Accepted for publication by the *Journal of Double Star Observations*

CCD DOUBLE STAR ASTROMETRY OF BINARY STARS WITH ROBOTIC TELESCOPES

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Abstract CCD images were acquired of three binary star systems using the iTelescope network. The astrometric solution, position angle, and separation were calculated with MaximDL v6 and Mira Pro x64 software suites. The results were consistent with historical measurements contained in the United States Naval Observatory Washington Double Star Catalog. Our analysis highlighted some differences in measurements between One Shot Color CCD cameras and traditional monochrome CCDs using a filter wheel.

Introduction

The Army and Navy Academy in Carlsbad, California, acquired a new suite of astronomy equipment in 2014 enabling new research capabilities not otherwise possible before. Our team's research goals were to utilize this new equipment in the imaging and measurement of various binary star systems, and compare these results against data obtained through the iTelescope network. We, in Figure 1, selected four candidate binary star systems with separations ranging from approximately 20" to over 60" with similar magnitudes in excess of ninth magnitude to avoid CCD blooming issues. We narrowed down our research to three double star systems from the Washington Double Star catalog from which to complete an astrometric analysis and comparison.

Figure 1. Aren Dennis, Yongyao Li, Faisal Al-Zaben, Dewei Li.

Due to the location of the Army and Navy Academy on the beach of Carlsbad, CA, our efforts to image with the Academy's telescopes were thwarted multiple times during March, 2015 due to fog and clouds. As a consequence we modified our plan and utilized the iTelescope network to acquire CCD images through telescopes located in New Mexico (Figure 2), and in Spain and Australia (Figure 3). This

change still enabled the goal of performing astrometric analysis with our MaximDL and Mira Pro x64 software suite.

Figure 2: T3 Takahashi TOA-150 New Mexico

Figure 3: T27 Planewave 27" CDK Australia

Through the iTelescope system, we imaged: WDS 06224+2640, WDS 06206+1803, and WDS 06145+1148, seven, five, and ten times, respectively, with different scopes and filters. We focused on obtaining astrometric calculations of theta (position angle) and rho (separation) of the double star systems for comparison to currently published data.

Equipment and Procedures

We utilized four different telescope/camera combinations via the iTelescope network in New Mexico, Australia, and Spain. Table 1 lists the telescopes, their locations, and CCD cameras. This diversity of location, image resolution, and imaging equipment allowed us to make comparative observations to enhance the credibility of our observations. The telescopes in New Mexico are located at a similar Latitude as ours in San Diego, while the Australia observations allowed a comparison from a different hemisphere.

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 Binary Star Research Program.

Each observation/image was scheduled via the iTelescope internet portal where we designated: RA & Dec coordinates, image time, number of images, date and time to acquire the image, and filter to be used. Once the images were acquired, the calibrated (darks and flats) were downloaded via an FTP server from iTelescope.

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 Astro-

graph Catalogue (UCAC4). Table 2 outlines the calibration data, matched stars, RA/Dec of the image, and Position Angle, Focal Length, and Plate Scale of each image. Once the astrometric calibration was complete, each file was saved with the World Coordinate System (WCS) data of the solution being loaded into the FITS header of each image.

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 Binary Star Image.

Each WCS calibrated image was then opened with Mirametrics software, Mira Pro x64, to determine an accurate positon angle and separation of the binary stars in each image. The first step was to analyze each image for saturation and quality using Mira's Mean Column plot seen in Figure 4.

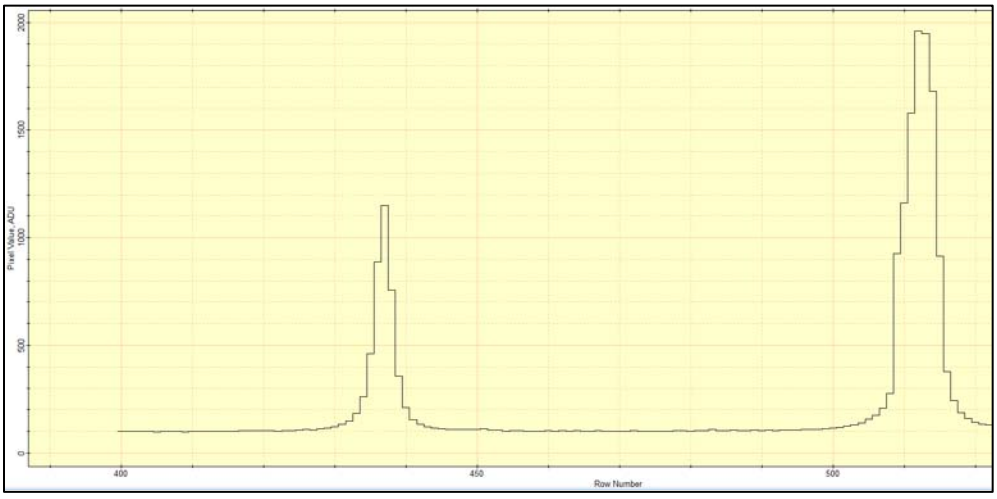

Figure 4: Mira Pro x64 Mean Column analysis.

Secondly, the point and click Distance & Angle function of Mira Pro was selected to measure the position angle and separation of the binary stars. When the first star is clicked upon, 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 that star's centroid position and provide the desired measurement from these centroid positions seen in Figure 5.

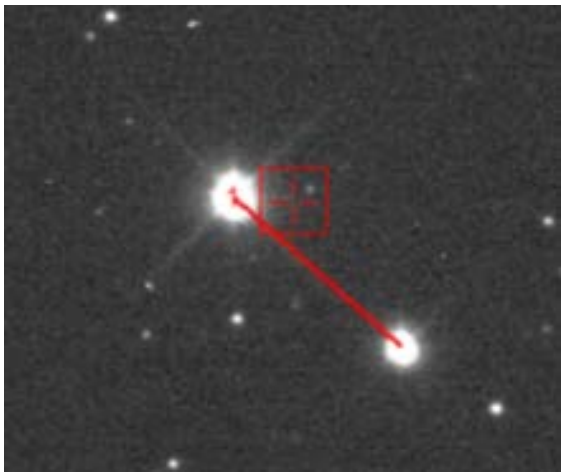

Figure 5: Position Angle and Separation measurements with Mira Pro x64.

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 binary star system. Once these were calculated, each image was compared to the Washington Double Star catalog (WDS) values. This comparison allowed us to characterize the performance of our processes to the historical data. 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 magnitude, so it is easy to err in the measurement. Examination of the FITS files showed that the A and B component were swapped during the initial measurement.

Results

The results of the above process for each binary star system are found in Table 3 below.

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: Position Angle, Separation, Average, Standard Deviation, and Standard Error of Mean for each Binary System imaged.

Table 4 outlines the WDS Catalog measurements for our three binary stars (first and last observations) and includes our 2015 measurements.

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 with new data from 2015.

Discussion

In an analysis of the data (Position Angle "θ" and Separation "ρ") received from our CCD images, there were some notable issues highlighted in Table 3 for two of the three stars. As noted in the tables, revised calculations were made to correct for these apparent errors.

WDS 06224+2640 contained two items that prompted further investigation. Note A highlights our initial discovery that the results were 180° from the latest WDS measurement. This prompted a review of our designation of the A and B stars, which upon that review were found to be reversed in the initial measurements. Adding 180° to the results revealed the expected measurements. Note B indicates a Position Angle measurement that is 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, a first image was taken with T3 and the results are 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 found the results were much more consistent, with its standard deviation jumping from 0.14 to 0.01, which demonstrates the high accuracy of the other six observations (Frey et al 2010).

An even more substantial outlier was noted when analyzing the images for WDS 06145+1148 from an image obtained from the T9 telescope. When this outlier was removed as noted in Table 3 from the data, 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 unusual. Analyzing the results for all three pairs against the published measurements of the United States Naval Observatory's (USNO) data showed that our data was very consistent.

Conclusion

The registered data was consistent with that of the USNO's, thereby confirming our data for all three binary star systems. Use of various telescopes and filters indicates that some discrepancies can occur on 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 and a measurement that was validated by other telescope/CCD systems. In total, however, the other measurements show considerable consistency regardless of location and telescope used.

Acknowledgements

We thank iTelescope for their service. We also thank Mirametrics for Mira's reduction capabilities and helping us with our project. We would like to thank Russ Genet for allowing us this opportunity to do research and introducing our team to astronomy and binary stars. Additionally, we thank the Boyce Re-

search Initiatives and Educational Foundation (B.R.I.E.F.) for their generous financial donation that allowed us to use the iTelescope robotic telescope system.

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