A High Precision Rotating Line Detection Method for the Rotation Angle Measurement Based on Machine Vision

Hao Cheng¹, Chenguang Cai²,a, Ying Wang³,a,ß, Zhihua Liu² and Ming Yang¹

¹College of Information Science and Technology, Beijing University of Chemical Technology, No. 15, Bei San Huan Dong Lu, Beijing, China
²National Institute of Metrology, No.18, Bei San Huan Dong Lu, Beijing, China
³Institute of Microelectronics of the Chinese Academy of Sciences, NO.3 Beituqcheng West Road, Beijing, China
⁴University of Chinese Academy of Sciences, No.19(A) Yuquan Road, Beijing, China

E-mail: acaichenguang@nim.ac.cn, bwangying@mail.buct.edu.cn

Abstract. The accuracy of the rotation angle measurement method based on machine vision with the line as the reference target is limited by line detection accuracy. The Line Segment Detector (LSD) method is a high precision and effective method, but there are detected false lines and discontinuous lines when the LSD method is actually used to detect the rotating lines in the images. In this paper, we adjust three parts of the LSD method: image scaling, gradient magnitude threshold, and aligned points density threshold to detect lines accurately. The high precision detection of the rotating line is obtained by our adjusted method. Besides, the rotation angle measurement accuracy with the lines detected by our adjusted LSD reaches the measurement error level of arcseconds, which proves its effective performance.

1. Introduction

In recent years, rotation angle measurement has been widely demanded in industrial, military, aerospace and other fields [1]. The high measurement accuracy of the rotation angle has been paid more attention [2]. At present, the machine vision method [3] has received widespread attention with its merits of simplicity, accuracy, efficiency, and it was used to measure the rotation angle. Generally, the machine vision method measures the rotation angle by the reference target fixed on the measured object [4]. Most reference targets are composed of points or lines, so we can get the rotation angle of the measured object by detecting the position change of points or lines. The angle measurement by the spot array achieves high measurement accuracy [5]. Compared with the spot array, the line target with simple manufacturing is easy to detect accurately. The rotating lines in the captured images are detected and fitted [6]. The rotation angle is measured by calculating the change of the detected line slopes at different positions. Obviously, the line detection accuracy in the image greatly affects the angle measurement accuracy. Therefore, it is very significant to find a high precision line detection method.

To accurately detect the position and direction of the rotating lines in the image in this paper, a fast and effective line detection method should be chosen. Generally, the line detection methods are divided into two categories: Hough transform method and perceptual grouping method [7]. The line detection methods based on Hough transform, such as PPHT [8] and MCMLSD [7], can not detect line endpoints.
and adjacent lines accurately. LSD [9] is a perceptual grouping method that has the advantages of higher accuracy, faster processing speed and no need to adjust parameters. However, there are detected false lines and discontinuous lines when the LSD method is actually used to detect the rotating lines in the images. Aiming to reduce the detected false lines and the discontinuous lines, we adjust three parts of the LSD method: image scaling, gradient magnitude threshold and aligned points density threshold in order to detect the high-precision lines.

2. Principle

2.1. The principle of the rotation angle measurement based on machine vision method
Figure 1 shows the rotation angle measurement sketch based on machine vision method. The reference target fixed on the working surface is a circle pattern consisting of several lines with equal angle intervals. And it has the same rotation angle as the working surface. The rotor can drive the working surface to certain angles. The camera optical axis is perpendicular to the working surface and the view field of the camera covers part of the reference target marked by the dotted rectangle. And the reference target images in the rectangle are captured by the camera and transmitted to the computer. The rotation angle is measured by the lines within the view field of the camera.

![Figure 1. Sketch of the rotation angle measurement based on machine vision method](image)

The position of lines in the 1st image is specified as the reference zero of the angle. Then we detect the position of the corresponding lines in the image at the rotated position. The rotation angle is measured by calculating the angle of corresponding lines between the image of the measured position and the 1st image. To improve the reliability of the angle measurement, three lines in each frame are selected and the average of their rotation angles is considered as the measured rotation angle. The rotation angle between the \(i\)th image and the 1st image is calculated by formula 1 as follows:

\[
\theta_n = \arctan \frac{k_{in} - k_{in}}{1 + k_{in}k_{in}}
\]

where \(k_{in}\) and \(k_{in}\) are respectively the slopes of the \(n\)th line in the 1st frame and the \(i\)th frame image and \(n = 1, 2, 3\). The rotation angle \(\theta\) is the average of \(\theta_n\). It is obvious that slopes \(k_{in}\) and \(k_{in}\) of the lines affect the measured accuracy of the rotation angle. Therefore, a high precision line detection method should be proposed to detect the rotating lines in images.
2.2. Line detection method based on the adjusted LSD

The typical LSD method is shown in figure 2. First, the original image is scaled to avoid image blur and line aliasing. The gray gradient magnitude and gradient direction of each pixel in the scaled image are calculated. Pixels with a high gradient magnitude and a similar gradient direction correspond to the contrasted straight-line edges. The gradient magnitude threshold and gradient direction tolerance are set to get the candidate pixels. And the line support region is generated by the candidate pixels. The minimum enclosing rectangle of the line support region is obtained by the approximation method. The aligned points density which represents the proportion of candidate pixels in the rectangle is used for adjusting the rectangle region. The principal inertia axis of the rectangle is the detected line.

The typical LSD gets the candidate pixels from the scaled images, which loses more grayscale information existing in the original image and decreases the line detection accuracy. In this paper, we directly use the original image instead of the scaled image to detect the line to improve the detection accuracy. Actually, there are a large number of gray distribution changes due to the uneven surface of the reference target. It leads to detect the false lines, which seriously interferes with the correct line detection. Besides, several short discontinuous lines often are detected instead of one line in the original image. As shown in the red dotted lines of figure 2, we adjust the LSD method by following steps to get higher line detection accuracy:

2.2.1. Canceling image scaling. Typical LSD method scales original images by Gaussian descending sampling which causes the blurred edge. To detect the precision line position, we cancel the image scaling instead by the original images directly which effectively reduces the number of detected false lines caused by image blur.

2.2.2. Increasing gradient magnitude threshold. The original image gradient is calculated by two 2x2 masks along x, y directions respectively as follow

\[
\begin{bmatrix}
-1 & -1 \\
1 & 1
\end{bmatrix}
\]
\[
\begin{bmatrix}
1 & 1 \\
-1 & 1
\end{bmatrix}
\]

The gradient magnitude is computed by

\[
G(x, y) = \sqrt{g^x(x, y)^2 + g^y(x, y)^2}
\]
where \( g_x(x, y), g_y(x, y) \) are the image gradients of the pixel by the two masks.

Because there are some noises in origin images, some pixels are determined as the candidate pixels of the line support region mistakenly with the parameters of the typical LSD method. These noises lead to the detected false lines. Therefore, we increase the gradient magnitude threshold whose value is between the gradient magnitude of noises and gradient magnitude of expected lines. This adjusted threshold reduces the detected false lines effectively and avoids affecting expected line detection.

2.2.3. Decreasing aligned points density threshold. The candidate pixels which satisfy gradient magnitude threshold and gradient direction tolerance in the rectangle are called aligned points. The density \( d \) of aligned points in the rectangle is calculated by

\[
d = \frac{k}{l_r \times w_r}
\]

where \( k \) is the number of aligned points and \( l_r, w_r \) are the length and the width of the rectangle.

\( T_d \) is the threshold of the aligned point density. If \( d \) is larger than \( T_d \), the rectangle is determined as the detected line. \( T_d \) set by the typical LSD is large which leads to detect multiple lines for one line. Therefore, we decrease \( T_d \) to avoid detecting some discontinuous lines for one line.

3. Experimental results

3.1. Rotating line detection experiment

To verify the applicability of our adjusted LSD method, we measured the rotation angle by the machine vision measurement system. The working surface is on the precision mechanical turntable and the reference target is fixed on it. The AVT Manta G-125B (resolution 1296x964 pixels and frame rate 30 fps) is applied to collect rotating line images. The expected six edge lines of the three lines in each image were detected by our adjusted LSD method.

As shown in figure 3(I), the lines in the captured image are detected by the typical LSD method and the adjusted LSD method respectively. The local enlarged images (figure 3(II, III)) are dotted by red and blue rectangles in figure 3(I) respectively. We can observe the detected false lines in figure 3(II) and the discontinuous lines by the local enlarged images. As figure 3(a) shown, there are some detected false lines and discontinuous lines in figure 3(III) by the typical LSD method. The detected false lines are reduced and discontinuous lines are increased by the typical LSD with the original image, as figure 3(b) shown. There are scarcely any detected false lines and discontinuous lines by increasing the gradient magnitude threshold and decreasing the aligned points density threshold with the original image as figure 3(c) shown. Lines in multiple images captured under the same hardware facilities and environmental conditions are detected by the typical LSD and our adjusted LSD respectively. Compared with the method in [9], there are no false lines and discontinuous lines by our adjusted LSD as shown in table 1.
Figure 3. The detection results of rotating lines with the typical LSD and the adjusted LSD

Table 1. Comparison of our adjusted LSD method and the typical LSD method

|                      | The number of detected lines | The number of false lines and discontinuous lines |
|----------------------|------------------------------|--------------------------------------------------|
| The typical LSD      | 105                          | 99                                               |
| Our adjusted LSD     | 6                            | 0                                                |

3.2. Measurement result of the rotation angle

To prove the feasibility of the adjusted line detection method, the mechanical turntable was controlled to rotate from 0° to 1°. The angel within this range was rotated with the 0.1° interval, and 11 angles were measured totally. The camera collected rotation line images, and 10 frames were collected at each position. We used the adjusted LSD method to detect the lines in these 11 sets of rotation images and the average of lines’ slopes in each set of images was regarded as the line slopes of this position. The rotation angles were calculated by the line slopes between the images of the reference zero position and the measured position. Three lines in each rotation line image were used, and the average of the rotation angle of each line was regarded as the measured rotation angle. As indicated in table 2, 11 measured rotation angles and their errors were listed.
Table 2. Measured rotation angles and errors.

| Text NO. | Theoretical Value (°) | Measurement Value (°) | Measurement Error ("') |
|----------|-----------------------|-----------------------|------------------------|
| 1        | 0                     | -0.00010              | -0.360                 |
| 2        | 0.1                   | 0.10005               | 0.187                  |
| 3        | 0.2                   | 0.20022               | 0.792                  |
| 4        | 0.3                   | 0.30022               | 0.781                  |
| 5        | 0.4                   | 0.40057               | 2.038                  |
| 6        | 0.5                   | 0.50015               | 0.536                  |
| 7        | 0.6                   | 0.60051               | 1.847                  |
| 8        | 0.7                   | 0.70034               | 1.228                  |
| 9        | 0.8                   | 0.79979               | -0.756                 |
| 10       | 0.9                   | 0.89982               | -0.659                 |
| 11       | 1                     | 0.99982               | -0.634                 |

4. Conclusions
In this paper, the adjusted LSD method was used to detect the rotating lines in the image. Experiments had well verified that the discontinuous lines and detected false lines were reduced by canceling the image scaling, increasing gradient magnitude threshold and decreasing aligned points density threshold. The adjusted LSD method improved the accuracy of rotating line detection and the measurement accuracy of rotation angles with the rotating lines detected by our adjusted LSD method was further improved meanwhile.

Acknowledgments
This work was supported by the National Key R&D Program of China (No. 2017YFF0205003), and the National Natural Science Foundation of China (No. 61675211).

References
[1] Wu Y, Cheng H and Wen Y 2018 High-precision rotation angle measurement method based on a lensless digital holographic microscope Applied optics 57 112-8
[2] Kim H, Yamakawa Y, Senoo T and Ishikawa M 2016 Visual encoder: robust and precise measurement method of rotation angle via high-speed RGB vision Optics Express 24 13375
[3] Suzuki and Takamasa 2001 Small-rotation-angle measurement using an imaging method Optical Engineering 40 426
[4] Jin J, Zhao L and Xu S 2014 High-precision rotation angle measurement method based on monocular vision JOSA A 31 1401-7
[5] Li W, Jin J, Li X and Li B 2010 Method of rotation angle measurement in machine vision based on calibration pattern with spot array Applied optics 49 1001-6
[6] Li L, Yu Q, Lei Z and Li J 2005 High-accuracy measurement of rotation angle based on image Acta Optica Sinica 25, 491–496
[7] Almazan E J, Tai R, Qian Y and Elder J H 2017 Mcmlsd: A dynamic programming approach to line segment detection. In: Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, pp 2031-9
[8] Matas J, Galambos C and Kittler J 2000 Robust Detection of Lines Using the Progressive Probabilistic Hough Transform Computer Vision & Image Understanding 78 119-37
[9] Von Gioi R G, Jakubowicz J, Morel J-M and Randall G 2008 LSD: A fast line segment detector with a false detection control IEEE transactions on pattern analysis and machine intelligence 32 722-32