Research on application of corner detection in thread vision measurement

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Abstract. With the rapid development of the automation field, automatic inspection of fasteners in the aviation field has become a top priority. It is precious to realize the fast measurement of important information in fastener production by non-contact. This paper aims to detect the optical image detection of the external thread angle of fasteners. We analyze the traditional Ramer algorithm's contour segmentation steps in separating thread edge from thread bottom arc to obtain accurate thread angle size and thread bottom arc radius. And Harris algorithm is proposed to find corners again by comparison. Finally, using a discrete point curvature to verify the Harris algorithm's accuracy in corner detection. Meanwhile, by comparing the edge fitted thread angle with the measured thread angle to verify the Harris algorithm's reliability in corner detection.

1. Introduction
Fasteners have great application value in the machinery industry. With the significant development of the aviation field, aviation fasteners' manufacturing accuracy has a tremendous influence on aircraft reliability and flight life. Traditional fastener inspection relies on the manual review with microscopic tools, which has many shortcomings. Based on this background, many enterprises and companies have proposed using visual inspection instead of human detection, which is efficient and faster [1].

The detection of the external thread is an integral part of the measurement of fasteners. The outer line's detection includes the size of significant diameter, middle diameter, minor diameter, thread angle, and thread bottom arc. In thread angle measurement, the thread's arc curve is obtained by edge extraction of the image, and then the arc curve is segmented [2]. It is necessary to find the tangent point between the thread bottom's arc and the thread edge's projection curve, which is generally called corner point, feature point, or salient point. The accuracy of this point's location has a significant influence on the thread edge slope fitting to obtain the half-angle of thread, as shown in Figure 1. When selecting the problem corner point, the thread height and thread angle can be found, as shown in in Figure 1 [3].

Corner detection has been studied since the last century. At the earliest time, the detection of feature points is generally divided into corner detection based on contour curvature, and the other is polygon approximation. Ramer algorithm is famous for finding corners by polygon approximation.
The polygon approximation method's limitation has been gradually replaced, and corner detection has become the mainstream algorithm at present [4]. There are three kinds of corner detection: corner detection based on gray image, corner detection based on binary image, and corner detection based on contour curve. Corner detection based on the gray image also includes gradient detection, template detection, and combined form detection [5]. The essence of template-based detection is to use a unique matrix to make convolution with local ideas.

In contrast, the convolution result at the corner and edge convolution result is distinguished by a specific formula threshold to judge the corner. Harris algorithm, SUSAN algorithm, and so on are commonly used in this method. At present, this kind of corner detection is mostly used in image matching and feature description, but the research on tangent point accuracy is less. In this paper, firstly, the Ramer algorithm is used in Halcon to get the thread edge tangent point, and then MATLAB is used to extract the thread edge tangent point preliminarily. At the same time, discrete points are used to get the approximate curvature to get the edge curvature to verify the thread angle edge tangent point. By comparing the two methods, the thread half angles are calculated respectively, and then the experimental data are demonstrated to verify the reliability of the Hariss algorithm.

2. Polygon approximation method based on Ramer

Ramer polygon approximation method is divided into two steps, first segmentation, then merging. Segmentation includes the following steps: (1) connecting the beginning and end points AB of the edge, as shown in figure 2, and selecting the farthest point c from the edge; (2) judging whether the distance between the farthest end of the border and the straight line exceeds the threshold, that is, calculating whether the distance AB exceeds the threshold; (3) If the threshold value is exceeded, this point is set as the middle corner point, connecting AC and BC; (4) Continue to find the farthest point from AC and BC on the curve, such as point D in the figure, then point CD and BD, and then repeat the above steps until the whole curve traverses; (5) Until the entire curve is divided into a polygon whose outline is closest to the turn, such as polygon ABDEC in the figure. In this step, multiple points that are not corner points are extracted. For example, both C and D are not needed corner points, so merging operation is required. For merging, the issues that are not corner points are combined, and the calculation process is consistent with the segmentation.

Figure 1. Thread projection thread model.
ion process. Connect AE and BE to judge whether the distance from C and D to AE and BE exceeds the merging threshold; if it exceeds, keep it; if it does not exceed, it will be annexed until all corner points in the segmentation process are traversed.

![Figure 2](image1.png)

**Figure 2.** Segmentation process in Ramer algorithm.

In Halcon, three variables need to be set for this algorithm. Besides the two thresholds described above, because the curve may be unsmooth, a Gaussian smoothing coefficient is added to smooth the curve, and then the curve is segmented and merged. It should be noted that the Gaussian smoothing coefficient of filing operation should not be too large, which will lead to a smooth transition and equal wiping of curve corners. As shown in Figure 3, which is the external thread image taken in a horizontal state. The idea is binarized, and then the edge is extracted. It can be seen from the impression that the edge of the thread is very uneven due to the impurity of the thread itself and the influence of the manufacturing process. As shown in Figure 4, which is the image extraction from outer edge.

![Figure 3](image2.png)  ![Figure 4](image3.png)

**Figure 3.** Original image of the external thread.  **Figure 4.** Image extraction from outer edge.

This paper mainly extracts the uppermost edge of the external thread in the image. The extracted advantage is segmented, in which the smoothing value of the image is 101, and then the first segmentation threshold is 15, and the second merging threshold is 40, as shown in Figure 5. In this edge, the tangent point coordinates between the thread bottom arc and the thread edge are (367.5, 1166.5). The advantage of this method is that the operation is simple, but the disadvantage is still apparent. First, the farthest point is the intersection of tangent and curve, so the curvature at digression may not be the maximum; Secondly, it is very dependent on the initial arc, and the different selection of the initial curve may lead to the deviation of the detected corners.
3. Corner detection method based on Harris

Based on the above situation, —Harris algorithm, which is one of the commonly used corner detection algorithms, is adopted. The basic idea of Harris corner detection is to observe the image features from the small local window. The movement of the window in any direction leads to apparent changes in the gray image scale. In the flat area, the little window movement in any order will not cause the growth of the gray image scale. When the small window moves along the edge, the gray level will not change, but moving along the non-edge will cause the gray level change. A small window will appear at the corner, and there will be noticeable gray changes when moving in any direction.

For a gray-scale image $I(x,y)$, if the window function is $\omega(x,y)$, when there are $u$ and $v$ motion changes in the direction $x,y$, the resulting changes $E(u,v)$ are as follows:

$$E(u,v) = \sum_{xy} \omega(x,y) \cdot [I(x+u,y+v) - I(x,y)]^2$$  \hspace{1cm} (3-1)

There are two kinds of window functions. One is a rectangular window, and the other is a Gaussian window function. When there is no periodic digital image signal in the image, and there are many burrs, using the Gaussian window function is better than the rectangular window, and the weight of the center point is higher than both sides.

In formula 3-1 $I(x+u,y+v)$, Taylor can expand as follows:

$$I(x+u,y+v) = I(x,y) + I_x u + I_y v + \sigma(u^2 + v^2)$$  \hspace{1cm} (3-2)

Therefore, there are:

$$E(u,v) = \sum_{xy} \omega(x,y) \cdot [I_x u + I_y v]^2$$  \hspace{1cm} (3-3)

Formula 3-3 is organized as follows:

$$E(u,v) = \sum_{xy} \omega(x,y) \cdot [u \quad v] \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} \begin{bmatrix} u \\ v \end{bmatrix}$$

$$= \begin{bmatrix} u & v \end{bmatrix} \cdot \sum_{xy} \omega(x,y) \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} \cdot \begin{bmatrix} u \\ v \end{bmatrix}$$

In which let $M = \sum_{xy} \omega(x,y) \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix}$, the change functions in each direction are as follows:

$$E(u,v) \approx \begin{bmatrix} u & v \end{bmatrix} \cdot M \cdot \begin{bmatrix} u \\ v \end{bmatrix}$$  \hspace{1cm} (3-4)

Therefore, the research focus of the Harris algorithm becomes the research of the $M$ matrix. $M$ matrix can be regarded as a convolution of window function and original image matrix. When the window function is a Gaussian window, the gradient of the original part is similar or equal to the original image in the flat area. The slope of the function convolved by the Gaussian window does not change at all; When in the edge area, there will be a situation where the rise in one direction remains unchanged and the gradient in the other changes. For the matrix $\begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix}$, it is equivalent to a significant difference in the main diagonal. One is a constant, and the other is a change value, which can distinguish the edge direction; when the gradient of the original matrix changes in any order at the corner, Figure 6 shows the relationship between M matrix and image.

To determine the boundary between corner and flat area and change the two-dimensional matrix into a one-dimensional number, Harris algorithm defines another variable $R$, which is called corner response function:

Figure 5. Extraction effect of thread edge segmentation.
The determinant of the matrix is the product of matrix eigenvalues. The trace of a matrix is the sum of elements on the matrix's main diagonal and eigenvalues, which reflect the degree of direction change of the matrix. If the direction change is small, the eigenvalue will be short, and the corresponding R will be small. This method can be judged that when R is less than zero, the trace of a matrix is relatively large, and the elements on the main diagonal are relatively large. When r is greater than 0, it is smaller and closer to 0, indicating that the image is flatter; on the contrary, the larger it is, the more it is at the corner.

In this method, the corner detection of the original image is completed in MATLAB. First, the idea is binarized, and then the noise is removed. After processing, the filter curve is smoothed, and the Sobel operator extracts the edge of the image, and the Harris corner detection is performed on the edge of the picture. The result is shown in Figure 7. The coordinates of the corner detection results of the upper edge in the figure are (345, 1209). Compared with the Ramer detection results, the detected points are on the upper side, which means that the half-angle of the thread will be larger, and the thread height will be smaller in fitting the straight-line area by using the Ramer algorithm.

![Figure 7. Harris corner detection results of thread angle.](image)

4. Discrete curvature detection

Curvature represents the bending degree of a line segment, and the formula can directly calculate the curvature of a line segment. Still, for discrete points, the calculation of curvature is more complicated. In this paper, the edge of the external thread is a pile of discrete points. Verifying the Harris and Ramer algorithm's accuracy, the approximate slope of discrete points of the outer edge is calculated.

There are three methods for the general curvature of discrete points. The first method is to use the three-point positioning method, which can determine a circle, and use it to calculate the curvature of every three points and find the curvature change. The second method is to use the proper approach to fit
first and then find the fitting curve slope; the third method is to set the step size and calculate the curvature approximately according to specific step size [6].

In this paper, the third scheme is adopted. It is known that in the x-axis direction, each pixel corresponds to a y-axis. Because there are cases where one x fits several y's in the edge extraction process, the pixels are unified on an approximate curve utilizing de-averaging. The approximate curvature of the curve is calculated pixel by pixel. Figure 8 shows the curvature change image drawn by MATLAB.

![Figure 8. Discrete curvature change.](image)

Figure 8 can reflect the overall change trend of the curve. Firstly, it is flat, enters an arc, smoothes the part, and then enters an arc segment. The first point approximately entering the arc segment is extracted in the figure, the abscissa of x is 344. Harris's feature point extraction is closer to the curvature change point by using the approximate curve method.

5. Conclusion

After comparing the Ramer algorithm with the Harris algorithm, using a 2-fold telecentric lens and a Daheng Mercury camera to measure the screw thread of a titanium alloy fastener, the screw thread is M8×1 type, with a large longitude of 8.0±0.25mm and a small diameter of 7±0.2mm. According to manual measurement, the thread shape height is 0.67mm, and the thread shape angle is 60.2. Figure 9 shows the acquisition platform, and the acquisition platform collects four groups of threads in different positions and different light intensities. The thread height and thread angle of the four groups of threads are measured respectively, and the measurement results are showed in Table 1.

![Figure 9. Acquisition platform and acquisition image.](image)

Because the fastener is a non-standard part, there is a significant deviation in different measurement results. Because manual measurement only measures the same position, the measurement results are
consistent. By analyzing the Ramer algorithm and the Harris algorithm's measurement results, we can know that the Harris algorithm's thread height is generally large. The thread angle is relatively small, which proves that Harris's corner point is closer to the tangent point, which is consistent with the discrete curvature detection result, and preliminarily verifies the reliability of Harris in corner detection.

### Table 1. Measurement results.

| Thread Picture | thread height (pixel) | thread angle (°) |
|----------------|----------------------|-----------------|
| **A**          | Ramer algorithm      | 388.4           |
|                | Harris algorithm     | 397.5           |
|                | Manual measurement   | 0.67mm          |
|                |                      | 60.8            |
|                | Ramer algorithm      | 383.3           |
| **B**          | Harris algorithm     | 395.8           |
|                | Manual measurement   | 0.67mm          |
|                |                      | 59.7            |
|                | Ramer algorithm      | 389.2           |
| **C**          | Harris algorithm     | 401.6           |
|                | Manual measurement   | 0.67mm          |
|                |                      | 59.6            |
|                | Ramer algorithm      | 375.9           |
| **D**          | Harris algorithm     | 392.8           |
|                | Manual measurement   | 0.67mm          |
|                |                      | 60.1            |

In this paper, aiming at the feature point detection of thread bottom arc and thread edge separation in thread shape half-angle vision measurement, use the Ramer algorithm and the Harris corner detection method. And the accuracy of the Harris corner detection direction is verified by calculating the approximate curvature of edge discrete points. Finally, using the experimental platform to measure the testing image and conclude that the slope is similar to that of discrete points is obtained.

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