

Long Exposure Webcams and Image Stacking Techniques

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Figure 4.1: M27, Dumbbell Nebula. Captured with an SC3 color Vesta and an SC3 B&W Vesta by Carsten Arnholm with a C8 scope and a Mogg .6 FR. 65x40sec color, 40x40sec B&W. K3CCDTools, Registax2, Photoshop.

Introduction

In recent years a new method for astrophotography has emerged which uses very affordable equipment and produces competitive results. Standard webcams, originally created for the consumer-oriented video-conferencing and cheap home-based photography markets, have turned out to be an excellent source of affordable astrophotography cameras. These cameras often cost between \$50 and \$150 dollars, and even after the modification described below, are still highly affordable compared to the astrophotography-oriented CCD cameras available from mainstream companies.

Planetary imaging can be performed with the right webcams without any modification and you can start immediately if that is your interest. For deep sky

imaging, webcams out of the box suffer from several problems, most of which can be minimized or eliminated.

Astronomical Cameras and Webcams

The first mass produced webcam, the black and white Quickcam made by Connectix, shared many similarities with a dedicated astronomical CCD cameras in production at the same time, including the type of CCD used and the control method which used the computers printer connector to directly control the sensor. Sadly the software that was supplied with the webcam had a bug which prevented the camera taking long exposures required for deep sky imaging. Dave Allmon started the first wave of interest in deep sky webcam imaging by writing a control program for this web camera that allowed long exposures and the imaging of faint objects. Dave's first deep sky images were of the Andromeda galaxy with many fainter objects such as the Horse Head nebula soon following. From this starting point developments in webcams and astronomical CCD cameras have driven these products in very different directions. Astronomical CCD cameras have maintained a relatively high price and have aimed for precise digitisation of the signal from each pixels of the CCD at the expense of image download time. Webcams have strived to achieve high frames rates of brightly lit subjects from color CCD's, quite often at the expense of image quality. In order to use modern webcams for deep sky imaging we need to address a number of issues including exposure time and image quality. The solutions are a combination of hardware and software modifications, and specialised image processing techniques

Modified Cameras

The specific details of the modifications are best gained from the websites given in table 1. Here we will only cover in subject in broad terms. Also bear in mind that astronomical cameras based on these designs are available commercially if soldering to surface mount components is not one of your skills. The first stage is acquiring a suitable webcam. While this sounds trivial time spent researching the best webcams for modification will be very worthwhile. At the time of writing the Philips ToUCam II Pro is regarded as the best with the Logitech Quick Cam Pro 4000 and Creatives ex Pro also worthy. All these cameras feature CCD sensors rather than CMOS devices. While some digital camera CMOS chips have been found to be very capable of astro imaging those currently used in webcams have invariably low sensitivity. This might change in the future so its worth checking web sources such as QCUIAG to find the currently favored webcams.

http://www.qcuiag.co.uk/
http://groups.yahoo.com/group/QCUIAG/
http://www.firmament.tk/
http://www.pmdo.com/wintro.htm

Table 1. Websites with background information on long exposure modified webcams.



Figure 4.2: SC modded ToUcam, by Ashley Roecklein.



Figure 4.3: Cooled SC modded ToUcam, by Ashley Roecklein.



Figure 4.4: modded Vesta, by Keith Wiley.

Without modification the cameras are limited to relatively bright objects such as the moon and major planets. This lack of sensitivity is not due to inherent

limitation in the CCDs' used in the webcams. Indeed the quantum efficiency of the best webcam CCDs' is on a par with dedicated astro cameras. The sensitivity problem is linked to the webcams producing a moving image consisting of at least 5 frames per second. To image deep sky objects we really need to take picture with exposures of 30 seconds or more rather than the 0.2 seconds offered by the standard webcam. So the solution developed by the authors was to place some of the webcams internal timing directly under the control of the PC. The electronic circuits needed to achieve this are very simple but the working on the surface mount components requires some skill and experience with a soldering iron. Good advice if you are considering going this work yourself is to find a scrap circuit board with some surface mounted chips to practice on. As the specifics of the modifications vary from camera to camera these are best referenced from the Internet. Once modified, the webcams exposures can be controlled to be any length the user likes by using software that is compatible with these modifications.

http://www.philip.davis.dsl.pipex.com/tcp2_mods.htm	ToUCam 2 by Phil Davis
http://mypage.bluewin.ch/bm98/13k/modification.htm	QC3000 by Martin Burri
http://www.foley-tax.com/Astro/modz/	Creative Ex Pro by Jack Reed
http://www.pmdo.com/wwhich.htm	List of webcam modification sites

Table 2. Sites giving camera specific modification details.

The modification to control length of exposure is fundamental to adapting webcams for deep sky use. In addition to this, other modifications to the camera's hardware is optional though can be beneficial. The CCDs used in the webcams feature on chip amplification circuitry. This significantly increases the quality of the images produced as it keeps the amount to electrical noise added to the imaging to a minimum. However this amplifier also emits photons by a process termed electroluminescence. In exposures lasting 30 seconds or more this results in an objectionable glow in a corner of an image corresponding to the part of the CCD array closest to this circuit. A solution is to drop the voltage to this circuit while the CCD is collecting its image and then to restore it when its needed while the image is read out of the CCD. This modification is known slightly confusingly as the amp off or amp switch modification. Also possible although not particularly popular is a modification to the webcams that allows half the CCD to be read out at a different speed to the rest of the array. This is can be

useful to simultaneously guide a telescope using exposures of one second or so while the main image is built up for a minute or two.

The CCD based webcams tend to use 1/4 inch color CCDs. The color information is gained from tiny red green blue filters that are place on top of the CCD structure. The arrangement is in blocks of 4 pixels each having 2 green and 1 red and 1 blue filter. This allows the webcam to take a full color image without requiring external filters but as the filters only let though a single color the sensitively is significantly reduced. Recently amateur astronomers have successfully replaced the standard CCD by unfiltered black and white versions. Also it is possible to swap the standard 1/4 inch CCD for something rather larger like a 1/3 or even a 1/2 inch CCD. When bought in small quantities CCD chips can be quite expensive so a 1/2 inch CCD will probably cost more than the camera it is going into. However, as the light gathered is proportional to the surface area of the sensor, these chip swaps can be very worthwhile.

http://www.astrosurf.com/astrobond/ebvnpbe.htm	Use of 1/4 inch B/W CCD. Etienne Bonduelle
http://www.pmdo.com/wsc3.htm	1/3 inch CCD. Steve Chambers
http://www.greg.beeke.btinternet.co.uk/icx414.htm	1/4 inch CCD. Greg Beeke

Table 3. Websites detailing CCD replacement modifications.

The final stage of hardware modifying a webcam is often building a new case for it. While it is possible to fit a modified webcam back in its original box there are advantages to using a bigger box that allows for better air circulation and allows some cooling. When a webcam is left running it consumes electrical power and produces some heat which if left to build up in the cameras case will raise the CCD temperature and increase the thermal noise its produces. Simply allowing air to circulate and take away this heat is surprisingly effective especially on a cold night. For greater cooling Peltier coolers are able to reduce chip temperatures to 40 degrees or more below ambient. This does generate a whole new set of problems in stopping the chip from dewing or even icing up. The standard lens in a webcam typically has a focal length of 7mm and a focal ratio of about 3. This is idea for capturing whole constellation pictures maybe including some foreground subject. To move onto specific deep sky objects a method for coupling the camera to a telescope is required. Probably the most versatile method is to incorporate a camera macro extension ring into the box design as this

will allow both 1.25" focuser adaptors to be used for prime focus telescope imaging and also camera lenses could be employed to give wide angle shots.



Figure 4.5: M16, Eagle Nebula. Captured with an SC1.5 Vesta by Keith Wiley with a Meade 8" f/6.3 LX200 and Mogg .6 FR. 44x90sec. Keith's Image Stacker, Photoshop 7..

After modifying the webcam hardware for use in deep sky imaging is also possible to change the setting for the camera to make the best use of these alterations. The standard drivers for webcams tend to concentrate on producing the best high frame rate images of brightly lit subjects by using high compression and artificially emphasising edges in images to give the appearance of sharpness. By writing directly to the memory chip within the webcam its is possible to override these settings in favor of those which are able to better represent the image formed on the CCD. This has been shown to give a very great improvement for the webcams retaining the standard color CCD where the image artifacts are much reduced. For webcams with black and white unfiltered CCD the improvements are even better as the higher resolution processing techniques can be unlocked.

http://groups.yahoo.com/group/twirg/ http://groups.yahoo.com/group/qcuiag/	Yahoo discussion groups on webcam reprogramming.
http://www.foley-tax.com/Astro/modz/Advanced.htm#ULTRA	Jack Reeds guide to webcam firmware
http://www.astrosurf.com/astrobond/ebrawe.htm	Etienne Bonduelle guide to 'Raw mode'

Table 4. Websites describing methods to alter the webcams factory settings.

Capturing Images

A webcam that has been modified to take long exposures it doesn't work very well with off-the-shelf webcam software anymore. Astrophotography is much more demanding for a number of reasons. The first reason is that ordinary software simply doesn't drive the camera properly anymore since it has no way to control the new exposure control circuit.



Figure 4.6: M51, WhirlPool galaxy. Captured with SC3 B&W Vesta and SC color Vesta by Etienne Bonduelle with a Meade LX-90 scope and a .63 FR. 53x90sec IRB, 42x60sec IRB. Astrosnap, Registax, Iris, Paint Shop Pro 7.

There are a variety of freeware and shareware programs that control cameras modified according to our design. These programs go to great length to acquire the cleanest data possible, by providing histograms that allow you to insure that you are not saturating any part of the image, and by performing no compression on the image before it is saved to disk for further processing. The most common capture programs are listed in table 2.

Maxim CCD
AstroArt
K3CCDTools for Windows
Iris for Windows
Astro-snap for Windows
AstroVideo for Windows
Keith's AstroImager for Mac
Equinox for Mac
Qastrocam for Linux
Many more....

Table 5. The most common programs used for capturing images from long exposure modified webcams.

The actual task of capturing images requires some understanding of how such images will be processed at a later time. Unlike film astrophotography and unlike most professional CCD astrophotography, webcam astrophotography practically requires a process called image stacking, explained in greater detail later. For now, realize that it means capturing numerous virtually identical images of an object during one session. Consequently, another function of the programs mentioned above is batch image capture, in which a series of long exposures are captured in series, perhaps for an hour or more at a time.

Your webcam is centered the object in question the next step is of course reacquiring your focus. Focusing is tricky with dim objects. If you have a computerized scope, we recommend slewing to a nearby bright star and doing your initial focus there. Medium brightness stars provide better focusing information than really bright stars, because really bright stars produce a huge washed out disk on your ccd. Once your focus is approximate, we highly recommend using a Hartmann mask or diffraction spikes to refine it even further. Remember to refine your focus throughout an imaging session as changes in temperature and the angle of the OTA tend to throw the focus off slowly.



Figure 4.7: M104, Sombrero Galaxy. Captured with an SC1.5 Vesta by Keith Wiley with a Meade 8" f/6.3 LX200 and Mogg .6 FR. 47x90sec. Keith's Image Stacker.

Once you are focused, you are pretty much ready to go. Different programs have slightly different interfaces, but you basically need to find the exposure time that suits your purposes and start capturing images. As we will see there is a balance to be struck between capturing a lot of short exposed images and a few much longer exposures. The balance will differ between different subjects but as a rule of thumb collecting lots of short exposures will give high image quality at the expense of detecting faint objects and vice versa.

So, how many images is enough? Webcams are not precision instruments and suffer from a large degree of random noise and detrimental artifacts that result from such causes as warm temperatures, electrical interference, and the on-chip amp. These problems can be reduced in a variety of ways, but ultimately no single raw image will be very impressive.



Figure 4.8: NGC7635, Bubble Nebula. Captured with an SC Vesta by Etienne Bonduelle with a Meade LX-90 scope and a .33 FR. 91x60sec. Astrosnap, Iris, Paint Shop Pro 7, Neat Image.

You will want to stack several images to reduce the noise. Additionally, webcams do not have a very good dynamic range, as they represent their images with only 8 bits by the time they are transferring those images to the computer. This means that objects with a wide dynamic range (such as most nebulae and galaxies) will be unobtainable in a single image. Bright parts of an object will saturate before you have recorded any discernable signal from dim objects. Stacking can reduce this problem by increasing the dynamic range.

You will get smaller and smaller returns for greater and greater amounts of stacking,. When possible, a huge number of images is best. With deep sky imaging, you might take images with exposure times ranging between fifteen seconds and three minutes. Clearly, you cannot capture more than a certain number of frames while the object is well placed in the sky. In short, the more frames you have the patience the collect, the better your final results will be.



Figure 4.9: M1, Crab Nebula. Captured with an SC3 Vesta by Carsten Arnholm with a C8 scope and a Mogg .6 FR. 55x40sec. K3CCDTools, Registax2, Photoshop.

Before you take your scope down for the evening it is important to take some darkframes as well. A darkframe is an image taken in complete darkness, say with the telescope cover on, or simply with a tight cover over the end of the camera-telescope adapter after removing the camera from the scope. The darkframes should match both the exposure time and the temperature of the actual frames. Darkframes suffer from the same maladies of noise as do actual images, so it is a good idea to take several darkframes and stack them to produce a single final darkframe that can be applied to the raw frames later. In addition to a darkframe, it is a good idea to take a flatfield frame. This needn't be done each session. Once will be enough. A flatfield is most easily captured against a twilight sky, and represents an even illumination of the camera's CCD. Flatfields can be used to counteract the effects of vignetting (a dimming of the edges of a image) and also artifacts caused by dust on the CCD. Though it could be argued that keeping the CCD clean is easier than processing out the dust artifacts!.

Postprocessing Techniques

After you capture a series of long exposure frames to your computer's hard drive, and after you go inside and warm up, it is time to begin the serious task of postprocessing your frames with powerful image processing software. Don't despair. The thing to realize is that the postprocessing stage represents half the effort, and half the fun! This hobby is different from other forms of astrophotography in that it is highly dependent on powerful image processing techniques, and using those techniques to your benefit to produce a beautiful final image is a large part of the satisfaction. The most common methods of postprocessing, in the order in which they are generally applied, are

- Stacking of multiple dark frames to a single dark frame
- Stacking of multiple flat frames to a single flat frame
- Selection of best frames
- Subtracting the darkframe from each raw frame
- Dividing each frame by the flatfield
- Aligning the frames to one another
- Stacking the frames
- Sharpening the stack
- Denoising the stack
- Level-adjusting the stack

Many of these steps require software that is specifically designed for processing astrophotos, most of which, are available free on the web. Table 3 shows a list of the most popular post-processing programs:

Registax for Windows
K3CCDTools for Windows
iMerge for Windows
Adobe Photoshop for Windows and Mac
Keith's Image Stacker for Mac

Table 6. The most popular postprocessing programs used for processing sets of images captured from long exposure modified webcams.

You start by producing a single dark frame that you will use for all of your raw frames. Do this by stacking all the darkframes you took and saving the result. Each program has a slightly different interface, but the basic task is the same.



Figure 4.10: IC2177, Seagull Nebula. Captured with an SC3 ToUcam by Jim Hommes with an ST f/2.5 scope. 6x180sec H-alpha, 16x8sec IRB, 12x12sec RGB. 4 frame mosaic. K3CDTools, Astroart, Photoshop.

After darkframe subtraction on each raw frame, you divide each result by the flatfield frame. At this point you have removed most of the thermal noise and accounted for most of the unevenness in the sensitivity of the CCD. This is what darkframe subtraction and flatfield division do. You are left with a series of frames that represent the true theoretical image the camera received, plus a rather large amount of generally random noise. The noise makes the image look fairly undesirable, but stacking will help.

In many cases, a number of your raw frames will be hopelessly degraded. There are a variety of possible degradations, including polar alignment error, periodic drive error, planes and satellites flying through the exposure, blurred images caused by wind gusts blowing the mount, bad seeing, and bad focus.

You simply toss the bad frames. In deep sky imaging this is fairly simple since there aren't very many frames to sift through.

You must carefully align all the frames to each other. In most programs you do this by designating one particularly good frame and aligning all the other frames to that frame. There are many ways in which alignment might be required, such as translation, rotation, and stretching. In practice, translational alignment is probably the only method you need to perform if your scope is polar aligned.



Figure 4.11: M42/M43, Orion Nebula. Captured with an SC1.5 Vesta by Keith Wiley with a Meade 8" f/6.3 LX200. Exposures ranging from 5 to 160 sec, stacked between 18 and 80 deep. 25 frame mosaic. Keith's Image Stacker, Photoshop 7.

At this stage you generate the stack. This is a single operation which happens without effort on your part. What you get is the stacked image. How the image is represented on the screen depends on which program you are using, but you can be sure, they are all performing some impressive tricks to squeeze the stack's large dynamic range into the mere 8-bit depth common to most image formats and most computer screens. Nevertheless, the actual stack, as stored in the computer's memory, contains the full dynamic range of the stacked data.

Stacking performs two feats at once. It increases the signal-to-noise ratio (snr) of the final image, and it increases the dynamic range of the final image. It is the first of these, the snr increase, that makes the stack look smoother and less grainy than the individual raw frames. The degree to which stacking accomplishes this feat scales with the square root of the number of frames you stack. So when you stack four frames, your snr goes up by a factor of two over each of the four raw frames. Notice however that in order to get another factor of two (so a factor of four overall by comparison to the raw frames), you need not eight frames as you might initially expect since that is twice the previous stack, but sixteen frames. This is why it was stated earlier that the discernable improvement in the stack that you get in return for stacking requires greater and greater numbers of raw frames the deeper your stack gets. For this reason, you should not get too concerned with whether you have thirty frames or thirty-four frames, or whether you have 100 frames or 120 frames. The results will vary by almost unnoticeable amounts in such cases.



Figure 4.12: NGC2244, Rosette Nebula. Captured with an SC3 ToUcam by Jim Hommes with an ST f/2.5 scope. 10x90 H-alpha, 18x4 IRB, 16x4 RGB. 4 frame mosaic. K3CDTools, Astroart, Photoshop.

Once you have a stack you can do a lot of nice things to it to further refine the final result. Sharpening is generally more useful on planetary stacks, but it can be

useful in deep sky stacks as well. There are a few different sharpening techniques, most of which are available in the stacking programs mentioned here.

In order to clean up the noise of the final stack further, there are some advanced methods of noise reduction, most of which use wavelets. It is always preferable first to reduce the noise through stacking, as stacking is the only method of noise reduction which is guaranteed to approximate the true recorded signal. Other denoising techniques, such as wavelet-shrinkage and expectation-maximization make assumptions and approximations in their efforts to reduce noise.

Level-adjustment is important. The stack will contain information from the bright cores of nebulas and galaxies as well as dim information from the perimeter of these objects. Proper level-adjustment is crucial to bringing up the dim areas without blowing out the bright areas.

Conclusions

Webcam astrophotography is only a few years old, and the progress that has been made so far is astounding. We invite you to join the online group QCUIAG. You can learn how to get in on this hobby yourself, for a fraction of the price of professional astrophotography equipment.

Biographies

Keith Wiley is a PhD student studying computer science at the University of New Mexico. While he has followed the developments of webcam hardware modifications quite closely, he is primarily a computer programmer, and as such, spends much of his time writing image acquisition and image processing software oriented toward astrophotography related imaging.

Steve Chambers is a professional biochemist and keen amateur astronomer. The background in biochemistry has played an important role in the development of Steves hobby by ensuring he has never quite enough money to buy off the self equipment. His DIY astronomy projects include a half meter computerized telescope and an automated sky survey. In 2001 Steve developed a method to allow modern webcams to be used to deep sky astronomy.