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A 3.2 kHz, Stereo Sensing Module Using Two Profile Sensors

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Abstract

We have developed an intelligent CMOS sensor named Profile Sensor with sampling rate at 3200Hz of X and Y projection images. The Profile Sensor is a unique CMOS sensor aimed at high-speed position sensing by detecting projection images of X and Y-axes. We have constructed a stereo sensing module by using two profile sensors and confirmed the characteristics of the module for high-speed three-dimensional position detection of multi spots using LEDs and reflectors as a target. We would like to show that the sensor has high-speed and high-accurate position measurement capabilities and can be useful for industrial and amusement applications.

1 Introduction

Intelligent sensor which is high-speed, high-accuracy, compact and low-cost, is desired as a key component in several image processing applications such as factory automation(FA), machine vision, intelligent transportation system(ITS), robot-control and optical measurement and control. Generally, conventional image sensing systems are based on two-dimensional area image sensors. However, in such a system have an I/O bottleneck problem because the sensor's processing speed limit derived from video frame rate (30 frame/s). Moreover, the increase of the number of pixels brings an enlargement of calculation and processing time.

In order to overcome the limitation, Ishikawa's group has proposed a S^3PE architecture [1] based on the concept of integration of detector and processing elements, and reported the advantages of 1ms visual feedback technology on a robot control, dynamics analysis, and man-machine interface [2, 3]. Based on the S^3PE architecture, we have designed and constructed a Column Parallel Vision (CPV) system to realize an intelligent and general purpose image processing system with higher frame rate within 1ms (i.e. 1000 frame/s) [4, 5].

We have developed high speed sensors with intelligent functions for those systems [6, 7]. Each application requires its original function such as edge enhancement, emboss operation, motion and position detection [8, 9]. In specific applications such as position detection, a CMOS image sensor, which specializes for a single function, is sometimes suitable than a high performance, multi-purpose CMOS image sensing system. Accordingly, we consider the intelligent sensor which focus on the necessary function is needed. Therefore, we have proposed an intelligent CMOS sensor named Profile Sensor with high-speed multi spot position detection, and we have constructed a three-dimensional measurement module by using two profile sensors [10] and applied the sensor for an absolute encoder system [11].

In this paper, we have evaluated experimentally the accuracy of position detection of the system by using LEDs and reflectors as multi spot targets.

2 Structure and Characteristics of Profile Sensor

The Profile Sensor is a two-dimensional intelligent CMOS sensor specialized in high-speed position detection of incoming light spots. The structure of the pixels of sensor is illustrated in Fig. 1. Each pixel has two photodiodes for detecting X axis and Y axis projection data (the profile data) independently. Each X axis pixels in same raw are connected by a metal line, and Each Y axis pixels in same column are connected too. Therefore, the outputs of all photodiodes in the same column and same raw are added as a result of sum of photo current.

Fig. 2 shows a sample output from profile sensor. A single light spot incoming the active area, the profile sensor acquires only the profile data of the X and Y axes. The height of the peak of profile data is output in response to the brightness of incoming light spot, and the width of the peak corresponding to the size of the light spot. And X and Y axis position of the peak is equivalent to the two-dimensional position of light spot.

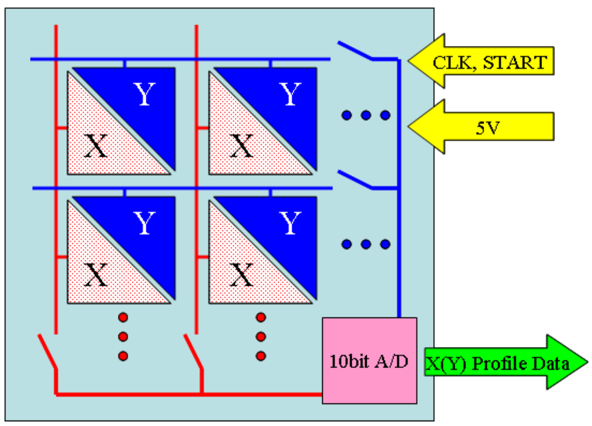

Fig.1 Pixel structure of the Profile Sensor

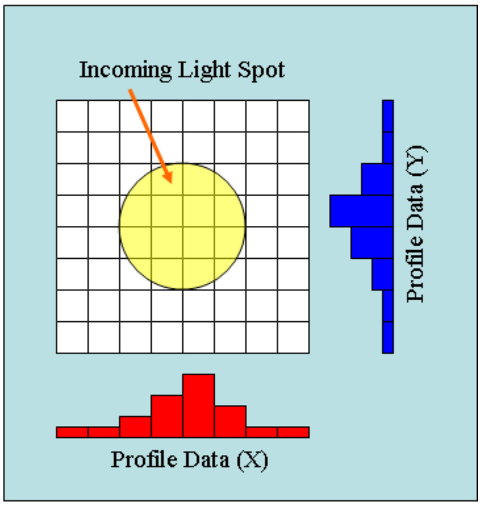

Fig.2 Sample output from Profile Sensor

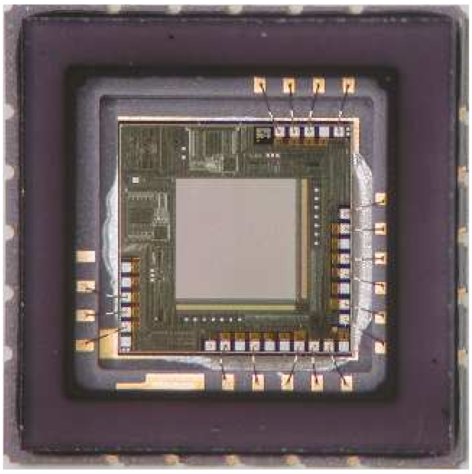

Fig.3 Photograph of Profile Sensor

Table 1 Main Characteristics of Profile Sensor

Number of pixels	256x256	512x512
Active area	2.0 x 2.0 [mm]	4.0 x 4.0 [mm]
Pixel pitch	7.8 [μm]	7.8 [μm]
Frame rate	3200fps(8bit) 1600fps(10bit)	1600fps(8bit) 800fps(10bit)
Power consumption	75 [mW]	-
Random noise	< 4.0 [mV]	-

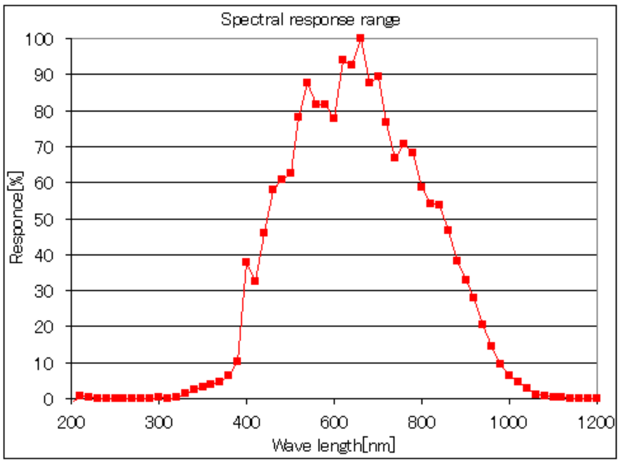

Fig. 4 Spectral response of Profile Sensor

A photograph of the Profile Sensor is shown in Fig. 3, and the main characteristics of Profile Sensor are listed in Table 1. The pixel pitch is 7.8μm and the active area is 2.0mm x 2.0mm (256x256) or 4.0mm x 4.0mm (512x512). A timing generator, amplifier, 10bit A/D converter and bias voltage generator are all integrated on the chip, allowing operations with a very simple external signal processing circuit and adding clock and start signals from outside. The maximum frame rate is 3200 frame/sec at 8-bit output mode in the case of 256x256 pixel sensor. As shown in Fig. 4, spectral response of Profile Sensor is the range of 380nm to 1000nm.

2.1 Compared with conventional 2D-PSDs

As a sensor for position detection, the two-dimensional image sensor and Two Dimensional Position Sensitive Detector (2D-PSDs) are used. Table 2 shows the comparison of these sensors.

Table 2 Comparison of sensors

	2D-PSD	Profile Sensor	2D-image sensor
Speed	◎	○	△
Multi Spot Position Detection	×	○	◎
Complexity of the external processing circuit	△	○	△

In comparison with the conventional 2D-PSDs, the Profile Sensor has these advantages: First, it is capable of high-speed position detection for multiple incoming spot lights. Figure 5 shows a target using three LED and output example of Profile Sensor. It is obtained that the sensor output corresponding to the three incoming light spots. Second, the sensor output is the only digital profile data and the amount of data of Profile Sensor is less than the 2D-PSDs output data. Therefore, the external signal processing circuits are simplified. On the other hand, in comparison with the conventional 2D-image sensor, the amount of data is much smaller than conventional image sensor. For example, we consider two-dimensional image sensor with N x N pixels. A Conventional sensor gives an output data in the order of a square of N. On the other hand, the Profile Sensor only gives an output data twice of N.

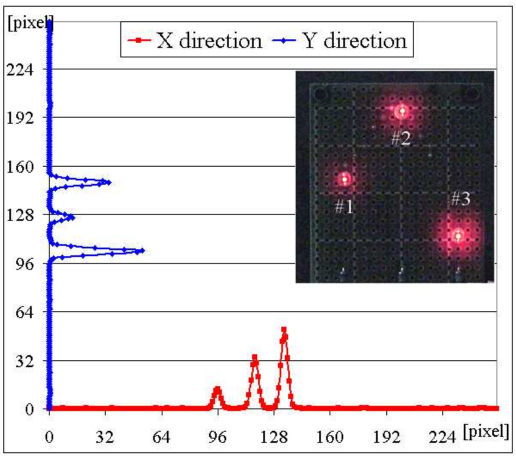

Fig.5 LED target and output example (three light spots)

3 Measurement Module and Experimental Results

3.1 Stereo Sensor Module

We have constructed stereo sensing module using two Profile Sensors as shown in Fig. 6. Two Profile Sensors are connected to processing circuit. The distance between two sensors (length of baseline) was 120mm. By using this structure, three dimensional measurement by stereoscopic is available.

3.2 Experimental Setup

In order to evaluate a basic characterization of the stereo sensing module, we performed the position measurement of LED target and reflector target. Fig. 7 shows an experimental setup and the experimental condition are listed in Table 3. The measurement module scans a 200mm x 200mm area and distance from sensor to target is 400mm. The targets were moved horizontally at the 0.05mm pitch and the profile data was acquired at 3200 frame/s. Then, we calculated of the one-dimensional center-of-gravity operation for the profile data and we have evaluated the accuracy of the module by measuring linearity and temporal fluctuation by the standard deviation of the measured position. When the direction of horizontal is set to X, the direction of vertical is set to Y and the depth direction is set to Z, the resolution of X and Y directions are 0.78mm/pixel, and the resolution of Z is 5.09mm/pixel. Fig.8 shows the target patterns of LEDs (left) and reflectors (right) which we used in the experiments. An example of the output from sensing module is indicated in Fig. 9. In this experiment, we used another three LEDs such that each LED had different brightness. The disparity of the spot position on X-axis indicates a parallax to know the distance between the sensor and the target.

3.3 Experimental Results

A result of X axis position movement of the LED target is shown in Fig. 10. The horizontal (X) axis represents the real target position in millimeters, and the vertical (Y) axis shows the measurement position. The results of another LEDs target are summarized in Table 4.

We have confirmed the system has accurate measurement capability such that RMS-Error of linearity was 0.04 pixels and temporal fluctuation by the standard deviation is 0.01 pixels. As shown in the results, the size and brightness of the target were affected the measurement accuracy and we have confirmed that the accuracy is obtained in approximately about 0.1 to 0.01 pixels.

We have also confirmed the accuracy of the reflector target as shown in Table 5. The result shows the reflector target which has suitable size (diameter = 4mm) has a capability to have adequate accuracy.

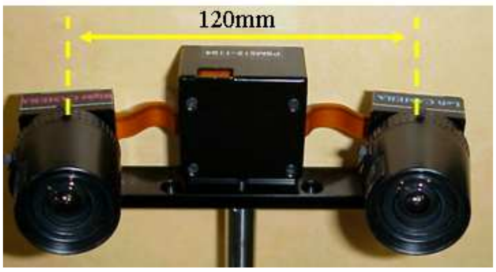

Fig.6 Photograph of stereo sensing module

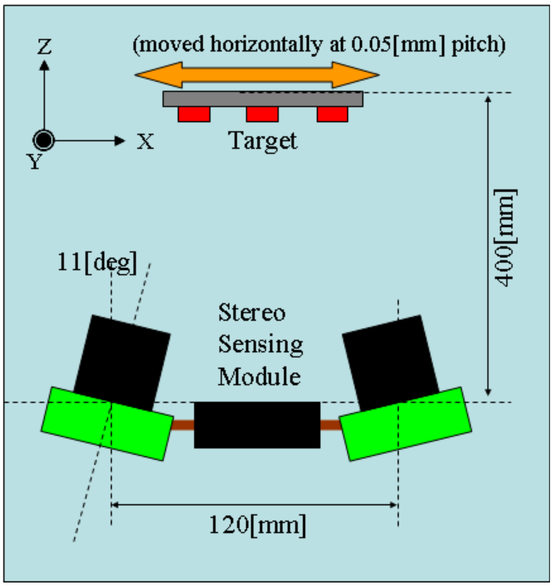

Fig.7 Experimental setup

Table 3 Experimental conditions

Profile Sensor	
Frame rate	3200 frame/s
Number of Pixels	256 x 256 pixel
Length of baseline	120 mm
Angle of sensor	11 degree
LED	
Wavelength	660 nm
Current	50mA
Movement pitch	0.05 mm(horizontally)

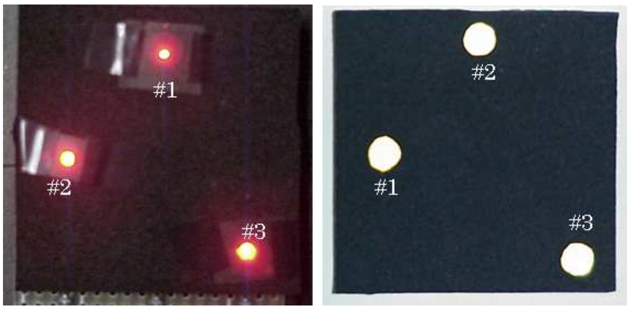

Fig.8 Targets of experiment (left: LEDs, right: reflectors)

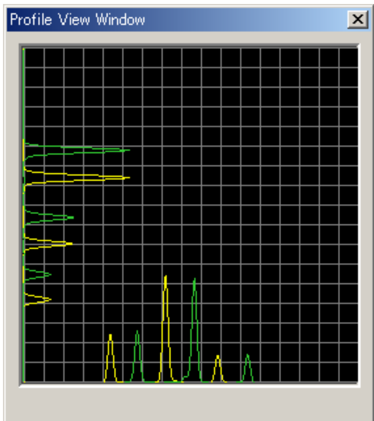

Fig.9 Output of the multi spot target from sensing module (Target: three LEDs)

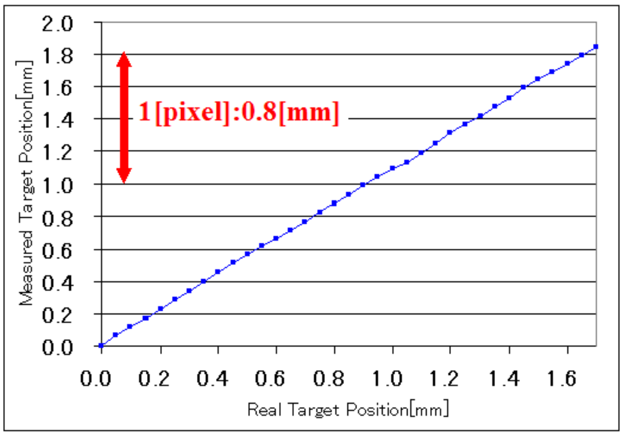

Fig.10 Experimental results of linearity (target: LED)

Table 4 Experimental results of LED target

LED size	RMS-error of Linearity [pixel]	Temporal fluctuation by standard deviation [pixel]
ϕ1mm	0.17	0.13
ϕ2mm	0.08	0.02
ϕ3mm	0.04	0.01

Table 5 Experimental results of reflector target

Reflector	RMS-error of Linearity [pixel]	Temporal fluctuation by standard deviation [pixel]
#1,#2,#3	0.06	0.02

4 Conclusions

We have developed Profile Sensor with a high-speed position detection function. We have applied the sensors to construct a stereo sensing module. We have confirmed experimentally that a 3D-measurement module has excellent characteristics of high-speed (3200Hz) and compactness.

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