An Adaptive Autoguider using a Starlight Xpress SX Camera

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Abstract

The acquisition of very faint deep sky objects, be it analog with film or digital with a CCD camera, requires a large integration time in order to achieve a high signal to noise ratio. If the telescope used for the acquisition is not polar aligned accurately the resulting image will be subject to motion blur, resulting in stars leaving tracks and extended image structure will be poorly resolved. This article describes how a temporal integration of any duration can be achieved using a CCD camera as a telescope autoguider.

Introduction

This article describes how a Starlight Xpress parallel port SX camera can be used as an adaptive autoguider for a telescope equipped with motors on both axes. Autoguiding is a process by which the tracking error, due to polar misalignment and periodic error, can be almost eliminated. Normally a small secondary charged coupled device (CCD) chip or camera is used to repeatedly image a guide star which is then inspected for any deviation from its initial position. If this guide star moves, the telescope is guided to bring the star back to its initial position. This device is mounted parallel to the main axis of the telescope either by using an off-axis guider or through a small telescope mounted on the main telescope.

The text will describe the development of such a system. It will explain the adaptive tracking algorithm and its implementation on a standard IBM personal computer (PC). The next section will cover the hardware configuration.

Hardware Configuration

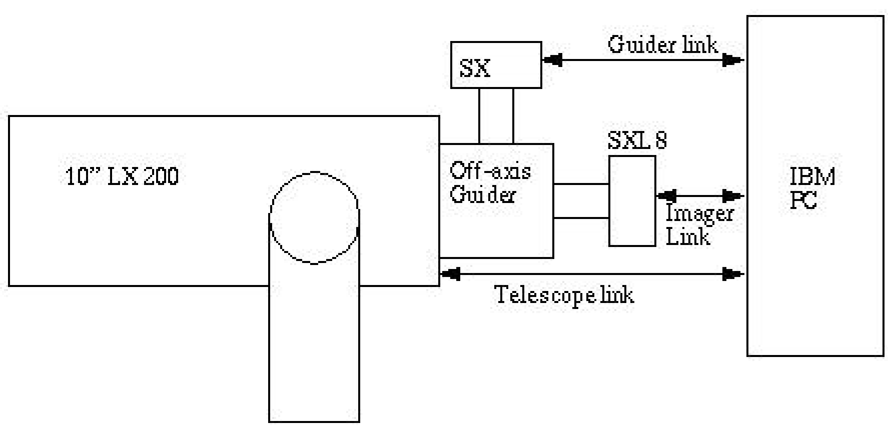


Figure 1 - Hardware Configuration

Figure 1 is a schematic of the hardware configuration. The telescope used for the development and for the experimental results was a 10” Schmidt Cassegrain (Meade LX200) that had a

Lumicon off-axis guider attached to it. The main imaging CCD was a Starlight Xpress SXL8 parallel port camera and the autoguider was a Starlight Xpress SX camera. Each camera was connected to the PC via its own parallel port connection. The telescope was connected to the PC via a serial communications link.

The telescope was not permanently erected and consequently every time it was used it had to be polar aligned. Although unguided exposures of up to five minutes were possible, longer integrations required telescope guidance.

Mathematical Formulation

The main problem can be summarized in the following statement:

"If the guide star moves from its initial position, in which direction and by how much do we move the telescope in order to bring this star back to its original position?"

For example, if the guide star moves along the Right Ascension (RA) axis only, then we know the telescope needs to move along this axis, but by how far and in which direction do we move the telescope to compensate for this movement? In this section we will seek answers to these problems.

Consider first the motion in the RA direction only, the Declination (Dec) analysis being identical. There are a number of assumptions that make the analysis simpler. First we assume that the axis of the guide camera and the axis of the telescope are perfectly aligned. It is also assumed that the telescope can be driven linearly. The control software for the LX200 allows movement along the RA axis to be started at a guide speed of twice sidereal rate. This motion will continue until a command is sent to return to normal sidereal rate. We shall call the time interval between the two commands dt, measured in milliseconds. Now if the distance moved, measured in arcseconds, is denoted by x during this time interval, then:

$$x = M_x \, dt \qquad (1)$$

where M_x is a constant of proportionality whose value must be determined. This simple equation relates how many arcseconds the guide star will move, x, in RA, for a given time delay dt.

M_x must now be evaluated. We shall use a calibration procedure in order to calculate this value. This involves measuring how far a calibration star moves for a given time delay. If this calibration time interval is denoted by dt_c and the measured distance is x_c, then from the above equation M_x can be evaluated using:

$$M_x = x_c / dt_c \qquad (2)$$

So for a given time delay dt_c, which is usually between 5 and 10 seconds, we measure the corresponding movement, x_c, and hence M_x is evaluated using the above equation. In fact an average is obtained for this value by moving the telescope back to its original position and again measuring the distance moved. Another value of M_x is found and the two are then averaged to give the final result. M_x can be thought of as the guide speed of the telescope.

When the autoguider is operating we in fact measure the movement of the guide star from its initial position and then calculate the required time delay. From equation (1) this delay can be found by rewriting this equation as:

$$dt = m_x\, x \qquad (3)$$

where

$$m_x = 1/M_x \qquad (4)$$

Equation (3) gives the required time delay for any given error. To bring the star back to its initial position, the telescope must be driven in the same direction as that first used in the calibration phase. For example, if the telescope was first moved West during the calibration phase then the telescope must be driven West for the calculated time delay. If however, equation (3) results in a negative time interval, then the telescope must be driven in the opposite direction to that used in the calibration phase, East in our example.

We have now obtained all the information required to correct for any error in the RA axis. A similar procedure is used to obtain the constant of proportionality for the Dec axis.

Going back to the original problem, stated above, we can now compensate for any deviation from the guide star's initial position. If x is the measured distance moved by the guide star, note x can be negative, then equation (3) gives the required time delay which will move the telescope so that the guide star will return to its initial position.

Implementation

The above procedure was integrated into a C++ program. The program runs under Microsoft Windows (3.1, 95, NT) and controls both cameras as well as sending the correction commands to the telescope. Figure 2 shows the dialog screen that is displayed when the autoguide option is selected.

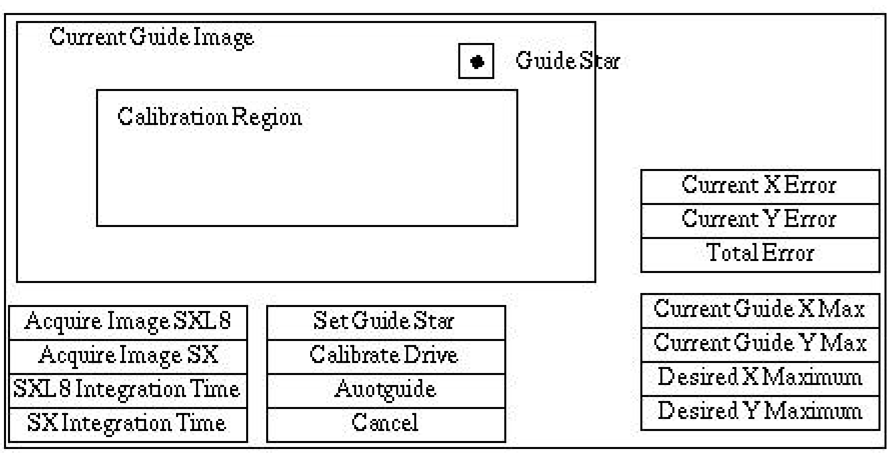


Figure 2 - The autoguider display

When the “Calibrate Drive” option is selected, the software automatically finds the brightest star in the calibration region, see Figure 2. The program will then move the telescope West for the calibration period and it will measure the distance that the calibration star has moved. The telescope is then moved East for the same calibration duration and again the distance moved by the calibration star will be measured. The constant of proportionality will then be found using Equation (2). The procedure is repeated for the Dec axis, first moving the telescope North and then South. Note this procedure will fail if during a calibration movement the calibration star moves out of the calibration region or if a star that is brighter than the calibration star moves into the region.

The tracking error is found using the SX camera by continuously imaging a bright guide star (above 12th magnitude) and calculating the distance that this star has moved from its initial position. The two telescope axes are processed independently. Figure 3 shows the control flow for the autoguider.

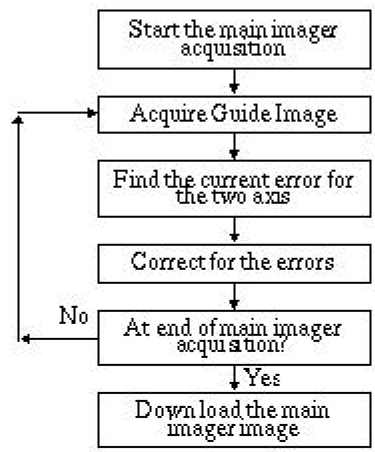
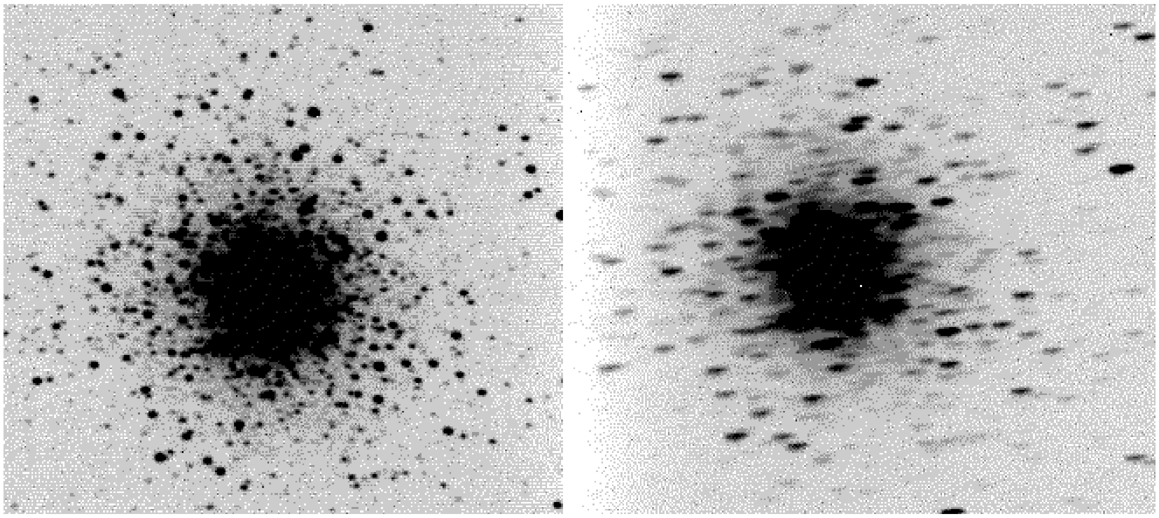


Figure 3 - Control flow for the autoguider

The position of the maximum intensity of the guide star needs to be measured to within a fraction of a pixel. This was achieved by fitting a Gaussian model, see reference 1, to the guide star profile and choosing the position of the maximum point of the model, a centroid method can have been used.

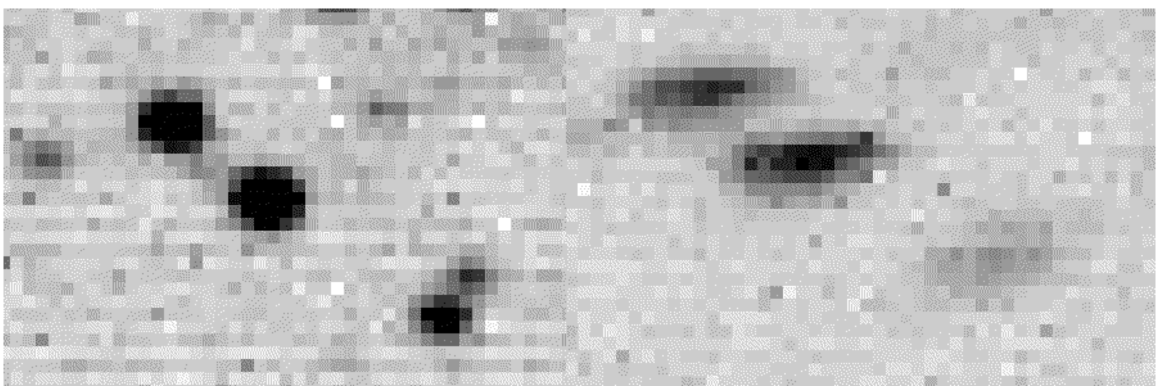
Results

The results presented here were obtained using the simple autoguider method described above. Figure 4a shows a fifteen minute guided observation of M15. No trailing is present in this image. Figure 4b is a similar observation without guidance, trailing is clearly visible. Figure 5a and 5b show a small area of the two images magnified ten times. Careful inspection of the image in Figure 5a still shows no trailing even at this magnification.



(a) (b)

Figure 4 - M15, fifteen minutes integration (a) with autoguiding and (b) without



(a) (b)

Figure 5 - Small subsection of the images in Figure 4, magnified ten times

A time history of the guide star movement was recorded and Figure 6 shows the error plotted against time for the two telescope axes. The guiding error is plotted in arcseconds and the time is plotted in minutes. The error for the RA axis was larger than the error for the Dec axis, this can be attributed to the fact that there was a periodic error associated with this axis and not with the Dec axis. However, the root mean square error values for the two axes were 1.47 and 0.66 arcseconds for the RA and Dec axis respectively. These values are well within the normal "seeing" conditions for the observing site, being about 2-3 arcseconds on a good night. Table 1 summarizes the time history statistics for the two telescope axes.

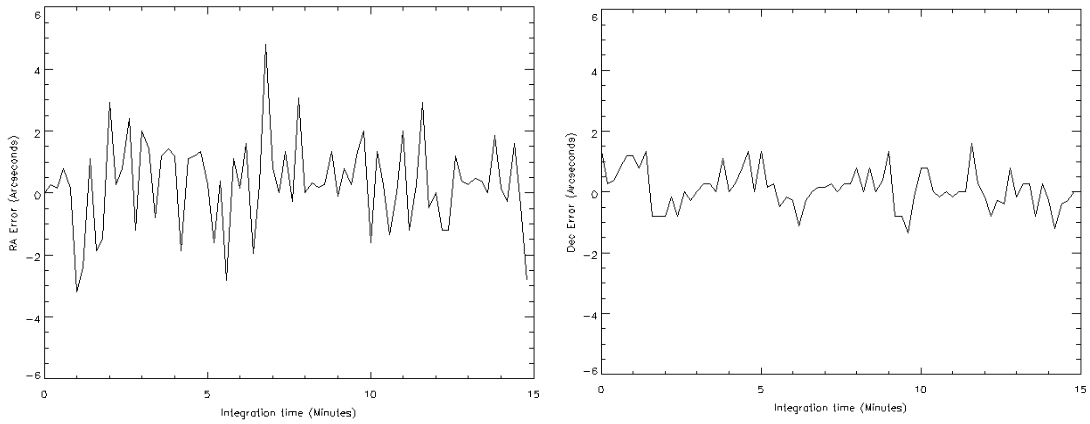


Figure 6 - The trailing error as a function of time for both axes

Axis	Maximum Error (arcseconds)	Minimum Error (arcseconds)	Mean Error (arcseconds)	Standard Deviation (arcseconds)	Root Mean Square Error (arcseconds)
RA	4.80	-3.20	0.32	1.44	1.47
Dec	1.60	-1.33	0.12	0.65	0.66

Table 1 - Trailing Error Statistics

Figure 7 shows two other observers using the autoguider. The first is a fifteen minute observation of M27 and the other image is a thirty minute observation of NGC891. These images demonstration the high signal to noise ratio that can be achieved using the simple autoguider.

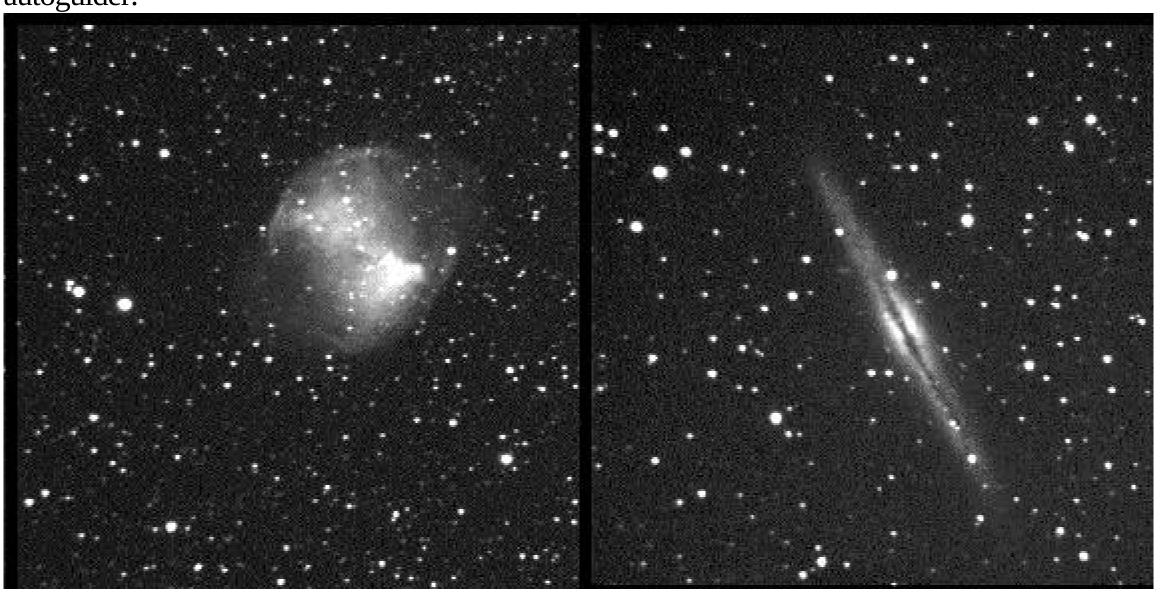


Figure 7 - Fifteen minute observation of M27 and a thirty minute observation of NGC891

Conclusions

There is no secret in acquiring good astrophotography images, be it with film or with a CCD camera. The principal considerations are as follows. First choose a good observing site that is very dark and choose a still clear night. Use a well focused camera and integrate for as long as possible. Last but not least use a good size telescope that has excellent tracking capabilities. This article has described a simple autoguiding method that can be employed to eliminate trailing errors for any integration period. The images acquired when using the autoguider are always well focused with no sign of trailing for any length of integration.

Reference

1 Buil, Christian, *CCD Astronomy*, Published by Willmann-Bell, Inc., 1991.

Acknowledgments

The work presented here would never have come into being if I had not been encouraged and helped by the following people, Terry Platt, Steve Webb, George Sallit and most of all my wife and children.

Profile

Steve Foulkes is a very keen amateur CCD astronomer. He is a member of the Webb society. He can be contacted via his e-mail address: sbfoulkes@dra.hmg.gb