Binary Stars, Orbital Motion, and a Webcam

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Abstract: Procedures for applying an inexpensive webcam for measuring double stars are described. Measures of the binary stars Xi Bootis (STF1888 AB), 70 Ophiuchi (STF2272 AB) and Xi Ursae Maioris (STF1523 AB) taken between 2005 and 2010 are presented. They allow to follow orbital motion and compare measures with the well known orbits of these systems.

Measuring Double Stars Cheaply

Inexpensive Webcams like the Philips ToUCam [9] have been used by amateurs to produce excellent Lunar and Planetary photos. In 2005 I acquired such a camera with the goal of measuring double stars. This is easily possible with this camera: it has a small CCD chip (Sony ICX098BQ) that is 4.6 by 4.0 mm in size made up of 5.6 micrometer pixels. This 640 x 480 pixel (0.33 megapixel) chip is quite sensitive. Price for the camera was €100, including a 1 1/4" eyepiece adapter. The model I use is discontinued, but there are several newer models from different manufacturers having the same or even better features.

Telescope setup with webcam

I use an apochromatic refractor of 130mm aperture with focal length 1040mm (model Astro-Physics 130EDT). The telescope mount stays outside all year on a south facing balcony and is well polar aligned and has a motor drive with hand control (model Vixen Super Polaris DX). To increase focal length a 3x Barlow lens was used which I mount in a zenith prism. The webcam without objective but with 1 1/4" holder inserts in the Barlow lens holder and has an IR/UV blocking filter since a refractor is used. Image scale was determined to be 0.3248 arc seconds per pixel with this setup. For this project, more than 20 different pairs were measured as given in the WDS [1] – either well known calibration pairs or pairs with well known orbit. The webcam is connected via USB 1.1 cable with an old notebook computer which was acquired very cheaply. It has 128 megabytes of RAM and a 6 Gbyte harddisk, sufficient for this setup.

Typical observing session

After focusing and centering the object a small video is taken of the double star. Software used is the VRecord utility supplied with the webcam. Usually the settings are 5 frames per second (more results in more compressed images having less quality), exposure time 1/25 second or less with brighter stars (like ξ UMa) and high gain which results in more noisy images but increased sensitivity.

For one video 300 frames are taken with the double near the center of the field (60 seconds). Then, the double is moved to the eastern edge of field with the RA motor at 2x speed. After several seconds (20-30 images) the double star is moved to the western edge of field, again with 2x motor speed. Again 20-30 images are taken. This gives the east-west direction. Then video recording is stopped with nearly 500 single images taken.

Four or five additional videos are taken of the same star. Between videos the webcam is rotated about 20-30 degrees in the eyepiece holder. I try to have at least one video where east-west is nearly horizontal and two videos with the webcam rotated counterclockwise and two clockwise in the eyepiece holder.

Observing one object takes 15-30 minutes depending on the time taken for finding (a good finder helps) and focusing (important).

Measuring the Videos for Distance and Position Angle

Most of this uses excellent free software (see links) for which I am very grateful to the software authors.

4.1. Preparing the videos for measuring

VRecord software stored the videos in AVI-format. The resulting 200-300 megabyte files are transferred to a more modern PC having more memory and CPU power.

Then each video file is split up in image files for each frame. This is done with Giotto software [2] which produces image files in BMP format.

For measuring systems wider than about 3 arc seconds, which are well separated, I use Registax software [3] to produce summary images stacked together from the best frames:

- stacked images for frames 0-99 (see Figure 1), 100-199, 200-299
- stacked images for the east and west frames (see Figures 2 and 3) providing east-west direction (Figure 4)

Registax is able to select only the better images (due to better seeing) automatically. I usually use only images having a "quality criterion" of 80% of best images or better. So ½ or ¾ of images are actually used in producing the stacked images.

For tight systems like Xi UMa automatic stacking produces images which are not good enough. Here I browse through the raw images with Irfanview [4] and hand select 10-15 good images for measuring and at least one good "east" and "west" image.

Measuring the stacked or selected images

This is done with AIP4WIN software [5] which is not free, but accompanies an excellent book by Richard Berry and Jim Burnell which helped me a lot to understand the workings of CCD chips and measuring of CCD images.

With wider pairs like ξ Boo, images are measured with the "distance tool" of the software. One has to click on the first star then the second. I try to have the "measure ring" just as large as the brighter star. The software gives separation in pixels and the angle relative to the CCD frame orientation. This is recorded in an OpenOffice spreadsheet[6]. For the "east" and "west" images the (X,Y) pixel coordinates are also transferred to the spreadsheet.

For close pairs like ξ UMa, first images are resampled with 10x enlargement and then measuring proceeds as before. Resulting pixel distances have to be divided by 10, of course.

Example of measuring video 01 of 70 Ophiuchi taken on 31 Jul 2010

Distance and angle measurements in pixels are given in Table 1. For separation, with 0.3248 arc seconds per pixel, this translates to 5.82 ±0.04 arc seconds.

Table 1: Measurements from Stacked Images

Stacked imagename	Distance [pixels]	Angle [degree]
70_Oph_01_r5_000_099.bmp	17.85	311.17
70_Oph_01_r5_100_199.bmp	17.96	310.20
70_Oph_01_r5_200_299.bmp	17.79	309.82
70_Oph_01_r5_310_338.bmp (east stack)	18.08	311.73 307.34
70_Oph_01_r5_402_445.bmp (west stack)	17.95	
Average	17.93	310.05
Standard deviation	0.11	1.70

For position angle we have to know to (X,Y) pixel coordinates of the brighter star A on the east image: (x1 = 31.8, y1 = 204.8) and west image: (x2 = 611.3, y2 = 194.8).

Image orientation is now given by

$$\text{orientation\_angle} = \arctan((x1 - x2) / (y1 - y2))$$

which is also calculated by the spreadsheet. In our case we get a value of -89.01 deg since this was a video were the webcam was oriented almost exactly east-west.

Now we calculate the position angle, see Table 2. In Table 2 the first column (Angle) is from the measurement above, the second column (Value1) is needed to rotate into the NESW system of PA

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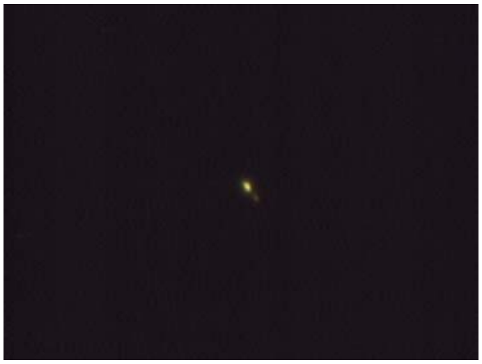

Figure 1: Image of ξ Bootis stacked from frames 0 - 99.

Figure 2: stacked "east" image of ξ Bootis.

Figure 3: stacked "west" image of ξ Bootis.

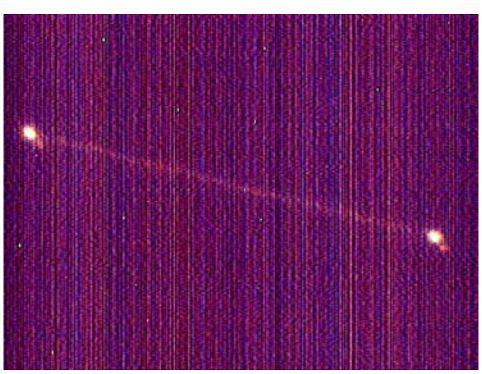

Figure 4: East image, west image and drift images providing east-west direction stacked.

Table 2: Calculation of Position Angle

Angle [degrees]	Value1: 90 + orientation angle	Value2: Angle + Value1	Position Angle: Value2 - 180
311.17	0.99	312.16	132.16
310.20	0.99	311.19	131.19
309.82	0.99	310.81	130.81
311.73	0.99	312.72	132.72
307.34	0.99	308.33	128.33
Average			131.04
Std dev			1.70

measurement, the third column (Value2) is the measured angle rotated to NESW system, and the fourth column is the real position angle. Depending on the orientation of camera and telescope (rightside up or upside down) you have to add or subtract 180 or 360 degrees from Value 2 to get the real position angle.

Averaging together the results of all 6 videos of 70 Oph taken on this evening, we get the results presented in Table 3.

Table 3: Final Result of PA and Sep. for 70 Oph

Value	Average	Std. dev.
Distance [pixels]	17.91	0.19
Distance [arc seconds]	5.82	0.06
Position angle [degrees]	130.98	1.03

Measuring a set of videos of one star on one evening takes around 1 to 2 hours on the PC.

The results of measures of Xi Bootis, 70 Ophiuchi, and Xi Ursae Majoris made between 2005 and 2010 are given in Tables 4 through 6.

Quality of results

Measurement quality is sufficient that change in position angle and/or distance is measurable from year to year for these rapidly moving systems. Results were also compared to the ephemeris taken from the spreadsheet by Brian Workman [7] which uses the orbits from [8]. For the ξ Bootis system, I have drawn diagrams showing the change of separation over time (Figure 5), change of PA over time (Figure 6), and orbit and measures by using and modifying Workman's spreadsheet (Figure 7). Similar diagrams for 70 Oph are shown in Figures 8, 9, and 10.

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Table 4: Measures of ξ Bootis (STF1888 AB)

Year	Sep. (a.s.)	PA [deg]	Nights
2005.36	6.29	313.00	1
2006.42	6.46	311.90	1
2007.28	6.17	311.20	1
2008.34	6.15	310.03	3
2009.26	6.00	308.56	1
2010.39	6.02	308.57	3

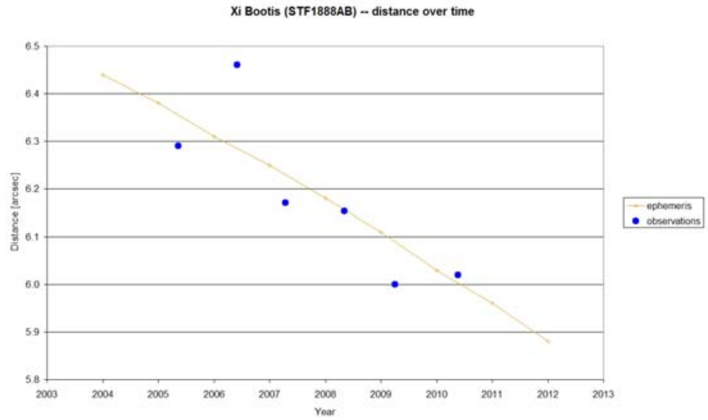

Figure 5: Measured separation over time compared to ephemeris for ξ Bootis.

Table 5: Measures of 70 Ophiuchi (STF2272)

Year	Sep. (a.s.)	PA [deg]	Nights
2005.55	5.06	138.00	2
2007.64	5.34	135.55	2
2008.53	5.46	132.97	1
2009.42	5.60	132.36	1
2010.50	5.81	131.00	2

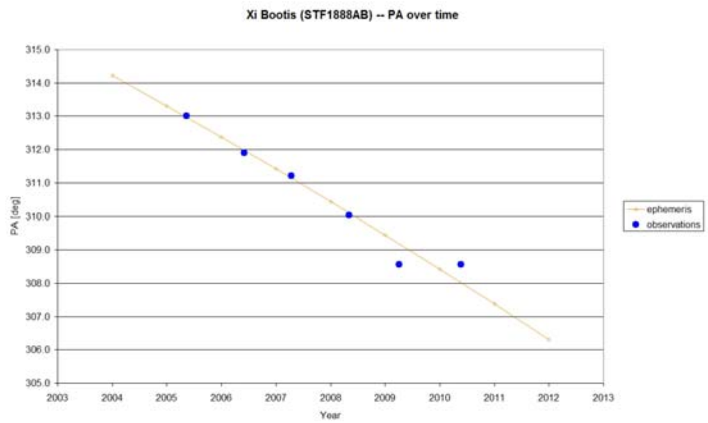

Figure 6: Measured PA over time compared to the ephemeris for ξ Bootis.

Table 6: Measures of ξ Ursae Majoris

Year	Sep. (a.s.)	PA [deg]	Nights
2005.322	1.85	242.68	4
2006.244	1.56	237.17	3
2007.191	1.59	228.91	3
2008.346	1.60	222.83	3
2009.252	1.59	214.13	1
2010.390	1.60	207.86	3

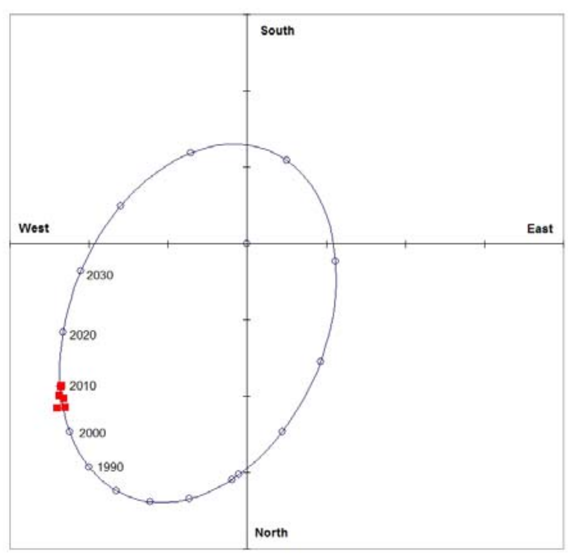

Figure 7: Orbit diagram of ξ Bootis with measured points in red.

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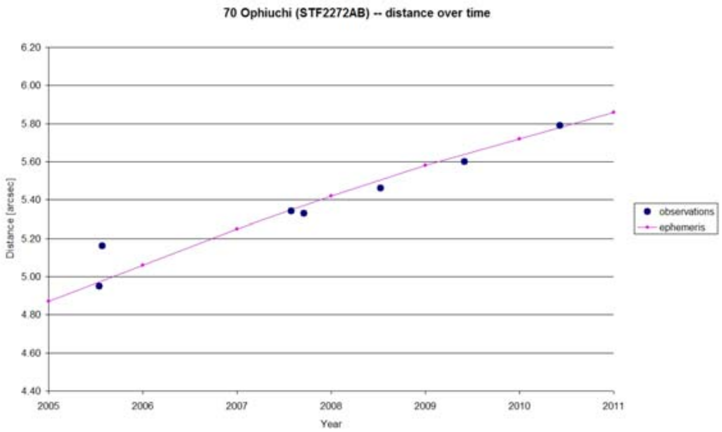

Figure 8: Measured separation over time compared to ephemeris for 70 Oph.

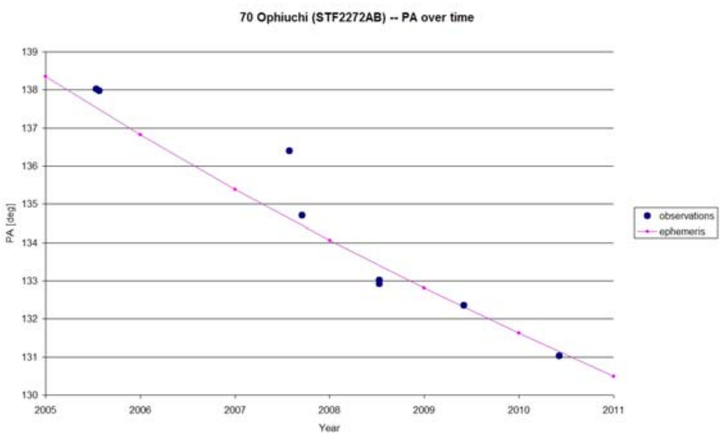

Figure 9: Measured PA over time compared to ephemeris for 70 Oph.

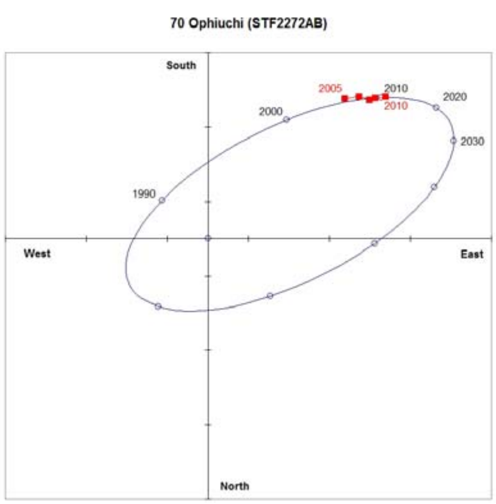

Figure 10: Orbit diagram of 70 Oph. with measured points in red.

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Conclusion

The Webcam results are very satisfying for me especially since they were obtained with simple amateur equipment which is also relatively cheap (except the telescope). Starting as a youngster of 14 years I enjoyed looking at double stars. I am now able to measure orbital motions of brighter pairs from my home.

Acknowledgments

This research has made use of the Washington Double Star Catalog maintained at the U.S. Naval Observatory.

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