Method for detecting the notch deviation based on corner point constraint

Zhitao Xiao\textsuperscript{1,2}, Quansheng Wei\textsuperscript{1,2} and Lei Geng\textsuperscript{1,2*}

\textsuperscript{1} School of Electronics and Information Engineering, Tianjin Polytechnic University, Tianjin, Tianjin, 300387, China
\textsuperscript{2} Tianjin Key Laboratory of Optoelectronic Detection Technology and System, Tianjin Polytechnic University, Tianjin, 300387, China
\textsuperscript{*}Corresponding author’s e-mail: genglei@tjpu.edu.cn

Abstract. The notch detection plays a critical role in influencing the quality control of cut-piece. It is difficult to measure the deviation of notch due to the deformation of cut-piece, which in turn affects the subsequent sewing process and the quality of cut-piece. In this paper, a notch detection method based on corner point constraint is proposed to solve this problem. Firstly, all the corner points are extracted from the CAD by using the improved Harris corner detection algorithm. The triangle constraint and the intersection constraint method are used to eliminate extra corner points that are not in the triangle area, and then the notch is obtained. Secondly, the cut-piece and the CAD are superimposed by affine transformation, and the approximate notch area on the cut-piece is obtained in the neighbourhood of the notch on the CAD. Finally, the improved Harris corner detection algorithm is used to extract all the corner points of the notch area on the cut-piece, and then the notch is extracted after removing the extra corner points. The experimental results have shown a good consistency with the expected performance which confirms the effectiveness of the proposed method.

1. Introduction
In recent years, measurement technology based on machine vision has developed rapidly due to its advantages of non-contact, high measurement accuracy, fast speed, and good adaptability. In the area of cutting processing, quality control of the cut-piece directly affects the quality of subsequent products. The purpose of inspection of cutting quality is to detect and replace the cut-piece which cannot attain the quality requirements, and to avoid the bad cut-piece flowing into the sewing process and affect product quality and production schedule. The traditional detection method mainly relies on the workers to compare the cut-piece with the sample, check whether the size and shape of each cut-piece is consistent with the sample, check whether the position of the notch and positioning hole is accurate and clear, whether there is leakage shear, and whether there is no upper and lower deviation. However, this detection method cannot know the specific deviation, the detection speed is slow, the workers are easy to fatigue, and the test results are easily affected by the subjective factors of the workers. Based on the above considerations, the measurement technology of the cut-piece based on machine vision has become a hot research topic.

The notch is the cut seam of the alignment stitch made at the edge of the cut-piece. The accuracy of the position and depth of the notch seriously affects the subsequent sewing process. Since the cut-piece is cut from a flexible material, it will deform to a certain extent, which causes the shape of the
notch to become non-standard. In this paper, the corner point constraint method is used to extract and detect the notch. Therefore, how to extract the apex (corner point) of the notch accurately is a first step.

At present, corner detection methods are mainly divided into two categories: image-based edge method [1] and image-based grayscale method [2]. The corner extraction algorithm based on image edge has higher requirements on image segmentation and edge extraction. The algorithm and processing steps are more complicated. When the edge of the image is interrupted, the corner points cannot be extracted well. Gray-based corner extraction algorithm, which will inevitably lead to some regions in the image that may have more pixel points whose gray value change greater than the empirical value and are extracted as corner points because of the difference of the grayscale level change in the whole image. This part of the area causes corner redundancy or corner clustering. In other areas, it may be that some pixels of the corner points are not detected because the gray level is not greater than the empirical value, resulting in the loss of some corner points. Based on the above situation, the CAD is converted to an image with the same gray level before the corner points are extracted, and then the corner points are extracted through the improved Harris corner detection algorithm [3]. The CAD is used as a reference when extracting the notch on the cut-piece. In the end, the deviation of the notch between the two is calculated in the same coordinate system and converted to the actual value by the pixel equivalent.

2. Camera calibration

Camera calibration is the necessary process to accurately measure the target object. Each lens has different degrees of distortion, which can be corrected by camera calibration, and calibration method for parts dimension measurement system based on depth constraint [4] is adopted in this paper. Camera calibration is actually the process of determining the internal and external parameters of the camera. Camera calibration involves a total of four coordinate systems, as shown in Figure 1, \( I \) is the internal parameter matrix, and \( O \) is the external parameter matrix.

![Four coordinate systems involved in camera calibration](image)

\[
I = \begin{bmatrix}
    f_x & 0 & u_0 \\
    0 & f_y & v_0 \\
    0 & 0 & 1
\end{bmatrix},
O = \begin{bmatrix}
    R & T \\
    0 & 1
\end{bmatrix}
\]

3. Overlapping display of the cut-piece and CAD

3.1. Match

The matching flow diagram is shown in Figure 2. Since the CAD is required as a reference when extracting the notch on the cut-piece, it is necessary to match and superimpose the two by affine transformation. There is a certain degree of deformation in the cut-piece. However, the traditional matching method requires that the target object does not change much in direction or scaling,
otherwise the matching will fail. Therefore, the matching method\cite{5} based on image edge contour is adopted in this paper and directly calculates the similarity by using the template (CAD) and comparing the obvious region of the edge features \cite{6, 7} in the image. The coordinate $(R, C)$ of the found instances of the model, the rotation angle $\alpha$ of the found instances of the model and the scale $S$ of the found instances of the model are obtained in the matching process.

![Figure 2. The matching flow diagram](image)

### 3.2. Affine transformation

Since there are geometric changes (translation, rotation, scaling, etc.) between the image to be detected and the template image, the image to be detected is affine transformed \cite{8} for aligning the image. In short, it can be understood as "following", and where the target object moves, where the corresponding contour, ROI (Region of Interest), etc. follow.

1. Generating affine transformation matrix

   \[
   H = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}
   \]  \hspace{1cm} (2)

2. Add rotation angle to affine transformation matrix

   Add a rotation to the homogeneous transformation matrix by angle $\alpha$ and return the result matrix in $H_r$. The rotation is described by a 2x2 rotation matrix $R$. It is executed relative to the global coordinate system; this corresponds to the following transformation matrix chain:

   \[
   H_r = \begin{bmatrix} R & 0 \\ 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}, \quad R = \begin{bmatrix} \cos(\alpha) & -\sin(\alpha) \\ \sin(\alpha) & \cos(\alpha) \end{bmatrix}
   \]  \hspace{1cm} (3)

3. Add scaling to the affine transformation matrix

   Adds a scaling by the scale factors $S_x$ and $S_y$ to the homogeneous transformation matrix $H_r$ and returns the resulting matrix in $H_s$. The scaling is described by a 2x2 scaling matrix $S$. It is performed relative to the global coordinate system; this corresponds to the following chain of transformation matrices:
4. Extract the notch

4.1. Extract the notch on the CAD

After extracting all the corner points on the CAD by using the Harris algorithm, in order to accurately extract the notch features, it is necessary to remove the corner points outside the notch area. The notch area is a standard triangle area, three vertices are three corner points, and these three corner points can form an isosceles triangle (as shown in Figure 3(a)). The corner points outside the notch area are divided into two cases: isolated corner points (no adjacent corner points within a certain distance, as shown in Figure 3(b)); extra corner points closer to the notch area (as shown in Figure 3(c)).

Based on the above situation, a triangle-constrained notch extraction method is proposed in this paper. The algorithm is as follows:

1. Eliminate isolated corners that are farther away from the notch area

The coordinates of all corner points on the CAD are \((x_1, y_1), (x_2, y_2), \ldots, (x_i, y_i), \ldots\) traverse all the corner points and calculate the minimum distance \(d\) among all the corner points. Draw a circle with any corner point as the centre and \(d\) as the radius. Through the equation of the circle, it can be seen that the points outside the circle satisfy the inequality:

\[
(x_1 - x)^2 + (y_1 - y)^2 > d^2
\]  

When drawing a circle with the corner points far away from the notch area as the centre, all other corner points are outside the circle. In this way, the corner points away from the notch area can be removed.

2. Eliminate extra corner points near the notch area

For any corner \(A\) on the CAD, find the two points \(B\) and \(C\) which are closest to the point \(A\) from the remaining corner points. \(A, B,\) and \(C\) can form a triangle \(\triangle ABC\). The area of the triangle \(\triangle ABC\) is \(S_1\), the area of the intersection of the cut-piece and \(\triangle ABC\) is \(S_2\), and the corner points of the notch area satisfies the following inequality:

\[
\frac{S_2}{S_1} < 0.1
\]

3. Get the main vertex and the minor vertex of the notch

After obtaining the corner points of the notch area, in order to determine the position and depth information of the notch, it is necessary to clarify the apex of the notch. Draw a circular area with the midpoint of the three sides of the triangle as the centre, as shown in Figure 4. The area of the circle is
\( S_3 \), and the area of the intersection of the circle and the cut-piece is \( S_4 \), and the circle with the midpoint of the two minor vertices as the centre satisfies \( S_4 = 0 \), The other two circles satisfy \( \frac{S_4}{S_3} = 0.5 \). Thereby, the main vertex and the minor vertex of the notch can be obtained.

![Figure 4. The main and minor vertices of the notch](image)

![Figure 5. The notch of cut-piece and CAD](image)

![Figure 6. The corner points of the notch area](image)

4.2. Extract the notch on the cut-piece

The material and cutting process of the cut-piece will cause a certain degree of deformation of the notch, so the notch on the cut-piece is not as good as the notch standard on the CAD. If the corner points on the cut-piece are directly extracted, it will be found that there are too many corner points in the non-notch area, it is not easy to eliminate the extra points, and the algorithm is too slow. In response to this problem, this paper uses the affine transformation to superimpose the CAD and the cut-piece, and the notch area of the cut-piece through the CAD is obtained. Assume that a certain notch area \( A \) on the CAD can obtain the approximate area of the cut-piece corresponding to the notch in the neighbourhood of \( A \). This is called the fuzzy notch area (as shown in Fig 5). After obtaining the approximate area of the notch on the cut-piece, the Harris corner detection algorithm is applied to extract all the corners of the area (as shown in Figure 6). In order to accurately obtain the three corner points of the notch, it is necessary to eliminate the extra corner points. The algorithm steps are as follows:

Step1: Eliminate the extra points near the notch area. The method is the same as 4.1 step (2).

Step2: Eliminate the extra corners in the notch area. For the corner points in the notch area, choose three corner points to form a triangle. The areas of these triangles are \( S_1, S_2, \ldots, S_i, \ldots \), \( S_{\text{max}} \) corresponding three corner points are the three vertices of the notch area.

Step3: Get the main vertex and the minor vertex of the notch. The method is the same as step (3) in 4.1.

5. Experimental results and analysis

The experimental system is shown in Figure 7. Experiments are performed on the cut-piece and CAD shown in Figures 8 and 9. When the measuring system is working, the cut-piece to be tested is placed on the measuring panel which is imaged in the optical system under the illumination of the backlight. The optical signal is converted into a charge signal by a CCD chip, and the analog signal is converted into a digital signal by an image capture card and transmitted to a computer. The image of the object to be measured is processed by a previously prepared measurement algorithm, and finally the measurement result is output. Calibration method for parts dimension measurement system based on depth constraint is used in this paper. The pixel equivalent of this system is 0.275, and the internal parameter matrix and the external parameter matrix are respectively \( I \) and \( O \). The matching degree is 99.6\%, the coordinate of the found instances of the model is (497.455, 647.428), the rotation angle of the found instances of the model is 6.2728 rad and the scale of the found instances of the model is 1.00778 after matching in this experiment. The cut-piece and the CAD are superimposed and displayed by affine transformation after the success of the matching, as shown in Figure 10.
The notch on the cut-piece and the CAD is extracted through the notch extraction algorithm, the
notch is numbered in the image, as shown in Figure 11. The notch on the CAD and cut-piece in the
same position are shown in Figure 12. Calculate the deviation between the two after the notch on the
CAD and the cut-piece are extracted, and then the deviation is converted to the actual value by pixel
equivalent and the results are shown in Table 1.
Table 1. The notch depth and position deviation

| Notch position deviation (mm) | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  |
|------------------------------|----|----|----|----|----|----|----|----|----|
| Notch depth deviation (mm)   | 0.76 | 0.24 | 0.2 | 0.24 | 0.16 | 0.13 | 0.26 | 0.15 | 0.58 |

6. Conclusions
In this paper, a method of notch extraction based on corner point constraint is proposed aiming at the difficulty in measuring the deviation of the notch on the cut-piece. The results show that the notch on the cut-piece can be accurately extracted, and the deviation of the notch on the cut-piece from the notch on the CAD can also be obtained. It can be found that this technology meets the industrial production standards after a lot of experiments.

Acknowledgments
This work is supported by National Nature Science Foundation of China, under grant No. 61771340 and supported by the Program for Innovative Research Team in University of Tianjin No.TD13-5034. And this work is supported by Tianjin Science and Technology Major Projects and Engineering, under grant No. 17ZXHLSY00040, No. 17ZXSCSY00060 and No. 17ZXSCSY00090. This work is also funded by the Tianjin Natural Science Foundation. The funding number is 17JCQNJC01400.

References
[1] Liu, B.C., Zhao, J., Sun, Q.(2013) Harris corner detection method based on edge improvement. J. Chinese Journal of Liquid crystals and Displays, 28: 939-942.
[2] Wang, M., Zhou, Z.Z., Li, C.H.(2015) Harris corner detection algorithm based on pixel point gray difference. J. Computer Engineering, 41: 227-230.
[3] Zhang, J.S., Zhang, H.M., Luo, Y.T.(2017) Image registration method for improved Harris corner detection. J. Laser &Infrared, 47: 230-233.
[4] Xiao, Z.T., Zhu, S.S., Geng, L.(2015) Calibration method for parts dimension measurement system based on depth constraint. J. Infrared and Laser Engineering, 44: 2831-2836.
[5] Wu, X.J., Zou, G.H.(2013) High performance template matching algorithm based on edge geometric features. J. Chinese Journal of Scientific Instrument, 34: 1462-1469.
[6] Duan, Z.Y., Wang, N., Zhao, W.Z. (2017) Sub-pixel edge location algorithm based on Gauss integral curved surface fitting. J. Chinese Journal of Scientific Instrument, 38: 219-225.
[7] Geng, L., Ye, K., Xiao, Z.T. (2016) Measuring method for planar sheet metal parts based on upperand lower edges distinguish algorithm. J. Infrared and Laser Engineering, 45: 204-210.
[8] Liu, X., L, X.L., X, C. (2014) Affine-SURF algorithm for image recognition. J. Application of Electronic Technique, 40: 130-136.