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Sub-pixel measurement system for grid's width and period based on an improved partial area effect

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ABSTRACT

Based on the partial area effect of charge-coupled device (CCD), a sub-pixel line detecting algorithm is proposed to measure the width and the period of a metal grid. An optical pointing system is developed and applied to accurately measure the line-width and the period of a grid. The grid's moving image is captured by the developed system. From the obtained images, one can determine position of a line with sub-pixel resolution. By controlling the grid's movement and aiming at the grid, the absolute coordinates of a grating ruler are obtained. Simulated calculations and experiments are performed with recorded video images to validate the performance of the proposed algorithm. The results show that the precision of the proposed estimation algorithm can reach 0.025 pixels for a moving image.

1. Introduction

Because of the characteristics such as nondestructive, high-resolution and ease of maintenance, the machine vision technique has been widely employed for the displacement measurement and geometrical measurement [1–4]. For the displacement measurement, there are two categories of displacement analysis technique, which are spatial domain technique and frequency domain technique [5]. For example, the block matching (BM) algorithm [6–9] is a typical spatial method. For the frequency methods, we can quote the cross-correlation [10–12] and the phase-correlation [13,14].

For geometrical measurement, it is essential to implement subpixel edge analysis for the acquired images to achieve a higher measurement accuracy. Sub-pixel edge methods can classified into three categories: interpolating-based, fitting-based and moment-based. Interpolating-based method performs the sub-pixel edge location by interpolating the image in terms of gray-distribution in actual images [15–17], which has a simple calculation process but susceptible to noise. The fitting-based method attempts to obtain sub-pixel edge location by fitting gray region of the image according to the given edge mode [18–20], which is insensitive to noise but slow to execution due to complex model. The moment-based method obtain the analytic solution of the edge position by gray or spatial integral [21,22], which is non-sensitive to noises but difficult to choose the applicable model.

In addition to the choice of various methods, there are significant differences caused by many factors between the acquired image and the original image. Diffraction effect and CCD pixel dark areas are existed in an image system. Accurate edge analysis at sub-pixel level is theoretical and engineering challenge. In order to solve such problem, we proposed a line edge analyze algorithm based on improved partial area effect. In addition to geometrical measurements, this method can also be used to measure displacement by tracking the positional changes of the same object's edge, and it has the same accuracy as the frequency domain correlation method. An experimental platform is built to validate the edge extraction and location capabilities of our proposed partial area effect based algorithm. Meanwhile, an optical pointing system and a set of line-width and period measurement system with sub-pixel resolution are developed for grid measurement.

In Section 2, the sub-pixel tracking method based on an improved partial area effect are introduced. In Section 3, the optical sighting system is numerically analyzed. In Section 4, the line-width and period measurement system are developed. Conclusions are given in Section 5.

2. Sub-pixel tracking of the line in a grid

Theoretically, for camera captured image, the edge luminosity of a moving object is variable even the sensor with the fill factor of 100% [5]. Because of optical diffraction, the change between dark and bright areas usually occurs in the range of several pixels, even the displacement is smaller than one pixel, as shown in Fig. 1. Therefore, one can measure the object displacement from the obtained images. The smallest detectable displacement is directly determined by the performance of CCD and the detection algorithm.

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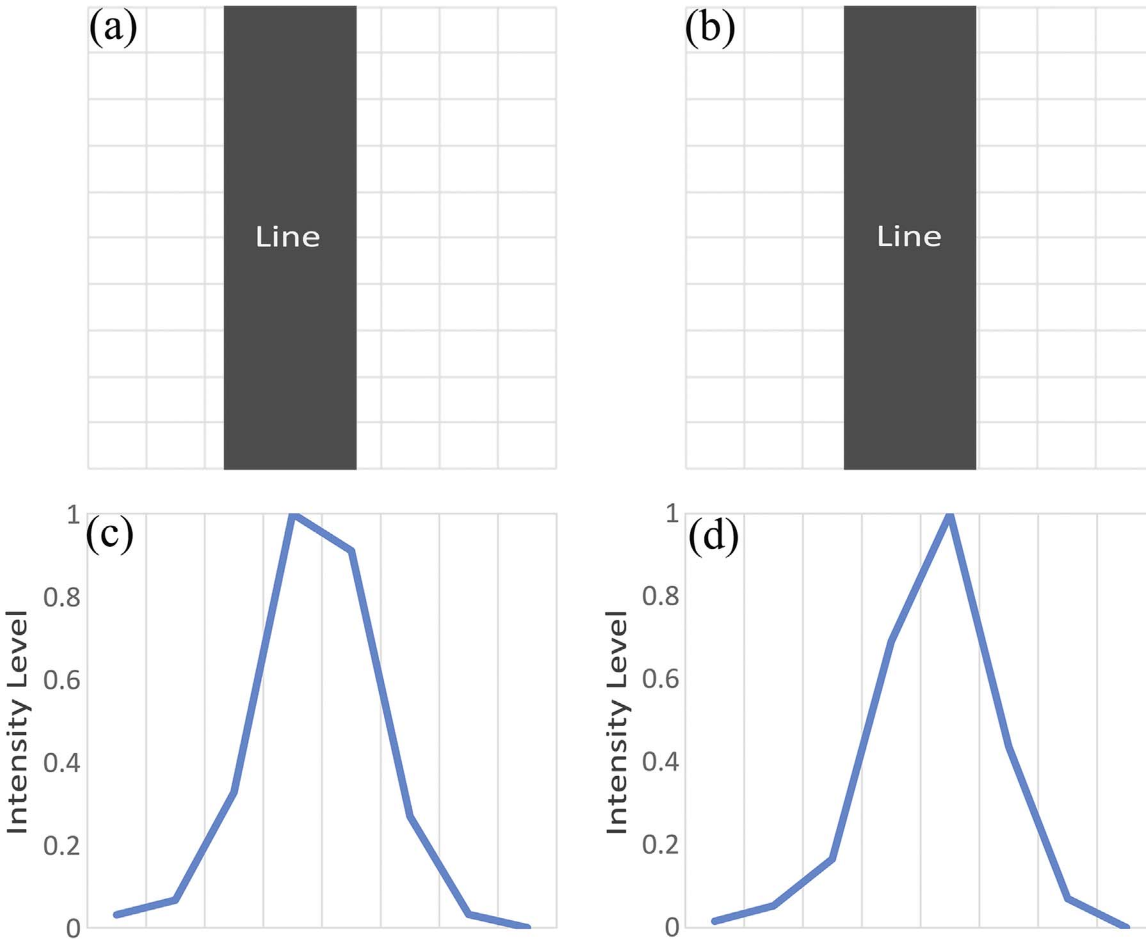

Fig. 1. Ideal case of a displacement for linear model. (a) Image of the original object and (b) image of the moved object. (c) and (d) are intensity projection curves of (a) and (b).

2.1. Extracting straight-line area

Assumed that the measured object is rigid, one can determine the grid displacement by any line in the obtained image to avoid the measurement of each pixel in image. In order to confirm the direction of grid motion in x-y plane, the measured object is set to the orthotropic straight lines. The horizontal and vertical lines are measured by the movement along y- and x- directions, respectively.

Because the grid image is a regular shape, the projection algorithm is applied to analyze the grid displacement. The projection points in the projection algorithm can extract the straight line directly. For the parallel lines in Fig. 2, one can obtain the following vertical projection integral,

$$P_j = \frac{1}{M}\sum_{\forall i} I_{i,j}, \tag{1}$$

where M is the sum of the row index i. The new vector P_j^* is the normalization of P_j and P_j^* is expressed as following,

$$P_j^* = \frac{P_j - \min(P_j)}{\max(P_j) - \min(P_j)}. \tag{2}$$

Similarly, the horizontal projection P_i^* is expressed as,

$$P_i^* = \frac{P_i - \min(P_i)}{\max(P_i) - \min(P_i)}. \tag{3}$$

To eliminate the aliasing effect, the adjacent area overlapping between the two lines is removed. Meanwhile, the rectilinear projection angle θ should be larger than atan(l/d). l is the length of the whole line of the grid, and d is the distance between two adjacent lines. A pixel $I_{i,j}$ is once traversed and the projection integral is time-saving.

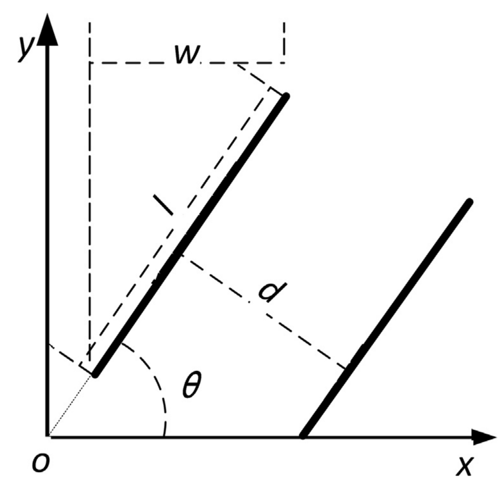

Fig. 2. Inclination of straight lines.

2.2. Straight line edge sub-pixel detection

In order to obtain the accurate position of a line, the sub-pixel edge detection based on partial area effect is employed to precisely locate the edge [23]. The principle of the partial pixel effect is displayed in Fig. 3(a). Considering the partial area effect, if an edge is crossing over pixel (i,j), the intensity $F_{i,j}$ of pixel (i, j) is governed by,

$$F_{ij} = \frac{I_A \cdot S_A + I_B \cdot S_B}{h^2}, \tag{4}$$

where I_A and I_B are the intensities at two sides of the edge. S_A and S_B