

Crystal Lake Observatory Double Star Measurements: Report #1

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Abstract: This paper reports updated astrometric measurements for 10 visual double stars located between 0 and -20 degrees declination and with magnitude between 10 and 12. Measurements were obtained using a 20 cm Ritchey–Chrétien telescope and CCD camera with photometric V filter and data reduction using Pixinsight™ software.

Instrumentation and Software

The telescope used is a GSO 20cm Ritchey–Chrétien design with a carbon fibre tube and 1624 mm focal length. The telescope is permanently mounted on an iOptron™ CEM60-EC mount and remotely operated over a CAT 6 network between the observatory and the data processing office.

The CCD camera is an SBIG STF-8300M. Combined with the telescope, the field of view is 38 x 29 arc-min and the plate scale is 0.685 arc-sec/pixel. The camera cooling system is set to operate at -5C. An Astrodon™ 50mm photometric V filter is fixed between the focuser and the camera.

SkyX™ software is used to remotely control the telescope, camera, focuser, and mount. The raw images are saved on a PC located at the observatory and later a copy transferred to a project computer in the lab.

Pixinsight software is used for the calibration, plate solving, astrometric, and photometric measurements. Custom software, written by Crystal Lake Observatory, is used to automate the process and format the results.

Methodology

For this dataset, each star was imaged twenty times over a period of twenty five minutes on an observing night. Due to clouds or instrument errors, the number of images measured may be less than this. These data

are then combined with those taken on subsequent observing nights and the mean and standard deviation of the separation and position angle calculated. The exposure time for each image is sixty seconds and all images recorded using a Johnson-Cousins V photometric filter.

The first step in the data reduction process is calibration of the raw images. The Pixinsight process ‘ImageCalibration’ was used to perform the standard image calibration functions including dark frame subtraction and flat frame correction. Noise evaluation is included in the process and used to remove unwanted images.

Next, the Pixinsight script, AperturePhotometry (AP), written by Andres del Pozo and Vicent Peris is used to determine the center of each star. First, a plate solve of the image is performed using the PPMX star catalogue. This defines the J2000 equatorial center of the image and a distortion model.

Following the plate solve, a Point Spread Function (PSF) model of the star profile is used to determine the precise center of the star. The PSF function can be configured to use a specific type of model (e.g., Moffat) or several types of models and select the best fit. A Mean Average Deviation (MAD), which measures the differences between the model and the actual star profile, is used to select the best model. For this dataset the Gaussian model was used because it provided the best solution (lowest MAD value) across all of the stars.

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	319		223				
Bounds		121.289596	16.058374	121.950322	15.582232		
Aperture		16	1	1			
Background ring window		20	40				
DATE_OBS	NAME	FILTER	CATRA	CATDEC			
2457474.8	3UCAC149-096628	Johnson V	121.316771	15.619054			

IMGRA	IMGDEC	IMGX	IMGY	f.mag	BKGROUND	BGSTDDEV	BGRJCT
121.316804	15.618982	141.107	2326.478	8.436	142.7808	21.13574	0.1614

PSF_A	PSF_SIGMAX	PSF_SIGMAY	PSF_THETA	PSF_MAD	FLUX16	SNR16	FLAG
0.7510268	5.10854291	4.61938076	177.80477	1.16E-02	1037774.2	977.2975	0

Figure 1. Example of the output file from Pixinsight. See text.

An example of the output file from Pixinsight is shown in Figure 1.

The CATRA and CATDEC values are the equatorial J2000 coordinates of the star taken from the UCAC3 catalog. IMGX and IMGY are the center (in pixels) of the star as determined from the PSF model. The IMGRA and IMGDEC values are the equatorial J2000 coordinates calculated using the plate solution and image distortion model from the plate solve process and the pixels coordinates from the PSF process.

Pixinsight also annotates a copy of the image to show the detected stars (Figure 2).

The primary star is the brighter one, the bottom star in Figure 2. Given the orientation of the camera, the position angle is measured counter clockwise with 0 at the bottom. In this case, the position angle is slightly past 180 degrees (the measured value is 187 degrees).

Determination of separation (ρ) and position angle (θ)

The final step uses a custom software program written by Crystal Lake Observatory to calculate the separation and position angle of the double star. There are two commonly used methods for calculating the separation and position angle using a CCD camera, (a) rectangular method using the pixel coordinates of the star centers, and (b) equatorial method using the calculated equatorial coordinates of the two stars. The two methods will normally result in equivalent results, but the equatorial method will account for any distortion of the image if the stars being measured are not near the center of the image, which could affect the accuracy of the measure. Therefore it was decided to use the equatorial method, although in this dataset all stars were located near the center of the image.

From the Pixinsight output file, IMGRA and IMGDEC are used to calculate the astrometric measures using the following two formulas (Greaney, 2015)

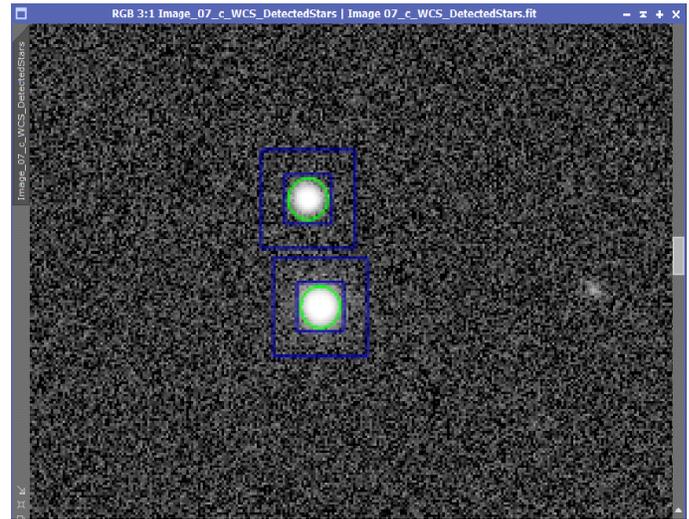


Figure 2. BVD 97. This cropped image is extracted from the detected stars images created by Pixinsight during the aperture photometry processing step.

The last equation places the position angle in the

$$\rho = \arccos[\sin(\text{primaryDEC})\sin(\text{secondaryDEC}) + \cos(\text{primaryDEC})\cos(\text{secondaryDEC})\cos(\text{secondaryRA} - \text{primaryRA})]$$

$$\theta = \arctan 2\{[\cos(\text{primaryDEC})\cos(\text{secondaryDEC})\sin(\text{secondaryRA} - \text{primaryRA})], [\sin(\text{secondaryDEC}) - \cos(\rho)\sin(\text{primaryDEC})]\}$$

if $\theta < 0.0$ then $\theta = 2.0\pi + \theta$

correct quadrant given the orientation of the camera on this system.

The Besselian date is calculated using the midpoint of the Julian date between the first and last image of the dataset:

$$BD = 1900.0 + ((jd2 - jd1) + jd1) - 2415020.31352 / 365.242198781$$

An audit trail of the entire process is saved with the raw images and provides a way to trace back the process and results for any given measurement. The audit trail includes:

- Raw images
- Calibrated images
- Calibrated image with plate solve parameters
- Detected stars images
- Output csv file from the Aperture Photometry script
- Output csv file from CLO Post Processor program

Measurements

Ten stars are measured and presented (Table 1). The column 'n' is the number of nights images were recorded. The column 'm' is the total number of meas-

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measurements (i.e., number of images measured). Ideally, m should be twenty times n , but some images were rejected due to clouds or tracking errors. The column ' $\sigma \theta$ ' is the standard deviation in position angle measured in degrees. The column ' $\sigma \rho$ ' is the standard error in separation measured in arc-seconds. The statistics are calculated on the entire dataset and not on an individual night. For example, for HJ 775 the mean and standard deviation are calculated from 17 measurements, and for HJ 131 from 113 measurements.

Discussion

One of the objectives of this first dataset is to evaluate the accuracy and precision of the methodology and look at changes to improve the efficiency of available telescope time.

A baseline was established by taking twenty images of each double star and repeating this on several nights. This resulted in a mean standard deviation of 0.02 arc-seconds for separation and 0.05 degrees for position angle across the entire dataset.

To check the accuracy of the measurements, the

statistics could be calculated for each night across the twenty images and an average and standard deviation of the means calculated across all of the observing nights. The standard deviation of the means would then indicate a level of confidence in the mean.

Using the data from WHC 9, Table 2 shows the mean and standard deviation for the position angle and separation across all nine observing nights. The 'All images per night' column uses all of the images from each night to calculate the statistics.

The results show excellent consistency across the observing nights with a standard deviation of the means well below the standard deviation of the samples for any given night. This indicates that one night's data could be used to derive an accurate measure of the star.

The '10 images per night' columns calculate the statistics based on using the first ten images recorded that night. The data shows there would be very little change in accuracy or precision in reducing the number of images from twenty to ten.

The '5 images per night' columns calculate the statistics based on using the first 5 images recorded that

Table 1. Basic Astrometric Measurements for 10 Selected Double Stars

Name	WDS	Date	θ	ρ	n	m	$\sigma \theta$	$\sigma \rho$	Notes
HJ 775	08053-1549	2016.237	178.12	11.27	1	17	0.07	0.04	
HJ 131	09201-0136	2016.263	123.30	16.27	6	113	0.06	0.02	1
J 1558	09466-0504	2016.282	169.85	11.10	5	96	0.06	0.01	
ARA 411	10289-1927	2016.300	329.04	12.67	9	168	0.05	0.01	
LDS 294	09593-1956	2016.278	169.67	24.25	7	140	0.03	0.01	
BVD 97	11544-2046	2016.304	186.97	30.31	7	133	0.02	0.01	2
WHC 9	11225-1028	2016.306	179.07	10.59	9	151	0.08	0.02	3
BAL1162	12432+0000	2016.327	303.38	15.06	5	77	0.04	0.01	4
HJ 1208	12051-0907	2016.304	99.59	10.49	7	136	0.10	0.02	
HJ 209	12239-0303	2016.327	146.53	23.76	6	95	0.03	0.02	

Notes:

- HJ 131. The last recorded values in the WDS catalogue are 123 degrees for position angle and 16.5 arc-sec for separation in the year 2007. The 2016 measures above shows a difference greater than the standard deviation of the data.
- BVD 97. The last recorded values in the WDS are 187 degrees for position angle and 30.4 arc-sec for separation in the year 2009. The 2016 measures above show a difference greater than the standard deviation of the data.
- WHC 9. The last recorded values in the WDS are 179 degrees for position angle and 10.7 arc-sec for separation in the year 2007. The 2016 measures above show a difference greater than the standard deviation of the data.
- BAL 1162. The last recorded values in the WDS are 303 degrees for position angle and 14.8 arc-sec for separation in the year 2009. The 2016 measures above show a difference that is much greater than the standard deviation of the data.

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Table 2. WHC 9. Comparison of measures vs number of images.

WHC 9	All images per night			10 images per night			5 images per night		
Date	N	ρ	θ	N	ρ	θ	N	ρ	θ
2016.237	19	10.59	179.07	10	10.59	179.07	5	10.60	179.06
		0.016	0.083		0.014	0.090		0.007	0.056
2016.245	19	10.59	179.07	10	10.59	179.08	5	10.58	179.09
		0.016	0.087		0.016	0.079		0.016	0.060
2016.264	18	10.59	179.05	10	10.59	179.05	5	10.59	179.09
		0.013	0.097		0.011	0.107		0.016	0.121
2016.286	20	10.58	179.07	10	10.58	179.07	5	10.58	179.06
		0.017	0.085		0.017	0.100		0.009	0.118
2016.289	19	10.59	179.05	10	10.59	179.05	5	10.59	179.06
		0.013	0.070		0.013	0.079		0.08	0.094
2016.319	20	10.58	179.06	10	10.59	179.04	5	10.59	179.02
		0.014	0.072		0.016	0.072		0.017	0.086
2016.349	17	10.58	179.07	10	10.58	179.05	5	10.57	179.02
		0.019	0.058		0.022	0.061		0.018	0.072
2016.362	9	10.58	179.09	9	10.58	179.09	5	10.58	179.07
		0.013	0.102		0.013	0.102		0.012	0.132
2016.376	5	10.59	179.08	5	10.59	179.08	5	10.59	179.08
		0.004	0.095		0.004	0.095		0.004	0.095
μ Means		10.59	179.07		10.59	179.06		10.59	179.06
σ Means		0.005	0.013		0.005	0.017		0.009	0.026

night. As above, the data shows there would be very little change in accuracy or precision in reducing the number of images from twenty to five.

Also notice that even though the standard deviation of the means increases when using less images per night, the mean for both position angle and separation remain accurate. This would indicate good randomness of the data thus providing a high confidence in the mean values.

Conclusion

Comparison of the above results with the WDS catalog, for six stars, show similar position angle and separation, within the statistical variance of the mean. This indicates the methodology can be used for the measurement of other double stars with good confidence in the results. The remaining four stars show a difference in separation and position angle that is greater than the statistical variance of the data. This indicates a change in the astrometric data of the observed star system, requiring additional observations of these stars to confirm

the movement and rate of change.

A review of the methodology shows a more efficient use of the available telescope time can be achieved by reducing the number of images recorded each night and the number of observing nights. The methodology shall therefore be updated to record 5 images per night and 3 nights used to check for any systematic errors.

Given the success of this methodology, additional stars will now be measured and reported. The stars reported in this paper will be measured again next year to provide more data for determining the proper motion of the stars and possible confirmation of whether they are a physical system. In addition, photometric measurements of the stars will be added.

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

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