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Sub-pixel Center Extraction Method for Line structured Light Stripe

Yuanjiong Liu¹,², Jian Song¹,²,*, Wenxin Yuan³, Hailang Xue¹,², Sanfeng Li¹

¹Key Laboratory of Metallurgical Equipment and Control of Ministry of Education, Wuhan University of Science and Technology, Wuhan 430081, Hubei, China; ²Hubei Key Laboratory of Mechanical Transmission and Manufacturing Engineering, Wuhan University of Science and Technology, Wuhan 430081, Hubei, China; ³Yixing Jiuzhou Head Co., Ltd., Jiangsu, China

*Corresponding author e-mail: songjian1026@foxmail.com

Abstract. The extraction of line structured light center is a key technology in line structured light measurement system. The precision of light stripe extraction affects the accuracy of the measurement system. Due to the differences of the materials and quality of the laser device, the light stripes is variable in different position that the energy distribution and morphological characteristics are easily changed. It is difficult to extract the center of the stripes by using traditional light stripe extraction methods accurately. Our study proposes an extraction algorithm for the light stripe center. First of all, separating a single stripe from the image according to the morphological characteristics of the light stripe, and the effective region of the light stripe was initially determined. Then, using the grayscale attribute method as well as the grayscale threshold method to determine the region of interest in the center of the light stripe. Finally, the sub-pixel center of the light stripe in the regions of interest was calculated by the grayscale barycenter method. The experimental results showed that the algorithm in the study can be used to extract light stripes with changeable characteristics. It is more accurate and stable comparing with the traditional extraction algorithm of light stripe center.

1. Introduction

Structured light measurement based on laser triangulation [1] is a non-contact measurement method with a wide range of applications, which is widely used in 3D reconstruction [2], guide the processing [3], work-piece measurement [4], and defect detection [5]. In the online structured light vision system, the extraction of the center of the light fringe is an important technology to ensure the accuracy of the system. Light stripe extraction methods are divided into geometric extraction and energy extraction generally. The geometric method is a method to find the center of the stripe according to the geometrical characteristics of the stripe, such as the grayscale threshold method [6] and the edge information method. Since the traditional geometric method is just suitable for the extraction of light fringe centers with uniform morphology and less noise, an adaptive grayscale threshold method and a variable threshold gravity center method have been proposed [7], which can eliminate deficiencies of the traditional method, but the precision of the extraction is not as expected. In order to improve the accuracy of extraction, the energy-centered extraction method was proposed, such as the grayscale barycenter method [8], the directional template method [9], and the Steger method [10]. For the
extraction of high-precision fringe, the directional template method requires more templates and consumes more time. Though Steger has high accuracy, it is not easy to achieve fast extraction of fringe centers with a large amount of calculation. In the grayscale gravity method, the center point of the stripes is used to replace the gravity center of the cross-section stripes. However, deviation errors may occur due to the effect of different pixel values on the cross-section and isolated noise points.

In the complex structured light measurement environment, it is hard to ensure that the energy distribution and morphological characteristics of the stripes remain stable, and which are usually affected by the reflectivity of the object. The energy and morphology of the stripes are changeable in different positions. The traditional extraction method is hard to be adapted to the complex light fringe changes and can’t guarantee the extraction accuracy. Here in this study we proposed a method, which separate single fringes from the mixed image firstly, then, determining the light fringe interested area by the grayscale attribute method [11] and the grayscale threshold method, finally, obtaining the sub-pixel of the region of interest by using the grayscale barycenter method.

2. Laser fringe characteristics

Generally, The line lasers can be considered as obeying Gaussian distribution, and the center point of the cross-section of the Gaussian fringe is the brightest area, and the sides gradually weaken outward. Because the light plane formed by the laser beam reflected by the cylindrical mirror has a certain thickness, the crossing line between the laser beam and the surface of the measured object also has a certain width, which is called light streaks. The distribution of light fringes on the cross section does not completely obey Gaussian distribution, because it is influenced by the external environment and the laser’s own property.

![Figure 1. Structure of structured light stripes](image)

3. Extraction of sub-pixel center

3.1 Image pre-processing

![Figure 2. Laser stripe pre-processing](image)
Firstly, threshold segmentation was performed on the light fringe image after grayscale processing. Then, finding the maximum value of each line of the fringe image, and the average of the maximum values in each row. Finally, using the average point \( P(i,j) \) as the center point of the light fringe. Generally, we often use 13 pixels to represent the width of the light stripes in the laser image. Due to the influence of energy changes and morphological characteristics, taking the point \( P(i,j) \) as the center and along the light fringe extension direction, taking 13 pixels on each side of the laser fringe cross section as the effective areas of the light stripes. Since noise is usually generated during image acquisition, median filtering is used to remove noise points after determining the effective region of fringe.

3.2 Central area determination

3.2.1 Grayscale attribute method. The grayscale attribute method is an energy-based light stripe extraction algorithm. Firstly, taking a region with a length of 7 pixels as computational domain, which include the first 3 pixels and the last 3 pixels of the center point, and assign a weight to each point in the neighborhood. Then, the effective areas of the stripes in the region with a length of 7 pixels are calculated in order. Finally, finding the maximum value and taking the position of the maximum value as the center of the light stripe line. The size of the images is \( (M, N) \), where the size of the pixel is \( I(i,j) \). The algorithm was implemented as follows:

Step1. Using the grayscale attribute method to obtain the maximum position of each line in the effective area of the stripe, and calculate \( A(i,j) \) for each point in the striped region.

\[
A(i,j) = [1 \ 1 \ 2 \ 4 \ 2 \ 1 \ 1] \\
\begin{bmatrix}
I(i,j-3) \\
I(i,j-2) \\
I(i,j-1) \\
I(i,j) \\
I(i,j+1) \\
I(i,j+2) \\
I(i,j+3)
\end{bmatrix}
\]

Step2. Calculating the eligible \( A(i,j) \) in turn. \( A(i,j) = \text{max}[A(i,j), i = 1,2, \cdots] \), the point \( I_{\max}(i,j) \) is the position with the largest gray value on the light stripe.

Step3. Point \( I_g(i,j) \) and point \( I_{\max}(i,j) \) are equal in size, where \( I_g(i,j) \) is the boundary point of the sub-pixel extraction center area. \( T_i \) is the effective value for segmentation threshold, where \( T_i = k \times (I_{\max}(i,j)) \), and \( k \) is the threshold segmentation coefficient.

3.2.2 Grayscale Threshold method. The grayscale threshold method is one of the methods for extracting the geometric center of light stripes. It is suitable for extracting the center of light stripes with uniform energy distribution. Firstly, completing the threshold segmentation of light stripes, then, selecting two thresholds in the cross section of the light fringe as the segmentation threshold, finally, calculating the midpoint of the segmentation threshold as the center point of the light stripe. The algorithm was implemented as follows:

![Figure 3 Schematic diagram of threshold segmentation](image)

Step1. Setting the segmentation threshold is \( T_i \), where \( k \) is 0.6.
Step 2. Using the grayscale threshold to segment the effective region of the light stripe, which is in the single-striped image. Finding out the points $p_{t_j}$ and $q_{t_j}$ that correspond to the segmentation threshold of each line, where $I_t(x_i, y_j)$ is the boundary point of the sub-pixel extraction center area.

\[
\begin{align*}
    p_{t_j} &= n + \frac{L - I(n)}{i(n+1)-i(n)} \\
    q_{t_j} &= m + \frac{L - I(m)}{i(m+1)-i(m)} \\
    x_i &= i \\
    y_j &= \frac{(p_{t_i} + q_{t_i})}{2}
\end{align*}
\] (1)

3.3 Extraction of fringe sub-pixel center

The grayscale barycentric method is an energy-based light fringe extraction method. Since the gray value of the light fringe in the cross section of each line obeys the Gaussian distribution, the gray center of gravity of light fringe was calculated and taken as the center of the light fringe. Using the grayscale attribute method and the grayscale threshold method to calculate the region of interest (ROI) in the center of the light stripe within the effective region. Calculating the final light stripe center point in the light stripe ROI by the gray barycenter method, and where the point $F_i(i, j)$ is the light pixel sub-pixel center of each line. The algorithm was as follows:

Step 1. Determination of ROI

Comparing the position of the center point between the grayscale attribute method and the grayscale threshold method to determine the effective region of the light fringe on each section. The point $I_l(i, j)$ is the left boundary point of the ROI region, while the right boundary is point $I_r(i, j)$, $I_g(i, j)$ is the center point of the light stripe extracted by the grayscale attribute method, and $I_t(i, j)$ is the light fringe center point extracted through the grayscale threshold method.

Determining the left boundary point of the ROI, which was extracted by the grayscale attribute method and the grayscale threshold method;

\[
\begin{align*}
    &\begin{cases}
    I_l(i, j) = I_g(i, j) \quad (I_g(i, j) < I_t(i, j)) \\
    I_l(i, j) = I_t(i, j) \quad (I_g(i, j) \geq I_t(i, j)) \\
    \end{cases}
\end{align*}
\] (3)

Determining the right boundary point of the ROI, which was extracted by the grayscale attribute method and the grayscale threshold method:

\[
\begin{align*}
    &\begin{cases}
    I_r(i, j) = I_g(i, j) \quad (I_g(i, j) > I_t(i, j)) \\
    I_r(i, j) = I_t(i, j) \quad (I_g(i, j) < I_t(i, j)) \\
    \end{cases}
\end{align*}
\] (4)

Step 2. Extracting sub-pixel center of the light stripes

The ROI of each row in the light stripe effective region is $(j_l, j_r)$. The center of each line in the ROI was extracted by the grayscale barycenter method. The ROI length of each row may be different that affected by external factors, such as reflectivity.

\[
\begin{align*}
    x_i &= i \\
    y_j &= \frac{\sum_{i=j_l}^{j_r} I(i, j) \cdot i}{\sum_{i=j_l}^{j_r} I(i, j)}
\end{align*}
\] (5)

The light fringe center $F_i(x_i, y_j)$ of each line was extracted by the grayscale barycenter method in turn till the full image acquisition was completed. Finally, fitting the extracted light fringe center with a straight line to obtain the final light fringe straight line.
4. Experiment and analysis

4.1 Introduction of the experimental system

The experimental system is shown in Figure 5. A line laser with a wavelength of 650 nm was used to project laser fringe on the work-piece. The light fringe information was collected with the Charge Coupled Device (CCD) camera. Setting the image resolution to 512×384. In the experiment, the laser fringe was projected on 6 different work-pieces, and the light fringe information was acquired through CCD, and then the light fringe center was extracted by the stripe center extraction algorithm. The extraction results were shown in Figure 6. The center of the extracted light stripe is approximately the
same as the center and direction of the actual light stripe, which is consistent with the expected center line distribution of the light fringe.

![Figure 6](image)

Figure 6 Extraction of light streak center of different shapes

### 4.2 Analysis

| Stripe type | Maximum deviation | Mean deviation | Mean square error |
|-------------|-------------------|----------------|------------------|
|             | Suggested         | Grayscale      | Grayscale        | Suggested         | Grayscale      | Suggested         | Grayscale      |
|             | algorithm         | barycenter     | threshold        | algorithm         | barycenter     | algorithm         | threshold        |
| a           | 3.5               | 10.7           | 7               | 0.94             | 3.33           | 2.11             | 0.79             | 2.17             | 1.56             |
| b           | 2.47              | 24.10          | 5.50            | 0.56             | 5.72           | 1.44             | 0.52             | 4.57             | 1.08             |
| c           | 0.93              | 8.75           | 2.50            | 0.021            | 2.63           | 0.31             | 0.107            | 1.72             | 0.322            |
| d           | 1.78              | 29.20          | 4.00            | 0.51             | 11.06          | 1.29             | 0.404            | 6.98             | 0.82             |
| e           | 4.54              | 29.10          | 35.1            | 0.28             | 8.43           | 1.13             | 0.451            | 4.77             | 2.77             |
| f           | 0                 | 6.53           | 1               | 0                | 1.60           | 0.20             | 0                | 1.27             | 0.24             |

The center of the fringe extracted by the grayscale attribute method is similar to the actual fringe, so it is used as the basis [12] to calculate the distance between the center of the fringe extracted by it and the suggested method, the traditional grayscale barycenter method and the grayscale threshold method. The analysis results are shown in Table 1. The light stripe extraction algorithm proposed in
this paper is more accurate and stable than the traditional grayscale barycenter method and the grayscale threshold method. The center of the light stripe is closer to the real light stripe.

5. Conclusions
Our study proposes a light stripe center extraction method that can be used in complex environments, and which combines the characteristics of the energy extraction method and the geometric extraction method. Then, establishing an experimental platform to get different types of light stripes, and the center of the light fringe was extracted by the method proposed in this paper, the traditional grayscale attribute method and the grayscale threshold method respectively. The results show that the method proposed in this study is more effective than others, and which can maintain a high extraction accuracy and the extraction accuracy reaches the sub-pixel level when the gray fringe cross-section feature distribution of the laser stripe is abnormal.

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