Wide Dynamic Range Photo Detector for Smart Position Sensor Using Log-response and Correlation Circuit

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1. Introduction

3-D measurement system has a wide variety of application fields 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, 3] 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[4] is one of 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 a optical neutral-density filter.

In this paper, we present wide dynamic range photo detector for smart position sensor using log-response and correlation circuit. Wide-dynamic-range position detection can be realized since this correlation technique can detect the position of projected light without saturation. This photo detector is designed and fabricated in $0.6\mu m$ 3-Metal 2-Poly-Si CMOS process. We report experimental results of the fabricated photo detector.

2. Pixel Circuit

Fig.1 illustrates the structure of wide dynamic range photo detector for smart position sensor using log-response and correlation circuit. Fig.2 shows a schematic of this photo detector. It has a logarithmic-response photo detector circuit and an amplifier of the photo current swing. Photo current $I_{PD}(t)$ generates the voltage $V_{sig}(t)$ at the node sig as follows:

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

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 frequency of projected light to be detected is f_0. $V_{ref}(t)$ is given by

$$V_{ref}(t) = V_{sig}(t - \frac{1}{2f_0}) \quad (2)$$

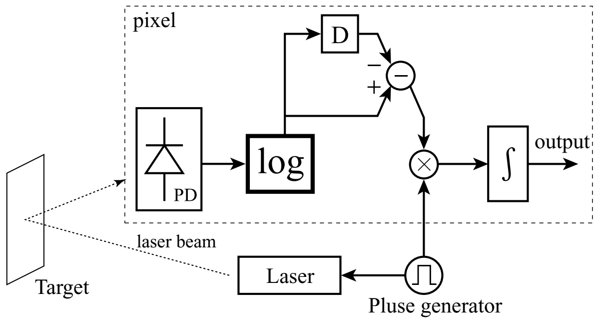

Fig 1. Pixel structure.

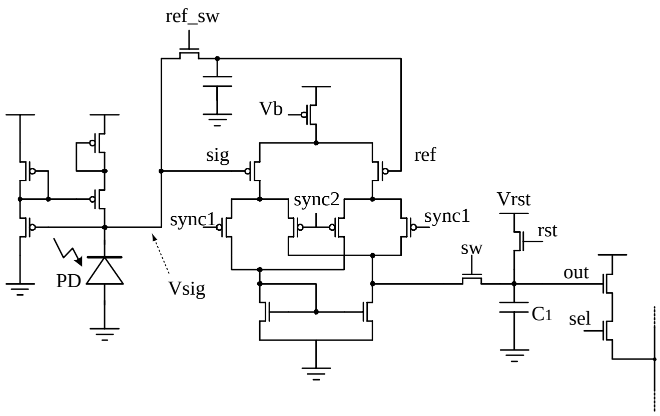

Fig 2. Schematic of a pixel.

The external global signal $sync1$ is synchronized with f_0 and the signal $sync2$ is given by

$$V_{sync2}(t) = V_{sync1}(t - \frac{1}{2f_0}) \quad (3)$$

The analog multiplier multiplies the differential input voltage ΔV_{sig} by ΔV_{sync} and outputs the current $I_{out}(t)$ as follows:

$$I_{out}(t) = I_b \cdot \frac{\kappa \Delta V_{sig}(t)}{2} \cdot \frac{\kappa \Delta V_{sync}(t)}{2} \quad (4)$$

where ΔV_{sig} and ΔV_{sync} are given by

$$\Delta V_{sig} = V_{sig}(t) - V_{ref}(t) \quad (5)$$

$$\Delta V_{sync} = V_{sync1}(t) - V_{sync2}(t) \quad (6)$$

The output current $I_{out}(t)$ is integrated at capacitance C_1 and results in the output voltage $V_{out}(t)$ as follows:

$$V_{out}(t) = \int_{t-T}^{t} I_{out}(\tau) d\tau \quad (7)$$

where T is frame time. 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.

3. Experimental results

We designed and fabricated the proposed photo detector in $0.6\mu m$ CMOS 3-Metal 2-Poly-Si process. Pixel size is $32\mu m \times 56\mu m$ and a photo diode occupies about 23.5% of the pixel's area. The photo diode is formed by an n^+-diffusion in a p-substrate. The output voltage of a pixel is compared with the external reference voltage and the pixel is decided to be activated or not.

The measurement system is composed of the fabricated sensor, a laser pointer (wavelength $635nm$), a light projector for background illumination, a luxmeter and optical neutral-density(ND) filters. Maximum output power of the laser pointer is 2.8mW and maximum modulation frequency is 1kHz. The laser intensity into the sensor is controlled by ND filters. The modulated laser is projected on the sensor plane through ND filters. The background illumination is generated by the light projector and the intensity of the background illumination increases slowly. Pixel is decided to be activated or not at each background intensity The limit of position detection is the background intensity at which the pixel is not activated though the modulated laser is projected on the pixel. In this measurement system, the modulation frequency of the laser is maximum frequency 1kHz and frame time is 5ms. The external reference voltage of a comparator is 1.2V, which is decided by simulation results.

Fig.3 shows the minimum laser intensity on the target objects versus the background intensity. We also show examples using conventional image sensor (b) and conventional correlation sensor (c) in Fig.3. This experimental result shows that the laser intensity can be weaker than the background intensity and this position detection doesn't cause saturation. For example, the laser intensity can be about 1.5×10^4 lux in outdoor environment, where the background intensity is about 1.0×10^5 lux in summer season. In addition, pixels are not activated at various background intensity in this measurement system when the modulated laser isn't projected on the sensor plane. In other words, the sensor with the proposed photo detectors can detect the position of the modulated laser even if the other positions have stronger intensity.

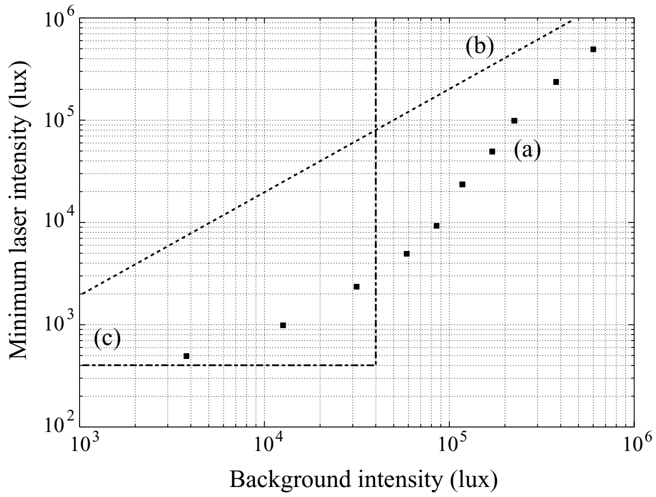

Fig 3. Minimum laser intensity on target objects: (a) the proposed photo detector, (b) the conventional image sensor, (c) the conventional correlation sensor.

4. Conclusion

We proposed wide dynamic range photo detector for smart position sensor using log-response and correlation circuit. We designed and fabricated this photo detector using $0.6\mu m$ CMOS 3-Metal 2-Poly-Si process and showed experimental results. In the 3-D measurement system using this photo detector, the laser intensity can be weaker than the background intensity. The position of modulated laser can be detected even if the other positions on the sensor plane have stronger intensity. And also the position detection using this photo detector doesn't cause saturation in strong background illumination. The smart position sensor using this photo detector can overcome some difficulties when a target object is placed in a non-ideal environment such as a strong background illumination.

Acknowledgement

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Reference

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