Introduction

When tracking an object east of the meridian (anti-meridian or AM), telescopes on German equatorial mounts, by their very design, will eventually hit the pier if an object is tracked across the meridian (post-meridian or PM). Various techniques have been developed to work around this fundamental limitation, for example, a meridian delay feature in the AP mounts. Such techniques server only to delay the inevitable pier event and can have unintended consequences. In the above example, a park command can usually not be issued as the mount no longer has a proper meridian reference and can attempt to slew under the pier – without success!

Taking advantage of modern software techniques used in CCDAutoPilot2, it is now possible to image across the meridian with AM-PM pointing changes under 10 arc-sec, less when guiding. This allows all mounts to predictably "flip the meridian" and resume imaging with a high degree of success and accuracy. With an instrument rotator and this software, your German equatorial mount can behave like a fork mount and allow unattended imaging through the least amount of atmosphere. Successful automatic meridian flipping is a complex undertaking and requires some initial user setup.

What happens?

When you choose the Meridian Flip task, the following steps occur automatically:

1. A brief image is taken and passed to an astrometric engine (CCDSoft/TheSky6 with CCDSoft or Maxim for camera control, or PinPoint if available). Starting with the mount's RA and Dec coordinates, which are written into the FITS header by CCDAutoPilot2, the engine pattern matches the star field of the image and determines the central RA and Dec. coordinates with arc-sec. precision or better. This is called "plate solving". These coordinates are saved as the target coordinates.
2. Given the target coordinates and other information, the meridian crossing is calculated.
3. Imaging now proceeds as programmed in CCDAutoPilot2.
4. When it is determined that the next sub-exposure will intrude into the meridian, the sequence is paused until the flip time.
5. At flip time plus 1 minute, the mount is instructed to slew to the target coordinates. The mount will cross the meridian and go to where it thinks the target is. Optionally, if a rotator is being used, it will rotate the camera by 180° so that the image orientation is the same as it was AM.
6. After completing the slew and settling, another brief image is taken and plate solved. Depending on the user choices, there are two alternatives on what happens next:
   a. The mount will be synchronized to the resultant plate solved coordinates of this image. This re-establishes the pointing reference of the mount. A subsequent slew to the target coordinates will now get the PM mount pointing within arc-seconds of the AM target location.
   b. If you have a high precision mount and/or a Tpoint model, it is not desirable or necessary to synchronize the mount. In this case, a correcting slew is calculated based on the plate solved coordinates and the original target coordinates. This slew will get the PM mount pointing within arc-seconds of the AM target location.

7. Finally the guider, if used, will be restarted. Depending on the user choices, the restart can be totally automatic with a guide star automatically found and guide restarted.

As can be seen, there is a lot going on both before and after a meridian flip. In order to have a successful unattended flip, plate solving is a key requirement. If a plate solve fails during the AM phase of the sequence, the sequence will abort. If it fails after the meridian flip, two additional attempts will be made to achieve a solution with each one using a factor or 2x longer exposure. If the plate solve fails three time, the run will continue unguided.

Plate Solving

A reliable plate solve depends on the particular scope, camera and astrometric software used. While no exact settings can be given, some guidelines might be in order. Here is the CCDAutoPilot2 Flip/Rot. Tab:
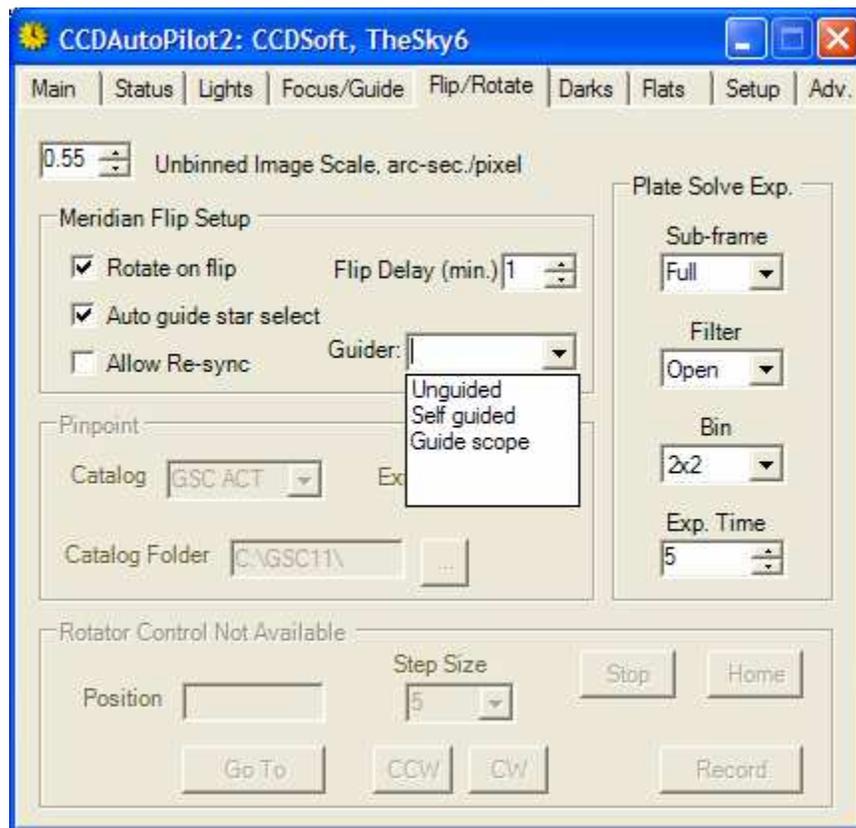
Unbinned Image Scale, arc-sec./pixel

This is a critical entry to get correct. This is the amount of the sky that is represented by each pixel in the camera. It can be calculated from:

$$Scale = \frac{206.26 Size}{FL}$$

Where

Scale = the unbinned Image scale in arc-sec./pixel
Size = the physical pixel size in microns (from your camera's manual)
FL = the focal length of your scope in mm.

For example, a camera has a pixel size of 9 micron. When used with a 14.5" F/9 scope with a focal length of 3315 mm. the resultant scale is 0.42 arc-sec./pixel This is the value that is entered in the box.

PinPoint

(These settings are not applicable to nor needed by CCDSoft/TheSky6.)

PinPoint is an astronometric engine that requires separate star catalogs. You should have these star catalogs on your hard disk. For normal work, the Guide Star Catalog (GSC1.1) is effective. If you have a small FOV, then you may want to consider USNO A2.0. Whatever catalog you choose, you must specify the catalog name and the path to the catalog. See the PinPoint documentation and help file for more information on these settings.

To avoid the cost of a PinPoint license, you can use CCDSoft and TheSky6 as your plate solving engine, even if you are using Maxim for camera control. Even if you don't have CCDSoft, its cost is less than PinPoint and you get another camera control and image processing program for increased flexibility.

Plate Solve Exposure

After your star catalog is set up (if necessary and once you have your image scale correctly entered, you can experiment developing optimal exposure parameters. One way to do this is by taking advantage of the Target button on the main tab. First, take an exposure with your camera manually but with CCDAutoPilot2 open. If you are using a large chip, you may want to use a half or even quarter sub-frame. Smaller frames are more important with wide field scopes. Perhaps start with a clear filter, 2x2 binning, 5 second exposure. Take and save an exposure. Now, hit the Target button. Navigate to the exposure you just obtained and select OK. If the image can be plate solved, the coordinates will be entered in the boxes in the lower right of the Main tab. If not, you will be notified. Try different combinations of settings for the exposure until you get a combination that gives a high success rate. Once you have reliable settings, enter them in the Plate Solve Exposure section.

Plate Solve Optimization

PinPoint: If you have a wide field imaging system, say a fast refractor or large imager or both, you should lower the expansion factor to keep the number of stars from overwhelming the astronometric engine.

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CCDSoft/TheSky6: Check your settings in TheSky6 under Tools | Image Link | Setup. There are some indications that lowering the required match percentage to 10% is very important to success.

Either Case: Make sure you sub-frame for wide field imaging systems. With the largest chip and a fast refractor, a sub-frame of 1/8 or 1/16 may be more successful. Make absolutely sure your image scale is correct.

Meridian Flip Setup

After the PM flip, the telescope will most likely not point exactly to the AM target coordinates. The PM plate solve tells where the mount is actually pointing. A correcting slew of the mount is needed to get it to the target coordinates. There are two ways of developing the parameters for the correcting slew and the choice depends on the accuracy of the mount.

Rotate on flip: If a camera rotator is available and present, checking this option will command compatible rotators to rotate 180° on a meridian flip event. Unchecked, a rotator will not rotate.

Allow guide star select: When checked, the brightest star in the field will be automatically selected and guiding will resume, using that star. If unchecked, the run will pause to allow the user to find a suitable guide star. Once a suitable guide star is found (and selected in CCDSoft), acknlowledging the message box will allow the run to continue. Obviously this is not for unattended operation as the user must be present to locate the guide star.

Allow Re-sync: When checked, the PM plate solve coordinates are used to sync the mount. This has the effect of telling the mount exactly where it is pointing. Then a slew to the AM target coordinates will be quite precise, since there won't be that much difference between where the mount thinks it is pointing, adjusted for the sync, and the target coordinates. When unchecked, the mount will take whatever the PM plate solve coordinates are, compare them to the AM target coordinates and then slew the difference. With reasonably precise mounts, this has the same effect without synchronizing the mount. Depending on the mount and the above choice, reasonable expectations of pointing accuracy after the flip are within 5 – 10 arc-sec. of the AM target coordinates.

Guider

Aside from unguided, there are two types of guiders that are used – a self-guided camera, which shares the same optical axis as the imaging camera, and a guide scope, which uses a guide camera mounted on a separate guide scope. The latter requires considerable care to remove differential flexure and becomes more challenging as larger and larger mirrors are used. Not only must the scopes not more relative to each other but also the mirror must not move. Clearly the self-guided approach is preferred as both the imaging and guide camera share the same optical axis.

Let's examine the three alternatives.

Unguided: Perhaps the simplest of all, no guiding is required. This requires a mount and OTA that are track excellently over significant portions of the sky, especially if long exposures are desired.

Typically this is made possible my modeling the mount and optical path movement and then predicting any tracking errors and correcting for them. Tpoint is the most successful method of achieving this goal.

A meridian flip here requires nothing special. If you have a rotator, you can check the Rotate on flip option to save your having to rotate all the sub-frames during processing.

Self-guided: Here the guider shares the same optical axis with the camera. SBIG has a patented dual chip camera in which the guider shares the same chamber as the imaging chip and a small pick-off mirror is used to direct some of the light cone to the guide chip. A more conventional off-axis guider achieves the same goal. A small pick-off mirror or prism is placed in the optical path ahead of the imager camera and the guide camera, usually at right angles, is used for pointing adjustments.

In this case, to have an unattended meridian flip pretty much requires a rotator. When flipping the meridian, the image at the OTA is inverted and thus the guider will see a different portion of the sky. If Rotate on flip is checked, the rotator will return the guider to the same part of the sky after the flip and, with the precision slew by CCDAutoPilot2, the same guide star from the AM side will be present on the PM side. If Auto guide star is selected, CCDAutoPilot2 handles any calibration changes automatically and restarts guiding. If you are in a star rich part of the sky and/or you have confirmed a guide star will be present, you can also check Auto guide star select. Otherwise, you will need to uncheck Auto guide star select and manually locate a guide star.

Guide Scope: When using a guider on a separate guide scope, the choice of Auto guide star select depends on the FOV of the guide scope and how well it is aligned with the pointing of the main scope. If you have a well-aligned, wide field guide scope, you will most likely be able to check Auto guide star select for unattended operation. On the other hand, a narrow field guide scope may require unchecking Auto guide star select. In either case, the rotator option is an image processing convenience.

Currently CCDAutoPilot2 supports two rotators, the RCOS Precision Instrument Rotator (PIR) and the Optec Pyxis rotator. The PIR is handled via the software interface to the Telescope Command Center; the Pyxis is handled by a native CCDAutoPilot driver.

Summary

The key to successful through-the-meridian imaging is a reliable plate solve setup and a good guide star if guiding. With the plate solve setup, don't scrimp on too short an exposure. You are investing hours most likely in the imaging run and a 10 – 20 second plate solve exposure, if that guarantees good reliability is a small price to pay. For guiding, make your guide exposures long enough so that the guide star isn't on the edge of detection but has sufficient margin to handle the variability of the evening sky. Here again, it is better to go a bit longer on the guide exposure than push it to the edge of detection.

One of the great advantages of imaging through the meridian is your luminance image can be timed to straddle the meridian, resulting in minimum air mass and best resolution. In fact, for LRGB

imaging, a good approach is to develop series that might look like this:

4R, 4G, 4B, 10L, 4B, 4G, 4R

The red sub-exposures are taken first since red is least impacted by atmospheric extinction. The greens are next followed by the blue, which is most impacted by atmospheric extinction. Center your luminance sub-exposures on the meridian and then "go down the other side" with the color images in reverse order. When you do your color combine and correct for extinction, the AM and PM color sub-exposures will be close enough to the same altitude that you can use one value for both. And needless to say, your luminance or clear-filtered images will be much nicer.

CCDAutoPilot2, when used in conjunction with an instrument rotator, can give high quality fork mount-like operation at a fraction of the cost. A fork mount that performs like your German equatorial would cost considerably more than the cost of an instrument rotator and CCDAutoPilot2. And, if you image unguided, the rotator becomes a luxury but not a necessity.