

## BASIC WEBCAM PHOTOMETRY

As a relatively new variable star observer (VSO), I hope the following detailed discussion of my limited experience thus far will give other amateur astronomers cause to try photometry with their webcams. I would be equally happy to elicit suggestions or constructive criticism from experienced VSO's.

Inspired by a web article (<http://sus.univ.szczecin.pl/~ecliptic/vesta3en.htm>) posted by G. Koralewski on the use of a Vesta webcam to generate photometric light curves for variable stars, I decided in Dec 2004 to try it myself with a SAC-7 CCD camera. (<http://www.cloudynights.com/astrophotography/SAC-intro.htm>). This modified webcam based on a Sony "HAD" chip is a 24-bit one-shot color imager (640x480) capable of performing long exposures, a feature necessary to capture faint stars.

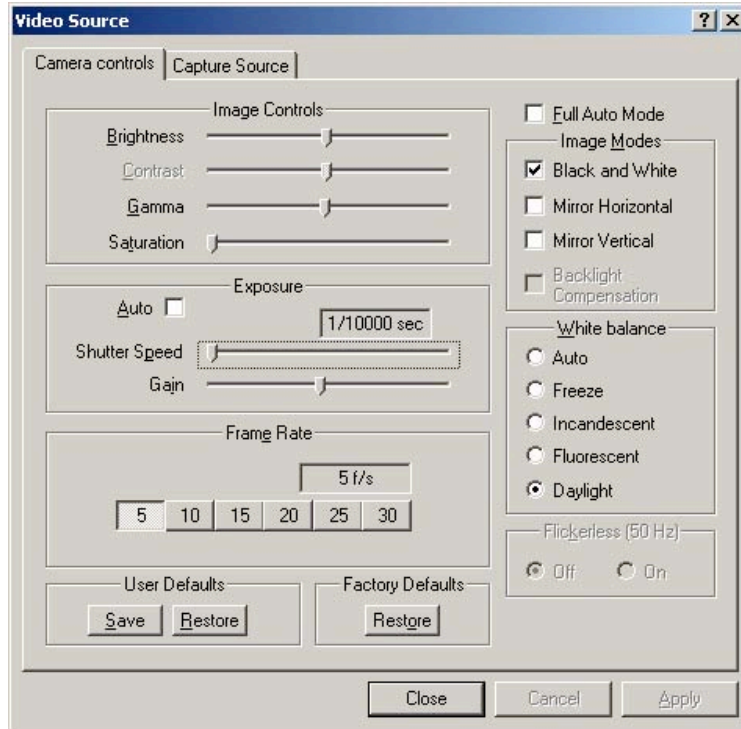
My setup for photometric imaging includes the following:

1. TV-76 mounted on Nexstar 8 GPS (EQ wedge) with Losmandy dovetail plate
2. SAC-7 operated in B&W mode (8 bit)
3. PC image acquisition with AstroVideo V3.1.9
4. Photometric data reduction with AIP4WIN V1.4.24
5. RegiStar V1.0.7 used to confirm star field against reference images
6. Celestron 9mm Plossl parfocalized to approximate SAC-7 FOV
7. 12 mm illuminated reticle (polar drift alignment)

The theoretical field-of-view (FOV) realized through the TV-76/SAC-7 combo is 19.3 x 25.7 arcmin with an image scale of 2.41 arcsec/pixel. In practice, this setup conveniently matches the actual FOV (within 10 mm of the target variable star) found in AAVSO finder charts scaled between 10" and 20"/mm. With very good seeing conditions, the limiting magnitude for unfiltered (clear) photometric determinations approaches 14.5. A larger aperture than 76mm would improve the upper limit of detection, however, not without creating a new set of problems particularly when my primary objective was to operate unguided and produce lightcurves by differential photometry. Differential photometry, which is relatively insensitive to air mass and many other deleterious effects, requires that the targeted variable and at least two reference stars (comparison and check stars) appear in the same image. For example with an 8"/f10 SCT, the FOV is a much smaller 4.5 x 6.1 arcmin and very few or no reference stars would likely be visible in the same image. Secondly, due to fairly severe and unfortunately uncorrectable (Celestron are you listening) periodic error, the Nexstar 8 GPS is not particularly adept at unguided tracking for longer than 15 seconds. It is, however, an excellent computerized GoTo platform which saves valuable imaging time while locating multiple stellar targets. Even with GoTo, finding and keeping a relatively dim (11-14 mag) star within the SAC-7 FOV is not always that easy. The following procedure seems to work most of the time. Polar alignment (PA) is critical to tracking eclipsing binaries over the many hours that it might take to capture sufficient readings of its periodicity. Drift PA (<http://www.darkskyimages.com/gpolar.html>) is iteratively performed through the Nexstar 8 optics with the aid of a 2xBarlowed 12mm illuminated reticle until no

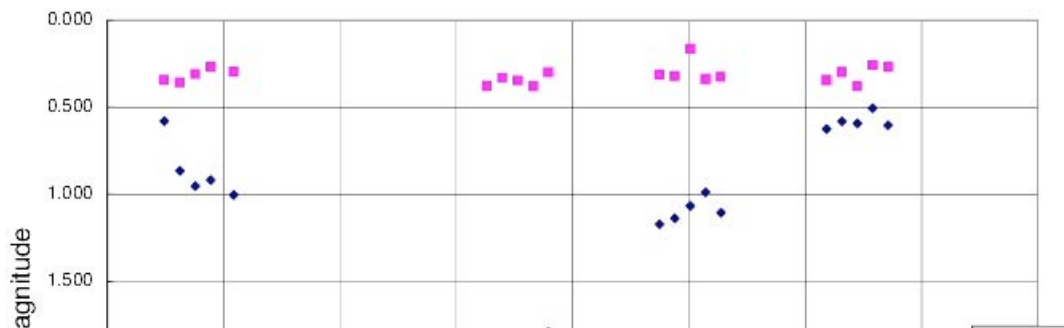
significant drift is observed for at least 5 minutes. The position of the Nexstar's tripod legs has been carefully marked on my deck, so this usually doesn't take longer than 20 minutes using a star on the meridian (DEC  $\sim 5^\circ$ ) and to the east (DEC  $\sim 30^\circ$ ). With an equatorial wedge, the EQ ALIGN procedure is initiated with two stars reasonably close and preferably bracketing the first program variable. Importantly, however, the piggybacked TV-76 is used throughout the star-align procedure, and not the SCT itself. Once this has been successfully completed, the first alignment star is centered with a parfocal eyepiece ( $\sim 9\text{mm}$ ) which has a similar FOV as the SAC-7. The eyepiece is then switched out with the CCD camera operating in long-exposure mode to ensure visualization of a star. Minor adjustments may be necessary to center the star and improve focus. This new position should be used to update the star-alignment calibration (align-replace) and the same procedure repeated with the second star. This approach will easily get you within 1-2 arc minutes of the J2000 RA and DEC coordinates for each stellar object.

The software package AIP4WIN is designed to automatically reduce monochromatic FITS images into photometric data. This dictated black-and-white operation of the SAC-7 which only produces one file per exposure rather than three (color). This is economical since it is very easy to consume 1-2 gigabytes of disc space during each recording session. Early experimentation under a variety of conditions suggested that at least 80 seconds of total integration time was necessary to get acceptable precision with stars ranging from mag 8 to mag 11.5. This was achieved by a stacking 10 eight second images after dark and flat frame calibration. In general, video brightness, and gain adjustment bars were started at mid-position and then adjusted according to conditions (temperature, stellar brightness, light and lunar pollution). It has been reported elsewhere (<http://www.warren-wilson.edu/~dcollins/WebCamPub/Webcam.htm>) that "gamma" should be positioned to the far left in order to improve linear response.



Since EQ Orionis (4:25:50.0, -03:26:03.7), my first target, varies between 10.3 and 13.3 mag over its 1.746d period, each point along the lightcurve was generated after stacking 10 slightly longer (10 sec) images. The comparison (C=TYC4741-01104-1) and check (K=TYC4741-01251-1) stars weigh in at 11.7 and 12.1 V-mag, respectively. RegiStar V1.0.7 was used to register and verify the target star field against reference images available on the web through tools like SIMBAD (<http://simbad.u-strasbg.fr/Simbad>) and Aladin (<http://aladin.u-strasbg.fr/aladin.gml>). You can also use your favorite sky charting program if it can reproduce stars down to mag 14-15.

CalSky (<http://www.calsky.com>) provided a predicted minima for EQ Ori at 20:20 hours (EST) on 19Feb05. The actual eclipse was scheduled to begin at 18:40 and end at 23:42. However, nightfall and clouds prevented the start of imaging until 20:00 while the roofline of my house quickly terminated this session at 21:30. Nonetheless, within these limitations a lightcurve was generated which fortuitously captured most of the minima. Images were processed using the photometry measuring routine in AIP4WIN and plotted using two very useful companion Excel spreadsheets (AIP4Plot and SunTIME) which were obtained from Lew Cooks website (<http://www.lewcook.com/>).



It's not altogether a work of art, but not too bad considering pesky clouds, 15-20 mph wind gusts and a very bright waxing gibbous Moon not 30° away to the northeast. The comparison-check star difference is a relatively constant number as it should be and  $\Delta$  magnitude approaches 2.5, not that far from predictions (3.0). Since this represents a snapshot near the minima, it is likely that the lightcurve would have started and/or ended 0.5 mag higher had I captured the true beginning and end of the eclipse.

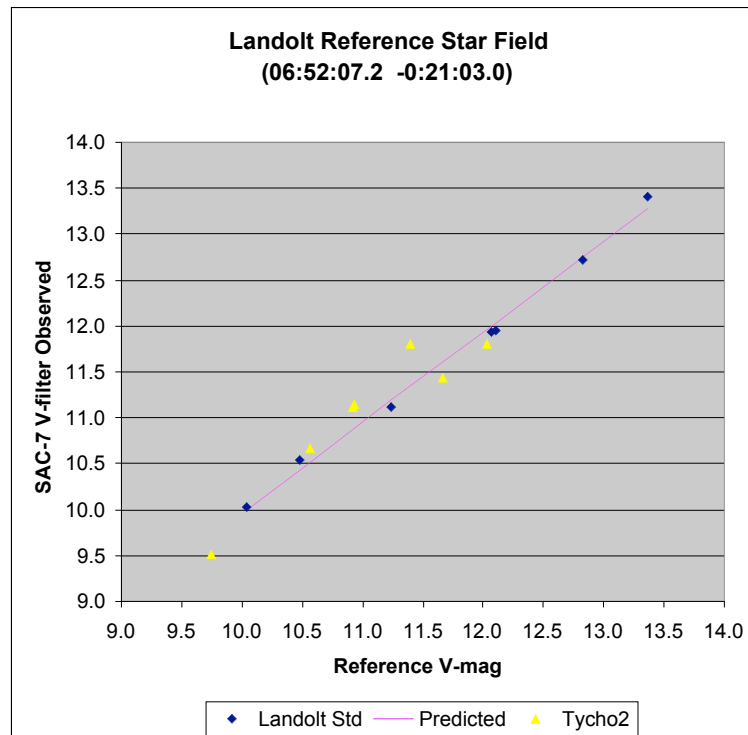
So what are the lessons learned thus far?

First of all, a modestly priced webcam is potentially capable of producing reasonably precise lightcurves (certainly within  $\pm 0.05$  mag) for many variable stars and minor planets (asteroids). No doubt the learning curve was steep, but I found the books/references/websites listed at the end of this article to be extremely useful in understanding the principles of CCD imaging, webcam photometry and/or eclipsing binaries. Secondly, as a professional scientist in a totally unrelated discipline, I find this research invigorating since my senior position no longer allows time for personal experimentation. It's obvious there is a huge laboratory out there free for the taking. My future plans include fine tuning the webcam settings for capture and integration of images to improve signal-to-noise and thereby achieving greater sensitivity and precision. A Schuler astro-imaging Johnson V-filter is on my short list of items to buy and would be an important acquisition so that stellar magnitudes can be standardized against literature data

Let's fast forward about 5 weeks (March 2005). Two key purchases have enabled a more serious venture into photometry. These include a Schuler V filter and MPO Canopus (Bdw Publishing) software which were obtained with a very modest investment of \$59 and \$50, respectively. BTW, add "CCD Photometry" by E. Norman Walker to the list of website references worth perusing ([http://www.britastro.com/vss/ccd\\_photometry.htm](http://www.britastro.com/vss/ccd_photometry.htm)).

Most of my attention is focused (pun intended) on using a technique called differential photometry as means to estimate the magnitude of a star. An excellent overview of the principles involved can be found at [http://reductionism.net.seanic.net/CCD\\_TE/cte.html](http://reductionism.net.seanic.net/CCD_TE/cte.html).

Since the program star and surrounding comparison stars are simultaneously captured in the same field of view, atmospheric extinction (the ability of air mass to dim starlight) is essentially the same. In an attempt to minimize the color-dependent effect air mass has on attenuating starlight (red light is scattered less by our atmosphere), all observations were made well above 30° altitude. Using this approach, photons have been captured and quantified from such far away places as AK CMi, AM Tau, EQ Ori, RW Mon, SS Vir, ST Aur, TZ Aur, T Cas, U Gem, U Ori, UV Per, and Y Leo. One of the limitations of using the SAC-7 and most other webcams is their relatively poor linear response due to 8-bit resolution and the anti-blooming circuitry which is intended to protect us amateurs from saturating an image. The accuracy of 8-bit measurements, which essentially limits the CCD detector to just 256 different levels of grey, can be improved by stacking many images together. Depending on transparency conditions and visible magnitude of the target, I have settled on averaging from 12 to 36 images, each with a 12-second exposure time. All images must be dark- and flat-field corrected prior to photometric reduction. As can be seen below from a group of observations taken with a Schuler V-filter, very strong correlation ( $r > 0.997$ ) between instrument derived magnitude and standard magnitudes from seven reference stars in a Landolt field was observed. Additional data from Tycho2 stars is also included and shows that linearity approaching 4 magnitudes can be achieved under these conditions. This working range (9-13.5) comfortably includes far more variable stars than could be regularly monitored by the average amateur living in NJ. Brighter stars require shorter exposure times, otherwise they would bloom (saturate) and fall into a region of non-linear response.



The Schuler V (visible) photometry filter conforms to a set of optical specifications in the UBV(RI) system centered at 530 nm. Importantly, this standardizes the transformation of instrument magnitudes into absolute values which can be shared between astronomers independent of equipment and observing conditions. However, there is a penalty to pay since by their nature filters decrease the total number of photons reaching a CCD detector. Without a filter, detection ( $S/N > 25$ ) of even lower magnitude objects ( $\sim 14.5$ ) can be achieved as shown (circled stars) in the Landolt field below.

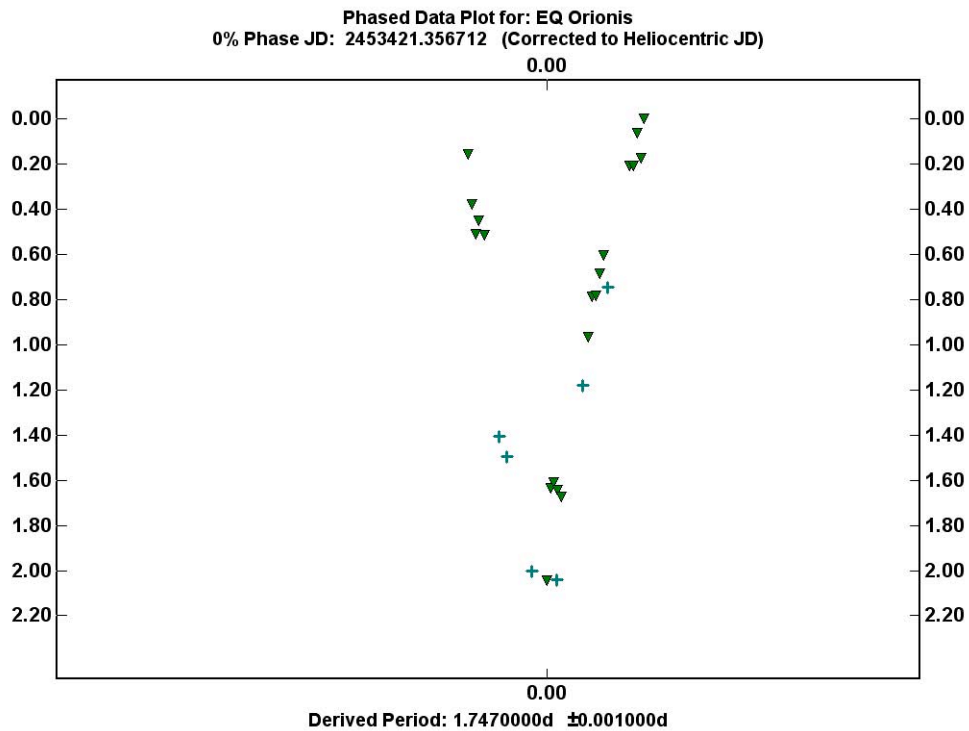


Despite 8-bits of resolution, good reproducibility ( $CV < 1.5\%$ ) was observed by average combining images (12 sec exposure) in groups of 12 that were collected over a half-hour period of time. For reference stars spanning Vmag 11.593 to 13.379, the standard deviation (S.D.) of the mean instrumental magnitude (I.M.) typically ranged from 0.03 to 0.05. Representative Clear filter results from the Landolt standard [SA98 194](#) are shown below in a table produced by PhotoRed (Bdw Publishing) and imported into Excel to calculate the appropriate statistics.

SA98 194      06 52.36 +0 21.6    Mag(B): 12.645    Mag(V): 12.234

Use	Date	Time	JD	I.M.	S.M.	Band	A.M.	SNR	BG	X	Y
T	2005 03 05	20:32:56	53435.35621	-8.598	0	C	1.332	103	35	469.562	230.272
T	2005 03 05	20:35:37	53435.35807	-8.473	0	C	1.335	95	34	470.023	230.496
T	2005 03 05	20:38:18	53435.35994	-8.580	0	C	1.338	103	34	470.243	227.559
T	2005 03 05	20:43:10	53435.36332	-8.544	0	C	1.343	101	34	468.731	226.369
T	2005 03 05	20:45:51	53435.36518	-8.578	0	C	1.347	103	34	466.635	222.811
T	2005 03 05	20:48:33	53435.36705	-8.525	0	C	1.351	100	34	468.919	221.572
T	2005 03 05	20:53:25	53435.37044	-8.582	0	C	1.358	103	34	464.416	221.771
T	2005 03 05	20:56:07	53435.37231	-8.536	0	C	1.362	100	34	472.516	219.250
T	2005 03 05	20:58:47	53435.37416	-8.438	0	C	1.366	97	34	470.754	220.313
T	2005 03 05	21:01:00	53435.37571	-8.502	0	C	1.370	97	34	467.501	219.381
			Mean	-8.536			Mean	100.2			
			SD	0.052			Error	0.010			
			%CV	0.612							

Since my first simple Excel-based lightcurve, additional photometric data has been collected for the eclipsing binary EQ Orionis. This time, however, Canopus (MPO) was used to overlay lightcurve data generated on two separate occasions (19Feb05 and 26Feb05) and predict the periodicity of its minima. This software uses a powerful Fourier analysis routine to find the period of a lightcurve.



In this case, even with partial data, a solution was found which very closely approaches the literature value (1.746035d) for its periodicity. Since spring has already sprung, this system will have to wait until next winter for further refinement. Other program stars that have thus far yielded partial light curves include YLeo, AK CMi, CC Com and RW Mon, all of which are eclipsing binaries.

Recapping, a webcam-based photometric system has been described which can routinely measure the visible light from stars (or asteroids) varying in magnitude up to 13.5 ( $\pm 0.05$ )

mag). Dimmer objects like UGem (8.2-14.9V) are a challenge but not impossible with excellent sky conditions. However, don't plan on monitoring the progress of asteroids having amplitudes on the order of 0.03-0.08 mag or  $\delta$ -Cephei variables with changes typically in the range of 0.01 to 0.3 mag. Nonetheless, the performance of this system is amenable to monitoring almost all the star systems tabulated in the eclipsing binary ephemeris available from the Milwaukee Astronomical Society (MAS) or the subset published by AAVSO.



1. Vesta Pro stellar photometry: A step by step guide, how to measure variable stars with a humble gadget called webcam by Grzegorz Koralewski.  
(<http://sus.univ.szczecin.pl/~ecliptic/vesta3en.htm>).
2. AASVO (American Association of Variable Star Observers):  
(<http://www.aavso.org/>)
3. Eclipsing Binary Stars (Dan Bruton, SFA Observatory:  
(<http://observe.phy.sfasu.edu/~ast305/Bruton/Misc/binstar.html>)
4. Up-to-Date Linear Elements of Eclipsing Binaries  
(<http://www.as.wsp.krakow.pl/ephem/>)
5. The Handbook of Astronomical Image Processing by Richard Berry & James Burnell. (<http://www.willbell.com/aip/index.htm>)
6. A Practical Guide to Lightcurve Photometry and Analysis by Brian D. Warner  
([http://www.minorplanetobserver.com/pgbook/practical\\_guide.htm](http://www.minorplanetobserver.com/pgbook/practical_guide.htm))
7. The New CCD Astronomy by Ron Wodaski  
(<http://www.newastro.com/newastro/default.asp>)
8. An Introduction to Astronomical Photometry Using CCDs by W. Romanishin  
(<http://observatory.ou.edu/book2513.html>)
9. The CCD Photometric Calibration Cookbook by J. Palmer & A.C. Davenhall  
(<http://www.starlink.rl.ac.uk/star/docs/sc6.htx/sc6.html#xref>)
10. Ronald E. Zissell, Evolution of the “Real” Visual Magnitude System, JAAVSO Volume 26, 1998
11. Timothy P. Castellano. “The Detection of Transits of Extrasolar Giant Planets with Inexpensive Telescopes and CCDs”  
(<http://www.skywokker.com/transitsearchobserving3.pdf>)
12. Bruce L. Gary. “CCD Transformation Equations For Use with Single Image (Differential) Photometry”  
([http://reductionism.net.seanic.net/CCD\\_TE/cte.html](http://reductionism.net.seanic.net/CCD_TE/cte.html))
13. “CCD Photometry” by E. Norman Walker  
([http://www.britastro.com/vss/ccd\\_photometry.htm](http://www.britastro.com/vss/ccd_photometry.htm)).

