Reaching Magnitude +16 with the Modified Video Drift Method

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Abstract: The video drift method of measuring double stars is a quick and efficient way to obtain position angle and separation measurements. With ordinary video cameras magnitude +12 and deeper double star systems often prove difficult or even impossible to measure without using an image intensifier. A simple modification to the video drift method and corresponding *VidPro* analysis program now makes reaching magnitude +16 a reality for modest amateur equipment.

Introduction

In our previous reports using the video drift method (Nugent and Iverson, 2011 - 2015), we have reported position angle and separation measurements obtained with our respective 14-inch (35 cm) Meade LX-200 Schmidt-Cassegrain telescopes and other, smaller aperture, telescopes. Author Nugent, using a non integrating *Watec 902H2 Ultimate* video camera fitted with a Collins I^3 image intensifier, has measured double stars down to magnitude +15.6 (Nugent and Iverson, 2014). This was accomplished in relatively dry air at his west Texas observatory. Unfortunately the Collins I^3 image intensifier is no longer being manufactured. Author Iverson measures double stars with a cooled variation of the Astrovid *Stella Cam 3* video camera (equivalent to the *Watec 120N+* camera) which can co-add (stack) video frames within the camera (integration). Co-adding 2 frames is the equivalent of doubling the exposure, co-adding 4 frames equates to quadrupling the exposure, and so on. Longer exposure times (with the telescope motor drive on, no drifting) allow reaching fainter stars unattainable with conventional non-integrating video cameras.

Although the Stella Cam 3 video camera is capable of virtually unlimited user-defined integration periods, hardware-defined integration periods extend up to 8.4 seconds (256 frames). Nugent and Iverson (2012) suggested that integration periods longer than 0.198 seconds (using a Stella Cam EX camera) are impractical with the original video drift method. As the integration time increases, the stars drift in increasingly longer jumps which eventually lead to smearing/streaking of the star images, making them unsuitable for measurement. The freeware program *Limovie* (Miyashita, 2006), used to measure the stars' (x,y) position in each video frame, has a difficult time following the longer jumps. When the program cannot keep up it begins to report inaccurate (x,y) coordinate positions and then it eventually loses the ability to track the stars. Due to this limitation and the humid, unstable air over his east Texas observatory, author Iverson has been unable to routinely measure doubles fainter than +12 magnitude.

While investigating the *Reduc* double star analysis program (Losse, 2011) and the combined *Reduc/VidPro* methodology used by Wasson (2014), it was realized that a few simple changes to the video drift method and a corresponding change to the *VidPro* double star analysis program would significantly increase the depth at which ordinary integrating cameras could measure double stars. These changes include (1) recording the double star at an integration level long enough to allow dim components to be easily seen while the telescope mount is tracking and (2) recording several drifts (no tracking) of a bright nearby star at the same declination to determine the scale factor and drift angle.

Methodology

In this study we used our respective equatorial mounted 14-inch (35 cm) Schmidt-Cassegrain telescopes and video recording equipment used in our previous papers (Nugent and Iverson, 2011-2015). At the beginning of an observing session, the video camera's chip was adjusted parallel to the approximate true east-west direction by trial and error rotation of the camera and slewing the telescope. Once aligned, the camera alignment was not changed. The *VidPro* program compensates for any remaining offset from true east-west. Data was only recorded when the target double star was within one hour of the meridian.

The modified video drift method records video when the telescope is tracking the double star (motor drive on) and when the double star is allowed to drift (motor drive off) across the field of view (FOV). The procedure for recording the necessary video is as follows:

1) Locate the target double star and center it in the video camera's FOV.

2) Choose a camera integration level and gain setting where the secondary star is visible but not saturated. Saturating the primary star is usually unavoidable, but this is not a problem as long as the secondary star doesn't merge with the primary.

3) With the telescope motor drive on, record up to 2.5 minutes of video. The stars may move slightly depending on the telescope balance, the telescope mounts ability to track the night sky, and/or accuracy of the polar alignment. This slight movement does not affect the results. Stop the recording.

4) Adjust the integration time to less than 0.132 seconds. Slew the telescope over to the nearest bright star that closely matches the target's declination (see below). If the primary star is visible then use it.

5) Resume recording and position this star at the eastern edge of the FOV. Turn the telescope motor drive off and allow this star to drift across the entire FOV. Repeat this east to west drift at least 3 or 4 times on this same recording. Now stop recording.

By recording a bright star drifting across the FOV, the video drift method and modified video drift method avoid using calibration (also known as reference or standard) doubles that some investigators rely on. Calibration doubles are believed to have stable position angle and separations over long periods, thus they provide a reference coordinate system frame for making new position angle and separation measurements for new targets. If the calibration double position angles and separations have not been updated or have significant errors, then these errors will propagate to the new targets being measured. The modified video drift method described here is completely self-calibrating thus no calibration/reference doubles are needed.

Measurement and Reduction

Once the video is obtained, it's analyzed in two stages. First, the video drifts are analyzed using the freeware programs *Limovie* and *VidPro* as previously described (Nugent and Iverson, 2011-2015) with one exception. It is important that both *Limovie* aperture rings are placed on the drifting star. Since only a single star is used during these drift videos, the *VidPro* program position angle and separation output cells will show meaningless results. This is not an issue since at this stage we are only interested in calculating the scale factor and camera offset from east to west (drift angle). The averaged result for both quantities will be manually entered into *VidPro* again during the second step of the reduction.

The second step uses *Limovie* and *VidPro* again but this time to reduce the tracking video file. *Limovie's* aperture rings are placed over the primary and secondary stars. Recall the target double star was not drifting, so the aperture rings will remain essentially stationary (see step 3 above). Because the stars are not drifting across the FOV, *VidPro* cannot calculate the scale factor or drift angle in this situation. The previously determined scale factor and drift angle from the first step are manually inserted into a modified version of *VidPro*. As before, *Limovie* creates a CSV file of (x,y) coordinates for the centroid of each star covered by an aperture ring for each video frame. The CSV file size should be limited to less than 5000 frames or about 2.5 minutes of video. This file is also manually copied into *VidPro*. When *VidPro* has all 3 inputs (scale factor, drift angle, and the CSV file), it automatically calculates the position angle and separation along with standard deviations.

The acquisition of the videos using this method takes a bit longer than the original drift method due to the extra time needed to make the tracking video. The level of integration used will significantly influence the amount of tracking data recorded. This is because as integration time increases, fewer new images are available in a given time interval. A camera integrating at sixteen frames outputs a new image approximately every 0.5 second at the NTSC video frame rate. At 128 frames, a new image will be output approximately every 4.2 seconds. The duplicate images do not affect the final result.

In order to prove that there is no significant difference in the results obtained from the conventional *VidPro* procedures and the modified *VidPro* procedures, 20 well studied double star systems were selected. Both the primary and secondary star needed to be bright enough to allow drift scanning with either no integration or, if used, then less than 0.132 seconds of integration. Each system was first processed using the traditional video drift method (Nugent and Iverson, 2011). The scale factor and drift angle measurements obtained were then averaged for each double star. Next, each double star was reprocessed using the modified video drift method (steps 1-5 above). The averaged scale factor and drift angle measurements obtained from the traditional analysis were inserted into a modified version of the *VidPro* designed for use with tracking data.

Ordinary drift scans are essential for *VidPro* to determine the scale factor and the offset of the camera's video chip from the true east west direction. If a replacement star is used then its declination should be close to the primary star's declination. From Equation 1, below, the cosine of the declination is used in determining the scale factor (Nugent and Iverson, 2011).

$$scalefactor = \frac{(drifttime)15.041068\cos(dec)}{\sqrt{(x_B - x_E)^2 + (y_B - y_E)^2}} \qquad (1)$$

x_B, y_B, x_E, y_E are the beginning and endpoints of the drift, and "dec" is the declination of the primary star or its substitute. *Drifttime*, in seconds, is defined by the number of frames (*x*,*y* pairs) divided by the camera frame rate. The National Television Standards Committee (NTSC) frame rate is 29.97 frames per second which we round to 30 for convenience.

Reaching fainter double stars with a common integrating video camera is significantly enhanced by using the *AviSynth* "Level" filter (http://avisynth.nl/index.php/Levels). It is a one line addition to the *AviSynth* script (Appendix I) used by *Limovie* to open the video file. This filter can be used to adjust the brightness, contrast, and gamma of the video clip (Appendix II).

In cases where observations were made over multiple nights or more than one observation was obtained in a single night, the position angle and separation values were merged using weighted averaging (Nugent and Iverson, 2013). The scale factor and drift angle measurements from multiple drifts were merged as a simple average. All references to stellar magnitudes have been copied from the online WDS summary catalogue.

Table 3 was compiled using the online WDS summary catalogue. It is intended to be only a rough estimate of the total number of double stars visible from the southern United States over the course of a year. The stars included covered a region of the night sky between 90° north and -30°south declination. Any entry in the WDS catalogue lacking a companion star magnitude was not considered. Double stars with a separation less than 5 arc seconds are probably not measurable by the modified video drift method and have been excluded from the table. Most of the southern hemisphere double stars were also excluded from consideration. Percentages were calculated based on a total of 59,590 double stars visible over the course of a year.

Results

As an initial test of the modified *VidPro* method, a number of doubles were picked at random from the doubles measured as part of our ongoing double star measurement program. The results from both the modified video drift method (tracking) and original video drifting method for these double stars are given in Table 1. The column titled *PA° tracking–drifting* presents the difference between the position angle results obtained by the two methods. The difference in position angle did not deviate by more than 0.1 degrees over the 20 examples. This is insignificant considering the online WDS summary catalogue gives the position angle to the nearest whole degree. The measured separations also varied by an insignificant amount. For the 20 doubles investigated, the separation did not vary by more than 0.04 arc seconds. Again, the WDS summary catalogue reports separation to the nearest tenth of an arc second. The WDS observational data base includes the known measurements for a double star. It typically reports precisions up to 2 decimal places for the position angle and 3 decimal places for the separation. Entries in this data base just mirror the precision reported by other authors in the literature using a variety of methods.

The standard deviations from the tracking data analysis have been included in Table 1. The standard deviations from the drift analysis are not presented, but they are similar to the values reported in our previous papers.

The next step was to determine the faintest double star that could be measured reliably. Table 2 reports position angle and separation measurements obtained

Table 1. Results of double star measurements using both the Video Drift Method and the Modified Video Drift Method.

WDS	Discover	PA° Track-ing	std. dev. Track-ing	PA° Drift-ing	PA° Track - Drift	Ave Sep" Track-ing	std. dev. Track-ing	Avg Sep" Drift-ing	Sep" Track - Drift	Date	No. Track-ing (x,y) pairs	Mag. Pri.	Mag. Sec.	No. Obs. Tracking	No. Obs. Drifting	No. Nights
00407-0421	HJ 323	285.5	0.30	285.5	0.0	62.84	0.34	62.81	0.03	2014.805	1953	6.01	8.46	1	4	1
14575-2125	H N 28AB	305.6	0.57	305.7	-0.1	25.68	0.28	25.65	0.03	2014.479	1348	5.88	8.18	2	2	1
15041+0530	STF1904	347.9	1.11	347.8	0.1	9.97	0.21	9.96	0.01	2014.479	1408	7.19	7.37	2	2	1
15127+1917	STF1919	10.3	0.48	10.2	0.1	23.06	0.21	23.07	-0.01	2014.479	1338	6.71	7.38	2	2	1
15145-1826	SHJ 195	139.8	0.28	139.8	0.0	46.77	0.27	46.79	-0.02	2014.479	1242	6.79	8.32	2	2	1
15187+1026	STF1931AB	166.5	0.80	166.5	0.0	13.17	0.21	13.18	-0.01	2014.479	1004	7.20	8.07	2	2	1
15201+2937	ENG 53	342.3	0.08	342.3	0.0	142.16	0.19	142.13	0.03	2014.499	3539	5.62	10.46	3	6	1
15202+3042	STF1935	289.0	1.16	289.1	-0.1	8.56	0.15	8.56	0.00	2014.499	5502	9.91	10.19	3	6	1
15282-0921	SHJ 202AB	132.2	0.23	132.2	0.0	52.06	0.24	52.06	0.00	2014.479	1089	6.95	7.61	2	2	1
15288+3101	A 1369AC	258.8	0.17	258.8	0.0	73.31	0.18	73.32	-0.01	2014.499	4113	10.66	10.48	3	6	1
15387-0847	STF1962	189.3	0.82	189.5	-0.1	11.60	0.20	11.60	0.00	2014.479	1079	6.44	6.49	2	2	1
15591-1956	SHJ 213	317.4	0.75	317.4	0.0	17.34	0.25	17.37	-0.03	2014.479	1153	8.11	8.50	2	2	1
16044-1127	STF1999AB	98.4	0.93	98.4	0.0	11.83	0.20	11.83	0.00	2014.479	1159	7.52	8.05	2	2	1
16060+1319	STF2007AB	321.5	0.32	321.5	0.0	38.33	0.23	38.29	0.04	2014.479	1088	6.89	7.98	2	2	1
16401+3038	LAU 3	262.6	0.13	262.6	0.0	80.01	0.16	79.99	0.02	2014.499	4846	9.86	10.52	3	6	1
16457+3000	STF2098AB	144.9	0.78	144.8	0.1	14.17	0.18	14.18	-0.01	2014.499	5588	8.77	9.61	3	6	1
16457+3000	STF2098AC	128.1	0.17	128.1	0.0	65.58	0.18	65.58	0.00	2014.499	5497	8.77	8.81	3	6	1
16534+2925	HEI 13	121.3	1.39	121.2	0.1	7.70	0.18	7.67	0.03	2014.499	5558	10.07	10.24	3	6	1
21576+1157	STTA227	32.6	0.24	32.6	0.0	77.94	0.33	77.96	-0.02	2014.805	1660	7.51	9.03	1	4	1
22451-0240	STF2938A, BC	341.8	0.94	341.8	0.0	19.82	0.36	19.81	0.01	2014.805	1393	9.41	9.55	1	4	1

for 22 doubles where the companion star is too dim or both the primary and companion star are too dim to be measured by the original video drift method. Three of these doubles were observed on multiple nights. The faintest double measured (01325+1417 LDS 1102) has a primary /secondary magnitude of +11.1/+16.9. Since measurements have only been made in the relatively humid, unstable air of east Texas, it is reasonable to expect that even fainter doubles can be measured in a dryer environment with better seeing.

Only 3 of the double stars studied were measured within in the last 5 years and most were measured 15 years ago or longer. Position angle and separation measurements obtained using the modified video drift method (Table 2) in general varied very little from their last historical measurements. In only 4 instances did the position angle change by more than one degree. The average change was 0.66 degrees. Only one double star (01325+1417 LDS 1102) showed a significant change (3.1 degrees). Inspection of the WDS historical data base suggested that this was not unreasonable given the high proper motions of the components. All 22 double stars studied showed very little change in separation from their historical measurements. The maximum change was 0.9 arc seconds while the average change was 0.30 arc seconds. The USNO CCD Astrographic Catalogue project (Hartkopf, W., *et al.*, 2013) derived position angle and separation measurements from the UCAC4 catalogue for 20 of the 22 doubles in Table 2. Inspection of the WDS historical database revealed that in all but 5 cases the most recent measurement was derived from either the 2 MASS catalogue (4 doubles) or the UCAC4 catalogue (13 doubles). The close agreement with the UCAC4 measurements sug-

Table 2. The results of 22 double stars using the Modified Video Drift method and long integration periods. These double stars were too dim to be measured by the original video drift method author Iverson's east Texas observatory.

WDS	Discover	PA°	std. dev.	Ave Sep"	std. dev.	Date	No. of Tracking (x,y) pairs	Mag. Pri.	Mag. Sec.	No. Obs.	Nights
00506-0121	HJ 1998	330.1	0.91	20.7	0.33	2014.871	1970	11.41	14.59	1	1
01285+0940	UC 561	236.6	0.78	18.4	0.31	2014.896	4528	11.50	15.50	1	1
01295-1120	UC 564	236.2	0.45	30.8	0.28	2014.951	7080	10.20	16.30	2	1
01298+0510	BAL2594	220.6	2.09	10.9	0.35	2014.929	6520	10.44	12.20	2	1
01324-0930	LDS2204	238.1	0.86	17.7	0.26	2014.929	8332	10.20	14.50	2	1
01325+1417	LDS1102	2.4	1.32	9.6	0.42	2014.951	4820	11.10	16.90	1	1
01567-0754	LDS5358	97.7	0.32	69.1	0.45	2014.948	4848	13.82	16.26	1	1
02354-0228	GWP 341	99.6	0.40	51.3	0.48	2014.951	4680	8.50	16.30	1	1
02444+1057	PLQ 35AB	315.3	0.82	24.6	0.34	2014.929	9718	11.20	15.20	2	1
02444+1057	SKF 20AC	107.7	0.78	20.7	0.31	2014.929	9924	11.20	15.30	2	1
02444+1057	SKF 20BC	122.8	0.49	43.9	0.43	2014.929	9866	15.20	15.30	2	1
02550-0029	MMA 33	337.1	0.49	17.7	0.20	2014.896	8002	12.00	15.40	2	1
03353+1725	GWP 483	88.4	0.40	23.6	0.19	2014.805	14204	11.50	15.30	3	2
04042+2416	POU 371AB	163.3	1.41	9.6	0.22	2014.948	9396	11.60	14.10	2	1
04042+2416	POU 372AC	227.5	0.68	20.9	0.20	2014.948	9399	13.01	16.25	2	1
04076+2322	POU 402	198.0	0.77	16.0	0.19	2014.805	12106	12.82	15.96	3	2
05136+2304	POU 590	330.7	0.61	11.8	0.15	2014.805	16631	13.30	15.50	4	2
05166-1048	GWP 665	117.2	0.30	49.7	0.27	2014.948	9651	11.52	16.12	2	1
06053+1838	GWP 737	333.1	0.34	46.9	0.25	2014.948	9534	10.60	16.11	2	1
22073-0002	BAL 934	337.7	1.06	14.4	0.29	2014.871	2046	10.84	12.03	1	1
22114+0057	BAL1240	274.4	1.62	10.1	0.32	2014.871	1664	11.89	12.02	1	1
23292+0049	HJ 3195	99.3	1.01	14.9	0.30	2014.871	2043	11.63	12.31	1	1

gest the modified video drift method is a useful method for studying faint double stars.

As demonstrated previously (Nugent and Iverson, 2015), the value for both the position angle and separation can be considerably in error based on the trend line formed by plotting the previously reported values. Considering the double stars in Table 2, the most frequently observed system has only 7 previous measurements. The majority of the double stars have less than 5 measurements. Graphical trend line analysis is not very meaningful in this situation.

Table 3 illustrates the increased accessibility of potentially measureable doubles that a southern United States observer might have using the modified video drift method. Using the limits established for author Iverson's observatory as an example, on a night with average seeing (magnitude +11), it is estimated that about 29 percent of the available double stars could be measured. On a night with good seeing (magnitude +12), this number increases to about 46 percent. However, using the modified video drift method, over 87 percent of the double star systems listed in the WDS

Table 3. The estimated number, by magnitude, and the relative percentage of double stars from 90° north down to -30° south declination. This estimate was compiled using the WDS online summary catalogue. See text for an explanation.

Magnitude	Number of Double Stars < magnitude	Percent of total
18.99	57225	96.0
17.99	54917	92.2
16.99	52248	87.7
15.99	48727	81.8
14.99	43590	73.1
13.99	36997	62.1
12.99	27582	46.3
11.99	17017	28.6
10.99	8495	14.3
9.99	3580	6.0

catalog should be within reach. Considerations such as locating the double star at its published coordinates, camera sensitivity to a star's spectral type, and the very slow drift rates at high declinations will limit the actual number of double stars that can be studied with a video camera.

Conclusions

We have demonstrated that with a 14-inch telescope, the position angle and separation of double stars down to at least magnitude +16 can be easily measured using the modified video drift method. It is a reasonable assumption that smaller telescopes might see a 3-4 magnitude gain and a corresponding increase in the number of double star systems that can be reached. Both the video drift method and modified video drift method are fast and efficient tools. Traditional CCD cameras which are often very expensive are no longer the only tool capable of measuring dim double star systems. With an integrating video camera, the time involved to collect and analyze the data can be a bit more involved, especially when working at fainter magnitudes. Unfortunately the Stella Cam 3 is now out of production but the principles presented apply equally to other integrating camera brands.

The Image Source line of video cameras may prove useful in double star work. Although they lack the high sensitivity normally found in an astronomical video camera, they are capable of very long exposure times and reduced output frame rates. Additional changes to the modified video drift method may be needed to accommodate these cameras. This type of camera offers two important advantages. First, unlike analog video cameras, the CCD chip uses square pixels, and second, the video signal is digitized inside the camera instead of an external frame grabber. The result is that an aspect correction does not need to be applied to make the recorded image closely match the night sky (Nugent and Iverson, 2014).

Acknowledgements

This research makes use of the Washington Double Star Catalog maintained at the US Naval Observatory.

Appendix I

The *AviSynth* script is used to define the aspect ratio and set the image brightness. See Nugent and Iverson (2015) for an explanation of why the aspect ratio needs to be adjusted to fit the observed night sky for each system.

```
##########################################################
#
#   AviSyth script used by Limovie to open a video file.
#
##########################################################

ClipMain = ("insert the video file path")
DirectShowSource(ClipMain)

LanczosResize(640,480)   #sets the image size used by
                         #Limovie to 640x480.  Adjust this
                         #value to match the observed sky.

Noise =25     #below this pixel value will be pure black
              #(the noise floor)

IH = 60       #above this pixel value will be pure white

Levels(Noise,1,IH,0,255-Noise,coring=false)

##########################################################
```

Appendix II

The *AviSynth* "Level" filter is used to adjust the brightness, contrast and gamma of the video clip. See the web page: http://avisynth.nl/index.php/Levels for a complete description.

The *AviSynth* script file syntax is:

Levels(I_L,G, I_H, O_L, O_H, coring)

I_L is the input pixel value that will be set to black and I_H is the input pixel value that will be set to white.

Gamma (G) controls the degree of nonlinearity in the conversion and should be set to 1 for black and white cameras. Making gamma less than 1 will brighten dim stars but it also has the negative effect of increasing the background noise. O_L is the output pixel value that will be set to black and O_H is the output pixel value that will be set to white. Increasing the input-low parameter (I_L) effectively raises the noise floor and increases contrast. This reduces the amount of noise seen in the *Limovie* 3D window. Settings up to 30 were common in our analysis. The input-high parameter (I_H) essentially acts as an inverse gain control. As the value decreases from 255, fainter star images become brighter and therefore easier for *Limovie* to follow. Settings as low as 50 were used. Changing the output pixel settings reduces the dynamic gray scale range of the image and should be avoided.

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