The Design and Construction of an Inexpensive CCD Camera for Astronomical Imaging

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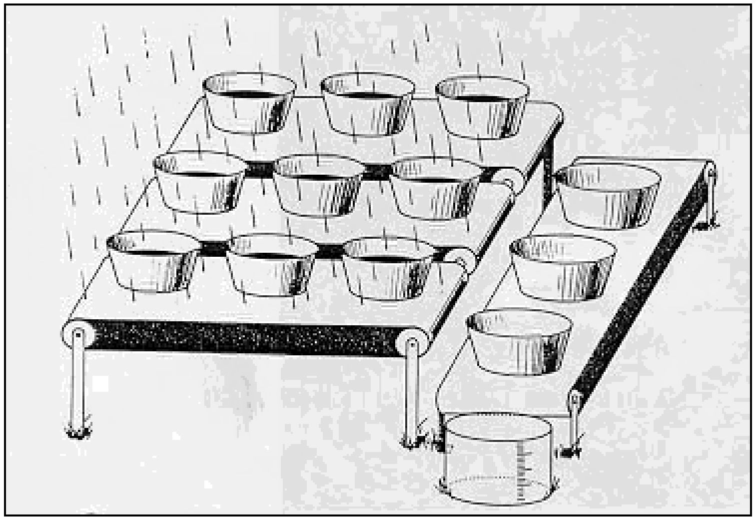
Abstract

The design, construction and testing results of an inexpensive CCD camera are presented. The CCD chip and electronics from a low cost, readily available camera is redesigned for astronomical imaging. The total cost of the system is under $100. Examples are given of the imaging results on bright astronomical objects such as the moon and planets. A direct comparison of image quali and other factors is made between this camera and a commercially available astronomical CCD which has a cost more than 30 ti the one presented here.

CCDs and Astronomical Imaging

A charged-coupled device, or CCD, is a solid-state imaging detector that is commonly found in video cameras and still-frame digital cameras. CCD cameras modified for low light detection are widely used by amateur and professional astronomers in place of photographic film. The CCD chip is a rectangular array of imaging elements called pixels, or photosites. The basic function of a CCD detector is to convert the incoming photons of light into electrons through a process known as the photoelectric effect. These freed electrons are stored in the pixels until the chip is read out. The more photons which strike a pixel, the higher the numerical value recorded for a pixel. The intensity of these photosites is displayed on a computer screen as an image. The light gathering area of a typical CCD is only a few millimeters on a side, smaller than a postage stamp, but it contains 400,000 or more light sensitive photosites.

The distribution of brightness of a celestial object such as the moon, on a CCD chip can be likened to measuring the rainfall at different points in a field during a rainstorm. The analogy is shown in the figure below taken from Janesick, and Blouke (1987). An array of buckets sitting on conveyor belts which cover the field collect rain during a storm. After the storm, the buckets in each row are moved across the field on the conveyer belts. As each one reaches the end of the conveyer, it is emptied into another bucket which carries it to the collection station where the amount of water in each bucket is measured. In this analogy, the raindrops correspond to photons and the buckets to pixels. The vertical conveyor belt corresponds to the serial register of the CCD and the collecting station is likened to the chip amplifier. A computer would later take these data and display a picture of how much rain fell on each part of the field. The greater amount of rainfall, the brighter the pixel in the image.



Noise Sources

The measurement of precisely how much light falls on a CCD is filled with uncertainties. Two adjacent pixels which receive the same amount of light will likely not have identical counts. This uncertainty in the measurement of how much light fell on a given pixel is called noise and can have a significant impact on the scientific usefulness of a CCD image. One of the advantages of the CCD technology is that because the data are stored in digital form in a computer file, noise sources can be mathematically subtracted or divided out of the image using appropriate software The four main noise sources are known as bias counts, dark counts, cosmic rays and flat field corrections.

Bias or readout noise is generated by the electronics of the chip. Taking a zero second exposure and subtracting this image from the other images corrects your bias noise.

Dark counts are due to the heat of the instrument which causes atoms in the CCD chip to vibrate free some electrons. These electrons are counted along with the ones generated by incoming photons. A dark image is taken in which no light strikes the CCD chip. The counts in the dark image are then mathematically subtracted from the object image, pixel by pixel for all 400,000 or more pixels.

Cosmic rays are highly energetic particles that strike the CCD, generate large counts in adjacent pixels and appear as a bright spot on the image. Cosmic ray hits are readily visible and can be mathematically subtracted out of the object image. See the poster at this conference by K. Banks and I. Lister for a good example of this.

There exists a sensitivity variation among the pixels of the CCD which can be corrected by **flat-fielding**. Sensitivity differences are due to variations in the manufacturing process or from obstructions such as dust particles in the optical path at the CCD and telescope. One may take flat-field images of uniformly illuminated surfaces such as the inside of the observatory dome and then use software to divide out much of the pixel-to-pixel sensitivity variations in the object image.

Construction of an Inexpensive CCD

Listed below are the materials needed along with the steps that were used in the design and construction of our inexpensive CCD. The total cost of the supplies, including the PC camera but excluding the tools, is less than $100.

Tools and Supplies

PC camera (connectix quick cam software)
Black project box (metal)
Copper tube (1.5" water pipe)
Center punch
Propane torch
Hammer
Black spray paint
Paper clip
Small flat head screwdriver
Small phillips screwdriver
Phillips screwdriver
Sand paper
Rubber silicon
File
Pencil

Step 1. Take a simple computer "eyeball" camera and remove the sticker label on the back of the camera near the computer cord, noticing the small hole.

Step 2. Use an open paper clip to press a button inside the small hole and then pry open the camera very gently with a small phillips screwdriver. (Do not stick the screwdriver in too far and damage the circuitry).

Step 3. Remove the outer covers, unscrew the black camera lens and remove the metal weight.

Step 4. Remove the secondary circuit board by pulling it away from main circuit.

Step 5. Take a small screwdriver and remove the black lens attacher. Remove the lens and blue infrared filter. (Be careful to not damage the circuit board.)

Step 6. Center the copper tube on top of the back metal plate of the project box. Using a pencil, trace the outer diameter of the copper tube on top of the metal plate.

Step 7. Take a center punch and cut out a circular hole in the metal plate.

Step 8. Insert the copper tube into the hole and make it flush with the metal plate by gentle use of a hammer. Use sandpaper to remove excess dirt, oil, etc., from around the copper tube against metal plate.

Step 9. Using a propane torch, heat and solder the copper tube to the metal plate. Let the box and tube cool before proceeding to the next step.

Step 10. Spray paint the tube and box flat black and let it dry.

Step 11. To attach the main circuit board inside the metal box, apply a dab of silicon on each gray can capacitor of the circuit board and place the capacitors against the metal plate. The silicon will take about 10 to 15 minutes to dry.

Step 12. Place the main circuit board against the metal plate and align your CCD chip as close to the center of the copper tube as possible (see below, left). Before the silicon dries, be certain that the main circuit board is aligned so that that the metal cover piece of the box can be placed level against the metal plate.

Step 13. Take the cover piece and file out a small notch or insert. This is for the secondary circuit board connection wire to

assure proper alignment of the project box. Your notch should be filed in the center of either smaller side of the rectangular cover piece. The above pictures show the computer cord exiting the box.

Step 14. Reattach the secondary board to the main circuit board. Attach the cover piece to the metal plate. Your project box has now become your own, personal CCD. The copper tube will be placed in the focusing tube of the telescope (above right).

The SBIG ST–7 Commercial CCD

We also gathered images of the moon with a commercially available, amateur grade CCD, a ST–7 that is manufactured by the Santa Barbara Instrument Group (SBIG) and has a base price of $2,950.00. For more details about the ST–7, see Taran Tulsee's poster at this conference. Our observational setup for both the ST–7 and the homemade CCD included a Celestron 8-inch, f/10, Schmidt-Cassegrain telescope plus a laptop computer to control each CCD and save the images.

Comparison Images

Figures 1 and 2 were taken with our homemade CCD, while Figures 3 and 4 are from the ST–7. The ST–7 images were taken through a thin layer of clouds so some scattered light is present in the figures.

Figure 1

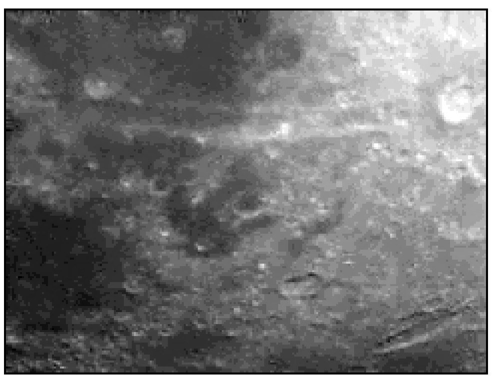
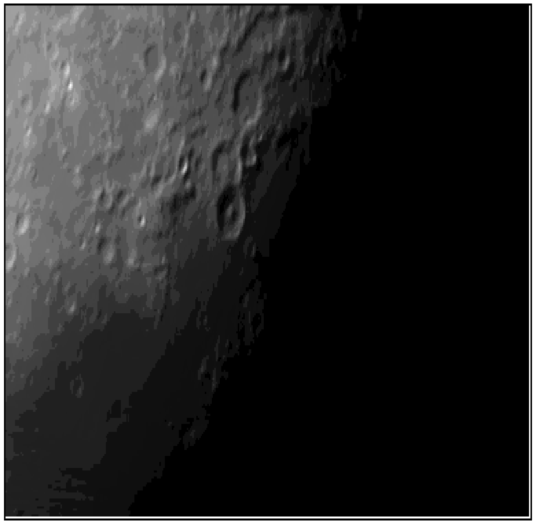


Figure 2



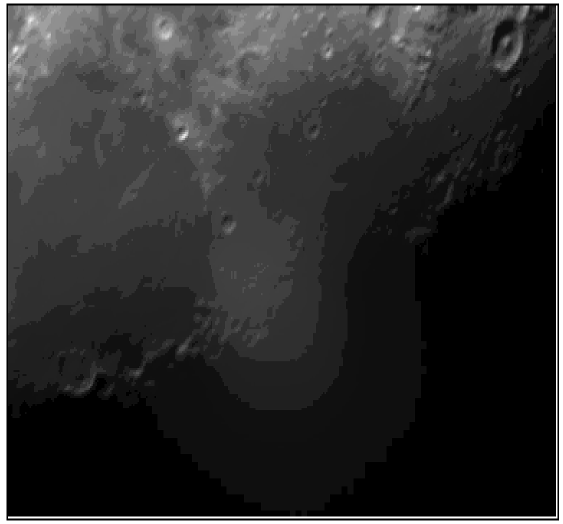


Figure 3

Figure 4

We also took images with the inexpensive CCD of Saturn and Jupiter shown in Figures 5 and 6. For comparison purposes, Figures 7 and 8 show images of the same two planets taken from the SBIG website (see Baker reference) using a setup similar to our own, an ST– 7 imaged through an eight-inch Celestron telescope.

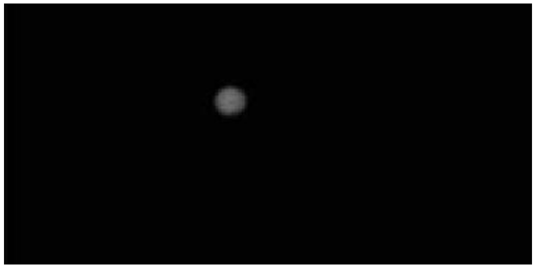


Figure 5 Figure 6

An enlargement of Figure 5 will show that our homemade CCD can just barely resolve the Giant Red Spot on Jupiter and it will show a hint of the bands across the disk of the planet. Likewise, with Figure 6 the ring system of Saturn is clearly visible, but lacking in detail. Figures 7 and 8 show the advantage of the SBIG camera. Much more spatial detail is possible as well as a greater range in intensity (dynamic range).

Figure 7 Figure

8

Summary

This study has resulted in the author developing a basic understanding of the design and operation of astronomical CCDs. An inexpensive design and construction of a CCD using easily available materials has been presented. The results of imaging with the $100 "home made" CCD camera and a $3,000 commercial CCD camera were presented. For a bright, large object such as the moon (and presumably the sun) the two cameras produce images which are similar in quality and spatial resolution. Images of the bright planets Jupiter and Saturn taken with the commercial camera show much greater spatial detail and dynamic range than the homemade camera.

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