Introduction

Accurate focusing is one of the most important, if not the most important aspects of imaging to get right and maintain during the course of an evening's imaging run. When an image is not accurately focused, not only does resolution suffer but signal suffers as well. This note will describe some of the issues impacting focus and suggest methods to deal with it. Finally, a description of how CCDAutoPilot2 can help you achieve and maintain optimal focus will be described.

The Problem

When we focus, we are seeking to minimize the apparent size of a point source, typically a star. The star does not focus to a point at only one point of focus travel but to a specific region called the critical focus zone (CFZ). The width of the CFZ is determined solely by the focal ratio (F) of a given optical system to be:

$$CFZ = 2.2\ F^2$$

For some typical focal ratios, here is the corresponding CFZ:

F	CFZ	
(Focal Ratio)	mm	inch
5	0.0550	0.0022
7	0.1078	0.0042
8	0.1408	0.0055
9	0.1782	0.0070
10	0.2200	0.0087

The position of the camera has to be maintained within the CFZ over the entire imaging run, if optimal results are to be achieved. Since most focusers have a digital control, it is instructive to determine how many counts corresponding to the CFZ of your system. One may is to move the camera a known amount via short spacers, extension tubes, etc. and see how much your focus point changes. For example, with my F/9 reflector, my focal point changes 500 counts with a spacer of .125". This tells me my focuser sensitivity is 500/.125 or 4000 counts per inch. So multiplying 4000 by the CFZ for an F/9 system, .007", tells me the focus point tolerance for this system is 28 counts.

Another way is to change your focus set point by a fixed amount and see how much your draw tube position changes. My F/5 refractor has a draw tube that is moved by a RoboFocus focuser. If I note the starting count, and move the focuser controller so that the draw tube extension changes by 0.5", I note my count changes by 1618 counts. Here my focus sensitivity is 1618/0.5 or 3236 counts per inch. Multiplying 3236 by the CFZ for an F/5 system, .0022", tells me the focus tolerance for this system is 7 counts.

This indicates just how demanding focus point stability is!

Factors that impact focus

Aside from the moon and planets, imaging requires focus be maintained over long periods of time. During this time, factors that contribute to loss of focus are:

Changing Temperature: Most telescopes have aluminum tubes. Aluminum contracts as the temperature decreases, changing the focus point. This issue can be circumvented to some degree by using different, temperature inert materials in place of aluminum. Of course these materials can add to the cost and their success depend on the stability of the optical components as well. Mirrors made of Zerodur and AstroSitall are more stable than those made of Pyrex for example.

Changing Telescope Attitude: Some compound telescopes such as unmodified SCT's, may have unstable primary mirror positions. Not only can this make guiding via a separate guide scope difficult, but it may in fact move the focusing, especially at fast focal ratios.

Inserting Different Filters: Some filters have different thickness, resulting in a change in focus position as different filters are inserted into the optical path. Even if the filters are parfocal, i.e. they all have the same thickness, telescopes with refractive elements will typically focus at different points for red and blue. Even very high quality APO refactors will show a change of 1 CFZ between red and blue light.

How to deal with these factors

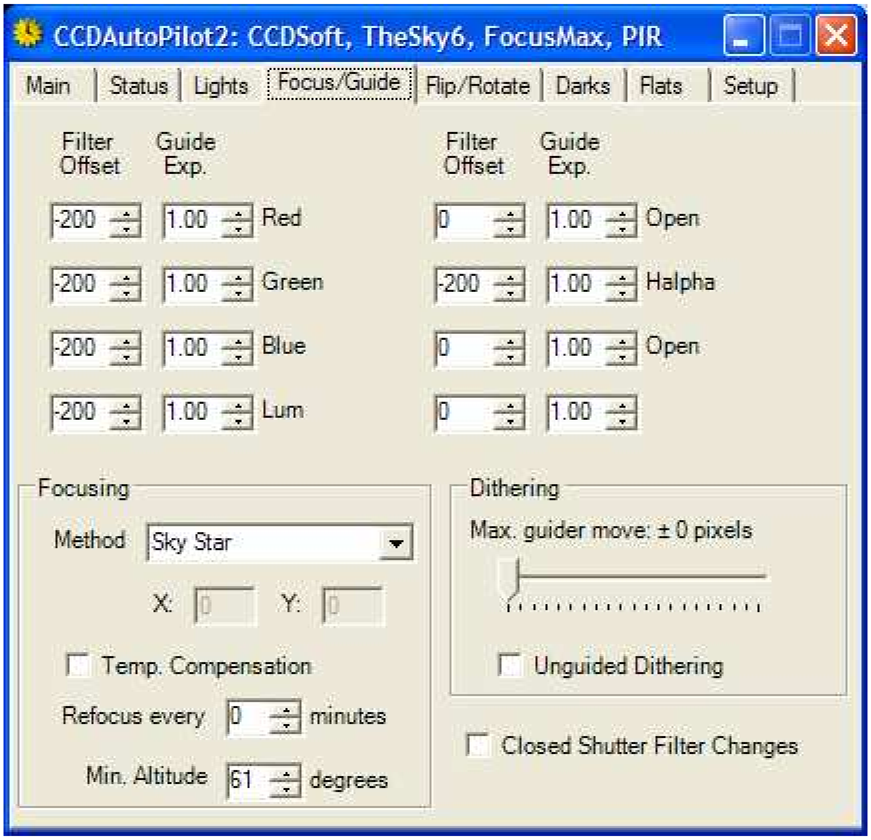
Temperature compensated focusers have tried to compensate for this change by a calibration of the focus point and predicting how much the focus would change and changing the focuser accordingly. This approach is variably successful, depending on the predictability of the focus change and the temperature probe instrumentation. Mirrors and other optical elements can be more securely mounted. Offsets for each filter are developed and the focuser is moved by an appropriate offset before the exposure is taken.

All of these techniques rely on what is called an "open-loop" control system. We *predict* the focuser position *assuming* we know precisely how the focus will change. Change is focus due to temperature and filters are assumed to be known and we try to move the focuser appropriately. Given the width of the CFZ and the factors involved, this is a compromise at best.

A "closed-loop" control system works by refocusing the telescope in *response* to the change. This reactive system is more appropriate to dealing with complex focusing factors. With the advent of FocusMax and CCDAutoPilot2, focusing can be maintained throughout all of the above changes. We call this technology SureFocus™

SureFocus™

Depending on what you are imaging, there are a number of techniques provided within CCDAutoPilot2 to provide complete and accurate focus control *without your intervention!* Let's consider the options.



This is the Focus/Guide tab of CCDAutoPilot2. The focuser is controlled via the free program, FocusMax. Options exist for the open loop techniques such as filter offsets and temperature compensation. CCDAutoPilot2 adds a number of closed-loop focusing options shown here:

If you select any method other than none, FocusMax will be invoked at the start of every series. A series is a number of exposures corresponding to a specific filter, binning and exposure duration. In addition to that, CCDAutoPilot2 will refocus at whatever time is entered in the Refocus every xx minutes box – automatically. Thus you have complete control over when and how often FocusMax needs to refocus your system. Let's review each of these Focusing Methods to see which ones to use where.

Focus at X, Y: This method focuses the telescope on a suitable star in the field of view at a point you specify. It is most effective when you have a sufficiently bright star in the field that is separate from your target of interest and far enough away from it. The technique consists of taking a 1x1 exposure of your target position and noting the pixel coordinates of the target star. It is then entered in the X and Y box above. When invoked, FocusMax will look in a box specified in its Setup tab, centered on the pixel coordinates. This method will not work if you image through the meridian without a rotator.

Brightest Star in FOV: With this method, FocusMax selects the brightest object in the FOV and attempts to focus on it. If that brightest object is a galaxy core, FocusMax will fail but if you are imaging a nebula region, it should work fine. This method is suitable for unattended imaging through the meridian.

Sky Star: This method focuses on a star whose magnitude range and altitude you specify. CCDAutoPilot2 notes your current target position to a high degree of accuracy that you specify. It then slews the telescope to an appropriate altitude if necessary. Using the power of TheSky6 (required for this method), it searches out stars of the magnitude you specified and moves to one of them. FocusMax focuses on that star. CCDAutoPilot2 then brings the telescope back to the target position, again plate solves and does a correcting slew to bring the telescope precisely to the original target position. This method is suitable for unattended imaging through the meridian.

Acquire Star: This method performs similarly Sky Star but requires the additional purchase of PinPoint, a product of DC-3 Dreams and setup and calibration in FocusMax.

Which method and strategy to use for focusing depends on a number of trade-offs. Certainly Sky Star is the most effective method but requires leaving and returning to the target. If there is no suitable star in the FOV, this is the only technique to achieve closed-loop focusing. If you can define a suitable star in the FOV and image through the meridian, then Focus at X,Y might suffice. It would even be suitable without a rotator as long as you image on one side of the meridian. Brightest Star in the FOV might make sense for another type of target.

Regardless which closed-loop method is used, it is worthwhile to have the filter offsets specified. FocusMax as an automated process can fail, however unlikely. If you depend on FocusMax entirely, you may lose data. If you have filter offsets programmed, at least you will be close, if the filters are not particularly parfocal. In the above screen shot, note that I use the open position (no filter) for my clear exposure. The other filters are parfocal and offset 200 counts from the open position. That way, if a red focus should fail for example, I would still get some data.

Summary

Hopefully by having a better understanding of the issues surrounding focusing, you can use the SureFocus™ tools provided in CCDAutoPilot2 to maximize your image quality without your having to monitor each and every exposure. As you get more familiar with this and other CCDAutoPilot2 technologies, your image quality will increase without more tedious work on your part.

