Measuring Double Stars with a Canon DSLR Camera

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Abstract: 76 target pairs were measured from August 17, 2017 to January 6, 2018 using an 8-inch Schmidt-Cassegrain telescope and a Canon EOS 600D DSLR camera. Some aspects of precision and the accuracy of the method were also tested.

Introduction

I started in 2017 the photographic observation and measurement of double stars. The goal of the project was to establish a routine procedure suitable to result in reliable measurements. This was my first observing project, therefore the selected target objects were brighter pairs with low magnitude differences, which were easier to find. Another factor was a newer entry in the Washington Visual Double Star Catalog (WDS) to obtain reference values for evaluating the accuracy of the method. Fainter companions in the selected systems and further systems found on the images were also measured.

Equipment and methods

The measurements were made with an 8-inch Celestron Schmidt-Cassegrain telescope equipped with a monochrome Canon EOS 600D DSLR camera on a Skywatcher HEQ-5 Pro GoTo mount. A 50 mm guidescope with an ASI120 MC camera was used for locating target objects and guiding the imaging sequence.

The designed image sequence for each target consists of ten ("light") images for measurement at ISO 100, with an exposure time set based on the brightness of the target (typically 5-10 sec, without saturating the target object), two images at ISO 800 with 60 sec exposure time for identifying star field and for calibrating plate scale (one before and one after the light images) and one image at ISO 100 with star trails (60 sec or 120 sec exposure time, turned off tracking).

Both ISO 800/60 sec images were used for determination of the plate scale from an astrometric solution with the software *astrometry.net*. The average of the

obtained plate scale values was used for measuring target pairs. The field orientation was determined with trail analysis option of the *REDUC* software. All star trails found on the image were measured and averaged before further use. Plate scale and field orientation were determined separately for each image series to avoid errors caused by accidental shift of the camera.

Target objects were identified on the plate-solved images with the software *AstroImageJ* and *Simbad*. *Simbad* and *VizieR* were used to get WDS Catalog entries. Further systems in the FOV were searched with *Stelle Doppie*.

The measurement of target pairs was made with the *REDUC* software using the average calibration coefficients from plate solution and trail analysis. After removing the outliers the mean of the separation and position angle and both standard deviations were reported.

Results

21 independent image series were made on eight different nights. Five series were made without a trail image. In these images only the separation was measured. There were two series with overexposed trail images. In the case of these image series the field orientation was calculated by the astrometry software that was used for measuring the plate scale.

Plate scale was determined with the astrometry software *astrometry.net*. Astrometric solution yielded a well reproducible plate scale. The overall average of measured plate scales is 0.44749 ± 0.00013 arcsec/pixel ($\alpha = .05$, $n = 68$).

The main method for determination of the field orientation was the trail analysis method with *REDUC*. 3 to 9 star trails were found and measured on the corre-

Measuring Double Stars with a Canon DSLR Camera

sponding images. The repeatability of the trail analysis was suitable: the average standard deviation of field orientation within an image was 0.09 ± 0.03 degrees (α = .05, n = 16), the maximum standard deviation was 0.29 degrees. The average field orientation values slightly changed between image series within a day: a difference of 0.01 degrees was found on 23-Aug-2017 (n = 2), 0.58 degrees on 28-Aug-2017 (n = 4) and 0.40 degrees on 30-Sep-2017 (n = 6).

Field orientation was also determined with the software *astrometry.net*. The average standard deviation of field orientation between the 2 images made for astrometry within an image series was 0.03 ± 0.03 degrees (α = .05, n = 23), the maximum standard deviation was 0.39 degrees. A slight change between imaging series within a day was also found. The differences were 0.33 (n = 3), 0.13 (n = 2), 0.66 (n = 4), 0.38 (n = 2), 0.45 (n = 6) and 0.16 (n = 3) degrees.

The field orientation determined with the trail analysis method was compared with the results obtained with the astrometric method, when both values were available. The obtained results are listed in the Table 1.

The average of differences is -0.002 ± 0.063 degrees (α = .05, n = 16). The result of the single sample t-test shows that the difference is not significantly different from 0 (α = .05, t = -0.05019, p = 0.96063).

STF 2470 (WDS 19088+3446) and STF 2474 + WAL 105 (WDS 19091+3436), which can be found in

Table 1: Comparison of field orientation angles obtained with different methods

Date	Trail analysis		Astrometric plate solution		Difference
	Count	Rotation angle	Count	Rotation angle	
2017.08.23	6	82.64	2	82.45	0.19
2017.08.23	9	82.65	2	82.58	0.08
2017.08.26	4	78.96	2	78.78	0.17
2017.08.28	8	79.01	2	79.05	-0.04
2017.08.28	5	79.06	2	78.98	0.08
2017.08.28	5	78.97	2	79.04	-0.07
2017.08.28	5	78.48	2	78.39	0.09
2017.09.07	3	79.98	2	79.84	0.14
2017.09.30	6	78.55	2	78.64	-0.09
2017.09.30	7	78.18	2	78.19	-0.01
2017.09.30	6	78.15	2	78.21	-0.06
2017.09.30	6	78.19	2	78.32	-0.14
2017.09.30	5	78.17	2	78.37	-0.20
2017.09.30	4	78.21	2	78.31	-0.10
2017.11.14	9	8.28	3	8.23	0.05
2018.01.06	9	9.76	2	9.86	-0.10

the same FOV, were used to evaluate the precision of the measurement procedure. Six image series were separately made and independent measured. The standard deviations of the independent measurements within a day and between days were calculated as shown in Table 2 and Table 3.

Table 2: Precision as standard deviation of 3 independent measurements made on 1 night

	STF 2470 AB			STF 2474 AB			WAL 105 AC		
	PA	Sep.	Count	PA	Sep.	Count	PA	Sep.	Count
2017.08.28	267.63	13.79	9	264.68	16.35	5	125.50	96.97	5
2017.08.28	266.78	13.84	9	264.27	16.08	8	125.48	97.22	9
2017.08.28	266.52	13.87	9	264.64	16.16	10	125.51	97.21	10
Count	–	–	27	–	–	23	–	–	24
Mean	266.98	13.83	–	264.53	16.20	–	125.49	97.13	–
SD	0.58	0.04	–	0.23	0.14	–	0.01	0.14	–
RSD%	0.22	0.28	–	0.09	0.87	–	0.01	0.15	–

Table 3: Precision as standard deviation of 6 independent measurements made on 4 different nights

	STF 2470 AB			STF 2474 AB			WAL 105 AC		
	PA	Sep.	Count	PA	Sep.	Count	PA	Sep.	Count
2017.08.23	267.43	13.62	8	262.93	15.72	9	125.41	98.08	8
2017.08.26	267.25	13.68	10	263.35	15.83	10	125.41	97.75	9
2017.08.28	267.63	13.79	9	264.68	16.35	5	125.50	96.97	5
2017.08.28	266.78	13.84	9	264.27	16.08	8	125.48	97.22	9
2017.08.28	266.52	13.87	9	264.64	16.16	10	125.51	97.21	10
2017.09.07	267.93	13.79	10	262.98	15.78	8	125.48	98.19	1
Count	–	–	55	–	–	50	–	–	42
Mean	267.26	13.77	–	263.81	15.99	–	125.46	97.57	–
SD	0.53	0.09	–	0.82	0.25	–	0.04	0.51	–
RSD%	0.20	0.69	–	0.31	1.56	–	0.03	0.52	–

Measuring Double Stars with a Canon DSLR Camera

STF 1169 AB (WDS 08165+7930) and STF 485 AE (WDS 04078+6220) were selected from the list of calibration pairs published by *Mauroy et al.* (2007) to evaluate the accuracy of the used method. The results are listed in Table 4. The measured and the reported values in the WDS and in the list of calibration pairs are consistent. STF 1169 AB is listed in the Sixth Catalog of Orbits of Visual Binary Stars. The calculated PA differs from all other data, therefore further investigation was carried out. PA and separation were calculated from RA and DEC (which were calculated after plate solving of stacked image) with the method described by *Smolinski* and *Osborn* (2006) and with the small angle approximation described by *Buchheim* (2008). A new image sequence was also made to repeat the measurement.

Measurements of 76 target pairs have been completed from 17-Aug-2017 to 06-Jan-2018 and are given in Table 5. In 3 cases the target was not visible in the single images, only in the stacked image. In these cases only the stacked images were measured without reporting SD. For the other pairs the single images in each image series were measured and 5 to 12 values were averaged after rejecting of outliers (in some cases the stacked image was also included in the measurement). If more independent image series (on the same night or on different days) of a target pair were made, the series were independently evaluated, the measured values were averaged, and the overall average and standard deviation were reported.

(Text continues on page 192)

Table 4: Results of calibration pair measurements

Discoverer Designation	Method	Sep	PA
STF 1169 AB	REDUC (14-Nov-2017, 19 images)	20.7	15.3
	Calculation (Ver. 1)	20.84	14.95
	Calculation (Ver. 2)	20.84	14.95
	REDUC (10-Feb-2018, 12 images)	20.7	14.9
	WDS (2005)	20.8	15
	Morlet-32	20.76	14.62
	Calculated orbit	20.501	16.5
STF 485 AE	REDUC (14-Nov-2017, 11 images)	17.9	304.9
	WDS (2016)	18	306
	Morlet-32	17.91	304.62

Table 5. Results of measured double stars

WDS coordinate	Discoverer designation	Component	D	S	Position angle in degrees			Separation in arcsecs			Obs. Date (Besselian year)
					N	Mean	SD	N	Mean	SD	
04067+6221	CTT 7	AB	1	1	10	216.3	0.09	10	44.0	0.04	2017.87246641
04078+6220	FYM 353	AS	1	1	1	261.7	–	1	20.1	–	2017.87246602
04078+6220	HLM 3	LM	1	1	8	216.5	0.82	8	5.8	0.19	2017.87246651
04078+6220	HZG 2	AN	1	1	11	205.9	0.05	11	115.9	0.08	2017.87246602
04078+6220	HZG 2	IJ	1	1	6	352.5	0.42	6	60.4	0.19	2017.87246638
04078+6220	HZG 2	IR	1	1	9	155.8	0.38	9	60.4	0.23	2017.87246612
04078+6220	HZG 2	LO	1	1	10	92.3	0.10	10	42.4	0.13	2017.87246572
04078+6220	HZG 2	OP	1	1	11	228.7	0.42	11	17.2	0.10	2017.87246602
04078+6220	STF 484	AG	1	1	10	260.2	0.06	10	59.9	0.14	2017.87246572
04078+6220	STF 484	AH	1	1	11	255.8	0.19	11	56.6	0.21	2017.87246602
04078+6220	STF 484	AI	1	1	10	278.8	0.14	10	69.4	0.12	2017.87246615
04078+6220	STF 484	EH	1	1	9	239.3	0.29	9	46.9	0.09	2017.87246545
04078+6220	STF 484	EI	1	1	9	270.3	0.11	9	53.7	0.08	2017.87246573
04078+6220	STF 484	GH	1	1	7	131.9	0.43	7	5.6	0.08	2017.87246565
04078+6220	STF 484	GI	1	1	10	335.6	0.20	10	22.7	0.08	2017.87246641
04078+6220	STF 484	HI	1	1	11	331.1	0.21	11	27.7	0.22	2017.87246602
04078+6220	STF 485	AC	1	1	10	0.6	0.76	10	11.0	0.12	2017.87246637
04078+6220	STF 485	AD	1	1	8	131.9	0.86	8	14.9	0.25	2017.87246564
04078+6220	STF 485	AE	1	1	11	304.9	0.11	11	17.9	0.03	2017.87246602
04078+6220	STF 485	AF	1	1	11	320.0	0.28	11	36.1	0.09	2017.87246602

Table 5 continues on the next page.

Measuring Double Stars with a Canon DSLR Camera

Table 5 (continued). Results of measured double stars

WDS coordinate	Discoverer designation	Component	D	S	Position angle in degrees			Separation in arcsecs			Obs. Date (Besselian year)
					N	Mean	SD	N	Mean	SD	
04078+6220	STF 485	AL	1	1	11	71.4	0.05	11	98.1	0.15	2017.87246602
04078+6220	STF 485	AO	1	1	9	77.6	0.06	9	138.4	0.10	2017.87246525
04078+6220	STF 485	EC	1	1	10	87.2	0.27	10	14.8	0.15	2017.87246623
04078+6220	STF 485	EF	1	1	9	333.9	0.46	9	19.3	0.08	2017.87246602
04078+6220	STF 485	EG	1	1	9	245.3	0.14	9	48.9	0.09	2017.87246631
04078+6220	WSI 20	AQ	1	1	11	324.5	0.33	11	45.4	0.13	2017.87246602
04078+6220	WSI 20	EQ	1	1	8	336.6	0.38	8	29.2	0.09	2017.87246597
04078+6220	WSI 20	FQ	1	1	7	341.7	0.45	7	9.9	0.20	2017.87246614
05353−0523	STF 748	AB	1	1	7	31.4	1.28	7	8.9	0.45	2018.01735127
05353−0523	STF 748	AC	1	1	8	132.1	0.08	8	12.8	0.07	2018.01735202
05353−0523	STF 748	AD	1	1	9	96.5	0.22	9	21.4	0.05	2018.01735206
05353−0523	STF 748	BC	1	1	5	164.0	0.91	5	16.8	0.41	2018.01735250
05353−0523	STF 748	BD	1	1	5	120.5	0.90	5	19.3	0.27	2018.01735250
05353−0523	STF 748	CD	1	1	7	61.9	0.09	7	13.3	0.04	2018.01735201
05354−0525	STFA 16	AB	1	1	9	93.4	0.11	9	52.2	0.04	2018.01735172
05354−0525	STFA 16	AC	1	1	10	98.3	0.10	10	128.5	0.13	2018.01735216
05354−0525	STFA 16	BC	1	1	10	101.8	0.12	10	76.6	0.12	2018.01735226
05354−0525	STFA 17	AD	1	1	9	314.7	0.04	9	134.4	0.11	2018.01735247
08165+7930	PKO 21	AC	1	2	19	124.2	0.09	19	66.0	0.13	2017.87239442
08165+7930	STF 1169	AB	1	2	19	15.3	0.17	19	20.7	0.09	2017.87239280
12056+6848	STF 1599	AC	1	1	5	331.9	0.12	5	108.4	0.15	2017.65922069
12056+6848	STF 1599	AD	1	1	7	85.9	0.21	7	125.6	0.09	2017.65922563
12056+6848	STF 1599	AE	1	1	5	181.9	0.07	5	125.3	0.16	2017.65922711
12056+6848	WAL 60	AF	1	1	5	109.0	0.45	5	142.5	0.09	2017.65922756
12071+6905	STF 1602	AB	1	1	8	179.5	0.28	8	21.1	0.08	2017.65922501
12071+6905	STF 1602	AC	1	1	7	314.7	0.08	7	153.8	0.08	2017.65922448
13239+5456	SMR 4	AD	1	1	8	101.8	0.03	8	492.8	0.20	2017.74921144
13239+5456	STF 1744	AB	1	1	8	153.3	0.53	8	14.4	0.12	2017.74921112
13239+5456	STF 1744	AC	1	1	8	71.5	0.03	8	707.7	0.37	2017.74921031
14065+7058	HJ 2703	AB	1	1	0	−	−	9	12.7	0.03	2017.68631900
15173+7113	H 5 86	AB	1	1	0	−	−	9	50.2	0.07	2017.68627416
15173+7113	H 5 86	AC	1	1	0	−	−	10	95.1	0.09	2017.68627398
17322+5511	STFA 35	AB	1	1	0	−	−	12	62.2	0.08	2017.62908759
18032+2522	BU 825	AB	1	1	8	185.2	0.36	8	16.8	0.08	2017.74925625
18032+2522	BU 825	BC	1	1	7	231.1	0.65	7	9.6	0.07	2017.74925644
18032+2522	STF 2268	AC	1	1	9	201.6	0.11	9	24.5	0.05	2017.74925634
18035+2515	HLM 10	AB	1	1	8	1.7	0.24	8	30.0	0.15	2017.74925585
18130+2815	H 5 93	AB	1	1	10	135.8	0.05	10	54.8	0.05	2017.74929218
18292+2933	HO 434	AB	1	1	6	184.0	0.98	6	18.6	0.08	2017.74932957
18292+2955	STF 2327	AB	1	1	10	314.4	0.16	10	19.5	0.08	2017.74933159
18295+2955	WAL 91	AC	1	1	7	351.5	0.15	7	53.9	0.14	2017.74933216
18295+2959	KU 118	AB	1	1	10	323.2	0.05	10	50.4	0.04	2017.74933159
18309+3840	STF 2338	AB	1	1	10	300.6	0.24	10	12.1	0.07	2017.74937578
18309+3840	STF 2338	AC	1	1	10	206.2	0.04	10	76.4	0.05	2017.74937578

Table 5 concludes on the next page.

Measuring Double Stars with a Canon DSLR Camera

Table 5 (conclusion). Results of measured double stars

WDS coordinate	Discoverer designation	Component	D	S	Position angle in degrees			Separation in arcsecs			Obs. Date (Besselian year)
					N	Mean	SD	N	Mean	SD	
18309+3840	STF 2338	AE	1	1	9	153.9	0.15	9	51.7	0.05	2017.74937525
18309+3840	STF 2338	CD	1	1	1	243.1	–	1	13.0	–	2017.74937578
18309+3840	STF 2338	CE	1	1	8	68.6	0.09	8	60.7	0.09	2017.74937540
18329+3850	STTA 171	AB	1	1	9	327.9	0.03	9	150.1	0.07	2017.74940641
18329+3850	STTA 171	AG	1	1	8	133.1	0.17	8	80.7	0.10	2017.74940597
19037+1658	STF 2442	AB	1	1	10	209.2	0.56	10	10.0	0.06	2017.64548159
19088+3446	STF 2470	AB	4	6	55	267.3	0.54	55	13.8	0.12	2017.66104349
19091+3436	STF 2474	AB	4	6	50	263.8	0.94	50	16.0	0.23	2017.65988534
19091+3436	WAL 105	AC	4	6	41	125.5	0.10	41	97.5	0.40	2017.65519962
19464+3344	STF 2580	AB	1	1	0	–	–	10	26.1	0.09	2017.62912233
19464+3344	STF 2580	AC	1	1	0	–	–	5	107.1	0.08	2017.62912130
21069+3845	STF 2758	AB	1	1	0	–	–	8	31.6	0.08	2017.62917198

D: number of nights image were taken

S: number of independent evaluated image series

N: number of evaluated images

Conclusions

Based on the obtained results, the calibration of plate scale with the astrometric method and the calibration of field orientation with both methods provide good results. The repeatability of the measuring procedure is also adequate. The average standard deviation of the separation measurements was 0.112 ± 0.016 arcsecs ($\alpha = .05$, $n = 90$) and 0.28 ± 0.06 degrees ($\alpha = .05$, $n = 83$) for position angle measurements. From this experience, a stricter selection of raw images (e.g. distorted star shape) and selecting fainter target objects, which allow longer exposure times, could improve the performance of the method further.

Acknowledgments

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