A GRAPH READER USING A CCD IMAGE SENSOR

Mike L. Seeti
Department of Physics, Makerere University P.O. Box 7062, Kampala, Uganda
E-mail: mseeti@physics.mak.ac.ug

(Submitted: 18 January, 2008; Accepted: 10 June,2008)

Abstract

There exist huge amounts of data collected as traces on recording paper. If these data are digitized in a convenient and too expensive way, then modern types of analysis using the digital computer can be employed. In this paper, the design and construction of an analog trace reader using a linear charge-coupled device (CCD) sensor is undertaken. The system minimizes the use of hardware by emphasizing the use of software whenever possible. The image is obtained by focusing a line object onto a line of light-sensitive pixel sites in the CCD. The line object is scanned by moving the object relative to the sensor using a stepper motor controlled by a software program in a microcontroller. A dark line on the object is represented by a group of dark pixels in the CCD sensor. The average pixel is the average of the two end pixels of the group. The average dark pixel number and the line number are recorded in a data file in a PC. Results of a graph trace converted into digital data are presented.

***Keywords**: CCD sensor, microcontroller, stepper motor and microcomputer.*

1. Introduction

The solid-state image sensor has found its way into many scientific and commercial applications (Awcock and Thomas, 1995; Cook and White, 1995 and Tseng Hsin-Fu *et al.*, 1985) which include, but not limited to, pattern recognition, facsimile, size and position monitoring, inspection, surveillance, astronomy, spectroscopy and x-ray detection. In most of these types of instruments digital techniques have been applied. But there are still a lot of older instruments with analog type of readout in use around the world, e.g., the mechanical gravimeter which is not based on electronics, and is very expensive to replace with digital readout. In this paper it is described how an optical analog-to-digital converter (ADC) using a charge-coupled device (CCD) image sensor (Theuwissen, 1995; Holst, 1995) can be used to read a graph on a strip of paper.

2. Methodology

2.1 The overall system

Figure 1 shows the block diagram of the overall system used. The blocks depict the circuits required. Apart from the stepper motor and the personal computer, the rest of the blocks could be realized on a single printed circuit board (PCB).

2.2 The CCD sensor

The CCD sensor used was the DE-Series RL1024DE, from EG&G

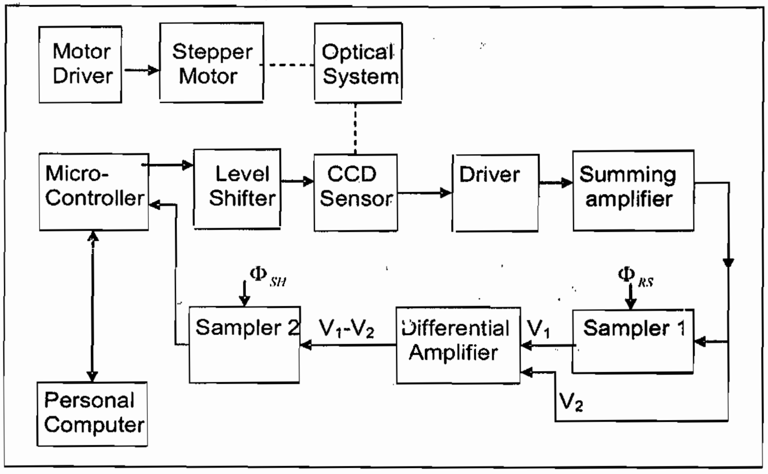

Fig. 1: Block diagram of the system

RETICON (EG&G Reticon, 1995/96), which is a linear CCD with a length of 1024 picture elements (pixels) and a single output capable of data transfer rates as high as 10MHz. The sensor requires a number of dc power supplies and a sequence of time clocks.

Figure 2 shows the clocks needed for the CCD. Φ_T is the transfer gate. When it is low, charge flow from the imaging register into the readout is prevented. The charge flow is permitted when the transfer gate is high. This mechanism allows for accumulation of charge on a new line while the previous line is being read out. The new integration period begins immediately when the transfer gate is pulled low. For the readout, there is a single horizontal readout shift register which is driven by two-phase clocks Φ_1 and Φ_2. The readout register receives charge from the imaging register and transfers the charge to an on-chip amplifier, one pixel at a time. The transfer of charge to the amplifier is done through a sample-and-hold circuit, clock Φ_{SH}. There is a reset transistor gated by the reset clock Φ_{RS}. The reset transistor is turned on when Φ_{RS} is pulsed high. When Φ_{RS} is low, the reset transistor is off and the signal charge is dumped to a capacitor when the phase-1 clock Φ_1 goes low. The signal is then measured as a voltage at the output of a three-stage amplifier. The signal is then sampled and the sensing mode is rest. This timing is repeated for the length of the array for a readout of one complete line of the image. The clocks for the CCD were produced using a microcontroller.

2.3 The microcontroller

The clock timing sequence can be produced either by hardware or by software. The latter method, used in this

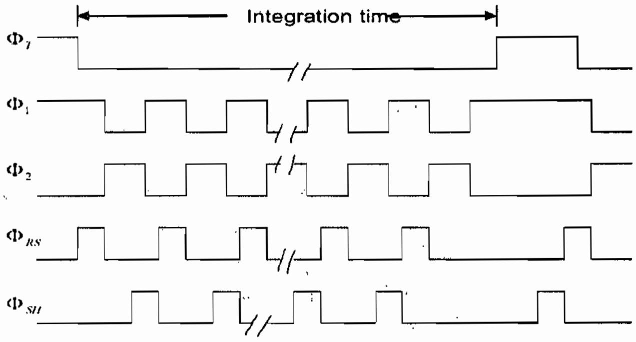

Fig. 2: Clocks for the linear CCD sensor: Φ_T =Transfer gate, Φ_1 =phase-1 clock, Φ_2 =phase-2 clock, Φ_{RS} =Reset gate, Φ_{SH} =Sample-and-Hold gate.

work, is done by execution of a program in a microcontroller. The software method considerably reduces the number of logic circuits needed. On the other hand the parameters of the clock timing sequence are closely tied to the microcontroller's performance. The CCD's readout frequency is limited by microcontroller's clock frequency and more specifically by the number of clock cyles needed to write to the input/output circuit. The clocks for the CCD were produced using a microcontroller, the PIC16C74A, from MICROCHIP. This microcontroller has an inbuilt 8-bit analog-to-digital converter (ADC) using the successive approximation method and operated by a software program.

2.4 The digital video signal

The video signal from the CCD output is first stripped of its dc voltage and amplified before being double-sampled. This is done using summing amplifier (Fig.1). In this arrangement the video signal plus a negative adjustable voltage are applied to the inverting imput. The circuit sums these two voltages so that the actual video signal is stripped of the dc component. The double-sampled signal is sent to the microcontroller for conversion to a digital equivalent signal. The digital video signal is compared to a dark signal reference to give the state of a pixel. The dark signal is a dc voltage in the range of 0 to 5V, and can therefore be simply produced by a potentiometer. If the signal level is less than the dark level, then the pixel state is zero, and if the signal level is greater than or equal to the dark level, then the pixelstate is set to one. This process is repeated for the whole length of the 1024 valid pixels.

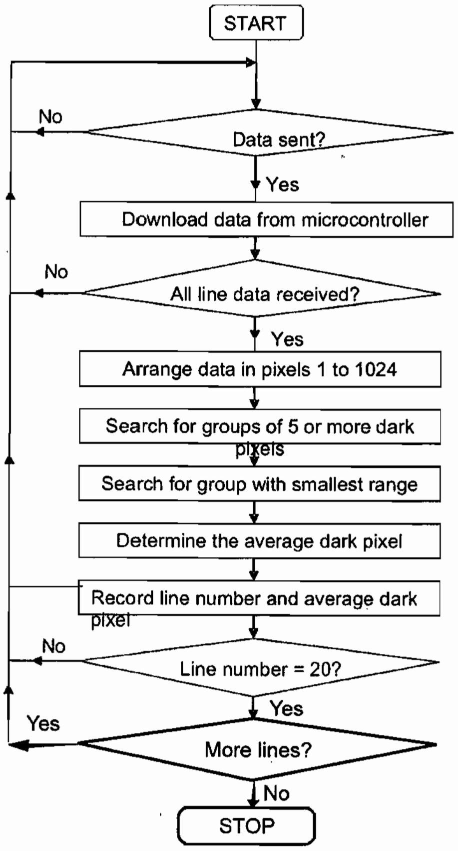

Fig. 3: Flowchart for the QUICKBASIC program

The RAM data memory of the microcontroller used was only 192 bytes and yet video information data for 1024 pixels had to be stored. The solution to this problem was obtained by representing the video information of a single pixel by one bit. With 192 bytes we have 192x8=1536 bits of memory available from which we can comfortably use 1024 bits to store the video information. After all the 1024 pixels have been read out and their corresponding 1024 binary data have been stored, these data are then transmitted serially to the PC, one byte at a time, until all the 128 bytes of data have been transmitted. After all the 128 bytes of data have been transmitted the program is ready to process a new image line.

2.5 Image scanning

To scan the image as a whole one can either move the detector, the CCD linear array, across a stationary image or move the image across a stationary detector (Hopwood, 1980 and

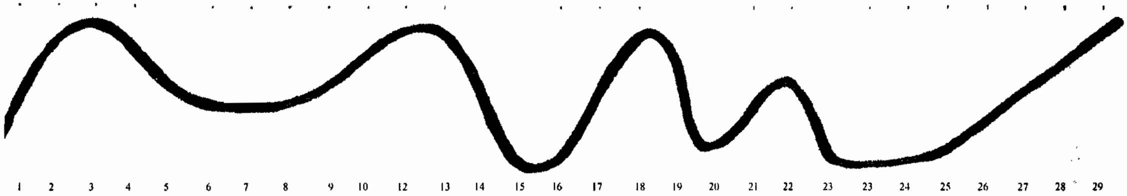

Fig. 4: Test graph

Schroeder, 1984). The latter method was preferred to avoid moving the detector together with its printed circuit board and lens system. The image formed on the linear array was displaced perpendicularly with respect to the linear array while the linear array was continuously read. The displacement was done by a stepper motor controlled by software in the PIC microcontroller.

3. Data Processing

The microcontroller, the CCD sensor, the stepper motor and the rest of the system are interfaced to the PC where data processing and overall control are done. A software program in QUICKBASIC is used to process the pixels. First the 1024 pixels of an image line are received from the microcontroller and a search of groups of dark pixels is made. A group of dark pixels is a number of consecutive dark pixels. It was found that groups of dark pixels with less than five pixels were not reliably accurate due to noise. Therefore groups of dark pixels with less than five pixels were neglected and only those with five or more pixels were taken into account. After the groups of dark pixels have been identified, the group with the smallest range is sorted out and noted. The average dark pixel of a line image is obtained by simply taking the mean of the first and the last pixels of the group with the smallest range. The pixels are numbered from 1 through 1024 and *integer division* is used. The average, together with the corresponding line number are then recorded in a data file. The PC then waits for the microcontroller which enables the stepper motor to advance the paper object before starting to process the next line. Figure 3 shows a flowchart of the QUICKBASIC program used. The number of lines processed can be selected, the limit depending on the memory available in the PC. The data file contains pairs of numbers or coordinates. The first number, the *line number*, gives the horizontal coordinate. All consecutive linenumbers are equidistant and their spatial resolution is fixed by the stepper motor. The second number, the *pixel number*, gives the average dark pixel number. It is a number in the range 1 to 1024. This range can represent any measurable quantity, e.g. voltage. All the values are positive. If negative values are included, a zero-level pixel number has to be chosen so that all pixel numbers below it are negative and all pixel numbers above it are positive. One notable drawback of the above program is that only one curve should be present in the object.

4. Results

The type of graphical data anticipated is usually a graph drawn on a strip of white paper in black or blue ink. As the paper strip is advanced the physical quantity plotted across the paper, perpendicular to the paper motion, varies between a maximum value and a minimum value. The width of the ink line made on the paper strip is important for the CCD image sensor. The sensitivity of the sensor depends on, among other things, the width of the line being read.

Figure 4 shows a graph drawn on a strip of white paper 50 mm wide. The graph was drawn using a blue marker pen and the width of the line was about 2.0 mm. The paper strip was advanced a distance of 10 mm for each image sensor reading. The object must be kept still while being sensed. The positioning of the object is done while the previous sensed image is being processed. As the microcontroller program simply detects the presence of dark pixels in an image line, it is the QUICKBASIC program in the computer (PC) that decides on the correct group of dark pixels corresponding to a dark line of the graph. The average dark pixel is the arithmetic mean of the two end pixels of a group of dark pixels. The average pixel numbers at equidistant positions 10 mm apart are obtained by scanning the graph in Figure 4. These results are used to reconstruct the graph. Figure 5 shows the reconstructed graph. The reconstructed graph can be made smoother if a shorter scanning distance is used.

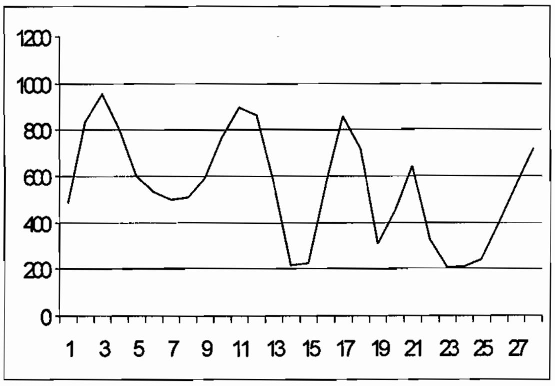

Fig. 5: Reconstructed test graph

5. Conclusion

The overall accuracy of the system described is highly dependent on the optical system. Due to the small dimensions of the linear array of pixels, a small change in the object distance has a big effect on the image distance. Thus the focusing of the object on to the imaging photosites of the CDD was very crucial. This problem could not be completely solved in the laboratory as it involved measuring short distances, as short as 13.6 mm for the image distance, accurately. In addition one had to make a correction for the distance of the line of pixels in the CCD from the top surface of the window of the CCD. What was done was that the lens was placed approximately 13.6 mm from the CCD top surface and the processed image from the CCD was monitored for the best position.

The width of the lines of the graph that could be detected by the sensor was limited to about 2.0 mm and above. Lines thinner than this could not be detected accurately. Graphs are usually made of lines as small as 0.5 mm. Also in the PC program, line widths represented by 5 pixels or less were found to be unreliable and were therefore neglected. Only lines represented by more than five pixels were found to be consistently accurate. The image sensor investigated can be used for reading graphs of lines whose width is more than 2.0 mm. The system needs to be improved to read thinner lines.

This work has shown that it is possible to use a linear CCD image sensor to read graphs. There is still a great deal of investigation to be done before such a system can be put to practical use. Some of the most important investigations to be done in the future, which can transform this work into a practical instrument, include optimizing the lighting conditions by enclosing the instrument into a casing, and improved well focused optical system.

Acknowledgements

The author is grateful to the NUFU Project "Basic Science for Technological Development in Uganda" for the financial support rendered and for making his visits to the University of Bergen, Norway, possible.

References

Awcock, G.J. and Thomas, R. (1995): *Applied Image processing.* Macmillan press Ltd., London.

Cook, B.M. and White, N.H. (1995): *Computer Peripherals.* Edward Arnold, London.

EG & G Reticon (1995/96): Image Sensing and Solid State Camera Products Data Book.

Holst, G.C. (1996): *CCD Arrays, Cameras, and Displays.* SPIE Optical Engineering Press, Washington, USA.

Hopwood, R.K. (1980): *Design Considerations for a Solid-State Image Sensing System.* Proceedings of the Society of Photo-Optical Instrumentation Engineers, 230, April 8-9, Washington D.C.

Schroder, H.E. (1984): *Practical Illumination Concept and Technique for Machine Vision Applications.* Society of Manufacturing Engineers Conference, June 4-7, Michigan, USA.

Theuwissen, A.J.P. (1995): *Solid-State Imaging with Charge-Coupled Devices.* Kluwer Academic Publishers, Dordrecht, The Netherlands.

Tseng Hsin-Fu, Ambrose John Robert and Fattahi Msouodi (1985): *Evolution of the Solid-State Image Sensor.* Journal of Imaging Science 29, 1-7.