Video Astrometry

A guide for:

Astrometrists who are unfamiliar with video observing techniques

and

Video occultation observers who are unfamiliar with astrometry

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Introduction

The prime tool for obtaining astrometry of moving objects such as asteroids is a CCD camera. The camera is typically controlled by software that triggers the exposure, reads the data from the CCD chip, and creates a FITS file with exposure details in the header. This file can then be read into software that identifies stellar images, matches them to star catalogue positions, and outputs a precise measurement of the position of any user-selected object in the image.

Typical accuracy of CCD astrometry is of the order of $0.3''$. [See the lists at http://www.cfa.harvard.edu/iau/special/residuals.txt.] The typical main-belt asteroid has a motion of less than 1 arc-sec per minute. Consequently for most astrometry of asteroids, errors arising from any uncertainty in the time of the image are of smaller significance than the measurement errors.

However, for asteroids that come close to the Earth, the motion can become much greater. For example, the motion of asteroid 2009 DD_{45} peaked at $1563''$/minute, or $26''$ per second. At this rate of motion, an astrometric accuracy of $0.3''$ corresponds to 10 milliseconds. Such rapid motion creates a range of problems for traditional CCD camera arrangements, such as:

- in order to prevent image trailing, very short exposures are required (< 0.1s) and these are beyond the capability of CCD cameras.
- the problems of measuring accurate positions from the ends of a trailed image;
- time base. 10-millisecond accuracy is not attainable from short-wave radio transmissions such as WWV [variable propagation delays are of greater magnitude]. Time over the internet using Network Timing Protocol (NTP) is good to 10msec if you have a fast internet connection and use a local NTP server; 50msec is what you might achieve on a slow connection and/or remote server. [This is independently measured data; don't rely on the self-assessed uncertainty provided by the NTP software.]
- the relationship between a mouse-click to commence the exposure, and when the exposure actually occurs – together with when the time is measured. For example, in a camera where the exposure is controlled by software, does the software take the time when the exposure actually occurs, or at some other point in the process (such as when the CCD is being cleared prior to exposure commencement). To what extent is the time read by the CCD software affected by computer system interrupts? [In Windows®, the displayed desktop clock can be late by up to several seconds because of interrupts – even though the actual system clock is on time.] In a camera with a mechanical shutter, is the time taken when the command is sent to actuate the shutter, or when the mechanical bits of the shutter actually move? And is the mid-time of the exposure constant across the CCD (a potential issue particularly for blind shutters)?

Analysis of CCD observations of 2009 DD$_{45}$ suggest the existence of timing errors of between 0.4 and 1.4 secs, with the variance (for different observatories) ranging between 0.04 and 0.4 secs)

For normal CCD imaging, these issues are of no significance. But with a fast-moving object, the uncertainty arising from these issues can dominate the uncertainty of the measurement. Most observers do not have the means to test their equipment to establish the relationship between reported exposure time and actual exposure time to anything less than a large fraction of a second.

In the last 5 years video has become the tool of choice for people observing occultations of stars by asteroids – the aim being to accurately measure the size and shape of the asteroid. A recent example is at:
http://www.asteroidoccultation.com/observations/Results/Data2008/HerthaProfileNEWcolor.jpg
The video cameras used were developed as security cameras – although some models are now being marketed specifically for astronomical use. The observation entails accurately recording the time a star disappears and reappears as seen from a number of locations. For that purpose accurate time is obtained from the GPS satellite system, and is inserted into the video stream from the camera – enabling images to be time-stamped with a precision of about 1msec.

Video cameras are not ideal tools for astrometric measurement. In a usual CCD camera the data from the CCD is read out in an ordered fashion to create a FITS file. In a Video camera, the output is a composite video signal corresponding to the standard height and width of standard TV images – and the CCD output has to be mapped to the scanning lines required. However, when an object is moving fast, any uncertainties arising from these transformations are less than the uncertainty associated with using a traditional CCD camera.

A video of a fast-moving asteroid (2009 DD$_{45}$) can be viewed at:
 http://www.youtube.com/watch?v=_RKKgMDK7A4
The image is centred on RA 9^h 57^m 30^s, -51° 50'. The field size is about 14' x 10'. The asteroid is moving at about 500″/minute. It was taken on a 35cm Meade SCT scope with a Watec 120N+ integrating camera, integrating 4 frames. The limiting magnitude is about 12.9. A frame from that video, as loaded into Astrometrica, is:
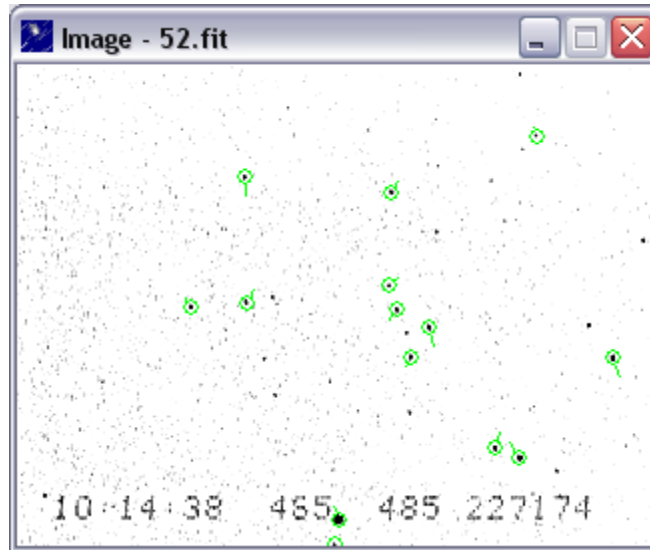
The asteroid is near the right edge of this field, above and to the left of the right-most reference star. The time stamp at the bottom of the image is 10h 14m 38.465s UTC. Nine astrometric positions reported on MPEC 2009-F01

http://www.cfa.harvard.edu/mpec/K09/K09F01.html

were measured from images like this derived from this video; those positions have an RMS residual of less than 0.3″. Altogether 32 astrometric positions derived from video have been published –13 from video taken by Hristo Pavlov and measured by John Broughton, and 19 by Dave Herald. The residuals are consistently small across different fields covered by the video, and the two different video observers.

In considering the relative sources of error between using a CCD camera and a video camera, it may be expected that the enhanced timing precision associated with a video camera will lead to it being the preferred astrometric tool if the motion of an asteroid is greater than about 100″/minute.

This guide is provided in recognition that the usual CCD astrometrists has no experience with video techniques and terminology, and that video occultation observers generally have no experience with astrometric measurements.

In putting this guide together, I am naturally going to have regard to the software and equipment that I use myself. In particular, the astrometric software I use is Astrometrica – a program which is dedicated entirely to astrometry – and so is well optimised for that task. It is shareware, and costs EU25. See http://www.astrometrica.at/

I would like to acknowledge the following people who have critiqued or otherwise assisted in putting this guide together.

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Video techniques for the astrometrist

In this section I shall outline what is required to get a FITS image that the astrometrist can measure.

Overview

There are three basic processes of converting a video observation to a FITS file for measurement, depending on the hardware used.

Processes for converting a video observation to a FITS file

# 1	# 2	# 3
Video camera, composite video output, GPS time inserter	Video camera, composite video output, GPS time inserter	Video camera, composite video output, GPS time inserter
Analogue video recorder (such as a VCR or Handicam)	Digital video recorder (such as newer Handicams, or Digital Video Recorder)	
Device on Computer to convert Composite video to an AVI file	Software to convert proprietary file formats to an AVI file	Device on Computer to convert Composite video to an AVI file
Software to convert AVI file to FITS	Software to convert AVI file to FITS	Software to convert AVI file to FITS

Typically the video will be recorded on a recorder of some type before segments of the recording are transferred to a computer. Reason – video files are large. A two-minute uncompressed video stream will create an AVI file of the order of 1GB.

The step that is the cause of most problems with using video is transferring the video to a readable AVI computer file – particularly if you run into problems with the Codec. But any such problems are strictly limited to the initial setting up. [They are also most likely to occur if you record to a digital video recorder or handicam.]

The issues to be considered are:
- the video camera
- accurate time source and linkage
- transferring the video to a computer file
- creating a FITS file

The video camera

Video standard

There are essentially two video standards used around the world. NTSC is used in North America and Japan. PAL is used in Europe and Australasia. When buying a camera, it is preferable (but not essential) to buy one consistent with your national TV standard. However a different nomenclature is typically used with small video cameras:
- EIA (which is NTSC), and
- CCIR (which is PAL).

The simple technical difference between EIA and CCIR (that is, between NTSC and PAL) is in the frame rate, and scan lines per image. [There are major differences in how colour is handled – but they are of no interest here.] The differences are.

	NTSC/EIA	PAL/CCIR
Frame rate	29.97	25.00
Scan lines	525	625

Two interesting issues arise from this. NTSC gives a better time resolution. PAL gives a better spatial resolution.

The composite video signal generated by the camera has various synchronisation pulses that maintain an accurate relationship between the signal components over the whole image. One set is for the start of each vertical scan of the image. Another set is for the start of each horizontal scan line. The processing of the data from the CCD involves a mapping of the CCD pixel array onto the standard format of a TV display. The subsequent processing needed to get a FITS image involves a further mapping to the video image format used in the AVI file created on the computer, and then a transfer to a FITS image to be measured.

Field structure

In a typical CCD camera, the image is exposed, and then the data is read out line by line of the CCD chip.

The architecture of a video camera is different. The video stream is made up of frames, with each frame being composed of two fields. The CCD chip is exposed and read in an interlaced manner. For the first half of a frame, the odd lines are exposed, while the even lines are read. In the second half of the frame the odd lines are read and the even lines are exposed. These are combined sequentially to make the 'composite video signal' that is output and can be played on your normal TV. While it is possible to extract each field separately, for astrometric purposes it is best to work with the composite interleaved frame.

Camera types

There are three types of cameras that can be used:

- **Non-integrating camera**. These are the cheapest cameras and can be bought for about U$100. There are still improvements in sensitivity being made with new models. A camera like the PC123CEX-2 can detect stars to about mag 13 on a 20cm scope.
- **Running-average Integrating camera.** One form of integrating camera includes a First-In-First-Out buffer. The normal video stream is passed into the buffer, and the output video stream is based on the sum of a number of frames in the buffer. This provides increased sensitivity and improved signal to noise. Typical of this is the GStar camera. (http://www.myastroshop.com.au/guides/gstar/index.htm).
- **'True' integrating camera.** In this type of camera, the CCD is not read at the usual frame rate. Rather the image is built up on the CCD for a number of frames before being read. And that image forms the basis of the output composite video signal until the next read of the CCD chip. For example, if the integration is set to 32 frames on a PAL system (which is 25 frames/sec), the image displayed on the monitor will change every 32/25 secs (1.3 secs). The advantage of this type of camera is lower readout noise, as the CCD is only being read once per integration rather than at the normal frame rate. Typical of this camera is the Watec 120N+ (http://www.watec.net/english/bw/wat_120n+.html) This costs around US$800

Good astrometry requires a reasonably well-exposed image to measure. For this reason an integrating camera is strongly preferred, as it allows you to adjust the image density at the telescope by changing the integration interval – keeping a balance between short duration and image density. Personally, I use the Watec 120N+ camera. Note that digitisation of the signals into an .avi file results in an 8-bit signal – compared to the usual 16-bit that is provided by a typical CCD camera.

These small video cameras are supplied with a "C" type mounting thread. C-mount to 1¼-inch eye-piece adaptors are available from numerous astronomical equipment outlets.

When used on a long focal length telescope, observers usually insert a focal reducer in the optical path. This increases the field size, and better matches the stellar image size to the pixel size. The video referred to on pages 4 and 5 was taken on a Meade 14" telescope using a 3x focal reducer.

Typical non-integrating video camera

Watec 120N+ control box, camera body, and 1¼" adaptor
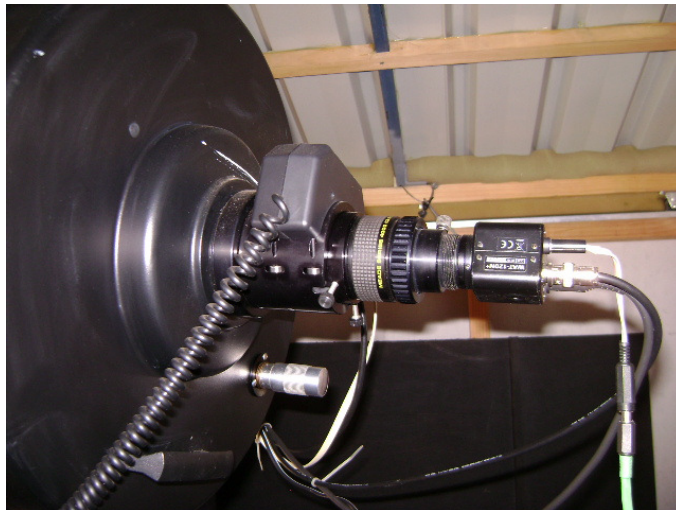
Watec 120N+ camera on 14" telescope

The time source

The best source of precise time is the GPS system, where time to an accuracy of a microsecond (UTC) can be extracted at any time and location. The approach to associating accurate time with the video image is to extract time from the GPS satellite system, and electronically insert it into the video stream. While over the years there have been several devices built to achieve this, the one device that has stood the test of time and is highly recommended, is the KIWI-OSD system (http://www.pfdsystems.com/kiwiosd.html)

This system, together with the relevant Garmin GPS, costs US$260. It was designed by Geoff Hitchcox of New Zealand - hence KIWI in the device name. (OSD stands for On Screen Display). It is manufactured in the USA. It operates as follows:

1. The Garmin GPS engine generates a 1 PPS signal - accurate to UTC to better than a microsecond. This is used to control an internal time counter.
2. The video signal from the camera is connected to the device.
3. The device monitors the video signal for vertical synchronisation pulses – which occurs at the start of each FIELD that is output from the camera (2 fields per frame) That pulse is used to trigger a read of the internal time display – and this time is inserted into the video stream at the bottom of the field with a millisecond precision.
4. The video stream with the inserted time is provided on an output to your video recorder.

End result – a video stream which is accurately time-stamped based on the vertical synchronisation pulse of each video field created by the camera. By this method, a timing precision of about 1 msec can be reliably associated with images. Note that the time stamp requires a correction to refer to the midtime of the exposure. The correction is camera dependant. Its determination is explained in the manual that comes with the KIWI system – under the heading 'Calculating your Camera's Personal Equation (PE)'.

Garmin-18 GPS unit, and KIWI system

Recording

There are several approaches to recording the video signal. For occultation work, portability is a key factor for observing 'in the field'. For observatory situations simple (and cheaper) VCR's are a sensible option. The basic approaches are:

Record to a video cassette recorder (VCR). Advantages – cheap, reliable. Disadvantage – not very portable, and may become obsolete technology in the near future.

Record to a handicam. Some hand-held video cameras can record the video signal from another camera. These can often be bought on EBay for a low price – but you need to get a camera of the right model. [eg Canon models MV400i to MV800i]

Record to a digital video recorder such as that described at:
http://www.hristopavlov.net/Articles/DigitalVideoRecorder.html

Record directly to a computer. For this you will need a device discussed in the next section. Importantly, video processing is very intensive on computer resources. You should ensure you are using a computer with CPU power equivalent to or better than a 1.5GHz P4 computer, and have no other significant programs running that might divert system resources. But remember that video will create huge files very quickly!

Transferring the recording to a computer .AVI file

The end objective is to have an '.avi' file corresponding to the video.

If you have recorded to a digital handicam, you will have a computer readable file. If the file is in a proprietary format, you will need to read the camera's manual to find out how to convert it to an AVI file. This option is also the one most likely to lead to Codec problems – see below.

If you have recorded the video on an analogue device (such as a VCR, or an analogue handicam), you will need a hardware device to convert the composite video signal to an AVI format. Possibilities are:

- A TV tuner card – as long as it has a Composite Video signal input. [This is probably the cheapest option.]
- A hardware device such as the Belkin HiSpeed USB2 DVD Video Input Adaptor (http://www.ciao.co.uk/Belkin_Components_Belkin_Hi_Speed_USB_2_0_DVD_Creator__5433344)
  There are a range of such devices on the market. They are often referred to as video grabbers or frame grabbers. Many (including the Belkin) merge the two fields of each frame. More information about grabbers (of a technical nature) is given at:
  http://www.dangl.at:80/ausruest/videogrb/vidgrb2_e.htm

The end result of the conversion is an AVI file.

When converting a video to an AVI file, you need to remember that it is a very intensive process. If the computer fails to keep up with the video stream, the result can be dropped frames, or duplicated frames. For this reason, you should:

- use a computer with a reasonably fast clock speed. A computer with CPU power equivalent to or better than a 1.5GHz P4 computer is preferable.
- if you are using a converter device that connects via a USB port, use a port that is connected to the mother board. Avoid connecting the device through an external USB hub.
- the hard drive the AVI file is being written to should not be in need of de-fragmentation. A heavily fragmented disk will slow down the writing speed, and can create a bottleneck for processing the video stream.

Once you have your AVI file, you need to note that not all AVI files are the same. An AVI file is fundamentally a holder for a series of images corresponding to each frame (or field) of the video. Within that holder there are numerous ways of compressing the image. The software for compressing and decompressing the images is referred to as a Codec. Your computer will have a range of Codecs already installed. If you have trouble viewing or converting your AVI file, the cause will almost certainly be that you do not have the relevant Codec on your computer. If this is an issue, the solution is to find and install the right Codec. Most of the modern video recorders use either DivX or XviD encoding – so you should ensure you have those two installed. If you still cannot play the video then download a free program called G-Spot (http://www.headbands.com/gspot/) that will identify the Codec used by a video and will direct you to the relevant company so you can download it. For more information see **Dealing with video codecs when processing video observations** at
http://www.hristopavlov.net/Articles/VideoCodecs.html

Software to control the transfer/recording

While a hardware device is generally required to take the composite video signal and convert it to an AVI file, you will also need some software to actually perform the process.

Many devices (and cameras) are supplied with software like **ULead Video Studio** – which is general purpose video editing software. Unless you want to process home videos, almost all of the features provided in such packages are of no interest – and the program files are large. There is no need to use such packages.

The best software to use is a GNU package called VirtualDub, available at:
http://www.virtualdub.org/index
Under the **File** menu item there is an item '**Capture AVI**'. It is from here that you can create an AVI file from your composite video recording. Two menu items to note are:

- **Video… Compression**. An uncompressed video file will run to about 1GB per minute or two. If you have Codecs installed on your computer, they will appear here. Compression will reduce the file size considerable. However for astrometry you may want to avoid any unnecessary processing.

- **Video… Levels**. Here you can adjust the brightness and contrast that is applied in the transfer stage – assuming the transfer device has such controls available. The settings here are useful to ensure your image is as clear as possible. Remember that the AVI file encodes the signal to 8 bits. I usually have contrast set to maximum. The brightness level might need to be adjusted if there is significant background illumination (such as images taken near full moon).

Note that you can use VirtualDub to control direct recording to your computer. You start the recording by pressing F5 (or F6), and end it by pressing ESC. The amount of disk space being consumed is continually displayed.

Software to create FITS files

The final step is to create FITS files that can be used in you astrometric software. The most convenient package I am aware of is the freeware package IRIS, available at: www.astrosurf.com/buil
Once installed, you need to set a working directory where files will get created [the default is set as the root directory…] Under **File… Settings**, set the '**Working Path**' to where you want the FITS files to be created.

To convert the AVI file to FITS files, click **File… AVI conversion**. Select the AVI file to convert, then click **Convert**. The program will now create a series of FITS files corresponding to each frame in the video. So you now have a series of precisely **time-stamped** FITS files that can be measured using your normal astrometric package. Note that the time information is not contained in the FITS header, and the time stamp will require a correction to refer to the middle of the exposure.

Astrometry for the video observer

Astrometry is a well established observational activity. Video observers should treat the following documents as **mandatory** reading:

- Guide to Minor Body Astrometry
  (http://www.cfa.harvard.edu/iau/info/Astrometry.html)

- How to report Astrometric Observations
  (http://www.cfa.harvard.edu/iau/info/TechInfo.html)

- Observation submission format
  (http://www.cfa.harvard.edu/iau/info/ObsFormat.html)

Video observers should also make themselves familiar with the MPC Ephemeris Service
(http://www.cfa.harvard.edu/iau/MPEph/MPEph.html)

Observers might also find it useful to browse the Index page of the Minor Planet Center
(http://www.cfa.harvard.edu/iau/TheIndex.html)

This guide assumes you have thoroughly read and understood the above documents. The focus will be on outlining what is required to get a FITS image from an AVI file. It is also assumed that the video observer knows how to obtain an AVI file from their video camera which can be read in software such as LiMovie
(http://www005.upp.so-net.ne.jp/k_miyash/occ02/limovie_en.html).

Overview of astrometry

Astrometry is the determination of an object's right ascension and declination. The problems to be solved are:

- The sky is a sphere – and the projection of that sphere onto a plane involves some distortion.
- the focal plane of the telescope might not be flat. Typically a SCT telescope will have a curved focal plane with consequential aberrations – and these distort the image.
- atmospheric refraction results in distortion in the vertical direction.
- the image plane might not be exactly normal to the optic axis of the telescope, introducing some distortions.

When these issues are considered from a theoretical perspective, they can be adequately modelled using a linear or quadratic relationship between measured coordinates and the objects position in the sky. The coefficients of the derived equations are referred to as the 'plate constants'. The astrometric process involves determining the plate constants using

known reference stars, and then using those constants to determine the position of any other object on the image.

There is an important planning issue associated with astrometry. Firstly, the minimum number of reference stars is three. Preferably, there should be quite a few more so that a least-squares fit can be performed. Secondly, imagine straight lines joining all the reference stars. You will be able to get good quality positions for anything contained within the outer boundary of those lines. But the accuracy rapidly degrades as you move outside of those bounds. For example, if there were three stars on one side of the image, and you were measuring the position of an object on the other side of the image, the accuracy of the measurement would be so poor as to make the measurement almost useless.

Consequently some care is required in pointing the telescope – to ensure that there are reference stars surrounding the asteroid.

A related issue is the orientation of the image. To fit the reference stars to the image, the astrometric software needs to approximately know the North direction on the image. If your scope is polar mounted, it is desirable to orient the camera in a consistent orientation with north at the top of the image. If you are using an alt-az configuration, it will be hard to align the camera with north at the top. Furthermore the orientation will change if the imaging extends for more than 5 or 10 minutes. As a result, you will need to adjust the astrometric software to identify the north orientation for each set of images being measured.

File format

The universal file format for astronomical images (and certainly for astrometric measurement) is FITS. Typically, a FITS file will store the values of each pixel in a CCD camera in an array corresponding to the CCD pixel array, and the astrometric software analyses the image on that basis.

To get an image that can be measured, you must convert the frames in an AVI file to FITS images. The most convenient package I am aware of is the freeware package IRIS, available at:
www.astrosurf.com/buil
Once installed, you need to set a working directory where files will get created [the default is set as the root directory…] Under **File… Settings**, set the '**Working Path**' to where you want the FITS files to be created.

To convert the AVI file to FITS files, click **File… AVI conversion**. Select the AVI file to convert, then click **Convert**. The program will now create a series of FITS files corresponding to each frame in the video.

There are other packages that will allow conversion from an AVI file to FITS file – such as Registax version 4 or later. (http://www.astronomie.be/registax/) It can also be done by

displaying the video on screen, copy the image area to the clipboard, paste into Paint as a BMP file, load the bmp file into a general-purpose image processing package such as AstroArt, and save as a FITS file from there. However the IRIS conversion is MUCH easier.

> **IMPORTANT**. The FITS file format includes an extensive header region. In normal CCD astrometry, the date and time of the exposure will be written to the header – and the astrometric software reads that information for a number of purposes. The conversion processes above do not write any date and time information to the header.

At this point, you have a FITS image that is ready to be measured.

Setting up Astrometrica to measure the image

Image orientation

Astrometrica needs to know whether the image needs to be flipped up/down, left/right, or both. This is needed to cater for the full range of CCD cameras. With Video, the output signal is ordered the same for all cameras. The relevant setting is contained in **File… Settings… CCD** tab.

If you have your video oriented so that North is to the top of the video image, AND your optical path includes an EVEN number of reflections (eg a SCT with no diagonal), the required settings are:
- Flip horizontal – clear
- Flip Vertical - check

If you have an odd number of reflections, and North is to the top, the required settings are:
- Flip horizontal – check
- Flip Vertical - check

> Note: The Flip Vertical option must be checked, even though your FITS image is oriented with North at the top,

Star catalogue

Astrometrica needs to access a star catalogue to retrieve star positions. The best catalogue to use (because of star coverage at the bright end) is NOMAD. Set this in the **File… Settings… Program** tab. Also set the lower limit to 13 mag or brighter – to avoid faint stars being matched to noise on the image.

Pixel size

Astrometrica needs to know the pixel size of the camera, in microns – under **File… Settings… CCD** tab. For the Watec120N+, the width is 8.6, and the height is 8.3. Other video cameras have a similar pixel size. It is not critical that these be specified correctly – in fact, below we will discuss changing the pixel width to compensate for one aspect of video signal processing.

Initial focal length

Astrometrica needs to know the focal length of the system – under **File… Settings… CCD** tab. Start off with the telescope focal length. Divide that by the effect of any focal reducer.

Adjusting focal length and image orientation

Astrometrica needs a reasonably accurate effective focal length to determine the correct scale, and the image orientation to fit the stars to the image. The pixel width also needs to be adjusted to compensate for scale changes that arise in the video image processing.

To achieve this:
- load a FITS image into Astrometrica [**File… Load**]
- If you have trouble seeing any objects on the displayed image, adjust the **Background and Range** (under the **Images** menu item) so that the background has little noise displayed, and the stars are clearly visible.
- Under **Astrometry**, click **Data Reduction**. In the dialogue box that appears, specify the approximate RA and declination of the center of the image (to about 5 arc mins accuracy). NOTE – for south declinations, do not use '-'. Click **OK**

It is unlikely that Astrometrica will be able to make a fit to the image – and in fact the following steps depend on Astrometrica not making a fit to the image. When Astrometrica cannot automatically fit an image, it comes up with a dialogue box giving three options. Select the first option – Manual fit.

First, you need to adjust the focal length until you see a pattern of stars that matches the stars on the image. If you have lots of stars displayed by Astrometrica, reduce the magnitude on the dialogue form.

Once you have visually identified stars that match the image, adjust the focal length and orientation to fit the displayed stars to the image. Because of the way the video signal is processed, you can expect the image to be stretched or shrunk in the horizontal direction. You need to note 3 things:
- The Position Angle that aligns the displayed stars with the image orientation
- The focal length which results in a good match to the star positions in the vertical direction (Call this F1), and
- The focal length which results in a good match to the star positions in the horizontal direction (call this F2)

Having noted those values, close the dialogue box. Open the Settings menu (**File… Settings**, and go to the **CCD** tab.

At the top left,
- set the focal length to the value of F1 as found above
- set the position angle to the value of the position angle as determined above.

At the top right, change the value of **pixel width** by the ratio of F1/F2

Save the Configuration settings (you can maintain numerous configuration files). Then reload the image, and repeat the fit. Astrometrica should be able to automatically fit any images taken with that configuration, even though the precise focal length and image orientation may change. If the dialogue box appears, but the orientation and scale seem

correct, you may need to reduce the Search Radius for reference star matching – under **Settings, Program.**

Once you have a fit, you are in a position to measure the coordinates of any object on the image – remembering that you should enure the object is surrounded by reference stars.

If you are using an Alt-Azimuth mounting, or the camera has not been oriented with North at the top, **do not digitally rotate the image** before measurement. Rather adjust the Position Angle setting in the Settings area of Astrometrica so that the reference stars are suitably rotated to match the image.

> Video processing will usually result in a scale difference between the X and Y coordinates. See (for example)
> http://www.dangl.at:80/ausruest/videogrb/vidgrb2_e.htm
> This difference can be easily corrected by adjusting the setting for pixel size (as described above), provided the distortion is strictly between the X and Y axes.
>
> If the image is rotated, this scale distortion cannot be corrected by adjusting the pixel dimensions. Although the astrometric software should be able to correct for this distortion – that will depend on there being sufficient reference stars, and for the scale distortions not being so large as to prevent the software from deriving a fit to the image.

Generating normal positions

Positions measured from video must be reported as 'normal' positions. A normal position is a position that represents an average of several positions, referenced to a specified time. There are two reasons why normal positions are used:

1. The current MPC reporting format only allows the date to be specified to 6 decimal places. That is, to 1 micro-day. To obtain maximum accuracy within this report constraint, the positions need to be referenced to an integral microday. The use of normal positions allows positions to be referenced to an integral microday.
2. For a typical CCD exposure lasting several seconds or more, scintillation results in blurred stellar images. In contrast, with the shorter exposures used in video scintillation appears as spatial distortions of the image – and this needs to be corrected by combining the measurements from several images.

In principle there are numerous ways a normal position could be generated. However the Minor Planet Center has created a web script to generate the normal positions. This is located at:

http://www.cfa.harvard.edu/iau/VideoObs/VideoNormalPlaces.html

and is the required tool for generating the positions to be reported to the MPC. The script allows positions to be pasted (or keyed) into a box in 4 different formats that are similar to the standard MPC format. Once entered, the observations are returned either in a text file, or on screen, as normal positions properly formatted and ready for submission to the MPC.

The web script will handle the following four formats:

- Each line is in the usual report format – but is preceded by a line giving the observation time in h m s to 0.001 sec.
- A modified report format specifying the day fraction in h m s format rather than decimal days.
- A modified report format, with 8 decimal places allowed for the fraction of a day.
- A modified report format, with 7 decimal places allowed for the fraction of a day.

The first format is particularly useful. The header of a FITS file created from a video record will not contain the exposure date and time (unless the observer manually edits the FITS header). In this format, the date and time is specified in a line separate from the usual observation line generated by astrometric software. The normal position is derived using this separate line, ignoring any date and time specified in the usual observation line generated by the astrometric software.

Full details about using the MPC web script are given in the Appendix at the end of this guide.

Other reporting issues

In addition to using normal places, the following matters should be included in the report

- The report line that specifies the telescope used (TEL) should include the text '**+ GPS-tagged video**' following the usual telescope details. This indicates that video has been used, with high-precision timing. This tag should ONLY be used when time derived from the GPS system has been recorded on the video stream by way of video insertion.
- The character immediately before the year of the observation needs to be a lower case 'n', to indicate the position is a normal position. [The MPC web script formats the observation line with this character.]

Measurement issues

There are a number of issues that may arise in the measuring environment.

- **Image brightness range.** A normal CCD camera has the data held as 16-bit value (0 -65535). The data from the video will be coded using just 8 bits (0-255). This makes the settings for the background level and image range sensitive. If the background is too low, the image will be dominated by noise. If too high, nothing will be present. You may need to adjust it for each image measured.

    Note that Astrometrica can handle up to 25 separate images. For a sequence of images from a video, it is appropriate to load up to 25 images (as long as they are of the same field), and apply the Background Level and Image Range setting to all images (using the check box on the form.)

- **Image measurement**. The header of the FITS files created in this process does not contain any information about the exposure. You either have to add the details before you measure, or edit the report generated by the astrometric package. NOTE that for a fast-moving object, the standard report format has insufficient places to record the time accurately – the MPC format is limited to a precision of 1 micro-day (0.000001 day). In this situation, you need to generate a Normal position – see above.

    If you use Astrometrica to generate the report, note that the default time precision is 1 second = 0.00001day. To have a report prepared to 0.1 sec (1 microday) you need to adjust the precision under the Settings option of Astrometrica, CCD tab, Time in File Header. This higher time precision should be specified if the motion per minute is greater than about 10″ per minute and you have accurate time associated with the image. It should not be used for slow moving asteroids.

    > Note: while a precision of less than 0.1 secs can be specified here, that is of no effect, it being provided for future use.

- **Recording the time. IMPORTANT.** The time stamp on the video recording is associated with the vertical sync pulse associated with the displayed video frame. However that does not mean that it is the time of the exposure – and in the case of an integrated camera, it is certainly not the time of the exposure. A constant correction needs to be applied.

    Typically the time stamp will represent the time as at the end of the displayed image. However on some cameras there is a delay of one field interval before an image is output in the composite video signal. In this situation, the time stamp will be consistently 'late' by that field interval. The instructions that come with the KIWI-OSD system tell you how to detect whether the camera output involves such a field delay. It is a simple task of recording the flashing LED on the KIWI system (which is

triggered at the start of each second, to a micro-second accuracy) – and noting the time stamp when the LED comes on.

Additionally there is the correction to convert from the time at the end of an image exposure to the time at the middle of the image exposure. For a non-integrating camera, this is half the frame interval. For an integrating camera, it is half the integration period.

> **EXAMPLE** On my Watec120N+, the time stamp on each field is inserted one field interval (or 0.020 secs on a PAL camera) after the end of the exposure that is displayed. Consequently the time at the end of an exposure is 0.020 secs (PAL) earlier than the time stamp on an image. The video of 2009 DD$_{45}$ that is on YouTube used a 4-frame integration – which is an interval of 0.160 secs. The mid-time of an image was therefore 0.080 secs prior to the end of the integration period. Therefore the midtime of an image is 0.020 + 0.080 = 0.100 secs before the time stamp on the first frame displaying that image.

These issues are well explained, with useful diagrams, at:
http://www.dangl.at/ausruest/vid_tim/vid_tim1.htm

- **Image 'Stack and Track'.**
  To stack images within Astrometrica, you will need to put the exposure time in the FITS headers, so that the images can be displaced according to the asteroid's predicted motion. While many packages allow viewing the FITS header, not many allow editing. A suitable package is FV, produced by Goddard Space Flight Center. It can be downloaded from:
  http://heasarc.gsfc.nasa.gov/ftools/fv/fv_download.html
  To insert the date and time, proceed as follows:
  - Using **Open… File,** load the FITS file.
  - In a form that appears, click the **Header** button. This will display a list of tokens and values in the Header. If you have created the file using IRIS, there will be no date and time data in the Header.
  - Click any line in the list. Then from the menu, click **Edit… Insert Key**
  - The edit box is at the very bottom of the form. Insert a line like
    DATE-OBS= '2004-03-19'
    Make sure that the inverted commas are included. Note that "**DATE-OBS**" is the key for the date, and the numbers between the inverted commas is the date in yyyy-mm-dd format. Press **Enter**.
  - Again, **Press Edit… Insert Key**. This time insert a line like:
    TIME-OBS= '21:54:29.923'
    where **TIME-OBS** is the key. Make sure that the inverted commas are included. Note that in this example the time is specified to 0.001 secs. Press **Enter**, and then **File… Save**

> **Note 1.** The author of Astrometrica has confirmed that Astrometrica uses the full precision of the exposure time as entered in the header, even though the time given in the report is limited to 1

microday. That is, the Track and Stack function will work properly with images separated by (for example) 0.04 secs.

If you use a different astrometric package, you will need to confirm with the author that it will read and use exposure times to a precision of 0.001 secs.

Note 2. Astrometrica includes a facility to generate the approximate position and motion of an asteroid, which is usually used for the Track and Stack function. While that position is corrected for parallax, it is based on the osculating orbit. Fast moving asteroids are (by their nature) passing close to the Earth – such that an osculating orbit may be inadequate. Additionally, such objects are typically discovered only a few days previous, and the orbits are poorly known and subject to frequent improvements. Accordingly you should generate a topocentric ephemeris of the asteroid using the MPC Ephemeris Service at:

http://www.cfa.harvard.edu/iau/MPEph/MPEph.html

to generate an ephemeris. This ephemeris will be based on the latest available orbit. It also includes the instantaneous motion in the format used in Astrometrica for the Track and Stack function.

- **Is it appropriate to use the software Registax to stack several video images?**
  Registax is a very useful utility for processing video images. Virtually all images of planets that show incredible detail are obtained via video processed with Registax. Registax is available at http://www.astronomie.be/registax/ . However the stacking performed by Registax assumes stationary objects. With a fast-moving asteroid, the stacking will result in either a trailed asteroid, or trailed reference stars – either of which results in a significant loss of measuring precision. For this reason, any stacking should be done in the astrometric package such as Astrometrica – where the reference star positions are extracted from the individual frames, and the images are displaced by the theoretical motion of the asteroid.

  However if the video is from a 'true' integrating video camera, where the output is a series of identical frames – there is a role for the Registax type of stacking. The output signal from such a camera has noise arising from the CCD and the read process, plus noise added during the subsequent signal processing. As a result, in any sequence of 'identical' images the star information is the same, the CCD read noise is the same, but the output noise varies from one frame to the next. A stacking of the identical frames will result in improved signal to noise over the output noise, and may lead to a better image to measure.

  Registax provides extensive tools for correcting images, using wavelet filtering. Working on the basis that images should not be 'processed' before measurement, this type of processing by Registax should be avoided unless it is absolutely necessary in order to get a measurable image.

- **Should I solve the plate constants using a cubic or fourth order fit?**
  In short – **NO**. The use of high-order solutions with the relatively small number or reference stars that will be available on a video image will likely degrade the quality of the measurement. The solution makes a least squares best fit to average out all

sorts of errors and distortions. High-order plate constants derived using a relatively small number of stars reduces the effectiveness of the averaging, and distorts the fit to align with the errors and distortions.

- **When I transfer the video to my computer, the image size is quite small.**
  If you find that when you display the AVI file on your computer, the image seems very small or highly distorted, it is likely that the cause is associated with settings in the hardware device or the software being used to transfer the video to your computer.

  If you are unable to find the cause, the freeware AviSynth may provide a solution. AviSynth is described at http://avisynth.org/mediawiki/Main_Page and can be downloaded from that location. It is a powerful utility that uses a scripting system to specify the manipulation to be done when the AVI file is read.

  However, working on the basis that an image should have minimal manipulation if it is being used for astrometry, AviSynth should not be used unless it is absolutely necessary.

- **With a 'true' integrating camera, how do I determine which is the first frame of a series of identical frames?**
  Accurate timing with a true integrating video camera depends upon being able to identify the first frame in a series of 'identical' frames that are output in the composite video signal.

  In fact, the frames are not strictly identical. While the image noise and CCD read noise is constant, noise is added as a result of the processing to generate the composite video output. Consequently when a series of images are viewed, there will be some components of noise that change with each displayed frame, and other components of noise that only change when the integrated image changes.

  Astrometrica can be used to identify the frame where the integrated image changes. Simply load a series of sequential FITS images into Astrometrica, and use the **Tools… Blink images** function to blink the images. Changes in the noise make it very easy to identify the frame where the integrated image changes.

  Having identified such a frame on the video, you can identify subsequent frames simply by adding a multiple of the number of frames being integrated.

  * * * * *

Appendix

Generating normal places using the MPC web script

The MPC web script for generating normal places is located at:
http://www.cfa.harvard.edu/iau/VideoObs/VideoNormalPlaces.html
All questions concerning the script should be directed to the Minor Planet Center.

Basic operation

- The observations to be normalized are entered as a group of observations;
- Typically use between 5 and 12 observations to create a single normal position. [However the script will work with between 2 and 100 observations]
- The script can generate a normal position for more than one group of observations. Merely ensure there is a blank line between each group of observations. Up to 300 observations can be handled by the script in a single query.
- Each normal position must be based on observations made over a period of less than two seconds. If the time span of the observations in any group exceeds 2 seconds, the output will include a warning message immediately prior to the affected normal position.
- Output can be to either a text file (the default) or to screen.
- The normal positions are correctly formatted for submission to the MPC. Merely incorporate the normal positions into an email to the MPC. Make sure that the usual other lines in the MPC report are included, but the individual positions used to create the normal positions are excluded.

Formatting observations for input

The web script to generate normal places will accept four different formats. All formats are variants of the standard format for reporting observations to the MPC. This means that when you measure the positions using your favourite astrometric package, you can generate an MPC report from that package, copy and paste the observations from that report into the web form, and then make the minimal editing changes to add the observation time with the required extra precision.

Format 1 – extra header line
In format 1, the time of the observation is specified in a line immediately preceding the observation line. This format has the advantage of not relying upon the date and time information in the observation line generated by the astrometric software. The following three lines compare Format 1 (the first two lines) with the usual MPC format, with the observation time being 10h 14m 36.365s.

```
#time 2009 03 02 101436.365
     K09D45D  C2009 03 02.42681009 56 54.57 -51 50 57.4                Z99
     K09D45D  C2009 03 02.42680909 56 54.57 -51 50 57.4                Z99
```

The format of the line specifying the time is:
#time_yyyy_mm_dd_hhmmss.sss
with '#time' being a tag (which must be in lower case).

If the FITS header does not include any date and time information, Astrometrica populates the date and time in the MPC report using the date when measuring the image, with the fraction of the day set to zero. Consequently an observation measured from a FITS image having no date and time information will look like the following when copied into the web script:

```
#time 2009 03 02 101436.365
     K09D45D  C2009 03 27.00000009 56 54.57 -51 50 57.4                    Z99
```

The time for the normal position will be based entirely on the header line.

Format 2 – specify hour, minute, second in the observation line
In format 2, the field giving the observation time as a decimal fraction of a day is replaced with the observation time in hours, minutes and seconds. The format is:_hhmmss.sss_. Note the leading space, which is where the decimal place would normally occur, and the trailing space. The following two lines compare Format 2 with the usual MPC format, with the observation time being 10h 14m 36.365s.

```
     K09D45D  C2009 03 02 101436.365 09 56 54.57 -51 50 57.4                Z99
     K09D45D  C2009 03 02.42680909 56 54.57 -51 50 57.4                     Z99
```

Format 3 – specify the fraction of a day to 8 decimal places
The MPC report format allows 6 decimal places for the fraction of a day. Format 3 expands the space for the fraction of a day by two decimal places. Additionally a space is added between the end of the day fraction and the start of the field for hours of right ascension. The following two lines compare Format 3 with the usual MPC format, with the observation time being 02.42680978 days.

```
     K09D45D  C2009 03 02.42680978 09 56 54.57 -51 50 57.4                  Z99
     K09D45D  C2009 03 02.42680909 56 54.57 -51 50 57.4                     Z99
```

Format 4 – specify the fraction of a day to 7 decimal places
The MPC report format allows 6 decimal places for the fraction of a day. Format 4 expands the space for the fraction of a day by one decimal place. Additionally a space is added between the end of the day fraction and the start of the field for hours of right ascension. The following two lines compare Format 4 with the usual MPC format, with the observation time being 02.4268098 days.

```
     K09D45D  C2009 03 02.4268098 09 56 54.57 -51 50 57.4                   Z99
     K09D45D  C2009 03 02.42680909 56 54.57 -51 50 57.4                     Z99
```

Constraints

- If a group of observations contains only one observation, the output will include an error message, and no corresponding position for that group.
- If more than 100 positions are included in a group, a warning message will be generated – with excess positions in that group being ignored.
- If more than a total of 300 positions are included, a warning message will be generated – with excess groups and positions being ignored.

Example

The following 4 groups of observations are formatted in accordance with each of the accepted formats. The observations in each group are identical. You can copy and paste the entire 4 groups of observations into the form, and generate the normal position for each group.

Note: when copying text from a PDF document, leading spaces and blank lines are dropped. Consequently you must ensure that the five spaces at the left, and the line breaks between the groups, are re-instated when the text is pasted into the web form.

```
#time 2009 03 02 101436.365
     K09D45D  C2009 03 02.42681009 56 54.57 -51 50 57.4                     Z99
#time 2009 03 02 101436.525
     K09D45D  C2009 03 02.42681209 56 54.68 -51 50 57.6                     Z99
#time 2009 03 02 101436.685
     K09D45D  C2009 03 02.42681309 56 54.84 -51 50 56.7                     Z99
#time 2009 03 02 101436.845
     K09D45D  C2009 03 02.42681509 56 54.94 -51 50 56.2                     Z99
#time 2009 03 02 101437.005
     K09D45D  C2009 03 02.42681709 56 55.09 -51 50 55.8                     Z99
#time 2009 03 02 101437.165
     K09D45D  C2009 03 02.42681909 56 55.18 -51 50 56.2                     Z99
#time 2009 03 02 101437.325
     K09D45D  C2009 03 02.42682109 56 55.34 -51 50 55.5                     Z99
#time 2009 03 02 101437.485
     K09D45D  C2009 03 02.42682309 56 55.50 -51 50 54.3                     Z99

     K09D45D  C2009 03 02 101436.365 09 56 54.57 -51 50 57.4                  Z99
     K09D45D  C2009 03 02 101436.525 09 56 54.68 -51 50 57.6                  Z99
     K09D45D  C2009 03 02 101436.685 09 56 54.84 -51 50 56.7                  Z99
     K09D45D  C2009 03 02 101436.845 09 56 54.94 -51 50 56.2                  Z99
     K09D45D  C2009 03 02 101437.005 09 56 55.09 -51 50 55.8                  Z99
     K09D45D  C2009 03 02 101437.165 09 56 55.18 -51 50 56.2                  Z99
     K09D45D  C2009 03 02 101437.325 09 56 55.34 -51 50 55.5                  Z99
     K09D45D  C2009 03 02 101437.485 09 56 55.50 -51 50 54.3                  Z99

     K09D45D  C2009 03 02.42680978 09 56 54.57 -51 50 57.4                    Z99
     K09D45D  C2009 03 02.42681163 09 56 54.68 -51 50 57.6                    Z99
     K09D45D  C2009 03 02.42681348 09 56 54.84 -51 50 56.7                    Z99
     K09D45D  C2009 03 02.42681534 09 56 54.94 -51 50 56.2                    Z99
     K09D45D  C2009 03 02.42681719 09 56 55.09 -51 50 55.8                    Z99
     K09D45D  C2009 03 02.42681904 09 56 55.18 -51 50 56.2                    Z99
     K09D45D  C2009 03 02.42682089 09 56 55.34 -51 50 55.5                    Z99
     K09D45D  C2009 03 02.42682274 09 56 55.50 -51 50 54.3                    Z99

     K09D45D  C2009 03 02.4268098 09 56 54.57 -51 50 57.4                     Z99
     K09D45D  C2009 03 02.4268116 09 56 54.68 -51 50 57.6                     Z99
     K09D45D  C2009 03 02.4268135 09 56 54.84 -51 50 56.7                     Z99
     K09D45D  C2009 03 02.4268153 09 56 54.94 -51 50 56.2                     Z99
     K09D45D  C2009 03 02.4268172 09 56 55.09 -51 50 55.8                     Z99
     K09D45D  C2009 03 02.4268190 09 56 55.18 -51 50 56.2                     Z99
     K09D45D  C2009 03 02.4268209 09 56 55.34 -51 50 55.5                     Z99
     K09D45D  C2009 03 02.4268227 09 56 55.50 -51 50 54.3                     Z99
```

The output generated by the script is:

```
     K09D45D  n2009 03 02.42681609 56 55.00 -51 50 56.3                     Z99
     K09D45D  n2009 03 02.42681609 56 55.00 -51 50 56.3                     Z99
     K09D45D  n2009 03 02.42681609 56 55.00 -51 50 56.3                     Z99
     K09D45D  n2009 03 02.42681609 56 55.00 -51 50 56.3                     Z99
```

* * * * *