Offbeat and wacky projects using a video meteor camera

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The proliferation of low cost video cameras for nightly meteor collection has almost exclusively been deployed for either moderate or all-sky fields of view. This presentation reviews various concepts using the latest off-the-shelf cameras typically used by meteorists, for some unconventional experiments in meteor detection, spectroscopy, high space-time resolution imaging, as well as non-meteor related projects.

1 Introduction

The relatively easy access to low light sensitive video cameras at very reasonable cost has made doing meteor astronomy reachable by most amateur enthusiasts. But the question arises as to why just do standard moderate field of view (FOV) collection with typically thirty degree sky coverage or alternatively, all-sky imaging with poorer limiting magnitude and resolution. The good news is that these systems are increasingly being deployed as part of distributed camera networks and are providing valuable monitoring and reliable radiant/orbit data year round. However, can we go to the next level and try to address questions beyond just meteor stream association and activity levels, which are within the abilities of amateur meteorists and also fall within their funding constraints. Thus, included herein are a series of project suggestions in both meteor and non-meteor related subject areas, some serious while others perhaps a bit offbeat and wacky, that may appeal to the more adventurous and those with an experimental nature. The goal is to stimulate the creative nature of our diverse community of amateur researchers that make up the IMO.

The discussion will start with a review of low to moderate cost video cameras and frame grabbers available circa 2014. The meteor related projects include daylight meteor detection, robotic meteor tracking, atypical low resolution spectroscopy, telescopic video meteor orbits, faint sporadic imaging, high temporal resolution light curves, and meteoroid impact characterization on the Moon. Non-meteor related projects that could utilize these same camera systems include a directional cosmic ray detector, massive compact halo object (MACHO) detection, and ornithology (bird) migration monitoring.

2 Video cameras and frame grabbers

The variety of choices in low to moderate cost video cameras and frame grabbers for analog NTSC and PAL formats has grown considerably due to the growing popularity of night-time video security surveillance systems. These surveillance cameras have the same features which are found to be desirable for meteor collection. That is, less reliance on image intensifiers and their associated operational concerns and export restrictions, good low light sensitivity in the monochrome camera versions, plus frame rate image capture permitting position estimates of multiple track segments during a meteor's inflight propagation. The summary of camera systems is listed in *Table 1* and is not to be considered all inclusive. High definition and digital cameras are not listed but it is expected their price point will continue dropping making those viable candidates as well.

The most notable change in the past year has been the release of the Effio line of Sony cameras. These cameras employ two chips on a small form factor board that often is embedded within a box-like camera housing that is very lightweight. One chip is used for onboard image processing and is where the Effio name for the cameras originates. Effio-E is the basic model and is adequate for meteor work. Effio-P and Effio-S are higher end image processing chips that have additional processing features like masking, wide dynamic range, stabilizer, and "sense-up" (time integration) that are not necessary to pay for in order to do meteor astronomy. The second more critical chip on the board is the sensor, and this has come in Effio-E variants that include Sony's Super HAD, Exview HAD, or Exview HAD-II in order of enhanced light level sensitivity. These are often color chips in the Effio line that revert to monochrome under low light conditions. One needs to be very cautious about purchasing an Effio-E to ensure the most sensitive chip Exview HAD-II is the embedded sensor. The Effio image processor chip also allegedly produces a digital output in additional to the standard NTSC or PAL analog, but this has not been investigated or tested as of this writing.

To record the analog image sequence onto a computer, one needs to employ a frame grabber or digitizer device. Again many variants can be found and *Table 2* shows a sampling from very low cost to higher quality systems that yield fewer dropped frames. Note that the original EasyCap dongle has been cloned and sold as cheap knock-off variants under the same name EasyCap that many users have experienced problems with. The authentic version is now called Ezcap.tv and originates out of the UK. Also note the Orion capture dongle produces only de-interlaced video so one loses the 2x sampling rate of an interlaced video sequence if using that device.

Table 1 – Low light cameras on the market circa 2014 used by the meteor community.

Camera	Sensor	Price US$
Watec 902H2 Ultimate	1/2” Exview HAD-II monochrome	342
Mintron 12V6HC	1/2” Exview HAD monochrome	425
Mallincam Jr. Pro	1/2” Exview HAD monochrome	700
Orion Star Shoot	1/2” Mintron 72S85HN-EX Color	500
Effio-E box with OSD	1/3” Exview HAD-II	65
Effio-E board only	1/3” Exview HAD-II	39

Table 2 – Digitizers available on the market circa 2014.

Frame Grabber / Digitizer	# channels/ interface	Price US$
Ezcap.tv	1 channel / USB dongle	32
Orion Video Capture	1 channel / USB dongle / de-interlaced only	50
Dazzle	1 channel / USB	62
ADVC-55	1 channel / USB	175
Sensoray 2255	4 channels / USB	472
Sensoray 812	8 channels / PCI 1x	199
Sensoray 817	16 channels / PCI 1x	1058

The bottom line is that for about US$130 including power supply and cables, one can acquire a good quality single channel video meteor camera. So what can a user do with that outside of standard meteor collection in moderate FOVs or all-sky fireball imaging?

3 Daylight meteor detection

There has been a desire by the optical meteor community to try and capture daylight meteors for fainter trails than just extremely bright fireballs. The issue preventing this has been the bright blue daylight sky that has a broad and continuous intensity profile from 450-650 nm and beyond due to scattered sunlight. Meteor intensity however is centered about a series of narrow emission lines arising from the excitation of both constituent materials such as Ca, Fe, Na, Mg as well as atmospheric O and N. One possible way to enhance the signal-to-noise of meteors relative to the bright sky background, is to place a colored pass band filter in front of the lens, that only passes wavelengths below 430 nm that would try to detect Ca and Fe emission lines. This is a region where the sky spectrum falls off but video cameras are still usually sensitive down to 380 nm. A second approach would be to use an extremely narrow band interference filter centered around any of the common meteor emission lines with the provision that the filter be placed in the optical path where there is little divergence of the light rays. This is necessary because with interference filters, off-axis incidence of the light rays causes the filter’s band center to shift, thus missing the narrow-bandwidth meteor emission line. Thus an interference filter cannot simply be placed in front of the lens due to the usually greater than 5 degree off-axis incidence angle of the light. Instead it might potentially be placed between the lens and CCD chip where the light rays are more nearly parallel. Ideally, an optical train where the lens and an additional optical element forms parallel rays, passes through the filter, and is then followed by a focusing element onto the CCD is desired.

4 Meteor acquisition and tracking

In November 2000, the author and George Varros met at Point of Rocks, Maryland, USA to exchange video equipment prior to a Leonid meteor campaign. An ongoing two hour discussion resulted in the origination of the idea of a real-time meteor tracker where a wide field meteor camera would cue the pointing of a narrow field camera before the meteor faded out. George went off to his garage and in two weeks built a two-axis rocker box with stepper motors that could point a camera within one-quarter second of a meteor’s first appearance, covering a seventy degree FOV. This evolved into a far more rapid response system using expensive (US$15000) galvanometers and mirrors that responded in 10 milliseconds covering a forty degree FOV with 50 mm clear aperture (Gural et al., 2004). This concept of zoomed imaging of meteors by pointing a single system (or steering the light) rather than deploying many narrow field instruments, can now be revisited a decade later using far less expensive technology.

The model aircraft radio control community commonly uses lightweight servo-motor based pan and tilt systems for recording their flights. These devices are very agile covering any direction of hemispherical pointing in a fraction of a second. They are also inexpensive costing less than US$150. The company RobotGeek sells a two-axis pan-tilt kit with servos that interfaces easily to a computer using Arduino controllers. A more expensive alternative is to explore the video conferencing pan-tilt systems some of which are highly agile and responsive. The goal would be to have an all-sky cueing camera that upon detection of a bright (i.e. long duration) meteor, that directs a narrow field camera to point and potentially track a meteor for high accuracy astrometry. If paired with other equivalent systems at different sites, then high quality trajectories and orbits become possible in all-sky coverage, with only two cameras deployed per site. A key issue in moving forward on a design is the responsiveness of the servo platform with camera mounted so that it slews and captures the meteor before it fades from view.

5 Low wavelength resolution meteor spectroscopy

Meteor spectroscopy typically involves the use of high dispersion gratings to resolve individual emission lines for determining temperature and abundance ratios. However, the meteor spectra yield is low due to the narrow FOV of such systems. An example is the deployment of multiple grating cameras called CAMSS (Jenniskens et al., 2013) to maximize spectral sky coverage between 30 and 55 degrees elevation. But amateurs may contribute in this arena by studying more general questions such as if a particular meteoroid stream is Fe deficient or Na enhanced. To do so only requires very low resolution spectroscopy covering broad bands of wavelength. One approach is to look at the colors of meteors in the respective red, green, and blue (RGB) sensors of a color camera. The new Sony Effio line of cameras is supposed to contain sensitive color chips that may provide broadband color information for brighter meteors (caution: these cameras may revert automatically to monochrome under low light conditions).

An approach that may be more realistic is to use the five Johnson-Cousins standard astronomical filters for UBVRI, one of each on a separate low light sensitive monochrome camera. If all pointed to the same patch of sky, then a fainter meteor than typically obtained by a grating camera could be captured in each of the bands and the relative strength of Ca and Fe in the B-band could be compared to Mg and forbidden O in the V-Band, Na in the R-Band, and atmospheric N and O in the I-Band. One might even consider a color index for meteors similar to one used for stars to categorize each stream. To take this further, since the Johnson-Cousins color filters may still be too broad in each wavelength band, one may consider using narrower band pass alternatives that focus more on each major contributing element species in meteors. In essence a way of choosing selective band passes without employing a grating, and thus obtaining relative line strengths between elements for various shower streams and sporadic meteors.

6 All-sky meteor spectroscopy

The use of a grating is often employed in meteor spectroscopy which is typically manufactured as a parallel set of ruled lines or grooves in a substrate. This limits the directionality of the grating dispersion to just one direction so meteors are effectively “seen” by the sensor off to one side in a narrow field of regard. Consider however, if the grooves were ruled in circles, then the dispersion direction would be radially directed inwards from all aspects (azimuths). Thus one could set up a monochrome imaging camera above such a reflection grating, not unlike the old all-sky meteor camera configurations that used a camera looking down on a mirrored dome or hubcap. Meteors from all aspects could be seen using a single camera. The elevation of the meteor above the horizon will dictate whether the meteor is observed as the first or second order spectrum.

A very inexpensive way to manufacture such a grating is to burn all ones or random one/zero bits on writable computer disk storage media. The write pattern is standardized and is comprised of a spiral series of pits with nominal inter-ring spacing of 1.60 microns for CDs, 0.74 microns for DVDs, 0.40 microns for HD-DVD, and 0.32 microns for Blu-Ray. Note that the 1379 lines/mm gratings used in CAMSS have 0.73 micron spacing. So the DVD spacing provides the same level of dispersion used in CAMSS for resolving critical emission lines in meteors. With the spiral (near circular) pit pattern, a low cost, all-aspect type grating can be coupled to a single camera to provide large area sky coverage. One needs to investigate the efficiency, dispersion pattern, and practicality of using a curved grating. Note that it is visible on DVDs that have NOT been written to, that there is a rainbow dispersion of white light reflected off its surface. It may be that the information (timing track?) embedded on the DVD surface may be sufficient to operate as a reflection grating as is, without having to burn pits into the media.

7 Telescopic video meteor orbits

It comes as a surprise that telescopic meteor work still lies in the domain of visual observers, especially when video camera systems can record trajectories far more accurately and reliably than human observers. The excellent performance of video systems for moderate to wide field of view meteor astronomy has been borne out in the past decade. So why not apply video to telescopic meteor studies done by amateurs? This would begin to cover a mass range of meteors with a greater relative proportion of sporadics for which high accuracy orbits are desired.

Part of the reluctance is two-fold. One issue is that automated detection software is not as well optimized for just one to three frames with very long streaks per frame, although the software suite MeteorScan has a separate detection algorithm for just this scenario. The second and perhaps greater issue is the angular velocity loss a meteor incurs as it rapidly sweeps across the focal plane. Take the Mighty-Mini 200mm f/2.5 system for occultation timing which is based on an Orion 80mm short focal length spotting scope (Degenhardt and Gural, 2009). It has a limiting magnitude stellar of +10.5 for a single frame at 30 fps. However, the faintest typical 40 km/sec meteor that can be seen above the sensor noise when using that system is only +6.8. This is because a meteor dwells in any given 12 arc-second pixel for only a small fraction of the 1/60 second interleave integration time. This is otherwise known as “trailing loss” or “angular velocity loss”. It can be mitigated to some extent with faster lenses and experiments with various optics configurations by the Croatian Meteor Network has indicated that a fast Canon 90mm f/1.0 lens can reach +8.0 or better meteor limiting magnitude without the use of an intensifier. Other low cost f/1.0 surplus lenses are currently under investigation by that same group to trade off focal length, limiting magnitude, and cost.

Assuming that a deep meteor limiting magnitude system can be assembled cheaply, there are some interesting features associated with deploying telescopic video. For two station meteor orbit estimation, the very narrow FOV produces a tiny cone angle in space making it far more difficult to find the camera attitude (geometric pointing) for the two widely separated sites to have the proper volume overlap. However, the small angular resolution of the focal plane pixels when using telescopic FOVs, allows the physical separation between observing sites to be reduced dramatically. Reliable short baseline triangulation has been suggested as possible (Gural 2012; Degenhardt and Gural, 2009) with as little as 5 km separation, but a study should be done to verify the best spacing. With a short baseline between telescopic sites, the attitude (pointing) optimization is far simpler. The two systems can aim to almost exactly the same star field with a simple calculation to determine the small pointing offset for 88 km altitude maximal coverage overlap. Also the near parallel alignment of the telescope viewing cones extend the volume coverage both closer (lower to the ground) and further away (above 90 km) along the mutual line of sight.

8 Faint sporadic detector

One way to mitigate the angular velocity loss in a telescopic FOV is to have the system “follow” the meteor. That is by slewing the sensing system to minimize the effective blurring motion of the meteor across the focal plane. This could be accomplished in one of a number ways and this list is by no means exhaustive. One approach is to simply mount the telescopic camera system on a rocker box and oscillate back and forth with an offset drive cam or direct servo motor. The servo motor would yield a more uniform angular velocity for most of the sensor’s travel cycle. A second approach is to rotate an angled camera so it traces out a cone (circle on the sky). A third approach tries to avoid the cable entanglement issue with the second method, by having a fixed telescopic camera stare at a rotating angled mirror that again effectively sweeps out a circle on the sky. A fourth more expensive approach mimics the early days of asteroid hunting called drift scan, wherein a fixed pointed sensor uses a CCD that shifts each row at a user desired rate thereby getting integration gain on moving objects. A fifth approach would be to try matched filter detection techniques (computationally expensive) on a fixed mounted telescopic camera to buy an extra 0.5 to 1.0 in limiting magnitude.

What would be the purpose of such an instrument? To probe into the very faint end of magnitude +9 and +10 sporadics. But there is a catch as these concepts only detect meteors in a narrow speed range and limited direction. But the sporadic flux goes up dramatically at these magnitudes so the geometric constraints may be offset by the sheer number of available events. Also the interesting case would be to explore the slow sporadic population which are often missed in video systems. The second issue is doing astrometry with a moving sensor and backing out the actual speed and direction of the meteor. A very challenging geometric problem.

9 Millisecond resolution meteor light curves

One interesting advantage to interleaved video (which may disappear with the advent of digital progressive scan cameras) is that the meteor tracks can be centroided on the even and odd “fields” and effectively sampled at twice the full frame rate. For a 30 fps NTSC camera, the integration time per field is 1/60 second alternating between even and odd rows. This yields a 15 millisecond temporal resolution in meteor light curves and measurements feeding trajectory analysis.

However, it is often evident that a meteor presents a streak in just one field of the image sequence. That is the meteor spans more than a single pixel. Thus for a vertically oriented meteor on the focal plane, one could extract the meteor intensity on a per row basis and obtain effectively a higher temporal resolution light curve (for horizontal meteors the extraction would be done by column). For moderate FOV cameras this may yield from 4 to 8 millisecond resolution depending on the meteor’s speed. With telescopic meteors, the effective resolution is approximately ten times higher than field level time spacing, so one could achieve close to millisecond resolution light curves.

Applying such analysis, it may be possible to view oscillations in the light curve from tumbling meteors, but there should be caution applied since some oscillations could be due to camera focal plane characteristics (less than 100% fill factor for example). This would require new analysis software to automatically extract the higher temporal information. Note that the higher spatial resolution and interleave can also assist in more finely estimating interleave breaks (for example the switch from even to odd fields) and thus provide better apparent angular velocity estimates than simple centroiding of the extremely long streak in telescopic meteors.

10 Lunar meteoroid impact characterization

The NASA/Marshall Meteoroids Environment Office has been monitoring the unlit portion of the near side of the Moon for several years and has accumulated 321 boulder sized impacts through June 2014. These hypervelocity impacts create light flashes typically near magnitude +5 with a duration of a few tens of milliseconds spanning only one or two frames at standard video rates. The interleave integration time of NTSC and PAL is too long to resolve the light curve adequately so high speed video of at least 300 fps would be desirable to better characterize the phenomena. To do so would require more light gathering power than is currently used, such as a one meter telescope coupled to a high frame rate camera. In addition, it would be interesting to obtain spectra of an impact flash but this is an even harder challenge due the faint nature of the flash and further loss in SNR due to dispersion of the spectrograph. Nevertheless, either aspect would be a worthwhile endeavor for an amateur with the right equipment and time to monitor the Moon for the few hours around first and last quarter each lunation cycle.

11 Directional cosmic ray detector

These next set of projects do not involve meteor research, but would use the typical video meteor camera setup as a starting point. A low-cost directional cosmic ray detector is a concept originally put forward by Damir Segon of the Croatian Meteor Network. It recognizes the fact that the low light cameras in use by amateur meteorists are sensitive to the secondary high energy particle shower that reaches the ground when a cosmic ray interacts with the Earth's atmosphere at tens of kilometers altitude. They typically show up as various length streaks on the focal plane image, sometimes jagged, that do not possess the point spread function blurring due to the normal lens optical train degradation. The streak length depends on the entry angle to the focal plane surface. It is proposed that a directional capability for detecting these tracks can be built by placing two imaging chips (board cameras or lens-less box cameras) face-to-face in a totally dark enclosure and let software monitor the two imagers for coincidental bright pixel traces. The relative spatial offset in row and column plus the face separation between the two focal planes, can be used to determine the angle of arrival. The high energy secondary particles being detected will easily pass through the electronics behind the focal planes. Lead shielding around the perimeter would help reduce off-axial false alarms in any given camera, but the coincidence in time processing will mostly mitigate this effect.

12 MACHO detection

Massive compact halo objects, or MACHOs, are postulated to be Jupiter sized planets that have been ejected from their originating star system and wandering through our galaxy. Their angular extent is sufficient to eclipse a distant star for a brief period time. Robert Hawkes proposed using an intensified video meteor camera that could easily see 400 stars in a single FOV, as a 400 channel photometer to try an detect an occultation (Parker et al., 2004). With the sensitivity of today's non-intensified cameras the same experiment can be tried using a pair of cameras at least one meter apart. The two camera setup is to ensure a time coincident event occurs on the same star and the occultation is not a false alarm from atmospheric scintillation or intervening flying wildlife. One recommendation is to use a dense star field, open cluster, or large globular cluster to maximize the number of star "channels" and increase the odds of an occultation.

13 Bird migration

There is also an interest in the ornithology field about bird migration and calibrating bird populations seen in radar returns. Initial experiments in even dark skies with no Moon or nearby city lights shows that birds present a brighter signature than the background sky. This is likely due to their heat signature in the near IR being picked up by today's Exview HAD II sensors. As in meteor work, ornithologists are interested in speed and altitude. But since the altitudes are at most a few hundred meters, the camera separation baseline can be much smaller, Designing a system for wide area coverage and the corresponding data reduction software, would be most welcome by the bird watching community.

14 Summary

In summary, there are many meteor related projects outside of the normal moderate and all-sky collection systems in common use today. Any thoughts on further exploration of any one of these or alternative ideas on a better approach are most welcome by the author. The author would like to thank Damir Segon and his Croatian Meteor Network team, Dr. Robert Hawkes, Dr. Peter Jenniskens, Dr. Robert Suggs, Dr. Alan Hildebrand, Dr. Peter Brown, and Dr. Margaret Campbell-Brown for many stimulating discussions over the years that have led to the formation of this project compendium.

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