INACCURACIES IN FOLLOWING OBJECTS WITH MOTOR DRIVEN MOUNTS

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During some development work on periodic error calibration and correction algorithms it has been necessary to try out various small telescope types to see how good they actually are. All of you may suspect driving problems when you end up with elongated or trailed stars on a photograph that should have nice round pinpoints for stars, but it may not necessarily be the case. You would usually resort to manual guiding to correct for any drive errors that may be present. It is, however, easy to untangle the various effects and present them for measurement, analysis and correction.

The first step is to work on a technique to reveal the problems. This is done by exposing film in the focal plane of the telescope for a considerable time, like 20 minutes with the mount deliberately offset from its true polar pointing position then there will be declination drift. The trails we produce graph out any RA following deficiencies with time. Any type of Equatorial mount can be used, although it could be a fork equatorially mounted (or an alt-az telescope with computer driving and offset from the pole after calibration).

The equations that govern the drift of objects refer to the elevation and azimuth error of the polar pointing ($\mathbf{M_{EL}}$, $\mathbf{M_{AZ}}$), the hour angle of the object (**H**) and the declination (**d**). They are

$$\text{delta } \mathbf{H} = \tan \mathbf{d} \, (\mathbf{M_{EL}} \sin \mathbf{H} - \mathbf{M}_{AZ} \cos \mathbf{H})$$
$$\text{delta } \mathbf{d} = \mathbf{M_{EL}} \cos \mathbf{H} + \mathbf{M_{AZ}} \sin \mathbf{H}$$

[From Trueblood & Genet - Microcomputer Control of Small Telescopes]

We need to see what happens to these corrections when **H** moves over 1 degree then we can work out which ones are significant.

cos 0 = 1   cos 1 degree = 0.9998 = sin 89 degree
sin 0 = 0   sin 1 degree = 0.01754 = cos 89 degree

So around **H**=0 the DEC drift is $\mathbf{M_{EL}}$ x 0.0002 + $\mathbf{M_{AZ}}$ x 0.01754
This is almost entirely due to an azimuth error in the pole. Similarly when **H** is around 6 hours the DEC drift is almost entirely due to an elevation error in the pole.

This result is important and we should note this is entirely relevant to setting up the telescope by the drift method. Do it at **H** = 0 and **H** = 6 hours then the two corrections to the polar axis are independent.

Having established this then we need to work out how to use it. We start with getting the camera at the focal plane. My 6” f-8 Newtonian needed a Barlow lens to bring the focal plane far enough out to image on film. Looking at the Moon the field of view through the camera viewfinder was about 30 arc minutes. So if we centre a star we want a star trail of no more than 15 arcminutes (0.25 degree) over the exposure time. The telescope in question has 180 teeth on the worm so the revolution period is 1440 / 180 or 8 minutes. To capture two revolutions we need to expose for 16 minutes (4 degrees of Hour angle). The required DEC drift can then be used to work out the polar offset in azimuth.

0.25 = $\mathbf{M_{AZ}}$ x 0.01754 x 4
therefore $\mathbf{M_{AZ}}$ =3.56 degrees.

Thus we polar align the telescope then offset the pole in azimuth by 3.5 degrees and we achieve the desired DEC drift when looking at a star on the Central Meridian. In an EQ6 polar scope this means offsetting Polaris to one side, but still visible in the polar scope. Stars brighter than mag 3 should be used otherwise the trails will be too faint, but experimentation is a virtue!

Having done this and managed to capture several photographs of trails you also need a calibration slide which happens to be a picture of the Moon taken at 1/30th second exposure. These are all done through the same optical system and so one can use the size of the Moon for calibration of the images. An alternative way of getting calibration is to stop the drive at the desired time for a star trail shot but keep the camera shutter open for a further 10 seconds. The trail will be 150 arc seconds long (at declination 0 degrees). The more accurate method is to photograph the Moon and look up its diameter on the date / time of photograph. Here are several such images using a factory fresh EQ6 mount. The star trails have a scale bar of 1 arcmin and the Moon has a scale bar of 10 arcmin.

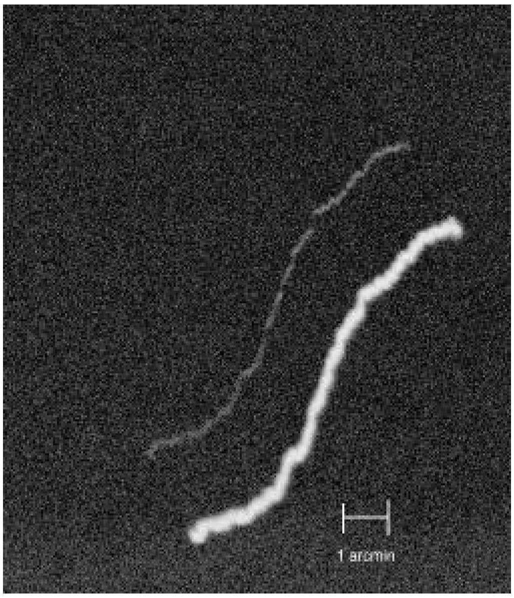

FIG 1 - PLEIADES STAR CLUSTER TRAIL 1st Dec 02, 10 minutes exposure.

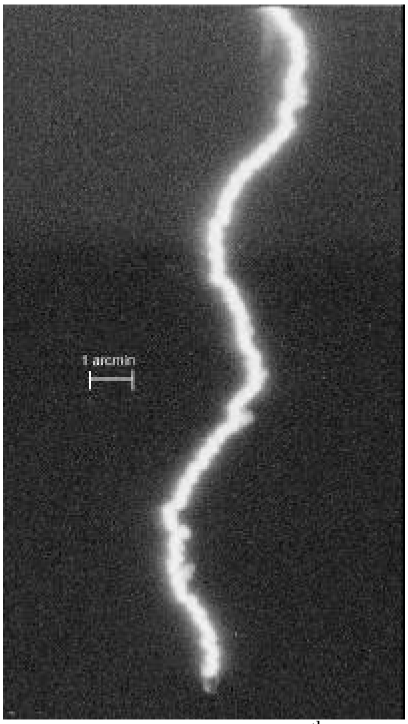

FIG 2 - VEGA TRAIL 18th Dec 02, 20 min

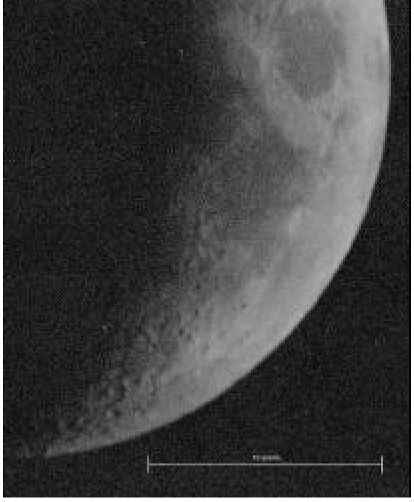

FIG 3 - MOON CAL SHOT

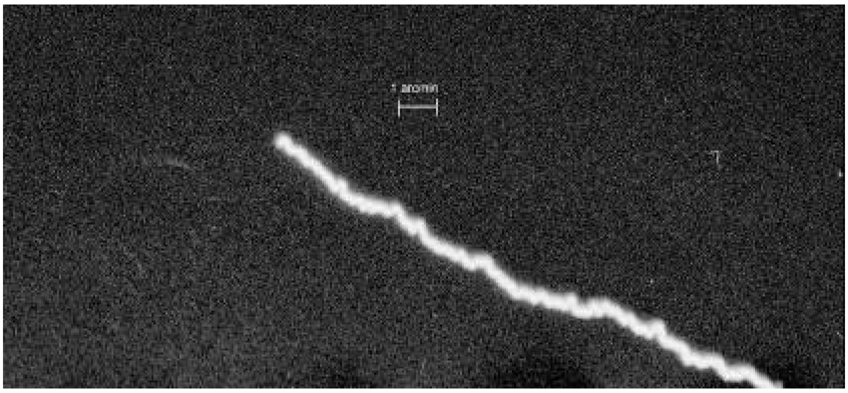

FIG 4 - Trail after periodic error cal. (SPICA)

Fig 1 - looks very empty for a star cluster with 5 stars just showing at the huge image scale we are working at. The periodic error is 55 arcsecond peak to peak. Fig 2 - shows the repetitive nature of the error but the trace has ‘cleaned up’ by using better quality motors and electronics. Fig 3 - the Moon on 9th December was 31.0 arcminutes diameter. Fig 4 - shows how the main components are removed , but you still end up with about 12 arcsecond peak to peak.

Fig 1 star trail shows that it is periodic with several components. The main component is a regular ‘sine like’ wave with a period of 8 minutes and peak to peak 55 arc seconds. It can be measured accurately by projecting the slides onto a screen, the Moon ended up 25 inches diameter! The 8 minutes period is the worm rotation period. Superimposed is a regular sine wave of period about 8 seconds and amplitude 5 arc seconds. This is an error due to the gear transfer of the motion from the gearbox to the worm wheel shaft. The tooth profile appears to be of non-involute form. This may bed in if the gears are used enough. The periodic error should be the same at other segments of the wheel when different teeth on the 180 tooth wheel are involved, but the backlash amounts may be different.

It should be remembered that the trace for a star will give an RA error measured which is of true size only when the declination is zero. Elsewhere the size will be smaller but the true size can be worked out by dividing by cos **d**.

Very little can be done mechanically to improve periodic error in a worm wheel as it is mostly due to non-concentricity of the worm on the axle. The normal procedure to reduce this is to lap the two components in situ which means nearly a complete strip down. The worm shaft has to be rotated at high speed (via an electric drill) with lapping oil present between the worm and the wheel. Eventually the high spots will be ground away, but you then close up the mesh by adjustment and start again (else you will just have increased the amount of backlash). The lapping oil needs to be flushed out when you are happy with it. This is not a task to be taken on lightly.

Electronically you can remove any periodic error by training the handset over a complete worm revolution, and playing back the recording of the button presses. This is done in many high end commercial drive systems. To be effective you need to train it over the part of the worm wheel you are going to use for the photograph and with the same telescope and fittings. It must also be done with a high power eyepiece fitted with a graticule and the handset buttons adjusted to keep the image on the same spot. A calibration trace can be absolute in nature if there is an index pulse coming from the worm shaft at exactly the same place in the revolution. The pulse per revolution would then start the playback from the beginning. A hardware sensor has to be present for this as is the case on Meade LX200 and ALTER D6 mounts. Otherwise you have to count encoder pulses as a fraction of the worm period conveted to encoder pulses when following a star. This procedure works well as shown by photographs here and in many other telescope reviews in Sky & Telescope magazine. It will only come out of synchronisation if the motor is decoupled from the worm wheel, or the motor rotates without the encoder pulses being counted.

A better calibration trace can be obtained if the handset adjust buttons work at a rate not much different from sidereal, say 10% of sidereal. Then the adjustments are not coarse and overshoot will not be a problem. A short button push of 0.2 seconds will then give a correction of 3 arcseconds. However the biggest problem is that there has to be a detectable error in order for you to correct it. If you are using ‘say’ Jupiter ‘which is wide enough to straddle the cross hair’ then you may be able to see 5 arc second error and hence correct it. But this could be 5 arc second slower or faster so the absolute peak to peak size of the resulting correction will be 10 arc seconds. It should be possible to do much better than this with practice. The limitation has to be the scintillation of the atmosphere where a star image will tend to dance about over a 2 arc second circle on all but the best nights.

However, periodic error can be bad and still enable you to get good long exposure unguided photographs. The worst part of the curve is at the steepest gradient which on these photographs is about 25 arcseconds per minute of exposure. You may be lucky in hitting the turning points in which case you would get less than 5 arcseconds error per minute of exposure limited to 2 minutes. With an exposure limited to 1 minute you would expect to get about 50% of the exposures being usable if they are started randomly through the periodic error cycle.

Modelling the periodic error function as a smooth sine wave then the amplitude (**a**) at time (**t**) is governed by the equation

$$\mathbf{a} = \mathbf{A} \sin (360\, \mathbf{t} / \mathbf{T})$$

Where **A** is half the peak to peak amplitude and **T** is the repeating period time.
The maximum gradient in this is the maximum movement compared to the stars in arc seconds per second of time. So we look at the zero crossing point (where the function is zero) and one second later as predicted by the equation. If **A** = 20 arc seconds and **T** = 480 seconds then we get a value for **a** of 0.26 arc seconds per second. So a maximum error in an exposure of 10 seconds will be 2.6 arc seconds, even with a 40 arc second periodic error. A more serious effect is that due to ‘cogging’ if there are gears involved. The period of this is very short and so it will introduce an appreciable error in even 2 second exposures.

An alternative view is that if you are doing CCD photography then it does not really matter what the drive errors are like because most modern CCD cameras designed for astronomical use also have autoguiding capability. These correct for any irregularities and can compensate adequately for the errors revealed by these photographs. The autoguiding will remove all effects, systematic or otherwise, which could upset the guiding of an image.

A CCD with autoguider does give additional benefits as this can be used as a tool to programme the periodic error correcting function in some drive systems where the buttons will be pressed automatically during calibration. It will give a much better calibration than is possible by visual use as it can detect very small inaccuracies in the guiding.