SIMPLE METHODS OF EDGE POSITION MEASUREMENT USING SHADOW PROJECTED ON CCD SENSOR

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Abstract. *The position of an object can be determined from its shadow projected on a CCD sensor without lens. A collimated light beam is usually used to illuminate the measured object. In this paper a method that applies a point light source is compared with this commonly used method. Results and applicability for simple position measurement are discussed.*

Keywords: *CCD sensor, position measurement, point light source*

1. INTRODUCTION

So called *shadow methods* of position measurement use a shadow projected by a measured object on a CCD sensor without lens to determine measured object's edge position. Both linear and array CCD sensors are applicable for these measurements (usage of a linear sensor will be assumed in following sections). The position of an object is determined from the position of the projected shadow (Fig. 1). Therefore the range of measurable positions is limited by the CCD sensor's length. The positions are considered with respect to some reference point, usually to the first pixel of the CCD sensor.

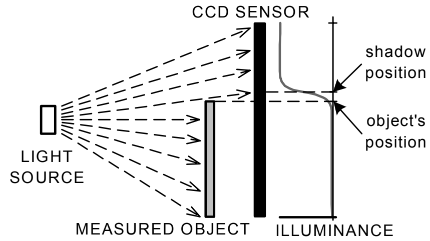


Fig. 1 Principle of measurement using a shadow projected on a CCD sensor

The relation between the measured object's edge position and the position of the edge in the illumination profile (shadow position) on the CCD sensor depends on the character of the light source.

First method we discuss in this paper uses a source of parallel beams. Such light source can be obtained by placing a point light source in a theoretically infinite distance from the CCD sensor or practically by placing a point light source in a focus of a collimating lens. The shadow position is in this case directly equal to the measured object's edge position.

To simplify the measurement set-up we have developed a method that uses a point light source with no lens to illuminate the measured object. The point light source is placed in a finite distance from the sensor. Therefore the divergence of light beams causes a displacement between the object's edge and the edge in the illumination profile. More complex processing is in this case needed.

2. POSITION MEASUREMENT USING A SOURCE OF PARALLEL BEAMS

Easiest construction of a light source of parallel beams applies a lens and a point light source placed in a focus of this lens (Fig. 2).

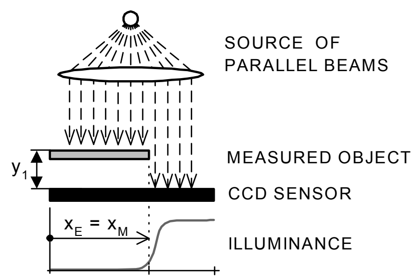


Fig. 2 Edge position measurement using a source of parallel beams

The position of the edge in the illumination profile (x_M) is in this case equal to the position of the measured object's edge (x_E):

$$x_E = x_M \tag{1}$$

Exact edge's position can be determined from diffraction of light on the edge of the measured object. The intensity of light on the CCD sensor is described by following formula [1]:

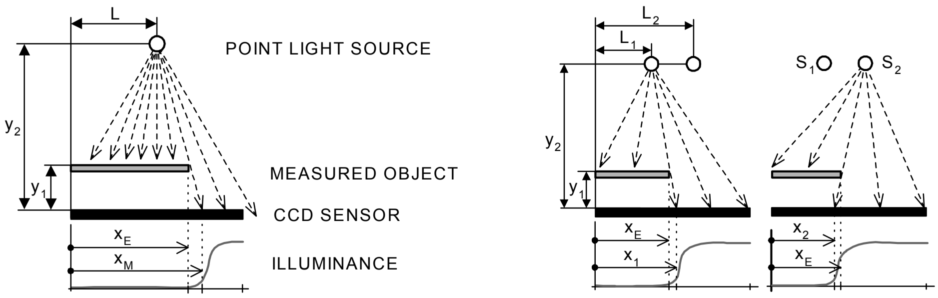
$$I = \frac{I_0}{2}\left| C\left(-\sqrt{\frac{2}{\lambda y_1}}x \right) - iS\left(-\sqrt{\frac{2}{\lambda y_1}}x \right) + \frac{1}{2}(1-i) \right|^2 \tag{2}$$

where λ is light's wavelength; y_1 is the distance between the measured object and the CCD sensor; $C(\alpha)$ and $S(\alpha)$ are Fresnel's integrals.

From Eq. 2 follows that the intensity of light at the position of the measured object's edge ($x = 0$) is equal to $0.25I_0$. The edge position can be therefore determined by comparing CCD sensor's output signal with a threshold level set to 25% of signal's amplitude.

3. POSITION MEASUREMENT USING A POINT LIGHT SOURCE

When using a point light source to illuminate the measured object, the object's edge position is different from the position of the edge in the illumination profile on the CCD sensor (Fig. 3a). This is caused by the divergence of the light beams emitted from the point light source.



a) one light source *b) two light sources*

Fig. 3 Position measurement using a point light source

The real position of the object's edge (x_E) can be determined from the light source's position (L), from the position of the edge in the illumination profile (x_M) and from distances measured object – CCD sensor (y_1) and light source – CCD sensor (y_2):

$$x_E = \frac{y_1}{y_2}(L - x_M) + x_M \tag{3}$$

Disadvantage of this method is that the distance between the measured object and the CCD sensor (y_1) must be known to determine the object's position. This can be eliminated by applying an additional light source (Fig. 3b).

The measurement then consists of two steps. In each step only one of the light sources is on. The object's position is then determined using following formula:

$$x_E = \frac{L_2 x_1 - L_1 x_2}{L_2 - L_1 + x_1 - x_2} \tag{4}$$

Although this method doesn't require the knowledge of the distance between the CCD sensor and the measured object (y_1), the measurement is still affected by this distance. The bigger this distance is the wider will the edge in the illumination profile be. This will decrease accuracy of the determination of this edge's position [2].

4. RESULTS OF MEASUREMENTS USING COLLIMATED BEAM OF LIGHT

The light source of parallel beams consists of a light emitting element and a collimation lens (Fig. 2). The light-emitting element should have emitting area as small as possible (ideal would be a point light source) and sufficient radiation intensity. These requirements are met by a laser diode. Low cost laser diode with output power 5 mW is applicable (e.g. SLD6505A).

The lens should have output aperture wide enough to cover whole length of the used CCD sensor. Typical linear CCD sensor with 2048 pixels (e.g. Sony ILX703A) has a length of 28.7 mm so a standard photographic objective can be used.

The illumination of the CCD sensor using this light source is not uniform (Fig. 4). This is caused by effects such as diffraction of light on lens's shutter, reflections in the laser diode's housing and non-homogeneous radiation across laser diode chip's area. This non-uniformity can affect accuracy of position determination.

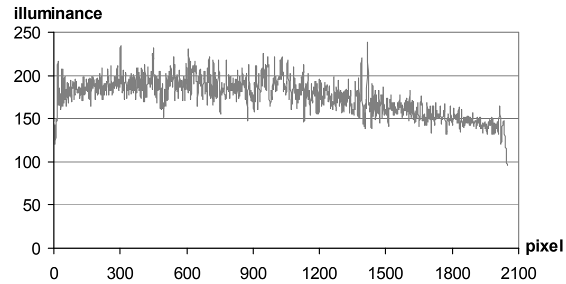


Fig. 4 Illumination profile – using a light source of parallel beams

This method was verified using a device we build. The device consisted of a light source constructed using a laser diode SLD6505A and a photograph objective with focal length 50 mm, linear CCD sensor Sony ILX703A and a sensor control and signal-processing unit. With this device we have performed several measurements such as linearity measurement (Fig. 5). The linearity error Δ was in range $\pm$ 30 μm. Position resolution (standard deviation) was 0.8 μm. Linear interpolation was used to increase resolution.

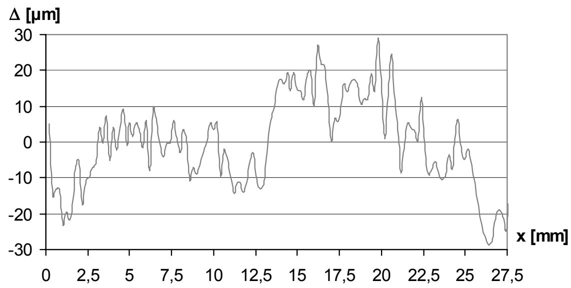
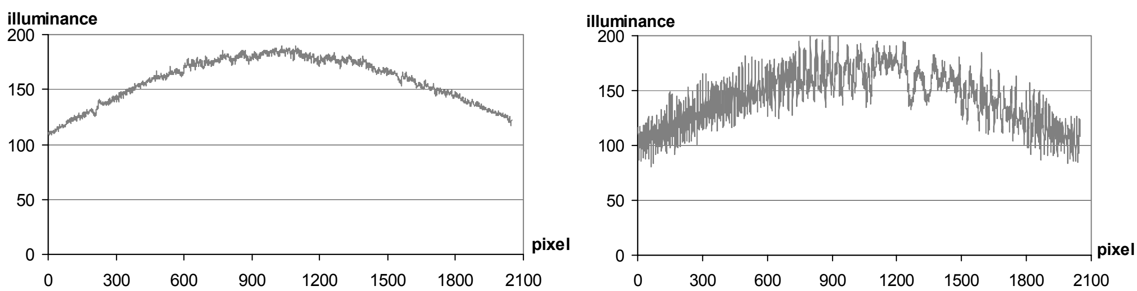


Fig. 5 Linearity error of position measurement using light source of parallel beams

5. RESULTS OF MEASUREMENTS USING POINT LIGHT SOURCE

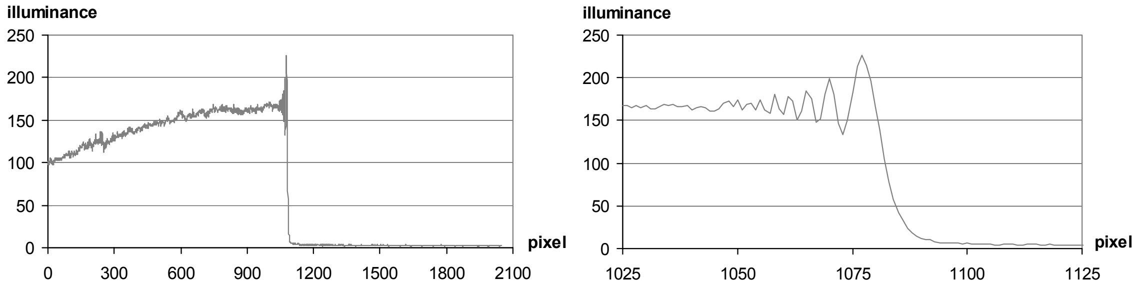
In this case no lens is needed for light source construction. The light-emitting element again should have small area, so laser diode is for this application also suitable. Some miniature LED's such as Osram LGU260-EO can be used also. The illumination profile of the CCD sensor illuminated by a laser diode is shown in Fig. 6. Note that this profile depends on the current that drives the laser diode. The profile is different for current below (Fig. 6a) and above (Fig. 6b) the threshold level.



a) driving current below threshold level *b) driving current above threshold level*

Fig. 6 Illumination profile – using a point light source

The illumination profile with the object placed in front of the CCD sensor and the detail of the edge in the profile are shown in Fig. 7. Both graphs are valid for laser diode's driving current below threshold level. The Fig. 7b shows that the diffraction of light on the measured object's edge takes also place when using a point light source.



a) overall image *b) edge detail*

Fig. 7 Illumination profile with an object

This method was verified with the same device as the previous method. The light source was built using laser diodes SLD6505A. Result of the linearity measurement is shown in Fig. 8. The linearity error Δ was in the range ± 6 µm. Position resolution was 0.9 µm.

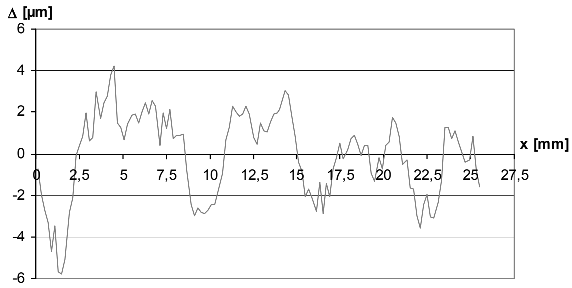


Fig. 8 Linearity error of position measurement using a point light source

6. CONCLUSION

Two simple methods of contact-less position measurement that use a shadow projected on a CCD sensor are discussed in this paper.

First (commonly used) method uses a collimated light beam to illuminate the measured object. Advantage of this method is that it needs no complex signal processing and the measured object's edge position is directly equal to the position of the edge in the illumination profile.

Second method (that we have developed) uses a point light source. Advantage of this method is, that the light source construction is simpler, cheaper and smaller. Disadvantage is the signal processing needed to compensate the divergence of light beams.

Results of measurement showed that good position resolution (approx. 1 µm) can be achieved with both methods. Subpixel resolution was obtained due to use of interpolation. Linearity error was smaller when using a point light source as an illuminator (Δ < 10 µm). The bigger error in case of the illuminator with source of a collimated beam (Δ = ± 30 µm) was caused by non-uniform illumination. The peaks in illumination can affect the accuracy of position determination resulting in linearity errors greater than the width of one pixel (which was 14 µm).

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