Development of CCD controller for scientific application

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Abstract. Photoelectric equipment has wide applications such as spectroscopy, temperature measurement in infrared region and in astronomical research etc. A photoelectric transducer converts radiant energy into electrical energy. There are two types of photoelectric transducers namely photo-multiplier tube (PMT) and charged couple device (CCD) are used to convert radiant energy into electrical signal. Now the entire modern instruments use CCD technology. We have designed and developed a CCD camera controller using camera chip CD47-10 of Marconi which has 1K x 1K pixel for space application only.

1. Introduction

CCD controller consists of three major parts 1. CCD Camera Chip, 2. Electronics and 3. Software. Out of them, CCD camera chip is the heart of the CCD camera system. It is very sensitive to the light and made of silicon arranged in array form. A portion of the CCD chip is shown in figure 1. When light falls on a pixel, it is converted to a charge and captured by the pixel without any reflection. The more light falls on the pixel, the more charges will be accumulated in the pixel. The amount of the charges is a measure of the amount of light that fell on the pixel [1]. To get the image in the computer, the amount of charges of every pixel has to be read. The charge detection node of CCD chip measures the charge of a pixel. Every pixel must be shifted to this device. The lowest line is able to shift pixels to the left in the direction of the device. So these pixels can be measured one by one. When all pixels of the line are measured, all lines are shifted one line down. Again the lowest line can be measured. This will be repeated until all lines are measured. The computer can read the measurements through the camera electronics. This phase can take a few seconds [2], [7].
2. Electronics

The electronics of the camera are the intermediate between the CCD chip and the computer. The block diagram of the CCD controller is shown in figure 2. The analog output of the CCD chip is applied to the pre-amplifier. The circuit diagram of pre-amplifier is shown in figure 3. The output of the pre-amplifier (figure 5a) is applied to the CDS (Correlated Double Sampling) circuit. The circuit diagram of CDS is shown in figure 4. The CDS processes the video waveform and converts to a digital number proportional to the size of the charge packet contained in the pixel [8]. Switches S1 and S4 close at the time of reset pulse up to t0 (Figure 5a). Since S4 is close, the output of the integrator will be zero. Capacitor C1 will charge through the switch S1. Between t1 and t2, the switch S2 will be close. The reference part of the waveform is sampled. The output of the integrator will start to ramp down linearly. Between t2 and t3, the charge dumping occurs in the CCD. The CCD output steps negatively by an amount proportional to the charge contained in the pixel. During this time the CDS is disconnected. Between t3 and t4, the switch S3 will be close and the signal part of the waveform is sampled. The input to the integrator will also be polarity switched. Therefore, the CDS output starts to ramp-up linearly. The width of the signal and sample windows must be same (i.e. t2-t1= t4-t3). After CDS, D.C. voltage corresponding to the pixel information will be received. The waveforms of different stages are given in figure 5(b). Digital Signal Acquisition and Control Board generates the clock pulses for I0, R, qR, DG and pulses for analog switches of CDS circuit. These pulses are shown in figure 6. The circuit diagram of Digital Signal Acquisition and control board is shown in figure 9. The proposed designed have used mechanical shutter. The circuit diagram of camera shutter controller is shown in figure 10 [6].

3. Implementation of Parallel Port (LPT1) in Our Project

LPT1 has three resisters 1. Status resister, 2. Control resister and 3. Data resister. From these resisters, one status bit (bit 7, pin 11), five control bits (bit 0, bit 1, bit 2, bit 3 and bit 5) and eight data bits (pins 2-9) are used for this purpose. Bit 4 of control register is used to enable the IRQ while bit 5 is used to enable the bi-directional port [3], [4]. An overall view of these resister bits is given below

For ADC status Pin 11, bit 7 of Status register
For Shutter open Pin 17, bit 3 of Control register
For Shutter close Pin 16, bit 2 of Control register
For reading start Pin 1, bit 1 of Control register
For DATA Pin 14, bit 2 of Control register Pin 2 to Pin 9, bit 0 to bit 7 of DATA register

Following instructions are used to control the camera.

For camera ON and charge collection 
Out32 (CONTROL, 0 × 0fh)

For camera OFF
Out32 (CONTROL, 0 × 03h)

To start reading
Out32 (CONTROL, 0 × 06h)

To read the status of ADC
Inp32 (STATUS)

Reset the system
Out32 (CONTROL, 0 × 04h)

Reading data (for MSB)
Out32 (CONTROL, 0 × 22h) and Inp32 (DATA)

Reading data (for LSB)
Out32 (CONTROL, 0 × 20h) and Inp32 (DATA)

Figure 5: (a) Pre-amplifier output (b) CDS output.
4. Software development

Windows XP platform and VC++6.0 software language are used to develop the software for the camera control [5]. The flowchart is given in figure 11.

Features of Camera Control Software:

- **Open**  
  To open the Shutter of the **CCD Camera**.

- **Acquire**  
  To capture the image data into **CCD Chip**.

- **Close**  
  To close the Shutter of the **CCD Camera**.

- **Read**  
  To read the image data from **Parallel Port**, which is connected with **CCD Camera**.

- **Store**  
  To store the image data in BIN file format.

Thus the generated binary file can be converted into image by ASTRO ART software or any other suitable software.
Figure 10: Camera Shutter control.

Figure 11: Flow Chart.

Figure 12: Pre-amplifier output.

5. Controller testing

Five individual cards (power supply, preamplifier, CDS, Digital signal acquisition and control board) are made and tested individually for their proper functioning. After this, all these cards are integrated and again the complete circuit is tested for its final functioning.
After confirming the circuit performance, the CCD chip is fixed in the circuit, camera right output (OSL) is connected to the pre-amplifier. After this, the camera is switched on to receive the desired signal, which is shown in figure 12.

6. **Image taken from CCD Controller**

Initially a dark frame and a frame in light are tried. It is observed that even if the camera shutter is opened in the dark room, too much signal is received. A very little difference in the count between dark frame and light frame is observed as shown in figure 13 and 14. Experimentally it is established that the sufficient difference in the count, we have to cool down it up to –55°C.

![Figure 13: dark frame.](image1)

![Figure 14: Frame with some light.](image2)

7. **Conclusion**

This report gives a brief overview of various CCD chips and developing phase of the CCD controller. There are many methods available to extract the pixel information from the output signal of the CCD chip. Proposed system has used correlated double sampling (CDS) method using dual integration and capacitor clamping technique. This is the simplest and effective method to minimize the read noise of the CCD by eliminating reset noise. The proposed system has used 15 bit DAC in which maximum output of the CCD chip is 450 mV.

Many camera controllers are available, that use either a PCI card or a memory chip. The main objective of this work was to develop a CCD controller using computer parallel port instead of using a PCI card or a memory chip.

The software developed for the controller controls the clock signals, camera shutter etc. require for the CCD chip and acquire the image data in bit format. Image acquisition of several minutes is possible with this system.

8. **Future Scope**

This proposed system can be modified in future according to the scientist requirement. In general, the modification may require in micro-controller program or in software according to the scientist choice. The camera controller, we have designed has covered only the electronics hardware. This can also be used for astronomy purpose by adding the following features.
- A cooling system to cool the CCD up to -20°C as mentioned in Finger Lakes Instrumentation model CM-2.
- A good optical focusing system.
- Software still has to be modified, to cover all the function, this require a software expertise.
- A good mechanical cover for CCD chip, to avoid the light during readout time.

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Figure 9: Digital Signal Acquisition and Control Board.