

A Novel Method of Double Star Astrometry Using a Webcam and Self-Calibrating Measurement Software

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Abstract: A new double star software application, BinStar, is described. This application takes AVI sequences of doubles drifting across the FOV as input, and uses the drift rate, frame rate and declination to self-calibrate both image scale and orientation, so that separate calibration images are not required.

I became interested in double star observing for a variety of reasons, not least of which is that it presented an opportunity to contribute to “professional” science. After reading the book *Observing and Measuring Visual Double Stars* (Argyle, 2004), I was also convinced that double star measures could be done both accurately and with inexpensive equipment – all that was required was a little ingenuity.

I experimented with a variety of methods, but found I was unable to accurately and reliably measure the separation and position angle of calibration stars from the WDS catalogue. I then came across the website of Florent Losse, a French double star observer who discussed the use of a webcam for making double star measurements, and who had developed a piece of software called REDUC for performing the analysis based on webcam images. I was quite taken by this piece of software, save for two small issues. Firstly, it required capturing a calibration pair at the beginning and end of a session, which meant that the camera could not be touched during the session. This precludes removing the camera to insert a Barlow lens, and means recalibration must be done if the camera is jostled at all. Secondly, to my mind, calibrating on a double star – even a wide pair with very little motion – seems somewhat circular. It occurred to me, however, that an analysis program like REDUC combined with drift measurements could provide accurate results that are self-calibrated. With great optimism, a smattering of programming experience in Delphi, and a

blissful ignorance of the amount of work required, I set about creating such a program, and thus was BinStar born.

The principle is, in theory, straightforward. To begin, an AVI video sequence is shot of a double star drifting across the field of view with the drive turned off. In other words, it is drifting at the sidereal rate. Given the declination of the pair and the frame rate of the sequence, it is straightforward to calculate the distance the star drifts between each frame, and from this the resolution scale (in pixels per arcsecond) can be established. It is then a matter of determining the separation of the stars in pixels, and converting that to arcseconds. In addition, the direction of drift is due west, and this can be used as a reference for determining the position angle. The inherent multiple sampling of a video sequence provides built-in averaging of many sample measures, which helps to compensate for atmospheric effects and camera noise.

In practice, this is not an easy set of tasks to automate for someone who is not an expert in image processing. The main difficulty in coding this application was getting the computer to find and track the stars reliably from frame to frame. Although it may have been simpler to have the user select the stars in each frame, this can be onerous with dozens or hundreds of frames. As a result, I developed two distinct methods of locating the stars from frame to frame.

The first method is a simple weighted average. The user begins by selecting the primary and second

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dary star in the first frame (or the first usable frame – one does not need to begin at frame zero), and three boxes are defined. One box is created around the primary, which then takes the monochrome value of each pixel within the box and finds the weighted mean point within the box. This is iterated a small number of times to zoom in on the true weighted mean point, which is then recorded to a precision of 0.01 pixels. The same procedure is completed for the secondary, and then for a “system box” as a whole, which finds the weighted mean “center of mass” of the two stars together. An offset vector for the primary box is calculated relative to the system box, and an offset vector of the secondary box is calculated from the primary. With each new video frame, the system box zooms in on the cm of the system, the primary box is placed at the offset position and iterated to center itself on the primary, and lastly the secondary box is placed at its offset and iterated to lock onto the secondary.

This method works effectively if the two stars are sufficiently separated. If the stars are too close, or if there is image glare between them, the centroiding boxes may drift off center, and in extreme cases one box may drift onto the other star.

The second method involves automatic peak identification. In this process, a smoothed copy of the system is sampled (the degree of smoothing is determined by the box size), and the pixel values are sorted in descending order by brightness (again using monochrome values). The brightest point is deemed to be the peak pixel of the primary. By going through the list, each point (which will be either the same brightness or slightly dimmer than the last) is tested for proximity to the primary peak. Any point that is adjacent to the primary peak (or another point labelled as part of the primary) is identified as part of the primary. The first point in the list that is *not* adjacent to a primary pixel is identified as the secondary peak. Further points in the list are then labelled as belonging to the primary, the secondary, or neither (to exclude noise). The pixel positions of the primary and secondary peaks are then used with the original (unsmoothed) image data to locate the centroid by identifying the mean from within one standard deviation of the peak. It is fairly crude by some standards, but I have been pleased with its effectiveness. This method can often detect the centers of even close pairs, where there may be some overlap between the primary and secondary bounding boxes. The downside of this method is that it does not work well for pairs that are very close in magnitude, as atmospheric effects can

alter which point is brighter from frame to frame. For these pairs, the weighted average method is preferred.

Once each frame is analyzed and the centroid positions are recorded, the complete data set is analyzed. First, frame data are tested to see if they are, within acceptable limits, close to the first frame data. If not, the data is deemed inactive. Dropped or repeated frames are also inactivated in order to not skew the data. All active data is then used to calculate the average separation in pixels, and then converted to arcseconds as described above using the declination of the pair and the frame rate of the video. Also, the position data for both the primary and secondary are analysed using least squares linear regression, and the average of the two values is taken as due west. The position angle is then calculated relative to this line.

As a final step, the user can step through the complete sequence frame by frame, activating or inactivating individual frames as desired to eliminate obvious miscalculations. Notes can be made (including qualitative comments on the data, and perhaps the image scale etc), and then the data can be exported to a tab delimited text file, which can be imported into any spreadsheet for later analysis or publication.

Let me outline a typical observing session. For observing doubles I use a Celestar 8" SCT, with RA and DEC motors, but no go-to capability. I find that with a telrad and RACI finder, I can locate objects quite quickly, so a computer is not required. My camera is a Celestron Neximage, mounted in a Meade 644 flip mirror diagonal. I typically use a 26 mm super Plossl to locate and center the target pair, and then flip up the mirror, decide whether a Barlow is required, focus the image on the camera chip and adjust the frame rate and gain to achieve the best image. I then move the scope west in RA, turn off the drive, and begin capturing the video sequence when the pair drifts into the FOV. I have recently been using K3CCD Tools, which allows me to set a capture time, so I do not have to stop the video manually as I would do with AMCap. I typically use the star designation as the filename (eg STF2140.AVI) to avoid later confusion. I may take several sequences of one pair, or if I feel confident that the capture was good (lots of frames with clearly separated star images) I move on. In this way I will capture a dozen or so double stars in a casual evening's session.

Later, on a cloudy evening, I will run the AVI's through BinStar and analyse the results. I type in the designation, RA and DEC values, and the software

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calculates the epoch (in Julian and Besselian dates) from the file data. I run through the video sequence to determine appropriate start and end frames (in case the star drifts out of the FOV), and choose an appropriate box size and select the star images. I always use a flip mirror, so it is a straight-through system, but there is a radio button to select if a diagonal is used. Then it is a matter of selecting the GO button, and watching what happens. A zoom window can be used to see an enlarged version of what is happening in the main video window. When the sequence is complete, the results are displayed at the bottom of the window. At this point, it is wise to step through the sequence to see if there are any glaring errors – frequently atmospheric effects can split a star image into two, fooling the peak search algorithm. These frames can be deselected, and the results can be recalculated. I find the pixels/arcsec value to be a useful reference check – I know my system is ~ 1.7 without a Barlow and ~ 4.2 with a Barlow. If the value is something other than these numbers, there is a problem – most probably the DEC value was entered incorrectly, but on one occasion the frame rate of the AVI was not recorded correctly. I typically use the notes section for comments on the image quality, and if there was much motion due to poor seeing or wind on the scope. I save the values to the results file, and repeat with the next sequence.

So far I have been very pleased with BinStar, and to be honest, pleased with myself for creating it. There are still several limitations to this software. It is limited to a maximum video resolution of 640x480 (typical for a webcam), and as it samples the screen pixels directly, it must be run in the foreground. Stars that are close to the poles may not yield great results due to the limited drift – but this concern may turn out to be unfounded due to the added benefit of a greater number of frames. Pairs with large magnitude differences may not work with many webcams, and very close pairs with similar brightness may fool both search algorithms. The system assumes square pixels in the webcam, which is not always a given, and slow frame rates, required for fainter stars, lead to elliptical star images. And lastly, the algorithms themselves are not infallible, so occasionally a large number of frames must be manually discarded.

Some results of my current observing program, which consists primarily of stars on the WDS Neglected Doubles list, are presented in Table 1.

The BinStar application is written in Delphi, and I am more than willing to accept the charity of more knowledgeable programmers who wish to help in developing this project. BinStar is free for individual use, and may be downloaded from my website at <http://budgetastronomer.ca/binary-stars>.

Name	RA+DEC	PA	Sep	Date	N	Notes
STF 222	02109+3902	36.1	16.76	2005.846	1	1
STF 305	02475+1922	306.5	3.57	2006.059	1	2
STF 664	05152+0826	176.2	4.85	2006.059	1	3
STF1110	07346+3153	59.6	4.37	2006.059	1	4
STF1196	08122+1738	71.3	5.9	2006.291	1	5
STF1424	10200+1950	124.5	4.52	2006.292	1	6
STF1888	14514+1906	310.9	6.39	2006.481	1	7
STF1954	15348+1032	173.1	4.05	2006.481	1	8
STF1985	15559-0209	349.9	5.91	2006.481	1	8
STF2032	16147+3351	236.7	7.04	2006.481	1	

Table 1: Measurements of neglected doubles made with BinStar (*continued on next page*).

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Name	RA+DEC	PA	Sep	Date	N	Notes
STF2140	17146+1423	103.5	4.68	2006.514	1	11
STF2272	18055+0230	136.1	5.34	2006.481	1	12
STF2382	18443+3940	349.8	2.33	2006.481	1	13
STF2383	18444+3936	80.2	2.32	2006.481	1	14
STF2486	19121+4951	205.7	7.38	2006.481	1	15
STF2727	20467+1607	266.4	9.1	2005.846	1	16

Table 1 (cont. from previous page): Measurements of neglected doubles made with BinStar.

Notes:

1. 194 frames, f/10
2. 71 frames, f/10, noisy signal due to high gain, looks like overestimation on rho
3. 92 frames, taken at F/10, seeing less than ideal. STF 664 is the same as CHE 79
4. 142 frames, taken at F/10. STF 1110 is Castor.
5. 275 frames, f/10
6. 210 frames, f/10, very windy night, so the images jumped up and down a bit, but the star images were very good.
7. 58 frames, Fairly steady
8. 86 frames, used weighted average method
9. 57 frames, f/10.
10. 189 frames, appears to be clean data
11. 84 frames, Delta Mag on CCD is higher than visual, weighted average used
12. 64 frames
13. 83 frames, one pair of epsilon-lyra, the "double-double". Not bad given the conditions and tight pairing, but likely an underestimate.
14. 80 frames, the other pair from the "double-double". Again, likely an underestimate due to the proximity of the stars.
15. 293 frames, Super data, tight stars - used weighted avg due to similarity in mag
16. Gamma Delphinus, mediocre seeing, averaged between 71 frames at f/10 and 28 frames at f/20

Ed trained as an evolutionary biologist and paleontologist. He has been working in science education for the last two decades, teaching in Canada and Switzerland. He has been a space enthusiast since the moon landings, and has been actively observing with his growing collection of telescopes for four years. Ed's musings on amateur astronomy can be found at www.budgetastronomer.ca. He currently lives outside of Toronto.