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Binobjective monocular optical module for single-chip stereo vision sensor LSI

Takashi Yoshida[1a)] **and Yutaka Arima**[1]

[1] *Center of Microelectronic System, Kyushu Institute of Technology*
680–4, Kawazu, Iizuka, Fukuoka 820–8502, Japan
a) *yoshida@cms.kyutech.ac.jp*

Abstract: A binobjective monocular optical module for single-chip stereo imagers is proposed. The proposed optical module employs a monocular structure to project a stereoscopic image. Using this structure, the base length can be made larger than the chip size, and the optical module enables long-range measurement. Using the proposed optical module, wide-range sensing equipment with single-chip stereo vision LSI can be constructed with low cost. The optical modules and stereo vision sensor LSI are prototyped, and a range measurement system is constructed using these prototypes. By evaluation experiments, the sufficient view angle and resolution of these modules are verified, and range measurement can be performed using the proposed system.

Keywords: binobjective, monocular, range sensor, stereo vision, optical module

Classification: Photonics devices, circuits, and systems

References

[1] H. Kuroda, F. Okai, and K. Takano, "A Study on Estimating the Aiming Angle Error of Millimeter Wave Radar for Automobile," *IEEJ Trans. Industry Applications*, vol. 125-D, no. 3, pp. 286–292, March 2005.

[2] N. Shima, M. Babazaki, Y. Akidzuki, K. F. Honda, T. Higuchi, H. Higashi, and Y. Nakamura, "Fusion Sensor for Driving Assistance System," *FUJITSU TEN Tech. J.*, vol. 19, no. 1, pp. 31–39, June 2001.

[3] T. Kato, S. Kawahito, K. Kobayashi, H. Sasaki, T. Eki, and T. Hisanaga, "A Binocular CMOS Range Image Sensor with Bit-Serial Block-Parallel Interface Using Cyclic Pipelined ADC's," *IEEE Symp. on VLSI Circuits Digest of Tech. Papers*, Honolulu, U.S.A. 19.3, pp. 270–271, June 2002.

[4] K. Sabe, T. Ohashi, K. Kawamoto, S. Gutmann, M. Fukuchi, and T. Yoshigahara, "Obstacle Avoidance and Path Planning for Humanoid Robot using Stereo Vision," *Proc. of National Symp. on Sensing via Image Information*, Kanagawa, Japan, B-41, 2002.

[5] T. Yoshida, K. Ono, and Y. Arima, "Binocular Range Image Sensor LSI with Fully Parallel Stereo Correlation Processing," *2006 Int. Conf. on Solid State Devices and Materials*, Kanagawa, Japan, Sept. 2006 (in press).

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1 Introduction

Range measurement sensors are used in various fields such as automotive systems and robotics. These sensors can be classified into "active-type sensors" such as millimeter-wave radar sensors [1, 2], and "passive-type sensors" such as stereo vision sensors [2, 3, 4].

The power consumption and equipment cost of the millimeter-wave radar sensor are disadvantages to its wide utilization. In the stereo vision sensor, the power consumption can be reduced, but the following problems remain.

Figure 1 (a) shows a stereo vision sensor constructed with a pair of cameras and a digital signal processor (DSP) [2]. In such a stereo image sensing system consisting of two cameras, the long base length is designed easily because there is no limit of the cameras' arrangement. This base length indicates the center spacing of two images. However, the equipment cost and the assembly accuracy of each camera are disadvantages for practical use. The assembly error of these cameras demands error correction processing with the DSP.

Figure 1 (b) shows the stereo image sensing system consisting of a single

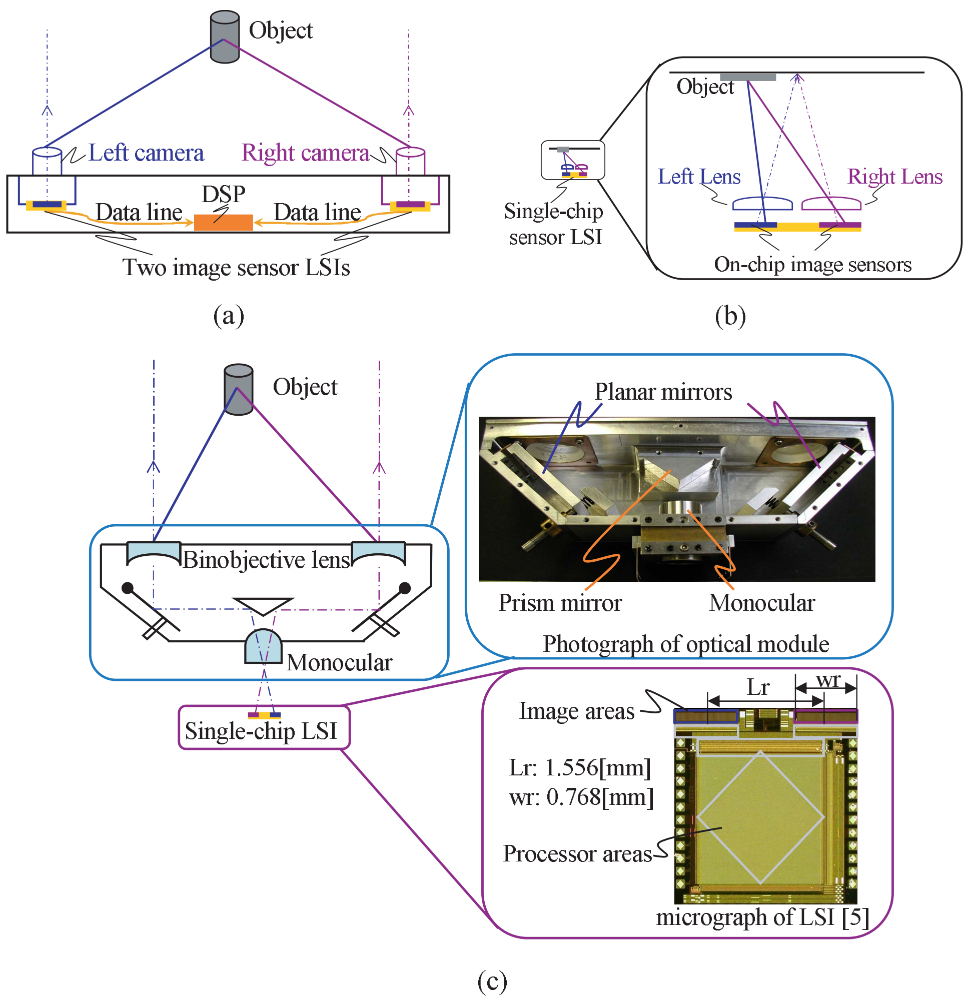

Fig. 1. Comparison of conventional and proposed structures: (a) Twin camera system, (b) Single-chip system, (c) Binobjective monocular system

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LSI that integrates two image sensors [3]. The equipment cost can be reduced, and high location accuracy is realized because it is based on the LSI manufacturing accuracy. However, the base length is restricted by the chip size; thus, the disadvantage of this system is its extremely short measurable range.

To solve these problems, an optical module for single-chip stereo vision sensor LSI is proposed. Figure 1 (c) shows the proposed optical module. This module employs a monocular structure to project stereo images on the LSI [5]. This is realized by a structure that deflects the optical path to make a long base length.

2 Structure of binobjective monocular optical module

As shown in Fig. 1 (c), the proposed binobjective monocular optical module is configured with the following components: left and right concave binobjective lenses, two angular adjustable plane mirrors, a prism mirror block, and a monocular.

The incoming stereo images from the binobjective lenses are deflected by each planar mirror, and projected on each specular surface of a prism mirror. These images are reflected by the prism mirror, are focused by the monocular, and are projected on two imagers in a single chip.

The objective lenses and a monocular are combined to form the image reducer.

The angle of planar mirrors can be adjusted to control the convergence angle.

Figure 2 (a) shows a sensing example of stereo vision range measurement with solid-state image sensors; the convergence angle ϕ is 0 [deg]. The yellow oval in Fig. 2 (a) shows a target object, and it is detected by the number "iL" pixel in the left sensor and the number "iR" pixel in the right sensor.

At that time, the distance to the object is "$D_{\text{iL-iR}}$" and its accuracy is "$\Delta D_{\text{iL-iR}}$"; the detecting angle equals the view angle "θ". iL is always larger than iR, so $1 \leq iL - iR \leq N - 1$. "$D_{\text{iL-iR}}$", "$\Delta D_{\text{iL-iR}}$", and "$\theta$" are expressed by the following formulas.

$$D_{iL-iR} = \frac{B \times f \times N}{w \times (iL - iR)}, \quad \Delta D_{iL-iR} = D_{iL-iR+1} - D_{iL-iR-1},$$
$$\theta = \arctan\left(\frac{2 \times f}{w}\right)$$

B: base length, f: focal length of combination lens, N: number of pixels, w: width of image area

Figure 2 (b) shows the optical path of the proposed module. In the proposed binobjective monocular optical module, the base length is designed without the restriction of the imager spacing "L" that is limited by chip size; it is realized by the optical deflection using mirrors and view angle expansion using the image reducer structure.

By adjusting the planar mirrors, the offset between the image circle and the image area is changed and the angle of incidence optical axis is changed

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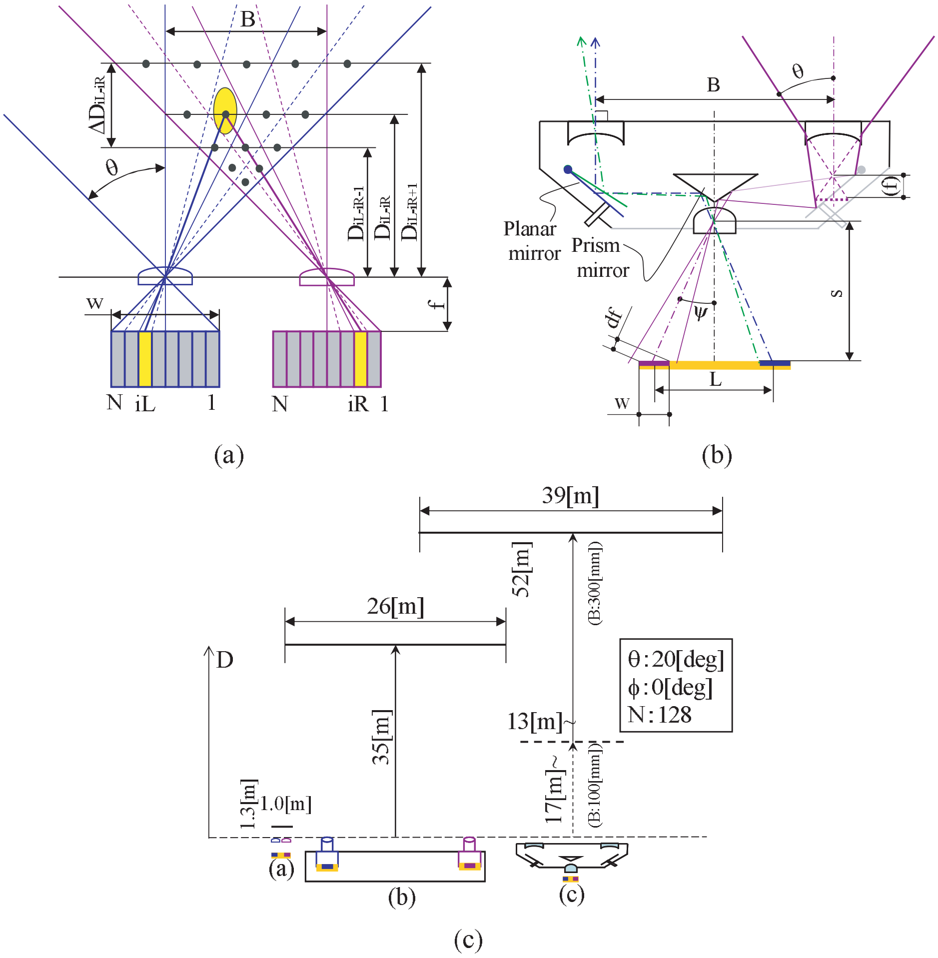

Fig. 2. Stereo vision range measurement: (a) sensing example of stereo vision range measurement, (b) Optical path of proposed module, (c) D_1 of stereo vision system in Fig. 1

too. By this adjustment, the convergence angle is modified and it realizes fine control of “D”.

However, in the proposed optical modular structure, there is a misalignment of the incidence optical path and the normal line of the imaging area. Therefore, focal blurring “df” occurs as shown in Fig. 2 (b).

$$df = w \times \sin(\psi)$$

ψ: *angle between light axis and image area’s normal line*

This is an inevitable problem of the proposed structure, but the adverse effect of this problem is moderated by suitably designing system parameters such as the resolution of the combined lens and the pixel pitch of the image sensors.

The binobjective monocular optical modules and stereo image sensor LSI [5] are prototyped. Two types of optical modules were produced, B: 100 [mm] and B: 300 [mm]. In the LSI, image sensors, edge extractors, and stereo disparity correlation processors are integrated. There are N: 64 [pixel] photosensors arranged in w: 768 [μm] in each left and right image sensor, and

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“L” is 1556 [μm].

In these prototyped optical modules, the resolution “R” of the combined lens is 6 [μm], “df” is 0.13 [mm], and the distance “s” between the monocular and the image sensor is 4.4 [mm]. In the prototyped vision sensor LSI, the pixel pitch “δ” is 12 [μm]. When a focus is united centering on the image circle, the effective resolution “Rr” is expressed by the following formula.

$$Rr = R \times \left(1 + \frac{df}{2 \times s}\right) = 6 \times \left(1 + \frac{0.13}{2 \times 4.4}\right) = 6.1 < \delta$$

The effective resolution is smaller than the pixel pitch. Thus, the focal blurring of the prototyped system is within the permissible range; the lower limit of δ is 6.1 [μm].

Figure 2 (c) shows a comparison of the systems shown Figs. 1 (a)$\sim$(c). Using the proposed binobjective monocular optical module, the long measurement range and wide detection angle can be acquired using the single-chip sensor.

3 Measurement Result

The range measurement system is constructed using the prototyped optical modules and prototyped sensor LSI, and evaluation experiments are conducted.

View angle verification

The view angle of the range measurement system is verified as follows: to capture the white cylinder (Φ: 60 [mm]) on the black background. Figure 3 (a) shows that the output image of these modules captured by a CCD sensor, and the CCD camera view from the same point. Purple circles show the image circles, and blue rectangles show the image areas of the prototyped LSI.

In the results, the view angles of these range measurement systems are 19.3 [deg] for the B: 100 [mm] module and 17.5 [deg] for the B: 300 [mm] module. It is proved that the range measurement systems have sufficient view angles.

Resolution verification

The resolution of the range measurement system is verified by the CCD area-image sensor. The pixel pitch of CCD is equal to the image sensors' pixel pitch in the prototyped LSI. Figure 3 (b) shows the CCD image of an object with width: 0.5 [m] and D: 50 [m], and the digital-camera view at the same point.

This object is detected by one pixel. It is considered that the range measurement system has a sufficient resolution that is smaller than δ, and it is proved that the optical modules project stereo images on image sensors without any problems.

LSI operation verification

The LSI operation is verified by the constructed range measurement system. Figure 3 (c) shows the monitor output of the stereo disparity correlation processing. The yellow lines show the edge line between the object and the

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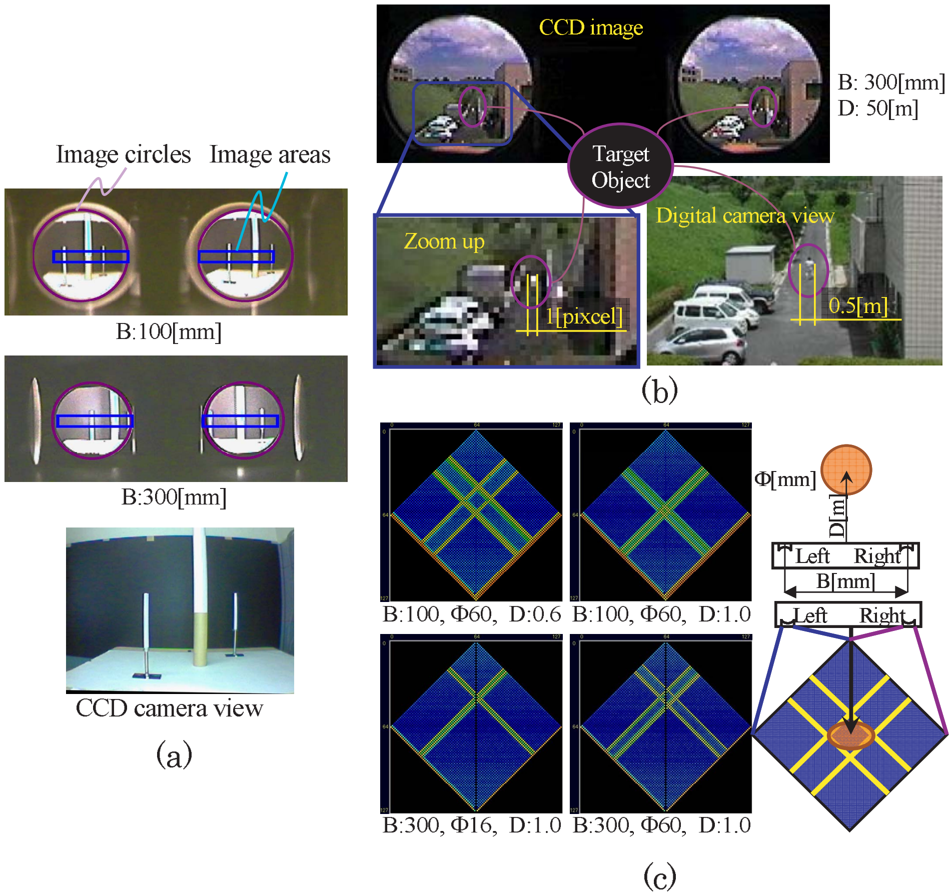

Fig. 3. Result of measurement experiment: (a) View angle verification, (b) Resolution verification, (c) LSI operation verification

background, and the intersections of the yellow lines show the object locations.

The interval and position of edge lines are changing according to the distance to the object, the object size, and the base length. It is proved that image sensors, edge extractors, and stereo disparity correlation processors operate by triangulation method.

4 Conclusion

The structure of binobjective monocular optical module was proposed in order to realize a range measurement system with single-chip LSI. This module has employed a structure that outputs long-base-length stereo images through a monocular. With this optical module, we realized the single-chip integration of two image sensors and the cost reduction of the range measurement system.

Binobjective monocular optical modules and a stereo image sensor LSI were prototyped, and the range measurement system was constructed using them. A measurement experiment was conducted, and sufficient results were obtained.

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