

Application Note

Making Astrometric and Photometric Measurements with the SBIG Cameras

This application note describes how to use the CCD and CCDOPS software to make astrometric (separations) and photometric (magnitude measurements). It also describes how the software uses the image pixel values to determine these quantities.

1. Astrometric Measurements.

Both the CCD software for the ST-4 and the CCDOPS software for all our other cameras allow measuring separations between objects in the field of view of an image. Essentially these measurements involve the user specifying two points in the image and the software calculating the separation in seconds of arc (1 second = 1/3600 of a degree) between the two points. The details of this process follow:

You can specify each of the two points using two methods or algorithms: 1) A point can be selected to be a pixel coordinate in the image; or 2) A point can be calculated by the software to be the centroid or center of light of the area near a pixel in the image. The latter works well when measuring separations involving stellar objects, the former should be used in all other cases.

The crosshairs mode of the operating software is used to make the astrometric measurements. Setting the positions of the two points is a five step process: 1) A determination of the background level is made, 2) The cursor is moved to the first point, 3) The position of the first point is recorded and the separation measurement zeroed, 4) The cursor is moved to the second point, 5) The separation is calculated and displayed. These steps are discussed in detail below:

- 1) If neither of the two points is stellar and measurements from pixel to pixel in the image are desired then you can skip ahead to step 2. If however you want the software to more accurately measure distances based upon stellar objects then you must let the software know what the background level is. Move the cursor to an area of sky free of stars and nebulosity and hit the 'B' key (for background).
- 2) Move the cursor to the desired location of the first point using the arrow keys or mouse (note that only the CCDOPS software supports the mouse). If the first location is a star then position the cursor near the center of the star.
- 3) If the first point is not a star and you desire to zero the separation on a pixel then hit the 'S' key (for set position) to set the position of the first point to the pixel coordinate of the crosshair. If however the first object is a star and you wish to zero the separation on the optical center of the star then hit the 'C' key (for centroid) and the computer will calculate the centroid of the star

under the crosshair and zero the separation measurement at that centroid position. The advantage of using the centroid is that the zero position can be set between pixels resulting in a more accurate measurement.

- 4) Move the cursor to the desired location of the second point. Each time the cursor is moved the separation between the 1st point and the current pixel coordinate of the cursor is calculated and displayed.
- 5) If the second point is not a star then you're done. The separation shown is the separation between the 1st point and the current pixel coordinate of the cursor in seconds of arc. If however the second point is a star and you wish to set the 2nd point to the centroid of the star then position the cursor near the center of the star and hit the 'P' key (for position). The computer will calculate the centroid of the area under the cursor and use that centroid location for calculating and displaying the separation. You will have to hit the 'P' key each time you move the cursor to a new location because as soon as you move the cursor the 2nd point is set to the pixel coordinate of the cursor and no new centroid is calculated. Finally note that in both cases you can make several separation measurements between the 1st point and the different 2nd points without having to re-set the position of the 1st point.

How does the computer calculate the separation you may ask? The separation calculations are discussed in detail at the end of this application note but in general the software does this by measuring the physical separation of the two points in the image and dividing by the focal length of the telescope. For this reason, accurate astrometric measurements depend on the correct setting of the focal length parameter in the image info command. This parameter should be set to the focal length of the telescope in inches.

An object with a known separation can be used to accurately determine the focal length as follows:

- 1) Set your focal length parameter in the telescope setup command approximately correct. For example if you have an 8-inch f/10 telescope the approximate focal length is 80 inches.
- 2) Then take an image of the known object and measure the separation.
- 3) Finally adjust the focal length parameter in both the image info command and the telescope setup command accordingly. For example if the measured separation is 10% lower than the actual value then you would lower the focal length parameter by 10%.

2. Photometric Measurements.

The camera operating software also allows you to make photometric measurements of objects in the field of view. These measurements include stellar magnitude and surface brightness (diffuse magnitude). Stellar magnitude measures the total energy in an object and calculates the magnitude. Surface brightness calculates the total energy per unit of area.

These measurements are made in the crosshairs mode and involve three steps: 1) A determination of the sky background is made to zero the calculations, 2) The crosshair is positioned on the star or portion of nebulosity, and 3) An appropriate box-size is determined for accurately measuring the magnitude. These three steps are detailed below:

- 1) Move the cursor to an area that is representative of the background surrounding the object you wish to measure. For example if you're trying to determine the magnitude of a star buried in nebulosity you would select a background area with roughly the same brightness as the nebulosity surrounding the star. If you are trying to measure the surface brightness of a galaxy then pick a location out in the sky background free of stars and nebulosity. Once the cursor is positioned, hit the 'B' key (for background) to calibrate the magnitude measurements based upon the background level.
- 2) Position the crosshair over the object of interest. For stellar objects get the crosshair close to the center of the star. For nebular objects place the crosshair over the region of interest.
- 3) The size of the box used to measure the magnitude is cycled through using the 'T' key (for toggle box size). For stellar objects you want the box size to be big enough to include all the light from the star but small enough to exclude other objects from the calculations. As you increase the size of the box from 3x3 thru 11x11 you should see the calculated magnitude decrease (stellar brightness increase) and plateau out as the box size includes all the star's light. For nebular objects set the size of the box large enough to get the desired smoothing effects of larger numbers of pixels but small enough to be able to measure any desired spatial variations in the surface brightness.

Accurate measurements of photometric quantities requires attention to several items. First the CCD's spectral response means it measures light from 4000Å through 9000Å with varying efficiencies. In general the CCD's response peaks near 6750Å and is roughly 50% (relative to the peak) at 4500Å and 7500Å. Using the CCD without any optical bandwidth filters is roughly equivalent to measuring photographic magnitudes. Second, the software needs to know the aperture area of the telescope. Larger apertures capture more light. This is set in the telescope setup command for images to be taken in the future and in the image info command for existing images. This aperture area should be the clear aperture area with any obstruction subtracted. The software also depends on a response or calibration factor to convert pixel counts to magnitudes. This parameter is in both the telescope setup and image info commands. The correct value for ST-4 cameras is roughly 12,000 and for the other cameras the correct value is roughly 1,000. The reason we say roughly is that the calibration parameter is adjusted to calibrate the magnitude to that of a known star or object. Reasons for the variation include transparencies of optical elements in the telescope, transmission of the atmosphere, and manufacturing variations from camera to camera. All this aside, the method you use to determine the correct setting of the CCD response factor is as follows:

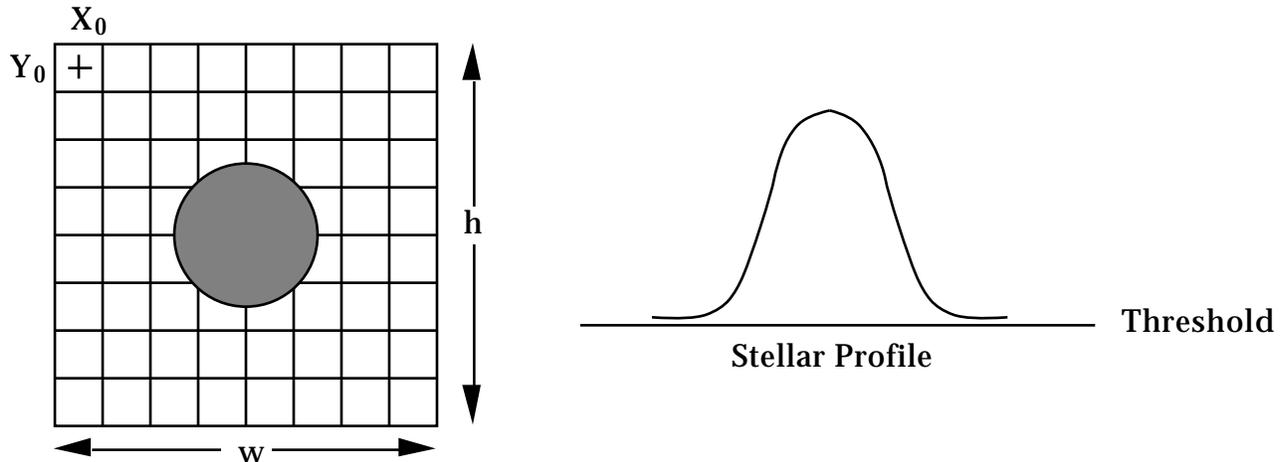
- 1) Select an object in the field of view for which you know the magnitude or take an image of a known object. The former is preferable because it takes into account any variations in atmospheric transmittance as a function of location in the sky. Objects at the zenith go through less air than objects near the horizon.
- 2) Make a background setting as described in the steps above.
- 3) Position the cursor over the known object and select the box size as described above. If the magnitude shown is incorrect use the '+' and '-' keys to adjust the calculated magnitude.

- 4) When the calculated magnitude is correct note the settings of the response factor parameter in the image info command. Copy this value to the settings in the telescope setup command so it will be used in future images¹.

If you're interested in the nuts and bolts of the photometric calculations read on. They're described in full detail below!

3. Calculation of Centroids

The centroid calculation is directly analogous to a center-of-mass calculation for an object if you represent the local mass density with the pixel intensity values and allow a discrimination level at the average background level. This is shown in the figures and formulas below:



$$Threshold = \frac{\sum_{i=0}^w \sum_{j=0}^h P(i, j)}{h \times w}$$

where in the formula above $P(i, j)$ represents the intensity value of the pixel at $x=i, y=j$. Also the *Threshold* value which will be used as a discrimination level in the centroid calculation is taken over the background area and represents the average pixel level in the background area.

$$X_{centroid} = X_0 + \frac{\sum_{i=0}^w \sum_{j=0}^h i \times (P(i, j) - Threshold)}{\sum_{i=0}^w \sum_{j=0}^h P(i, j) - Threshold}$$

$$Y_{centroid} = Y_0 + \frac{\sum_{i=0}^w \sum_{j=0}^h j \times (P(i, j) - Threshold)}{\sum_{i=0}^w \sum_{j=0}^h P(i, j) - Threshold}$$

where in the formulas above should quantity $P(i, j) - Threshold$ be less than zero, zero is substituted on a pixel-by-pixel basis.

¹ The star's spectral class can produce ± 0.5 magnitude errors in this determination. For the greatest accuracy calibrate the response factor on a star with a similar spectral class.

4. Calculation of Separation

The angular separation between two points on the image is determined by calculating the corresponding physical separation between the points on the CCD and dividing by the focal length, keeping track of the units:

$$Separation = \frac{3600 \times 180}{\pi} \times \frac{\sqrt{(x \times 0.01375)^2 + (y \times 0.016)^2}}{25.4 \times fl}$$

where *Separation* is in seconds of arc, *x* and *y* are the x and y separations between the two points in pixels and *fl* is the focal length of the telescope in inches².

5. Calculation of Magnitude

The calculation of magnitude involves calculating the total energy in a star, subtracting the background, correcting for the exposure time, aperture area and CCD response factor and taking a scaled logarithm. The calculation is broken down into several steps below:

$$L = \sum_{i,j} P(i,j)$$

$$B = \sum_{i,j} P(i,j)$$

where *L* and *B* are the sum of all pixel values in the box centered on the star and background areas respectively.

$$Magnitude = -2.5 \times \log_{10} \frac{L - B}{A \times C \times T}$$

where *A* is the aperture area in square inches, *C* is the CCD's response factor and *T* is the exposure duration in seconds. Note that the units of *C* are counts per second per square inch of aperture for a 0th magnitude star. Also note that with all cameras besides the ST-4 the *C* used in the calculation above is actually the ratio of 6700 divided by the camera's electronic gain (e-/ADU) with that ratio then multiplied by the CCD's response factor entered in the image info and telescope setup commands.

6. Calculation of Diffuse Magnitude

Diffuse magnitude is the magnitude per square arc-second of subtended area. The calculation uses the Magnitude calculated above and the area of the box as shown below³:

$$BoxArea = \frac{3600 \times 180}{\pi} \times \frac{BoxSize^2 \times 0.016 \times 0.01375}{(fl \times 25.4)^2}$$

where *BoxArea* is the area of the box over which the diffuse magnitude is calculated in square arc-seconds, *BoxSize* is the size of box in pixels and *fl* is the focal length of the telescope in inches. Finally:

$$DiffuseMagnitude = \frac{Magnitude}{BoxArea}$$

² The pixel sizes shown are for the ST-4 (0.01375 x 0.016 millimeters). For the the other cameras substitute the X and Y pixel sizes shown in the Image Parameters command.

³ Refer to footnote 2.