Guider camera and software for 1.5m echelle

A. Tokovinin

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1 Current status

The fiber-linked echelle spectrograph is a new instrument at the CTIO 1.5-m telescope. Its front-end module is attached to GAM and fed by a mirror on the GAM probe, which should be placed in a fixed, well-defined position. Moving the probe to look for offset guide stars is not possible. If, by chance, the fixed GAM field contains some stars, the existing guiding system can be used, if not, the guiding can be done manually.

Acquisition of stars in the fiber feed and their centering on the entrance hole (analogue of a spectrograph slit) is done with an analogue TV camera WAT902HS by observing the signal on the monitor. Manual guiding is possible. This camera suffers from saturation for bright stars and lacks sensitivity for faint stars, especially when they are centered in the hole and only a faint residual halo is seen. An adjustable LED can be used to activate the camera automatic exposure control, reducing the saturation on bright stars. For very bright targets such as α Cen, a neutral density filter is placed in the guider manually, causing some image degradation.

There are two CTIO guide cameras installed at 1.5m, one in the GAM probe, another in the RC spectrograph (as a slit viewer). Each camera uses a custom interface connecting it to the acquisition board (ISA slot) in a Linux PC. The guiding software written by R.Cantarutti in C is driven by a GUI, it sends the correction commands to the TCS computer (VxWorks diskless machine) through serial line. The GAM probe is controlled by another Windows PC. Overall, telescope control and guiding is done with four PC computers.

2 Requirements

A definitive guiding system on the echelle has to fulfill the following requirements:

- Digital CCD camera of VGA resolution (640x480 pixels) or larger with adequate sensitivity and remote exposure control. Pixel size from 5 to 10 μm.
- CS-mount camera interface (back focal distance 12.6 mm). The space from the CS-mount flange to the wall in the GAM is 100 mm for the short-focus guider configuration and 85 mm for the long-focus configuration. The camera length including connector and cables must not exceed 100 mm.

- The signal from the guide camera must be brought to the control room, where a PC computer will be located.
- Exposure time t remotely adjustable from $10\,\mu$s to 1 s. The frame rate no less than 10 Hz with full CCD readout (for $t < 0.1$ s).
- Working temperature range from $-5°$ to $+25°$.
- The existing guiding software should be preferably adapted for the new system, with the same GUI.

3 Implementation

3.1 CCD camera

There are many models of *machine-vision* cameras available on the market. These cameras enable fast acquisition of un-compressed images in digital format (8 or 12 bits per pixel), either color or monochrome. The PC interface can be of USB, FireWire (IEEE 1394a or IEEE 1394b) or Gigabit Ethernet (GigE) type. As the length of USB and FireWire connections is limited (to 5 m and 10 m, respectively), these cameras would require repeaters. Repeaters for both USB and FireWire are readily available, using optical fibers, Ethernet (CAT5) cables or wireless link for signal transmission. On the other hand, GigE cameras can be up to a 75 m distance from the PC. They usually require a dedicated high-speed Ethernet port on the PC, distinct from the general network port.

The software of most USB cameras is written for Windows (with some exceptions). FireWire cameras compliant with the DCAM standard have drivers and software for Linux. The GigE cameras also have an interface standard, GeniCam (or GigE Vision), for which Linux support is available. The GeniCam standard actually encompasses also the IEEE 1394, Cameralink, and smart cameras, and offers a unified API for all those protocols.

Considering the increasing popularity of the GigE standard and the ease of connection, we chose this standard. A GC650 camera with line-transfer CCD from Prosilica satisfies the requirements (Table 1). There are possibilities of horizontal (up to 8 pixels) and vertical binning, ROI, triggering, etc. The camera is powered by 12V, with power consumption less than 3 W. This power is already available for the existing TV camera. A somewhat larger (but cheaper, USD795) GigE Scout camera from Basler with the same sensor is included in Table 1 for comparison (a Pylon driver is sold separately for \$475). Basler offers the same camera with the sensor oriented at 90° that would fit the space requirements.

We have some experience with cameras from Prosilica. The EC650 camera (FireWire standard, same sensor) has a measured readout noise of 11 electrons, with 2.1 el/ADU for the zero gain setting. A GE680 GigE camera with a CMOS sensor has a noise of 13.4 electrons. The quantum efficiency of these sensors is about 0.4 at 500 nm. The working temperature range is slightly out of specification but, considering camera's internal heating, this should be acceptable. Moreover, V.Kornilov has informed us that he tested thses cameras at $-10°$C and they work well. The manufacturer confirmed that these low working temperatures are appropriate.

A star of $V = 12.5^m$ will give a signal of 2000 photo-electrons per 0.1s exposure time (system efficiency 0.2 is assumed). If 90% of the light goes into the fiber, the remaining 200 photons must be

Table 1: Specifications of two GigE monochrome cameras

Parameter	GC650 (Prosilica)	scA640-70 (Basler)
Sensor type	CCD Sony ICX424AL	CCD Sony ICX424AL
Resolution	659x493 pixels	659x480
Pixel size	7.4x7.4 μm	7.4x7.4 μm
Full resolution frame rate	90 Hz	71 Hz
Digitization	8-12 bits	8-12 bits
Exposure time	10 μs to 60 s	80 μs to ?
Lens mount	C/CS	C/CS
Size (HxWxL)	33x46x59 mm	29x44x73.7 mm
Operating temperature	0 to 50°	0 to 50°
Software interface standard	GigE Vision Standard 1.0	GeniCam

used for guiding. Fainter stars will rarely be observed, for them the exposure time will be increased and a 2x2 binning can be used. On the other hand, a $V = 0^m$ star in 10 μs exposure will give a signal of 20 000 electrons. Considering that the signal is distributed in several pixels and that the large part of light goes into the fiber, the saturation level (12 bit, 4096 ADU, or 8000 electrons) will not be reached.

With a short-focus optics in the guider, the image is de-magnified by 2.8 times. In this case, the pixel scale is $0.38''$, or 7 pixels across the entrance-fiber hole. The existing guider also has $0.4''$ pixels.

If a full frame is read out at 10 Hz with 2-byte signal depth, the information rate is 52 Mb/s (megabit per second). Both cameras in Table 1 support the 100 Mb Ethernet, so the GigE connection is really needed only for faster frame rates. Even with 100 Mb, a fast readout is possible for a ROI or a binned image.

3.2 PC computer

The guiding PC computer will run under Linux. It will have two Ethernet ports: one Gb dedicated to the camera (peer-to-peer), other 100Mb for general network. One of those ports will likely be implemented with an additional board. R. Cantarutti has identified a suitable PC with two GigE ports at orbitmicro.com.

3.3 Software

R.Cantarutti will adapt the existing guider software to be compliant with the GeniCam standard. The estimate of time needed for this work is as follows: 1 wk for SDK installation, learning the GeniCam standard, running examples, integrating the driver to the existing guider software. Another week for testing and setup at the teelsope.

Table 2: Hardware components and costs

Item	Cost, USD
GC650 camera from Prosilica	1500? (quotation pending)
PC computer	1318

3.4 Cost

4 The echelle guider as a prototype

The existing CTIO guiders require PC computers with ISA slot which become obsolete. These systems have other drawbacks like large size. If the proposed guider proves adequate, it can serve as a prototype for progressive replacement of other CTIO guiders. The actual CTIO guide cameras use 385x288 pixel frame transfer CCDs from e2v with $22\,\mu$m pixels, Peltier-cooled to $-45°$. The readout noise is about 11 electrons. The typical frame rate is $10\,$Hz, a faster rate is possible with ROI.