are shown as (a), (b), (c) and (d) in Fig. 2.

(a)

(b)



(c)



(d)

Figure 2. Image preprocessing.

For the template matching method proposed in this paper, the preprocessing process not only includes image graying, image binarization and morphological operation, but also includes the segmentation of target image and the rotation operation of template images. Image segmentation is to obtain multiple sub images containing only one target part, and the rotation of template images is to get different states of the same template. These preparations will be used for the template matching process.

Image segmentation is based on the connected domain of the image. The binary image of the parts to be sorted has multiple connected domains, and each connected domain represents a target part. We make each connected domain a new sub image and numbered for them. The sequence of a sub image is determined by its position in the original image. For the binary image shown in Fig. 3, the pixels of the image are scanned by column. The sequence number of each connected domain is arranged in the order of scanning. We mark the sequence of sub images with arrows in Fig. 3. And the target parts image before and after the segmentation is shown respectively by (a) and (b) in Fig. 4. After image segmentation, matching process using search window to slide on target image can be transformed into matching process between sub images and template images, in other words, the template matching can be completed by comparing the features of the template image and the features of the sub image. In this way, a large number of unrelated pixels to participate in the operation are avoided.

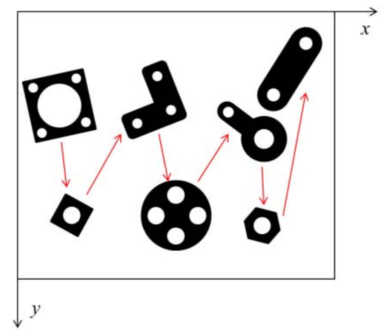
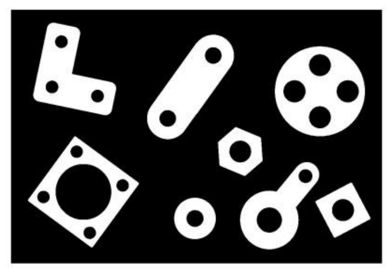
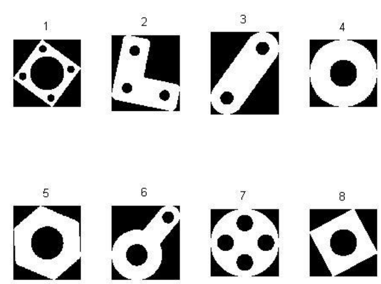



Figure 3. Sequence of image segmentation.



(a)




(b)

Figure 4. Image segmentation.

For the template images used in the matching process, when they are rotated, the calculation of the feature will produce errors. To make the extracted features of the template more accurate, we rotate the template image by clockwise to get templates of multiple states, the step length is 15 degrees, and the rotation angle is from 0 degrees to 345 Degrees, so that we get 24 different template images in different rotation angles. A set of template images obtained through the rotation operation are shown in Fig. 5. When calculating the feature values of a template image, all the 24 states of the template are involved in the operation. Their feature values are calculated respectively. Then, the average values of them are taken to eliminate the error. The feature values calculated according to the above method have excellent rotation invariance.

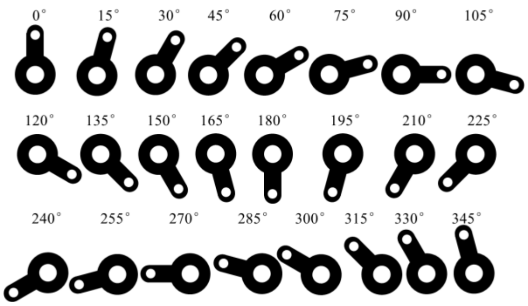


Figure 5. Template images with different rotation angles.

### *B. Feature Extraction*

After the preprocessing and segmentation of target image, the next step is to extract the feature values of the target sub images and the template images. It is also necessary to combine these feature values into one-dimensional vectors.

First, the features of the target sub images are extracted. In target sub image, the feature values needed to be calculated include the circumference of the target part outline, the projection area of the target part and the first three order Hu invariant moments of the target part shape. Hu invariant moment was proposed by Ming-Kuei Hu in 1962 [9]. The Hu invariant moment consists of 7 values, and it has invariance to the translation and rotation of the image. The area and circumference of a shape do not change with the translation and rotation of the image. So they can also be used to describe the feature of an image.

Because the value of the high order Hu invariant moments are very small and the calculation procedure is complex, so this paper only uses the first three order of the Hu invariant moments. Using M1, M2, and M3 respectively to represent the first three order of Hu invariant moments, and the formulas for calculating the first three order Hu invariant moments is as follows (The size of the image is m * n pixels):

$$\mu_{pq} = \sum_{x=1}^{m}\sum_{y=1}^{n}\left(x-\bar{x}\right)^{p}\left(y-\bar{y}\right)^{q} f\left(x,y\right) \quad (2)$$

$$p,q = 0,1,2...$$

$$M_1 = \eta_{20} + \eta_{02} \quad (3)$$

$$M_2 = \left(\eta_{20} - \eta_{02}\right)^2 + 4\eta_{11}^2 \quad (4)$$

$$M_3 = \left(\eta_{30} - 3\eta_{12}\right)^2 + \left(3\eta_{21} - \eta_{03}\right)^2 \quad (5)$$

In the above formula, f(x, y) denotes the value of pixel, x denotes the abscissa of pixels and y denotes the ordinate of pixels.

After calculating the first three Hu invariant moments of the target image, they are combined with the circumference and area into a one-dimensional feature vector. This vector used to describe the feature of the target part image is recorded as $\boldsymbol{C}_{img}$, and $\boldsymbol{C}_{img}$ = ( $L_{img}$, $S_{img}$, $Hu_{img1}$, $Hu_{img2}$, $Hu_{img3}$ ). $L_{img}$ is the circumference of the target part outline. $S_{img}$ is the projection area of the target part. And $Hu_{img1}$, $Hu_{img2}$, $Hu_{img3}$ represent the first three order Hu invariant moments of the shape of the target part, respectively. Store the feature value $\boldsymbol{C}_{img}$ of each sub image into the lookup table $Tab_{img}$. The sequence number of $\boldsymbol{C}_{img}$ stored in $Tab_{img}$ is the same as the sequence number of the sub image corresponding to the $\boldsymbol{C}_{img}$.

Then, the features of the template images are extracted. In the Ⅱ.A section, we have rotated the template images and obtained the templates at multiple rotation angles. In this section, we calculate the circumference, area and the first three order Hu invariant moments of these templates and take the average values. Similar to the feature extraction of the target part image, the feature values after the averaging are composed of a one-dimensional feature vector, which is recorded as $\boldsymbol{C}_{tmpl}$, and $\boldsymbol{C}_{tmpl}$ = ( $L_{tmpl}$, $S_{tmpl}$, $Hu_{tmpl1}$, $Hu_{tmpl2}$, $Hu_{tmpl3}$ ). $L_{tmpl}$ is the circumference of the template outline. $S_{tmpl}$ is the projection area of the template. And $Hu_{tmpl1}$, $Hu_{tmpl2}$, $Hu_{tmpl3}$ represent the first three Hu invariant moments of the templates, respectively. We define the sequence numbers for the feature values $\boldsymbol{C}_{tmpl}$ of all the template images and store them in the lookup table $Tab_{tmpl}$ in this order.

After the feature extraction of target part images and template images, we will further define the similarity measure function to evaluate the similarity between target and template, and based on this to implement template matching.

## III. TARGET PARTS RECOGNITION AND POSITIONING

### *A. Part Recognition*

*(1) Similarity measure function*

The template matching method proposed in this paper does not need to traverse the target image by search window. By calculating the similarity between the feature value $\boldsymbol{C}_{img}$ of the target image and the feature value $\boldsymbol{C}_{tmpl}$ of the template, all the targets can be matched and recognition. Next, we will define a similarity measure function to evaluate the similarity between $\boldsymbol{C}_{img}$ and $\boldsymbol{C}_{tmpl}$.

Referring to the method of calculating the Manhattan distance between the two vectors [10], and considering the great difference in the numeric value of the elements in the feature vector $\boldsymbol{C}_{img}$ and $\boldsymbol{C}_{tmpl}$, we first define the relative distance $d_{C_{img},C_{tmpl}}$ between two vectors $\boldsymbol{C}_{img}$ and $\boldsymbol{C}_{tmpl}$:

$$d_{C_{img},C_{tmpl}} = \sum_{k=1}^{5}\left|\frac{C_{img,k} - C_{tmpl,k}}{C_{tmpl,k}}\right| \quad (6)$$

In the above formula, $C_{tmpl,k}$ denotes the k-th elements in the feature vector $\boldsymbol{C}_{img}$, and $C_{tmpl,k}$ represents the k-th elements in the feature vector $\boldsymbol{C}_{tmpl}$. The value of $d_{C_{img},C_{tmpl}}$ reflects the proximity of the two feature vectors, that is, the similarity between the target image and the template image. The smaller the value of $d_{C_{img},C_{tmpl}}$, the more similar the two images are. Considering that the value of $d_{C_{img},C_{tmpl}}$ is within the interval [0, 1], we further define the following similarity measure function, and make the function value larger with the increase of similarity between two images:

$$f\left(C_{img}, C_{tmpl}\right) = \sum_{k=1}^{5}\left(1 - \left|\frac{C_{img,k} - C_{tmpl,k}}{C_{tmpl,k}}\right|\right) \quad (7)$$

Among them, $C_{img,k}$ denotes the k-th element in the image feature vector $\boldsymbol{C}_{img}$; $C_{tmpl,k}$ represents the k-th element in the template image feature vector $\boldsymbol{C}_{tmpl}$.

In the next target part recognition process, the defined similarity measure function, $f(\boldsymbol{C}_{img}, \boldsymbol{C}_{tmpl})$, will be used for template matching to recognize the type of target parts.

*(2) Template matching*

In the previous section, we have calculated the feature vector $\boldsymbol{C}_{img}$ of each target part image and store them into the lookup table $Tab_{img}$ in a certain order. We have also calculated the feature vector $\boldsymbol{C}_{tmpl}$ of each template image and stored them into the lookup table $Tab_{tmpl}$ in the defined order. A similarity measure function $f(\boldsymbol{C}_{img}, \boldsymbol{C}_{tmpl})$ for evaluating the similarity between $\boldsymbol{C}_{img}$ and $\boldsymbol{C}_{tmpl}$ is also defined. Using the data in $Tab_{img}$ and $Tab_{tmpl}$, the specific steps for template matching and recognition of the target parts through the function $f(\boldsymbol{C}_{img}, \boldsymbol{C}_{tmpl})$ are as follows:

Step1: Read a feature vector $\boldsymbol{C}_{img}$ of a target part image from the $Tab_{img}$ table.

Step2: Use the similarity measure function $f(\boldsymbol{C}_{img}, \boldsymbol{C}_{tmpl})$ to evaluate the similarity between $\boldsymbol{C}_{img}$ and the feature vectors $\boldsymbol{C}_{tmpl}$ of each template in the $Tab_{tmpl}$ table, and the calculated values of the function are recorded in one-dimensional vector $\boldsymbol{V}_{sim}$.

Step3: Determine if at least one element in $\boldsymbol{V}_{sim}$ is greater than the set threshold. If all the elements in $\boldsymbol{V}_{sim}$ are smaller than the threshold, the target is judged to be not a part in the template library. Otherwise the step 4 is executed.

Step4: Set the template with the maximum similarity with the current target part as the matching result.

Step5: Repeat the above process until all parts are recognized.

When the types of parts are less, the number of templates that need to be matched is less. In this case, for each target part, it is convenient and fast to compare with all the templates to get the matching result. However, when there are more types of parts, the number of templates that need to be compared is large and the above method becomes inefficient. Therefore, by using Binary Search, this paper makes an improvement on the matching method in the case of more number of templates.

First, all templates are sorted in descending order according to the $S_{tmpl}$ element in template feature vector $\boldsymbol{C}_{tmpl}$, that is, the projected area of template part, and the median $M_{tmpl}$ of all $S_{tmpl}$ elements are obtained.

In the template matching process, when calculating the similarity between the target feature vectors and the template feature vectors, we first compare the relationship between median $M_{tmpl}$ and $S_{img}$ of the current target parts. When the $S_{img}$ is greater than the median $M_{tmpl}$, the image is matched with the first half of templates arranged in descending order according to $S_{tmpl}$, otherwise, it is matched with the latter half of the templates.

## *B. Part Positioning*

In this paper, the part sorting system uses an electromagnetic sucker as the end-effecter. And the system works according to the following sorting strategy: Pick up the same type of parts in a certain order, place them in the specified position, and then pick up the next type of parts. Therefore, for a certain type of parts to pick up, it is necessary to plan a continuous path through all of these parts. In order to get this path, the target parts should be positioned first.

The position of the part also uses the binary image of the target parts. As shown in Fig. 6, the white area is the projection of the part on the workbench plane. The centroid position coordinates of each part are obtained by the following formula (The size of the image is m * n pixels):

$$M_{00} = \sum_{i=1}^{m}\sum_{j=1}^{n} v(i,j) \quad (8)$$

$$M_{10} = \sum_{i=1}^{m}\sum_{j=1}^{n} v(i,j) \quad (9)$$

$$M_{01} = \sum_{i=1}^{m}\sum_{j=1}^{n} v(i,j) \quad (10)$$

$$x_c = \frac{M_{10}}{M_{00}}, y_c = \frac{M_{01}}{M_{00}} \quad (11)$$

$M_{00}$—Zero order moment of image

$M_{10}$,$M_{01}$—First order moment of image

v(i, j) —The value of the pixel point of (i, j)

$x_c$—The abscissa of the centroid

$y_c$—The ordinate of the centroid

The centroid position of the target part is represented by * in Fig. 6. After positioning the target parts according to the centroid, the next step is to plan the sorting path of the target parts.

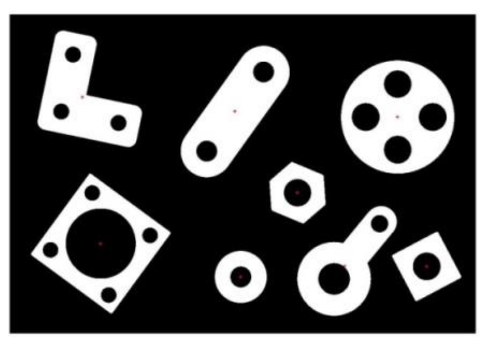


Figure 6. Part positioning.

## IV. PATH PLANING FOR PART SORTING

According to the sorting strategy mentioned above, it is known that, for the grip of the same type of parts, the end-effecter electromagnetic sucker needs to pass the top of target centroid in turn.

If the planned path is required to pass through these centroid positions without repetition and has the shortest length, the path planning process can be transformed into a solution to the Traveling Salesman Problem (TSP). In this paper, genetic algorithm (GA) is tried to be used to solve this problem [11]. We carry out a simulation experiment on the pickup path planning of 30 parts of the same type in MATLAB. The experimental results show that it takes an average of 120 seconds to iterate more than 500 times before the shortest path can be obtained. The total time of part sorting includes three parts: recognition and positioning of target parts, path planning and action execution. The time saved by the shortest path planned by the genetic algorithm for grabbing is negligible compared to the amount of time spent in the path planning. Therefore, we no longer plan the shortest sorting path. Instead, the target parts are grabbed in sequence according to the ordinal numbers defined in the target part image segmentation.

## V. SIMULATION EXPERIMENTS AND RESULTS

In view of the sorting method proposed in previous section, we conduct the following simulation experiments in MATLAB. The CPU of the simulation environment is Core i5-7600 dual core, its main frequency is 3.5GHz. The memory is 8GB, the memory frequency is 2400MHz. The operation system is Microsoft Win10 professional version (64 bits). MATLAB version is R2014a. Considering that the sorting method proposed in this paper is only different from the traditional method in target part recognition method, the experiment only simulates template matching process.

The experiment was divided into 20 groups. In the 1st to 20th groups, the number of template types is 1 to 20, respectively. In each group of experiments, there are 100 parts to be sorted on the workbench, and 3 of them are not the parts in the template library which need to be removed.

In each group, we use the matching method based on Hausdorff distance proposed in [3], method proposed in this paper and its improved method to conduct the simulation experiment of target part recognition. For example, when the number of part type is 8, the binary image of the target parts is shown as (a) in Fig. 7. The color tagging of template parts is shown in (b). The parts that need to be removed are shown in (c), and (d) is the result of template matching.

Change the target part image and the type of template parts, repeat the experiment 10 times, count the time consumed by the three methods respectively. Calculate the average time and accuracy of the program running, as shown in Tab. 1:

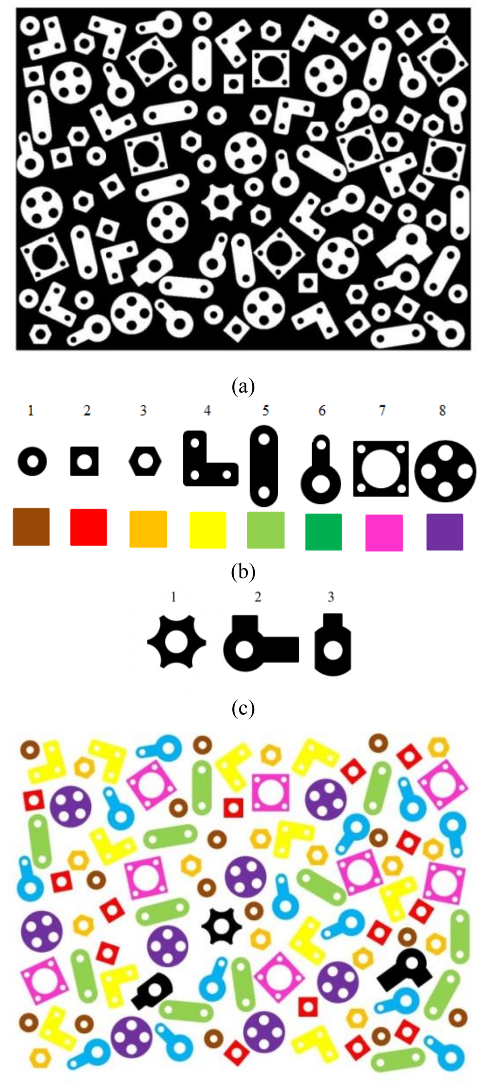


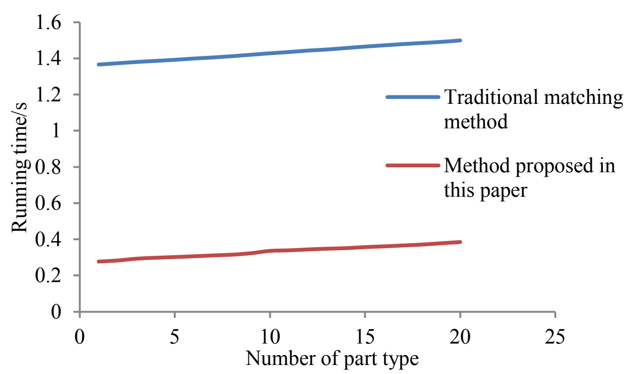

Figure 7. Target part image and template images.

TABLE I. EXPERIENCE RESULTS

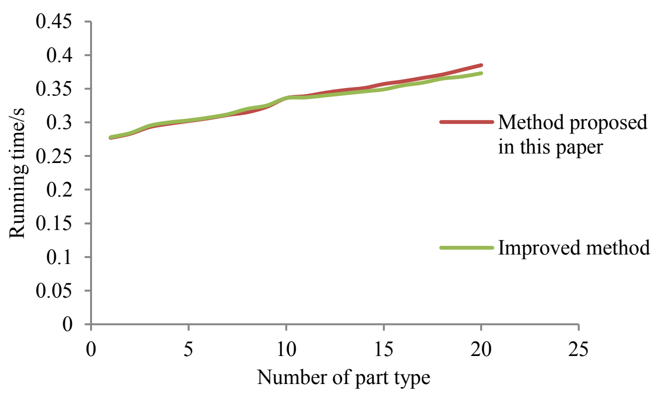
| Type | Traditional Matching Method | | Method Proposed in This Paper | | Improved Method | |
|---|---|---|---|---|---|---|
| | *Running time/s* | *Accuracy rate* | *Running time/s* | *Accuracy rate* | *Running time/s* | *Accuracy rate* |
| 1 | 1.366 | 100% | 0.277 | 100% | 0.278 | 100% |
| 2 | 1.373 | 100% | 0.283 | 100% | 0.284 | 100% |
| 3 | 1.380 | 100% | 0.293 | 100% | 0.295 | 100% |
| 4 | 1.386 | 100% | 0.298 | 100% | 0.300 | 99.6% |
| 5 | 1.392 | 100% | 0.302 | 99.8% | 0.303 | 99.8% |
| 6 | 1.399 | 99.9% | 0.306 | 99.6% | 0.307 | 100% |
| 7 | 1.405 | 100% | 0.311 | 100% | 0.312 | 100% |
| 8 | 1.412 | 100% | 0.315 | 99.6% | 0.320 | 98.6% |
| 9 | 1.420 | 100% | 0.323 | 98.9% | 0.325 | 98.9% |
| 10 | 1.428 | 99.7% | 0.336 | 98.8% | 0.336 | 98.3% |
| 11 | 1.435 | 98.6% | 0.339 | 98.8% | 0.337 | 98.3% |
| 12 | 1.443 | 99.2% | 0.344 | 96.1% | 0.340 | 97.5% |
| 13 | 1.449 | 99.5% | 0.348 | 97.9% | 0.343 | 97.5% |

| | | | | | | |
|---|---|---|---|---|---|---|
| 14 | 1.457 | 99.5% | 0.351 | 98.3% | 0.346 | 97.3% |
| 15 | 1.465 | 98.5% | 0.357 | 97.9% | 0.349 | 98.9% |
| 16 | 1.472 | 98.2% | 0.361 | 97.9% | 0.355 | 97.6% |
| 17 | 1.479 | 98.3% | 0.366 | 97.1% | 0.359 | 97.2% |
| 18 | 1.485 | 98.4% | 0.371 | 97.5% | 0.365 | 96.8% |
| 19 | 1.491 | 98.1% | 0.378 | 97.1% | 0.368 | 96.3% |
| 20 | 1.499 | 97.9% | 0.385 | 96.7% | 0.373 | 96.9% |

In order to compare the three methods more intuitively, the running time of them is drawn into a diagram. The number of templates is expressed in the abscissa and the running time is expressed in the ordinate, as shown in Fig. 8. It can be seen from the diagram that the matching method proposed in this paper is better than the traditional method based on Hausdorff distance in the matching efficiency. In addition, when the number of templates is greater than 10, the improved method is faster. Therefore, a suitable sorting recognition algorithm can be selected according to the number of templates to improve the operation speed.




(a) Traditional matching method and method proposed in this paper




(b) Method proposed in this paper and its improved method

Figure 8. Experience results.

## VI. Conclusion

In this paper, a method of part sorting based on fast template matching is proposed. First, a fast template matching method based on shape feature vector and similarity measure function is proposed. The use of this method to recognize the target parts avoids the shortcomings of the traditional search window matching methods that need to traverse a large number of unrelated pixels, so it can improve the matching speed. Then, Binary Search is also used to further improve the matching speed. When the number of template types is huge, the acceleration effect of the improved method is more obvious. After position the target parts by their centroids, the Genetic Algorithm is also tried to use to plan the sorting path, but the effect is not good. The simulation experiment shows that the sorting method proposed in this paper meets the requirements of accuracy and rapidity.

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