ASTROPHOTOGRAPHY

Inexpensive webcams with simple modifications are producing high-quality astronomical portraits. /// BY KEITH WILEY

Imaging with webcams

Above, **THE PHILIPS VESTA PRO 675,** shown here in its unmodified state, is a popular webcam for astrophotography. KEITH WILEY

At one time, astrophotography was limited to professionals. Then retail CCD (charge-coupled device) cameras came along, but they continue to cost several thousand dollars each. Just recently, it became possible for amateurs on limited budgets to take long exposures of both planets and deep-sky objects. This breakthrough has been made possible by affordable webcams — devices initially used for 2-way visual communication using personal computers. With cameras that cost less than $200 and readily available software, amateurs can produce striking images matching those taken with much more expensive photographic and imaging equipment.

THE BLACKEYE GALAXY (M64) in Coma Berenices. Fifty-nine 25-second exposures were stacked.

IRREGULAR GALAXY M82 in Ursa Major. Forty 30-second exposures were stacked.

THE CRAB NEBULA (M1) in Taurus. Exposures of 170 seconds, 163 seconds, and ninety-six 20-second exposures were stacked.

These three images were made with a modified Philips ToUcam Pro on the author's 10-inch Meade LX200 Schmidt-Cassegrain telescope at f/10 with a 0.33 focal reducer and a Sirius Optics MV-1 filter. The capturing and processing software used included K3CCDTools and AiGfxLab. KEITH WILEY

Unfortunately, standard webcams are not ideal for most forms of astrophotography, especially deep-sky photography. The main problem is their limited exposure range. Clever astrophotographers modify webcams to allow longer exposures, but this causes new problems: heat buildup, calibration images that contain unwanted bright spots, and an on-chip amplifier (to boost the brightness) that introduces stray light into the image. Some of these problems can be minimized with hardware, and others can be fixed with software. In combination, these corrective measures enable astrophotographers to take both planetary and deep-sky images that are nothing short of astonishing — without spending lots of money.

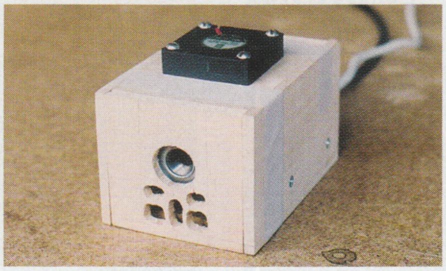
Hardware modifications and software methods used by webcam astrophotographers have been propagated primarily by the on-line community QCUIAG, the QuickCam and Unconventional Imaging Astronomy Group. Newcomers to the group and experienced astrophotographers alike trade tips, experiences, and digital images on a regular basis. If you are considering deep-sky webcam astrophotography, start by looking at the QCUIAG web site (www.qcuiag.co.uk). Group member Steve Chambers, who developed the webcam modification discussed below, offers detailed information on his own site (home.clara.net/smunch/wguide.htm).

Equipment

It's important to select the right webcam. Choose a webcam with a CCD sensor, not a CMOS (complimentary metal-oxide silicon) sensor. CMOS webcams incorporate low-sensitivity sensors and are not suited for astrophotography. For planetary imaging, the QCUIAG community widely believes the Philips ToUcam Pro 740K is one of the best webcams. This camera has a more sensitive CCD sensor than those in most other webcams and also produces excellent color balance. Unfortunately, this camera is out of production and the supply is drying up.

Popular alternatives include the Philips Vesta webcams with CCD sensors such as the 675, the 680, and the 690, and the Logitech QuickCam Pro 4000, which

THIS LOGITECH QUICKCAM PRO 3000 has been modified for long-exposure astrophotography. It cannot be attached to a telescope, however, without a device such as the Mogg telescope adapter. KEITH WILEY



THIS PHILIPS VESTA PRO 675 webcam has been modified to allow long exposures to be taken. When the Mogg telescope adapter is attached (see image to left), the webcam can be mounted to the telescope's focuser. KEITH WILEY

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/// **Various examples of webcam imaging**

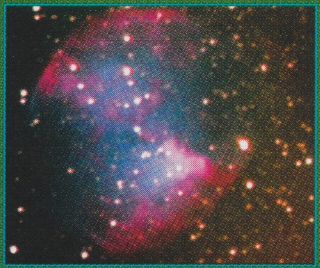

THE SWAN NEBULA (M17), KEITH WILEY


THE DUMBBELL NEBULA (M27), KEITH WILEY


M64, KEITH WILEY


THE SOMBRERO GALAXY, (M104) KEITH WILEY

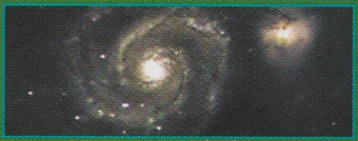

THE HORSEHEAD NEBULA, JIM THOMAS


THE DUMBBELL NEBULA, PETER KATRENIAK


THE ESKIMO NEBULA (NGC 2392), KEITH WILEY


NGC 4565, KEITH WILEY


THE RING NEBULA (M57), PETER KATRENIAK


THE WHIRLPOOL GALAXY (M51), ASHLEY ROECKELEIN

recently replaced the functionally identical QuickCam Pro 3000. Vestas also are out of production, but they are easier to find and cheaper than the ToUcam Pro. For long exposures of deep-sky objects, the experience of the QCUIAG community indicates none of these cameras is better than the others. Also, whichever webcam you buy must be modified for long exposures, as explained below. My modified webcam is a QuickCam Pro 3000, which does a great job.

Hooking up

The first concern is how to attach the webcam to the telescope. Various adapters are available, such as "Mogg" adapters (webcaddy.com.au/astro/adapter.htm), which screw into the webcam in place of the removed webcam lens.

When using an unmodified webcam for planetary imaging, use a Barlow lens to increase the size of the planet. If you are doing deep-sky imaging, use a focal reducer to fit large objects (like galaxies) onto the webcam's tiny CCD chip. This has the secondary benefit of increasing the object's surface brightness and decreasing the required exposure time.

Capturing planetary images

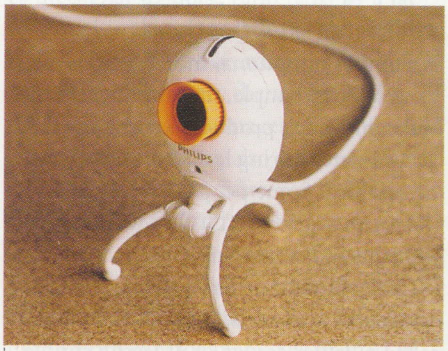
Planetary imaging is relatively simple. Because there's no need to modify the webcam for long exposures, the easiest approach is to use standard webcam software to capture a series of frames. Each frame is one image of the planet. For convenience, capture the images into an AVI or QuickTime movie file. Later, you can batch (or combine) the individual images.

Be aware that a USB connection has a limited bandwidth, meaning it can send data from the webcam to the computer only at a limited rate. Webcams commonly support rates as high as 30 frames per second (fps), this rate is achieved only by performing compression on the images (making them smaller) before sending them over the USB connection. This compression is "lossy." That is, some of the image data is lost. Webcams can support frame rates as slow as 5 fps, and that's the rate I suggest you use. My own tests indicate that transferring files at 10 fps can result in some image degradation, but other people believe 10 fps is acceptable.

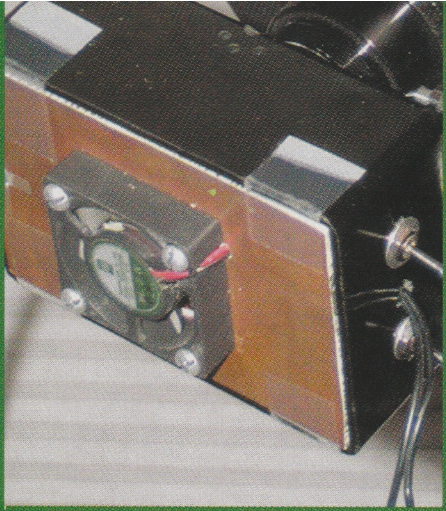
Set the gamma control of the webcam (which adjusts the middle tones of the image) to the lowest possible setting. Experimenting will reveal the best settings for shutter speed and gain (relative brightness). High shutter speeds produce images that are not as sharp, so I recommend slow shutter speeds as long as the seeing is good enough to support longer exposures. The goal is to obtain raw frames that are as bright as possible without oversaturating any part of the image.

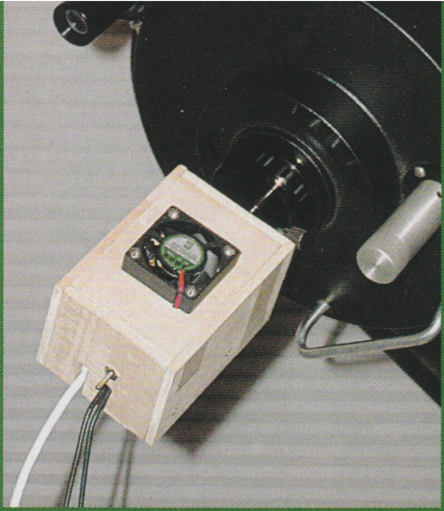
Modifying webcams

Most deep-sky objects are quite dim and require special webcam modifications to permit long exposures. Ordinarily, most webcams cannot take pictures requiring an exposure longer than one-fifth of a second due to built-in shutter speed limitations. A few years ago, however, Dave Allmon and Steve Chambers, two members of the QCUAIG, discovered that some webcams can be modified to take long exposures.

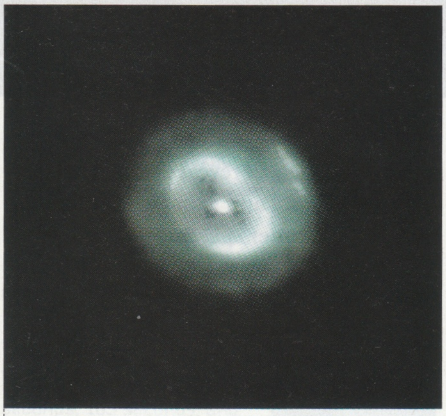


THE PHILIPS ToUcam PRO 740K has the ability to take quality astroimages even in its unmodified form. Add the Mogg telescope adapter (right) to connect the webcam to a telescope. KEITH WILEY

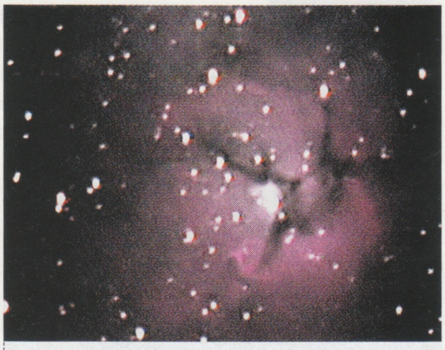




THE AUTHOR'S 8-INCH CELESTRON Schmidt-Cassegrain telescope makes an excellent instrument for webcam testing and comparison. A modified QuickCam Pro 3000 webcam (left) and a modified Philips Vesta webcam (center) both have small fans attached to aid cooling. A ToUcam Pro webcam (right) is shown in its unmodified form mounted to the telescope. Because it is unmodified, the webcam's maximum exposure is limited to ⅕ second or less. KEITH WILEY



THE BLUE SNOWBALL (NGC 7662) in Andromeda was imaged by Alan Leggett with a modified Philips Vesta 680, Peltier cooled, on a 10-inch Meade Schmidt-Cassegrain telescope. Forty 20-second exposures were stacked to produce this image. The capturing and processing of this image were accomplished using K3CCDTools software.



THE TRIFID NEBULA (M20) in Sagittarius was imaged by Peter Katreniak of Kosice, Slovakia, with an 8-inch Orion Europa Newtonian reflector at f/6 and a modified Philips Vesta Pro 675 webcam. Eleven 25-second exposures were stacked. The capturing and processing software used were K3CCDTools, MaximDL, Corel PhotoPaint, and Neat Image.

The simplest modification required to obtain long exposures consists of disabling the camera's one-fifth second exposure upper time limit and splicing in a switch. This switch can specify the start and end for an exposure of arbitrary length. For Windows users, the switch can be controlled through a parallel port by software.

For Macintoshes, which do not have parallel ports, other workable solutions exist. I developed original software that allows me to manually control individual exposures with a switch. I can tell the camera when to start and stop an exposure, after which the software sends it to the Macintosh over its standard USB connection. Once the image reaches the Macintosh, a program I wrote automatically detects its arrival and saves it. Computer control of the exposure time not only helps ensure that multiple exposures are precisely the same duration (important for later combination of images), but it also allows the computer to capture an entire batch of long exposures without any human intervention.

Additional modifications

A number of optional modifications exist as well. For example, the amplifier on the webcam, which produces a soft glow that accumulates during long exposures, can be disabled. Some people have replaced a webcam's original CCD chip with a more sensitive and larger chip.

CCD chips, whether in standard CCD cameras or webcams, heat up. Use a device called a Peltier cooler, or at least a simple fan, to cool the CCD and reduce "noise" generated by heat. The QCUIAG web site has general information on modifying webcams for long exposures, including links to numerous personal web sites that have detailed instructions on how to perform this modification.

Exposure limits

How long an exposure can you make with a modified webcam? Unlike users of standard CCD cameras, which can expose a single image for more than an hour, members of QCUIAG usually shoot "long" exposures in the range of 10 to 120 seconds, the upper limit imposed by simpler modifications. More advanced modifications allow somewhat longer exposures but suffer from the webcam's 8-bit CCD chip, which saturates with skyglow fairly quickly.

Webcam imagers have learned the power of image stacking (combining multiple images to create a single, final image) and thus prefer twenty 30-second exposures to a single 10-minute exposure. Image stacking produces a much better image than a single, extremely long exposure.

Image postprocessing

For a single deep-sky object, members of QCUIAG often capture ten to one hundred images. When imaging planets, they can capture several hundred frames in no more than a minute or two. Postprocessing — using software to improve the images after you have created them — produces a single, final image.

When shooting a long exposure, the CCD accumulates dark noise. Dark noise consists of the information a CCD chip gathers during an exposure taken in complete darkness (such as with a cover over the webcam). Such an image is called a dark frame. Because of its name and the way it's made, you would expect a dark frame to be perfectly black, but it is not. Because dark frames don't represent actual light hitting the CCD chip but rather electronic noise that is part of the system, the best solution is to "subtract" the dark frame from individual images before any other processing takes place. Use dark frames that correspond to the exposure time of your images and the temperature at which they were taken (dark frame noise varies with temperature). You also should capture a few dark frames for each set of images you take because temperatures can vary nightly — and even hourly.

It can help to divide the image by a flat field — an image of an object with even brightness. This procedure compensates for uneven sensitivities across the CCD's imaging area. For example, some focal reducers (used to decrease the focal ratio of telescopes to produce a "faster" system) introduce soft vignetting into the image, which makes the image darker around its edge. To capture a flat field, shoot the twilight sky (it has a very even illumination).

The best way to increase the quality of the final image is to stack many images of the same object. Before stacking, however, it is important to register (or align) the images. Alignment consists of adjusting the horizontal and vertical positions of each image so they all line up perfectly.

THE ORION NEBULA (M42) was imaged with a modified Logitech QuickCam Pro 3000 mounted on a Meade 8-inch LX200 Schmidt-Cassegrain telescope at f/6.3 with a 0.6 focal reducer. Exposures of 1, 2, 5, and 20 seconds were stacked. The capturing and processing software used included Keith's AstroImager, Keith's Image Stacker, and Photoshop. KEITH WILEY

Stacking every image you've captured is generally counterproductive. In a set of planetary images, for example, some will be subject to bad seeing. A fraction of the images of a deep-sky object may show drift errors associated with bad polar alignment. Even a slight breeze can blow your telescope just enough to smear a long exposure. Such bad individual images obviously would degrade the stack. Image postprocessing software lets you manually discard individual frames. It even automatically selects good frames without too much intervention on your part. The software does this by favoring images with strong energy in the higher frequencies — in other words, sharper frames.

Stacking serves two purposes. It increases the signal-to-noise ratio (s/n) by a factor equal to the square root of the number of images stacked. For example, stacking nine images increases the s/n by three; stacking twenty-five images gives a fivefold s/n increase. Stacking also increases the dynamic range (the difference between the maximum and minimum brightnesses of an image). The s/n increase that accompanies stacking produces an image better than any of the original images. This is useful primarily for planetary images, in which the object has a low dynamic range and single frames are unclear.

The effect of s/n improvement can seem downright magical the first time you witness it. The increased dynamic range allows objects with both bright and dark regions to preserve a wide range of luminosity. S/n improvement also is essential for deep-sky objects such as galaxies, in which the cores are often much brighter than the outlying regions.

Once some form of stacking has reduced your set of images to a single image, still more can be done to improve its quality. Stacked images are often blurry. Sharpening techniques contained in image-processing software can reveal greater detail. Histogram remapping (or level adjustment) is a common tool used to reduce the range of that part of the image's histogram that doesn't contain much information and stretch ranges that are interesting. This makes the details within those ranges more visible.

Recent webcam developments provide many opportunities for amateur astronomers to obtain fantastic photographs of planets and deep-sky objects. Taking advantage of these opportunities requires only two simple components: hardware modifications of inexpensive webcams and software for image processing that is now available on the Internet. ■

To learn more about CCD imaging, visit www.astronomy.com/toc

/// IMAGE PROCESSING

Processing images is just as important as obtaining them. The most important image-processing operations employed by astrophotographers are dark-frame subtraction, flat-field division, image registration (or alignment), stacking (or averaging), sharpening, and histogram remapping (or level adjustment). The programs listed below perform these operations and are available at no cost.

For Macintosh:

- Keith's Image Stacker by Keith Wiley, www.unm.edu/~keithw/keithsImageStacker.html

For Windows:

- Registax by Cor Berrevoets, aberrator.astronomy.net/registax
- K3CCDTools by Peter Katreniak, www.pk3.org/Astro (click on "My Software")
- AstroVideo by the COAA, www.ip.pt/coaa/astrovideo.htm
- Astrostack by Robert Stekelenburg, www.astrostack.com