ASP-DAC 2002/VLSI 2002 Best Papers

Best Paper Award:
Floorplan Evaluation with Timing Driven Global Wireplanning, Pin Assignment and Buffer/Wire Sizing
C. Albrecht, A. B. Kahng, Ion Mandoiu, A. Zelikovsky – Univ. of California, San Diego, USA

Best Student Paper Award:
Mode Selection and Mode dependency Modeling for Power Aware Embedded Systems
Deixin Li, Pai H. Chou, Nader Bagherzadeh – Univ. of California, Irvine, USA

Honorable Mention Award:
Design of On-chip Test Pattern Generator without PPS
N. Ganguly, Sikdar, P. Pal Chaudhuri – Bengal Engineering College, Howrah, India

Design Contest Award:
High-sensitivity and Wide-dynamic-range Position Sensor Using Logarithmic-response and Correlation Circuit
Yusuke Oike, Makoto Ikeda, Kunihiro Asada – University of Tokyo, Japan
VLSI Design 2002 Conference Awards

Technical Paper Awards

Best Paper Award
“Floorplan Evaluation with Timing Driven Global Wireplanning, Pin Assignment and Buffer/Wire Sizing”
C. Albrecht, A. B. Kahng, Ion Mandoiu, and A. Zelikovsky
University of California at San Diego, USA

Best Student Paper Award
“Mode Selection and Mode Dependency Modeling for Power Aware Embedded Systems”
Deixin Li, Pai H. Chou, and Nader Bagherzadeh
University of California at Irvine, USA

Honorable Mention Award
“Design of On-Chip Test Pattern Generator without PPS”
N. Ganguly, B. K. Sikdar, and P. Pal Chaudhuri
Bengal Engineering College, Howrah, India

Design Contest Award

Best Design
Yusuke Oike
Dept. of Electronic Engineering, The University of Tokyo, Japan
Makoto Ikeda and Kunihiro Asada
VLSI Design and Education Center, The University of Tokyo
High-sensitivity and Wide-dynamic-range Position Sensor Using Logarithmic-response and Correlation Circuit

Yusuke Oike, Makoto Ikeda and Kunihiro Asada
Dept. of Electronic Engineering (VLSI Design and Education Center), The University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
Tel: +81-3-5841-6771, Fax: +81-3-5800-5797
e-mail: \{y-oike,ikeda,asada\}@isicon.u-tokyo.ac.jp

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 × 64 pixels on a 4.8 mm × 4.8 mm die of a 0.5 μm CMOS 3-metal 1-poly-Si process.

1. 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 a 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:

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

Here $\alpha$ stands for the characteristics 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 modulating 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:

$$V_{out}(t) = \int_{t-T}^{t} I_0 \cdot \frac{\kappa \Delta V_{sig}(\tau)}{2} \cdot \frac{\kappa \Delta V_{sync}(\tau)}{2} d\tau$$ (2)

where $T$ is frame time and $\kappa$ 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.
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 (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 $3 \times 10^3lx$ in outdoor environment, where the background intensity is about $1 \times 10^3lx$ 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 x 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.

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 x 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

The VLSI chip in this study has been fabricated in the chip fabrication program of VLSI Design and Education Center (VDEC), the University of Tokyo with the collaboration by Hitachi Hokkai Semiconductor Ltd. and Dai Nippon Printing Corporation.

References

**Introduction**

Application of 3-D measurement

Robot Vision

Computer Vision

Recognition System

Position Adjustment

3-D Modeling System

Virtual Reality

High-performance position sensor can realize advanced 3-D measurement

**Motivation**

3-D measurement system using triangulation-based light projection method

The features of the active 3-D measurement method

- **advantage**: This method can realize high accuracy and high sensitivity. A range map can be acquired by simple calculation.
- **disadvantage**: This method needs a scanning light source, and a target object and a measurement environment are limited.

Advanced application cannot be realized by the reasons as follows:

- Strong laser beam projection is dangerous.
- System should be available in various background illuminations.

**Required Performance of Position Detection**

- **High Speed**
- **High Accuracy**
- **High Sensitivity**
- **Wide Dynamic Range**

Compensation for the disadvantages of the active 3-D measurement method

High-sensitivity and wide-dynamic-range position sensor is required

High sensitivity should be realized in wide range of background illumination

**Performance Evaluation**

Multiple light system can be realized due to high selectivity

High sensitivity is realized in wide dynamic range of background

**High-Sensitivity Position Detection**

The conventional sensors can't detect the position:

- 1. when the laser beam is projected at stronger backgrounds
- 2. when peak intensities exist at other places

The proposed sensor can detect the positions clearly, which can't be detected by the conventional sensors

**Application to 3-D Measurement System**

3-D Measurement System

Accuracy of 3-D Measurement

Measurement result of a flat panel

Max. error: 14.6mm at a distance of 1418mm

Accuracy of ±5% (with 64 x 64 pixels)

**Designed and Fabricated Sensor**

Specifications

- **Process**: 0.8um CMOS process
- **Chip Size**: 4.9mm × 4.8mm
- **Num. of Pixels**: 64 x 64 pixels
- **Pixel Size**: 40µm × 40µm
- **Photo Diode**: 10.15µm × 28.45µm
- **n*-diff and p-sub
- **T/R Factor**: 180ΩΩ
- **Num. of trans.**: 114 transistors

Measurement Results

- **Supply Voltage**: 3.3V
- **Min. SBR**: ~14.4dB
- **Dynamic Range**: 46dB (SBR ~10dB)
- **Range Resolution**: ±5% at 1400mm
- **Power Dissipation**: 400mW at 200fps
- **Frame Rate**: Max. 2000fps (f0=10kHz)

**Proposed Sensing Scheme**

Sensing Scheme

Modulated laser beam is projected on the target object

Logarithmic suppression at photo diode

The previous input signal is subtracted from the current input signal

The input signal is multiplied by the external signals

The output of multiplier is integrated with or without integration

Schematic of the pixel

**Sensing Process**

Photo current is generated by input signal:

\[ I_{\text{IPD}} = I_{\text{sig}}(t) \times (I_{\text{b}} + V_{\text{cmp}}) \]

\[ I_{\text{IPD}} = I_{\text{sig}}(t) \times I_{\text{b}} \]

\[ I_{\text{IPD}} = I_{\text{sig}}(t) \times V_{\text{cmp}} \]

\[ I_{\text{IPD}} = I_{\text{sig}}(t) \times V_{\text{cmp}} + I_{\text{b}} \]

\[ I_{\text{IPD}} = I_{\text{sig}}(t) \times V_{\text{cmp}} + V_{\text{ref}} \]

\[ I_{\text{IPD}} = I_{\text{sig}}(t) \times V_{\text{cmp}} + V_{\text{ref}} + I_{\text{b}} \]

\[ I_{\text{IPD}} = I_{\text{sig}}(t) \times V_{\text{cmp}} + V_{\text{ref}} + V_{\text{sig}}(t) \]

\[ I_{\text{IPD}} = I_{\text{sig}}(t) \times V_{\text{cmp}} + V_{\text{ref}} + V_{\text{sig}}(t) + I_{\text{b}} \]

\[ I_{\text{IPD}} = I_{\text{sig}}(t) \times V_{\text{cmp}} + V_{\text{ref}} + V_{\text{sig}}(t) + I_{\text{b}} \]

\[ I_{\text{IPD}} = I_{\text{sig}}(t) \times V_{\text{cmp}} + V_{\text{ref}} + V_{\text{sig}}(t) + I_{\text{b}} \]

\[ I_{\text{IPD}} = I_{\text{sig}}(t) \times V_{\text{cmp}} + V_{\text{ref}} + V_{\text{sig}}(t) + I_{\text{b}} \]

\[ I_{\text{IPD}} = I_{\text{sig}}(t) \times V_{\text{cmp}} + V_{\text{ref}} + V_{\text{sig}}(t) + I_{\text{b}} \]

\[ I_{\text{IPD}} = I_{\text{sig}}(t) \times V_{\text{cmp}} + V_{\text{ref}} + V_{\text{sig}}(t) + I_{\text{b}} \]

\[ I_{\text{IPD}} = I_{\text{sig}}(t) \times V_{\text{cmp}} + V_{\text{ref}} + V_{\text{sig}}(t) + I_{\text{b}} \]

\[ I_{\text{IPD}} = I_{\text{sig}}(t) \times V_{\text{cmp}} + V_{\text{ref}} + V_{\text{sig}}(t) + I_{\text{b}} \]

\[ I_{\text{IPD}} = I_{\text{sig}}(t) \times V_{\text{cmp}} + V_{\text{ref}} + V_{\text{sig}}(t) + I_{\text{b}} \]