Remote Use of the SOAR 4.25m Telescope with LabVIEW

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ABSTRACT

The SOAR telescope will begin science operations in 2Q 2003. From the outset, astronomers at all U.S. research universities will be able to use it remotely, avoiding 24+ hrs of travel, and allowing half-nights to be scheduled to enhance scientific return. Most SOAR telescope systems, detector array controllers, and instruments will operate under LabVIEW control. LabVIEW enables efficient intercommunication between modules executing on dispersed computers, and is operating-system independent. We have developed LabVIEW modules for remote observing that minimize bandwidth to the shared LAN atop Cerro Pachón. These include control of a Polycom videoconferencing unit, export of instrument control GUI's and telescope telemetry to tactical displays, and a browser that first compresses an image in Chile by a factor of 256:1 from FITS to JPEG2000 and then sends it to the remote astronomer. Wherever the user settles the cursor, a region-of-interest window of lossless compressed data is downloaded for full fidelity. As an example of a dedicated facility, we show layout and hardware costs of the Remote Observing Center at UNC, where instruments on SOAR, SALT, and other telescopes available to UNC-CH astronomers will be operated.

Keywords: Remote observing, LabVIEW, image compression, video conferencing

1. Introduction

Sky conditions can vary greatly during a traditional "observing block" of several nights, requiring that diligent users be prepared to execute several programs. But, backups do not necessarily best exploit a facility whose capital cost depreciates by several thousand dollars each night. So soon after commissioning, non-optimized systems may limit telescope performance. Travel costs are increasing as fuel prices rise, and security delays are becoming common.

Fortunately, communication costs continue to drop rapidly as bandwidth increases**.** The arrival of Abeline (previously known as Internet-2, http://www.internet2.edu) at Cerro Pachón *via* La Serena and Florida International University now provides up to 1 Mbps connection between the SOAR (Southern Observatory for Astrophysical Research) telescope and its users at any research university in the U.S.; many Brazilian users of SOAR can also anticipate a fast link. A remote user desires both rapid data transfer and the illusion of "telepresence". Abeline specifically supports broadcast quality video conferencing. Video, separate from astronomical data, comes as a low latency stream (H.323) at useful rates from 128 to 768 Kbps and higher. From La Serena to computers in Chapel Hill, typical delay is under 200 milli-seconds, with more than half of this time spent jumping from South to North America.

We are exploring issues related to remote control of SOAR science programs to maximize productivity:

1. Optimal subdivision of bandwidth between video and data by dis/re-connecting video conferencing under software control. Reconnection takes less than 5 seconds.
2. Minimizing real-time data rates from large detector mosaics by first sending a compressed rendition with sufficient fidelity for the remote observer to define regions of interest (ROI) that are then sent at full bit resolution before the rest of the image is refined.
3. Integration of telescope and site status telemetry into tactical displays for the remote observer and the telescope operator. Several of these are based on the PROAS package, written by N. Cardiel at IAS (Canary Islands).
4. Remote, low latency use of instrument control GUI's.

The current release of National Instrument (NI) Inc.'s LabVIEW (version 6.1, http://www.ni.com) accomplishs all of these tasks in an efficient and very transparent fashion that is independent of operating-system idiosyncrasies. In this

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paper, we describe our prototypes and show sample displays. We are using mid-range Polycom video conferencing units (models SP, MP, and H323) that can be panned and zoomed remotely, have excellent compression/decompression (codec) hardware, sensitive voice-activated microphones, and are available starting at about $2800 (academic pricing in 8/02); a TV set or PC graphics card with video output (e.g. WinTV) is also required. This is comparable in cost to an airplane ticket from North America plus internal travel and board in Chile for a 3 day observing run, plus institutional overhead. So, after one "run", remote observing is free. How the NOAO community will access its 30% SOAR time share is an open question. However, adequate PC-top cameras without pan and zoom are available in 8/02 for under $400, and could be loaned to successful PI's to discourage travel along with other incentives such as backup time in the event of bad weather. Not traveling might encourage more graduate, undergraduate or even K-12 student participation in the run, a legitimate tap into NASA/NSF educational add-on funds for a modest hardware investment.

2. Image Display, the Remote Observing Tool

Detector array controllers for SOAR facility instruments[1] are driven by a LabVIEW package developed by Imaginatics Inc. called ArcVIEW[2]. ArcVIEW organizes the datastreams from the array controller into a FITS file held in the RAM of the Data Server PC, and provides a display GUI for an astronomer at the telescope. We have developed a plug-in module, the Observing Tool Server (OTServer), which is optimized for remote observing. ArcVIEW notifies OTServer when a new image is available. Interaction with data begins when OTClient on the remote user's computer requests that an image be compressed in Chile. OTServer in Chile then sends a lossy version (whose quality is set according to bandwidth and user preference), for display in a window. The observer selects ROI's with the cursor or by various masks, and these tiles then overwrite areas of the compressed rendition at full bit resolution (Fig. 1). The result can be saved in several formats, including FITS.
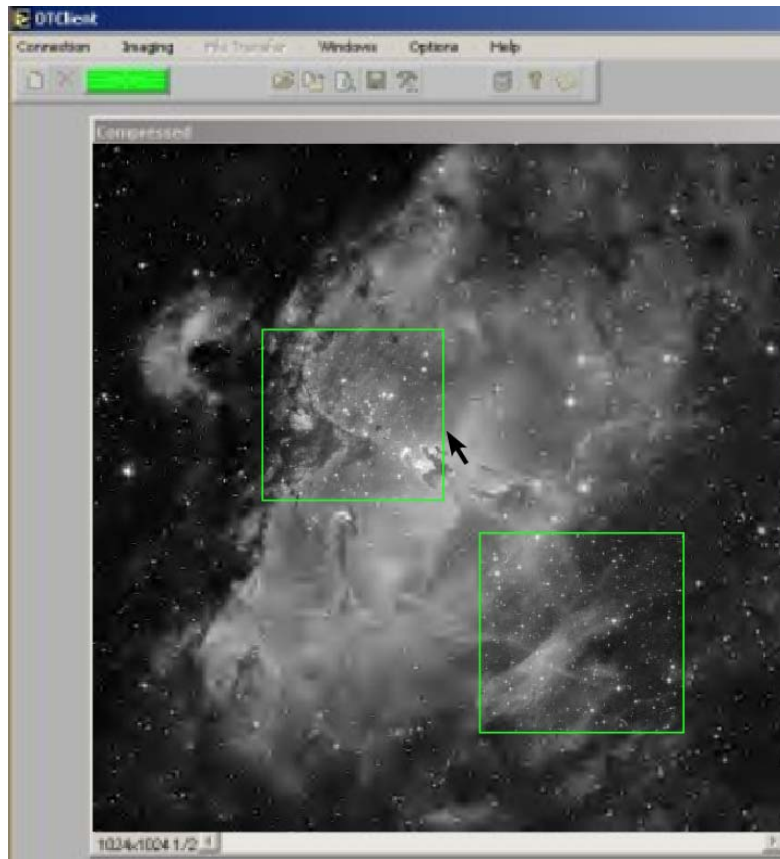

Figure 1. Image Browsing tool at the observer's end, the front panel of OTClient. The background image of the Eagle Nebula has been lossy compressed by 512:1; each of the two outlined ROI's was retrieved from Chile at full resolution by a cursor click.

IMAQ Vision for LabVIEW, an NI graphics package in C for Windows, handles this display (NI has not yet released a Linux version). We added 16-bit lookup tables to allow click-and-drag brightness/contrast adjustment in a way that mimics familiar FITS file viewers such as DS9 and Ximtool.

2.1. Compression

We tried several Fourier- and wavelet-based video codecs, including JPEG and hcompress (www.stsci.edu/software/hcompress.html), settling on JPEG2000 (www.jpeg.org/JPEG2000.htm) as the most effective for our application; our experiments use the freeware JASPER library at www.ece.ubc.ca/~mdadams/jasper JPEG2000 provides excellent lossless and lossy compression, as well as ROI's that are sent before the background stream with different (even lossless) compression. On a 2.4 GHz Pentium-4 PC running Windows 2000 in 512 MB RAM, it takes only a few seconds to compress a $4K^2$ 16-bit image, the largest from 1st-generation SOAR instruments. Figure 2 shows an image at various JPEG2000 compressions.
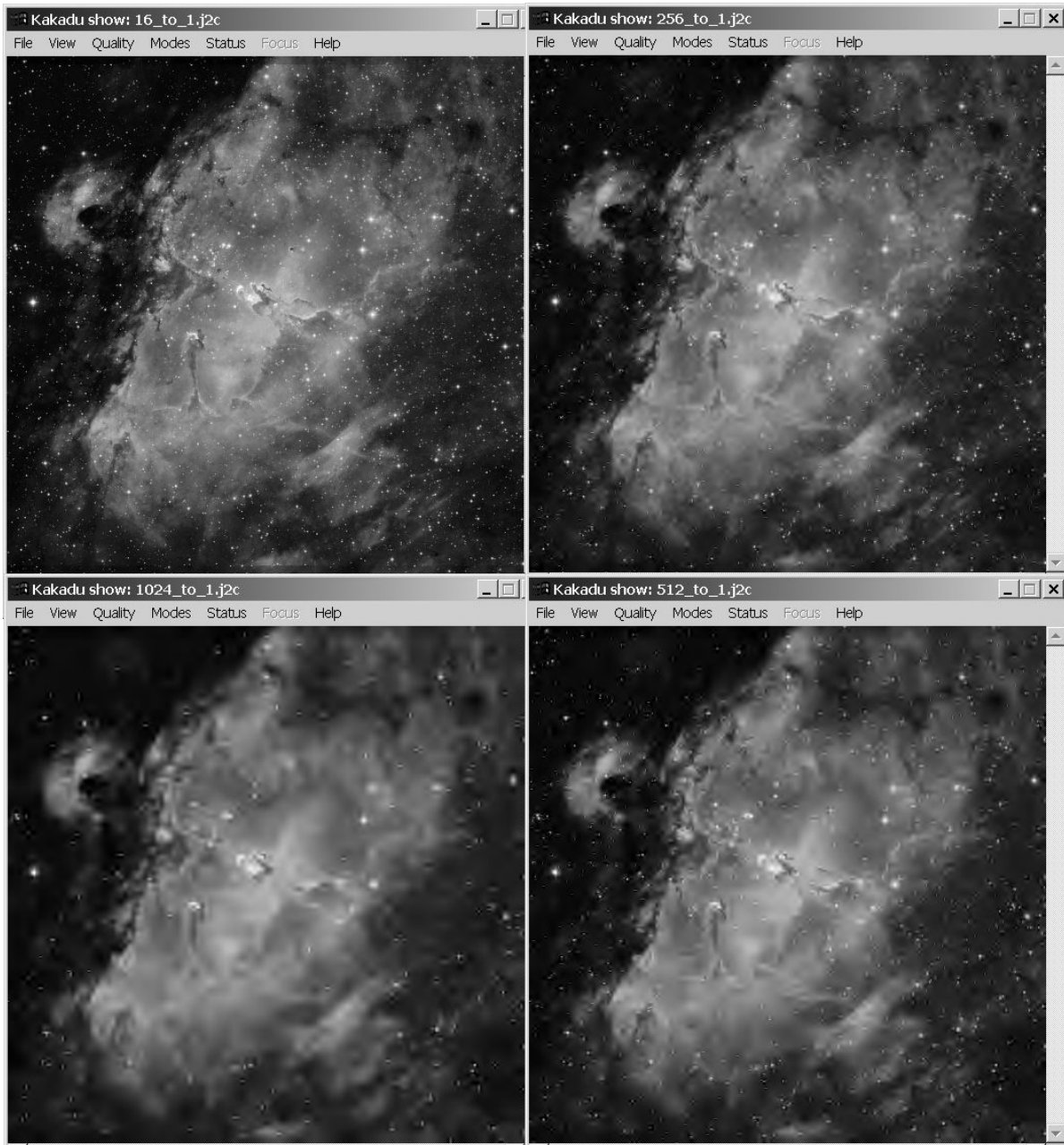
Figure 2. NOAO Mosaic image, compressed (clockwise, from top left) 16-, 256-, 512-, 1024-fold using a lossy mode of JPEG2000.

2.2. Behind the Scenes

Intercommunication between OTServer and OTClient is by a traditional client-server scheme[3]. Our Remote Observing Tool (ROT) has its own efficient protocol built atop TCP/IP. The server awaits client requests, processing them sequentially. The protocol currently has only seven commands each with one parameter, but ROT can be extended easily. Flexible debug logging is provided at both ends. The Polycom video unit is commanded through its firmware telnet window. This was much easier to program than the firmware Web interface, and allows script execution (for example, to detach and then resume a video session). We have occasionally forced reconnection because of audio breakup; audio, surprisingly, tends to be more finicky than the video. These usually occur in daytime, sometimes

accompanied with degraded video, and likely arise from router problems somewhere along the 17 typical hops between Cerro Pachón and North America. We plan to monitor network quality to ban routes that are recurrently problematic.
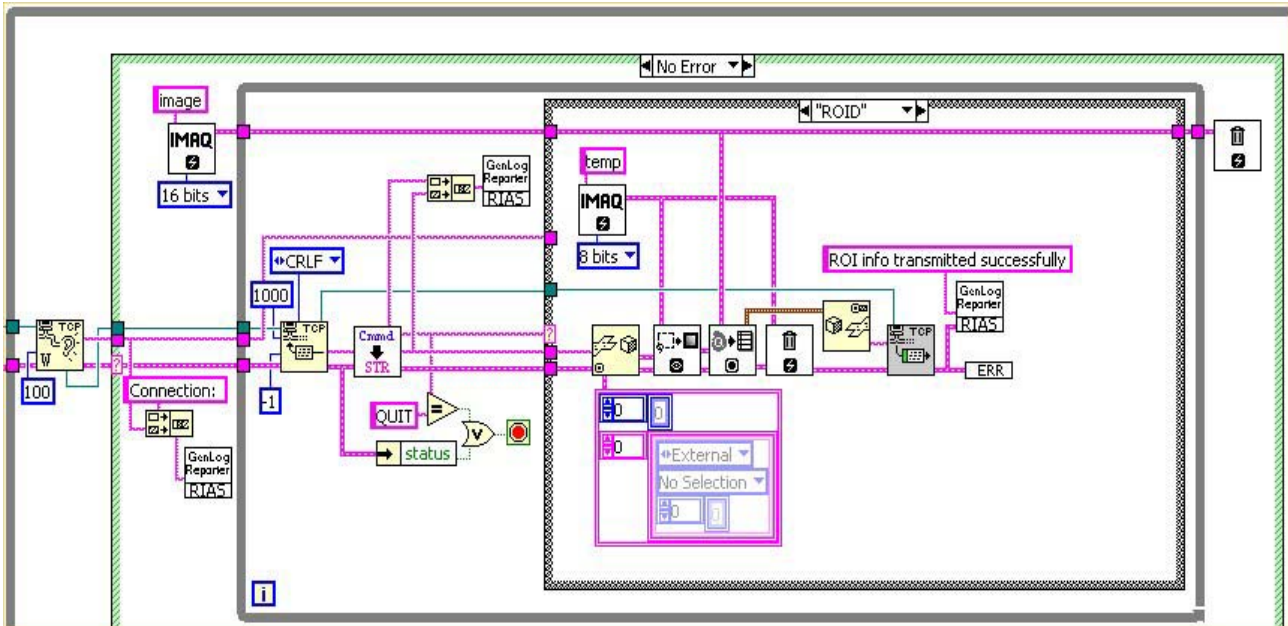

Figure 3. OTServer in LabVIEW dataflow g-code, calling various IMAQ and eventually SOAR Communications library modules.

2.3. Masks and Data Rates

A powerful functionality of JPEG2000 is to send first ROI's with lossless compression, and then progressive compressions of the rest of the image. While the astronomer is interacting with data in the small ROI's (e.g. measuring the sky brightness or the object PSF, or taking a power spectrum to assess background noise), the lossy compressed full image is arriving at a rate that does not impede the fidelity of the video conferencing link. Useful masks to define ROI's are those set by levels of image brightness (e.g. "all pixels brighter than X-times the mean local sky"), connection to previous ROI's, and wavelength/spatial ranges of interest in multislit or integral field spectra. Note that the entire image may eventually arrive, but SOAR always archives the lossless compressed version in Chile for later access.

Data rates from 1st-generation SOAR instruments will average about 4.6 GB/night (1.6 TB/year), peaking at about 8.5 GB/night. Assuming 2:1 (50%) lossless compression, a night's data can be retrieved to La Serena on the 75 Mbps link in 10-20 minutes using only 1% of link capacity to preserve the rest for others. In La Serena, data will be retained in a "disk farm" running as a software level-1 (disk mirroring) RAID array. Firewire-interface disks are so cheap/GB that the entire SOAR archive can grow online by adding less than 10 disks over a year. Sending a night's data to the U.S. will require 3.3-6.9 hours on the AURA dedicated 4 Mbps Abeline link (taking 16-30% of the link capacity, so several video conferencing/data transfer sessions by other observatories can also be ongoing). The disk archive will be replicated somewhere in the U.S. and in Brazil, and its contents eventually ingested into the National Virtual Observatory.

3. Tactical Displays

Tactical displays provide the remote astronomer not only with a sense of what is happening now, but also the context of these events within the entire observing session. The SOAR Telescope Control System[4] pointing and environmental telemetry streams are relevant. The SOAR telescope will also access several multi-wavelength databases as it points around the sky. This information will be available to the remote astronomer for planning and for science context during observing if desired. Following are what we regard as the important elements in a useful tactical display that serves to replace the often cursory, midnight "reality check" performed by restless astronomers.

3.1. All-Sky View

The centerpiece is the real time view of the sky provided by PASCA, the Pachón All-Sky Camera (the almost identical Tololo version is described at http://www.ctio.noao.edu/~david/tasca.htm). This is a 1 K^2 CCD coupled to a Nikon f/2.8 fisheye lens that takes 1200 sky images nightly (e.g. Fig. 4). It has B, R, Na, and Hg filters to assess the effects of clouds, airglow, sodium, and mercury light pollution. Differencing images from night to night easily highlights even tenuous cirrus. We outline these intruders as contours of % attenuation at the wavelength of observation, permitting the astronomer to steer clear. If clouds drift perceptibly, a few vectors are drawn to show probable motions during the current exposure.

Also contributing to attenuation contours even in photometric conditions is zenith-angle and wavelength dependent extinction. The underlying measure will be mean extinctions initially, but we anticipate that in a couple of years more informative data will come from an automated photometric telescope (APT) that would constantly patrol the critical range of zenith angles, stellar temperatures, and observing wavebands. Derived extinction data will go into the observatory database and image headers.
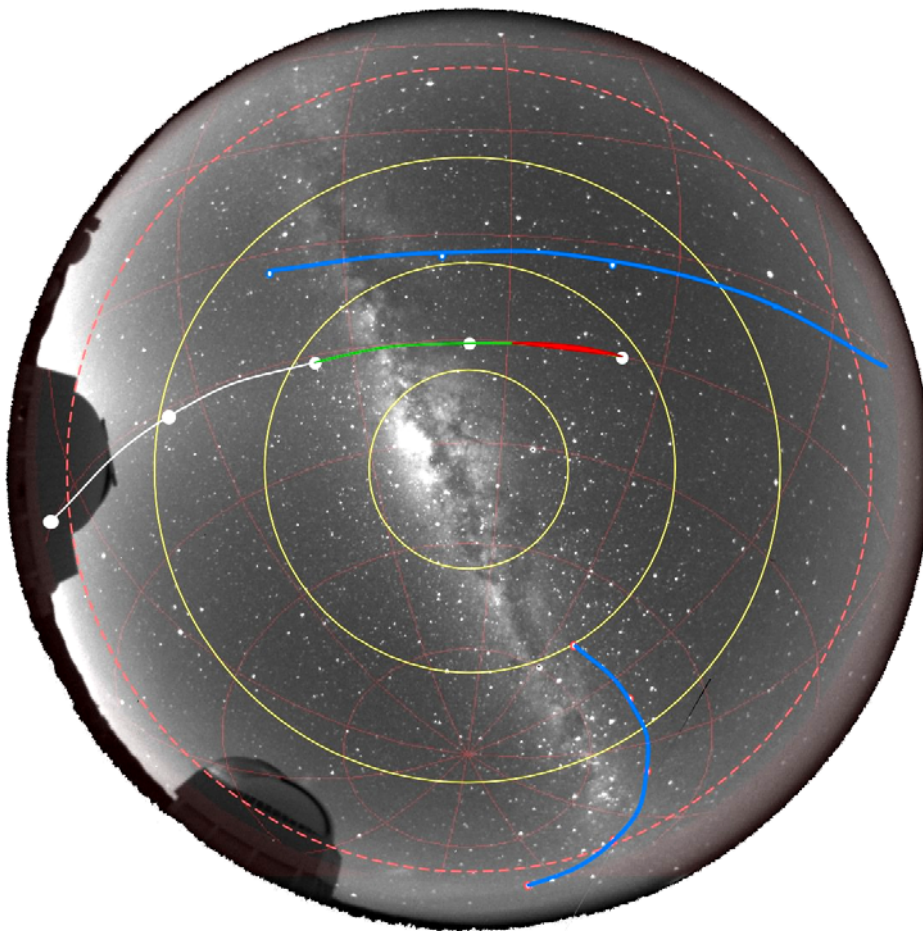

Figure 4. All-sky image (from CTIO taken by Roger Smith) with target tracks. Extinction contours are not shown here.

On the updating all-sky view are drawn tracks of all targets in the current session. The current point in the ongoing observation is highlighted, along with what remains to be done. Clicking on a track brings up observation details (parsed from the XML observing proposal) and the instrument configuration editor.

Supplementary displays are windowed around the all-sky display:

3.2. Seeing Histograms

An important datum to the remote astronomer is the recent history of astronomical image quality. SOAR will deliver tip-tilt stabilized images from the outset, using a CCD-based probe within the isokinetic patch. While the guider will usually bin a star's PSF into a quad cell for maximum sensitivity in short exposures, its control software will allow unbinned measurements every second or so, to read directly the stabilized half-power width. These measurements will be histogramed to monitor image quality delivered to the entrance of the instrument in use. The median value will be reported after scaling to other wavelengths and zenith distances according to the Kolmogorov prescription, to anticipate results for upcoming observations, and to monitor telescope and instrument for abrupt changes in image quality that may signify system or hardware problems.

SOAR is installing a Differential Image Motion Monitor (DIMM) 10's of meters from the dome to provide real time seeing estimates near the observing sky patch. This information will also be incorporated into the tactical display.

3.3. Culminating Object Display

Progress through the night is summarized in a plot similar to Figure 5. This shows target culmination along with proposed exposures, the path of interfering objects like the Moon, and anticipated attenuation by extinction.
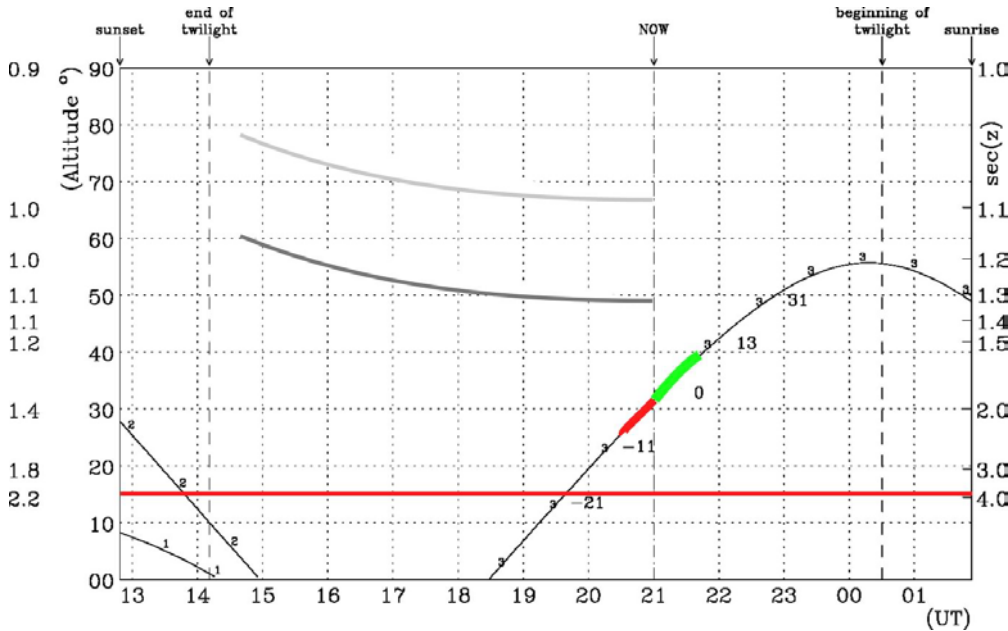

Figure 5. The left-most column shows current seeing, estimated from the guide camera and DIMM measurements elsewhere in the sky, extrapolated for all zenith distances. This is averaged every few minutes. Extinction curves for the wavelength of observation are shown as gray contours. This information is obtained from mean extinctions or a future APT. Parallactic angles for slit spectroscopy can also be plotted.

3.4. Other Displays

We also use the fine work of others, for example the JSky tool developed by Gemini to access sky catalogs, FITS images, and to overlay instrument and guider apertures. We are encapsulating this as a module within LabVIEW. Other Web based tools are also incorporated or driven by LabVIEW easily.

3.5. Instrument GUI's

LabVIEW allows instrument GUI's to be operated remotely in a very efficient fashion. Operating remotely, one never sees trails of "slow cursors" or other irritants, in our experience not the case even with X or VNC servers that export only screen differences. Note that there is no need for the remote astronomer to have a licensed LabVIEW installation running locally. LabVIEW can export any application as a complete Run-Time environment. Merely execute the file once and all necessary software is unpacked and installed on your computer. Successful SOAR PI's could be instructed to download the current version a day or so before their remote observing session; an automatic test is then done to verify successful functions.

LabVIEW instrument GUI's are not just text, they have pictures that can move and talk according to changing instrument and observing configurations. A prototype for the SOAR Mosaic Imager is shown in Figure 6. Of course, all button functions are programmed via dataflow "wires" to LabVIEW modules.

4. Remote Operations at UNC-Chapel Hill

A wonderful feature of LabVIEW is the ease of changing what is displayed and where. However, we feel that successful intercommunication between the remote observer and telescope operator occurs only if they see exactly the same tactical and instrument display layout (of course, labels can also appear translated into Spanish or Portuguese).
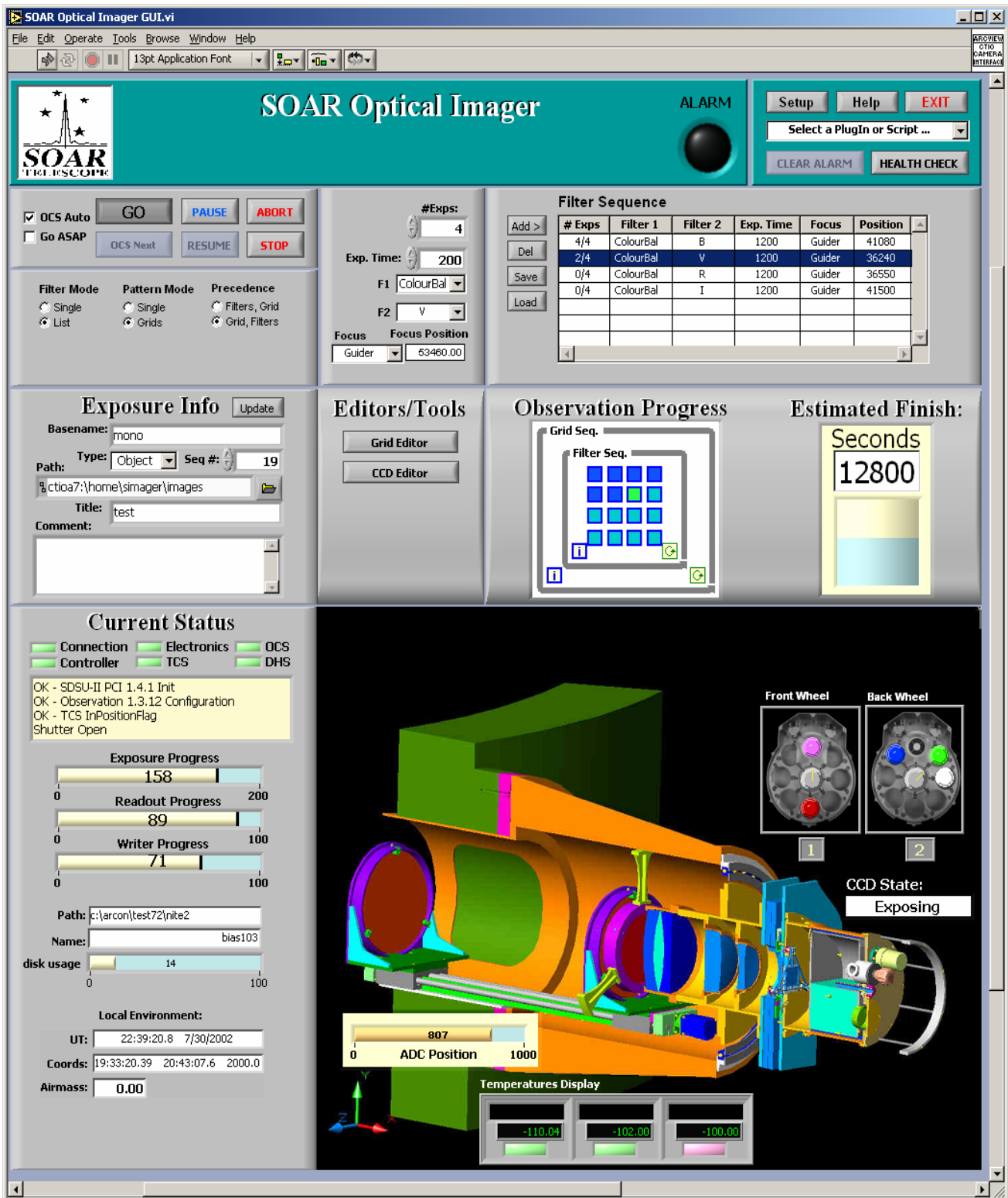
Figure 6. Prototype control GUI in LabVIEW for the SOAR Mosaic Imager. (Image courtesy of CTIO.)

One could certainly use the SOAR telescope from a laptop PC with a clip-on camera. One might also imagine observing in pajamas from home, although consumer high-speed internet does not support low-latency video conferencing and tends to go down for maintenance when sensible people are asleep. There is considerable appeal in adding the hardware for SOAR remote observing to one's desk clutter, and indeed video over Abeline is a real improvement over email or telephone science discussions with suitably equipped colleagues. But, to maintain a certain formality appropriate when using an expensive shared facility with other professionals, and to provide something tangible to show university administrators and potential donors, we have also renovated space in a science building into a remote observing facility and have allocated such space in a new physical sciences complex under construction on the UNC-CH campus. Down the hall is a bathroom with shower, allowing one to stumble into class after several hours of night work looking no more disheveled than usual. Comfortable office furniture is provided, nothing more because we find that custom telescope consoles soon resemble cardboard props from cheap science fiction films. The astronomer has (currently) a PC with a triple-head Matrox Parhelia-512 display. The tactical display has 2730x1024 pixels, projected to 11x4.5 feet by a pair of Hitachi SX5500W units ($4995 each, all costs 8/02). This large display rests the eyes so that one is not constantly focused in close. A dual-processor PC with 1 GB RAM, a couple of 80 Gb disks for RAID disk-mirroring, and a DVD burner total about $3600. A 1600x1200 20" Viewsonic VX2000 LCD ($1490) is the third display that shows a Linux X-session running as the guest OS under VMWare (the host OS is Windows XP Professional, which supports NI/IMAQ). This display can be expanded or moved onto the video wall as desired. Video is also displayed in a moveable, scaleable window.

5. Current Status, the Future, & Conclusions

Following demonstration of remote image browsing and with experience gained by participating in Abeline-based video conferences, the SOAR Science and Operations Advisory Committee has endorsed plans for an aggressive early science program enabled by remote astronomers. This tactic should minimize disruptions caused by telescope or instrument issues during transition from telescope commissioning to science. Of course telepresence will also benefit telescope and instrument debugging from La Serena and the home institutions of SOAR instrument teams. We anticipate that instrument support during observing will be handled largely by multi-party video conferences. The Polycom MP model at the SOAR end handles up to 4-way interactions well, and could also be used to hold the next observer on "hot standby" until their remote session begins.

Polycom Corp. has effectively extended its ISDN-based products to work under the H.323 protocol and TCP/IP available free to academic users; our hardware costs are low because of the large business market. As business continues to switch to cost-of-service Internet, video resolution will continue to improve. The JPEG2000 and MPEG-4 codecs support DVD-quality 480p images and stereo sound at about 1.8 Mbps, albeit "redlining" a multi-GHz PC during compression; presumably dedicated hardware for this will be available commercially in a few years. The virtual office environment under development at the UNC-CH Computer Science department requires many GHz of bandwidth, so is still more than 5 years away.

While our experiments could have used other software, we benefited enormously from LabVIEW 6.1's instant interpretation, linked GUI's, "wiring" diagrams, clear dataflow paradigm, operating system independence, new network features, and ease of encapsulating external C++/Java code into VI's. These fundamental aspects of LabVIEW are some of the reasons why it was selected as the software basis for SOAR control.

REFERENCES
1. G. Cecil, "First Generation Instruments for the 4.25m SOAR Telescope", SPIE, 4008, 83, 2000
2. M. C. Ashe, M. Bonati, S. Heathcote, "ArcVIEW: A LabVIEW-based Astronomical Instrument Control System", SPIE, 4848, in press, 2002
3. J. Travis, *Internet Applications in LabVIEW*, Chapters 4 & 5, Prentice Hall, NJ, 2000

4. M. C. Ashe, G. Schumacher, T. A. Sebring, "SOAR Control System Operation: OCS and TCS", SPIE, 4848, in press, 2002