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Data Acquisition for Optical Tomography System based on Complementary Metal Oxide Semiconductor Area Image Sensor

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ABSTRACT
This paper describes the development of a low power consumption and low cost data acquisition system (DAQ), which is used to capture images for optical tomography system. The system used a Complementary Metal Oxide Semiconductor (CMOS) image sensor as an optical sensor. Arduino Mega 2560 is used as the control circuit to produce its own DAQ. To test the functionality of the system, several tests were conducted to capture the shape of the object. The results showed that the images of the objects were successfully being reconstructed. With 5.2µm2 of pixel size, this will produce high resolution reconstructed image for the optical tomography.

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INTRODUCTION

Process tomography interrogates the internal behavior of a process vessel in order to obtain a rigorous cross sectional images of the its internal characteristics (Dickin *et al.*, 1992)(Ibrahim, Green, Dutton, & Rahim, 2000)(R. H. A. Rahim, 2004). A process tomography consists of a lighting system, a sensoring unit that captures the internal behavior inside the process vessel and an imaging system to obtain its internal characteristics. A lighting system is vital to ensure that the optical sensor receives sufficient light, thus produce accurate data for image reconstruction. In this research, a Complementary Metal Oxide Semiconductor (CMOS) image sensor is used as an optical sensor. Idroas (2010) used charged couple device (CCD) image sensor, Schleicher (2008) used optical fiber (Schleicher *et al*., 2008), Abdul Rahim (2005) adopted photo-detector (R. A. Rahim, Chan, Pang, & Leong, 2005) and Abdul Rahim (2004) applied PIN photodiode as a receiver (R. H. A. Rahim, 2004). To simplify the hardware development in optical tomography system, the CMOS image sensor is used in the developed optical tomography system. The CMOS area image sensor has the advantage of its digital output readout. The sensors have been used widely in various sectors such as surveillance, monitoring, medical imaging, and others.

Data acquisition (daq) circuit:

Data acquisition is a process of gathering information of electrical measurements such as voltage, current, pressure etc. with a computer. A complete DAQ contains sensors, signal conditioning circuit, analog-to-digital (ADC) circuit and computer. The vital part in any optical tomography system is the optical sensor. In the developed optical tomography system, a Complementary Metal Oxide Semiconductor (CMOS) Model MT9M001 from Aptina is used as the optical sensor. It is an area image sensor which consists of 1280x1024 effective pixels. Unlike a Charge-Coupled Device image sensor (CCD) , a CMOS image sensor comprises pixels, analog signal processors, analog-to-digital converters, bias generators, timing generators, digital logic and memory (Bigas, Cabruja, Forest, & Salvi, 2006).This advantage makes the DAQ for this optical tomography become simple yet low cost.

To ensure the CMOS area image sensor receives uniform and unsaturated light, 650nm laser light and Galilean beam expander were used. Refer to
Fig. **1**, 650nm laser light which is in red color is chosen because MT9M001 is sensitive to red light and also inexpensive. Galilean beam expander is a combination of plano-concave lens and achromatic lens and it is

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utilized to increase and collimate the beam diameter of laser light. It will magnify 10 times of 4mm diameter of laser light (approximately 40mm) to fully cover the image sensor.
Fig**. 2** shows the arrangement of both laser light and Galilean beam expander.

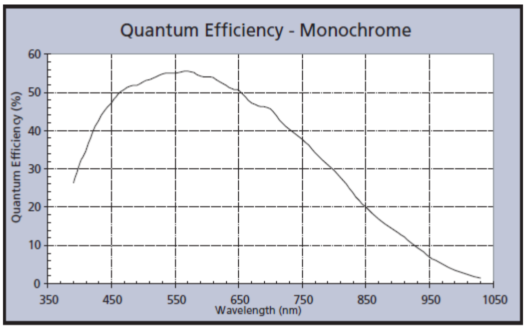

Fig. 1: Quantum Efficiency versus wavelength for MT9M001 CMOS area image sensor (Micron Technology, 2004).

Fig. 2: Lighting System.

1- CMOS Image Sensor, MT9M001:

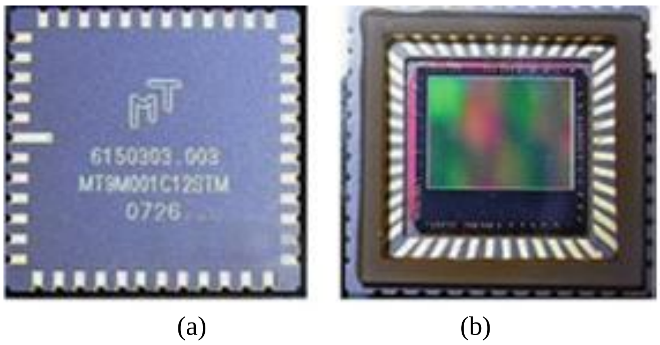

Fig. 3: MT9M001 CMOS area image sensor (a) rear view (b) front view.

CMOS area image sensor, MT9M001 is a product from Aptina. It consists of 1.3 Megapixels with 1028x1024 active pixels. Each pixel has a dimension of 5.2 µm x 5.2 µm. It is low power device which operates at 3 ± 0.3 volts. The CMOS area image sensor is chosen instead of commercial digital camera for the tomography system because it is much easier to acquire direct access to each of the pixel value (Philippson, 2007).

2- Control Circuit and synchronization signals:

The hardware for this project is straight-forward. It consists of Arduino Mega 2560 as the main processor and CMOS area image sensor as an optical sensor (**Error! Reference source not found.**). Arduino Mega 2560 is a board based on ATMEGA2560. It is operating at 5 volts with a clock speed of 16MHz. To configure the image size, the image sensor's registers need to be programmed. The image sensor consists of 16 bits register that can be set through two wire serial interface (TWI). Table 1 shows the register value to set the resolution of the image sensor to 80x80 pixels by configure the value of the row height and column height. The sensor starts at pixel (12, 20).The rest of the registers values are remain the same.

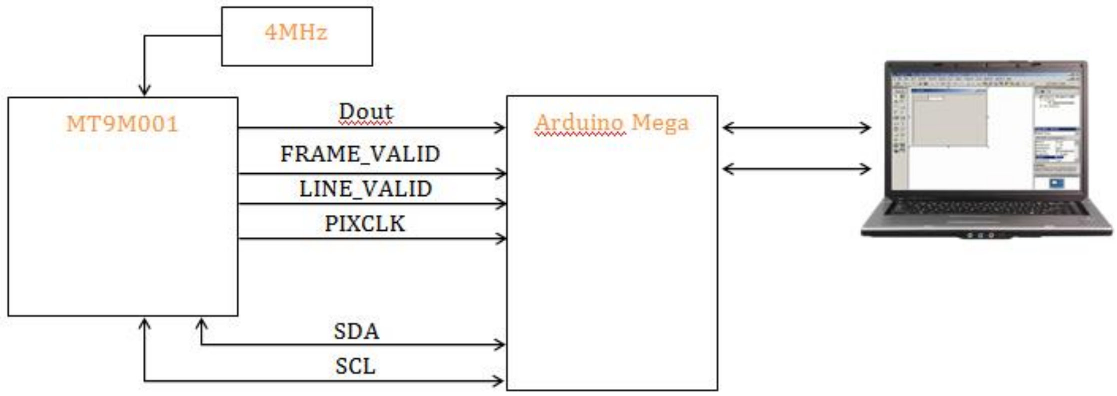

Fig. 4: DAQ block diagram.

Table 1: MT9M001 Register setting.

Register	Description	Default value	Chosen Value
0x01	Row Start	0x000C	0x000C
0x02	Column Start	0x0014	0x0014
0x03	Row Size (Window Height)	0x03FF	0x0050
0x04	Column Size (Window Width)	0x04FF	0x0050

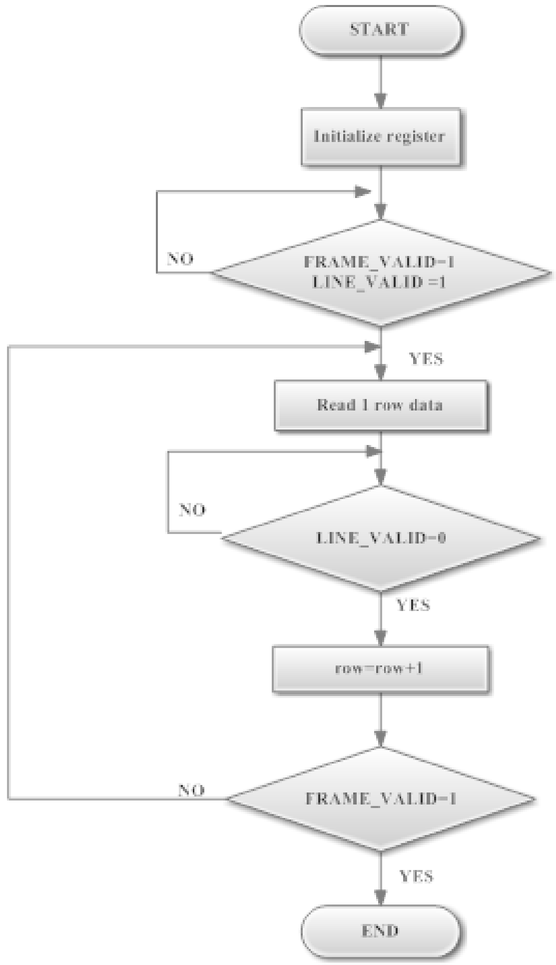

Fig. 4: Flowchart to read data from image sensor.

The image sensor runs at 4MHz and output its pixel data when the FRAME_VALID and LINE_VALID signals are high. The Dout are sent to the Arduino Mega at the rising edge of PIXCLK.
Fig. **4** shows the process to acquire image data from the MT9M001 CMOS area image sensor.

RESULTS AND DISCUSSIONS

The arrangement of lighting system with the respective CMOS area image sensor is shown in Fig. **5**. The Lighting system is positioned opposite to the CMOS area image sensor to ensure that the laser light is well-collimated and strikes the image sensor accurately.

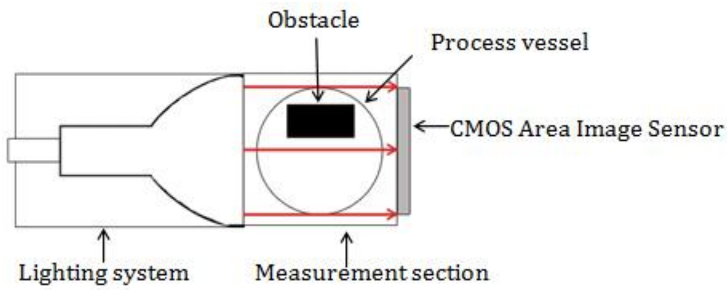

Fig. 5: The arrangement of one projection.

The active surface of the CMOS area image sensor faced the obstacle inside the process vessel. For the purpose of testing, 80x80 pixels from the entire effective pixel is used, which is from (12,20) until (92,100) to represent (row, column). To verify the functionality of the CMOS image sensor, seven (7) conditions were tested:

i. Fully exposed
ii. Fully blocked
iii. Partially right blocked
iv. Partially left blocked
v. Partially upper blocked
vi. Partially lower blocked
vii. Wire shape blocked

The output from the CMOS area image sensor is in term of digital value which represents the light energy falling at the corresponding pixel. For the 8 bit data output, a value 0 will represent white and 255 will denote as black, and the values in between are shades in grey.

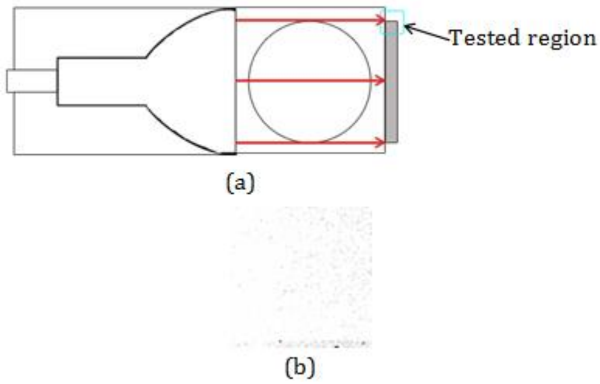

Fig. 7: (a) Fully exposed block diagram (b) Image.

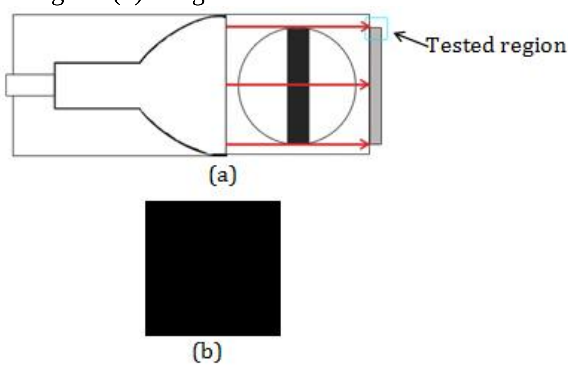

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Fig. 8: (a) Fully blocked block diagram (b) Image

Error! Reference source not found.(a) and **Error! Reference source not found.**(a) indicate the arrangement to test the pixel area when it is fully exposed to the light and fully closed by the obstacle, respectively. A blue box is a pixel area that is being tested. **Error! Reference source not found.**(b) is the image captured when the image sensor is free from any obstacle, and **Error! Reference source not found.**(b) shows when the image sensor is fully blocked. Visual Basic 6.0 is used as a medium to display the image that is being captured by the CMOS area image sensor.

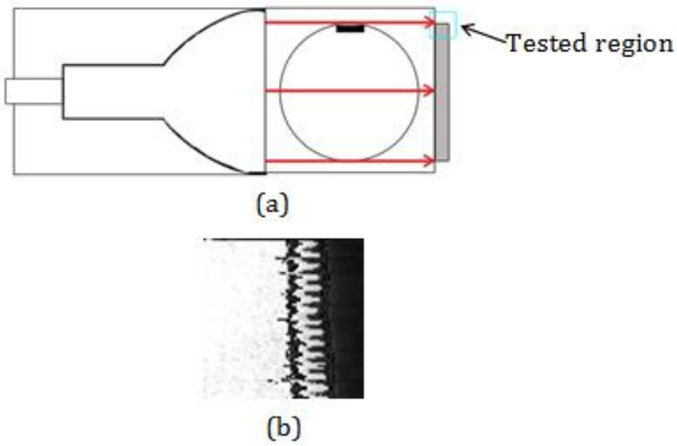

Fig. 10: (a) Partially right blocked block diagram (b) Image.

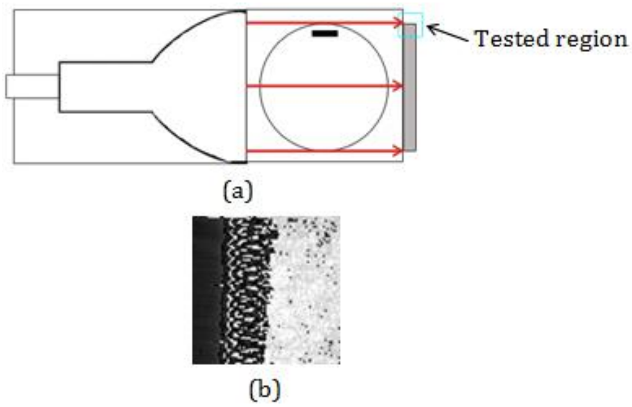

Fig. 9: (a) Partially left blocked block diagram (b) Image.

The image captured by the image sensor when it is being obstructed at the right (**Error! Reference source not found.** (a)) and left (**Error! Reference source not found.**(a)) can be seen in **Error! Reference source not found.**(b) and **Error! Reference source not found.**(b) respectively. When the pixel is blocked by an object, the pixel value will represent the decimal value approaching 255.

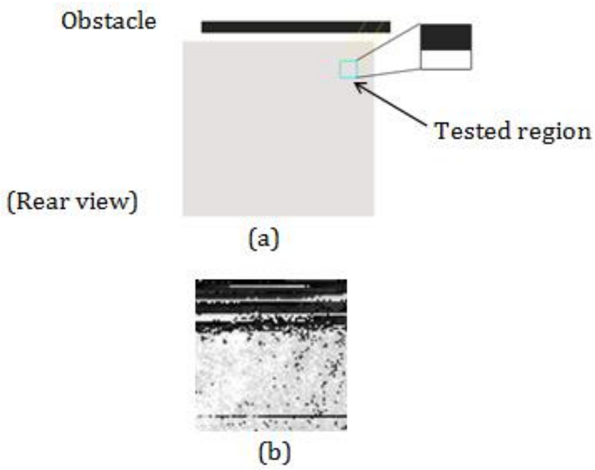

Fig. 12: (a) Partially upper blocked block diagram (b) Image.

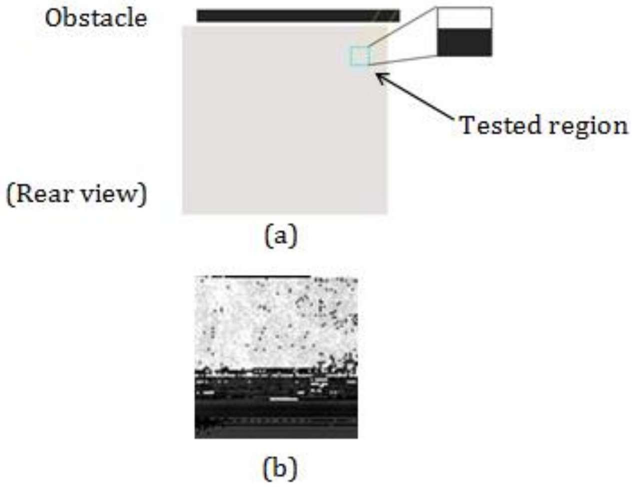

Fig. 11: (a) Partially lower blocked block diagram (b) Image.

Error! Reference source not found. (b) and **Error! Reference source not found.** (b) displayed the image from VB 6.0 to indicate the image that has been snapped when the tested pixel area is partially blocked at upper region (**Error! Reference source not found.**(a)) and lower region (**Error! Reference source not found.** (a)).

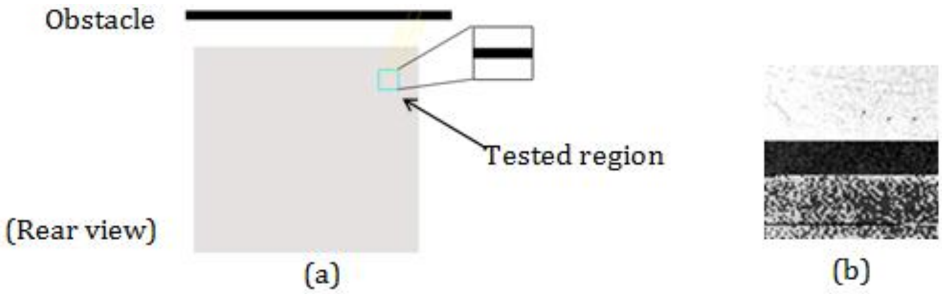

Fig. 13: (a) Closed by wire shape block diagram (b) Image.

A wire has been placed in front of the CMOS image sensor (**Error! Reference source not found.**(a)). Only half of the object is included in the test area due to the size of the object is bigger than the test region. The image shows by VB 6.0 (**Error! Reference source not found.**(b)) indicates that the image sensor is successfully captured the shadow of the wire that is positioned in front of it.

Conclusion:

The CMOS area image sensor used in the developed optical tomography is capable to visualize the internal characteristic of a process with high resolution image. By applying two dimensional imaging systems, the image generated from the system will more accurate and validation of the internal behavior can be done. The developed optical tomography system is low cost and easy to be integrated to the microcontroller to produce its own DAQ.

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