Design of Real-Time VGA 3-D Image Sensor Using Mixed-Signal Techniques

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Abstract— We have developed the first real-time 3-D image sensor with VGA pixel resolution using mixed-signal techniques to achieve high-speed and high-accuracy range calculation based on a light-section method. Our mixed-signal position detector, which consists of an adaptive threshold circuit and time-domain approximate ADCs, provides significant information for range finding quickly during high-speed analog-to-digital conversion. Moreover the position address and the intensity profile of a projected beam are selectively provided by the next digital stage to reduce data transmission. Our 3-D imager also has a standard analog readout circuit to get a 2-D image. Measurement results show that it achieves 65.1 range_maps/sec with 0.87 mm range resolution at 1200 mm distance.

I. Introduction

Recently we often see 3-D computer graphics in movies and televisions, and handle them interactively using personal computers and video game machines. Latest and future 3-D applications require both higher pixel resolution for accurate range finding and higher frame rate for real time. Fig.1 shows a principle of a light-section range finding method, which allows higher range accuracy with simple calculation than other typical methods such as a stereo-matching method and a time-of-flight method. In the light-section system, an image sensor receives the reflection of a projected sheet beam from a target object, and detects the position of the incident beam on the sensor plane. The range data can be calculated from the detected positions and the projected angle by triangulation. The positions of a scanning sheet beam provide a range map of a target object. Therefore the range finding system requires very high-speed position detection such as 30k fps with 1M pixel resolution. It is difficult for a standard readout architecture such as CCD. Even the high-speed CMOS APS with column-parallel ADCs realizes 500 fps [1]. The state-of-the-art 3-D image sensors [2]–[4] achieve >15 range_maps/sec, however their resolutions are 24k pixels at most.

We have developed the first real-time 3-D image sensor with VGA pixel resolution using mixed-signal techniques to achieve high-speed and high-accuracy range calculation based on a light-section method [5]. Our mixed-signal position detector, which consists of an adaptive thresholding circuit and time-domain approximate ADCs, provides significant information for range finding quickly during high-speed analog-to-digital conversion. Moreover the position address and the intensity profile of a projected beam are selectively provided by the next digital stage to reduce data transmission.

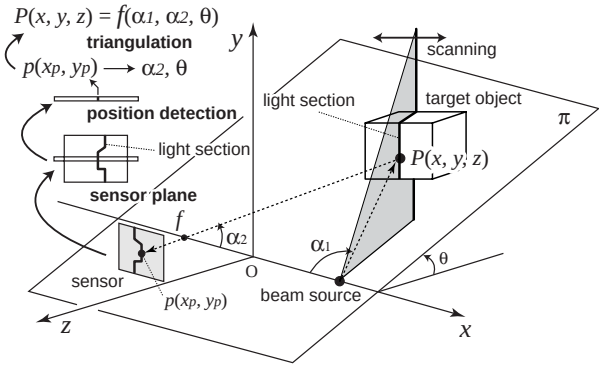

Fig. 1. Principle of Light-Section Range Finding.

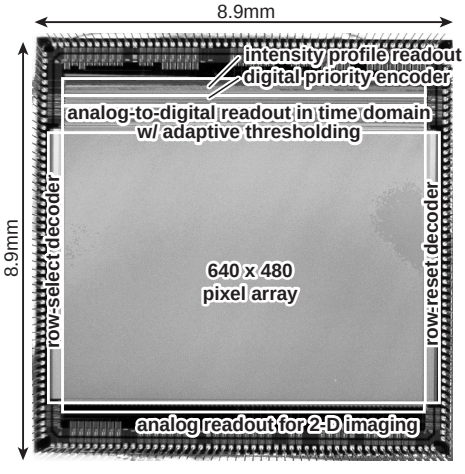

Fig. 2. Chip microphotograph and block diagram.

II. Sensor Design and Chip Implementation

The real-time VGA 3-D image sensor has been designed and fabricated in 0.6 μm CMOS process[1] as shown in Fig.2. It consists of a 640×480 pixel array with row select/reset decoders, analog readout circuits for 2-D imaging, time-domain analog-to-digital readout circuits with adaptive thresholding, and two digital stages to provide the detected positions and intensity profile. The specifications of the fabricated sensor are shown in Table I.

Fig.3 and Fig.4 show the circuit configuration and the sensing scheme of our mixed-signal position detector. It consists of an adaptive thresholding circuit and time-domain approxi-

[1]The chip has been fabricated through VLSI Design and Education Center, University of Tokyo in collaboration with Rohm Co., Toppan Printing Co.

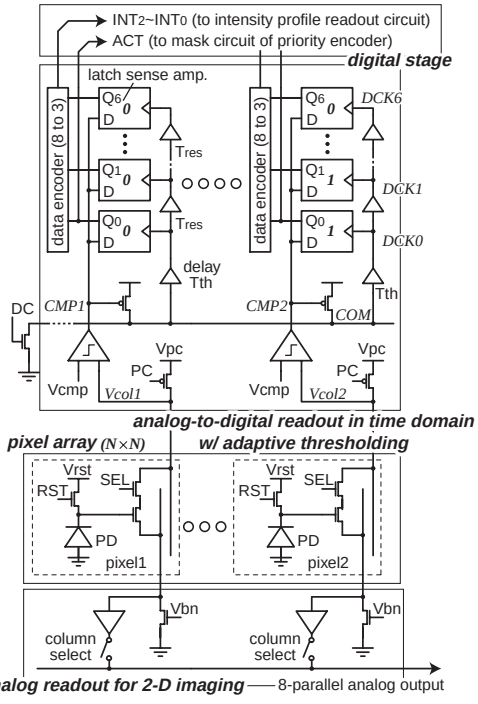

Fig. 3. Circuit configuration of mixed-signal position detector.

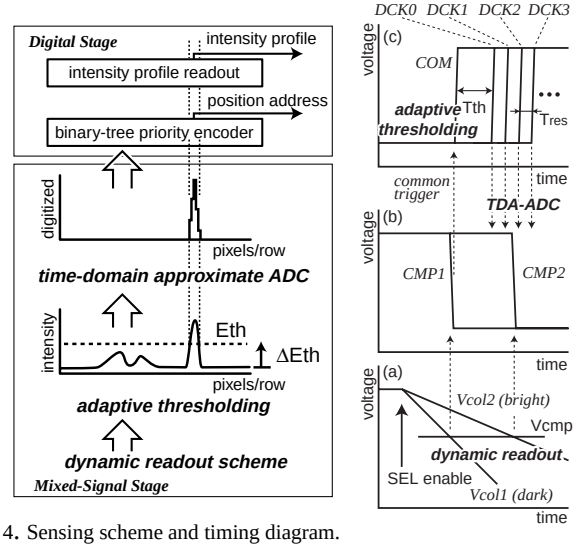

Fig. 4. Sensing scheme and timing diagram.

mate ADCs (TDA-ADC) in column parallel. In 3-D imaging mode, a row line is accessed using a dynamic readout scheme after precharged as shown in Fig.4(a). Some pixels, where a strong light incidents, are detected when the pixel value is over the threshold level decided by dark pixel values adaptively. Here the pixel values are estimated in time domain as shown in Fig.4(c). In the same operation, the intensity profile of activated pixels are acquired by the time-domain ADCs to improve sub-pixel accuracy as shown in Fig.4(b).

The adaptive thresholding circuit suppresses overall ambient light intensity and fluctuation of access speed in each row. Moreover the threshold level and the resolution of ADCs are controllable by some external voltages, V_{rst}, V_{pc} and V_{cmp} after fabrication. These features are important to design the mixed-signal position detector under various measurement situations.

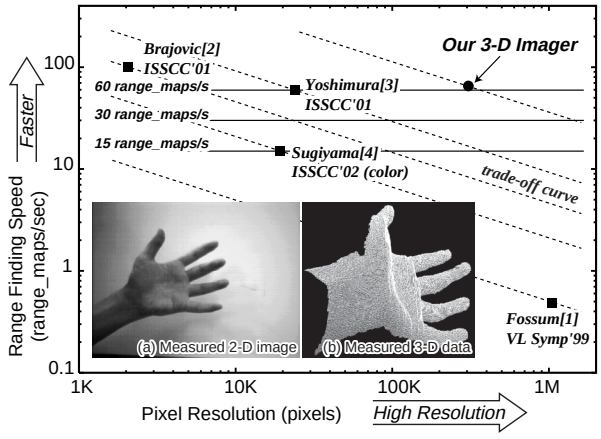

Fig. 5. Measurement results and performance comparision.

TABLE I
SENSOR SPECIFICATION AND PERFORMANCE.

Process	0.6 μm CMOS process
Chip size	8.9×8.9 mm^2 (1.12M Tr.)
# of pixels	640×480 pixels (VGA)
Pixel size	1 PD / 3 Tr. (12.0×12.0 μm^2)
Fill factor	29.54 %
Power supply voltage	5.0 V
Power dissipation	305 mW (@ 10 MHz)
Max. 2-D imaging rate	13.0 frames/sec
Max. position detection rate	41.7k lines/sec
Max. range finding rate	65.1 range_maps/sec
Range accuracy (max. error)	0.87 mm (@ 1200 mm)

III. MEASUREMENT RESULTS AND PERFORMANCE COMPARISON

Fig.5 shows the measured 2-D/3-D images and performance comparison among a high-speed 2-D imager [1] and the state-of-the-art 3-D imagers [2]–[4]. Our 3-D imager achieves 65.1 range_maps/sec with VGA pixel resolution. The maximum range error is 0.87 mm and the standard deviation is 0.26 mm at a distance of 1200 mm. The acquired intensity profile achieves ~1/2 range error of the conventional binary-based 3-D imagers. The performances are summarized in Table I.

IV. CONCLUSIONS

We have developed the first real-time 3-D image sensor with VGA pixel resolution using mixed-signal techniques, which achieves 65.1 range_maps/sec and 0.87 mm range resolution at 1200 mm. The performance is realized by the mixed-signal position/profile detector in time-domain analog-to-digital conversion. Our designed 3-D imager will provide future and attractive applications with high-quality 3-D images.

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