CCD Astrometry with Robotic Telescopes

Faisal AlZaben[1], Dewei Li[1], Yongyao Li[1], Aren Dennis[1],
Michael Fene[2], Grady Boyce[3], and Pat Boyce[3]

1. Army and Navy Academy, Carlsbad, California
2. University of California, Riverside
3. Boyce Research Initiatives and Educational Foundation

Abstract CCD images were acquired of three binary star systems: WDS06145+1148, WDS06206+1803, and WDS06224+2640. The astrometric solution, position angle, and separation of each system were calculated with MaximDL v6 and Mira Pro x64 software suites. The results were consistent with historical measurements in the Washington Double Star Catalog. Our analysis found some differences in measurements between single-shot color CCD cameras and traditional monochrome CCDs using a filter wheel.

Introduction

Students at the Army and Navy Academy in Carlsbad, California (Figure 1) selected three double star systems with separations ranging from approximately 20" to over 60" and with similar magnitudes. The separations and position angles of the systems (WDS06145+1148, WDS06206+1803, and WDS06224+2640) were measured and compared to historical values.

Figure 1: (left to right) Aren Dennis, Yongyao Li, Faisal AlZaben, and Dewei Li.

The iTelescope network was used to acquire CCD images through locations in New Mexico (Figure 2), Spain, and Australia (Figure 3). The astrometric analysis was performed using MaximDL and Mira Pro x64 software suite. Through the iTelescope system, we imaged WDS06145+1148 ten times, WDS06206+1803 five times, and WDS06224+2640 seven times with different scopes and filters.

Figure 2: The T3 Takahashi TOA-150 telescope in New Mexico.

Figure 3: The T27 Planewave 27" CDK in Australia.

Equipment and Procedures

We utilized four different telescope/camera combinations via the iTelescope network. Table 1 lists the telescopes, their locations, and CCD cameras. This diversity of image resolution and equipment allowed us to make comparative observations to enhance the credibility of our observations.

Location	Name	Telescope	CCD	Mount	Resolution	FOV
New Mexico (Elevation 7,500')	T3	***Takahashi TOA-150***	SBIG ST-8300C	Paramount GTS	1.02"/pixel	42.4' x 56.3'
	T11	***Planewave 20" CDK***	FLI ProLine	Planewave Ascension 200HR	0.81"/pixel	36.2' x 54.3'
Australia (Elevation 1,500')	T27	***Planewave 27" CDK***	FLI ProLine PL16803	Planewave Ascension 200HR	0.4"/pixel	27.4' x 27.4'
	T9	***RCOS 12.5"***	SBIG ST-10XME	Paramount PME	0.8"/ pixel	13.6' x 20.4'
Spain	T18	***Planewave 12"CDK***	KAF-6303E	Paramount PME	0.73"/ pixel	37.41'x 24.94'

Table 1. iTelescope Platforms used in the Army and Navy Academy's double star research.

Each observation/image was scheduled via the iTelescope internet portal where we designated celestial coordinates, image time, number of images, date and time to acquire the images, and the filter to be used. Images were calibrated with darks and flats by iTelescope and downloaded via an FTP server.

MaximDL was used to establish an astrometric plate solution for each image by locating a number of stars in the image and comparing their positions against the Fourth U.S. Naval Observatory CCD Astrograph Catalogue (UCAC4). Table 2 outlines the calibration data for each image. Each file was saved with the World Coordinate System (WCS) data of the solution loaded into the FITS header.

WDS	Tel.	Date	Filter	# UCAC4 Stars	RA/DEC	Camera Angle, Focal Length, Plate Scale
06145+1148	T9	3/14/2015	Red	438 of 828	RA 06h 14m 32.0s, Dec +11° 47' 49.3"	+359° 27.2', FL 2313.4 mm, 0.80"/Pixel
	T9	3/14/2015	Ha	274 of 828	RA 06h 14m 29.5s, Dec +11° 47' 50.6"	+359° 27.5', FL 2313.7 mm, 0.80"/Pixel
	T27	3/8/2014	Red	386 of 2217	RA 06h 14m 31.2s, Dec +11° 47' 48.3"	+359° 53.0' (R), FL 4532.4 mm, 0.55"/Pixel
	T27	3/8/2015	Ha	359 of 2217	RA 06h 14m 31.0s, Dec +11° 47' 49.2"	+359° 51.9' (R), FL 4532.3 mm, 0.55"/Pixel
06206+1803	T3	3/10/2015	Color	457 of 6878	RA 06h 20m 34.4s, Dec +18° 02' 55.6"	+04° 11.4', FL 1105.3 mm, 1.01"/Pixel
	T3	3/14/2015	Color	437 of 6878	RA 06h 20m 34.8s, Dec +18° 03' 03.1"	+04° 09.0', FL 1105.4 mm, 1.01"/Pixel
	T18	3/27/2015	Ha	151 of 2789	RA 06h 20m 34.6s, Dec +18° 02' 55.5"	+220° 20.0', FL 2546.2 mm, 0.73"/Pixel
	T18	3/27/2015	Ha	89 of 2789	RA 06h 20m 34.2s, Dec +18° 02' 53.8"	+220° 21.0', FL 2547.1 mm, 0.73"/Pixel
	T18	3/27/2015	Red	419 of 2789	RA 06h 20m 33.6s, Dec +18° 02' 50.6"	+220° 20.3', FL 2546.5 mm, 0.73"/Pixel
06224+2640	T3	3/14/2015	Color	432 of 7082	RA 06h 22m 25.2s, Dec +26° 40' 14.0"	+04° 09.9', FL 1105.3 mm, 1.01"/Pixel
	T3	3/27/2015	Color	276 of 7082	RA 06h 22m 37.0s, Dec +26° 42' 48.7"	+04° 11.4', FL 1105.2 mm, 1.01"/Pixel
	T18	3/27/2015	Ha	154 of 2853	RA 06h 22m 25.6s, Dec +26° 40' 06.9"	+220° 20.7', FL 2547.0 mm, 0.73"/Pixel

Table 2: MaximDL astrometric solution data for each double star image.

Each WCS calibrated image was then opened with Mira Pro x64 to determine an accurate position angle and separation of the double stars in each image. Each image was checked for saturation using Mira's mean column plot (Figure 4).

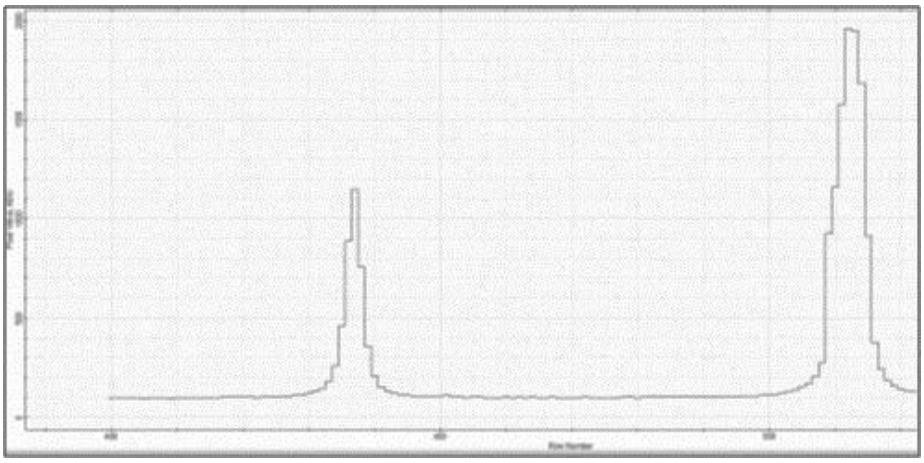

Figure 4: Mira Pro x64 mean column analysis.

The distance and angle function of Mira Pro was used to measure the position angle and separation of the double stars. When the first star is clicked on, Mira calculates the centroid of the star and synchronizes the start of the measurement from that point. Releasing the mouse button on the second star allowed Mira to locate the second star's centroid position and provide the desired measurement from these centroid positions. The process is illustrated in Figure 5 (below).

After completion of the position angle and separation measurements, the data was placed into an Excel spreadsheet to help determine the average, standard deviation, and standard error of the mean for each double star system. Once these were calculated, each image was compared to the Washington Double Star Catalog (WDS) values. The comparison highlighted an error in our initial measurements for WDS 06224+2640 indicating position angles 180° from the latest WDS published measurement. These stars have nearly identical apparent magnitudes, so it is easy to err in the measurement. Examination of the FITS files showed that the A and B components were swapped during the initial measurement. A 180° correction was made to these measurements

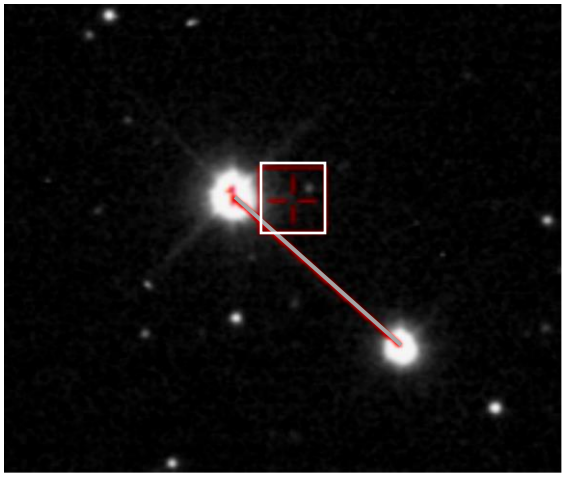

Figure 5: Position angle and separation measurements with Mira Pro x64.

Results

The results of the above process for each double star system are found in Table 3 (below). Table 3 shows anomalous data for two of the three stars. As noted in the tables, revised calculations were made to correct for these apparent errors. Table 4 outlines the first and last WDS measurements for the three double stars. Our 2015 measurement is included for comparison.

Discussion

Note B in Table 3 for WDS06224+2640 indicates a position angle measurement that is about 3° from the rest of the images taken. This image was acquired through telescope T3, a one-shot color system. Twelve days prior to this image, T3 took an image in line with those from T18 and T11. Therefore, it was concluded that there was an imaging error with the second T3 image. This measurement was removed from our analysis and the average, standard deviation, and standard error of the mean were recalculated (noted in the highlighted section). Calculating the data without the outlier made its standard deviation jump from 0.14 to 0.01. This demonstrates the high precision of the other six observations (Frey et al. 2010).

An even more substantial outlier was noted when analyzing the images from the T9 telescope for WDS 06145+1148. When this outlier was removed, as noted in Table 3, the resulting standard deviation dropped from 2.64° to 0.89° for the position angle and from 2.91" for separation to 0.13". Both measures were then much more consistent with the historical data.

The third star pair, 06206+1803, had greater standard deviations but no observations appeared to be outliers. Our observations of all three pairs are consistent with recent WDS data.

Conclusion

Our results show that some discrepancies can occur in data received from the same telescope/CCD combination, thus highlighting the value of repeated images of a particular target of interest. Both T3 and T9 contained an erroneous measurement that could be identified using other equipment. The students successfully measured the position angles and separations of three double stars.

Acknowledgements

We thank iTelescope for their service. We thank Russ Genet for allowing us this opportunity to do research and introducing our team to astronomy and double stars. Additionally, we thank the Boyce Research Initiatives and Educational Foundation (B.R.I.E.F.) for their generous financial donation that allowed us to use the iTelescope robotic telescope system.

Telescopes	
iTelescope #	(aperture in m location)
NM = New Mexico	
S = Spain	
A = Australia	

Filter codes	
R	optical red
red (A)	Astrodon red
Ha	hydrogen alpha

WDS 06224+2640

Epoch	Telescope	Exposure	Filter		Position Angle	Separation	Original	A
2015.200	T3 (.15 NM)	240 secs	color		348.081	18.016	168.081	
2015.233	T3 (.15 NM)	240	color		345.590	18.373	165.590	B
2015.236	T18 (.3 S)	180	Ha		348.644	18.011	168.644	
2015.249	T11 (.5 NM)	180	Ha		348.614	17.989	168.614	
2015.249	T11 (.5 NM)	180	Ha		348.642	18.002	168.642	
2015.249	T11 (.5 NM)	180	red (A)		348.721	17.983	168.721	
2015.249	T11 (.5 NM)	180	red (A)		348.761	17.997	168.761	
			Average		348.15	18.05		
			Standard Deviation		1.15	0.14		
			Std. Error of Mean		0.165	0.020		

Note A: The A and B stars were reversed. Added 180 degrees. A and B magnitudes are similar.

Note B: The T3 observation on 3/26/15 was inconsistent with the other measures.

Revised after removing outlier:		
Average	348.58	18.00
Standard Deviation	0.25	0.01
Std. Error of Mean	0.042	0.002

WDS 06206+1803

Epoch	Telescope	Exposure	Filter		Position Angle	Separation
2015.189	T3 (.15 NM)	240 secs	color		128.673	47.861
2015.200	T3 (.15 NM)	240	color		130.597	46.029
2015.236	T18 (.3 S)	180	Ha		129.376	47.047
2015.236	T18 (.3 S)	180	Ha		129.413	47.027
2015.236	T18 (.3 S)	180	R		127.656	47.464
			Average		129.14	47.09
			Standard Deviation		1.08	0.68
			Std. Error of Mean		0.216	0.137

WDS 06145+1148

Epoch	Telescope	Exposure	Filter		Position Angle	Separation	
2015.200	T9 (.3 A)	240 secs	R		304.452	81.8165	C
2015.200	T9 (.3 A)	240	Ha		311.540	90.3178	
2015.184	T27 (.7 A)	180	red (A)		314.157	90.7556	
2015.184	T27 (.7 A)	240	Ha		311.680	90.4789	
2015.236	T11 (.5 NM)	180	Ha		311.636	90.5533	
2015.236	T11 (.5 NM)	180	Ha		311.636	90.5533	
2015.236	T11 (.5 NM)	180	Ha		311.667	90.5159	
2015.236	T11 (.5 NM)	180	red (A)		311.683	90.6353	
2015.236	T11 (.5 NM)	180	Ha		311.641	90.5054	
			Average		311.12	89.57	
			Standard Deviation		2.64	2.91	
			Std. Error of Mean		0.293	0.323	

Note C: The first T9 observation on 3/14/15 was inconsistent with the other measures.

Revised after removing outlier:		
Average	311.96	90.54
Standard Deviation	0.89	0.13
Std. Error of Mean	0.111	0.016

Table 3: The average position angle and separation with standard deviation and standard error of mean for each double star system.

WDS Number	Observations			Position angle			Separation		
	WDS Catalog			WDS Catalog		*NEW*	WDS Catalog		*NEW*
	#	First	Last	First	Last	2015	First	Last	2015
06145+1148	27	1875	2012	310.1	312.0	312.0	89.53	91.3	90.54
06206+1803	22	1876	2007	127.4	129.3	129.14	47.51	46.91	47.09
06224+2640	30	1827	2006	350.0	348.7	348.58	20.0	18.27	18.00

Table 4: Comparison of historical WDS data to the present study.

References

Frey, Thomas G., Johnson, Jolyon M., Almich, Christopher J., and Genet, Russell M. 2010. Visual Double Star Measurements with Equatorial and Alt-Azimuth Telescopes. *Small Telescopes and Astronomical Research*. Eds Russell M. Genet, Jolyon M. Johnson, and Vera Wallen. Collins Foundation Press.

Mason, B. and Hartkopf, W. The Washington Double Star Catalog, March 2015. Astrometry Department, U.S. Naval Observatory. http://ad.usno.navy.mil/wds/wds.html.

Mason, B. and Hartkopf, W. USNO CCD Astrograph Catalog (UCAC), March 2011. Astrometry Department, U.S. Naval Observatory. http://www.usno.navy.mil/USNO/astrometry/optical-IR-prod/ucac.