Template Matching of Round Features of Aluminum Alloy Castings Based on Hu Constant Moment

Jing Lin¹, Wenbin Zhang¹, Yongyue Liu², Wendi Zhou¹, Wenhong Dong³ and Xuechang Zhang³

¹School of Light Industry, Harbin University Of Commerce, Harbin 150000, P.R. China
²Ningbo Heli Mould Technology Shareholding Co., LTD
³School of Mechanical Engineering, Ningbo Tech University, Ningbo 315100, P.R. China
¹linlin681020@126.com
¹chen_bin99@126.com
²yongyue.liu@helimould.com
³21825212@zju.edu.cn
³21925137@zju.edu.cn
³xczhang@nit.zju.edu.cn

Abstract. Automobile structural parts, that is automobile frame, are used as load-bearing equipment with advanced mechanical properties so that it need to be strictly inspected. There are geometric characteristics, uneven distribution of positions, and large volume for automobile structural castings of aluminum alloy. Thus, it is necessary that the feature matching deals with the automobile structural casting by detection of visual image. However, the traditional visual image has exposed many essential problems, such as lower degree and lower field-of-view stitching accuracy. According to the above phenomenon, a template detection method is proposed based on Hu moment, combined with the target of round feature under the front sub-frame of a certain model of Zotye Automobile. The picture is converted into a binary image with the connected domain label. The feature values are obtained by the template image and the regional features is calculated. Secondly, the Euclidean distance is applied to judge the similarity before finishing the template matching. Finally, the matching accuracy can reach 100%, but also running time of the algorithm is less than 0.08s for the round holes of the front sub-frame under experimental data.

1. Introduction

With the increasing number of private cars, new energy vehicles, as a new problem in the automotive field, are solving environmental pollution problem. Automobile lightweight and automobile energy saving are the main research directions about new energy vehicles. Aluminum alloy material is one of the ways to solve the problem of automobile lightweight, which is widely used in automobile engine, chassis and other large parts. Automobile structural parts are used as load-bearing parts in automobiles, which are installed on the nodes of the body structure and connected with other members to form a high-
strength frame that resists deformation. What’s more, the feature of structural parts is very complicated, such as large size, complex structure and wall thin. Automobile structural parts which is advanced mechanical properties so that to ensure the reliability and safety of automobile during driving. So automotive aluminum alloy structural parts must be strictly detected for the quality and reliability [1-2]. Nowadays, the theme of enterprise production is automation and intelligence for manufacture, so the online inspection method is used for the quality inspection of automotive aluminum alloy castings.

Machine vision, as the current research hotspot, has been widely used in enterprise practice for quality inspection. However, there are many geometrical features on the surface of the casting, and the character of larger size for complex castings lead to the whole picture cannot be obtained at once when the camera collected pictures. Besides, the production environment, which is complex for large-scale and complex components, such as workshop dust, light intensity and high temperature, will affect the quality of the image. The visual inspection is hindered by these factors in large-size castings.

Now, there have some research on large-scale and complex components, and machine vision have been applied in the online inspection for large-scale and complex. In reference [4], a geometric model, the binocular vision measurement network, was proposed for a large propeller blade, which can solve the problem of high-temperature forging measurement by completing layout planning. In reference [5], a light plane calibration method was proposed by used binocular cameras. Furthermore, a modified space circle fitting method was proposed for the standard ball hand-eye calibration, the proposed measurement technique can accurately measure 3-D shape for large-scale objects. The overall size of the forgings can be obtained through the fusion of the data of the size information of each part for the large size forging in reference [6]. A fast measurement method based on feature line reconstruction of stereo vision was proposed in reference [7], which can be calculated directly based on the matched image lines and camera matrices, for hot manufacturing part. In Reference [8], a multi-camera calibration system was proposed for the measurement of large-size parts, which can be used for on-site calibration in industrial large-scale measurement. Reference [9] image processing technology was applied to detect the size of the bearing, but it is less effective for larger-sized parts. The large-scale workpiece was decomposed into multiple parts for acquisition and a coordinate conversion mathematical model was established so that the large-scale workpiece can be measured in Reference [10]. A length dimension measurement system for large hot forgings is designed in Reference [11]. The images, which is each moment in the process of green laser scanning forgings, are analyzed in this system, so that the forging can be measured according to the edge information of forgings. In reference [12], the size and the center distance between of each mounting hole for automobile was measured by edge detection and image stitching methods. In Reference [13], an image stitching technology, was proposed for the measure of the full size of large-sized workpieces. But this method was greatly affected by the lighting environment. From the research above that the dimensional inspection is mostly overall size inspection for large and complex castings. Therefore, the online quality inspection is significant for large-size complex castings.

The front sub-frame is one of the important parts of automobile, which is more important for vibration and noise reduction, and can bring better maneuverability and comfort [14]. It is important for the quality inspection of the front sub-frame. The front sub-frame of Zotye Automobile, which are 940mm × 510mm × 280mm for the external dimensions, that is used as detection object in this paper. The reason of template matching method is adopted is because there are many round hole features on the surface of the front sub-frame, and it is different for the distribution and the inside diameter of round hole features. As shown in Figure 1, it is the front sub-frame.
To find the best matching position by compare the similarity between two images in the target image is defined as template matching [15]. During template matching, the search window with the same size as the template image is moved in the target image to find the best matching position. This search process is shown in Figure 2.

![Figure 2. Search process.](image)

There are three main parts for template matching, which are the acquisition of image feature space, the determination of matching criteria and the selection of search strategies. The image features can be obtained through gray features and shape features two ways. The standard whether two images can be successfully matched is defined match criterion. The speed of template matching is closely concerned with search strategy, if the search strategy is better, the speed of template matching will be faster. Reference [16] presented a new closed contour template matching method which is suitable for two dimensional objects. Coarse-to-fine searching strategy is used to improve the matching efficiency and a partial computation elimination scheme is proposed to further speed up the searching process. In reference [17], a target tracking algorithm was proposed based on mean shift and template matching. At the template matching stage, combine with mean shift method, a fast template matching was used to complete the stable tracking of the target. Reference [18] proposed a novel adaptive radial ring code histograms (ARRCH) image descriptor for large-scale and rotation-invariant template matching. Reference [19] proposed a template matching method, which is combining grayscale features and gradient direction histogram features, can improve the running speed of the algorithm, and realize real-time tracking. Reference [20] proposed a template matching method based on improved Hu constant moment, combine with image pyramid, the speed of template matching was accelerated. Meanwhile, this method also has translation, rotation, and scale invariance. From the above research, the speed of template matching has improved compared with traditional template matching, but the template matching still not avoid traversing a large number of unrelated pixels.
In order to detect the circular features for large-size complex aluminum alloy castings, a template matching method is proposed based on Hu moment in this paper. The picture first is converted into a binary image by image preprocessing, and then the template matching is simplified and accelerated through the connected domain labeling method. Secondly, feature values are obtained by template image and regional features is calculated by Hu moment. Finally, similarity measure function is applied to judge the similarity between template image and target image before finishing the template matching. At the end of this paper, this method of template matching is verified by experiments.

2. Template matching process
The key is to extract the shape features for the template matching of Hu invariant moment. Therefore, in order to obtain the image feature value, the image must be preprocessed to get the contour features. And to judge the similarity before finishing the template matching [21]. The general process of template matching is given in Figure 3.

![Figure 3. Template matching process.](image)

2.1. Image preprocessing
The template matching process is based on the shape features of the target parts Hu constant moment, so the image needs to get the binary image of the target by image preprocessing. The purpose of image preprocessing is to obtain the edge information and contour features of the image, which can increase the reliability for Hu moment feature value and also can increase the accuracy for template matching [22]. First, the template image and the target image are first converted to gray images by weighted average method. The relationship between the gray value of the gray image and the RGB value of the color image is shown as:

$$Gray = 0.3R + 0.59G + 0.11B$$  \hspace{1cm} (1)

Then, to obtain a clear edge for the gray image by Gaussian filtering. So the gray image need to be smoothed by Gaussian filtering. It is different for the collected images about brightness because of the large size and uneven illumination for the front sub-frame. The complete binary image cannot be obtained if the threshold is selected through the gray histogram. So the gray image is converted into binary image by local adaptive threshold segmentation [23-24]. The process is as follows:

1. Set a threshold initial value $\theta$, the initial value should be between the maximum gray value and the minimum gray value;
2. Image pixels should be divided two types of pixel sets into A and B, and the average value should be calculated.
3. If the number of iterations is n, the value is updated to:

$$\theta_n = \frac{1}{2} (u_A + u_B)$$  \hspace{1cm} (2)

4. Repeat steps 3 and 4 until the difference in the iteration is smaller than the previously specified parameters.
After obtaining the binary image by the above method, the holes are eliminated in the image by morphological operation, and then the main features are obtained through delete some connected domains for the binary image. As shown in Figure 4, it is the image preprocessing process, where (a), (b), (c), (d) are the original image, grayscale image, binary image, and processed binary image.

![Figure 4. Image preprocessing.](image1)

2.2. Principles of template matching

2.2.1. Feature extraction.

After image processing, the next step is to extract the feature values of the template image and the target image.

For the image of $M \times N$. Its $(p + q)$ order moment is:

$$M_{pq} = \sum_{i=1}^{M} \sum_{j=1}^{N} i^p j^q f(i, j)(p, q = 0,1,2...)$$  \hspace{1cm} (3)

In order to ensure the invariance of the image, the center of distance is defined as:

$$u_{pq} = \sum_{i=1}^{M} \sum_{j=1}^{N} (i - \bar{i})^p (j - \bar{j})^q f(i, j)(p, q = 0,1,2...)$$  \hspace{1cm} (4)

For the above center distance, the constant moment of translation and rotation:

$$v_{pq} = \frac{u_{pq}}{\left(u_{00}^{p+q} + 1\right)}$$  \hspace{1cm} (5)

Using the above formula, the Hu constant of the image is:

$$\varphi_1 = v_{20} + v_{02}$$  \hspace{1cm} (6)

$$\varphi_2 = (v_{20} - \bar{v}_{02})^2 + 4v_{11}^2$$  \hspace{1cm} (7)
After calculating the seven Hu invariant moments of the template image, there are formed a one-dimensional vector. This vector used to describe the feature of the template image is recorded as $C_{\text{tmpl}}$, and $C_{\text{tmpl}} = (h_{\text{tmpl}1}, h_{\text{tmpl}2}, h_{\text{tmpl}3}, h_{\text{tmpl}4}, h_{\text{tmpl}5}, h_{\text{tmpl}6}, h_{\text{tmpl}7})$. And $h_{\text{tmpl}1}, h_{\text{tmpl}2}, h_{\text{tmpl}3}, h_{\text{tmpl}4}, h_{\text{tmpl}5}, h_{\text{tmpl}6}, h_{\text{tmpl}7}$ are represent the seven order Hu invariant moments of the shape of the template image, respectively. Then, the features of the target images are extracted. Similar to the feature extraction of the template image, the feature values are composed of a one-dimensional feature vector, which is recorded as $C_{\text{img}}$, and $C_{\text{img}} = (h_{\text{img}1}, h_{\text{img}2}, h_{\text{img}3}, h_{\text{img}4}, h_{\text{img}5}, h_{\text{img}6}, h_{\text{img}7})$. And $h_{\text{img}1}, h_{\text{img}2}, h_{\text{img}3}, h_{\text{img}4}, h_{\text{img}5}, h_{\text{img}6}, h_{\text{img}7}$ are represent the seven order Hu invariant moments of the shape of the target image, respectively. Store the feature value $C_{\text{img}}$ of each region into the lookup table $T_{\text{img}}$. The sequence number of $C_{\text{img}}$ stored in $T_{\text{img}}$ is the same as the sequence number of the region corresponding to the $C_{\text{img}}$. The value, which is calculated by Hu invariant moment, is shown in Figure 5 for some circular holes in the target image. And $h_1, h_2, h_3, h_4, h_5, h_6, h_7$ are represent the seven order Hu invariant moments of some circular holes.

After calculating the seven Hu invariant moments of the template image, there are formed a one-dimensional vector. This vector used to describe the feature of the template image is recorded as $C_{\text{tmpl}}$, and $C_{\text{tmpl}} = (h_{\text{tmpl}1}, h_{\text{tmpl}2}, h_{\text{tmpl}3}, h_{\text{tmpl}4}, h_{\text{tmpl}5}, h_{\text{tmpl}6}, h_{\text{tmpl}7})$. And $h_{\text{tmpl}1}, h_{\text{tmpl}2}, h_{\text{tmpl}3}, h_{\text{tmpl}4}, h_{\text{tmpl}5}, h_{\text{tmpl}6}, h_{\text{tmpl}7}$ are represent the seven order Hu invariant moments of the shape of the template image, respectively. Then, the features of the target images are extracted. Similar to the feature extraction of the template image, the feature values are composed of a one-dimensional feature vector, which is recorded as $C_{\text{img}}$, and $C_{\text{img}} = (h_{\text{img}1}, h_{\text{img}2}, h_{\text{img}3}, h_{\text{img}4}, h_{\text{img}5}, h_{\text{img}6}, h_{\text{img}7})$. And $h_{\text{img}1}, h_{\text{img}2}, h_{\text{img}3}, h_{\text{img}4}, h_{\text{img}5}, h_{\text{img}6}, h_{\text{img}7}$ are represent the seven order Hu invariant moments of the shape of the target image, respectively. Store the feature value $C_{\text{img}}$ of each region into the lookup table $T_{\text{img}}$. The sequence number of $C_{\text{img}}$ stored in $T_{\text{img}}$ is the same as the sequence number of the region corresponding to the $C_{\text{img}}$. The value, which is calculated by Hu invariant moment, is shown in Figure 5 for some circular holes in the target image. And $h_1, h_2, h_3, h_4, h_5, h_6, h_7$ are represent the seven order Hu invariant moments of some circular holes.

2.2.2. Similarity measure function
The template matching method proposed in this paper does need to calculate a lot of pixels. By calculating the similarity between the feature value of the template image and the feature value of the target image, all the round hole can be matched and recognition. Therefore, we must first define a
similarity measurement function to evaluate the similarity between them. We choose the traditional Euclidean distance as the similarity calculation method.

\[ d_{V_{\text{img}},V_{\text{tmpl}}} = \sum_{k}^{7} \sqrt{(V_{\text{img},k} - V_{\text{tmpl}})^2} \]  

(13)

In the formula, \( d_{V_{\text{img}},V_{\text{tmpl}}} \) represents the matching degree, \( V_{\text{img},k} \) is the feature vector of the image to be detected, \( k \) represents the Hu moment feature vector of the \( k \)th connected domain; \( V_{\text{tmpl}} \) is the feature vector of the template image. When the value of \( d_{V_{\text{img}},V_{\text{tmpl}}} \) is smaller, it means that the two images are more similar. At the same time, \( d_{V_{\text{img}},V_{\text{tmpl}}} \) will also be used in the later template matching process for target recognition and matching.

2.2.3. Template matching steps

The similarity measurement function is a criterion for evaluating whether the template image and target image are similar, and is related to whether the target image can be matched and recognized [25]. The feature vector \( C_{\text{tmpl}} \) and feature vector \( C_{\text{img}} \) have been calculated for the images and store them into the lookup table \( T_{\text{img}} \) in a certain order. A similarity measure function \( d_{V_{\text{img}},V_{\text{tmpl}}} \) is also defined for evaluating the similarity between \( C_{\text{img}} \) and \( C_{\text{tmpl}} \). The template matching steps for template matching and recognition of the target parts through function \( d_{V_{\text{img}},V_{\text{tmpl}}} \) are as follows:

1. First, to calculating the feature value by Hu constant moment for each feature in the template image and the target image.
2. Use the similarity measure function to evaluate the similarity between \( C_{\text{tmpl}} \) and \( C_{\text{img}} \). And the values of the function are recorded in one-dimensional vector \( V_{\text{sim}} \)
3. Set a threshold. If the calculated similarity value is greater than this threshold, it means that the template cannot match the image to be detected.
4. All similar values less than this threshold are considered as round features, and finally the matching result is displayed on the image.

3. Experimental simulation

A template matching method is proposed based on Hu invariant moments, with the target of round feature under the front sub-frame of a certain model of Zotye Automobile. The picture cannot be captured through camera for the front sub-frame that is large and complex. So the parts with more round holes should be first extracted in the sub-frame. In view of the matching method, the experiment is run. The following is the process of template matching for the parts with more round holes in the sub-frame. Figure 8 shows the matching results, where (a) is the template image, and (b), (c), (d) are the front sub matching results of different parts of the frame.
Figure 6. Template matching results.

The template matching experiment was divided into 10 groups for different parts, and calculated the average time and accuracy. Calculate the average time and accuracy of the program running, as shown in Table 1. Finally, the matching accuracy can reach 100%, but also the running time is less than 0.08s.

Table 1. Multiple matching results.

| Figure | Average time of 10 runs /s | Accuracy |
|--------|---------------------------|----------|
| Figure b | 0.080 | 100% |
| Figure c | 0.072 | 100% |
| Figure d | 0.077 | 100% |

4. Conclusion

A template matching method is proposed based on Hu invariant moment so that to ensure the size of the round hole in the sub-frame. The binarized image is obtained by image preprocessing and the values are calculated by Hu constant moment for target image and template image. And the similarity measure function is applied to judge the similarity between template image and target image before finishing the template matching. And connected domain labeling method, which can avoid traversing a large number of unrelated pixels, is used to improve the matching speed. According to the experiment, the round hole can be matched in the front frame and the average running time is less than 0.08s. This method can meet the requirements of accuracy and rapidity.

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