In his article on Starizona’s Hyperstar system (ATT April 2007, p. 28), Scott Tucker described astrophotography as something that, at least historically, require a “certain borderline lunacy.” Astrophotography is typically not for the impatient, casual amateur, nor is it typically for those without fat wallets. Take, for example, the relatively simple, unavoidable fact that the earth rotates. The result of this inescapable fact is that the stars move slowly across the sky. “Slow” is a relative term, of course, and if you use a large amount of magnification (e.g., by using a high-power eyepiece), you can see the stars race across the field of view.

The solution to this is, of course, quite simple and well-known. With a single motor turning the telescope about an axis that is parallel to the earth’s axis of rotation (i.e., that points at the celestial pole), we can counteract that motion and keep the target from drifting away. For visual observation, this is all we need. It matters little if, over the course of 10 minutes, the target rocks back and forth in the eyepiece by a half an arcminute. At 200x in a Plossl eyepiece, a half an arcminute corresponds to under 4% of the field of view. You’re losing sleep over observing, not over this slow, small, wobble of the image.

To an astrophotographer, this slow, small, wobble of the image is a serious problem to lose sleep over in and of itself. If we have a camera exposing this entire time, the wobble will make the stars become lines rather than points. For example, if we image at a fairly typical image scale of 1.5 arcseconds/pixel, instead of the star being perhaps 4 pixels in diameter, it might be 4 pixels high and over 20 pixels wide.

The solution to this problem is also quite well-known. If, in addition to exposing our main image we carefully watch a star, we can use this “guide star” to see the error the mount is making and correct for it as it happens. As the star starts to drift to one side, we send a signal to the mount to either reduce or increase the speed of the motor briefly so that the star will be pulled back to the proper position. We can do this either manually, by physically watching a star and pressing buttons (manual guiding) or automatically, by having a separate camera watch the star and send commands to the mount (autoguiding).

This sounds simple. Where’s the problem? Why doesn’t everyone guide their mounts and take pictures with nice round stars? Historically, there have been a lot of problems, hurdles, and myths that have kept guiding out of reach of many astrophotographers. For example, many are told that astrophotography cannot be done on basic, mass-produced mounts. Bigger and more precise mounts have not only less error overall, but error that is “smoother” and more easily fixed with guiding. These are also priced out of reach of many amateurs. If you must spend $3,000 to get a mount that is considered entry-level for astrophotography purposes (and still need to guide), many will shy away. Even if you have a suitable mount, you may be presented with a bewildering array of parameters. For example, you may be asked to enter in the number of arcseconds/pixel, the RA and Dec aggressiveness, their hysteresis, the amount of backlash in milliseconds, which way north is in the guide image, whether it is mirrored N-S and/or E-W, how much error to tolerate, etc. While some of these are easily determined, others are not and with so many to set, the chance of user error is high and finding the source of the error can be challenging.

I remember not-so-fondly trying to use several systems and becoming so frustrated that I abandoned guiding.
Sometimes I’d hit “guide” and the star would race off 10x faster than the slow drift it had shown. Other times, the program would lock onto a hot pixel and insist my mount was perfect (funny how they don’t move) or would work for a short while and then degrade. My “favorite” night was when it was working well in RA but after about 5 minutes of joy, drift in declination began to build up and the program and I had a disagreement as to which way “north” was. Its corrections only made the error bigger and the star promptly shot off the chip. I can still remember the literal pain in my neck manually guiding was and despite a number of valiant efforts, I never managed to produce round stars (it didn’t help that I too would forget which axes I should keep in the same layout as the buttons and which should be mirrored).

I abandoned guiding in favor of the ease of unguided imaging and lived with the noisier images my shorter exposures produced, always wanting a better way. In early 2006, I had already written and released Nebulosity, a program designed to both capture and process astrophotography images. Its mantra was to be powerful, but easy to use. I know first-hand that much of the time when doing this, I’m standing in a dark field that is either freezing cold or infested with mosquitoes. On top of that, I’m generally tired and it doesn’t take a cognitive psychologist or cognitive neuroscientist to tell you that under these conditions, you don’t work or think your best. (If you do feel you need a cognitive psychologist or cognitive neuroscientist to tell you this, consider yourself so-told.) It’s at times like these that one really appreciates a clean, simple, user interface that offloads as much as possible from the user’s brain to the computer. After one night of not being able to image as long as I’d wanted, I decided to write PHD Guiding, taking the same approach I’d taken in Nebulosity. The name comes from both its attempt to be intelligent (or at least well-informed and an expert in a particularly small domain) and to be “Push Here Dummy” simple.

Hardware
Before we cover how to autoguide with something like PHD, we need to cover the bits and pieces of hardware you need for guiding. There are three basic things you need: 1) a second camera chip, 2) a means of projecting an image onto that chip (e.g., a guide scope), and 3) some way to have your computer tell your mount which way to move. We’ll take these each in turn.

Guide Cameras
The same pixels you’re using to take a long-exposure image of a DSO cannot be used for guiding. Sorry, it’s true. Once you dump the charge from the CCD wells to read off an image, that charge is gone and cannot be replaced to let the image build up more. Some SBIGs have two CCDs in the same camera head to get around this
problem. With their Star-2000 system, Starlight Xpress used half of the lines (e.g., the odd lines) to build up an image while the other half (e.g., the even lines) were read off for guiding purposes. But, in neither setup are the same pixels being used for guiding and imaging at the same time.

If not using one of these systems, we need a separate guide camera. Numerous choices exist for a guide camera since the quality of the image is not paramount. That said, some cameras work better than others. In general, the best guide cameras will be a) monochrome and b) capable of true exposures of at least a second or so. It is true that you can guide using a simple webcam, but the color filter array over the sensor and the short exposures typically available on webcams conspire to place real limitations on how faint a star you can guide on. A one second exposure captures 30 times as many photons as a 1/30 second exposure and a filter designed to pass only red, green, or blue light passes less than a third as many photons as no filter. Put these together and a monochrome camera with a one second exposure captures about 100 times as many photons as a webcam running at 1/30 second. While you can stack short exposures on the fly to get closer to a long exposure (and PHD Guiding does this), you’re facing a difference of five star magnitudes. What this means is simply that the right choice of guide camera will make finding a suitable guide star far easier.

Guide Scopes and Off-Axis Guiders

We need some way to form the image on our guide camera. One method is to use an off-axis guider (OAG) – a device that uses a small prism to pick off a portion of the light from your scope that is headed for an area just outside the main camera’s sensor. By directing this light to your guide camera, you can use any star that’s available here as your guide star.

Off-axis guiders have several advantages. First, you don’t need any other telescope since your main imaging scope feeds both cameras. Second, you don’t need to worry about things like mirror-flop or flex in the mounting of your guide scope, so you’re always sure the main camera and the guide camera stay pointed in the same direction. That said, off-axis guiders do have their own issues. First, they take up a bit of focus distance (you need to make sure you have enough inward travel in your focuser to make up for the thickness of the OAG). Second, you have to find a guide star at the focal length you’re imaging at and in the small part of the sky covered by the pick-off prism.

Difficulty with this aspect is what
drives most to use a separate guide scope. Guide scopes are typically small refractors attached to the main telescope (or mounted side-by-side with the main scope) and held in place with adjustable rings. There is no need for the guide scope to be of particularly high quality (or even that it be a refractor), but you do want to make sure it is mounted rigidly and that its focuser can handle the weight of your guide camera without flexing. If modest pressure on your guide camera lets you move it relative to the main scope, you will be limited in how long you can expose without your stars trailing. As the mount rotates, gravity acts on the two setups and flex will result in it acting on them differently. The guide star may therefore remain stationary on the guide camera while the image in the main camera slowly drifts. Addressing this flex in my own setup let me move from 2-minute exposures to 20-minute exposures.

Back in the days of film imaging and manual guiding, there used to be a rule of thumb that the guide scope should be at least half the focal length if not the same focal length as your imaging scope. This was so that with typical reticle eyepieces, you could see the motion soon enough and react accurately enough to manually guide out the mount’s error. With CCD-based autoguiding this rule can be thrown away. Computers are far better at spotting very small movements and far faster and more accurate in their reactions.

With modern guide software, motions that are small fractions of a pixel can be accurately estimated. Subpixel guiding only requires that a star’s light covers several pixels (which, even with short focal length guide scopes and large CCD pixels, can be created with a slight defocus). Suppose, for example, that a star’s light strikes four pixels in a 2x2 grid and that the star is placed exactly at the center of this grid. Each pixel in this 2x2 grid would therefore be equally bright. Now, suppose the star moves ever so slightly to the right – a tiny fraction of a pixel to the right. As its Airy disk’s energy is now centered up/down but is slightly off center left/right on this 2x2 grid, the two pixels on the right will get more energy and be a bit brighter than the two on the left. Move it down a bit and the lower-right would get the most energy and the upper-left the least.

It is this basic notion that allows us to use short focal length guide scopes. Personally, I use a 66-mm telescope with a 388-mm focal length (William Optics Zenithstar 66 SD doublet). I know many who use scopes of similar focal lengths and have even seen excellent results from an 8x50 finderscope that had been converted into a guide scope (200-mm focal length). The SBIG eFinder accessory for their STV guider is even shorter at only 100 mm! The days of very long focal length guidescopes are over.

**Getting Guide Signals to the Mount**

At this point, you’ve got an image of the stars from your guide scope on your guide camera. You still need some software...
that will capture these images and figure out what commands to send to the mount and you need some way to get those commands to the mount. We’ll take on this latter bit first.

There are two basic ways of nudging your mount during guiding. First, if you have a computerized mount, you can use the same cable used for controlling the mount from your computer (e.g., via some planetarium package) and for updating it. Generally, this is a serial (RS-232) cable or a combination of a USB→serial adapter and a serial cable. When sending commands over this connection, your guide software either needs to know the particular dialect spoken by your mount (i.e., the specific commands needed to nudge a Meade Autostar vs. a Celestron Nexstar vs. a Losmandy Gemini, etc.) or it needs to know how to talk to something else that knows this dialect. In Windows, the ASCOM platform (www.ascom-standards.org) provides this intermediary and many software packages rely on ASCOM as a result. Individual drivers are written that translate “ASCOM-speak” into each individual telescope’s dialect and other programs just need to know how to “speak ASCOM” to then end up successfully working with a wide range of telescopes. The vast majority of ASCOM drivers are free and most mounts will be able to be controlled with the drivers included in the download. Don’t expect tech support via a toll-free call, however, as ASCOM is a collection of programmers helping the community out in their spare time.

For many mounts, guiding via the serial port can be very effective and accurate. For some mounts, guiding via the serial port (either directly or via ASCOM) is not as accurate as one would like. The reason for this can usually be traced to the small computer present in the mount and to the nature of the commands that can be sent. These small CPUs may listen for a new command once every quarter second or so, allowing them to spend most of their time...
executing commands, keeping up with the data coming from the position encoders on the axes, etc. When listening for GOTO commands and the like, four times per second is plenty fast. If guide commands take the format of “Guide East ON” and “Guide East Off”, we run into a problem. The shortest guide pulse we could execute in such a system would be a quarter second as it would take at least this long (and sometimes twice this long) to process the commands. Modern GOTO setups usually have a more complex command that allows you to specify how long the pulse should be (e.g., “Guide East for 79 ms”) to get around this problem. The generic term for this is now “Pulse Guiding” – an adaptation of a more complex scheme originally designed for Astro-Physics’ mounts.

The second way of getting commands to your mount is required for mounts that do not support this command syntax, for non-computerized mounts, and is even used by many for their computerized GOTO mounts (e.g., when using planetarium software to control the GOTO aspects of the mount). This method uses the “auto-guide” or “ST-4” input port found on most mounts (developed by SBIG for their ST-IV autoguiding system and adopted now as the de facto standard). Each direction of movement corresponds to one pin on the connector and a fifth is the “common” pin. In the simplest systems, these pins are directly connected to the motors or to your handbox’s arrows. Moving the mount amounts to electrically connecting the common pin to the desired direction’s pin.

No computer ships with an ST-4 output port (and no, you can’t use the modem or network ports). Thus, we need some hardware to get an ST-4 output from your computer. Shoestring Astronomy (www.shoestringastronomy.com) sells versions that attach to your parallel (GPINT) or USB (GPUSB) ports and plans for the parallel-port version are readily available on the Web for those inclined to build themselves (and those who still have a parallel port on their computer). In addition, a number of cameras come with ST-4 output ports built into the camera. This negates the need for something like a Shoestring adaptor as the guiding software can send commands to this onboard ST-4 port that are then sent to the mount itself.

Preparing Your Mount

Before guiding, you need to make sure your mount is working well. You do not necessarily need a very expensive or high-end mount, but you do need to make sure it is working well. What this means is:

a) It must not be overloaded. For mass-market mounts, find the most weight the manufacturer ships with the mount and don’t get very close to this. Some suggest a 50% de-rating of the capacity, but I have found that very good results can be had with less conservative de-rating. Unless this is a very high end mount, don’t run it at full-capacity.

b) It must operate smoothly. If your
mount has large shards of detritus embedded in grease that resembles epoxy and if it takes 30 seconds for your mount to begin to respond when you reverse directions due to excessive backlash, it’s time to clean and tune up the mount.

c) It must be well-balanced. For guiding purposes, this usually means a slight eastward bias to the weight balance (so that the motors are working slightly against gravity).

d) It must be reasonably well polar aligned. Perfect alignment is not needed but guiding accuracy will be significantly improved if you have a reasonable polar alignment. A rough drift alignment, a few minutes with an iterative GOTO alignment, or alignment with a good polar scope will suffice. But, you should not see the star drifting away with a quick look through a high-power eyepiece.

Software Choices

With the hardware in place, we now need something that will get the image of the star, figure out how much it’s moved, figure out what guide direction(s) should be engaged and for how long, and then send those guide commands. Many options exist here and many are either very affordable or free. A large number of options exist for Windows and there are solutions for the Mac and Linux as well. When choosing what software to use, make sure it will work with your hardware (computer, mount/mount interface, and camera) and that it provides an interface that you are comfortable with. Since you have many choices that are free or that have free demos (or that may even exist in other software you have), give a look at several to find one that you like.

I have tried several, but know one exceptionally well having written it. Given this, the fact that it is available for both Windows and OS X, that it supports a wide range of hardware, and that it is free, PHD Guiding (www.stark-labs.com) will be used as the sample program in the How-To shown on pages 54 and 55.

As you can see in the How-To, there are only a handful of simple steps to get guiding up and going. When I head out to image, this is all I do and start-to-finish it takes about five minutes. You don’t need to orient the camera in any particular way or tell PHD anything more than what kind of camera and mount you use. If you need to move the mount (e.g., change to a new target or reframe the current one), just press Stop, start looping exposures, find a new guide star when you’re done moving the scope, click on it, hit Stop, and then hit the PHD button and it’ll start guiding again.

Can it really be that simple?

Yes. For many, it is this simple and help is available from other users and myself via the Stark Labs Yahoo Group (http://tech.groups.yahoo.com/group/stark-labs-astronomy-software/) should you hit snags. If you want to make it a bit more complex and you want to tune things up a bit more, you can make a number of adjustments by entering the Advanced setup (brain icon). Over a dozen settings exist in this dialog and odds are you’ll not need to use any of them to get things up and going. Here are some you may want to explore, however, as you try to fine tune your guiding accuracy:

a) Calibration step: During calibration, PHD sends short pulses to the mount. If you’re using a very short focal length setup, you may want to increase this so that more movement takes place on each step. (If PHD doesn’t detect much motion after 60 tries, it gives up). Conversely, if you’re on a very long focal length setup, this step may make the star move so much it is lost, so try reducing it. The default works well for the majority, however.

b) Dec guide mode: By default, PHD guides in declination. When you are

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Astronomy Technology Today 53
**PHD Guiding: How-To**

PHD Guiding is designed to be as close to “Push Here Dummy” as possible. When you start it up, you are presented with a single screen. Getting guiding up and going is a matter of a few simple steps.

1) Tell PHD what kind of mount interface you will be using. From the Mount menu, select the appropriate item. PHD will remember this choice, so odds are you only need to do this once. The default is ASCOM on Windows and if you’re on a Mac, you’ll notice the only available choices are for the Shoestring GPUSB and for your camera’s onboard ST-4.

2) Connect to the camera. Press the icon that looks like a camera (far left) and a dialog will appear asking you what kind of camera you have. Select the appropriate camera (many more are available in Windows than in the OS X dialog shown here) and hit OK. If all goes well, the Status Bar on the bottom should tell you the camera was connected. In addition, on the right side of the Status Bar, the “No cam” indicator will change to “Camera.”

3) Connect to the mount. Press the icon that looks like a telescope (second from the left). If you’re using ASCOM, a dialog will appear and ask you to choose which mount you’re using. At times, the correct choice isn’t entirely obvious. For example, if you’re using a Meade LXD-75, you’d select “Meade LX200 and Autostar” since the LXD-75 uses the Autostar system (which uses the LX200 protocol). If you’re using an ST-4 adaptor, no dialog will appear and it will connect directly to the adapter you’d indicated in Step 1. The “No scope” in the right-hand portion of the Status Bar will become “Scope” and on the left, it will tell you that the mount has been connected.

4) Press the “Loop” button (third from the left, looking like a green looping arrow). This will start capturing images from your camera and displaying them on screen. The default exposure duration is 200 ms (0.2 s) and if you’re near a bright star and close to focus, this should let you see something. PHD will automatically stretch the image for display purposes (the slider next to the buttons controls the gamma - a mix of brightness and contrast) so that you can see your stars. If you can’t see any (and you’re pretty sure some should be there), odds are you’re out of focus. I find it useful to increase the exposure duration (pull-down next to the buttons) until I can see the large, faint, out of focus star and to adjust focus from there. I may drop the exposure duration back down to make fine focusing easier, but don’t fret too much about focus. If you still can’t see something, put an eyepiece in place of your guide camera and make sure you’re on something and then rack the focuser around with the camera on until you can see stars.
5) Set the exposure duration to somewhere between one and three seconds. This is a nice range for exposure durations while actually guiding as it is long enough to let atmospheric turbulence (seeing) blur the star to a nice average position and yet short enough to fix the mount’s errors and not let it get too far astray. Don’t be tempted to use very short exposures here as you’re more likely to end up “chasing the seeing” and trying to fix errors due to turbulence rather than errors due to your mount. Seeing changes faster than you can move the mount, so that’s a race you’ll never win.

6) Click on a star. This will be your guide star. If the star is too bright, PHD will tell you so in the Status Bar. Too bright is as bad as too dim. A box will appear on the star that should turn green. If it is orange, PHD can’t locate the star. If it is green, PHD has locked onto the star.

7) Press the Stop button (fifth button). If you forgot to select a star, you can do so now. But once you have pressed Stop, the image will no longer loop and update in real time.

8) Press the PHD button (fourth button, target with an arrow in the bulls-eye and labeled “PHD”). Orange crosshairs will now appear on the original lock position and PHD will enter its calibration phase. During calibration, PHD tries to move the star first in RA and then in Dec as it watches where the star moves. It needs to get it to move a bit in each direction to get a good estimate of how it moves when guide commands are sent. So, you should see the box remain on the star and move during calibration (the crosshairs will stay fixed). Once calibration is done, the crosshairs will turn green (they may move a bit from the original location), the status bar will say “Cal” and it will begin guiding automatically. Start taking images in your main camera.
not aligned directly on the pole, the stars will drift slowly in declination. PHD will attempt to guide this out and to do so intelligently. Its “resist switching” algorithm tries to determine which way the drift is and to stay on one side of the worm gear, switching to the other only when a lot of evidence has built up saying it’s guess of the drift direction is wrong. If you know your drift is only to the north or south, however, you can skip all this guessing and tell PHD to only guide in one direction in declination.

c) Noise reduction: Some guide cameras have a lot of noise (e.g., hot pixels). Passing a filter over this can eliminate the hot pixels without dark frames and without significant loss of accuracy in estimating the guide star’s location. Try 3x3 median if there are a lot of hot pixels in your image.

d) Aggressiveness and Hysteresis: These are values found in a number of guide packages and control what proportion of the measured error is to be used (aggressiveness) when determining the length of the pulse to send and how much of a “history” (hysteresis) is to be used. Odds are that the current error is, in truth, the same as the last error as our mounts’ periodic errors are roughly sine waves that change very slowly. If it’s going too fast now, it’s likely going too fast the next second as well. Together, these two can be adjusted to balance out how rapidly the mount attempts to respond to errors.

e) Force calibration: If you’ve moved to a very different portion of the sky, the calibration PHD will no longer be valid. Check this and the next time you tell it to guide, it will re-calibrate.

Conclusions

My goal in writing PHD Guiding and releasing it as freeware was to get more people to be able to extend their exposures, go deeper, and make better images. To get more people autoguiding, the user experience had to be simple, yet the underlying guiding had to be accurate.

I take real joy in seeing first-light shots from new users posted to groups or e-mailed to me. Some of my favorites come from users who say, “I wanted to start with something easy, so I tried 1 minute exposures. Since that worked, I set it for 10 minute exposures and collected images all night.” That a user is naive enough to the historical difficulty of autoguiding to even consider jumping to 10 minute exposures after a 1 minute “test shot” (I remember struggling to get 1 minute shots!), and that he can produce round stars on the first night or so out, puts a smile on my face.

As it can be easy enough for new users to quickly get going and powerful enough for experienced users to image as long as their light pollution permits, PHD shows autoguiding can be both simple and accurate.