Encoder Grating Engraved-line Detection System Design Based on Machine Vision

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Abstract. The detection of encoder grating engraved-line uniformity, is important in the encoder production debugging. Aiming at the shortcomings of the traditional method of signal processing using the encoder output, the real-time performance of the encoder is not strong, the operation is complex, the precision is not high, the debugging is inconvenient and so on, a black and white ratio detection method based on image processing is proposed. Using the CCD industrial camera to image acquisition and the edge image of the grating engraved-line is obtained by the image processing, and the edge of the grating line is obtained by the least squares straight line fitting. The actual black and white ratio is obtained by the ratio of the adjacent straight lines distance from the point to the two sides, Compared with the design value obtained by the black and white margin error to evaluate its uniformity. The experimental results show that the method can effectively to test the grating engraved-line uniformity.

1. Introduction

Photoelectric encoder is a set of light, machine, electrical technology in one of the digital angular displacement sensor [1]. It is widely used in industrial production and scientific research of radar, precision instruments, and robots and so on. It is ideal for automation equipment as an angle sensor. Sources of error in encoder production include assembly errors and self-error. The self-error includes the code-track-error, engraving-error and uniformity-error. And Uniformity errors include optical density inconsistency, surface defects and the change of grating line-width [2]. In the actual production, the subdivision precision of fine code signal mainly depends on the engraving process [3]. Uniformity of grating engraved-line is an important means of grating engraving production. Changes in grating engraved-line width are the determinants factors of encoder uniformity error, and it represented by the ratio of black and white [4].so the study of the black and white ratio of the grating engraved-line is of great significance to the encoder production before entering the factory quality inspection.

At present, for the grating line-width scoring uniformity error detection, mainly using photoelectric conversion to obtain the distribution of grating engraved-line such as the method of comparing-phase which invented by the Institute of Optical-mechanical Chang Chun [5].Based on the method of electrical signal processing, the circuit system is complex, the detection is not accurate, and can not be very effective and fast realization of the encoder grating engraved-line uniformity detection.
Machine vision is to replace the human eye with the machine to complete the observation and judgment, commonly used in mass production process of product quality testing and not suitable for people's dangerous environment and human eye is difficult to meet the occasion [6]. Machine vision can greatly improve the accuracy and speed of detection, to improve productivity and avoid deviation and error in human visual detection.

In order to solve the existing problem that circuit-based design method, such as the accuracy of the encoder is not strong, the stability is not strong, the speed is not fast, real-time is not strong, the method based on image processing that the ratio of the black and white is proposed. First, the PC software which created by matlab is used to control the CCD industrial cramea to acquisit the image of the grating and then extracted the feature edge of the grating engraved-line through image processing. finally, the least squares linear fitting is applied to fit the edge of the grating engraved-line. The distance between the points and the straight line is calculated by the parameters of the linear equation, and the corresponding black and white ratio is obtained.

Since the engraving processing, the grating of the encoder is black and white in the image, so the quality of the grating engraved-line can be measured by the ratio of black and white. And the ratio of black and white can be used to represent the error of grating engraved-line uniformity. The black and white ratio of the grating engraved-line can be expressed as the ratio of the spacing of adjacent radial edges of the grating engraved-line image.

2. System composition and working principle

2.1. Hardware section
The tested parts involved in the system research is the grating, and the designed width of fine grating engraved-line is 0.5mm. the designed value of the ratio of black and white is 1.1. and the range of the grating engraved-line uniformity error is ±5%. the tested parts is showed in figure 1, And the structure of the grating engraved-line detection system is showed in figure2.

![Figure 1. Grating](image1)

![Figure 2. Hardware section](image2)

The system mainly consists of hardware part, software part and display part. When grating engraved-line error calculation, by the stage with the CCD camera to capture multiple grating images. Using the PC software written by MATLAB to process the acquired image, and combined with the design error algorithm to obtain the error of the grating engraved-line.

2.2. System working principle
The system works as follows: The tested grating is placed on a mobile platform, adjust the mobile platform so that grating will be in the best photographing state when captured its image. The ring light
to provide a stable light source, the use of forward lighting on the tested grating. TD-CD-type CCD industrial camera connected to the XDS-0745 standard microscope lens, and the camera through the USB serial cable connected to the PC. The image is directly transmitted to the computer, and the feature extraction of the grating engraved-line edge is performed by using the calculation software, the edge straight line is fitted, and then the grating engraved-line error is calculated. Image computing software has the features included: Control the camera, Capture images, Image preprocessing [7] (Banalization, Image filtering, Edge extraction), Region segmentation, grating engraved-line edge fitting, the ratio of black and white calculation. Because the lens limitations of vision, and to measure the uniformity of the grating engraved-line of encoder code, it is necessary to collect the entire circumference of the grating engraved-line image, the grating image acquisition need to rotate the mobile platform, to achieve whole grating engraved-line image.

3. The key algorithm of the system software

3.1. Image preprocessing

In the image acquisition, transmission and other links will be accompanied by some noise, Lens-distortion, etc., if not handled properly will affect the accuracy of experimental results. Image preprocessing is mainly used to simplify image data, facilitate image transmission, and filter out image noise to improve image signal-to-noise ratio. The original image and the Image preprocessing results are shown in Figure 3, Figure 4, Figure 5, respectively.

3.2. Edge detection and region segmentation

It is necessary that detected the edge of scoring-line because the Error detection grating scoring-lines concerned line edge. According to algorithm design, the region of interest we concerned only five line in the picture, so the operation of the area segmentation must be down. This saves memory and increases the speed and efficiency of the algorithm. The results are shown in Figure 6, Figure 7, Figure 8, respectively.
3.3. The method of the ratio of black and white based on the distance between point and line.

3.3.1. The ratio of the spacing of adjacent straight lines. In the coordinate system XOY, there are three adjacent lines L1, L2, L3. As shown in Figure 9.

![Figure 9. Schematic diagram](image)

Assume that the linear equation of L1 is:

$$Ax + By + C = 0$$  \(1\)

The distance from the point M \((x_i, y_i)\) which is on the line L2 to the straight line L1 is:

$$D = \frac{|Ax_i + By_i + C|}{\sqrt{1 + (\frac{A}{B})^2}}$$  \(2\)

Take \(k = -\frac{A}{B}\) as the slope of the line L1, and the \(b = -\frac{C}{B}\) as the intercept of line L1. So the distance from the point M \((x_i, y_i)\) to the line L1 is that:

$$D_{21} = \frac{|y_i - y_i'|}{\sqrt{1 + k^2}}$$  \(3\)

\(y'_i, y_i\) are the values of \(x_i\) in the corresponding L1 and L2.

Similarly, the distance between the M point on the straight line L2 and the adjacent straight line L3 can be obtained. It is marked as \(D_{23}\). If the lines L1, L2, L3 are the adjacent radial edges extracted by the image of grating engraved-line, and take the distance between L1 and L2 as the width of black grating engraved-line, the distance between L2 and L3 as the width of white grating engraved-line. So the black and white ratio of the grating engraved-line can be defined as:

$$R = \frac{D_{21}}{D_{23}}$$  \(4\)
3.3.2. Linear Fitting Method of Edge Pixel. The edge pixels on the code channel image are not in a straight line. By the least squares linear fitting method used in code edge pixels, the equation of edge fitting straight line is obtained. The least squares linear fit is that the N group of data \((x_i, y_i), i = 1 \sim N\) obtained for equal precision measurements, and all errors are only determined by \(y_i\) [10]. When the parameters estimating with the least squares method, needing the weighted sum of squares of the deviations of the observed values is minimized. The parameters are as follows:

\[
\begin{align*}
    k &= \frac{\left(\sum_{i=1}^{N} x_i^2\right)\left(\sum_{i=1}^{N} x_i y_i\right) - \left(\sum_{i=1}^{N} x_i\right)\left(\sum_{i=1}^{N} x_i y_i\right)}{N\left(\sum_{i=1}^{N} x_i^2\right) - \left(\sum_{i=1}^{N} x_i\right)^2} \\
    b &= \frac{N\left(\sum_{i=1}^{N} x_i y_i\right) - \left(\sum_{i=1}^{N} x_i\right)\left(\sum_{i=1}^{N} y_i\right)}{N\left(\sum_{i=1}^{N} x_i^2\right) - \left(\sum_{i=1}^{N} x_i\right)^2}
\end{align*}
\]

The slope of the edge fitting line is \(k\), and its intercept is \(b\).

3.3.3. The ratio of Black and white. Take a number of points from the fitting line, and get the distance \(D_1\) and \(D_2\) from the adjacent edges fitting line on both sides. Calculating the black and white ratio \(R\), getting the error after comparing the design value (=1.1) with \(R\)’s average. We will get four straight line (L0 ~ 3) by fitting the upper and lower edge of the grating scoring-line as shown in Figure10. And the ratios of black and white are shown in Figure11, and their errors are shown in Table 1.

![Figure 10. The edge line fitting](image1)

![Figure 11. The ratio of black and white](image2)

**Table 1.** The ratio of black and white error

| \(i\) | \(\text{min}\Delta R_i\) | \(\text{max}\Delta R_i\) |
|------|----------------|----------------|
| 1    | 0.002          | 0.040          |
| 2    | -0.016         | 0.046          |
| 3    | -0.011         | 0.039          |
4. Software Design
Based on the above research, the software design of grating line detection system was completed. It includes Image acquisition module, Image processing module, GUI interface and Algorithm implementation module. The System software design framework are shown in Figure 12, System interface screenshot shown in Figure 13.

![System software design framework](image)

**Figure 12.** The system software design framework

![System interface screenshot](image)

**Figure 13.** System interface screenshot

5. Conclusions
In this paper, we studied a grating engraved-line quality detection system based on machine vision. And the image processing technology is applied to the grating engraved-line of encoder. Proposed a method of least squares fitting line to acquired black-white ratio of the grating engraved-line. To overcome the shortcoming of the traditional hardware-based circuit approach, with high precision measurement, real-time good, convenient and so on.

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