Paramount MyT – Part 7 – Periodic Error Correction

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Nothing is so wretched or foolish as to anticipate misfortunes. What madness is it to be expecting evil before it comes.

-Seneca

Mistakes are almost always of a sacred nature. Never try to correct them. On the contrary: rationalize them, understand them thoroughly. After that, it will be possible for you to sublimate them.

-Salvador Dali

As described before, no mount is perfect. Not even a Paramount. Although the MyT's drive train is built to minimize unevenness, a relatively small amount of tracking error can still occur. Some error may be random, but much of this remaining error is related to the relationship of the gear faces to each other, in particular the worm gear. Think about that, though, the MyT is guaranteed to have less than a seven arc-second peak-to-peak periodic error. This is a tiny amount of movement in the real world and PEC and guiding are both meant to reduce the error even further. Not only is it difficult to correct this tiny amount of error, it's also difficult to even measure that error in any sort of consistent manner.

Because the worm is fairly small and rotates repeatedly during an imaging session, many of the errors associated with the worm occur on a regular, or periodic, basis. Since these errors are periodic, you can consider them somewhat predictable.

The Periodic Error Correction feature of the Bisque Telescope Control System (TCS) allows you to make a recording of these errors, clean the recording to minimize noise caused by seeing or other random perturbations, calculate corrections and load those corrections into the mount for automatic play-back during tracking.

The method for calculating a tracking log is the same as that used for collecting a guiding log with two crucial differences:

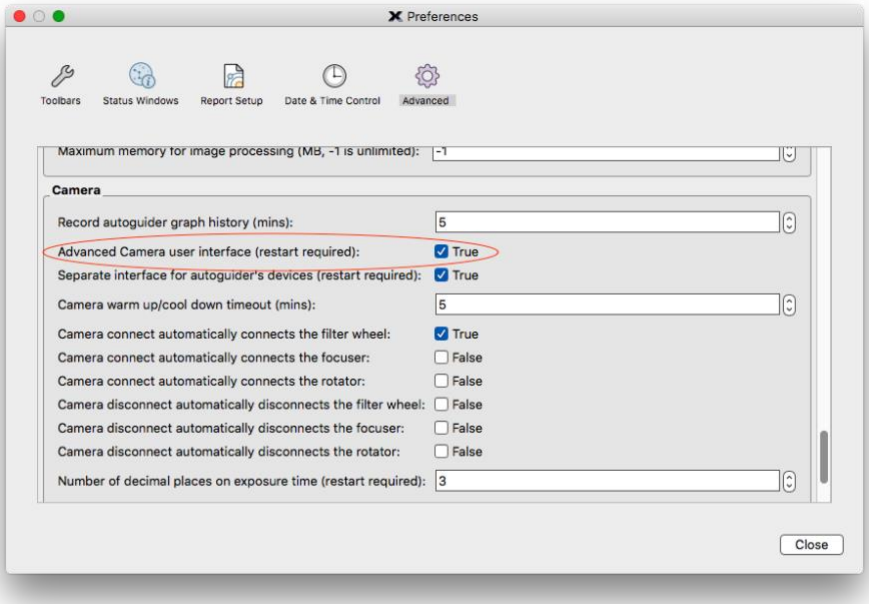
1.) Guide camera corrections must be disabled. Think about this. If the guider is correcting the mount's Periodic Error (PE) then you'll never get to see the mount's natural PE.
2.) The camera must be mounted such that the sensor's X axis is aligned with the mount's RA axis. Unlike the autoguider graph module, the PEC module within the Bisque TCS control panel cannot figure out which sensor axis matches which mount axis.

Most imaging systems have both an imaging camera and a guiding camera. The imaging camera is typically a higher resolution, lower noise camera rigidly attached to the main OTA and centered within the OTA's light cone. Guiding cameras are usually lower resolution, suffer from greater noise and are either attached to a separate OTA or look at the potentially distorted edge of the main OTA's light cone.

It is, therefore, a best practice to create your tracking log with the main camera recording a focused and non-saturated star near the celestial equator (as with guider calibration). Moreover, it is logistically simpler to record the motion of a star on the east side of the meridian with the OTA on the west side of the meridian. In other words, it is best to record a tracking log with the MyT mirror-flipped across the meridian from its home position.

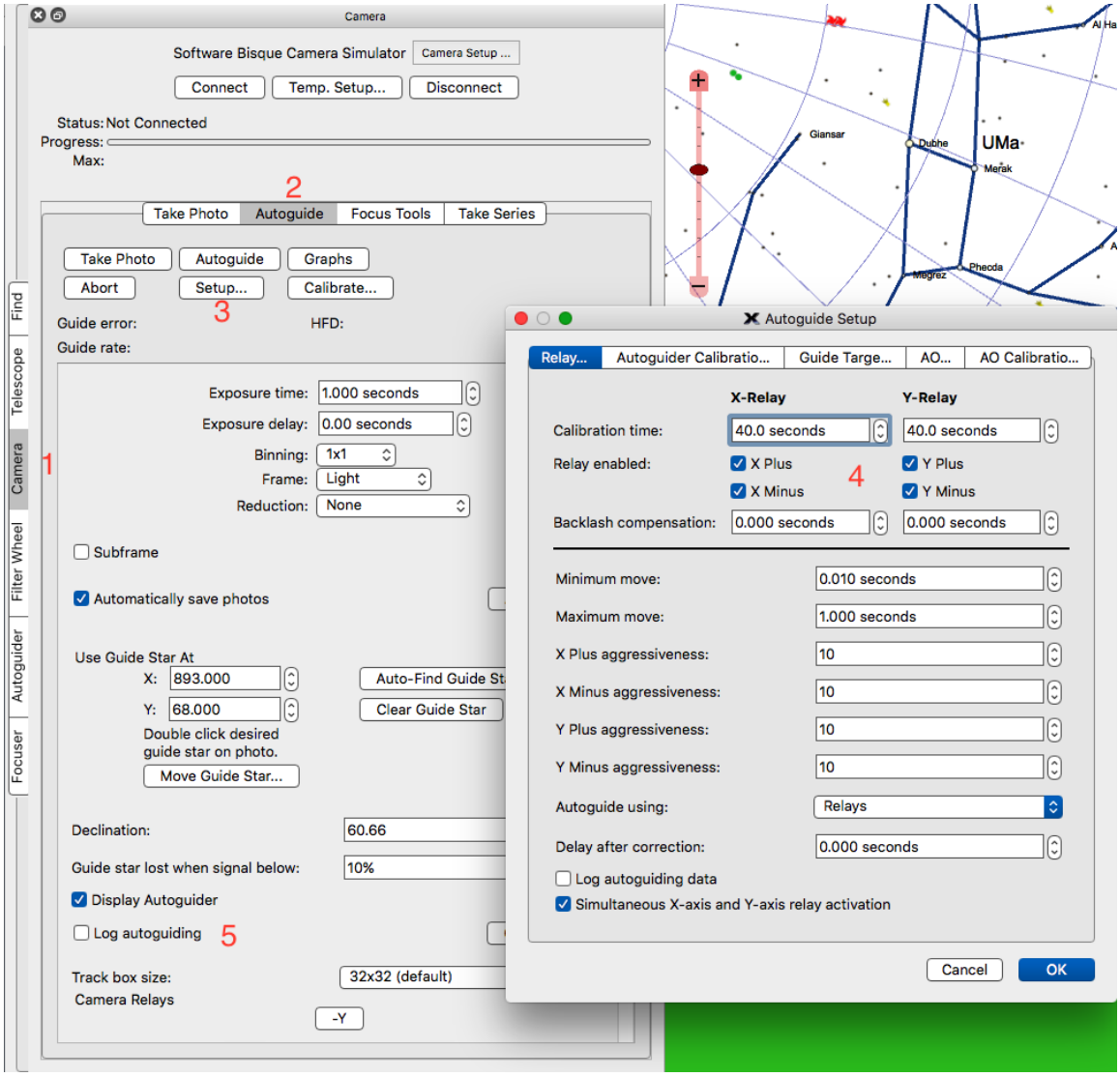
A final point of philosophical discussion – In the past, standard advice was to simplify the mount's condition and better reflect the mechanical characteristics of the mount by turning off Pro Track. While it is still certainly fine to do so, more recent thinking is that it shouldn't make a significant difference because Pro Track may modify the rate of change, but not the pattern at each index position. Additionally, in the real world, you will have Pro Track engaged.

As mentioned above, the camera's X axis should be aligned with the mount's RA axis. You can test this easily enough by taking a series of images as you move the mount in RA. Does the star move across the image from left-to-right? Another approach, if possible, is to use Image Link to analyze the camera's image and see if the positional angle is at either zero or 180 degrees. You will now use the main camera as if it were a guider to record a guide log, but with the guider corrections turned off.



Before you can use the main camera as a guider, though, you'll need to turn on that feature by checking the Preferences -> Advanced -> "Advanced Camera user interface" box.

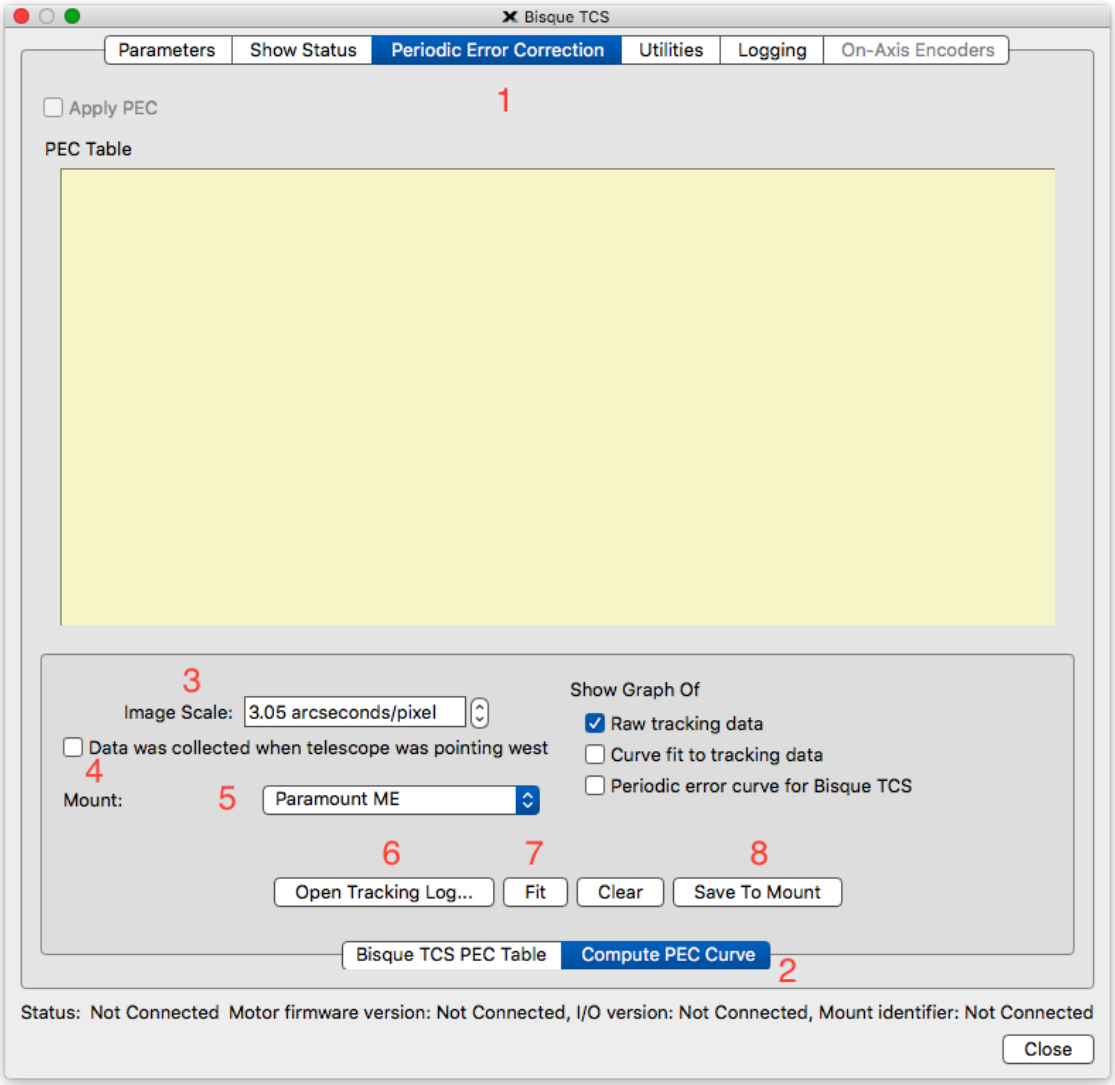
You are now ready to turn off the camera's guiding relays and activate the guiding log under the camera (follow the red numbers):



Once that is done, you simply take a picture through the imaging camera, select a star in the FOV and tell the camera to guide – exactly as you would with your usual guide camera. Now, open the guiding graph and scroll the view out to see the error line as the mount moves. If the star exits the tracking box, feel free to resize the tracking box by selecting a larger size from the drop-down menu and try again. Allow the MyT to track long enough so that you will have recorded several worm periods in the log. Twenty minutes should be more than enough on the MyT. When

you stop guiding, you will find the log file was written to whatever directory your imaging camera is configured to use to auto-save images.

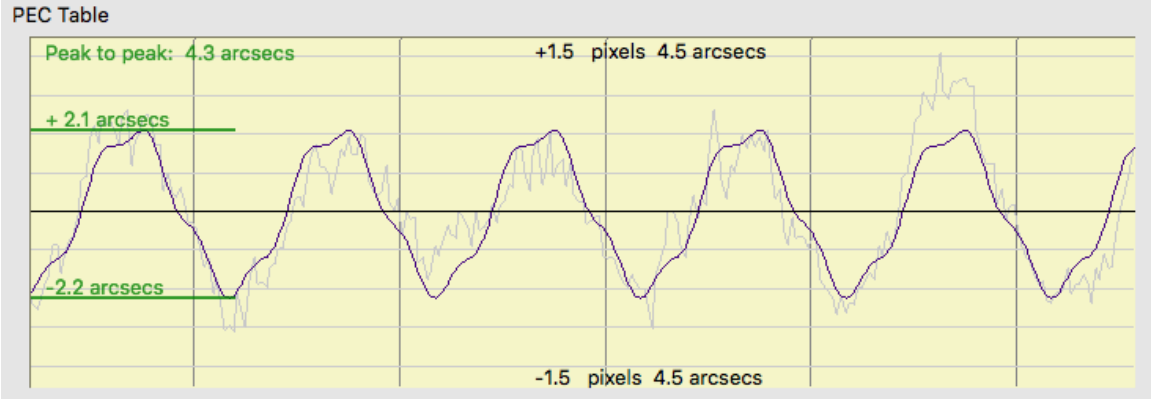
If you prefer to record a tracking log with the guider, you may certainly do so, but be aware that an under-sampled guider with dubious attachment may record a low-quality tracking log.



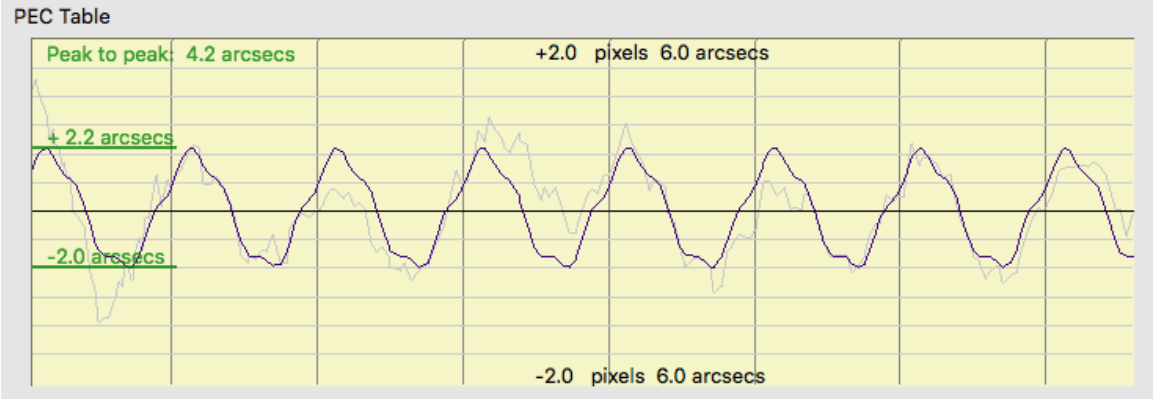
When you have recorded the log, open up the “Bisque TCS…” control panel from under the “Telescope Mount” -> Tools menu. Now, choose “Periodic Error Correction” from the top list of tabs. Next, choose “Computer PEC Curve” from the lower list of tabs. You must now enter the imaging scale for the appropriate camera in the appropriate field, ensure that “Paramount MyT” is selected in the Mount field. Now, click the “Open Tracking Log” button and choose the tracking log that you just

created. Finally, press the “Fit” button. You will now see both the actual recording as well as the cleaned and smoothed curve that was fit to the raw data in the tracking log. This fitted curve represents the system’s attempt to isolate the mount’s PE from the noisy raw data in the tracking log.

Below is a tracking curve recorded by my off-axis guide camera (An SX Lodestar X2) facing East.



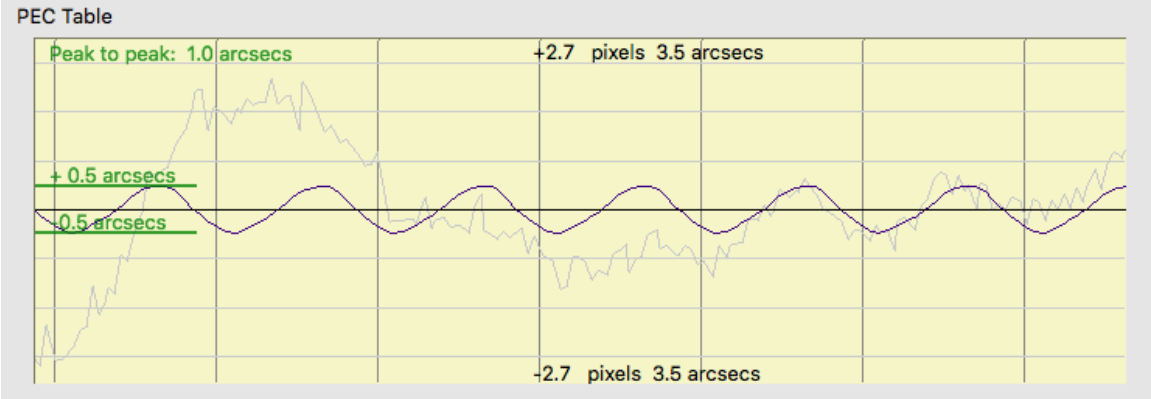
Despite the standard advice to use the imaging camera, below this paragraph is a tracking log collected by the same camera, but a few days later with the mount facing west. You can see, because the camera was flipped on the other side of the meridian, that the periodic error curve is inverted. Notice how the flatter double peak was on the top in the east-facing picture above, but is now under the center-line in the picture below. You can also see how the 2.2 pixel error side was on the bottom of the east-facing image, but is on the top in the west-facing tracking log. This inversion makes no difference from a curve fitting standpoint, but it is vitally important to ensure that the TCS knows which way the image was taken so that it can invert the corrections when they are stored in the mount’s memory.



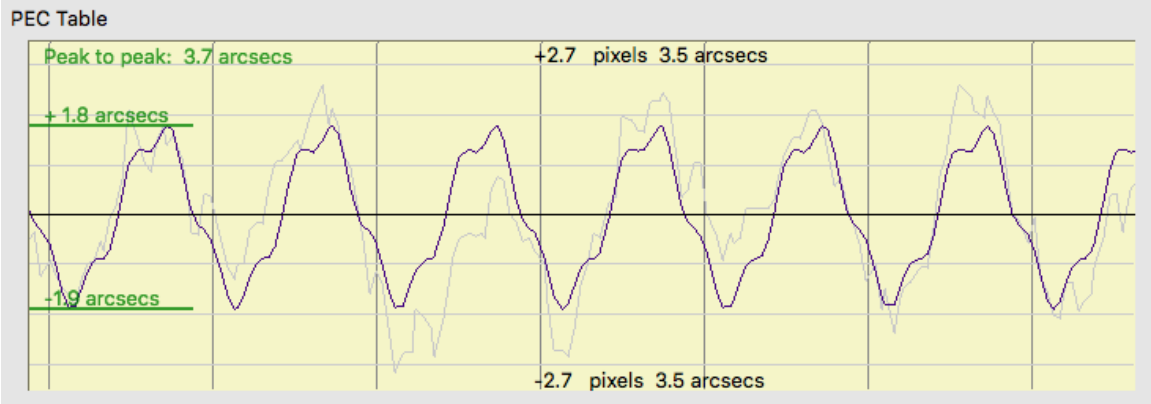
Also notice how the background, light colored, tracking log is a bit different in each image due to seeing and noise, but the curve calculated based on the data is essentially the same. The similar curves and the similar error levels show a pretty good consistency despite pointing to different parts of the sky on different nights. We can therefore be pretty sure that the error is periodic and related to the mount.

Aside from the east or west orientation, you should be aware of other possible tracking log issues. For example, if the camera is not oriented at a 90-degree angle then the dimension on the camera, which would normally be associated almost entirely with the right ascension axis, will now be polluted by noise or drift from the declination axis. As discussed earlier, if you have the camera rotated to a 90 or 270 degree angle then the right ascension error would be recorded on the axis of the camera that the TCS associated with declination and vice versa.

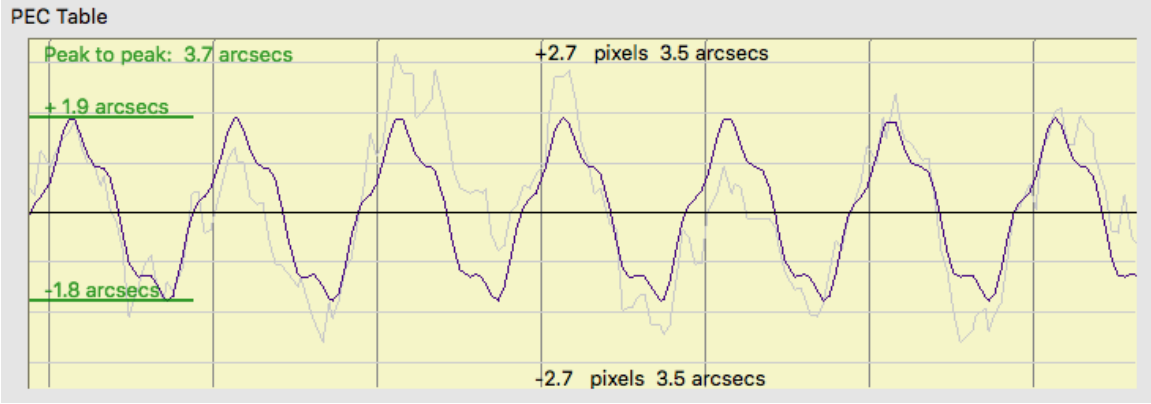
For example, like many people who use QSI cameras, I have oriented my camera such that the OAG camera is on the "top" of the OT when it is facing the north pole with weights down. This also means that the giant QSI logo is right-side up when the OTA is in the same orientation. Unfortunately, technically, this puts the camera at a 90-degree angle. In other words, right ascension movement is recorded on the Y axis of the chip rather than the X axis as TCS expects. When this tracking log from this configuration is loaded into TCS, the data, and resulting PEC curve is for the wrong axis:



You can see that, although TCS dutifully tried to fit a curve, the original collected data isn't very periodic as compared to the vertical "worm period" bars. Also, frankly, the error from that cleaned curve is unbelievably small. In order to use the data collected from a "90-degree camera", you have to use a data editor, or a text editor with block selection mode (such as KEdit or vim). You could also probably use Excel or R if you are comfortable with those tools. The first step is to swap the X and Y error columns. Which will get you this:



Now, that looks like a reasonable periodic error curve. In fact, it looks quite like the east-facing curve captured from the guide camera above. Except, the mount was actually pointing west. If you look closely, you'll notice that the 90-degree rotation didn't just swap the axis, it also inverted the data. If we reverse the signs on the Y-guider column (which corresponds to RA) then the graph and curve (below) resemble the west-facing guide camera, with the double-peak on the negative side of the centerline. Moreover, you'll also see that the error on the top half (positive side) of the graph is slightly higher than the error of the negative side. The log now matches the actual aiming of the camera.



Also notice that the 3.7 AS peak-to-peak error recorded by the 1.3 AS/pixel imaging camera is similar to the 4.2 AS/pixel or 4.3 AS/pixel errors seen by the lower resolution 3.0 AS/pixel guiding camera. Although it is recommended to use the imaging camera for PEC training, in this case, the guide camera isn't terribly different from the corrected curve from the imaging camera. The higher-resolution imaging camera does show a bit more definition to the double peaks.

Once you have the appropriate fitted curve displayed in the Bisque TCS control panel, assuming the log was recorded on a star east of the meridian, you press the

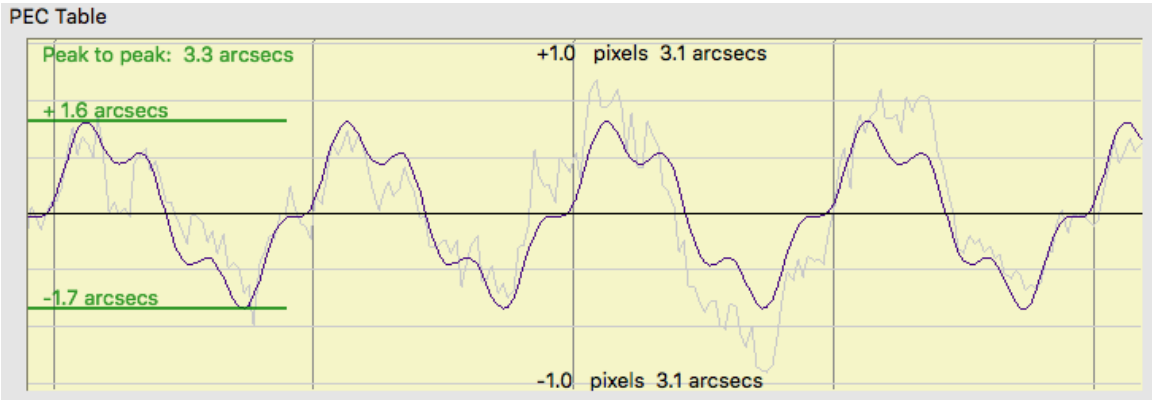
“Save to Mount” button, ensure that the “Activate PEC” checkbox at the top is ticked and then close the Bisque TCS control panel.

When it came time to program the PEC curve on my MyT, I used the tracking log collected from the cleaner, and higher resolution, imaging camera along with the “west” checkbox ticked. In this case, I suspect that the guide camera data would have worked fine, too. Using the east-facing guide camera would have also prevented all of the column-swapping data gymnastics and concern about the “west” checkbox.

The next question is to find out if PEC actually improved the mount’s performance. In other words, does it work? Several weeks after uploading the PEC curve into the MyT, I collected a PEC-enabled tracking log with my OAG-mounted Lodestar. I aimed the telescope at a star around the equator, in the eastern sky, and switched off guiding corrections. I then loaded the log into the Bisque TCS module within the SkyX and ran the “fitting” routine to clean the data and align the curve to the axis.

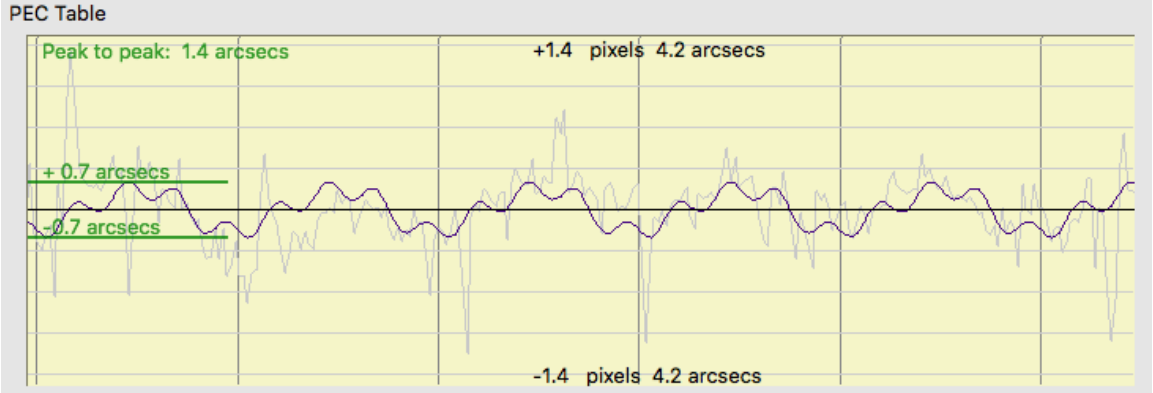
The next section about my initial poor performance due to poor seeing may be interesting from an academic standpoint, but if everything went well, your periodic error with PEC enabled should be considerably better than without PEC enabled. While no guarantee, it is not unusual for well-dialed PEC to bring the mount’s PE down to below an arcsecond. Feel free to skip ahead to the postscript.

This is what I found:



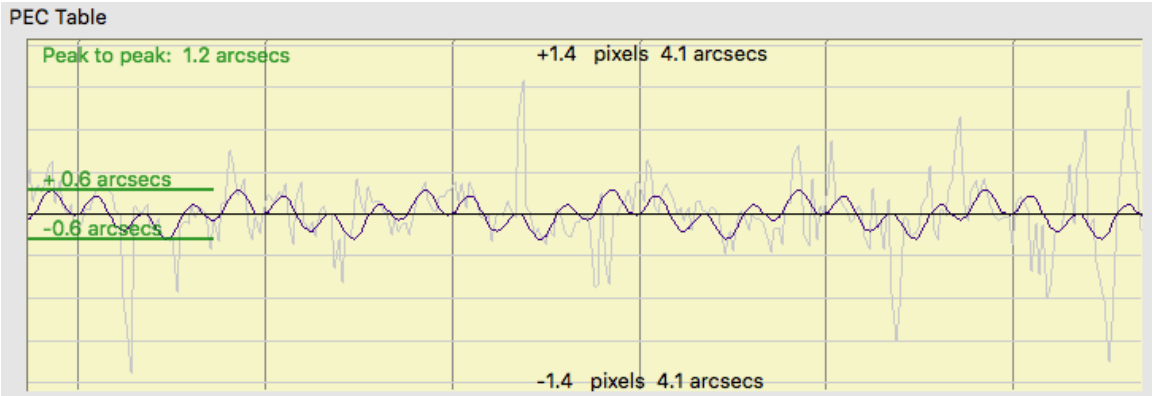
While there still appears to be a bit of a periodic phenomenon, notice that the peak-to-peak error is 3.3 AS compared to the 4.3 AS peak-to-peak which was previously collected by the guide camera facing east. While not an amazing difference, it represents a 30% improvement. Or, more pragmatically, PEC represents an improvement equal to 76% of a pixel on my imaging camera.

Of course, like most people, I use a guide camera. In this case, the idea behind PEC is that, by reducing the periodic swings, it should help the guide camera to work less. Here is an example of a guiding log with PEC **disabled**:



We would expect that PEC would have less over-all effect with the guider than without, because the guider will attempt to correct tracking errors regardless of the source. Moreover, my environment in Denver suffers from poor seeing. The larger (longer duration) seeing effects probably cause more guide star movement than the PE of an already low-PE mount.

Here is a guiding log with PEC **enabled**:



As expected, PEC shows an improvement with guiding, but not a major improvement. The difference is only about 0.2 AS. In other words, the improvement is about 6% of an under-sampled Lodestar mounted OAG. This is a meaningless real-world difference.

At the end of the evening, though, what we want is an improvement in our images. Right Ascension tracking errors typically show up in the form of eccentricity in the final image. Here are the measures of five 180s images collected back-to-back **without** the use of PEC:

Index	Name (3 approved/5)	Weight	FWHM (pixel)	Eccentricity
☑	5 SVQ-QSI_M_57_Clear_Li...	1.484	1.912	0.4762
☑	2 SVQ-QSI_M_57_Clear_Li...	1.427	1.992	0.5069
☑	4 SVQ-QSI_M_57_Clear_Li...	1.458	1.849	0.5453
☐	1 SVQ-QSI_M_57_Clear_Li...	1.285	2.283	0.6668
☐	3 SVQ-QSI_M_57_Clear_Li...	1.338	2.123	0.7284
	Subframe Median	1.427	1.992	0.5453
	Subframe MeanDeviation	0.06366	0.1290	0.08242

Here are the statistics for five images taken immediately after with PEC **enabled**:

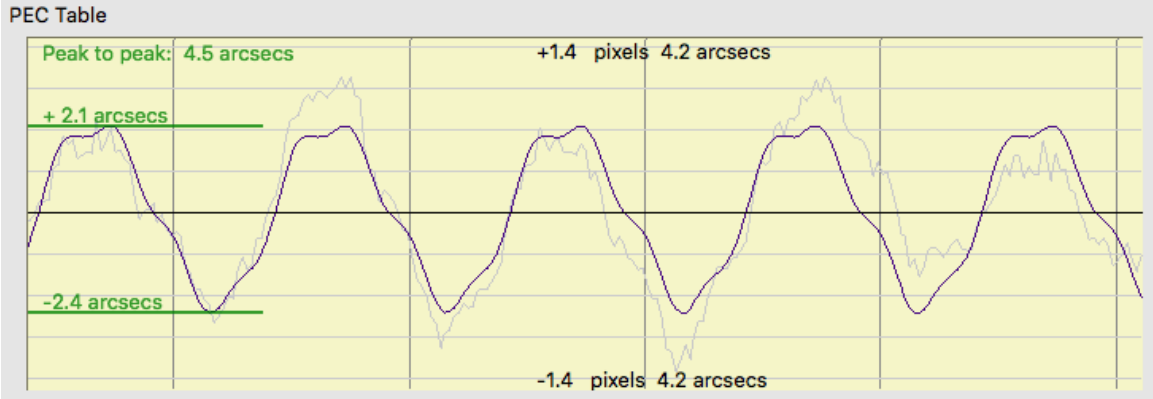
Index	Name (3 approved/5)	Weight	FWHM (pixel)	Eccentricity
☑	4 SVQ-QSI_M_57_Clear_Li...	1.473	1.953	0.4378
☑	2 SVQ-QSI_M_57_Clear_Li...	1.478	1.865	0.4572
☑	3 SVQ-QSI_M_57_Clear_Li...	1.408	2.076	0.4848
☐	1 SVQ-QSI_M_57_Clear_Li...	1.350	2.034	0.5547
☐	5 SVQ-QSI_M_57_Clear_Li...	1.355	2.136	0.6209
	Subframe Median	1.408	2.034	0.4848
	Subframe MeanDeviation	0.04912	0.07868	0.05611

For me, in the real world with this set of images, using PEC with guiding looks to improve image eccentricity by about 12%. After my sub-frames are culled and weighted before integration, the end result won't make much difference.

The relatively minor improvement from PEC may make one question the quality of the PEC curve that was used to program the mount. If the PEC curve were inverted or dramatically incorrect then we'd expect to see performance **with** PEC enabled to be worse that performance **without** PEC. Yet, this is **not** what we see. Performance with PEC is better than without.

It is also true that the comparison data were taken several weeks after the PEC curve was generated. Perhaps the atmospheric quality is different or the mount has changed? We can check this by recording another tracking log and comparing it to the results from the original night. Here is a tracking log taken from the OAG

Lodestar pointing east the same night as the above guiding logs and comparison images:



As you can see, it has essentially the same shape, same magnitude and same direction. Moreover, the peak-to-peak error is 95% the same.

We can, therefore, step away from the experience convinced that the tracking log and the PE that it represents is consistent. We can also see that using PEC improves the system's performance. Yet, in my case, that improvement is less than what may be wished for. Why might that be?

1.) If mount had greater PE error to start with, then there would be more dramatic PE for PEC to mitigate. Because the Paramount is a well-made machine, the PE is proportionally small compared to the seeing-induced error in my particular location.

2.) Because the PE is relatively low and smooth, it is fairly easy for the guider to compensate for the PE. Once again, compared to the seeing, the PE is relatively small and smooth.

3.) If my rig were higher resolution, perhaps the tracking log would be higher quality and the improvements made by PEC would be more noticeable.

4.) If my seeing were better then the quality of the tracking log would be higher and the Bisque TCS module within SkyX Pro would be able to generate an even cleaner curve. Moreover, if my seeing were better then PE would represent a higher proportion of total seeing error. Finally, if seeing were better, then the stars we are using for indirect performance measures (tracking logs, image analysis) would be less confounded which would result in a better quality performance measurement.

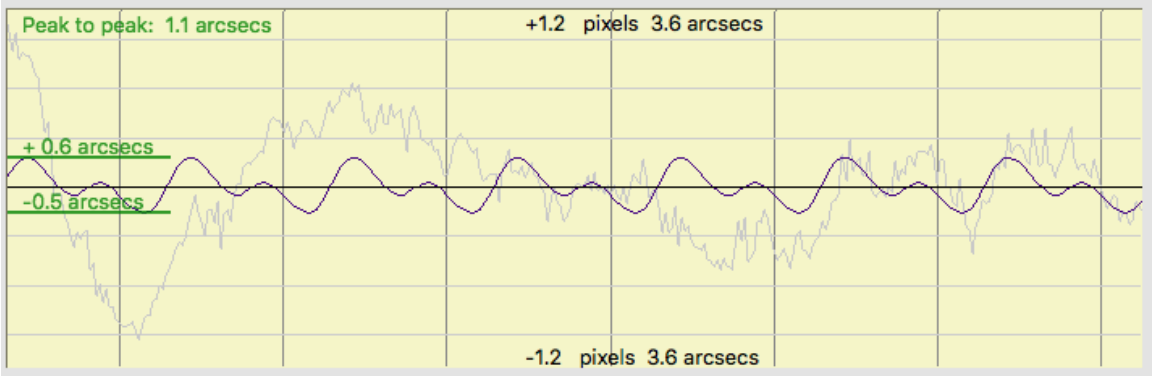
5.) While we can agree that the PE curve used to model the mount is valid, perhaps camera choice does have a role to play. While the use of a higher resolution camera makes a tremendous amount of sense, recording the curve with a slightly under-sampled camera might be more resilient against the effects of poor seeing. In other words, higher resolution is better unless that resolution is only capturing noise. As with guiding, when it comes to PEC corrections, less can be more.

Before running out and creating your own PEC curve, this would be an excellent time to read through the Paramount Robotic Telescope System User Guide. The section on PEC begins on page 140 in the February 2018 edition.

I hope that you have found this article to be interesting and that it has helped you understand the method for collecting a tracking log and generating a PEC curve. Most importantly, though, I hope that it has helped you see that there are few "monkey see, monkey do" recipes. Relying on established tradecraft and other people's advice may get you close, but you will probably have to walk the last mile on your own. In addition to consulting the manual, I'd also recommend Charles Walker's helpful video, here.

Postscript:

After some discussion on the Bisque Forum, I experimented with averaging multiple PEC curves and managed to bring my MyT's PE down to 1.1 AS peak-to-peak.



Rick McAlister then created a Windows-based tool to simplify the analysis and averaging of PEC curves. I subsequently experimented a little more with different qualities of PEC curves, which you can read about here. Finally, Rick wrote the definitive article on the subject, here.