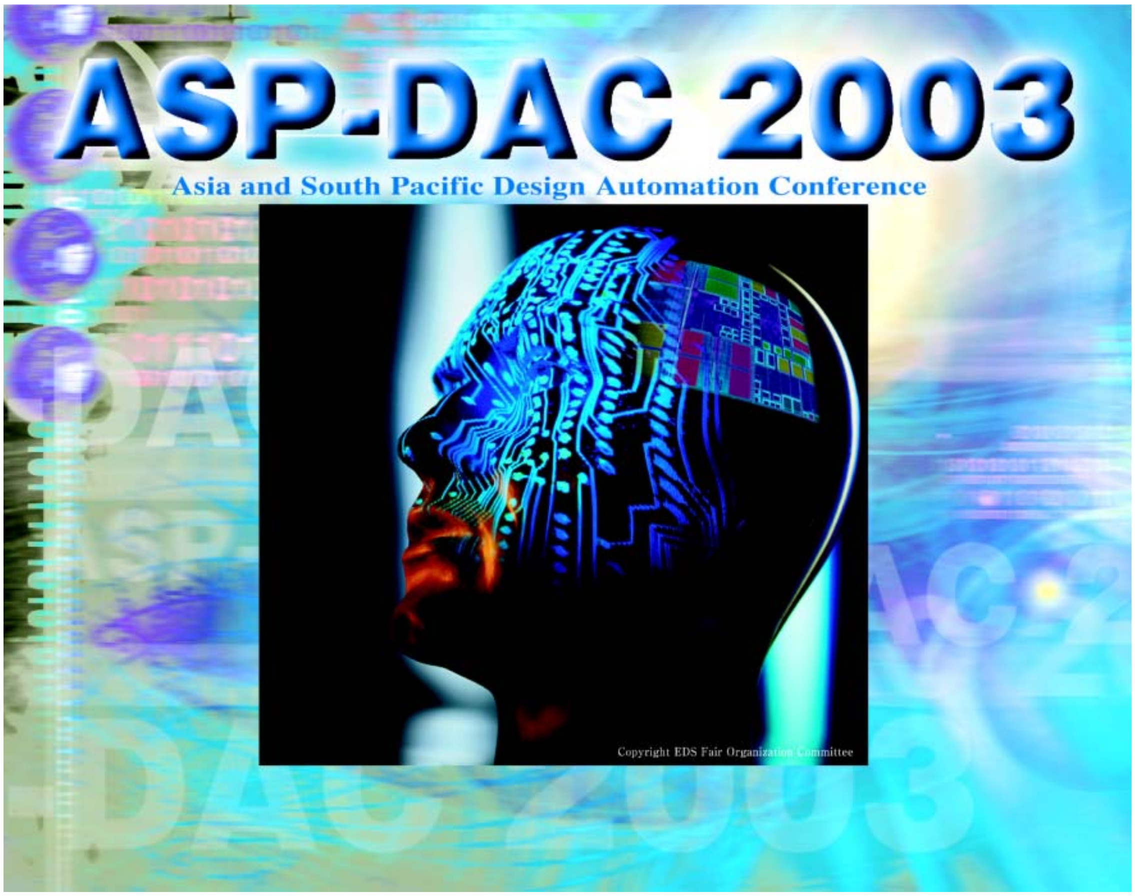
PROCEEDINGS



January 21 - 24, 2003
Kitakyushu International Conference Center
Kitakyushu, Japan

ASIA SOUTH PACIFIC DAC DESIGN AUTOMATION CONFERENCE

http://www.aspdac.com

Sponsored by:
IEEE CAS, ACM SIGDA, IEICE, IPSJ

Supported by:
JEITA, STARC, Kitakyushu City, ASIAS KYUSHU, Kitakyushu Convention Bureau, Promotion Committee for Fukuoka System LSI R&D Hub

In Corporation with:
JIEP

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:

Desing 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

"High-Sensitivity and Wide-Dynamic-Range Position Sensor Using Logarithmic-Response and Correlation Circuit"

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}@silicon.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 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-

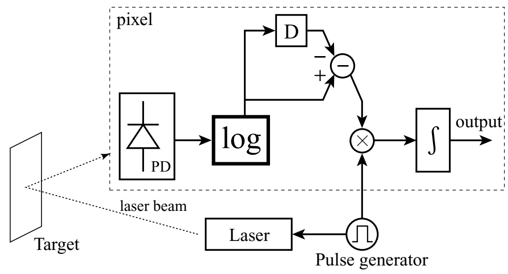


Fig. 1. Pixel structure.

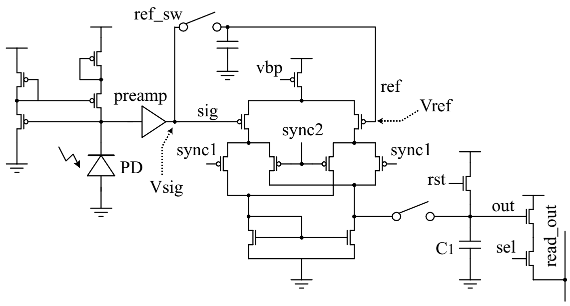


Fig. 2. Schematic of a pixel.

dynamic-range photo detection. Photo current $I_{PD}(t)$ generates the voltage $V_{sig}(t)$ at the node sig as follows:

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

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.

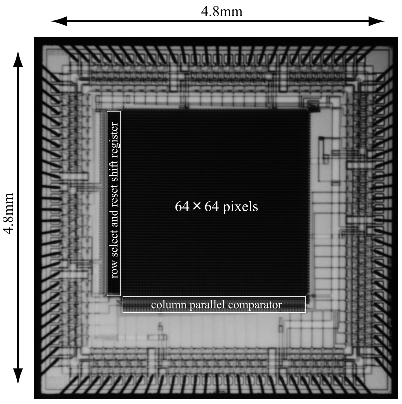


Fig. 3. Microphotograph of the sensor.

TABLE I
SUMMARY OF THE POSITION SENSOR.

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

III. Experimental results

Fig.3 shows a microphotograph of the sensor. The sensor is fabricated in 0.5μm 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 × 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.

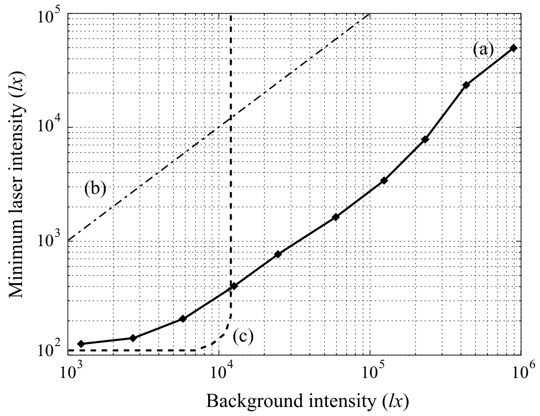


Fig. 4. Minimum laser intensity on target objects: (a) the proposed position sensor, (b) the conventional image sensor, (c) the conventional correlation sensor.

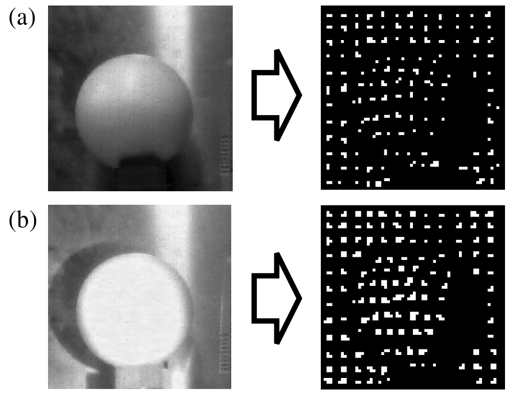


Fig. 5. Acquired images for 3-D measurement: laser intensity is about (a) 400 lx, (b) 1900 lx and max. background intensity is about (a) 1600 lx, (b) 28000 lx.

IV. Conclusions

A high-sensitivity and wide-dynamic-range position sensor using logarithmic-response and correlation circuit has been developed and successfully fabricated in 0.5μm 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 × 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

[1] M. de Bakker, P. W. Verbeek, E. Nieuwkoop and G. K. Steenvoorden, "A Smart Range Image Sensor," *Proc. of European Solid-State Circuits Conference*, pp.208-211, 1998.

[2] T. Nezuka, M. Hoshino, M. Ikeda and K. Asada, "A Smart Position Sensor for 3-D Measurement," *Proc. of Asia South-Pacific Design Automation Conference*, pp.21-22, 2001.

[3] A. Kimachi and S. Ando, "Time-Domain Correlation Image Sensor: First CMOS Realization and Evaluation," *Transducers '99*, pp.958-961, June 1999.

High-Sensitivity and Wide-Dynamic-Range Position Sensor Using Logarithmic-Response and Correlation Circuit

Yusuke Oike, Makoto Ikeda, and Kunihiro Asada

Department of Electronic Engineering, and
VLSI Design and Education Center (VDEC),
University of Tokyo, JAPAN

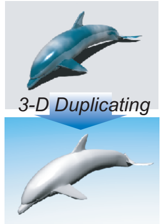
1

Introduction

Applicaton of 3-D measurement

Robot Vision
Computer Vision
Recognition System
Position Adjustment
3-D Modeling System
Virtual Reality

Robot Vision



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

PROCESS

The sensor detects the reflection positon of projected light (position detection)

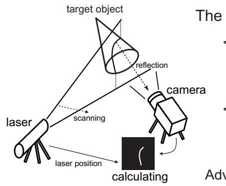
The distance is calculated using triangulation principle

High performance position sensor can realize advanced 3-D measurement

2

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
A range map can acquired by simple calculation

<disadvantage>
This method needs a scanning light source
A target object and a measuremenet environment are limited

Advanced application can't 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

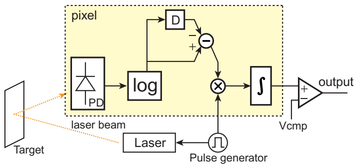
High Speed | High Accuracy | High Sensitivity | Wide Dynamic Range

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

High-sensivitiy and wide-dynamic-range position sensor is required
High sensitiviy should be realized in wide range of background illumination

3

Proposed Sensing Scheme



Sensing Scheme

Modulated laser beam is projected on the target object

Logarithmic suppression at photo diode

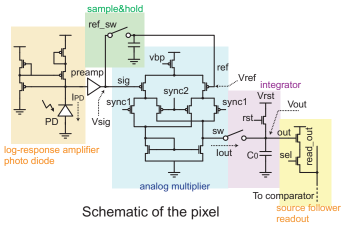
The previous input singal is subtracted from the current input signal

The input signal is multiplied by the external signals

The output of multiplier is integrated

with integration | without integration

Projected light is detected | Input signal has no projected light



Schematic of the pixel

4

Sensing Process

Photo current is generated by input signal

$V_{sig}(t) = \alpha \log I_{PD}(t)$
α : a gain factor of pre-amplifier
I_{PD} : photo current

Vref is generated at S&H circuit and multiplied by Vsync

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

$I_{out}(t) = I_b \tanh\frac{\kappa \Delta V_{sig}(t)}{2} \tanh\frac{\kappa \Delta V_{sync}(t)}{2}$
Ib : bias current
Vsync : external signals synchronized with the correlation frequency

The output of multiplier is integrated

$V_{out}(t) = \frac{1}{C_0}\int_{t-T}^{t} I_{out}(\tau)\, d\tau + V_o$
T : frame interval
Vo : bias voltage of integrator

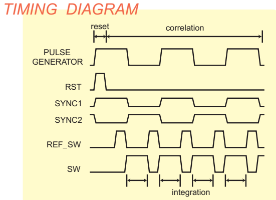
Input signal has the correlation frequency f0
The output of multiplier is always positive value
The voltage of integrator is monotonously increasing

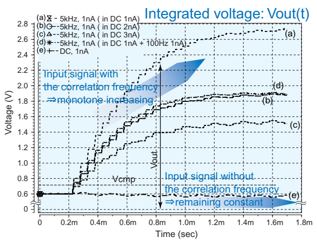
Input signal doesn't have the correlation frequency f0
The voltage of integrator fluctuates
Especially, input signal is only background illumination
The voltage of integrator remains constant

Comparison between Vout and Vcmp

$V_{out} \geqq V_{cmp}$
Vcmp : the reference voltage of comparator

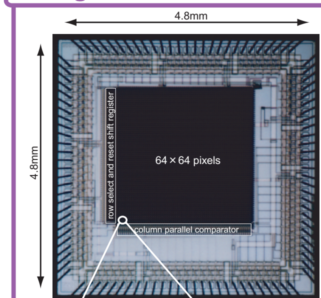
TIMING DIAGRAM



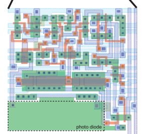


5

Designed and Fabricated Sensor



Microphotograph of the sensor



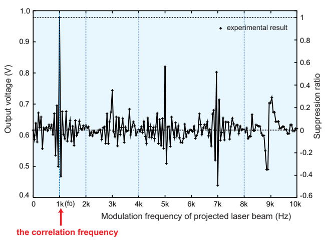
The pixel layout

Specifications	
Process	0.5µm CMOS process
Chip Size	4.8mm × 4.8mm
Num. of Pixels	64 × 64 pixels
Pixel Size	40µm × 40µm
Photo Diode	10.15µm × 28.45µm n+-dif and p-sub
Fill Factor	18.05%
Num. of Trans.	114k 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)

6

Performance Evaluation

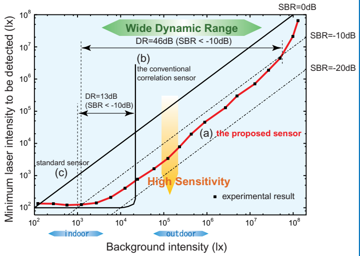


High suppression ratio at even harmonics of the correlation frequency

High selectivity is realized using a set of even-harmonics frequencies

Multiple light system can be realized due to high selectivity

*SBR: Signal-to-Background Ratio = 10 log(Elaser/Ebg)
Sensitivity of position detection



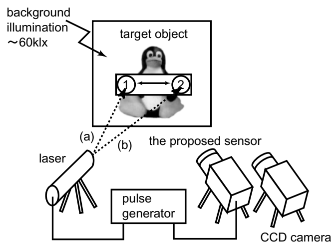
(a) The proposed position sensor
High sensitivity........... Minimum SBR* : -14.4dB
Wide dynamic range.. Dynamic Range : 46dB (SBR < -10dB)
(b) The conventional correlation sensor
Dynamic Range is limited due to the voltage saturation
(c) Standard sensor

High sensitivity is realized in wide dynamic range of background

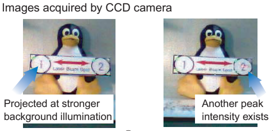
7

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

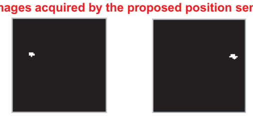


Images acquired by CCD camera



Laser beam is projected at ① | Laser beam is projected at ②

Images acquired by the proposed position sensor



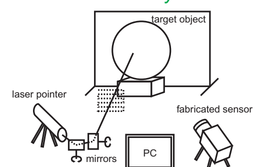
The intensity of background illumination at ① 60klx
The intensity of projected laser beam 4klx

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

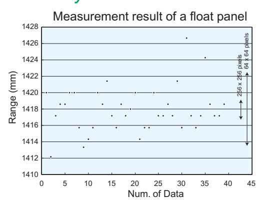
8

Application to 3-D Measurement System

3-D Measurement System



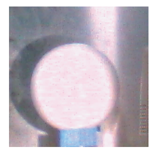
Accuracy of 3-D Measurement



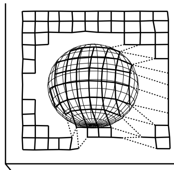
Max. error : 14.6mm at a distance of 1418mm

Accuracy of ±0.5% (with 64 × 64 pixels)

Measured Range Map



Target object



Reproduced wire frame

Measurement Environment
Strong background illumination (28 klx)
Weak projected laser beam (1.6 klx)

The proposed sensor realizes both :
Availability in various backgounds
Safe light projection for human eyes

9