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Drift Scan-o-Meter

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Abstract

This paper describes a new method of performing a drift scan to measure asteroid occultations. To perform a drift scan, one deliberately causes the scope tracking to drift, thus smearing the star and asteroid trails across the CCD image. I have developed a method of timing this process to better than 0.1 sec using a special gps device.

Introduction

Most asteroid occultations are recorded using a telescope equipped with a low light TV camera feeding into a tape recorder. The images are then analyzed later to determine the presence and timing of an occultation. To provide highly accurate GPS based timing, the video signal may be passed through a device that imprints each video frame with GPS time before it is recorded. It is desirable to know the UTC time and the time resolution of events to better than 0.1 sec, which this system easily provides.

An alternative method of recording the occultation is to use a telescope equipped with a CCD camera whose images are recorded in a computer. Such a camera is more sensitive than most TV cameras; however, a CCD camera is designed for long exposures (seconds to minutes) and requires many seconds to read out each exposure. Using the drift scan method, the camera may be opened (ie, an exposure begun) several seconds before the expected occultation and continued until after the occultation is presumed to occur. When the exposure begins, the stars in the field begin to build an image. If one then shuts off the telescope mount drive, the earth's rotation will move the stars across the field, thus creating star streaks. Knowing the rate of star movement and the time of start of the drift scan, one can measure the timing of any brightness dimunition (occultation). Typical drift rates are 10-15 pixels per second, so 0.1 sec. timing is entirely feasible.

There are several potential problems using drift scan:

- The starting of events (exposure start, drift scan start) must be properly coordinated (on a cold night, with the usual glitches and confusion, this is easy to get wrong)
- The timing of events to high accuracy is difficult to do by hand.
- To reduce background light in the image (ie, to improve sensitivity) it is desirable to "squeeze down" to a minimum the wasted drift time.
- Non-target stars may intrude on the drift scan, complicating analysis

The usual approach has been to start the drift, then start the exposure at a known time. Because of uncertain shutter delays, this may require some electronic or audio pickup to determine when the shutter operates, and its synchronization to a WWV or other time signal.

The purpose here is to describe a different approach. The Drift Scanometer is a simple electronic device that obtains the UTC time from a simple GPS sensor (or manually from another time source). The user enters the predicted occultation UTC time, and the required drift duration (in seconds). The scanometer computes the correct start and stop time for the drift scan. At an appropriate time before the drift is to start (eg. 5sec), the user starts the exposure (choosing an exposure perhaps 10 sec longer than the scan duration). When the UTC time matches the start scan time, the Scanometer stops the telescope clock drive via the mount guide input, thus starting the drift. At the end of the duration, the Scanometer restarts the telescope mount, and a few seconds later, the camera closes its shutter. The result is an image with streaks of the stars. Each streak will have a bright spot at each end, while an occultation will show as a brightness reduction at some point in the scan. The distance between the spots corresponds to the drift duration, so it is then easy to calculate the timing of an occultation.

In more detail, the Scanometer actually allows the user to perform drift scanning on any of the four axes because it can drive the mount relative to normal tracking just as the user manual control guide buttons can do. The user can evaluate the nearby stars that may drift overtop the target star, and choose the drift direction to minimize the problem (including going N-S or a combination of RA and Dec).

A future variant of the Scanometer will connect to a utility program in the controlling PC to allow the Scanometer to call for the exposure start and duration directly (requires use of MaximDL to control the camera). This will allow remote or unattended operation, and avoid last second operator errors.

Setting Scanometer Parameters

Control of the scanometer setting is performed by connecting a serial (9600 baud) line to the PC serial port using any terminal program on the PC. When the Scanometer is turned on, it starts a simple menu and response to set the parameters . Menu questions are

- Timing Mode--GPS or manual
- Scan Blip-cause a 2 second interruption of the scan 2 seconds into the scan, or not (provides additional timing marks and identifies the starting end of the scan).
- ScanDuration-how long you want the scan to continue in seconds. Operating with a small chip (ST7) at 1 a-s/pixel will support 50sec scans.
- Choose RA and/or Dec scan directions
- Occult Time-best estimate of the center time of the occultation, Scanometer will calculate proper scan start time.
- If in manual time setting, user will enter the Time Mark, and will push the menu button when the TimeMark has arrived.

After setting the parameters, the Scanometer will send data to the PC every second including current time, programmed scan start time and scan duration. If the GPS timing mode is invoked, the Scanometer will also send the Lat/Long and date data to the PC (saving the comm. Log will save this data).

There is a small DIP switch that allows the user to select to which lines EW/NS the control will be applied (usually East).

Operation

Here are some hints.

- Evaluate the Scan Duration. A drift scan of 60 sec will cover 15a-m of sky for an object at Dec=0. A C11 at f6.3 with a camera having 9u pixels (eg., ST7 or 402) will have about 1a-s/pixel. Thus 15a-m will cover 900 pixels. An ST7 has 765 pixels across, so 60 sec will go off the end. In practice, an ST7 (402) will support about 46 sec for an object at Dec=0 and longer at higher Dec. Operating at f3.5 will give longer scans (or use an f6.3 reducer at greater than recommended lens-CCD distance). In practice, simply direct the scope to the star field and try different scan durations to determine what you want to do.

- Guide Rate and Telescope Direction. Different mounts have slightly different behaviors on the "guide" rate, ie., the rate used by the hand buttons and the guide input cable to control the mount. You will normally want to check that the guide rate is set to 1x, ie., one times the sidereal rate. The usual drift scan goal is to stop the equatorial drive, ie., the control will actually start driving the mount 1x to the East, counteracting the 1x internal drive to the west that tracks the stars. If North is up on your image, the stars will drift to the left (east). Alternatively, you can drive the mount in any of the other directions by selecting a different control line. Hint: using TheSky, Telescope/MotionControls, MOVE (not jog), GUIDE Rate, you can use the mouse to push and hold the EWNS buttons to move the scope in this same manner.

- Pointing the Scope. Using the CCD camera, find the target star and record a good image. Position the scope to place the target star at the proper place on the FOV for the beginning of the drift (eg., position it near the east side of the image). To avoid confusion, synch the mount at this point, so it will be easy to return to this starting point. You should do a drift scan ahead of time to verify that the settings are correct. Important: When the DriftScan operates, the mount will be driven in a particular direction (eg., East) relative to the star position on the image. If you use a German Equatorial, when the scope flips, the image rotates 180deg. So, on one side of the mount, the object star should be set to the East (conventionally left) side of the image and will drift to the right (west on the image), but on the other side of the mount, you will want to start with the star at the right (still east) side of the image so it will drift to the left (west).

- Evaluate competing stars. Star streaks from stars close to the same dec will overlap the target star if they are as close as the drift scan length. When planning your drift, you do need to check both up- and down-stream of the target star to be sure you have no overlapping stars. You may choose to do a drift scan at right angles (ie.., N-S) to avoid this (you can rotate the camera to get more span). If not, the analysis of the drift scan will have to eliminate the effect of the second star (usually not a major problem unless it is a very bright star).

- Determine Exposure. You will likely want to start the exposure five sec before the drift scan starts, and continue it 5 sec longer than the drift scan (this gives good star images to mark the ends of the drift scan). Be sure to set the exposure duration properly (50 sec for a 40 sec scan duration). Write down the time to start the exposure (5 sec before the drift scan start), and then use the Scanometer timing output from the PC comm program to guide your operation.

- Expose. For safety, be sure immediately to save your raw image twice (with different file names) before *any* image manipulation. If you do an additional drift scan immediately after taking the actual occultation data image, you can subtract the occultation drift scan from the non-occultation drift scan to highlight the occultation.

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- Analyze results. These comments assume use of MaximDL. First, of course, calibrate the image and apply any necessary corrections (eg removing gradients). The drift will normally not be exactly horizontal on the image because the camera is not aligned perfectly, so use Edit/Rotate to make the scans horizontal. Then use View/LineProfile, horizontal box, to make a profile of the scan covering the full width of the image and drift scan, and save the file. You may also do a background and comp star. Open a spreadsheet (I can provide a sample), and use WordPad to copy each profile and paste it into the spreadsheet (using Data/TextToCol if needed). Identify the start and stop target star images, and enter the pixel numbers. The spreadsheet will compute the drift rate, etc. You can then analyze the data, identify the time of the events in the data, etc.

Cost

The Scanometer uses a small microcontroller in a simple circuit. Parts cost is about $25. I will make the circuit design and firmware available at no cost. To use GPS based timing requires purchase of a dedicated GPS sensor that provides a 1 Hz signal (cost about $90, same one as used in the Kiwi).

Mount Response Assumption

The Scanometer timing accuracy relies on there being a known delay time between the signal sent to stop the drive (ie, to start the drift) and the actual achievement of the new velocity (ie., the actual beginning of the drift). I tested the Scanometer with an AP900 mount with a C11 and video camera feeding a PC frame grabber. The video camera was equipped with an LED that shone onto the CCD, and was triggered at the beginning of the scan (this causes a bright flash on the video frame). I then triggered the drift scan on several stars, and measured the speed of the start of the drift scan by measuring the number of video frames that pass before the drift begins (ends). In each test, the delay was too small to measure, that is, well under one frame or 1/15th sec. In the future, I will repeat this using a vide0 tape recording to achieve 1/60 sec resolution, and will test other mounts having guide ports similar to the AP900. It is likely that most will have delays of under 0.1 sec.

Typical Results

Here are the results of a typical scan, using a C11 at f/6 with an ST7E on an AP900 mount. The night was dark and clear, with some high clouds. The first image shows the 50 sec exposure, 40 sec drift. Using the lowest trace as the test, the star is about 13.0mag, and shows the initial exposure of the star, 2 sec of travel, 2 sec of exposure, 36 sec of travel, and the remaining exposure. Note that on this optical setup, a non-integrating video camera would normally be barely able to record only to about 10.5 mag, while an integrating camera operated at x2 (to give about 1/15 sec time res) would still barely do 11 mag. There is some gain of sensitivity using a cooled CCD camera, as well as the opportunity to use an existing detector setup (and not mess with video).

Using MaximDL, I rotated the image to make the traces horizontal, then using the Edit/Line/HorxontalBox function, I created a text file for the test trace (the lower one), and a text file for the adjacent background. I then pasted those into an Excel spreadsheet, took the difference, and plotted the results. The first graph is the overall result, while the second is the same, but with a larger scale.

Note that the background levels in the image were approximately 250adu (inc 100 count pedestal), while the trace showed a level of 254. The large variations the result of three major components

- Noise in the image background (which will be higher if there is a larger amount of light pollution or a longer scan duration)
- Statistical variation in the arriving starlight(a faint star such as this one will have larger percent variation)
- Scintillation which affects all stars of all brightness (reduced with larger telescope or steady seeing)

In this case, the last two contribute most of the noise.

Although a mere four counts of "signal" is not much, it is sufficient. The 40 sec scan is spread over 582 pixels, giving a rate of 14.55 pixels/sec. Even in the second graph, it is clear that an occultation lasting more than a second or so and with a x3 reduction in amplitude would stand out from the noise. The third graph shows the same data averaged over five pixels the better to show details of the trace.