Optical method for detecting displacement of a car in stereo images

Osami Sasaki, MEMBER SPIE
Kenichi Sakata
Takamasa Suzuki, MEMBER SPIE
Niigata University
Faculty of Engineering
Niigata-shi 950-2181, Japan
E-mail: osami@eng.niigata-u.ac.jp

Abstract. We propose an optical method for detecting the displacement of an object in stereo images. Two images are displayed on two liquid crystal displays (LCDs), respectively, which are placed at a constant distance. Several plane waves of different propagating directions are illuminated to the LCDs. We can measure the displacement of the object by detecting which plane wave presents the strongest intensity after the plane waves pass through the LCDs. The method is applied to measuring the distance between cars from stereo images of a car. [DOI: 10.1117/1.1577576]

Subject terms: displacement; liquid crystal display; stereo images; distance.

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1 Introduction

Measurement of the distance of an object by stereo vision involves detection of the displacement of the object in the stereo images. This displacement detection has been well studied and video-rate stereo processing with digital computation has been accomplished.[1,2] However, if the displacement detection is carried out with an optical technique, the detection speed inherently becomes very high compared to the computational technique.

In this paper, we propose an optical method for detecting the displacement of an object in two images. An optical device that executes the method will contribute to the development of stereo vision because of its ability for high-speed processing. Two images are displayed on two liquid crystal displays (LCDs), respectively, which are placed at a constant distance. Several plane waves of different propagating directions are illuminated to the LCDs. We can measure the displacement of the object by detecting which plane wave presents the strongest intensity after the plane waves pass through the LCDs. Key devices of a setup based on the optical method are laser diodes (LDs) and two LCDs. Several LDs and a lens easily produce plane waves of different propagating directions. A setup is constructed to show that the optical method can be applied to measurement of a distance between cars from stereo images of a car.

2 Optical Detection of the Displacement

A top view of the setup for measuring the displacement of an object is schematically depicted in Fig. 1. A binary image containing an object is displayed on liquid crystal display 1 (LCD1). Another image in which the object is displaced in the horizontal direction by X_L pixels is displayed on LCD2. This display of images is shown in Fig. 2, where an object is a rectangular pattern. The light source is an LD array in which five LDs are arranged at a constant distance s. Output beams $S_m (m=0\ldots4)$ from the LDs are transformed to plane waves with lens 1. The inclination angles θ_m of the plane waves to the optical axis are given by

$$\tan\theta_m = m(s/f_{L1}) \quad (m=0\ldots4), \tag{1}$$

where f_{L1} is the focal length of lens 1. The two LCDs are perpendicular to the optical axis. The plane waves are incident first onto LCD1. The white level in the binary image enables the light to pass through LD1, and the black level in the binary image does not. An object has many pixels of white level. Distance D_L between the two LCDs must satisfy the equation

$$D_L(s/f_{L1}) = pc, \tag{2}$$

where p is a positive integer, and c is the interval of the pixels in the LCDs. Equation (2) means that the incident position on LCD2 of a light ray with the inclination angle θ_m is shifted in the horizontal direction by mpc pixels compared with that on LCD1. If displacement X_L of the object is pM pixels, some portion of the plane wave of the inclination angle θ_M $(m=M)$ passes through the two LCDs. The objects on the LCDs work as the widest apertures for the plane wave of the inclination angle θ_M compared with the other plane waves. Beams coming out from LCD2 are collected by lens 2 and intensity distribution I is detected on the focal plane of the lens 2 with a linear CCD image

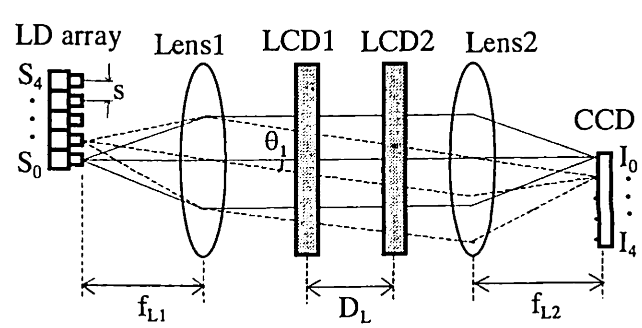

Fig. 1 Schematics of a setup for measuring a displacement of an object.

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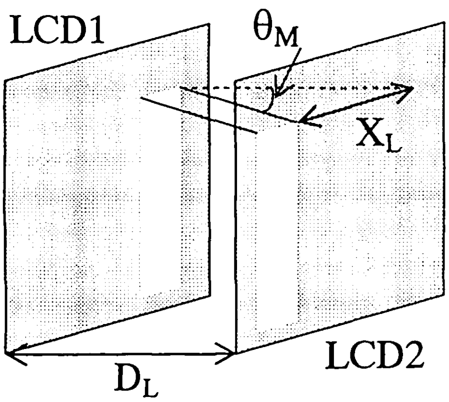

Fig. 2 Two binary images displayed on LCD1 and LCD2, respectively.

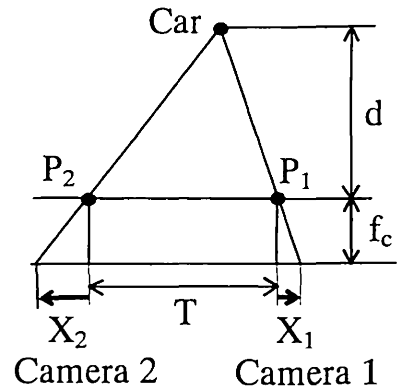

Fig. 4 Configuration of a car and two cameras.

sensor. When all of the output beams pass through the two LCDs, the intensity distribution contains five peaks $I_m(m=0\ldots4)$, which are produced from the output beam S_m $(m=0\ldots4)$, respectively. Peak I_M becomes the largest value when displacement X_L of the object is pM pixels. When displacement X_L of the object is $2M+1$ pixels and $p=2$, it is expected that the peak values of I_M and I_{M+1} is almost the same. This means that the resolution in the displacement detection is expected to be 1 pixel at $p=2$, and we adopt $p=2$.

3 Displacement Detection of a Rectangular Pattern

We constructed the setup shown in Fig. 1. The output power of the LD was 10 mW and the space s between two LDs was 9.6 mm. This value of s was the smallest one that we could employ for the LD array. The parameters were as follows: $f_{L1}=500$ mm, $c=0.161$ mm, and $p=2$. These values led to $D_L=16.8$ mm in Eq. (2). The focal length f_{L2} of lens 2 was 100 mm. The diameters of the plane waves were sufficient to illuminate the LCDs of 512×512 pixels. The frame rate of the LCDs was 30 Hz.

We displayed a rectangular pattern of 7 and 60 pixels in horizontal and vertical widths, respectively, on the LCDs, as shown in Fig. 2. We gave displacement X_L from 0 to 8 pixels to the rectangular pattern on LCD2. The detected intensity distributions at $X_L=2$ and 3 pixels are shown in Fig. 3. When $X_L=2$ pixels, peak I_1 was the largest. When $X_L=3$ pixels, peaks I_1 and I_2 were almost identical. The results for the others values of X_L were also the same as what we expected. We made it clear that the setup shown in Fig. 1 can detect the displacement from 0 to 8 pixels with a resolution of 1 pixel.

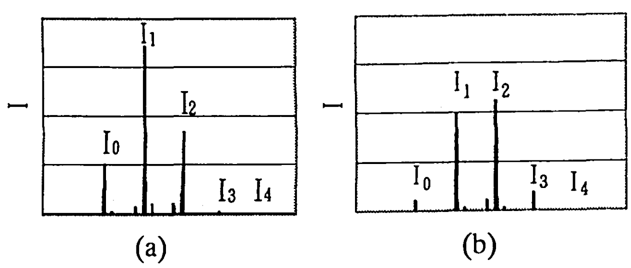

Fig. 3 Detected intensity distributions at (a) $X_L=2$ pixels and (b) $X_L=3$ pixels.

4 Stereo Images of a Car

We use the stereo imaging method to measure a distance between cars. Figure 4 shows a configuration of a car and two cameras. The distance between two cameras located at P_1 and P_2 is T, and the distance between the car and the plane containing the cameras is d. The images of the car on the focal plane of the cameras depart from the center position of the focal plane by amounts of X_1 and X_2, respectively. Leting the focal length of the cameras be f_c, we have the relation

$$d=Tf_c/X, \tag{3}$$

where $X=X_1+X_2$, and X is a displacement of the car to be detected by the setup shown in Fig. 1; T and f_c were 200 and 7.4 mm, respectively. Since the pixel size of the video camera was 0.105 mm, the relation between the displacement X mm and the displacement X_o pixels in the stereo images is given by

$$X=0.105X_o. \tag{4}$$

Considering that the detection resolution ΔX_o in the displacement X_o is 1 pixel, measurement resolution Δd in distance d is obtained from Eqs. (3) and (4) as

$$\Delta d=0.105d^2/Tf_c. \tag{5}$$

Figure 5 shows the calculation result for Δd.

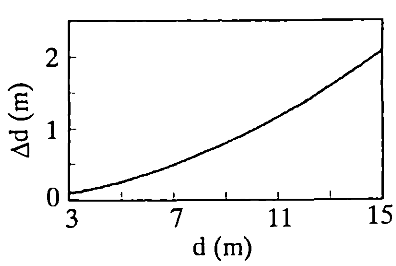

Fig. 5 Measurement resolution Δd in distance d.

(a) (b)

Fig. 6 (a) Binary image and (b) image obtained from (a) by vertical edge detection.

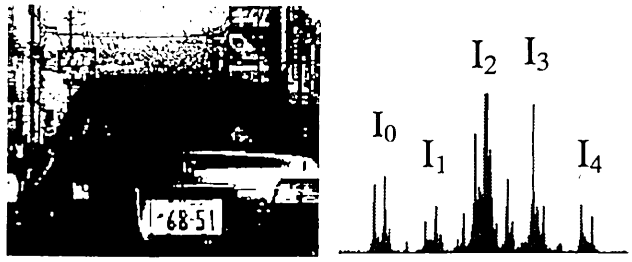

Fig. 8 Original binary image and intensity distribution detected at OF=22.

5 Image Processing for Display on LCD

Images of the car detected with the cameras were processed with electric circuits to obtain images to be displayed on the LCD. First, the output image of the camera was converted to the binary image shown in Fig. 6(a) with a comparator circuit. Then vertical edge detection was executed with a differentiation circuit for the binary image shown in Fig. 6(a) to obtain the image shown in Fig. 6(b).

Next, extraction of downside part of the image was carried out to eliminate the background image to some extent. Figure 7 shows images whose upper sides were cut off at different sizes. Binary images of the car, on which the edge detection and the object extraction were performed, were displaced on the LCDs, and intensity distribution I was detected with the linear CCD image sensor. The results for the two different images of Figs. 7(a) and 7(b) are also shown in Fig. 7. In the case of Fig. 7(a) one peak did not appear in the intensity distribution because the background portion of the image was too great. From this result it was determined that half of the image is used as the display image on the LCDs.

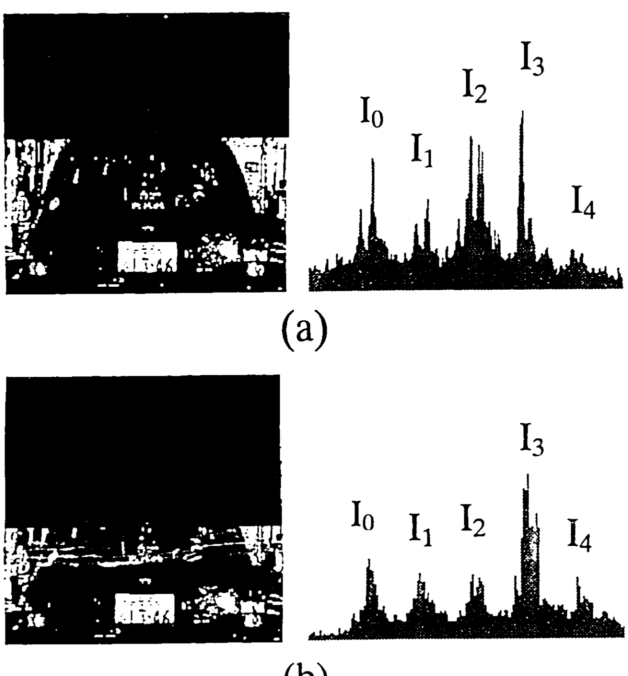

Fig. 7 Intensity distributions detected for images whose upper sides were cut off at different sizes.

Finally, displacement X_o in the stereo images was converted to displacement X_L for the display on the LCDs since the detectable range of displacement X_L in the setup is between 0 to 8 pixels. When distance d is from 6 to 15 m, displacement X_o in the stereo images is from 34 to 14 pixels. We give offset displacement OF to one image in the stereo images so that displacement X_L became $X_L=X_o-\text{OF}$. The initial value of OF was 30 pixels, and we detected the intensity distribution. If the maximum value in the detected intensity distribution was less than a specified value, we decreased the value of OF by 8 pixels. This decrement in OF was continued until the maximum value became more than the specified value.

6 Measurement of Distance between Cars

First we stopped the car at distances of $d=6$, 9, and 12 m from the cameras. We confirmed that we could measure the distance between the car and the plane containing the cameras. Next the cameras and the setup were mounted on a car and we measured a distance between cars. Figure 8 shows an original binary image of a car and an intensity distribution detected at OF=22. We detected a very weak intensity distribution at OF=30 and 14, where the maximum value of the intensity was one-sixth of that at OF=22. The intensity distribution shown in Fig. 8 had two peaks at I_2 and I_3, which led to $X_L=5$ and $X_o=27$. We substituted a value of X_o into Eq. (4) and used Eq. (3) to obtain a value of d. We had a final result of $d=6.9$ m. Figure 9 shows an original binary image of a car and an intensity distribution detected at OF=6. We achieved the results of $X_L=6$, $X_o=12$, and $d=15.4$ m. These results make it clear that the setup pro-

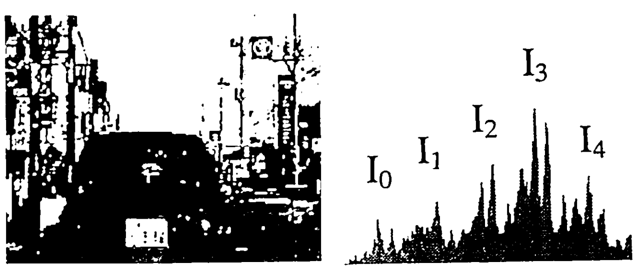

Fig. 9 Original binary image and intensity distribution detected at OF=6.

posed here can be applied to measure a distance between cars with the resolution shown in Fig. 4.

7 Conclusion

We proposed the optical method for detecting a displacement of an object in two images. The setup was constructed by using five LDs and two LCDs. The displacement of the object was detected with a resolution of 1 pixel in the range from 0 to 8 pixels. The distance between cars was measured with the setup from the stereo binary images on which the edge detection, the object extraction, and the offset displacement were performed with electric circuits. If a very small setup is constructed by using LCDs of small size and a high frame rate, the optical method proposed here will become more practical and useful for real-time stereo processing.

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Biographies and photographs of the authors not available.