Size and Pose Identification of Bolts Based on Monocular Vision

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Abstract. Machine vision has extensively developed in automatic image recognition research, and the automatic identification of bolts can improve the degree of automation greatly for bolts operation. This paper provides a method to extract the outline and the geometrical shape of the bolt thereby to identify the target bolt and locate the position according to the shape and the size of a kind of common six-angle bolt. A dynamic threshold segmentation method is used to extract the bolt geometry information and set the target area as region of interests (ROI). By the sub pixel boundary calculation, Ramer algorithm for segmentation of contours, and Tukey weight function with five iterations for linear fitting, the intersection features which are the bolt corners can be obtained. Through calibration, the relative position of bolt can be located and the size of bolt can be acquired.

Introduction

Machine vision is widely used in industrial automation applications [1]. Gray threshold method is a common feature extraction method for machine vision. However, when the external environment of mixed light or light intensity is different, the single channel gray threshold method is not good enough to meet the needs of the majority, especially under the closed environment and harsh lighting limit when using machine vision in industrial applications [2]. So, a dynamic threshold segmentation method is proposed. Through the method of noise reduction and dynamic threshold segmentation, the influence of external environment on the image processing can be reduced effectively, which includes step filtering, low-pass filtering, recursive smoothing and other operations. Besides morphological processing is used to reduce the interference of noise or object to the target area, which includes expansion corrosion and filling up operation. And the object features can be excluded from other body interference by morphological features [3]. Linear features of the general objects are more obvious, so straight line fitting is an effective method to improve the positioning accuracy. This paper uses the straight line fitting method to get the accurate features and the position of the bolt.

Currently common usage of image processing tools includes MATLAB, HALCON and OpenCV based on VC++. In this paper, the algorithm is completed based on HALCON. HALCON is developed by MVtec, it can provide a rich library of functions, and has the integrated machine vision development environment. The application of the software can improve the efficiency of image analysis and processing, and it is widely used in the analysis and processing of machine vision. Besides, it opens a wide variety of functions and application programming interfaces (APIs) to user. We can use these APIs to simplify research and development cycle (R&D cycle). Its API can be compiled using C++, C#, BASIC and other computer language compiler tools. The camera model used in the experiment is WAT-231S2 a color CCD camera by Watec Company, which is a zoom camera of the effective working distance of 35cm to 80cm shown in Fig. 1.

Image Segmentation

Image Acquisition

The experimental pictures are collected in the case of 40cm working distance. According to the
illumination angle and the different light conditions, a number of sample pictures were collected. As shown in Fig. 2, Fig. 2(a) is a picture with a single bolt. Fig. 2(b), which contains three bolts, is representative of the case containing a number of bolts. Fig. 2(c) contains a bolt, a knob and a box, which represents the situation of interference with other objects. In the samples, the periphery of the bolts is arranged in a metal ring. It represents a situation in which the bolt is closed, and the work piece shape can also be a triangle, a square, and other polygons.

![Figure 1. Camera used in experiment.](image1)

![Figure 2. Collected samples.](image2)

**Dynamic Threshold Segmentation**

Mean filter is used for image denoising. Using filtering mask template size $11 \times 11$, the effect is shown in Fig. 3. The mean filter is used to create a comparison window which is with mean gray value as the background gray value. Since the background image and the original image gray values are different on the contour boundary, the comparison window is aimed to compare the images of all objects contour region. This is called the process of dynamic threshold segmentation. A dynamic threshold segmentation algorithm for an object is shown as the Eq. 1.

$$S = \left\{(r, c) \in R \mid f_{r,c} - g_{r,c} \geq g_{diff}\right\}$$ (1)

Where $f_{r,c}$ means input image, $g_{r,c}$ means smoothed image. The $g_{diff}$ in the formula is the minimum difference when compared the gray level. In this paper, $g_{diff}$ value equals to 4.

![Figure 3. Results after noise reduction.](image3)
Dynamic threshold method is to obtain the region in a high frequency, which is more obvious in the boundary. This method can reduce the uneven illumination, and can be used under disturbance of the illumination change. For fragmentary noise generated in the system area, the morphological processing will exclude most regions of noise. The dynamic threshold segmentation results are shown in Fig. 4. From these three pieces of graph, it can be found that bolts, squares, cobs, rings and the objects in the outer contour of the region after the processing are fully revealed.

**Extraction of Six Edge Region of Bolt**

Firstly, the connected domain of the region is defined, so the single value image is defined as the separated region. Distinguishing connected domain is the prerequisite of feature selection [4]. Then morphological processing is used and the separation area including complete bolt shape and other interference region is filled up. Finally, target regions is screened by morphological features of different regions

**Connected Region Analysis**

Connected region analysis is a common and basic method in image analysis and processing. In this paper, seed method issued to segment the connected domain, and the neighbor relationship of pixels is 4. Segmented regions are marked as individuals. This makes the following morphological identification convenient.

**Morphological Processing**

In order to display the full bolt shape, the filling algorithm is used to fill up the connected domain. After filling process, the hexagon area of the bolt is fully displayed as shown in Fig. 5.

![Figure 5. Results after filling up and selecting area.](image)

The expansion corrosion process is used to solve the problem that the boundary of the connected bolts is not so clear. Expansion processing will expand the processing region, so when transforming the image areas with unconnected region into a complete region, the method of expansion process is needed. Corrosion process can make the object area smaller, it can separate the object from each other [5]. As shown in Fig. 6(a), bolts are connected from the image point of view. After extracting the connected domain and a feature filtering, the image is shown in Figure 6(b), in which two bolt regions are connected. But in fact only the above bolt is the target region that we want. At this point, the corrosion process can be used to separate the two bolts, corrosion results are shown in Fig. 6(c).
Figure 6. Connected bolts and images after dynamic threshold, corrosion and filling up.

Region Selection Using Morphological Features

Interference regions are excluded by morphological processing. Area in the image is represented as number of pixels. Then roundness, circularity, compactness and convexity features are used to describe a region. Roundness is defined as the distance between the contour and the center of the region. Circularity calculates the similarity of the input region with a circle. Compactness and convexity calculates the comprehensive feature of a solid hexagon region. Fig. 7 shows the region selection process. Fig. 7(a) shows the aim of the bolts with a disruptor, Fig. 7(b) and Fig. 7(c) show the results of the method with different features parameters.

Extracting Contour of Bolt

After finding the hexagon region of the bolt, the outermost contour region of the bolt area is extracted. The result is shown in Fig. 8. Fig. 8 can be found in the profile area with pixels display. Then the contour curve can be fitted using the sub pixel curve whose unit size is 1/50 pixels [6]. Sub pixel precision defines a contour line, contour sub pixel accuracy is divided into three factors, first is the outer contour line in the pixel boundary. The second is the inner contour line boundary pixels and the third is the pixel boundary of the internal and external contours of the middle line. In the extraction of the angle of the bolt, contour line is often used. To find the outline, bilinear interpolation operation is done on the sidelines. Bilinear interpolation can slash fitting the contour (also known as contour smooth). After fitting the results are shown in Fig. 9. Fig. 9(a) shows the original sub pixel profile, Fig. 9(b) shows sub pixel profile after bilinear interpolation, Fig. 9(c) contrasts the profile between Fig. 9(a) and Fig. 9(b).
Straight Line Fitting and Corner Point Extraction

It can be found in Fig. 9 that bolt contour lines on each side are formed by small line segments from head to tail connected together. Rammer algorithm is used to achieve the recognition of the curve corner. For a closed contour, the two ends of the line are connected by a line segment, and then the distance between the two ends of the line is the shortest line. If the distance between lines is bigger than the preset threshold, the contour points will be divided into two sections. Rammer segmentation algorithm is shown in Fig. 10. Bolts in the outer contour of the results are shown in Fig. 11, in which six different side is marked with different gray value. Using the robust algorithm to the linear contour, segmentation is fitted as a standard line. The line may appear in any direction of the image. To meet the requirements of its arbitrary, Hesse model are used to represent a straight line [7], shown in the Eq. 2.

\[ ar + bc + \gamma = 0 \]

Where \((r, c)\) form the points on specific line with parameter \(\alpha, \beta\) and \(\gamma\). Distance of contour points to the line is calculated, as shown in the Eq. 3.

\[ \varepsilon^2 = \sum_{i=1}^{n} (ar_i + bc_i + \gamma)^2 \]

Where \((r_i, c_i)\) refers all the points on the fitting region. To get the least squares solution, \(\alpha, \beta\) and \(\gamma\) are determined. Thereby the specific linear analytic formula is obtained. And the intersection points will be regarded as the points of bolts. This method produce a deviation from the actual line when points are far from fitting line exist. So the points should be eliminated. In order to improve the accuracy of the linear fitting, correlation value is introduced for each point of the contour. For those far off the line the point values should be far less than 1. Correlation values is assumed to be calculated. As shown in the Eq. 5.

\[ \varepsilon^2 = \sum_{i=1}^{n} \omega_i (ar_i + bc_i + \gamma)^2 \]

Where \(\omega_i\) refers correlation value. The points far away need to be made with a small correlation value, so the value is defined by distance as \(\delta_i = |\alpha r_i + \beta c_i + \gamma|\). Initially, there is no straight line available, so the distance is not defined at the beginning. In this paper, iteration method is used five times to fit the lines. In the first iteration, the value of \(\omega_i\) equals to 1, initial straight line is calculated using the distance \(\delta_i\). Then by the function Tukey, as shown in the Eq. 5, the distance can be obtained to define the relevant values, and finally, the correlation value is for the subsequent conducts iterative processing.
\[ \omega(\delta) = \begin{cases} \left[1 - \frac{\delta}{\tau}\right]^2 & |\delta| \leq \tau \\ 0 & |\delta| > \tau \end{cases} \]  

(5)

Where clipping factor \( \tau \) represents a distance. This function ignores the points whose distance to the line are greater than \( \tau \). The value of \( \tau \) in this paper is 2. Fig. 12 shows the angular information obtained by improved linear fitting method.

![Figure 12. Extracted bolts corner.](image)

The position and orientation of the bolt are mainly composed of 3 parts: the bolt rotation angle, the bolt orientation and the bolt position. The bolt rotation angle is represented by the straight line along two edges. For the bolts on the plane, the bolts are toward the plane normal direction. The position of the bolt can be expressed by the middle point of the characteristic region.

**Analysis of Bolt Size and Position**

The position and orientation of the bolt are mainly composed of 3 parts: the bolt rotation angle, the bolt orientation and the bolt position. The bolt rotation angle is represented by the straight line along two edges. For the bolts on the plane, the bolts are toward the plane normal direction. The position of the bolt can be expressed by the middle point of the characteristic region.

**Image Calibration**

In the image, the position of the bolt is represented by the pixel coordinate. For fixed focal length and position of a camera, the calibration method can be used to get the relationship between target point position and the work piece in camera coordinate system and the world coordinate system [8, 9]. HALCON’s calibration board file completes the calibration board production. The calibration board form is shown in Fig. 13.

![Figure 13. Calibration board.](image)
Bolt Size Calculation

The bolt size is obtained from the feature region. For the same camera, the region of the bolts on the image is consistent [10], so the area threshold is a good way to distinguish the bolt type. The size of bolts can also be expressed from the two points’ diagonal distance. Table 1 shows S values for different types of bolts under GB30 standard of China.

<table>
<thead>
<tr>
<th>Bolt type</th>
<th>M10</th>
<th>M12</th>
<th>M14</th>
<th>M16</th>
<th>M18</th>
<th>M20</th>
<th>M22</th>
</tr>
</thead>
<tbody>
<tr>
<td>S (mm)</td>
<td>17</td>
<td>19</td>
<td>22</td>
<td>24</td>
<td>27</td>
<td>30</td>
<td>32</td>
</tr>
</tbody>
</table>

Bolt Orientation Calculation

Based on the diagonal edges of two points on a bolt, the bolt direction is calculated. There are 3 groups of equivalent directions to express the bolt rotation angle. So the arithmetic mean is used to promote the accuracy of the screw rotation angle. And use range of 0 to 60 degrees to determine the rotation angle of the bolt. As shown in the Fig. 14.

\[
\alpha = (\theta_1 + \theta_2 + \theta_3) / 3
\]

(6)

Where \( \theta_1, \theta_2, \) and \( \theta_3 \) refers to the angle 1, 2 and 3. Horizontal line is the benchmark. The arithmetic mean is used to determine the accuracy of the screw rotation angle. And the range of 0 to 60 degrees is used to express rotation angle.

![Figure 14. Angle calculation.](image)

Bolt Position Calculation

The bolt position is obtained from the center position of the bolt’s region in the image. The size can be converted form the scale of pixel to actual size by image calibration.

Test and Error Analysis

In order to achieve the tightening process, bolt location error to is less than the tolerance value (when total error does not exceed the value, blots can be automatically tighten). Bolt size can be recognized straight-forward, because the different S value between the two adjacent sizes of bolt is large. So according to the Table 2, when the total S error is less than 1.5mm, visual size detection can be adopted. Table II shows the experimental S value of bolts.

<table>
<thead>
<tr>
<th>S value (mm)</th>
<th>The first group (M16)</th>
<th>The second group (M16)</th>
<th>The third groups (M20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24.9</td>
<td>0.80</td>
<td>0.33</td>
<td>0.47</td>
</tr>
<tr>
<td>24.8</td>
<td>23.2</td>
<td>24.1</td>
<td>30.9</td>
</tr>
<tr>
<td>24.7</td>
<td>23.9</td>
<td>30.4</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. S value of experimental bolts.
Total position error is composed of two factors: the one is the accuracy of each two edges on the diagonal, and the other is the center point. Three groups of the orientation and position values of the bolts are shown in Table 3 and Table 4.

Table 3 shows rotation angle that different conditions of bolts possess, value of which is calculated based on position of bolt edges extracted by methods above. According to the table, mean angle of different bolts is about 1°, which is available to industrial automation assembly.

Table 3. Rotation angle of different types of bolts.

<table>
<thead>
<tr>
<th></th>
<th>The first group (M16)</th>
<th>The second group (M16)</th>
<th>The third groups (M20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotation angle (degree)</td>
<td>1.089</td>
<td>34.238</td>
<td>42.521</td>
</tr>
<tr>
<td>Actual measurement (degree)</td>
<td>2</td>
<td>35</td>
<td>41</td>
</tr>
<tr>
<td>Mean angle error (degree)</td>
<td>0.940</td>
<td>0.908</td>
<td>1.428</td>
</tr>
</tbody>
</table>

Table 4 shows position measured by this method and the actual value. Centering error is used to evaluate position of the bolt installation. From Table 4, the max centering error calculated is 0.848mm, and max average centering error is 0.635mm from group 1. The factors of error include the display of the calibration board, the technology of the camera, the lens quality and the measuring error of the actual position. In conclusion, for detection of bolts location. This method could meet the industrial demand to guidance manipulator positioning. For the process to tight the bolt, force sensors and other detection equipment is needed to recognize force and promote accuracy.

Table 4. Position of different types of bolts.

<table>
<thead>
<tr>
<th></th>
<th>The first group (M16)</th>
<th>The second group (M16)</th>
<th>The third groups (M20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position (mm)</td>
<td>(8.20,31.36)</td>
<td>(-14.37,9.72)</td>
<td>(-21.14,14.78)</td>
</tr>
<tr>
<td>Actual measurement (mm)</td>
<td>(13.01,18.15)</td>
<td>(-10.91,23.33)</td>
<td>(-14.42,-1.26)</td>
</tr>
<tr>
<td></td>
<td>(22.32,27.18)</td>
<td>(-1.12,13.56)</td>
<td>(-3.72,12.13)</td>
</tr>
<tr>
<td>Mean position error (mm)</td>
<td>0.635</td>
<td>0.295</td>
<td>0.420</td>
</tr>
<tr>
<td>Max position error (mm)</td>
<td>0.848</td>
<td>0.385</td>
<td>0.494</td>
</tr>
</tbody>
</table>

Summary

This paper introduces a feature extraction method based on monocular machine vision, which can reduce the interference of light under the external condition. At the same time, the influence of noise on the target area is reduced by morphological processing. Then, the corner extraction algorithm is designed. By this method, the position and rotation angle of the bolt are obtained. Based on the area of the bolt region, the size of the bolt can be calculated. The experiment results show that the method can detect the existence of bolts, calculate the position of the bolt in the allowable range avoiding varies of interferences. The accuracy of the bolt size calculated is relatively high for the requirement. As far as other types of bolts, this method can also be applied to the size and pose identification.

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References


