Visual Double Star Measurements with an Alt-Azimuth Telescope

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Abstract: An alt-az mounted Newtonian telescope was used to determine the separation and position angle of seven known and five neglected double stars. The problem of field rotation was solved by modifying the usual observing technique. Separation and position angle determinations are described, and the standard deviations and mean errors for these measurements are presented. The direction of future studies is outlined.

Introduction

Professional astronomers have carried out visual double star measurements for over 200 years. These scientists measured the separation between double stars in arc seconds, and the position angle in degrees that defined the orientation of pairs with respect to celestial north. Over time, the orbital motion of each star can create a change in the observed separation and position angle if the pair proves to be binary in nature. A binary star revolves around a common center of mass.

Today's amateur astronomers continue to evaluate these changes with fairly simple equipment. The usual recommended setup includes an equatorial mounted telescope with tracking motors, a laser-etched astrometric eyepiece, and a stopwatch.

This study, however, utilizes an altitude-azimuth (alt-az) mounted telescope instead of an equatorial mounted telescope. Alt-az mounts are seldom used in double star measurements due to the rotation observed in the field of view. This motion can affect both the accuracy and precision of the measurement of the position angle. Yet, with minor adjustments made at regular intervals during the observing session, both separation and position angle measurements made on known double stars correlate closely to literature values. Once it was determined that the measuring techniques were accurate and precise, additional measurements on neglected double stars listed in the Washington Double Star Catalogue were made.

Double Star Observation: Equatorial vs. Alt-Az Mounts

Most observers involved in double star measurements, including Argyle (p.*x*) and Teague (p.112), recommend the use of equatorial mounted telescopes. Such telescopes have drive motors that are oriented so the right ascension axis rotates around the north celestial pole, canceling out the Earth's rotation and the image in the eyepiece remains stationary.

The equatorial telescope can be equipped with an illuminated reticle eyepiece such as the 12.5 mm Celestron Micro Guide or the 12 mm Meade astrometric eyepiece. Both eyepieces have similar configurations: a linear scale in the middle and a 360° protractor scale around the circumference of the field of the eyepiece. The linear scales are divided into 60 and 50 equal divisions on the Celestron and Meade eyepieces, respectively. Sometimes an external protractor scale is mounted to the base of the eyepiece to more accurately measure the position angles, as described by Tanguay (p.116) and Johnson and Genet (p.147).

Separation between double stars is determined by using the slow motion control of the equatorial telescope to align the pair on the linear scale. Then estimate the number of divisions on the scale between the centers of the stars to the nearest tenth. The number of arc seconds represented by each scale division is previously determined by using either the drift method with a star of known celestial coordinates, or calibration double stars alone, that have had no change in separation in 50 years.

Position angles are measured again by using a slow motion control, this time to move the primary star to the center of the linear scale. The eyepiece is rotated until the secondary star is also on the linear scale. The drive motors are turned off and the pair drifts across the field of view until the primary reaches the protractor scale at the outer edge of the field. The drive motors are re-engaged and the position angle is indicated by the position of the primary star on the protractor scale.

The axis of a telescope attached to an alt-az mount rotates about the zenith, not the celestial pole like an equatorial mount. Even if the alt-az telescope is equipped with drive motors, stars in the field of view rotate around objects in the center of the field. The closer a celestial object is to the zenith, the faster the rotation in the field. This rotation makes any type of imaging (astrophotography or CCD imaging) problematic. It also can affect double star measurements, especially position angle determination. Field rotation can be compensated for by using a de-rotator attached to the eyepiece focuser, but this requires an additional motor and adds additional complexity and expense to the instrumentation.

Argyle (p. 286) and Napier-Munn (p. 22) both point out that the rate of field rotation observed in alt-az mounted telescopes is greatest at the zenith and zero when a star crosses the prime vertical, that is, when the star is due east or due west. As a result, initial double star measurements were conducted in an easterly direction and between altitudes of about 20-80°.

It will be shown in this study that if simple adjustments are made to the reticle eyepiece of an alt-az telescope during double star data collecting, excellent results can be achieved in separation and position angle measurements that closely agree with data obtained with traditional equatorial telescopes.

Equipment Used

The telescope used in this research was an Obsession f/4.5 18-inch Newtonian telescope with a Dobsonian (or alt-az) mount. It was equipped with a ServoCAT tracking and GOTO system made by StellarCAT. This system is controlled with a Wildcat Argo Navis computer. The Meade 12.5 mm astrometric eyepiece was used for all double star measurements. A RadioShack LCD Stopwatch with 0.01 second resolution was used to calibrate the linear scale of the Meade eyepiece.

The observation sessions were held in San Luis Obispo, CA and Atascadero, CA. San Luis Obispo is located at latitude 35°16’ N, altitude 360 feet, in an area where light pollution is extensive and an evening marine layer limits the time of effective seeing. Atascadero is located approximately 15 miles north of San Luis Obispo at 35°30’N, altitude 1050 feet, in an area of limited light pollution and no marine layer.

Calibration of the Meade Astrometric Eyepiece

The linear scale of the reticle eyepiece must be calibrated to the telescope being used. To determine the number of arc seconds per division, Argyle (p. 152) recommends using a star of medium brightness (magnitude 5-6) with a declination of 60-75° and allowing it to pass along the length of the linear scale. This is carefully timed to the nearest 0.01 seconds. To reduce random errors in the process, 8-10 different drift times were recorded and the average determined.

The average drift time is used in the following equation:

$$Z = \frac{15.0411 T_{avg} \cos(\delta_{RS})}{D}$$

where Z is the scale constant in arc seconds per division, T_{avg} is the average drift time of the reference star across the scale in seconds, 15.0411 is the sidereal motion in arc seconds per second of Earth’s rotation, $\cos(\delta_{RS})$ is the cosine of the declination of the reference star, and D is 50, the number of divisions for the Meade eyepiece

Both Alpha Cephei (Alderamin) and Gamma Cassiopeiae (Navi) were used as calibration stars, depending on the time of the year the observations were conducted. Typical examples of the calibrations are indicted in Table 1. The units for the scale constant are arc seconds per division (a.s./div).

Procedure for Measuring Separation

After determining the scale constant for the Meade astrometric eyepiece, the telescope was two-star aligned and the tracking motors engaged. The primary star was centered in the eyepiece and the

Star	Bess. Epoch	Dec. (°)	# Obs.	Av Drift Time(sec)	Std. Dev.	Mean Error	Scale Constant (a.s/div)
α Cephei	B2007.618	62.58	16	88.17	0.283	0.071	12.21
γ Cass	B2007.769	63.67	12	83.49	0.280	0.081	12.22

Table 1: Determination of the scale constant

eyepiece rotated so that both stars were co-aligned on the linear scale. The number of divisions between the stars was noted and estimated to the nearest 0.1 division. The slow motion control on the ServoCAT was then used to move the double star along the scale to a new location and another reading recorded. This was done to reduce the random error in assigning the number of divisions. Usually, no fewer than 10 readings were recorded and the average number of divisions calculated. The separation in arc seconds was calculated by multiplying the scale constant, Z, by the average number of divisions between the double stars.

Procedure for Measuring Position Angle

Initial Attempts

Initial position angle measurements mimicked procedures used with equatorial mounted telescopes. The slow motion controls were used to center the primary, or brightest, star of the double star on the center mark of the linear scale, i.e. on the 25th division. Due to the presence of backlash, this was tedious, frustrating, and not always successful. Then the eyepiece was rotated, ensuring the stars were aligned on the linear scale. This sometimes resulted in having to re-center the primary star. If successful alignment was achieved, the servo-motors were disengaged and the double star allowed to drift to the edge of the eyepiece. As the primary crossed the outer protractor scale, the position angle was noted and recorded.

The eyepiece was rotated 180° to prevent random errors of alignment. Then the procedure of two-star alignment was repeated using the Argo Navis computer, the primary star centered in the eyepiece, the secondary star aligned on the linear scale, and the motors disengaged. This procedure was time consuming, especially the centering of the primary star. It was tempting to use an off-centered primary that was "close enough", which would have resulted in an erroneous position angle. It was necessary to find another technique of accurately centering the primary star.

Final Procedure Adopted

Instead of doing repetitive two-star alignments with the Argo Navis computer after every position angle measurement, the tracking motors were disengaged after the separation measurements were conducted. This allowed manual movement of the telescope. The eyepiece was rotated until the double stars were aligned on the linear scale. Then the telescope was moved so that the primary star accurately drifted through the central division mark. In practice, the primary was situated about 5-8 division marks away from the central mark and allowed to drift. If the star drifted through the central mark, the drift sequence was allowed to continue until the primary star passed across the outer protractor scale, and the angle recorded. If it missed the central mark, the scope was moved and another pass was attempted. This was much more successful and efficient than the former method. Also, after the position angle was recorded, the telescope was moved immediately until the star was repositioned in the center of the field of view.

The reticle eyepiece was rotated 180° after every other drift measurement to allow constant realignment of the double stars with linear scale. Of course 180° had to be subtracted from half of the measurements so correct position angles were evaluated. This eyepiece rotation cancelled random errors that could have occurred if the eyepiece had been left in a single orientation.

The majority of the known and neglected double stars selected for this study had separations greater than 34 arc seconds. Only one double star, Eta Casseopeiae, with an observed separation of 12.8 arc seconds, was included, since this was one of the initial trials performed. It was determined that any separation spanning less than 3 divisions on the linear scale made it very difficult to align the stars for position angle drift. If double stars with separations less than about 30 arc-seconds were to be studied, a Barlow lens should be employed. Indeed, Napier-Munn (p.25) found the use of a Barlow problematical except with

		Separation(arc seconds)					Position Angle(degrees)					
Double Star	Bess. Epoch	# Obs.	SD/ME	Obs. Sep.	Lit. Sep.	ΔSep.	# Obs.	SD/ME	Obs. PA	Lit. PA	ΔPA	Lit. Epoch
Pi And	B2007.670	5	0.04/0.02	36.9	36.4	+0.5	9	1.31/0.44	171.4	175	-3.6	WDS2006
Eta Cas	B2007.673	4	0.06/0.03	12.8	12.9	-0.1	4	1.93/0.97	315.6	319	-3.4	WDS2005

Table 2: Separation and Position Angle for Pi Andromedae and Eta Cassiopeiae

separations of 3 divisions or less on the reticle. All observations in this study used just the Meade astrometric eyepiece alone.

Results and Analysis of Observations

Known Double Stars

Table 2. lists the results obtained for the two initial double stars studied. These observations were performed in San Luis Obispo, CA. Due to a lingering marine layer and light pollution in the city, only bright double stars were investigated. Pi Andromedae, m_1:m_2, 4.3:7.1, and Eta Cassiopeiae, m_1:m_2, 3.5:7.4, were appropriate initial studies, except for the fairly small separation for Eta Cassiopeia. The observed separation and position angle are listed with their corresponding standard deviations (SD) and mean errors (ME). The columns headed ΔSep and ΔPA indicates the differences between the observed and literature values for separation and position angle, respectively.

The telescope was moved farther from the effects of coastal fog and light pollution of San Luis Obispo 15 miles north to higher elevation and drier, darker skies in Atascadero, CA at Hill House Observatory. Longer observation sessions with steadier skies were possible due to this move. Five additional known double stars were measured at this location. Table 3 lists the results of the separation and position angle (PA) measurements, along with the standard deviations (SD) and mean errors (ME) for the number of observations recorded.

The values for separation and position angle obtained in the current study for Mu Herculis and STF 698AB closely compare to other recent observations. See Tables 4 and 5.

Neglected Double Stars

Five neglected double stars were measured at Hill House Observatory. Table 6 lists the results of the separation and position angle measurements, respectively, along with their statistical evaluations.

Conclusions

The purpose of this study was to attempt separation and position angle measurements of known and neglected double stars with an alt-az mounted telescope. Prior investigations strongly recommended equatorial mounted telescopes be used for such studies due to the field rotation observed in alt-az mounted telescopes. It was suggested that separation measurements could be easily and accurately performed using the ServoCAT/Argo Navis control system with an alt-az telescope.

Initial position angle measurements were attempted by using the handpad controls on the ServoCAT/Argo Navis system to center the primary star, but the jerky backlash that occurred made it difficult and frustrating to try to center the primary star on

			Separation(arc seconds)				Position Angle(degrees)				
Double Star	Identifer	Bess. Epoch	# Obs.	SD/ME	Obs. Sep.	Lit. Sep.	# Obs.	SD/ME	Obs. PA	Lit. PA	Lit. Epoch
Tau Tau	04422+2257	B2007.769	8	0.05/0.02	62.7	63.0	10	1.11/0.35	213.2	214	WDS1999
Mu Her	17465+2743	B2007.771	10	0.19/0.06	34.9	34.9	13	2.79/0.77	248.2	249	WDS2000
Beta Cam	05034+6027	B2007.793	18	0.10/0.02	85.3	83.0	13	0.92/0.26	208.3	210	WDS2003
STF 698AB	05252+3451	B2007.769	8	0.18/0.06	31.2	31.2	14	1.50/0.40	349.8	347	WDS2004
FRK 11	22301+4921	B2007.793	9	0.11/0.04	67.2	66.4	10	1.23/0.39	91.8	91	WDS1998

Table 3: Separation and Position Angle for Five Known Double Stars

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Year	Separation	Position Angle	Source
1973	35.00″	248.0°	Comellas
1980	35.00″	249.0°	Comellas
1987	32.00″	247.0°	Schnabel
2007	34.9″	248.2°	Frey

Table 4: Separation and Position Angle for Mu Herculis since 1973

Year	Separation	Position Angle	Source
1970	31.00″	346.0°	Comellas
1980	31.00″	346.0″	Comellas
1994	29.30″	348.0°	Rojo
2007	31.2″	349.8°	Frey

Table 5: Separation and position angle for STF 698AB since 1970

the middle division of the linear scale of the reticle eyepiece. When the servo-motors were disengaged and the primary star manually moved into a position where the star could drift through the center division, accurate and precise position angles could be repeatedly recorded.

To verify that alt-az mounted telescopes could be used to make accurate measurements on double stars, seven double stars with known fixed separations and position angles were observed and compared to literature values. The differences in separation and position angles (DSep and DPA, respectively) and the percent differences between the observed and literature values for five of the seven known double stars studied are given in Table 7. Negative values indicate the observed value was less than the literature value; positive values indicate a greater value than literature.

The low values shown in Table 7 indicate that the observed values for separation and position angles are very close to the literature values demonstrating that alt-az mounted telescopes can be used for accurate and precise measurements of double stars. The larger values for difference and % difference for Beta Cam may be explained by sky conditions. The double star was observed in the evening at the low altitude of 16° and it was windy.

Five neglected double stars were then observed. The differences and percent difference between observed and literature values for these double stars are given in Table 8. Negative values indicate the observed value was less than the literature value; positive values indicate a greater value than literature.

Again, the low percent differences for most of the neglected double stars in Table 8 demonstrate the accuracy of the alt-az system. It should be noted that percent differences for BUP 91AC and STT 23AC separations are prominently larger than the other neglected double stars studied. The reason for this difference was pointed out by Dave Arnold (personal communication). Arnold stated that BUP 91AC and STT 23AC are both composed of multiple star systems. For STT 23 the A and B components are in common proper motion but the C component is a background star having no physical connection to A and B. So the difference in separation between A and C in the current study (50.1”) to that observed in 1909 (56.97”) is due to proper motion from component A,

			Separation(arc seconds)				Position Angle(degrees)				
Double Star	Identifer	Bess. Epoch	# Obs	SD/ME	Obs. Sep.	Lit. Sep.	# Obs.	SD/ME	Obs. PA	Lit. PA	Lit. Epoch
BU 492AC	00453+5513	B2007.834	10	0.16/0.05	89.1	88.6	13	0.81/0.22	24.7	26°	WDS2000
BUP 91AC	06377+6129	B2007.840	10	0.16/0.05	393.1	379.9	12	0.58/0.17	91.7	94°	WDS1929
STF 10AC	00148+6250	B2007.840	11	0.13/0.04	55.9	55.7	10	0.26/0.08	102.3	101°	WDS2000
STT 23AC	01101+5145	B2007.840	10	0.24/0.07	57.0	50.1	12	1.08/0.31	92.2	94°	WDS1909
STF 70AC	00538+5242	B2007.848	11	0.07/0.02	73.5	75.3	12	0.83/0.24	154.0	151°	WDS1985

Table 6: Separation and Position Angle Measurements for Five Neglected Double Stars

Double Star	D Sep (arc secs)	Sep % Difference	D PA (degrees)	PA % Difference
Tau Tau	-0.3	-0.48	-0.8	-0.37
Mu Her	0	0	-0.8	-0.32
Beta Cam	2.3	2.73	-1.7	-0.81
STF 698AB	0	0	2.8	0.80
FRK 11	0.8	1.20	0.8	0.88
Average	0.56	0.69	0.06	0.03

Table 7: Differences and % Differences between Observed and Literature Values for Separation and Position Angles of Five Known Double Stars

not by orbital motion.

He also states that BUP 91AC form an optical double star, because the proper motion vectors of these stars diverge. The values of the A component are -208 mas/yr (milliarc seconds/ year) in right ascension and -275 mas/yr in declination. The values for the C component are +8 and -25 mas/yr, respectively. Again, this was due to the proper motion of component A compared to the background star, C.

Standard deviation and mean error analysis for drift times across the linear scale, estimated divisions between the double stars, and drift positions measured on the protractor were calculated. These statistics, summarized in Table 9, were used in determining the scale constants, separations, and position angles (PAs), respectively. Except for an elevated standard deviation value for the position angle of the known stars, all other statistics have very low values, indicating a fairly precise series of observations.

The larger standard deviations for the position angles of the known double stars are probably the results of the author's initial inexperience in making these measurements. The drift method used for position angle measurement took quite a bit of practice to position the telescope so the primary star drifted through the exact center of the eyepiece. Initial attempts were slightly off the mark. Also, as the primary star drifted across the field of view and crossed the outer protractor scale, a parallax was observed. Different values of the position angle were detected depending on how you looked through the eyepiece. It took several sessions before I knew exactly where to position my eye to get precise results.

New Directions with an Alt-Az Telescope

At Hill House Observatory, the lower limit of visual perception was estimated to be magnitude 12. Such stars could only be seen using averted vision. This was most challenging when position angle measurements were attempted. The star would "disappear" behind the main line of the linear scale. To visualize the star, one had to look about 5-8 division marks above or below the linear scale and estimate the corresponding measurement. Two ways of solving this problem come to mind.

First, although Hill House was excellent for double star observation for magnitude 10 and less, a darker site would improve the ability of seeing these very faint stars. There was still some light pollution from the city lights of Atascadero.

Second, use of the Celestron Micro Guide eyepiece instead of the Meade astrometric eyepiece is suggested. The Celestron model has two parallel lines running the length of the linear scale instead of just the single line on the Meade model. Faint stars would be more visible between the two lines than behind or on a single line.

The light generated by the illuminated reticle can also prevent the detection of faint stars. The eyepiece has an adjustable switch that can vary the amount of illumination desired. But it can only be dimmed to a certain level. This minimum intensity may still interfere with seeing faint stars. This problem can be solved by purposely using weak batteries or by placing a piece of aluminum foil between the battery and the

Double Star	D Sep (arc secs)	Sep % Difference	D PA (degrees)	PA % Difference
BU 492AC	0.5	0.56	-1.3	-5.13
BUP 91AC	13.2	3.42	-2.3	-2.48
STF 10AC	0.2	0.36	1.3	1.28
STT 23AC	6.9	12.89	-1.8	-1.93
STF 70AC	-1.8	-2.42	3.0	1.97
Average	3.8	2.96	-0.22	-1.26

Table 8: Differences and % Differences between Observed and Literature Values for Separation and Position Angles of Five Neglected Double Stars

Double Star Type	SD for all separations	SD for all PAs	ME for all separations	ME for all PAs
Known	<0.20	<2.80	<0.07	<1.00
Neglected	<0.25	<1.10	<0.08	<0.32

Table 9: Standard Deviation (SD) and Mean Error (ME) Trends for Separation and Position Angle Measurements Determined for Known and Neglected Double Stars.

electrical contact on the battery case. Both methods will reduce the illumination of the reticle eyepiece.

Double stars with separations greater than 30" were chosen for the current paper. It is difficult to get repeatedly accurate alignment of the double stars on the linear scale for position angle measurements of less than three divisions. To measure double stars with smaller separations than 30", a Barlow lens should be employed. A 2x or 5x Barlow will magnify the separation and make division estimates easier. However, if the seeing is marginal, as it often is in coastal regions, the Barlow will magnify the seeing problems as well. Such studies should be done at dark sky sites when the sky is very steady.

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