Measuring Double Stars with a Micrometer and Digital Image

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INTRODUCTION

The observation and measurement of visual double stars is an important area of study in astronomy and astrophysics. This type of observing is an area of research well suited for amateur participation. The amateur can still carry out important scientific work, and make a valuable contribution to astronomy. While accurate measurements of visual double stars does not necessarily require the use of an expensive micrometer the process is never the less made easier and highly accurate using such instruments.

To find the apparent separation of a pair of close stars, or double stars as they are called, with a telescope one may use a measuring device such as a micrometer and a digital image. Micrometers are usually made with adjustable webs, needlepoints, or an eyepiece reticle with graduated lines ruled in the glass. The webs, needlepoints (***Carroll-Bohanon micrometer***), or reticle lines are positioned at the focal plane, in focus with the image, and magnified. An image can be aligned between the micrometer webs, points, or the ruled lines of the reticle and the separation noted on a dial or scribed on the reticle in either fractions of an inch or millimeters (See Figures 1 through 4).

Figure 1. TOP: A Bi-Filar Micrometer produced by Ron Darbinian. It was sold with either a 12mm or 27mm eyepiece attached to the black box that contains the webs and web holding mechanism. The silver handle to right is the micrometer thimble and spindle to adjust the movable web. A protractor shown is shown behind the black box and is free to rotate 360 degrees to measure the position angle of the double stars. BOTTOM: Darbinian micrometer thimble and spindle for reading separation in millimeters.

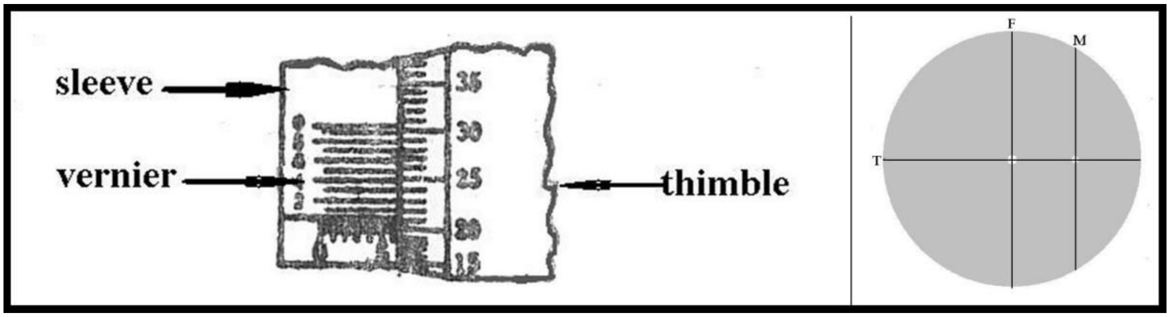

Figure 2. Darbinian micrometer thimble and spindle for reading separation in millimeters. Appearance of double stars in the *right* image between web (F) and movable web (M) The web (T) is used for centering.

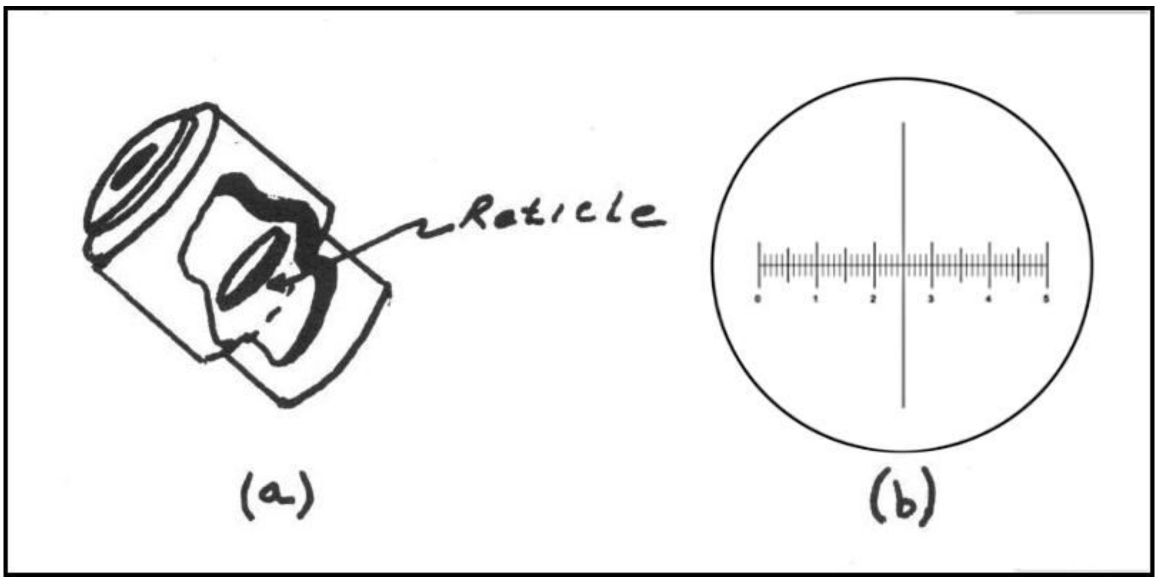

Figure 3. The Eyepiece Reticule Micrometer. A cross-section view is presented in view (a) and the image of the reticule and Mars is shown in (b)

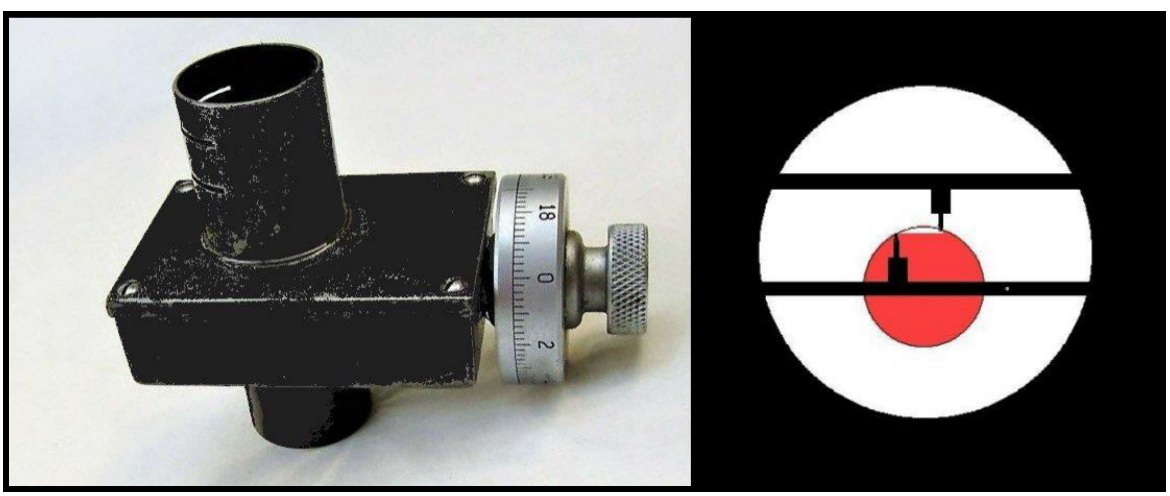

Figure 4. The Carroll-Bohanon Needlepoint Filar Micrometer. A cross-section view is presented in view (a) and the image of the reticule and Mars is shown in (b)

SOME BASIC METHODS

First it would be wise to find the orientation of the micrometer in the telescope field relative to the celestial sky. As we know the celestial sphere is marked off in the astronomer's mind using an imaginary grid and we refer to the direction west and east as Right Ascension (RA). The north-south direction or Declination (DEC) equates to the latitude of the celestial sky that is marked off is degrees. RA is graduated in hours, minutes and seconds, and equated with the longitude of the celestial sky. The celestial equator is at 0° Declination, the north pole is 90° and the south pole is -90°.

The position angle of a double star pair or polar coordinates are relative to the celestial north, so we must rotate the micrometer so that the two stars drift exactly east to west along the centerline (T) web or etched centerline in the reticule eyepiece field. If the primary, or brightest, star is centered in the field and the dimmer star is on the west side of the primary then the micrometer is correctly oriented to the north (See Figure 5).

After the image is positioned at the focal plane between the webs or hash marks of the reticule, the telescope drives are adjusted so one star is centered in the movable (M), centerline (T) and the fixed (F) webs. The separation is read from the micrometer thimble and spindle (See Figure 5), or lines on the reticule and noted.

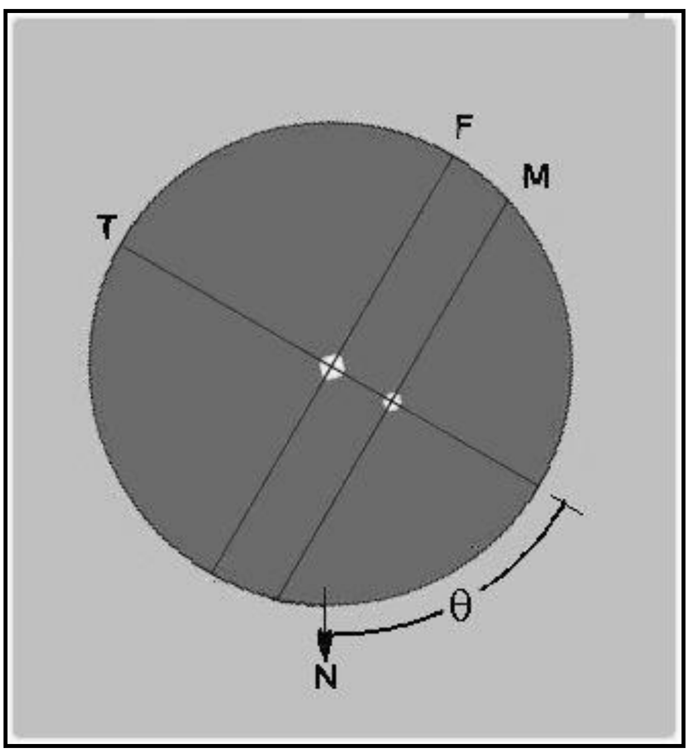

Figure 5. Double stars orientated with primary centered in field and companion to right side after north has been established. Position angle of a double star pair indicated by the symbol 'Theta'

After the image is positioned at the focal plane between the webs or hash marks of the reticule, the telescope drives are adjusted so one star is centered in the movable (**M**) and centerline (**T**) webs, and the fixed (**F**) and centerline (**T**) webs. The separation is read from the micrometer thimble and spindle (See Figure 2), or lines on the reticule and noted.

To reduce our measurements into some useful terms, we must first establish what our readings mean. Each increment on the micrometer dial head is a linear measure, in radians, of the image at the focal plane, which represents the apparent angle of the object being measured. The linear separation between two points in the magnified image is directly proportional to the apparent angle of the object and the effective focal length of the telescope.

The ratio between the focal length and the linear measurement is the micrometer "screw constant" (in arc-seconds per inch or millimeter). This is found by using the formula 206,265 / EFL. For example, the screw constant or image scale for a 16-inch (406.4mm) f/6.91 aperture telescope with a F.L. of 2806.7 millimeters is: 206,265 / 2806.7mm or 73.49 arc-seconds per millimeter.

Since many of the objects subtend very small angles, usually in the seconds of arc, we must increase the effective focal length (EFL) of our telescope to allow the image to be large enough to be separated by several increments. A large image also results in a higher resolution in the micrometer readings. The Barlow lens is a good way to accomplish this. If a 30.4x Barlow system is used on the above telescope then the EFL will be:

EFL = 2806.7mm x 3.04 = 8,532.4mm and the SC = 206,265 / 8,532.4mm, or 24.17 arc-seconds per millimeter.

For example, if the telescope has an effective focal length (efl) of 8,532 millimeters and the reading on the dial of the micrometer indicates a separation of 5 millimeters, the measurement represents an angle of 124.7 arc-seconds. This is accomplished by means of the mathematical formula; (206,265 x Reading) / Effective Focal Length. The number of arc-seconds in one radian is equal to 206,265. In our example, we substitute the values above to give:

(206,265 x 5 mm) / 8,532.4 = 1,031,325 / 8,532.4 = 120.87 arcsec

Another method to determine the screw constant is to turn the telescope's drive off and record the time it takes an object, such as a star, to cross the field of the micrometer from one point to another point at a prescribed separation (see **Figure** 6). The time in seconds that the object takes to cross the separation can be converted to an angle in arc-seconds and is the screw constant and can be found by the formula;

Screw constant = ($\mathbf{\Delta T}$ x 15.041068 x Cos $\boldsymbol{\delta}$) / separation, where $\mathbf{\Delta T}$ is the average time in seconds derived from several timings, $\boldsymbol{\delta}$ is the declination of the star

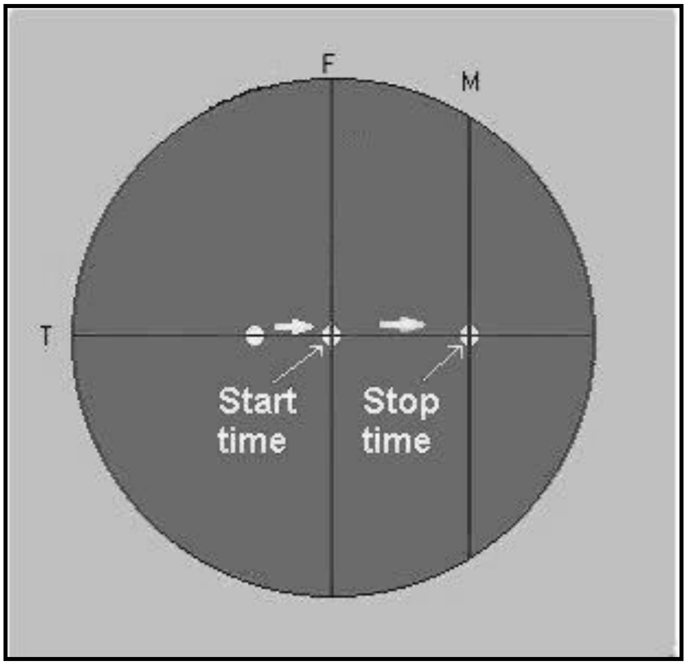

Figure 6. Check north point of micrometer in telescope using drift method. With telescope drive off cause a star at or very near the celestial equator to drift along the centerline web (T) of the micrometer between the fixed (F) and movable (M) webs. Record time it takes the drifting star to pass from the fixed to moveable webs that is set to a predetermined separation

To find the Screw Constant (**SC**) in this example, we take several timings of a star across the micrometer webs set to millimeters in the focal plane and find the average of 9.1 seconds; then the screw constant is:

$$SC = (9.1 \times 15.04106864025 \times \cos -27.99167) / 5 = 24.17 \text{ arcsec/mm}$$

Let's use a micrometer to measure a double star from The Aitken Double Star catalogue, (RA00:09:21.1, DEC -27:59.17), 2002 [kappa-1 Scl], separated by 1.4 seconds of arc and position angle 261 degrees. Since this pair is nearly at the same visual magnitude then find the star that appears a little brighter and position it in the center of the field on the centerline (**T**) web and the fixed (**F**).

You can find the separation by subtracting the micrometer "zero," that is, the dial reading where the webs or points are centered on each other. To determine the micrometer zero one positions the movable web exactly over the fixed web, then reading the micrometer. The Darbainian Bi-Filar Micometer this author uses has a micrometer zero at 10.6772. If we measure the separation of the double stars using a web type Bi-filar micrometer with a read of 10.7471 mm -- the separation of the double stars: separation = 10.7471 - 10.6073 = 0.0579 mm. Given the above image scale of 24.94mm/arcsec then the size of the image is: separation = 0.0579 x 24.17 = 1.4 arcsec

Of course, this was just a check to see if this particular double is still situated as catalogued and it appears that it is still separated by 1.4 seconds of arc and at 261 degrees position angle.

Another double close by is ***Aitken Double Star catalogue***, (RA01:45:38.8, DEC -25:03:09), 2002 [epsilon Scl], separated by 4.9 seconds of arc and position angle 24 degrees. Our micrometer separation is 0.2026mm so 0.2027 x 24.17 = 4.9 arcsec

DIGITAL IMAGE

Using the digital image illustrated in Figure 7 one can determine the position angle (**θ**) and separation (**ρ**) by image processing software. Simply point the cursor to the bright star in the pair and copy the X and Y pixel positions within the frame. Then find the X and Y position of the other star. In this example the digital image format is set to 640x480 pixel resolution (the width and height of the rectangular image below).

In this example we may use a digital camera attached to a 16" f/6.91 telescope with an EFL of 15,016mm and software that represents a 640 x 480 pixel image and a projection magnification of our telescope system is 206,265 / 15,016mm = 13.74 arcsec / mm. The particular CCD image chip pixels are 5.6 μm wide, so the image scale (**S**) = 206.265 μm / F = (206.265 * 5.6 μm) / 15,016mm = 0.0769 arcsec / pix.

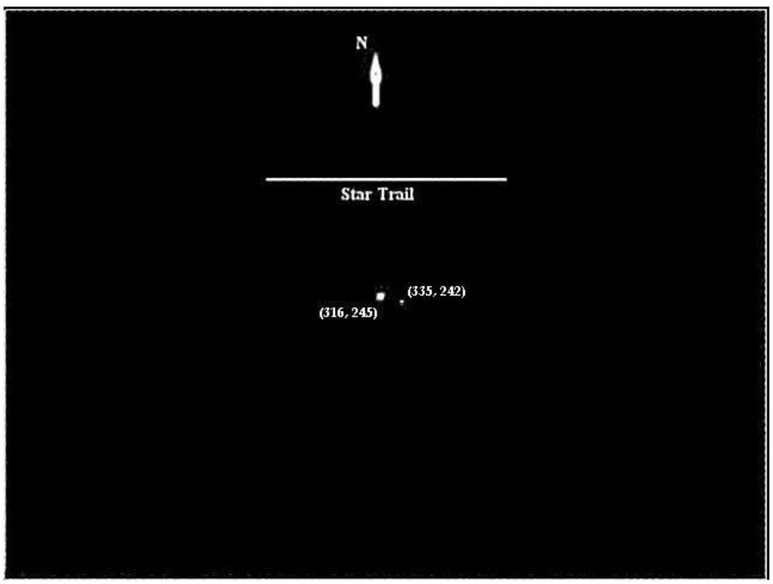

Figure 7. Illustration of double star system imaged on either a CCD or stacked webcam image. Using image processing software the X,Y points or pixel positions can be ascertained the position angle and separation can be determined. South is at top.

We find from the resized screen image in Figure 7 that the first star is (316, 245) pixels on the fame and the other star is (335, 242) pixel positions. So, the slope or position angle is measured counterclockwise from the north point and can be fund using the following equation. **Note:** In this case **Φ** was found to be 180˚ and represents the rotation angle of the pixel array coordinates relative to the equatorial coordinates on the sky [***Smolinski***1, 2006]:

$\boldsymbol{\theta} = \text{Tan}\,(X_2 - X_1) / (Y_2 - Y_1) + \Phi$, where $\Phi = 180^\circ$, $X_2 = 335$, $X_1 = 316$, $Y_2 = 245$ and $Y_1 = 242$. So,

$$\text{Tan}\,\boldsymbol{\theta} = (335 - 316) / (245 - 242) + \Phi = 6.3333$$
$$\boldsymbol{\theta} = \text{Tan}^{-1}\, 6.3333 + 180^\circ = 81^\circ + 180^\circ = 261^\circ$$

The separation in pixels can be found by rotating the image 261˚ and measure the separation to be: $\boldsymbol{\rho} = \sqrt{}\,(X_2 - X_1)^2 + (Y_2 - Y_1)^2\,(\mathbf{S})$, where S = 0.0769 and we find that: $\rho = \sqrt{[(335 - 316)^2 + (245 - 242)^2]}\ (0.0769) = \sqrt{(370)} = 19$ pixels * 0.0769 = 1.48 arcsec

The second double, ***epsilon Scl***, we find $X_2 = 290$, $X_1 = 316$, $Y_2 = 187$ and $Y_1 = 245$. So,

$$\text{Tan}\ \theta = (290 - 316) / (187 - 245) + \Phi = 0.44828$$

$$\theta = \text{Tan}^{-1}\ 0.44828 + 180^\circ = 204.15^\circ + 180^\circ = 24.15^\circ$$

Note that (187 - 245) <0 so add 180˚ for the correct quadrant, as one would use the ATN2 function in some computer programming, and then normalize result for <360˚

$$\rho = \sqrt{[(290 - 316)^2 + (187 - 245)^2]}\ (0.0769) = \sqrt{(4040)} = 64 \text{ pixels} * 0.0769 = 4.9 \text{ arcsec}$$

In order to join in the fun with other double star observers you may wish to surf the web for the Journal of Double Star Observations at: http://www.jdso.org/

REFERENCE

Smolinski1, J. and W. Osborn1 (2006), "MEASUREMENT OF DOUBLE STARS WITH A CCD CAMERA: TWO METHODS," RevMexAA (Serie de Conferencias), 25, 65-68. http://www.astroscu.unam.mx/rmaa/RMxAC..25/PDF/RMxAC..25_jsmolinski.pdf

FURTHER READING

An on-line catalogue of speckle Interferometery maintained the Georgia State University is at: http://www.chara.gsu.edu/CHARA/DoubleStars/Speckle/intro.html

Couteau, Paul, **Observing Visual Double Stars**, ISBN 0-262-03077-2, The MIT Press, Cambridge, MA.

Dobbins, T. A., D.C. Parker, and C.F. Capen, (1981), **Introduction to Observing and Photographing the Solar System** , Willmann-Bell, 1988, Chapter 15, 193 - 201.

Gerald North, **Advanced Amateur Astronomy** (Edinburgh University Press)

Peek, B.M., **The Planet Jupiter: The Observer's Handbook,** Rev. ed, London; Faber and Faber Limited, 1981.

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