Proceedings SOFIA Upper Deck Science Opportunities Workshop, NASA Ames Research Center, Moffett Field, CA, June 22-23, 2004.

DIGITAL VIDEO IMAGING WITH SMALL TELESCOPES – POSSIBLE APPLICATIONS FOR RESEARCH AND EDUCATION USING THE SOFIA UPPER DECK RESEARCH FACILITY

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ABSTRACT

The amateur astronomy community has a long tradition of performing routine visual observations of the planets with small telescopes, but in the last decade, CCD imaging has largely replaced visual observing as the primary method of recording planetary detail. Low cost 24bit color CCD video conferencing cameras (webcams) coupled to amateur telescopes (typically 0.2-0.3m aperture) have become powerful tools for high resolution planetary imaging. The high sensitivity of webcam CCD chips permits a series of short individual exposures to be obtained as a video stream directly into a personal computer. Software is used to selected out individual frames blurred by poor seeing , sharp frames are then stacked to increase the signal to noise ratio and finally wavelet processing is used to reveal fine detail. Under good seeing conditions resolution of planetary detail approaching the diffraction limit of the telescope (<0.5”) is possible with this technology. Additionally, by aligning and summing relatively short exposures (typically 100ms to 5s) it is possible to image faint objects, such as comets and asteroids, without the need for accurate sidereal tracking. Amateur planetary imaging programs have permitted tracking of small scale atmospheric structure on Jupiter, measurement of drift rates of small mid latitude white ovals on Saturn, monitoring of changes in cloud structure on Venus and observation of the development of small dust storms and water ice clouds on Mars. The optical and imaging equipment routinely used by amateurs could be adapted to exploit the unique observing conditions available on the upper deck of the SOFIA for research as well as education and outreach activities.

HIGH RESOLUTION PLANETARY IMAGING USING SMALL TELESCOPES AND DIGITAL VIDEO

Planetary observing has traditionally been a major focus of amateur observing programs. Detecting fine planetary detail requires good seeing (low scintillation) and excellent optics. For this reason experienced visual observers are often able to detect and record subtle planetary detail during brief moments of good seeing. In the 1980’s advanced amateurs, began to obtaining high resolution images using fast photographic film and relatively large (~0.4m) amateur telescopes (Eicher and Troiani, 1988). However, routine high resolution planetary imaging using small telescopes only became feasible with the advent of small CCD cameras in the early 1990’s.

The high sensitivity of modern CCD based cameras permits very short exposures of planetary images to be obtained through small telescopes (typically 0.2-0.3m aperture). Therefore, by taking a series of CCD images it is possible to capture sharp planetary images in brief periods of steady seeing. Furthermore, imaging is possible in the both the near infra-red and ultraviolet, since many CCD’s have reasonable sensitivity in the 350nm to 1000+nm range.

The relatively high cost of dedicated astronomical CCD cameras limited the number of amateur astronomers who could exploit this technology for planetary imaging through most of the 1990’s. However, CCD arrays are often used in consumer electronic imaging devices, such as low light security video cameras and webcams, which have been successfully adapted as low cost imaging systems for amateur telescopes. Ron Dantowitz (1998) demonstrated that it was possible to obtain diffraction limited images of the planets, stars and even orbiting spacecraft using a low light video camera, capturing video at 1/60s exposure, coupled to a small telescope. Dantowitz manually selected the sharpest frames from a video sequence, then aligned and combined them to increase the signal to noise ratio of the final image since individual frames were inherently noisy.

Currently the most popular camera systems used for planetary imaging by amateurs are webcams (computer video conferencing cameras). Modern webcams provide high resolution color video input directly into a personal computer, permitting immediate processing of the raw images. Although webcams were first adapted to astroimaging several years ago (Buchanan, 1998), it wasn't until the recent availability of fast personal computers with large disk storage space that this technology could be fully exploited.

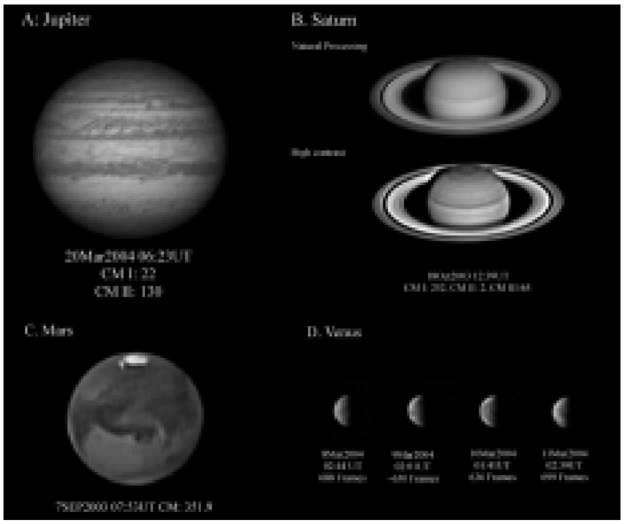

Fig. 1. High resolution planetary images obtained using a small Schmitt-Cassegrain telescopes (SCT) and modified webcams.

Examples of planetary images that can be obtained with a small telescope and a webcam. All images were obtained by the author using a 235mm schmitt-cassegrain and a Philips ToUcam Pro webcam unless otherwise indicated. (A) Jupiter, imaged under excellent seeing conditions. Note the fine structure in the belts, including small discrete ovals. (B) Saturn. After stacking of raw frames the image was wavelet processed to give a natural image (upper) and a high contrast image (lower). In the A-ring the Encke division is visible near the ansae of the rings. The high contrast processing is useful for revealing fine structures, including a series of mid latitude white ovals which were tracked for several weeks by amateurs in the fall of 2003. (C) Mars just past opposition, the 25" disk reveals a wealth of fine detail. Note also the water ice clouds near the left and lower limbs which are well recorded in the blue channel of the camera (image by Jason P Hatton and Bob Haberman, 250mm SCT and ToUcam Pro). (D) Venus imaged at approximately 24h intervals using a UV filter (SAC-8 CCD camera). Cloud structures are revealed, which show significant changes between each observation. The movement of individual clouds have been tracked by observers at different longitudes imaging at intervals of 2 to 8 hours.

A typical webcam, such as the Philips Toucam, consists of a 640x480 pixel array, overlaid with a bayer pattern of red, green and blue filters to give a 24bit color image (8 bits per color channel). Since the individual pixels are relatively small (5.6_m) it is possible to achieve a good image scale with a relatively short focal length for any given telescope, hence ensuring the planet image remains bright on the CCD array. Many amateurs use commercially available Schmitt-Cassegrain telescopes which generally have excellent optics and are well adapted for planetary imaging. To achieve a sufficiently large image scale to satisfy the Nyquist criterior (Grafton, 2004) for image sampling (ie. at least two CCD pixels for minimum angular size theoretically resolvable by the telescope optics) a telenegative lens is used to magnify the image. Good results are generally achieved with a 235mm Schmitt-Cassegrain at between f20 and f35. Video is usually acquired at 5-10 frames per second, with exposures varying from 1/5s to 1/50s. Typically, several hundred to a few thousand video frames are acquired for each final image.

Video images of Jupiter were acquired by the author using a 235mm SCT working at ~f35 using a Philips ToUcam Pro. Approx 1200 24bit 640x480 color frames were acquired as video at 10fps, with individual exposures of 100ms. *Registax* software was used to select the sharpest frames, stack and process the final image. (A) Raw frames reveal some detail, but are relatively noisy and lack contrast. (B) Stacking 1154 of the sharpest frames reduces noise. (C) Wavelet processing was applied to the stacked image to reveal fine detail. Note the detail on Ganymede to the lower right of the planet.

Fig. 2. Acquisition and processing of planetary images.

Amateur developed software, such as *Registax* (Berrevoets, 2004) can automatically select the sharpest frames from a video sequence, align the planetary images on individual frames and stack the frames to provide a final image with a good signal to noise ratio (Berrevoets, 2004; Davis and Staup, 2003). Finally, wavelet processing can be applied to the stacked image to reveal fine detail. Under excellent seeing conditions these imaging and processing techniques are capable of revealing planetary detail at the resolution limit of typical amateur telescopes (0.3”-0.5” resolution). Even under poor seeing conditions image resolution is often sufficient to permit routine monitoring of cloud and surface detail activity on the planets.

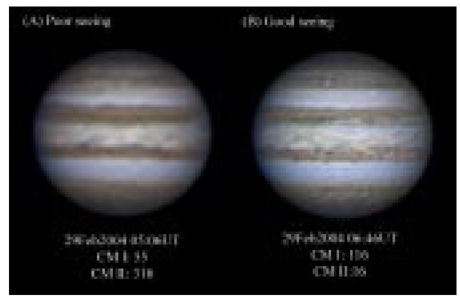

Fig. 3. The effect of seeing (scintillation) on final image quality. Two images of Jupiter obtained by the author in the same evening, using the equipment described in figure 2, under poor (A) and good (B) seeing conditions. Planetary imaging using video permits some of the effects of poor seeing to be overcome by only selecting sharp frames and aligning planet images on individual frames shifted by seeing during stacking. However, ultimately the resolution of the final image depends on seeing conditions.

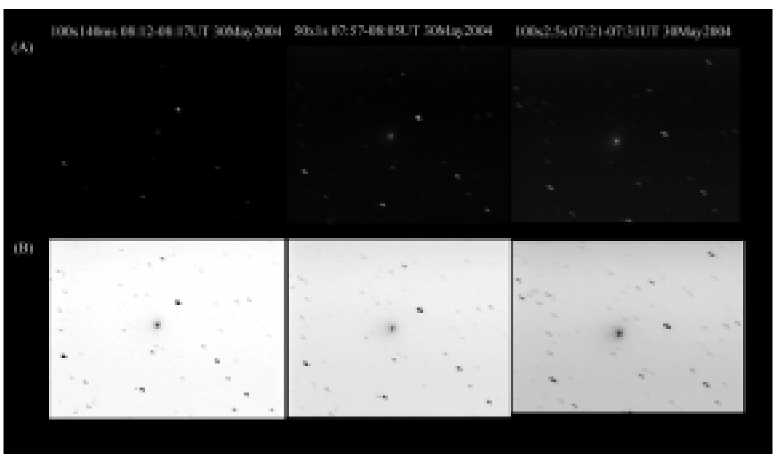

Fig. 4. Faint object imaging with modified webcams.

Unfiltered images of Comet C/2003-K4 Linear (then at approx mag+9.5) obtained by the author using a 235mm SCT and a CCD camera that is based on webcam technology (a SAC-8). A series of relatively short exposures (140ms, 1s and 2.5s) were taken, aligned and summed to give a longer integrated exposure time. Since individual exposures are short, alignment of individual frames can be used to overcome misalignment of the telescope polar axis, poor sidereal tracking or used to follow a moving object. In this example the comet nucleus, which was moving relative to the stars, was used as the reference for alignment of the individual images, resulting in a sharp image.

FAINT OBJECT IMAGING WITH MODIFIED DIGITAL VIDEO TECHNOLOGY

Although the CCD chips in webcams are very sensitive the ability to record faint objects is ultimately limited by the short exposures (typically <200ms) used when acquiring video. This can partly overcome by aligning and adding (summing) individual frames to achieve a longer integrated exposure, although again the sensitivity if this technique is limited by the information contained in the individual images. However, the webcam circuitry can be easily modified to permit longer individual exposures and cooling fans and / or peltier elements can be used to cool the CCD chip to minimize electronic noise (Chambers and Wainwright, 2004). Again relatively short individual exposures (500ms to 10s) can be aligned and summed to achieve a long integrated exposure duration. A significant advantage of this technique is that accurate sidereal tracking is not required, since individual images can be aligned and those smeared by poor tracking rejected. Furthermore, individual frames can be easily aligned on moving objects such as comets and asteroids.

RECENT RESULTS OF AMATEUR PLANETARY IMAGING CAMPAIGNS

The British Astronomical Association (BAA) and Association of Lunar and Planetary Observers (ALPO) have coordinated, analyzed and archived amateur observations of the planets for several decades. These organizations continue to analyze CCD and webcam images of the planets and provide data for the professional community. Additionally, organizations such as the International Outer Planet Watch (IOPW) maintain regularly updated archives of planetary images which are accessible via the internet. Recent results of amateur planetary imaging programs are summarized below.

Jupiter: Routine amateur observations of Jupiter date back over 100 years, providing a long term record of changes in Jupiter's cloud structure (Rogers, 1995). Currently, tracking of the longitude of cloud is based largely on CCD and webcam images, which have superceded traditional visual transit timings. To facilitate accurate analysis of the large number of images generated each apparition, software (Mettig, 2004) is used to determine the longitude / latitude of cloud features. These data can then be used to determine the rate of drift of features within the different current systems of Jupiter. The recent increase in the number of high resolution amateur images has permitted extensive observations of a number of small structures, which were previously only observable with large professional telescopes or spacecraft. These include the development of small jetstream spots on the southern edge of the south equatorial belt and their interaction with the great red spot (GRS), as well as small spots in the main belts (Rogers, 2004). Around opposition the planet was often imaged at high resolution by different observers at intervals of only a few hours apart, permitting near continuous monitoring of the development of small features. Furthermore, the development of well known features and phenomena (eg. the GRS and north equatorial belt (NEB) dark projections and plumes) could be followed in fine detail.

Saturn: Saturn is a beautiful object in any telescope, but detail on the planet's disk is often subtle and indistinct. Current amateur images reveal the principle belts and fine structure in the rings. Recently a number of mid-latitude small white ovals were tracked by amateurs for several weeks, including two which were initially discovered by the Hubble Space Telescope (HST), permitting determination of the drift rate of these features.

Mars: A large number of amateur astronomers attempted to image Mars over the course of the very favorable perihelic opposition of August 2003. Images were obtained which sometimes showed remarkably fine surface detail, including the caldera of Olympus mons and the retreat of the south polar cap (di Cicco, 2003). Two regional dust storms were tracked at high spatial and temporal resolution, while water ice clouds were recorded using blue filters. Close to opposition the HST obtained images of the planet, which were useful references to validating the accuracy of amateur images of Mars (13).

Venus: In visible light the cloud deck of Venus is largely featureless. However, UV images with amateur telescopes reveal cloud structure. During the course of the recent evening apparition of the planet a small group of amateurs, observing at different longitudes, were able to track movements of clouds in the UV over the course of few hours, as well as changes at daily intervals. Recently, Christophe Pellier successfully imaged the 1μm nightside surface emission of Venus using a 0.35m telescope and a CCD camera based on webcam technology (Shiga, 2004).

POTENTIAL APPLICATIONS OF DIGITAL IMAGING TECHNOLOGY ABOARD SOFIA

The upper deck of the SOFIA potentially provides a useful platform for a wide range of scientific observations, some of which may be achievable using digital video / imaging technology routinely used by amateur astronomers. Compared to ground based observations, SOFIA will provide a relatively dark sky background, low extinction close to the horizon and a lower twilight glow when the sun is just below the horizon. Sensitivite CCD cameras based on modified webcam technology, which take individual exposures in the 100ms-5s range, would permit wide and medium field imaging of objects too faint to be detected with low light video cameras. Since these cameras align and integrate many short exposures, accurate pointing of the camera would not be required. Some possible applications of this technology may include: 1) imaging of comets, particularly those with a low solar elongation which are difficult to observe due to twilight glow, 2) imaging of aurora, noctilucent clouds, and airglow, and 3) observations of the zodiac light

The low scintillation environment of SOFIA would permit consistent high resolution imaging of the planets and bright objects provided a good quality optical window was available and the telescope could be stabilized accurately. When the main SOFIA telescope is used for infrared planetary observations simultaneous planetary observations in the visible / near-IR range (350nm-1000nm) would be possible using a small telescope imaging system from the upper deck. Additionally, a small telescope could be used to image planets close to solar conjunction, when ground based observations are very difficult due to the bright twilight glow & strong turbulence close to the horizon. This would be especially useful for Jupiter, where global-scale changes occur unpredictably. If a significant event occurs close to conjunction it may be either missed or poorly characterized with current ground based observations.

Finally, many of the observing techniques used by amateur astronomers could be applied to education and outreach activities using the SOFIA upper deck. These could range from simple visual observations of the view of the sky from SOFIA, to wide and narrow field digital imaging using equipment routinely employed by amateur astronomers. After participating in a flight aboard SOFIA, an educator could perform the same observations on the ground with their students using the same methods and equipment (digital cameras, small telescopes, etc) used in-flight. Students could then compare the results of their own observations with those made on SOFIA, providing a tangible means to understand the rationale for doing science aboard SOFIA.

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Manuscript received 2004 June 15; accepted 2004 June 15.