A Low-Cost Data Acquisition for CMOS-based Optical Tomography System

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***Abstract*— This paper presents the development of a portable, effective and economical Data Acquisition (DAQ) for optical tomography system. DAQ is a core unit that is essential for acquiring an accurate yield for data sampling in Tomography System. However, there are extremely limited quantities of equipment in market that can accurately implemented as DAQ for the optical tomography system. This project offers a microprocessor-based data acquisition system which able to demonstrate the output pixel of CMOS image sensor in GUI application. The project drives the control unit (LPC2103) to perform data sampling for CMOS image sensor and allocate 128x64 of data pixels into a visualized image inside the GUI application.**

***Index Terms*— CMOS Image Sensor; Data Acquisition; LPC2103; Optical Tomography.**

I. INTRODUCTION

Tomography was originated from a sequence of two Greek words which are 'tomos' and 'graph'. 'Tomos' represents piece or slice while 'graph' represents picture or image. Thus, 'Tomography' implies a piece of an image [9]. According to Oxford English Dictionary 2016, Tomography is a method of demonstrating a cross-section through solid object or human body. Generally, Tomography System is divided into four main sections; sensor, data acquisition system, image reconstruction system and display unit which is illustrated in Figure 1.

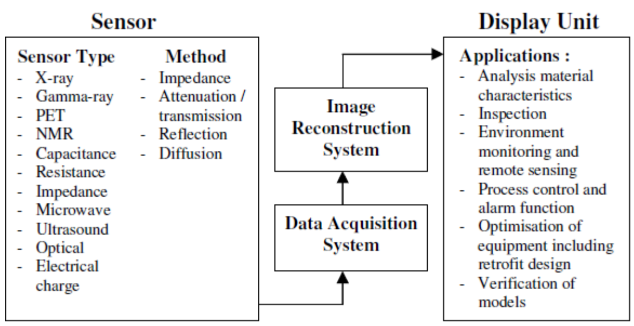

Figure 1: Tomography System

Tomography was originally used for medical imaging procedure especially in Computed Tomography (CT) scan, X-ray and Magnetic Resonance Imaging (MRI) [10]. Presently, industrial field uses tomography system for system monitoring in industrial process; recognized as Industrial Process Tomography. Optical tomography is one of the Tomography System that applies non-invasive optical sensors to implement image reconstruction in process system. The system requires a DAQ to convert the raw data signal from image sensor, into a constructive data to be processed in image reconstruction system [1-8]. The important rules of DAQ makes the demand of this system increasing each year. Conversely, there is a limited number of equipment in market which is able to perform an effective DAQ unit for an optical tomography system. This scenario makes the DAQ become costlier.

There are a lot of expensive DAQ equipment commercially available in market offers various specifications for data processing. For example, Keithley Metrabyte DAS cost more than USD300 per unit. Majority of the researcher in this field choose to use an expensive 'ready-made' data acquisition system for their project. However, many of its specifications are unnecessary for the intended purchase. Up till now, those 'ready-made' DAQ are too expensive plus only some of their capabilities need to be used for the whole Tomography System. Practically, DAQ involved in analyzing and converting signal from image sensor into valid data information that can be used for image reconstruction.

Based on this situation, there is no comprehensive method to solve this difficulty. By applying the embedded system design; researcher can avoid the use of expensive DAQ system for their intended research. The embedded system proved to be cheaper, stable and commonly used in electronics industry for a long time. Furthermore, the embedded system design has the capability to create a high-performance controller for data measurement. It also is able to support a standard communication protocols for optical image sensor. Therefore, this project is presented to introduce an economical microprocessor-based DAQ for optical tomography system by applying Complementary Metal Oxide Semiconductor (CMOS) as an image sensor.

II. SYSTEM DESIGN

Overall system design is divided into two categories; hardware and software design. The hardware system design involves a sensor unit, controller unit and communication unit. The software system design in data sampling algorithm involves Visual Basic development through Universal Asynchronous Receiver/Transmitter (UART) communication. The whole system block diagram is demonstrated in Figure 2.

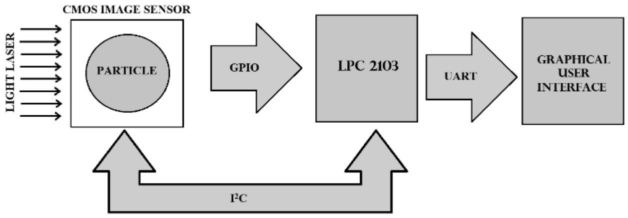

Figure 2: System Design Block Diagram

A. Sensor Unit

Sensor unit is divided of two elements; light laser and CMOS image sensor. The light laser supplies monochrome light source to CMOS image sensor to generate 10 bits of parallel digitized data output from the light intensity. In place of the light source; Idroas, M., et al. reports the light falling needs to well collimate in order to produce an accurate result since the image sensors are light sensitive and easily saturated. Therefore, choosing a type of light source is important in order to get a perfect output result in optical tomography system.

Basically, there are two common types of light source; white light and light laser. The white light is a combination of three primary colour; red, green and blue. These combinations will result three different focal points which causes image height error due to colour aberration. However, light laser is a less aberration light source, monochromatic and have a low error due to colour aberration compared to white light. This statement officially approved by Idroas, M., et al. as presented in Figure 3. Therefore, light laser has been chosen to be a light source for this project.

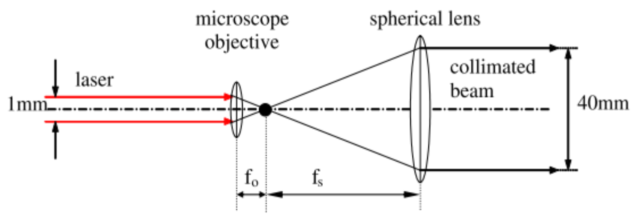

Figure 3: Laser Beam Properties [11]

There are two types of image sensors generally used in optical tomography system; Charge-Coupled Devices (CCD) image sensor and CMOS image sensor. CCD image sensors were developed several years before CMOS image sensors. Therefore, the technology of CCD sensors more matured which provides high quality and more pixels with a low noise of output images compared to CMOS image sensors. However, CCD consumes 100 times more power compared to CMOS. Furthermore, this image sensor is capable of scanning only a line of an object and produce analog output [14]. On the other hand, CMOS sensor has high integration and low power consumption compared to CCD sensor [19]. CMOS sensors are manufactured using standard silicon fabrication makes the production cost significantly decreases. In addition, CMOS image sensors are small sized, have a low power consumption, high anti-radiation and only require a simple driver circuit [17]. Compared to scanning line by line by CCD image sensor, CMOS are able to capture and produce a parallel digital output at one time [19]. This attribute makes CMOS a high-speed image sensor [20]. In this paper, a CMOS sensor; MT9V034C12STM from APTINA Corps, is used as a part of sensor unit for this project. Figure 4 illustrates a 48-CLCC packaging pinout of MT9V034C12STM CMOS image sensor.

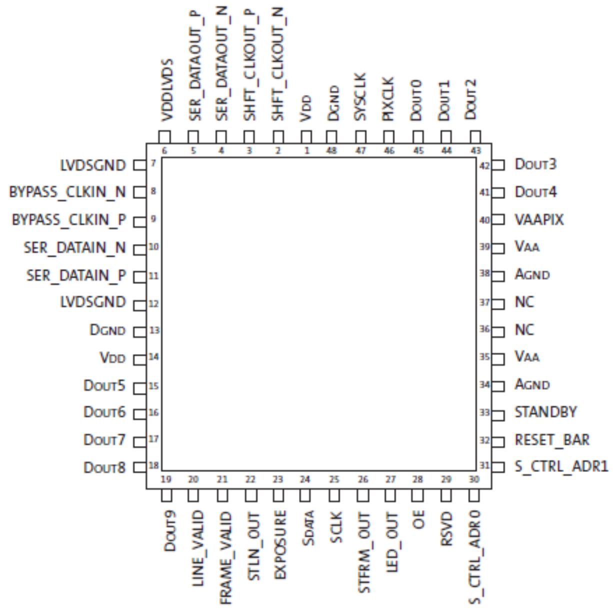

Figure 4: 48-CLCC Packaging of MT9V034C12STM

B. Controller Unit

Controller unit act as a core part of the system to compile the entire sections in an optical tomography system. It can be described as a 'brain of the system'. Thus, the controller unit affects the performance of the whole system. In this paper, the LPC2103 advanced microprocessor-based is used as a controller unit. LPC2103 drives by 5 volt direct current from USB cable get the power input from USB cable an brings 8MHz of the main clock which have an enough speed to communicate between MT9V034C12STM. Due to the low power consumption, small physical and low-priced microprocessor-based board, LPC2103 is the best controller to develop a portable, effective, and economical DAQ. LPC2103 reserved P0.0 and P0.1 for UART communication; P0.2 and P0.3 for I^{2}C communication. Furthermore, the remaining port; P0.4 until P0.3, can be operated for normal GPIO communication to collect data pixel from image sensor. Figure 5 below illustrates LPC2103 pin configuration.

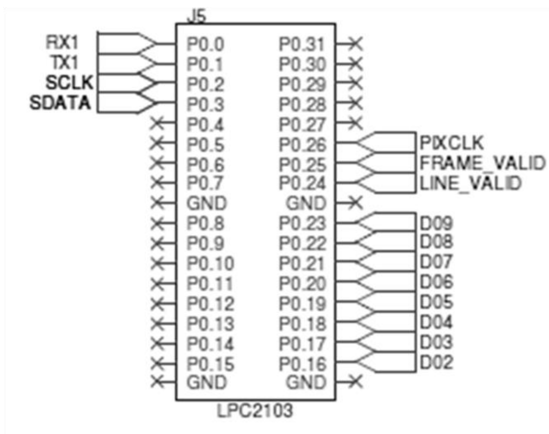

Figure 5: LPC2103 Pin Configuration

C. Communication Unit: I²C Protocol for feature setting

MT9V034C12STM can be operated in default mode or modified-mode for its feature such as image exposure, frame size, gain setting and other parameters. MT9V034C12STM features parameter can be modified by change over the register value inside image sensor. The column and row binning feature needs to be modify to adjust the sensitivity of MT9V034C12STM while operate in a small resolution. For this project, this feature needs to be set twice from the default value to make the data pixel rate reduced twice than the default value respectively. Figure 6 shows the data pixel output when register setting by default (a) and register setting twice from default value (b).

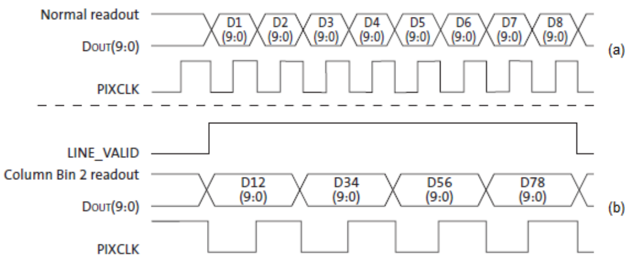

Figure 6: Output Pixel in Binning Feature

To enable the column and row binning feature; 16 bits of I²C protocol will be wrote through two-wired serial interface bus in order to set value of register R0x0D and R0x0E. Initially, a series of S+ADDRESS+W/R (0xB8) will send to image sensor to enable the serial interface for I²C communication. After get an Acknowledgment (ACK) from Slave (MT9V034C12STM), Master (LPC2103) will send desire register address to be amended; 0x0D for column binning or 0x0E for row binning. After get an ACK, Master will send a sequence of 16 bits data 0x0308 to setup column binning feature and 0x0002 for row binning feature. Finally, Master will send the STOP signal to Slave to terminate the communication. This sequence clearly illustrates in Figure 7.

```
void init_MT9V034()
{
  delay_10u();
  send_addr(0xb8);
  send_data(0x0d);  //Read mode context A reg address 0x0d
  send_data(0x03);  //MSB
  send_data(0x08);  //LSB > column bin = 2 (0x08)
  stop();
  delay_10u();

  send_addr(0xb8);
  send_data(0x0e);  //Read mode context A reg address 0x0e
  send_data(0x00);  //MSB
  send_data(0x02);  //LSB > row bin = 2 (0x02)
  stop();
  delay_10u();
}
```

Figure 7: Enable Column and Row Binning Feature

D. Data sampling Algorithm

Essentially, CMOS image sensor generates four types of output signal which are DOUT (0:9), LINEVALID (LV), FRAMEVALID (FV), and PIXCLK. LV is a row pixel indicator. This means, when the CMOS image sensor captures an image, one row of data pixel will be fully generated in one complete LV cycle. When a frame of an image is complete, it will be indicated by FV. Figure 8 shows that data output; DOUT, is synchronized with PIXCLK output. When LV is HIGH, 10-bit valid pixel of data output; DOUT (0:9) is asserted in every PIXCLK period. DOUT is only valid on rising edge of PIXCLK.

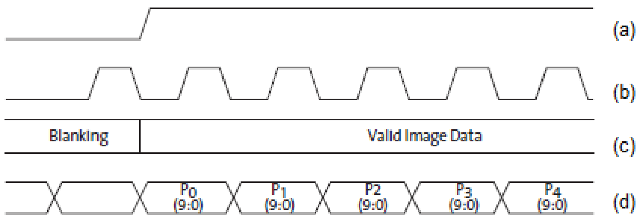

Figure 8: Output Signal from CMOS Image Sensor
(a) LINEVALID, (b) PIXCLK, (c) Valid Image Data (d) DOUT (9:0)

Figure 9 shows a flowchart of data sampling. After initialize LPC2103 ports, MT9V034C12STM register and UART communication, LPC2103 will wait the "U" character from GUI application. Once the user clicks on the start button, the controller unit will get ready to start sampling pixel output. Sampling data output start right after new FV is asserted; by using the algorithm illustrated in Figure 8. The data is sampled and stored into a memory. A complete one image frame size (128x64) can be accessed by the GUI application.

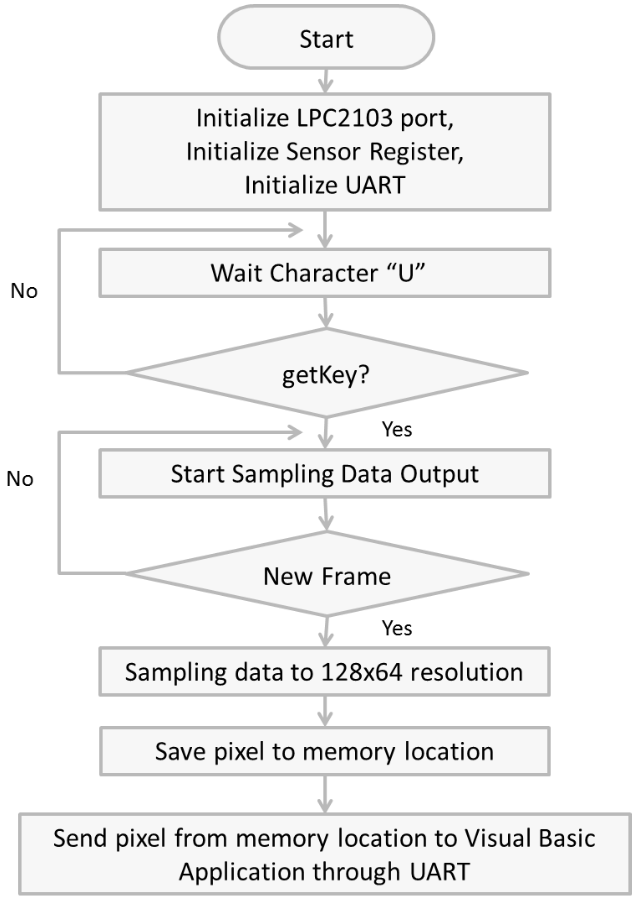

Figure 9: Data Sampling Flowchart

E. Image Pixel Display in GUI

The raw output data from image sensor are represented in the range of 0 to 255; based on monochrome colour chart as shown in Figure 11. "0" indicates pure black colour while "255" indicates pure white colour. The image can be displayed through the GUI application.

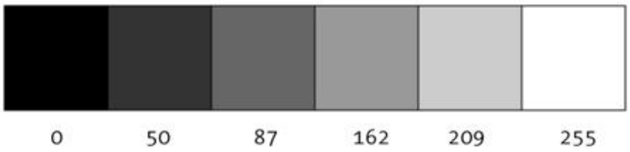

Figure 11: Basic Monochrome Colour Chart

The GUI application was developed using Visual Basic programming language. The GUI supports serial communication that integrate computer with LPC2103. Figure 12 shows the GUI application design interface. This interface includes Select COM Port, Time Taken, Start Button, Export Button, Clear Button, Cancel Button, Exit Button, Image Frame, Packet Received and Pixel Received. The user is required to choose the COM port first before starting the experiment. When the start button is pressed, sampling of the output pixel will start. The system will calculate how many packets and pixels received from the sensor and image will displayed on the GUI. The user can simply export the raw output pixel value into excel file by clicking on Export Button.

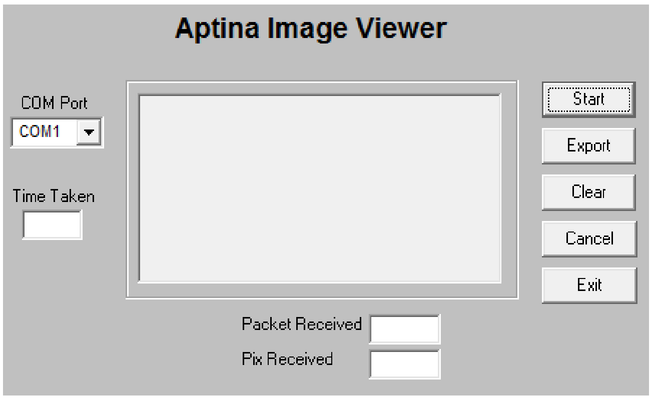

Figure 12: Graphical User Interface Application

III. RESULT AND DISCUSSIONS

Figure 13 illustrates hardware experimental setup which consists of hardware implementation. The project experiments end up by displaying 128x64 output pixels in GUI application as shown in Figure 14 (a) to Figure 14 (b) and the raw output data pixel can be export in form of excel file.

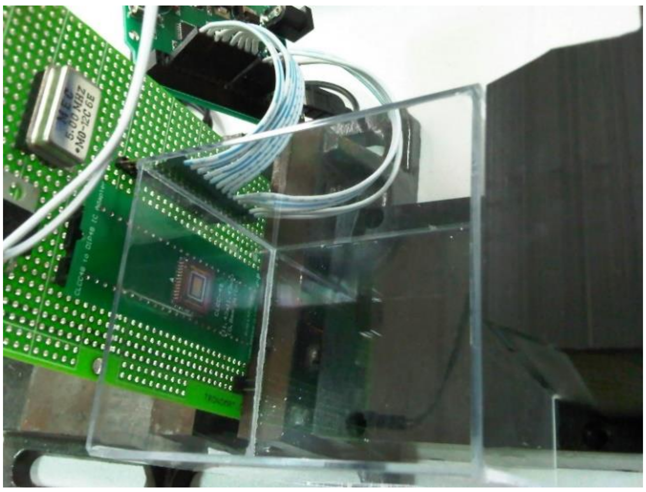

Figure 13: Experimental Setup

A. *Experimental Result*

Figure 14 (a) to Figure 14 (e) demonstrates condition of the sensor and how it is displayed on GUI application. In Figure 14 (a) the sensor fully uncovered. The second experiment set-up is to handles row pixel testing while the third experiment will be tested on column pixel. To set these two conditions by placed a piece of a dark paperboard on the top and right side of image sensor. Next experiment handles for both row and column pixel testing by placed a piece of black object across image sensor. Last sensor condition to be tested on this experiment is fully covered condition.

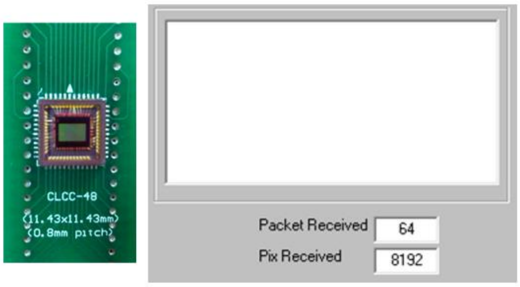

Figure 14 (a): Sensor Uncovered

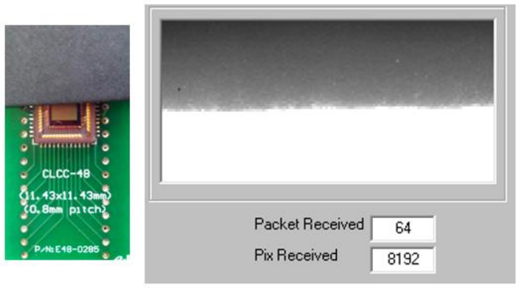

Figure 14 (b): Top Covered Sensor Condition

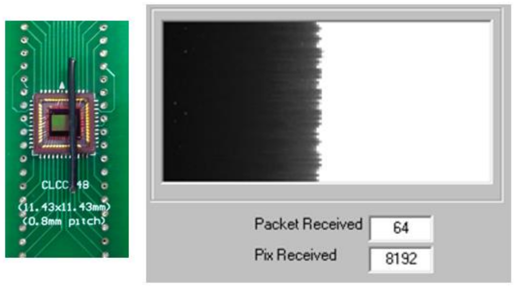

Figure 14 (c): Right Covered Sensor Condition

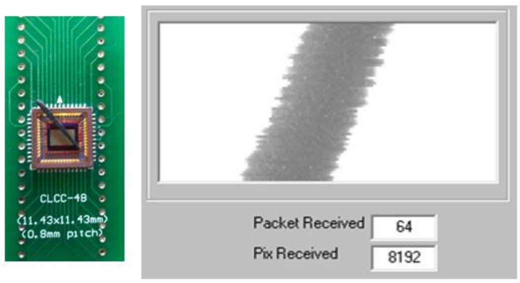

Figure 14 (d): Cross Covered Sensor Condition

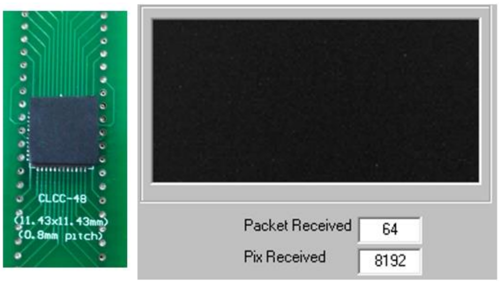

Figure 14 (e): Sensor Fully Covered

B. *Overall System Cost*

Summarize of the whole system are shown in Table 1 shows that this project give an economic DAQ systems. The total price of this project is reasonable compared to the data acquisition system that available in market based on eBay website; as presented in Table 2.

Table 1
Total System Cost

Items	Price (USD)
Sensor Unit	
MT9V034C12STM	30.00
CLCC-48 to DIP-48 IC Adapter	34.25
Controller Unit	
LPC2103 Development Board	16.50
Total Cost	**80.75**

Table 2
Data Acquisition System Cost Comparison

Product	Price (USD)
Z126536 Keithley DAS-1802HC 14257 REV 3 w/ STP-100 Breakout Board and Cable	**850.00**
Keithley Das-1801HC/1802HC 14257 Board	**800.00**
Keithley DAS-1801HC/1802HC 14257 Rev A PC8632 Board	**750.00**
Keithley DAS-8PGA Analog To Digital ISA Circuit Board	**449.10**
KEITHLEY DAS-1702HR DATA ACQUISITION BOARD	**195.00**
Keithley, DAS-1601, 100kS/s ISA Digital Analog I/O Card Board 9830/V Maxconn	**350.00**
Keithley Instruments DAS-1802ST, 14278 Rev. A, 9806/F/378931,	**299.00**

IV. CONCLUSION AND FUTURE WORKS

The aim of this project is to design a portable, effective and economical DAQ for optical tomography system. Based on the result and discussion made, the designed microprocessor-based data acquisition system is able to integrate with CMOS image sensor and display the output result in GUI application. The core unit in the optical tomography system for obtaining accurate outputs is successfully developed. Moreover, by comparing the whole project cost; USD80.75, with the current price of DAQ system in market, this project provides the solution of the pricy DAQ problem for optical tomography system. Furthermore, there are some recommendations for project future works. First, implement of USB or JTAG peripheral to replace UART as a communication medium between computer and controller unit. By using this technology, data output can be sent to computer at higher speed compared to UART. On this state, display unit will possible to display a lot of frame per second. Secondly, this project is only considered to sampling 128x64 size of image output frame. The quality of data sampling can be improved by increasing window size and sampling in large image resolution. Further development can be carried out using more powerful controller unit such as an FPGA or ASIC to improve data acquisition speed. Implement the latest application for GUI development and update the user interface to have more function available.

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