The realization of 3D Display by using 2D sensor

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Abstract

To make 3D camera system, we check the possibility of advanced range camera module based on measuring the time delay of modulated infrared light , using a single detector chip fabricated on standard CMOS process.
To depth information, electronic shutter and interlaced scanning method of 2D sensor is needed.
Especially, we design "lens system, illumination unit" and review simulation result.

1. Introduction

The objective of this paper is to check the possibility of 3D display by using 2D sensor
To make 3D display, we can use the laws of physics using methods such as - interferometer, triangulation or TOF methods.
Our approach is entirely focused on a time-of-flight (TOF) distance measuring principle.
Actually, there are a few manufacturers on the basis of this principle such as - PMDTec (Germany), Cannesta (U.S.A), Swiss-ranger (Swiss)
We briefly describe the principle of TOF (Time-of Flight).
The depth information is generally solved by two means.
The arrays of infrared LED are modulated 3~20MHz and emitted infrared LED are reflected by object and finally detected by camera.
If we demodulate the incoming signal by sampling four times (A0; A1; A2; A3), where the four samples are equally distributed over the period, the incoming signal can be computed according to the following formulae:

Phase shift = arc tan [(A3-A1)/(A2-A0)]

Finally, the distance D from the target can be calculated directly by equation.
Especially, we use the principle of 2-tap architecture, which was suggested by PMDTec.

$$D = \frac{\varphi}{2\pi}\frac{c}{2\nu}$$

2. Experimental

2.1 The 2-tap pixel architecture

The 2-tap pixel architecture is that all photo-generated electrons are exploited.
The dumped electrons represent just the opposite Sampling signal. The sampling duration is set to half the modulation period: during the first half all electrons drift to one output, during the second half all electrons are transferred to the opposite output. Therefore, the samples A0 and A2 (A1 and A3, respectively) are acquired simultaneously.

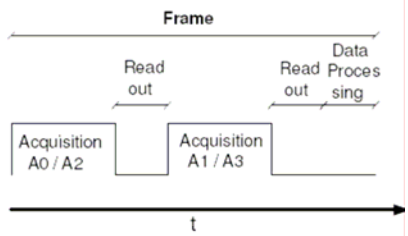

Fig. 1. Two-Tap Architecture Diagram.

2.2 2D Sensor

The CMOS camera used in this case, is black and white camera with VGA resolution (640 x 480).
The data output of the CMOS sensor is synchronized with the PIXCLX output. When LINE_VALID is

High, one 10-bit pixel datum is output every PIXCLK period.

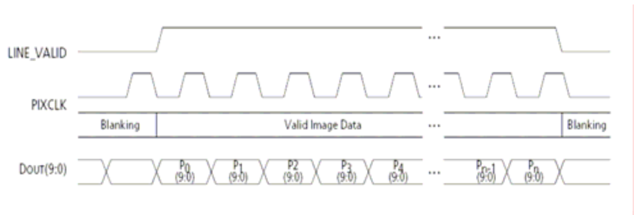

Fig. 2. Output data Timing

The formats for reading out four rows and two vertical blanking rows are shown as below.
The LINE_VALID signal is the XOR between the continuous LINE_VALID signal and the FRAME_VALID signal.

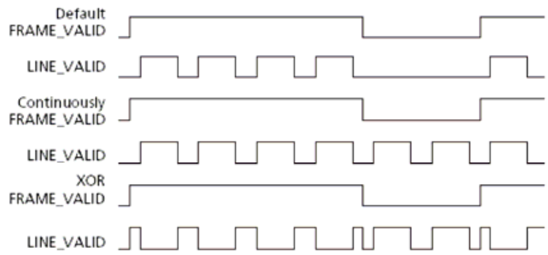

Fig. 3. Output data timing of Interlaced scanning

The Row Start register determines which field gets read out; if the row start register is even, the even field is read out; if row start address is odd, the odd field is read out.

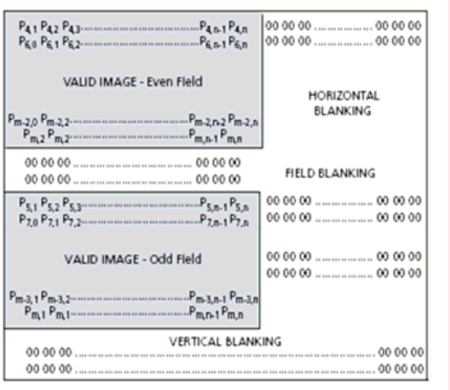

Fig. 4. Interlaced Image Readout

To realize depth information, we have assumption that one pixel is made by combination of even field one pixel and odd field one pixel. (Ex: First Pixel: P4, 1 + P6, 0 /Second Pixel: P4, 2 + P6, 1/ Third Pixel P4, 3+P6, 2…)
By use of electronic shutter, even field and odd field will separately have process of image readout.
When it is compared with two-tap architecture, the even field pixel represents Acquisition A0/A2 and the odd field pixel also represents Acquisition A1/A3.
This analog data finally is changed as 10 bit digital data.

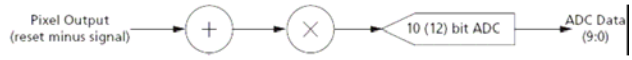

Fig. 5. AGC and ADC

The even field digital data and odd field digital data can be separately expressed as matrix.

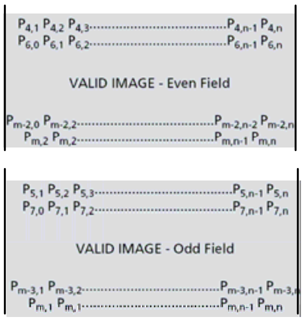

Fig. 6. Digital data of even and odd field

They mean that pixel data are storaged in the memory address register.

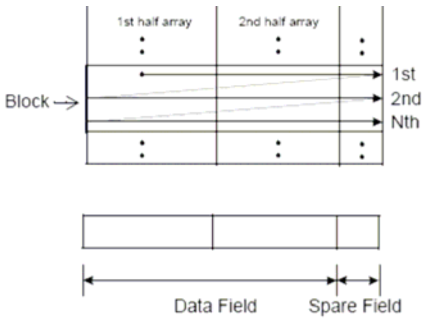

Fig. 7. The concept of memory address register

2.3 FPGA and Micro-controller

FPGA(Field-Programmable gate array) executes the timing and driving of the 2D sensor, the LEDs and the ADCs.
Micro-controller executes the task of communicating with the PC either via Ethernet or IEEE 1394; analyzing the data; and controlling the FPGA.

2.4 Lens system and LED Board

Lens system is designed on the basis of wavelength 850nm±30nm.
MTF of this lens system is focused on 20line/mm.
Moreover, the spherical aberration and astigmatism aberration is minimized at the field of 0.7.
LED board will generate 20MHz modulation (Non-ambiguity distance is 7.5m).

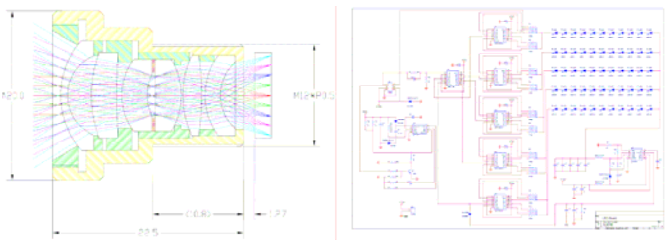

Fig. 8 Lens system (Simulation: CODE V) and LED Modulation Board

3. Results and discussion

3.1 Experimental details

The IR rays received at the receiver end will be correlated with the transmitted rays, and hence sensor shutter (to control the exposure time of the sensor programmatically) will be open for correlated time to accumulate the charge.

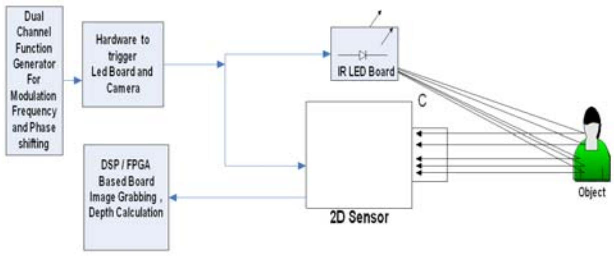

Fig. 9. System block diagram

1) The IR LED board is used to illuminate the scene.

2)Function generator will generate different phases shift modulated signal with different frequencies.
3) Modulated signal will be fed to led board as well as the camera.

4) Modulated signal fed to camera will trigger it for accumulating the charge

5) Modulated signal fed to Led board will generate the modulated IR rays; IR rays after reflection from the object (at certain distance) will fall on the camera where the triggered camera will accumulate the charge.

6) FPGA/DSP board will be used to grab the image and carry out calculation for Intensity Image and depth Calculation.

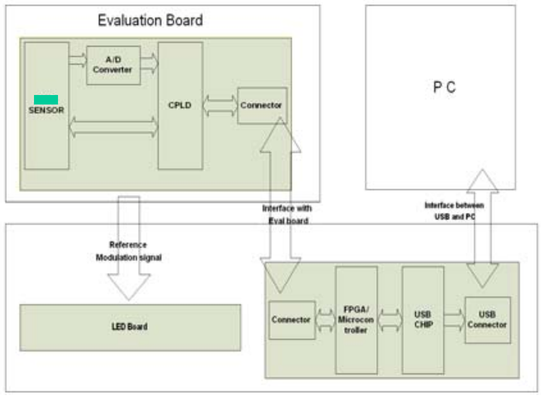

Fig. 10. System block diagram

3.2 Optical simulation result

Illumination unit have to cover as uniformly as possible when it is captured by the Lens system.
The uniformity of illumination unit is much better as long as object is far away.

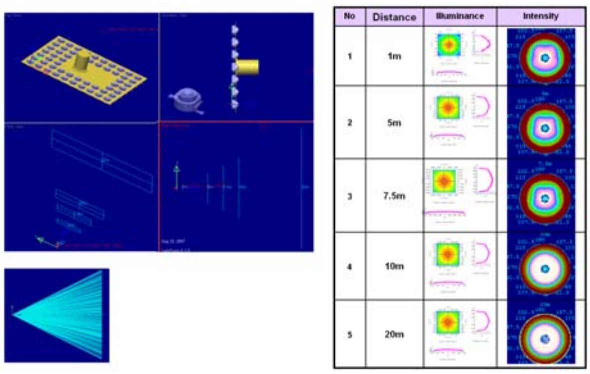

Fig. 11. IR LED intensity vs. distance (Simulation: Lightool)

But, the intensity of IR LED decreases according to the following formulae:

$$P_{\text{light source}} = \frac{N_e \cdot \frac{A_{\text{image}}}{A_{\text{pix}}} \cdot h \cdot c}{\rho \cdot \left(\frac{D}{2 \cdot R}\right)^2 \cdot k_{\text{lens}} \cdot \mathrm{QE}(\lambda) \cdot \lambda \cdot T_{\text{int}}}$$

where

N_e	number of electrons per pixel:
A_{image}	image size in sensor plane:
A_{pix}	light-sensitive area of pixel:
h	Planck's constant:
c	speed of light in vacuum:
ρ	reflectivity of object:
D	aperture of lens:
R	distance of object:
k_{lens}	losses of objective and filters:
$\mathrm{QE}(\lambda)$	quantum efficiency:
λ	wavelength of light:
T_{int}	integration time.

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To sum it up, the results of this system have not still tangible outcome.
But, we can check any possibility of tangible outcome at the laboratory.
This system would be well operated under the condition of perfect synchronization between 2D sensor and LED modulation, enough intensity of IR LED, successful elimination of outdoor IR, dynamic range of over 100dB.

4. Summary

3D imaging technology by using 2D sensor of high dynamic range is proposed. To depth information, electronic shutter and interlaced scanning method of 2D sensor is needed. Although this kind of concept still has many problems, in the foreseeable future this TOF camera system will have sufficient possibility of commercialization.

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