An improved measurement method of size of mechanical parts based on monocular vision

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Abstract: During the monocular measurement of multiple mechanical parts with non-negligible thickness at the same time, the physical dimensions of the pixels on the upper and lower surface edges of the mechanical parts in the image taken by the camera are different, resulting in the deviation of the actual measurement results of the mechanical parts. In this paper, a measurement method based on unit pixel size compensation is proposed. This method compensates the measurement data by the distance between the upper and lower surfaces of the mechanical parts and the camera, thus reducing or even eliminating the measurement error caused by the thickness of mechanical parts. The simulation results show that, under the same measuring platform, for the mechanical parts of different sizes and thicknesses, this method can achieve a significant improvement in measurement accuracy.

1. Introduction

In mechanical parts manufacture, along with the increase of production, the use time of mechanical parts machine and the vibration of the uncontrollable factors, will lead to produce the mechanical parts size does not require even with defects. In order to improve the degree of automation of production and improve production efficiency, it is necessary to automatically detect the unqualified parts. The measurement technology based on machine vision can accurately measure the size of the work piece and other information, and can quickly detect the unqualified size of the mechanical parts, which is widely used in the intelligent manufacturing industry [1][2].

At present, many scholars have studied this aspect. Yoon et al. used microscopic imaging technology to measure the small hole with a diameter of 0.03mm, with an absolute accuracy of 0.5um [3]. Rosta et al. designed an online measurement system with an average measurement of 3.4072mm and standard deviation of 0.0169mm to measure the tiny accessories on glasses [4]. Park et al., in order to measure the thickness of 6.36 mm glass, designed a kind of measure by using laser vision measurement system, the absolute error at about 0.005 mm [5][6]. In order to measure the external diameter of spur gear, Elmwala designed a visual measurement system, which can measure the absolute error of 156mm diameter gear under 0.101mm [6]. Chen fang et al. designed a monocular vision measurement system, which proposed an adaptive gray threshold edge extraction algorithm and could eliminate image rotation deviation, and the relative error was less than 0.005 when measuring 1000mm mechanical parts [7]. In order to measure the size of ceramic tiles, Lu Qinghua et al. designed an optical measurement system, which used a measurement algorithm based on boundary search fitting and dynamic compensation. When measuring ceramic tiles with a size of 600mm×600mm and 800mm×800mm, the size deviation was less than 0.02mm [8]. Ouyang zhixi et al. proposed an edge detection algorithm with an absolute error of less than 0.1mm, which is used to measure mechanical parts with a size less than 100mm. The principle is to combine threshold segmentation with edge...
Most cameras of measurement system based on machine vision use telecentric lens to image the measured object, while industrial-grade telecentric lens is relatively expensive. In addition, it is often required that the geometric center of the mechanical parts to be measured is on the optical axis of the camera in the measurement process, which leads to the single measurement of one mechanical parts and limits the detection efficiency of the mechanical parts. If more than one mechanical parts is measured in one picture at the same time, the thickness of the mechanical parts will affect the measurement result and reduce the accuracy of measurement because it is not guaranteed that each mechanical parts is aligned with the optical center of the camera. Therefore, this paper proposes a compensation method based on the actual size change represented by pixels, which can reduce the measurement error caused by the thickness of the mechanical parts.

2. Image preprocessing

Image preprocessing can eliminate the irrelevant information in the image to be tested and the noise mixed in the transmission process, so as to improve the detectability of the image to be tested and simplify the data to be processed. Image preprocessing can also improve the reliability of image feature extraction and recognition and speed and precision of machine vision measurement [10].

2.1. Image filtering

Due to the insufficient sensitivity of components in the photovoltaic conversion process of the imaging system, various kinds of noise pollution are often introduced in the imaging and transmission. These noises are often expressed as isolated pixels or blocks in the image, which will affect the subsequent processing. Usually, the noise signal has nothing to do with the object to be studied. For digital image signal, noise is the maximum or minimum value. When these poles are preprocessed, they will affect the real gray value of the image, cause light and dark spot interference, and affect the quality of the image and the subsequent image feature extraction, image recognition and other work. Therefore, the main research content of image filtering is to remove the noise while keeping the original details of the image as much as possible [11]. The common image filtering methods include median filtering, mean filtering and Gaussian filtering:

(1) Mean filtering method: mean filtering is a classical image filtering method, which is a linear processing method. The average neighborhood method is adopted for image processing. The gray value of the original image is \( f(x,y) \), and the size of the domain template is set as 3×3, then the image processed by mean filtering is:

\[
g(x,y) = \frac{1}{3 \times 3} \sum_{i=-1}^{1} \sum_{j=-1}^{1} f(x+i, y+j)
\] (1)

(2) Median filtering method: median filtering method is also a kind of classic image filtering method, its application is a nonlinear filtering method is used. The principle is to sort the gray value of each pixel in the neighborhood of pixel point \((x,y)\), and take the middle value after sorting as the gray value after filtering the pixel point. That is, set the gray value of the original image as \( f(x,y) \) and the size of the filtering window as \( S \), and then the image after the median filtering:

\[
g(x,y) = Med\{ f(x+s, y+t), (s,t) \in S(x,y) \}
\] (2)

(3) Gaussian filtering: the specific operation of Gaussian filtering is: a template is used to scan every pixel in the image, and the weighted average gray value of the pixel in the neighborhood determined by the template is used to replace the value of the pixel in the center of the template.

If use the 3 x 3 template, the images taken by the Gaussian filter:

\[
g(x,y) = \{ f(x-1, y-1) + f(x-1, y+1) + f(x+1, y-1) + f(x+1, y+1) + \}
\[
\left[ f(x-1, y) + f(x, y-1) + f(x+1, y) + f(x, y+1) \right] \times 2 + f(x, y) \times 4 / 16
\] (3)
2.2. Edge detection

When the measurement system based on machine vision collects the image of the test mechanical parts, it is necessary to detect the edge of the test mechanical parts and remove other image information in the view[12]. Edge detection algorithms mainly include Roberts operator, Sobel operator, Prewitt operator and Candy operator. Through these edge detection operators to find the edge of the image, the essence is to use the derivative principle to segment the image[13].

The formula for the Roberts operator is:

\[ R(x, y) = \left( f(x, y) - f(x+1, y+1) \right)^2 + \left( f(x+1, y) - f(x+1, y) \right)^2 \]

Roberts operator has the advantage of diagonally. When we focus on extracting the edges of the diagonal direction of the image, the extraction effect is more obvious. The gray difference of the four adjacent areas of the center pixel calculated by Prewitt operator is expressed as:

\[ G_x = [f(x-1, y-1) + f(x-1, y) + f(x-1, y+1)] - [f(x+1, y-1) + f(x+1, y) + f(x+1, y+1)] \]

\[ G_y = [f(x-1, y+1) + f(x, y+1) + f(x+1, y+1)] - [f(x-1, y-1) + f(x, y-1) + f(x+1, y-1)] \]

Compared with Prewitt operator, Sobel operator increases the weight of gray difference of four neighborhoods:

\[ G_x = [f(x-1, y-1) + 2f(x-1, y) + f(x-1, y+1)] - [f(x+1, y-1) + 2f(x+1, y) + f(x+1, y+1)] \]

\[ G_y = [f(x-1, y+1) + 2f(x, y+1) + f(x+1, y+1)] - [f(x-1, y-1) + 2f(x, y-1) + f(x+1, y-1)] \]

Prewitt operator and Sobel operator can extract vertical and horizontal edges well, but compared with Roberts operator, the edge extraction ability along the diagonal direction is weak, but the filtering template can be modified to improve the edge extraction ability along the diagonal direction.

Compared with the above three edge detection operators, Candy operator has the best edge detection effect, which is reflected in better noise resistance, more accurate edge detection and positioning. The implementation process is as follows:

1. Extract the maximum point of gradient value: after the direction of the edge is obtained, traverse the entire image, and compare the gray value of each pixel on the image in the direction of gradient with the neighboring two pixels. If the maximum value is not the maximum value, set it to 0, and if the maximum value is the maximum value, keep it.

2. Threshold detection: set the high and low thresholds as candy_high and candy_low, respectively. If the grayscale value of any point in the image is \( f(x, y) < \text{candy\_high} \), then this point is an edge point; if \( f(x, y) < \text{candy\_low} \), then this point is set as 0; if in between, whether the neighborhood pixel of this point exists \( f(x', y') < \text{candy\_high} \) is detected; if it exists, then this point is an edge point; if not, then it is set as 0.

3. The measurement method of mechanical parts should not be ignored for thickness

Plane of actual measurement, if the test mechanical parts thickness can be ignored, and can approximate think mechanical parts surface on the edge and bottom edge of the overlap in the images, can be directly calculated at this time we needed a size, if the actual measurement of the thickness of the mechanical parts can not be ignored, and because of the influence of measurement environment, lead to collect images of the mechanical parts contains a mechanical parts profile, mechanical parts thickness will cause a lot of measurement error. As is shown in:
Figure 1 Measurement of 20mm×35mm standard mechanical parts

Figure 2. Principle of error caused by mechanical parts thickness

Cause the measuring error is mainly composed of two aspects, as shown in figure 2, \( P_{w_1}, P_{w_3} \) are the mechanical parts under the surface of the edge points, the points of the corresponding in the camera image plane theory for \( P_{c_1}, P_{c_3} \), but in actual measurement, on the one hand, on the surface of the mechanical parts on the edge point \( P_{w_2} \) will edge point \( P_{w_3} \) on the surface of the block, causes in the imaging plane, can't get real \( P_{c_1}P_{c_3} \) pixel size of mechanical parts, on the other hand, \( P_{w_1} \) and \( P_{w_2} \), respectively, located at the top and bottom surface of the mechanical parts, the unit pixels to represent the actual physical size is different, so measurement error will be generated when the measured pixel size \( P_{c_1}P_{c_2} \) is used to calculate the actual plane size \( P_{c_1}P_{c_2} \) of the mechanical parts, especially when the mechanical parts is thicker, the measurement error will be larger.

According to the linear imaging model of the camera, the actual physical size \( f(x) \) represented by unit pixel has a linear relationship with the distance \( x \) from the object to the camera. So we can set the linear equation to be:

\[
f(x) = px + w \quad (9)
\]

Set the pixel length of the mechanical parts after imaging as \( l \), then the mechanical parts length \( L \) can be obtained:

\[
L = lf(x) \quad (10)
\]

As shown in figure 2, by calibrating the measuring environment, it can be known that the distance between the mechanical parts' bottom surface and the lens is \( h_1 \), and the actual physical size represented by unit pixel is \( f(x_1) \). The distance between the top surface of the mechanical parts and the camera is \( h_2 \), and the actual physical size represented by unit pixel is \( f(x_2) \). Substitute it into the equation to calculate the values of \( p \) and \( w \).

Then, after the compensation of unit pixel size, the actual size \( L' \) of \( P_{w_1}P_{w_2} \) should be expressed
as:

\[ L = l \int_{h_2}^{h_1} f(x)dh = l\left(\frac{P}{2}(h_1^2 - h_2^2) + w(h_1 - h_2)\right) \]  \hspace{1cm} (11)

After eliminating the difference in unit pixel size of the upper and lower surfaces of the mechanical parts, the actual size of the mechanical parts surface can be calculated and set as \( L_0 \):

\[ L_0 = \sqrt{L^2 - (h_1 - h_2)^2} \]  \hspace{1cm} (12)

4. Simulation experiment and analysis

4.1. Mechanical parts image filtering analysis
In this paper, median filtering, mean filtering and Gaussian filtering are adopted to filter Gaussian noise and salt-pepper noise respectively, and the effect is shown in figure 3. As can be seen from the figure, mean filtering will blur the image edges, which will have an adverse impact on the back edge extraction. The filtering effect of median filtering and Gaussian filtering is more suitable for the measurement environment of this paper. Considering the higher efficiency of median filtering, this paper adopts median filtering to remove noise.

![FIG. 3 Comparison of filtering effect](image)

4.2. Edge extraction analysis
After median filtering, Roberts operator, Sobel operator, Prewitt operator, LOG operator and Candy operator are adopted in this paper to conduct edge detection on test mechanical parts, and the results are shown in figure 4. Compared with other operators, the edge detection effect of Candy operator is the most accurate. After comprehensive consideration, this paper adopts Candy operator to extract the edge of mechanical parts.
4.3. Measurement data analysis
In order to reflect the universality of the method proposed in this paper, photos and measurements were taken of the 1-yuan coin with a diameter of 25mm and a thickness of 1.67mm, the long side of the no. No. 1 mechanical parts with a diameter of 35mm×20mm and a thickness of 11.5mm, and the no. 2 mechanical parts with a thickness of 81mm×81mm and a thickness of 60mm, as shown in figure 5:

![Object diagram](image)

(a) 1-yuan coin (b) No. 1 mechanical parts (c) No. 2 mechanical parts

Figure 5 Object diagram

It can be seen that the edge extraction algorithm cannot identify the upper surface edge and the lower surface edge of the mechanical parts to be tested, resulting in a large error in the measurement results, and the thicker the measured mechanical parts thickness, the greater the error. Therefore, the algorithm proposed in section 3 of this paper needs to be used for error compensation of measurement results. In this paper, the mechanical parts is repeatedly measured at 250mm height of the camera distance measurement plane, and the coin width and mechanical parts width data with large measurement errors due to thickness are recorded. The results are shown in table 1:
Table 1 Measurement results (Unit :mm)

| Coin size | Measurement data before dimension compensation | Coin size | Measurement data after dimension compensation |
|-----------|------------------------------------------------|-----------|-----------------------------------------------|
|           | Size of no. 1 mechanical parts | Size of no. 2 mechanical parts | Size of no. 1 mechanical parts | Size of no. 2 mechanical parts |
| 1         | 25.194 | 36.557 | 90.387 | 25.029 | 35.073 | 81.121 |
| 2         | 25.187 | 36.576 | 90.386 | 25.028 | 35.081 | 81.195 |
| 3         | 25.177 | 36.544 | 90.376 | 25.027 | 35.079 | 81.202 |
| 4         | 25.176 | 36.549 | 90.390 | 25.027 | 35.074 | 81.198 |
| 5         | 25.186 | 36.565 | 90.380 | 25.028 | 35.077 | 81.188 |
| 6         | 25.173 | 36.561 | 90.377 | 25.030 | 35.068 | 81.191 |
| 7         | 25.195 | 36.552 | 90.387 | 25.029 | 35.069 | 81.199 |
| 8         | 25.197 | 36.543 | 90.390 | 25.027 | 35.075 | 81.203 |
| 9         | 25.179 | 36.572 | 90.385 | 25.027 | 35.072 | 81.188 |
| 10        | 25.189 | 36.567 | 90.376 | 25.028 | 35.079 | 81.184 |
| Mean value| 25.185 | 36.559 | 90.383 | 25.028 | 35.075 | 81.196 |
| Absolute error | 0.185 | 1.599 | 9.383 | 0.028 | 0.075 | 0.196 |
| Relative error | 0.74% | 4.45% | 11.58% | 0.112% | 0.214% | 0.242% |

From the above two groups of experimental data, it can be seen that the measurement error obtained by direct measurement without compensating the size of the mechanical parts is large, the relative error of the coin is 0.74%, and the relative error of the two mechanical parts is 4.45% and 11.58%. After using the method mentioned in section 3 of this paper to compensate its size, the relative measurement error of the coin is reduced to 0.112%, and the relative error of the two mechanical parts is reduced to 0.214% and 0.242%, effectively improving the measurement accuracy. Moreover, according to the above data, the thicker the mechanical parts is, the greater the measurement error is, and the better the lifting effect is after using this method.

5. Conclusion

With the continuous development of the modern manufacturing industry, the industrial manufacturing field has put forward higher requirements for the quality of the products produced. In order to make product quality inspection more intelligent, efficient and accurate, visual measurement technology is bound to become an important part of industrial production, and undertake heavier measurement tasks in the quality inspection process. This paper mainly discusses the monocular vision measurement of mechanical parts. In image processing, the common filtering algorithm and edge detection algorithm are analyzed. The image preprocessing algorithm of mechanical parts in this paper is used to calculate the speed and processing effect. On the other hand, according to the reason that the thickness of mechanical parts cannot ignore the decrease of measuring accuracy, a new measuring method is put forward, which is the measuring of mechanical parts of different sizes. The validity of this method is verified.

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