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Hardware Development for Optical Tomography System based on Complementary Metal Oxide Semiconductor Linear Image Sensor

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Abstract

Nowadays, particle characterization such as size, count and shape, has been widely used in industrial processes to provide better understanding on their products. An optical tomography system has proven to be a useful approach in characterizing particles due to its ability to determine the content of a closed system without any physical contact. Thus, this paper presents the use of Complementary Metal Oxide Semiconductor linear image sensor in the development of optical tomography system, where the system is used for solid particle characterization. The developed system used the CMOS S10077 Linear Image Sensor as the optical detector, and Arduino Nano microcontroller to control the sensor's operation and to provide a data acquisition system for the CMOS S10077. The Data Display Serial Port application is used to display data from the sensor in a numeric array to allow pattern plotting of its result. Particle characterization experiments based on count is conducted after the completion of the hardware and software setup. The experimental results are collected and analyzed. The verification of the experimental and actual results is determined based on the analysis of the particle counts.

Keywords: CMOS, Hardware, Microcontroller, Tomography

1. Introduction

Particle characterization in today's industry has become an important tool for production and processing. Particle size is one of the most significant properties which is useful for industrial processes and has led to much research related to it. The particle size has given a direct influence on reactivity rate, texture, flow, viscosity and packing density[7]. The study of particle characterization becomes crucial in industrial processes as it provides a better control of product quality[1,8]. Thus, it grants economic benefits such as the ability to charge a higher premium for the product and reduce the probability of customer rejection rates[2]. The study of particle characterization also aids companies to have a better understanding of their products, ingredients and processes[3].

Process tomography is a non-intrusive technique that produces tomographic images based on data from obtained image sensors. Optical tomography is one of the most growing technologies in tomographic field where it involves projecting a beam of light source (e.g., LED, infrared or fiber-optic) through a medium from a boundary point and detecting level light received at another boundary using a sensor[4]. The optical tomography process does not involve any interruption inside a flow pipe in determining characterization of particle inside it[5].

This paper presents the hardware development of the optical tomography system based on CMOS linear image sensor. The study requires data collection and analysis to verify the validity of particle characterization based on this technique. The developed optical tomography system consists of four projections, where the CMOS linear image sensors S10077 are used as the optical detector. Four CMOS S10077 sensors are mounted around a flow pipe using octagonal-shaped measurement rig. The Arduino Nano microcontroller is used to control the

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operation of optical tomography system and also for clock generation of CMOS S10077 data acquisition. Nowadays, many industrial processes use flow pipe to convey particles in the form of solid, liquid and gas[6]. However, due to its enclosing and solid structure of the pipe, monitoring and examining the particles inside would be difficult as it requires physical contact, which would eventually disturb the flow of the pipe. Thus, a system needs to be developed where it can visualize the behavior of the particles without interrupting the flow occurred inside the pipe.

2. Experimental Setup

The optical tomography system mainly comprises of the optical module (light source), image sensor, data acquisition, microcontroller, data acquisition system and computer for data display and image formation. An octagonal-shaped measurement rig was designed between the optical module and the image sensor, with a cylindrical flow pipe mounted in the middle. Figure 1 shows the overview of the optical tomography system for one projection system.

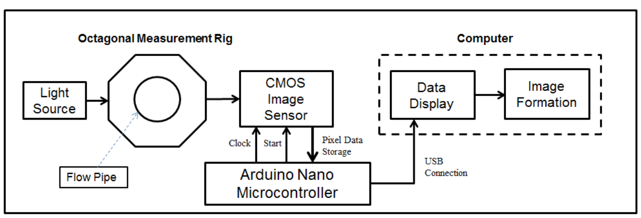

Figure 1. Block diagram of the optical tomography system for one projection.

Figure 2 illustrates the overall concept of a CMOS based optical tomography system for one projection. The complete system consists of a collimated lighting system, a measurement section, CMOS linear image sensors, the Arduino Nano microcontroller system and PC for data display. The Arduino Nano and computer were interfaced using a USB cable.

A laser diode module implemented in this project produced 600 nm wavelength of red light. The laser light travels through the objective lens and the focusing lens to produce collimated light. The collimated light is then illuminated the CMOS image sensor. One projection is applied for calibration of the corresponding image sensor. To examine or experimenting the behavior of particles inside the pipeline requires more than one projection to allow different image pixels obtained in different directions. Therefore, four CMOS linear image sensors, in correspond to four laser projections are implemented in the system, where all of the output pins are connected to a common multiplexer (MUX). The MUX will deliver one of the sensor three output signals, which are EOC, Trig (D) and DO to the microcontroller for the data acquisition. Figure 3 shows the overall optical tomography system.

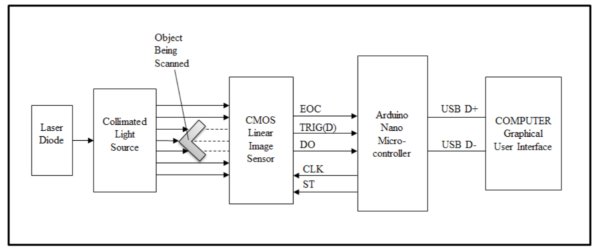

Figure 2. Concept of the optical tomography system based on one projection of transmitted laser light.

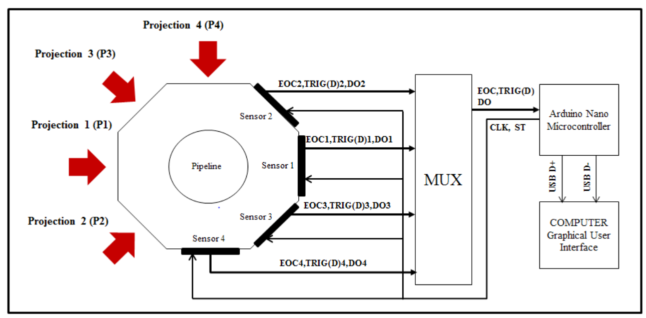

Figure 3. Overall concept of the optical tomography system based on four projections.

This project aimed at studying the behavior of objects when placed in a close system, which was the translucent pipeline. The CMOS image sensor will detect any shadow of an object in the pipe, with 1024 pixels of data. The Arduino Nano microcontroller is used to provide triggering signals to the CMOS sensor and also to retrieve the 1024 pixels of CMOS sensor for the data acquisition process. The data were sent out serially from the microcontroller to the computer at a baud rate of 115200.

3. Image Reconstruction System

The Arduino Nano microcontroller and the CMOS S10077 linear image sensor board are the main modules of the system. Figure 4 shows the connection setup between the Arduino Nano board and the S10077 sensor board.

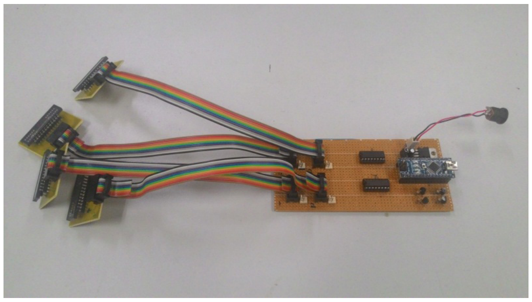

Figure 4. Connection between S10077 CMOS sensor boards and arduino nano microcontroller board using rainbow wires.

3.1 S10077 CMOS Linear Image Sensor Board

The CMOS linear image sensor, S10077, is a product from Hamamatsu Company. The image sensor provides switchable analogue-digital for 8-bit or 10-bit. The S10077 features a pixel at a pitch of 14 µm and 50 µm height. The CMOS S10077 consists of 1024 pixels. Each of the pixels is placed in an array up to 1024 numbers, thus forming a window of the image sensor. The sensor is operated between 3.3 V and 5 V, making it as a low power consumption device. Since it features a built-in-timing generator, the sensor can operate with only start and clock triggering signals. Figure 5 shows the pin configuration of the CMOS sensor and the optical sensing window in the middle.

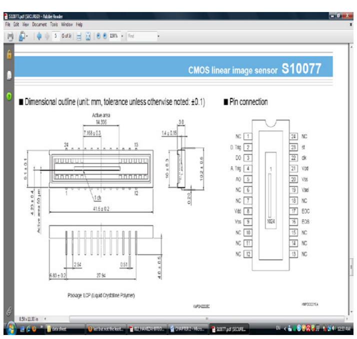

Figure 5. The pin configuration of CMOS S10077 linear image sensor.

The project emphasized on the use of CMOS S10077 digital outputs. Thus, 8-bit built-in AD conversion was chosen to obtain 8-bit output from the sensor. Four units of S10077 CMOS sensors were used for the optical tomography system for four projection data.

3.2 Arduino Nano Microcontroller Board

The Arduino Nano microcontroller was used for controlling the operation of the optical tomography system. The microcontroller needs to generate clock and pulse signal to the CMOS S10077. The S10077 sensor requires a clock frequency range from 1MHz to 12MHz in order to operate in 8-bit mode. Thus, the minimum clock frequency needs to be triggered by the microcontroller should be at greater than 1MHz. In this project, the clock frequency was set up at 2MHZ in order to meet the minimum requirement for the sensor's operation.

Apart from generating clock signal to the CMOS image sensor, the same microcontroller served another function, which is to retrieve the digital output from the CMOS sensor. The output data are sent to the computer for data acquisition process. The Arduino Nano can store up to 2000 bytes of Random Access Memory (RAM), which is sufficient for 1024 bytes of digital output data storage. Figure 6 shows the schematic circuit diagram of the microcontroller.

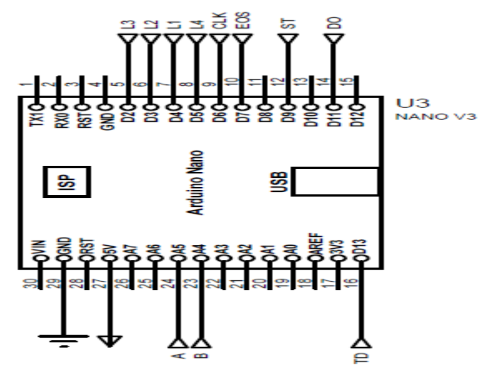

Figure 6. Schematic circuit of the arduino nano microcontroller.

3.3 Dual 4x1 Multiplexer, GD74LS153

A multiplexer (MUX) is described as a selector of inputs and forwards the selected input onto a single line. Since four CMOS image sensors were implemented in the system, only one of them can be operated at a time. In addition, each sensor needs to deliver three signals, which are D0, D.Trig and EOS to the microcontroller for data acquisition purposes. Thus, two units of dual 4x1 MUX, IC GD74LS153 were used to select these signals from one of the image sensors. Figure 7 shows the configuration of two IC GDL74L153 on the microcontroller board. Figure 8 shows the schematic diagram of the multiplexer circuit.

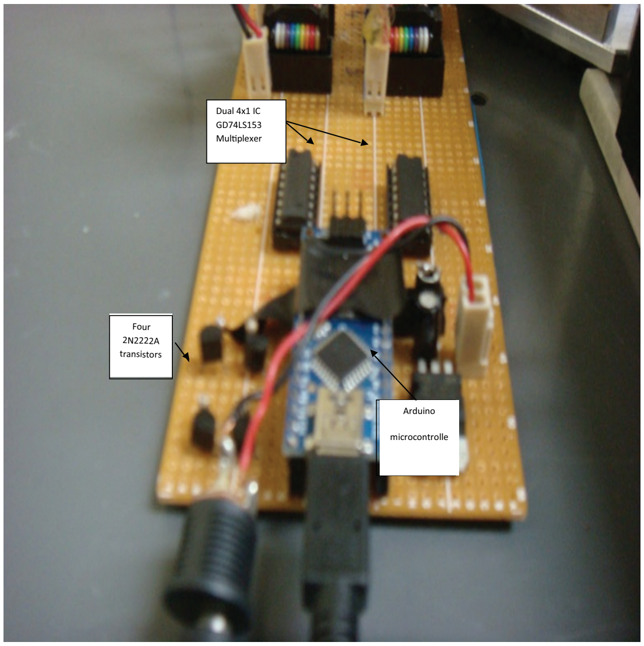

Figure 7. Configuration of two IC GDL74L153 on the microcontroller board.

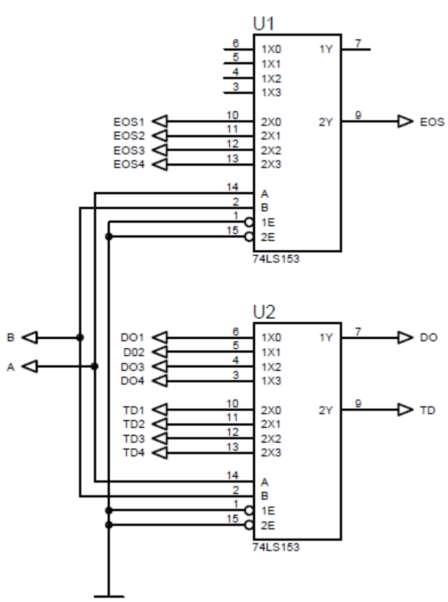

Figure 8. Schematic circuit of multiplexer circuit of two IC GD74LS153.

3.4 Driving Circuit of CMOS S10077

The CMOS S10077 sensor can only be properly operated when there is the clocking signal and start pulse signal. The Arduino Nano microcontroller was used to generate both signals as well as synchronizing them with the sensor.

The datasheet of the CMOS S10077 sensor provides the specifications for the generation of these signals, which are generated by the microcontroller. The minimum frequency needs to operate the image sensor is 1 MHz. In this project, the clock frequency set by the microcontroller was 2 MHz to meet the requirement of the specification. Once the clock frequency is known, the duty cycle of the start pulse signal must be set. Based on the sensor datasheet, the minimum start pulse low period (TLP) and start pulse high period (THP) for the applied clock frequency must be at 0.0025 ms and 3 ms, respectively. Hence, the TLP was set at 10ms whereas the THP was at 22.5 ms. The flowchart of the clock and pulse signal generation is shown in the Figure 9.

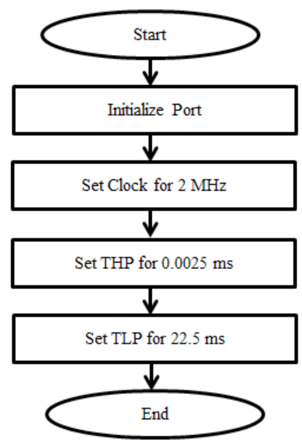

Figure 9. Flowchart for running the clock and start pulse signal generated by the Arduino Nano microcontroller.

For the data acquisition of CMOS S10077, once the clocking and start signals have been set, the CMOS image sensor can begin to operate. The image sensor will generate three signals, which are End of Conversion (EOC), Digital Output (DO) and Digital Trigger (Trig.D) as shown in Figure 10. When obtaining the DO, it is read at the falling edge of Trig.D. The EOC is high once a set of DO is successfully obtained and read by the microcontroller.

The Arduino Nano microcontroller retrieved the data from the CMOS S10077 sensor and saved them in the RAM storage. The output data will be sent to the computer from the microcontroller using a Mini-B type Universal Serial Bus (USB) interface for data acquisition.

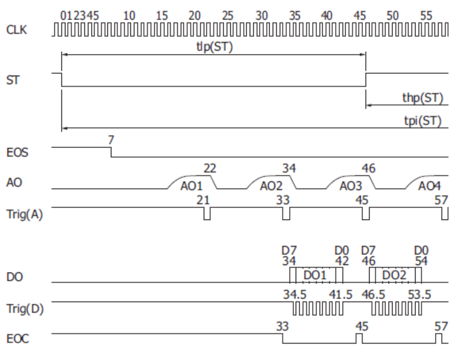

Figure 10. Generation of digital output, digital triggering signal and digital end conversion signal based on CMOS S10077 linear image sensor.

3.5 Display Data

Display Data Serial Port application is used for end-level user controlling purposes of the optical tomography system. Selection of sensors is configured so that the user can choose which sensor operates at a time. The digital output of the CMOS pixels will also be displayed in this application in a numeric array. The numerical data can be saved in Notepad application so that plotting pattern can be done using Microsoft Excel for data analysis. Figure 11 shows the Graphical User Interface (GUI) of the application.

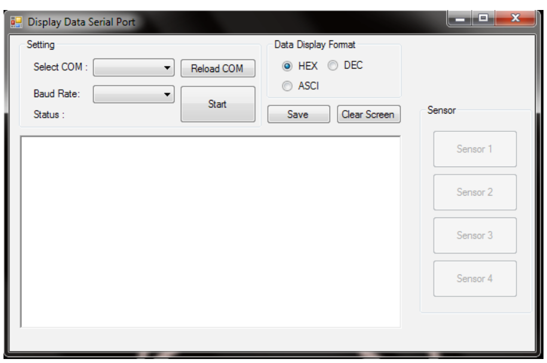

Figure 11. The GUI of the display data serial port application.

4. Experimental Results

All five boards, the Arduino Nano microcontroller board and the four CMOSS10077 linear image sensors are connected together using rainbow wires. The USB cable was connected between the microcontroller board and the computer. The AC-DC adapter 9V was used to supply the voltage to the microcontroller board and the laser source. LEDs of the microcontroller were turned ON as shown in Figure 13 to indicate there was a presence of power supply connection from the adapter.

Using this application, the sensor button is virtually connected to the microcontroller. Each sensor button initiates the corresponding switching transistor for laser diode transmission, CMOS sensor operation and also the MUX to deliver the three corresponding signals to the microcontroller for data storage. The system takes all of the output data from the CMOS image sensors. Figure 12 shows the flowchart of the optical tomography system operation based on the Arduino Nano microcontroller.

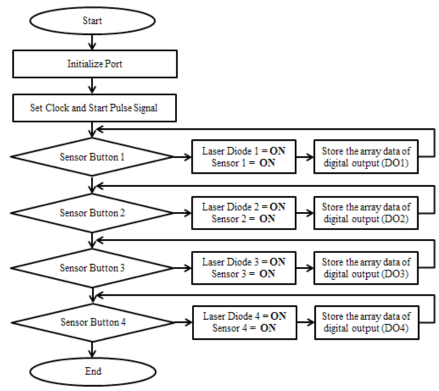

Figure 12. Flowchart of the optical tomography system operation.

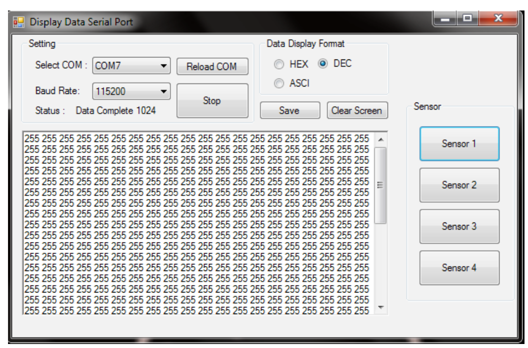

Figure 13. Operation settings of display data serial application.

Before starting the experiment, calibration must be done to ensure the consistency of the readings from the CMOS sensor. This can be done by testing two conditions of the CMOS sensor. The first condition is when the CMOS sensor is fully exposed to the ambient light. Maximum output data should be obtained in all 1024 pixels. The next condition is to block the light transmission on the CMOS sensor by covering it with a black paper as well as the absence of the ambient light. With very low detection of light intensity by the image sensor, the output data generated should be low across the pixels.

The particle characterization based on particle counting was made by using 3 mm beads as the experimental subjects. In this experiment, one, two and three beads were tested for counting. The objects were placed in the pipeline for image capturing by the CMOS S1077 image sensor. To identify the number of beads inside, numbers of attenuated area detected by the CMOS image sensor must be known. Therefore, the images in the pipeline are taken from four different projections for the identification of beads.

Figure 14 shows when one bead is placed inside the pipeline. In this case, the CMOS image sensor should detect only one significant low signal from all projections to indicate the presence of the single bead. The results from four projections are shown in the Figure 15.

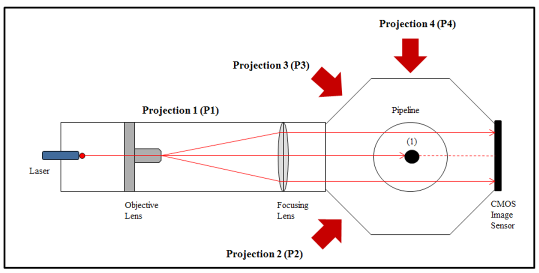

Figure 14. Two-dimensional view from four projections one 3 mm bead.

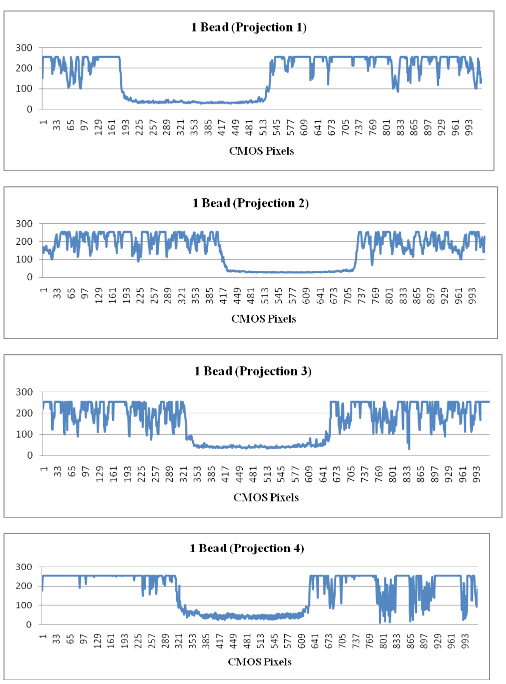

Figure 15. Diffraction patterns of one bead from four different projections.

Similarly, Figure 16 shows when two beads are placed inside the pipeline. In this case, the CMOS image sensor detected two significant low signals, depending on which projection, to indicate the presence of the beads. The results from four projections are shown in Figure 17.

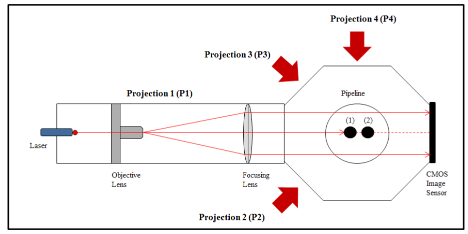

Figure 16. Two-dimensional view from four projections for two 3 mm beads.

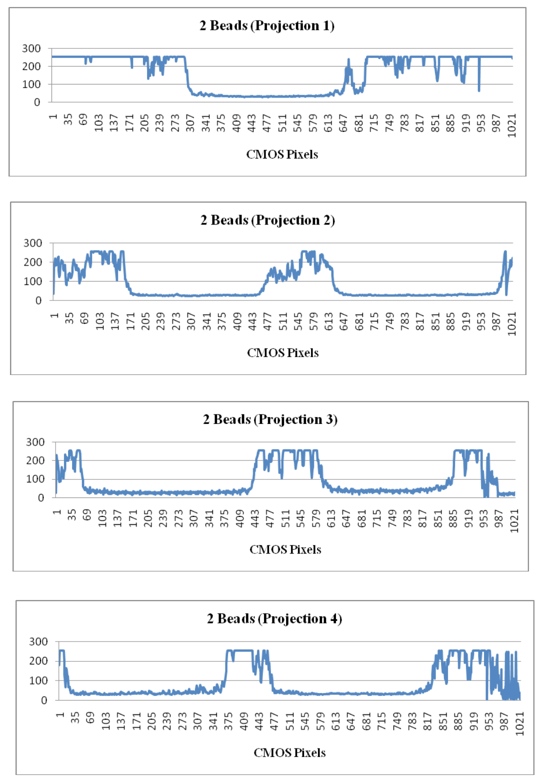

Figure 17. Diffraction patterns of two beads from four different projections.

5. Conclusions

The developed optical tomography system based on CMOS linear image sensor can detect particles in a pipe. The system has the capability to monitor particle concentration and other particle characterization elements such as particle size and concentration profile.

6. Acknowledgement

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7. References

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