High-sensitivity and Wide-dynamic-range Position Sensor Using Logarithmic-response and Correlation Circuit

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Abstract— A high-sensitivity and wide-dynamic-range position sensor has been designed and successfully tested. The sensor can acquire the position of projected light in strong background illumination without saturation since this sensor has a log-response and correlation circuit. Minimum sensitivity in terms of the ratio of the projected light to the background illumination is 0.036. The sensor integrates 64 $\times$ 64 pixels on a 4.8 mm $\times$ 4.8 mm die of a 0.5 μ m CMOS 3-metal 1-poly-Si process.

I. Introduction

3-D measurement system has a wide variety of application field such as robot vision, computer vision and position adjustment. In 3-D measurement system, the sensor detects the position of projected light on the sensor plane. The conventional image sensors and position sensors such as [1, 2] detect positions of peak intensity to acquire the positions of projected light. This method has some difficulties when a target object is placed in a non-ideal environment such as a strong background illumination. Correlation technique[3] is one of the solutions to the difficulties. The correlation sensor can suppress the background illumination to obtain a high sensitivity. Its dynamic range is, however, limited by the linear difference circuit due to the voltage signal saturation. It is not applicable for a strong contrast image in outdoor environment without optical neutral-density filters.

In this study, we have developed and tested a high-sensitivity and wide-dynamic-range position sensor. This can be realized using a logarithmic-response circuit so that the correlation circuit can detect the position of projected light without saturation.

II. Circuit Realization

Fig.1 illustrates the pixel structure of the high-sensitivity and wide-dynamic-range position sensor using logarithmic-response and correlation circuit. It consists of a logarithmic-response photo detector circuit, an amplifier of the photo current swing, a sample and hold circuit, an analog multiplier for correlation, an integrator and a source follower circuit. Fig.2 shows a schematic of the pixel. The logarithmic-response circuit realizes wide-dynamic-range photo detection. Photo current $I_{PD}(t)$ generates the voltage $V_{sig}(t)$ at the node sig as follows:

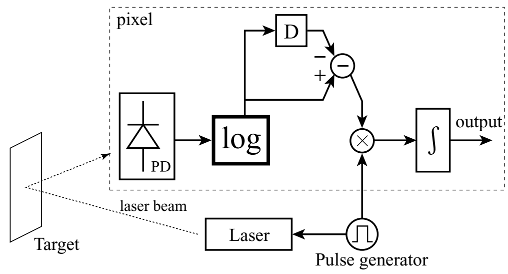

Fig. 1. Pixel structure.

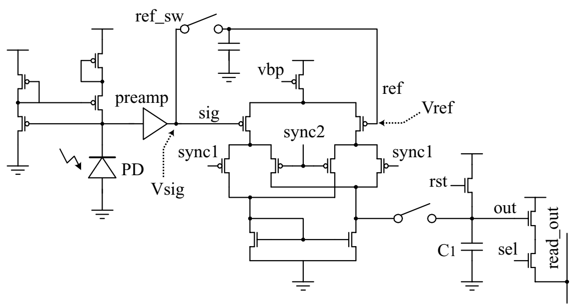

Fig. 2. Schematic of a pixel.

$$V_{sig}(t) = \alpha \log I_{PD}(t) \tag{1}$$

Here α stands for the charactaristics of the pre-amplifier. At the sample and hold circuit, the signal ref_sw synchronized with $2f_0$ generates the voltage $V_{ref}(t)$ at the node ref when the modulation frequency of projected light to be detected is f_0. The differential voltage $\Delta V_{sig}(t)$ between $V_{sig}(t)$ and $V_{ref}(t)$ is multiplied by the external differential signal $\Delta V_{sync}(t)$ between V_{sync1} and V_{sync2} for correlation. The output current $I_{out}(t)$ is integrated at capacitance C_1 and results in the output voltage $V_{out}(t)$ as follows:

$$V_{out}(t) = \int_{t-T}^{t} I_b \cdot \frac{\kappa \Delta V_{sig}(\tau)}{2} \cdot \frac{\kappa \Delta V_{sync}(\tau)}{2} d\tau \tag{2}$$

where T is frame time and κ is a gain factor of the multiplier. The voltage $V_{out}(t)$ increases monotonously and the pixel is activated only when the voltage $V_{sig}(t)$ has the frequency to be detected.

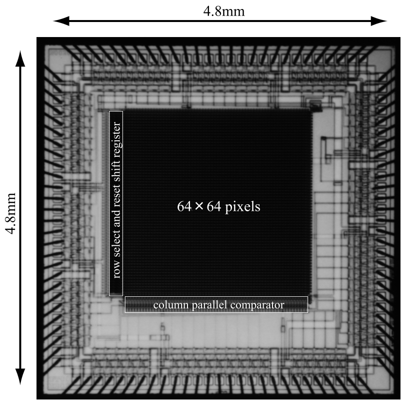

Fig. 3. Microphotograph of the sensor.

TABLE I
Summary of the position sensor.

Process	0.5 μm CMOS 3-metal 1-poly-Si
Chip size	4.8 mm $\times$ 4.8 mm
Num. of pixels	64 $\times$ 64 pixels
Pixel size	40.0 μm $\times$ 40.0 μm
Photo diode size	10.15 μm $\times$ 28.45 μm
Fill-Factor	18.05 %

III. Experimental results

Fig.3 shows a microphotograph of the sensor. The sensor is fabricated in $0.5\mu m$ CMOS 3-Metal 1-Poly-Si process. Table I shows a summary of the sensor.

Fig.4 shows the minimum laser intensity on the target objects versus the background intensity when the sensor can acquire the position of the laser beam. We also show examples using an image sensor without correlator (b) and the conventional correlation sensor[3] (c) in Fig.4. The measurement system is composed of the fabricated sensor, a laser pointer (wavelength $635nm$), a light projector for background illumination, a luxmeter. In this measurement system, the modulation frequency is 1kHz, the maximum frequency of the laser, and the frame interval is 5ms. This experimental result shows that the present sensor can suppress the background illumination and acquire the position of the projected light in a strong background illumination. For example, the laser intensity can be about $3 \times 10^4 lx$ in outdoor environment, where the background intensity is about $1 \times 10^5 lx$ in summer season. In addition, this result shows the sensor doesn't saturate and the suppression is effective in various background illuminations.

Fig.5 shows acquired images of scanning laser spot for 3-D measurement at two background illuminations, $1600lx$ and 28000 lx. The 3-D measurement system is composed of the fabricated sensor, a laser with mirrors and a PC with digital I/O boards. In this measurement, the acquired images have 12 $\times$ 12 positions of scanning laser spot projected on a sphere-shaped object. 3-D range map can be calculated from this acquired image and the positions of the sensor and the projected light source using triangulation.

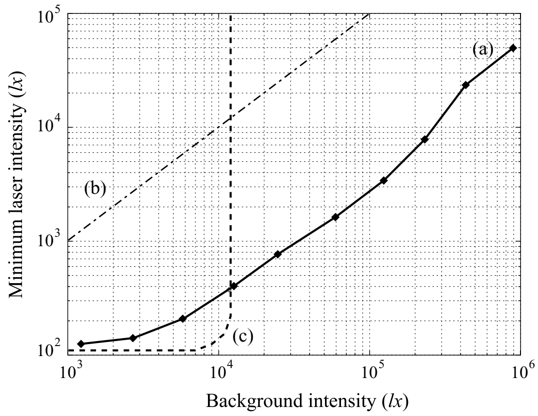

Fig. 4. Minimum laser intensity on target objects: (a) the proposed position sensor, (b) the conventional image sensor, (c) the conventional correlation sensor.

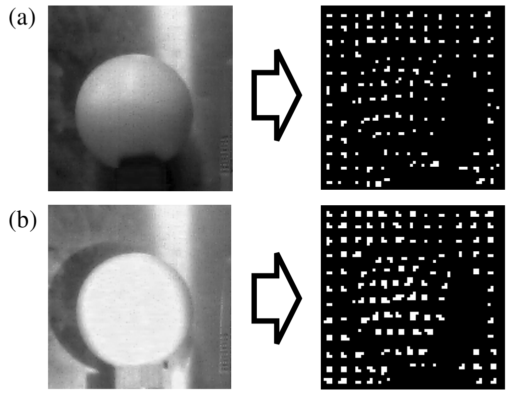

Fig. 5. Acquired images for 3-D measurement: laser intensity is about (a) 400 lx, (b) 1900 lx and max. background intensity is about (a) 1600 lx, (b) 28000 lx.

IV. Conclusions

A high-sensitivity and wide-dynamic-range position sensor using logarithmic-response and correlation circuit has been developed and successfully fabricated in $0.5\mu m$ CMOS 3-metal 1-poly-Si process. The sensor can acquire the position of projected light in strong background illuminations. The fabricated sensor has a 64 $\times$ 64 pixel array. Minimum sensitivity in terms of the ratio of the projected light to the background illumination is 0.036. The suppression is effective in wide range of the background intensity.

Acknowledgements

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