User Interface and Control Software for the HIRES Image Rotator on Keck-1

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ABSTRACT

We describe the control and user interface software for the image rotator on the High Resolution Echelle Spectrometer (HIRES), located at the Nasmyth focus of the Keck-1 10-meter Telescope. This image rotator counteracts the field rotation induced by the alt-az telescope mount and aligns the image delivered to the spectrometer slit and the slit-viewing TV camera. The rotator can align the image so that either a specified position angle on the sky or the atmospheric dispersion vector is held fixed relative to the slit.

The rotator is physically an integral part of the spectrometer; but, since it affects telescope pointing and auto-guiding, it can also be considered part of the telescope. Accordingly, it interacts with the control systems for both the telescope and spectrometer. The apportionment of rotator control functions between these two systems poses interesting operational challenges. Since the telescope operator and the observer each need to operate the rotator at various times, their respective user interfaces must provide consistent rotator control and status functions.

Keywords: image rotator, user interface

1. INTRODUCTION

1.1. Motivation

The HIRES Spectrometer[1] (see Fig. 1) was commissioned on the right Nasmyth platform of the Keck-1 Telescope in late 1993. Due to funding constraints, neither an image rotator nor an atmospheric dispersion compensator (ADC) were part of the original instrument, although an effort was made to leave sufficient room in the slit area to permit the future addition of these devices. Since HIRES has no direct imaging mode and is used primarily for single-object spectroscopy, a wide range of scientific programs can be effectively pursued without an image rotator. During its first three years of operation HIRES proved to be an extremely productive instrument despite its lack of an image rotator and ADC.

Nonetheless, the absence of a rotator precludes or severely constrains some significant observing modes and also makes offset guiding much more difficult. Coupled with the lack of an ADC, instrumental throughput is reduced, particularly when operating in the blue and using a narrow slit for high resolution work. Atmospheric dispersion elongates the image and field rotation causes portions of that elongated image to rotate out of the slit, resulting in wavelength-dependent losses at the slit. In addition, we can now operate HIRES in a limited multi-slit mode by opening up the HIRES slit and replacing one of the HIRES decker plates with a multi-aperture plate. But except for work with bright objects requiring very short exposure times, such multi-slit operation is not feasible with a rotating field.

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1.2. History

To overcome these limitations, the HIRES image rotator upgrade project was initiated in 1994 with David Tytler of UCSD as the Principal Investigator. Tytler, working from Vogt's initial optical design along with inputs from David Walker's group at UCL, developed the final optical design in conjunction with optical consultant Brian Neff. The optics were fabricated at Zygo. The mechanical and electronic design and fabrication for the rotator mechanism were done at UCO/Lick Observatory, as were the design and implementation of both the low-level rotator control software and the interface between that software and the Keck Telescope Drive and Control System (DCS).[2] The completed optics were received in May 1996 and integration, alignment and testing of the mechanism conducted at UCO/Lick during the summer. In August, the rotator was shipped to Hawaii and installed into HIRES. Software integration with the DCS continued during the Fall and rotator commissioning was completed in late 1996.

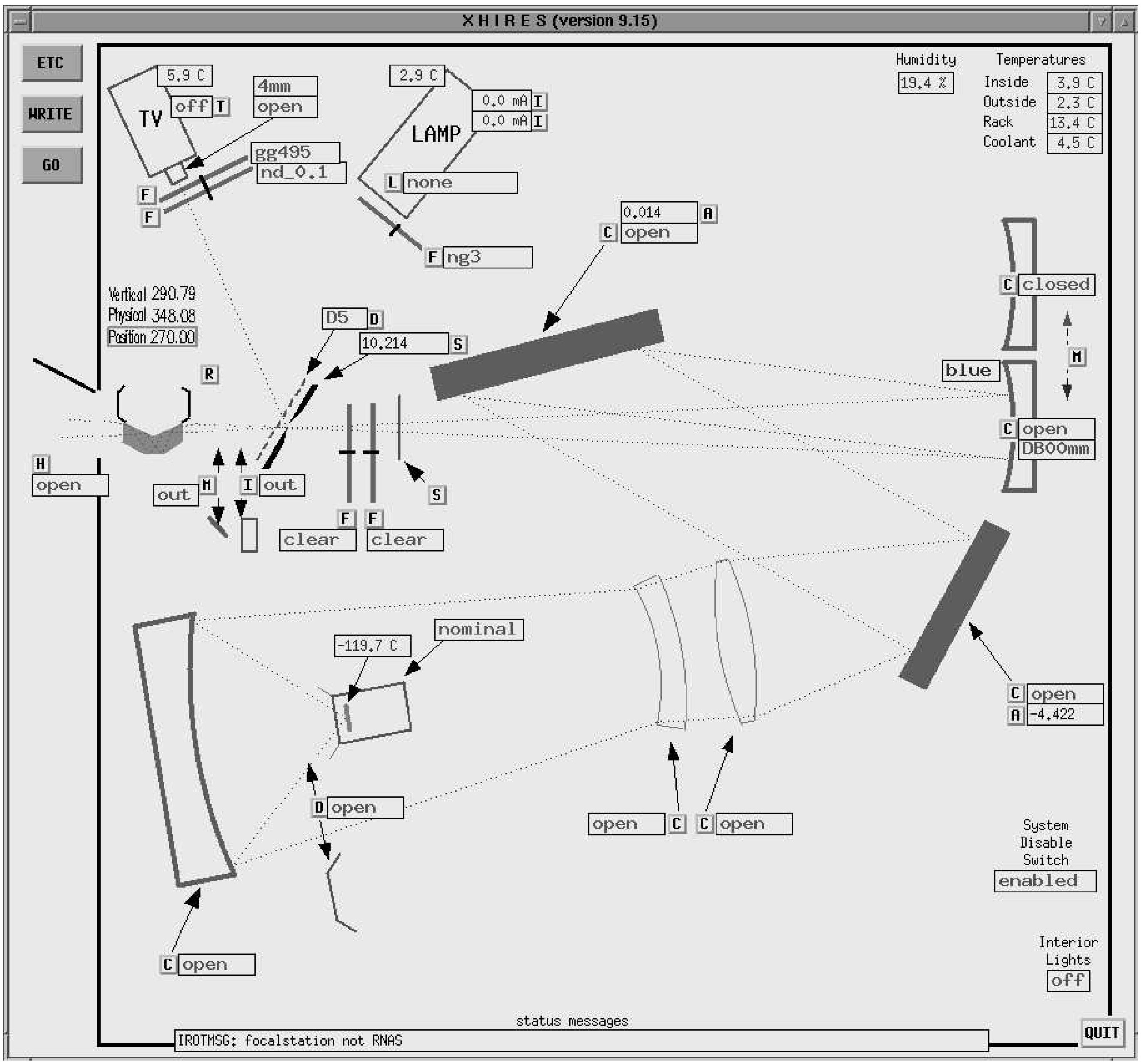

Figure 1. Simplified functional schematic of HIRES optical system. This is actually the **xhires** graphical user interface.

In February 1997, the Keck-1 Telescope was taken out of service for one month and the existing DCS hardware and software were retrofitted to the new EPICS-based DCS.[3] The HIRES image rotator software was then modified and re-commissioned with the new DCS in March 1997.

1.3. Overview of rotator mechanism and optics

The HIRES image rotator sits in front of the HIRES slit and is housed within that portion of the slit area that extends into elevation bearing of the Keck-1 telescope (see Fig. 2).

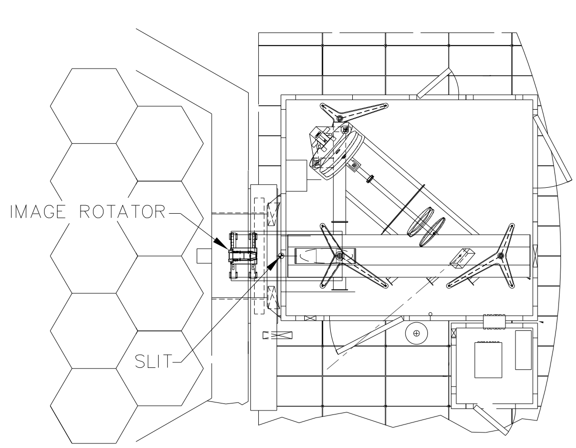

Figure 2. Location relative to instrument and telescope

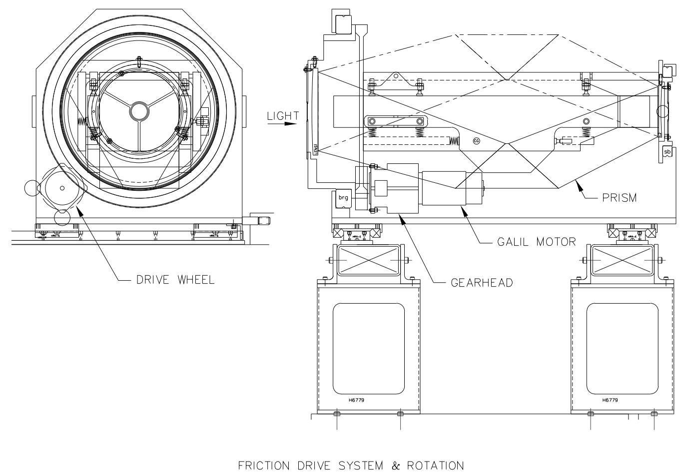

Figure 3. HIRES image rotator assembly

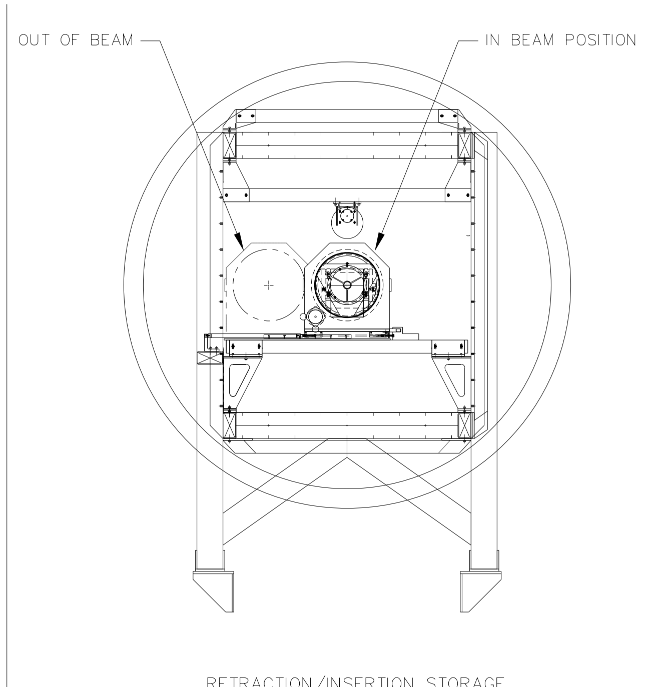

Figure 4. Rotator insertion mechanism.

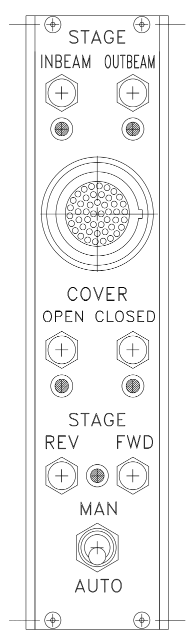

Figure 5. HIRES manual control box.

The rotator consists of a sandwich of dovetail prisms mounted in a rotating frame (see Fig. 3). These optics rotate the image by two degrees for each degree the prisms are rotated and also introduce a flip in the handedness of the image. The rotating mass weighs approximately 36 kilograms. The rotation stage is driven by a Galil 50-1000

DC servo motor via a 100:1 gear reducer followed by a 4:1 friction drive. The physical rotation angle of the prisms is encoded by a 900,000 count per revolution Gurley series 8325 optical incremental rotary encoder that is coupled to the rotator assembly by a 4:1 friction roller, yielding an effective resolution of 0.36 arcseconds per encoder step. An optical interrupter device mounted to the stationary portion of the stage senses the edge of a flat vane attached to the rotating portion and is used to provide an accurate and repeatable home reference position. To correct for accumulated error incurred from slippage of the friction-roller-coupled incremental encoder,[4] the encoder position is re-initialized whenever the home position is crossed while slewing to a new position angle.

In addition to the servo-motor-driven rotation stage, the rotator assembly has two mechanisms driven by air cylinders that are controlled using electrically-operated air solenoids. One of these mechanisms is used to drive the entire rotator assembly (mounted on a pair of rails) into and out of the HIRES optical beam (see Fig. 4). The other mechanism is used to open or close a pair of dust covers at each end of the prisms.

2. DESIGN CONSIDERATIONS

With the exception of HIRES, field de-rotation for all first-generation Keck instruments is accomplished by instrument rotator modules that are physically a part of the telescope and which are directly controlled by the DCS. Instruments are installed within these rotator modules, which are in turn rotated by the DCS to compensate for the field rotation induced by the alt-az telescope mounting.

This physical model is not practical for HIRES, which was designed for mounting at Nasmyth focus due to its large size and mass as well as its need to maintain a fixed orientation with respect to gravity for instrument stability. Thus, an image rotator which optically rotates the incoming image rather than rotating the instrument itself is the only practical alternative.

A question which arose early in the design was whether the image rotator should be logically part of the telescope and directly controlled by DCS software, or considered part of the instrument and controlled by HIRES software. There was ample precedent for the former approach since field rotation was handled in this fashion for all other first-generation instruments. However, in all of those cases, the rotating mechanism (i.e., the rotator module) was indeed physically a part of the telescope and not contained within the instrument. The HIRES rotator is considerably different since its rotating mechanism is internal to the instrument and not physically a part of the telescope. In this respect, it is comparable to any other rotating mechanism (e.g., filter wheels, grating rotation stages, etc.) within HIRES and presumably should be controlled by the same instrument control system as those other rotating mechanisms.

We decided to control the image rotator from the HIRES instrument control system for a number of reasons:

1. As a matter of safety, we felt it vital that the image rotator operate in a manner consistent with all other HIRES mechanized stages and be subject to the same global and individual safety interlocks as all other HIRES stages.
2. Such consistency would also simplify maintenance of the rotator, since it would use the same hardware and standardized cables as all other HIRES stages.
3. By providing low-level rotator control directly from the HIRES control system, we insured that the rotator could be remotely operated for engineering and maintenance purposes regardless of whether the DCS was "up". Since the original Keck-1 DCS was often left in a disabled state during most of the daytime hours, this was a significant concern.
4. It eliminated the need for any changes to the external wiring to HIRES and kept all wiring changes internal to the instrument. If the rotator were driven directly by the DCS, a new cable would need to be installed in the telescope azimuth cable wrap to connect the DCS controller crates in the computer room with the HIRES rotator hardware at the right Nasmyth focus. Significant modifications to the HIRES instrument enclosure would also be required so that those external DCS cables could be brought inside the enclosure.
5. The HIRES rotator assembly contains two other mechanisms (rotator insertion/removal and covers open/close) which do not exist on any of the telescope rotator modules and thus the existing DCS rotator hardware and software has no capability for controlling these devices. It would be confusing and awkward for maintenance

and testing to have the rotation mechanism controlled by the DCS and the other two mechanisms controlled from the HIRES control system.

6. The control requirements for an image rotator are not identical to those for an instrument rotator, and the identical DCS control algorithms can not be applied. In particular, due to the optics of the prisms, which yield 2 degrees of optical rotation for each degree of physical rotation, a rotator such as the HIRES image rotator is driven at half the speed of a comparable instrument rotator. It is also driven in the opposite direction, since an image rotator needs to optically de-rotate the rotating telescope field (and thus has to rotate in the opposite direction to field rotation) while an instrument rotator rotates in the same direction as field rotation so that the instrument follows the rotating field.

7. Since the image rotator mechanism was being fabricated and assembled at UCO/Lick, we needed to test the control hardware and software prior to shipping the assembly to Hawaii. While we were familiar with how the HIRES control system operates and could build a minimal HIRES system to support such testing using spare HIRES components, we had no such spares for nor any familiarity with operating the Keck DCS hardware and software.

The rotator tracking accuracy must be considered in deciding which control system should control the image rotator. Due to the small field of view of the HIRES slit (slightly less than 1 arcminute) and the absence of any direct imaging capability, the tracking accuracy requirement for the HIRES rotator is not particularly stringent: ± 5 arcminutes of rotation angle on the sky, or ± 2.5 arcminutes of rotation angle of the prisms. Thus the rotator control does not need to be very tightly coupled to the motion of the telescope. If this tracking accuracy requirement was significantly tighter (e.g., 1-2 arcseconds on the sky) it would be a more serious concern and would give greater weight towards direct control of the image rotator by the DCS.

3. SYSTEM DESIGN

3.1. Hardware

The electronics hardware for controlling the image rotator (Galil DMC-330 servo motor controller VME boards and model ESA-10/75R servo amplifiers) are identical to those used for all other servo-motor-driven HIRES stages. The air-cylinder-operated mechanisms are controlled using the same XYCOM digital input/output VME boards used by similar HIRES stages. Both types of VME boards are controlled by a Sun Sparc-1E CPU board running VxWorks 5.0.2b. All of the VME boards are contained within the HIRES instrument control VME crate which is located in the thermally-controlled electronics vault adjacent to the instrument enclosure. This HIRES VME crate is connected to the instrument computer in the control room via a Thin-net Ethernet 50-ohm coaxial cable routed through the telescope's azimuth cable wrap. Pre-ship testing at UCO/Lick was conducted using a spare VME chassis, spare VME CPU and controller boards, and spare servo amplifiers. Like all other HIRES stages, the image rotator has its own manual control box (see Fig 5) which allows local, stand-alone control of all rotator functions from within the instrument. When the auto/manual toggle switch is set to manual, local controls are enabled and remote operations from the instrument computer are locked out.

3.2. Software

3.2.1. Low-level software: The HIRES IROT keywords

Like all HIRES stages, the image rotator is controlled using KTL keywords[5] that are contained within the HIRES keyword sharable library (libhires_keyword.so) and which are used in conjunction with the Keck Task Libraries (KTL).[6] These keywords, which are similar in structure to FITS keywords, provide a simple and consistent applications programming interface (API) for interacting with the underlying hardware. For example, the current position of a stage can be obtained by reading the keyword corresponding to that stage; the stage can be commanded to a new position by writing a new value to that keyword. Callback routines can be mapped to specific keywords so that a callback is invoked whenever its associated keyword changes value. These same keywords are also used to document within FITS headers the position of each stage at the time a given image was taken. Observers generally do not use these keywords directly, since a graphical user interface (GUI), *xhires* (see section 3.2.4), provides the primary method by which the observer operates the rotator. However, the HIRES keywords can also be used directly from within various types of scripts (e.g., csh, Tcl) to perform automated sequences of commands for either diagnostic or observational purposes.

Table 1. HIRES image rotator keywords

Keyword	Function	Sense	Units or values
IROTAHOM	Enables automatic re-homing on fiducial crossing	Read/Write	T or F
IROTATOR	Command image rotator into or out of beam	Write-only	IN or OUT
IROTIN	Is image rotator in the beam?	Read-only	T or F
IROTOUT	Is image rotator out of the beam?	Read-only	T or F
IROTCOVR	Command rotator covers open or closed	Write-only	Open or Close
IROTCVCL	Is image rotator cover closed?	Read-only	T or F
IROTCVOP	Is image rotator cover opened?	Read-only	T or F
IROTENAB	Enable all image rotator functions?	Read/Write	T or F
IROTHALT	Halt the rotator and keep it halted	Read/Write	T or F
IROTMODE	Image rotator mode	Read/Write	*
IROTMSG	Image rotator status messages	Read/Write	ASCII String
IROTSEQF	Name of file to use for SEQUENCE MODE	Read/Write	ASCII String
IROTCON	State of image rotator auto/manual switch	Read-only	Auto or Manual
IROTINH	State of rotator servo amplifier inhibit bit	Read/Write	T or F
IROTSTAT	Image rotator status value	Read-only	numeric code
IROTCAL	Request calibration of rotator motor encoder	Read/Write	reset or homed
IROTDEST	Rotator motor encoder target position	Read-only	encoder counts
IROTNAME	Rotator named motor encoder position	Read/Write	ASCII string
IROTPOS	Rotator ordinal motor encoder position	Read/Write	integer
IROTPERR	Rotator servo tracking error	Read-only	arcseconds
IROTRAW	Rotator motor encoder raw position	Read/Write	encoder counts
IROTREL	Rotator motor encoder relative position	Read/Write	encoder counts
IROTANGL	Rotator motor encoder position in degrees	Read/Write	degrees
IROT2CAL	Request calibration of rotator secondary encoder	Read/Write	reset or homed
IROT2RAW	Rotator secondary encoder raw position	Read-only	encoder counts
IROT2ANG	Rotator secondary encoder position in degrees	Read-only	degrees
IROTEVEL	Enable rotator velocity mode	Read/Write	T or F
IROTTVEL	Image rotator motor encoder velocity	Read/Write	Steps/second
IROTAVEL	Image rotator motor encoder velocity in degrees	Read/Write	Degrees/second

Table 1 lists the HIRES keywords that were implemented for control of the image rotator. For ease of recognition, all of these keywords begin with the four letter prefix IROT. Most of these keywords are similar in form to those used for all other HIRES stages and the implementation of most IROT keywords only required changes to configuration tables and rebuilding of the HIRES keyword sharable library. However, the image rotator is the first (and currently the only) HIRES stage that can be operated in velocity mode (as well as in position mode) using keywords. A significant amount of new software on the HIRES VME crate was required to support this mode. Additional modifications to the existing position-mode software were needed to overcome the position range limitations imposed by the 24-bit hardware encoder buffers used in the Galil DMC-330 servo motor controller VME boards so that continuous rotation of the rotator stage would not result in position overflow. Further modifications were required to provide independent access to and initialization of both the motor encoder and secondary encoder for the image rotation stage.

*In addition to the DCS rotator modes VERTICAL, POSITION, and PHYSICAL, the IROTMODE keyword supports the additional engineering modes SPIN LEFT, SPIN RIGHT, and SEQUENCE mode.

3.2.2. Rotator-related DCS keywords

The Keck DCS has its own keyword sharable library (libdcs_keyword.so) which provides a similar style API for all of the various functions of the DCS. A set of DCS keywords involves rotator control and they define a general purpose rotator interface that is used with all instrument rotators and image rotators at all telescope foci. Table 2 lists these rotator-related DCS keywords, as well as several other DCS keywords used to indicate which instrument is the currently receiving the light from the telescope.†

Table 2. DCS rotator-related keywords

Keyword	Function	Sense	Units or values
CURRINST	currently selected instrument	Read-Only	string
FOCALSTN	currently selected focal station	Read/Write	enum
INSTANGL	pointing origin to instrument-angle	Read/Write	radians
PARANG	parallactic-angle astrometric	Read-Only	radians
PARANTEL	parallactic-angle telescope	Read-Only	radians
PRESROT	preserve rotator position over slew	Read/Write	sky or physical
ROTCCWLM	rotator CCW-limit	Read-Only	radians
ROTCWLM	rotator CW-limit	Read-Only	radians
ROTDEST	rotator user specified destination	Read/Write	radians
ROTDETS1	rotator destination timestamp 1	Read-Only	ut1
ROTDETS2	rotator destination timestamp 2	Read-Only	ut1
ROTERRS	rotator error string	Read/Write	string
ROTERVL	rotator error status level	Read/Write	integer
ROTHALT	rotator HALT command	Read/Write	T or F
ROTHALTC	rotator HALT command complement	Read/Write	T or F
ROTHERE	make current rotator position desired	Write-Only	T or F
ROTINIT	rotator initialization command	Read-Write	T or F
ROTINITC	rotator initialization command complement	Read-Write	T or F
ROTMODE	rotator tracking mode	Read-Write	‡
ROTNEED	rotator needed	Read-Write	T or F
ROTNEWS	rotator new destination counter	Read-Write	integer
ROTPDEST	rotator physical destination (20 Hz)	Read-Write	radians
ROTPDSTS	rotator physical-destination (2 Hz)	Read-Write	radians
ROTPOSN	rotator user achieved position	Read-Write	radians
ROTPOTS1	rotator position timestamp 1	Read-Write	ut1
ROTPOTS2	rotator position timestamp 2	Read-Write	ut1
ROTPPOSN	rotator physical achieved position	Read-Write	radians
ROTSEL	rotator select	Read-Write	enum
ROTSRVER	rotator servo error	Read-Write	radians
ROTSTAT	rotator state	Read-Write	enumm
ROTSTBY	rotator standby command	Read-Write	T or F
ROTSTBYC	rotator standby command complement	Read-Write	T or F
ROTSTST	rotator state string	Read-Write	string
ROTZERO	rotator zero angle	Read-Write	string

Like the HIRES keywords, these DCS keywords are usually used via the command line interface only during tests and are primarily visible to observers via the FITS headers into which they are logged. The DCS provides several GUIs (see Section 3.2.5) to allow the observing assistant (who operates the telescope) to control rotator-related functions.

†Detailed descriptions of all DCS keywords are provided in Keck Software Document 46.

‡Vertical angle, Position angle, or Physical angle.

3.2.3. The interface between HIRES and DCS: watch_hirot

As noted in section 2, most Keck rotators are controlled directly by the DCS. However, these control functions are divided between two DCS tasks: pointing and rotator control. These two tasks communicate via the rotator-related DCS keywords, as illustrated in Fig. 6.[§] In the case of an instrument-supplied rotator such as the HIRES image rotator, DCS uses an instrument-supplied rotator control task in place of its own. The DCS keyword ROTSEL is used to inform DCS whether it should use its own rotator control task or one supplied by the instrument.

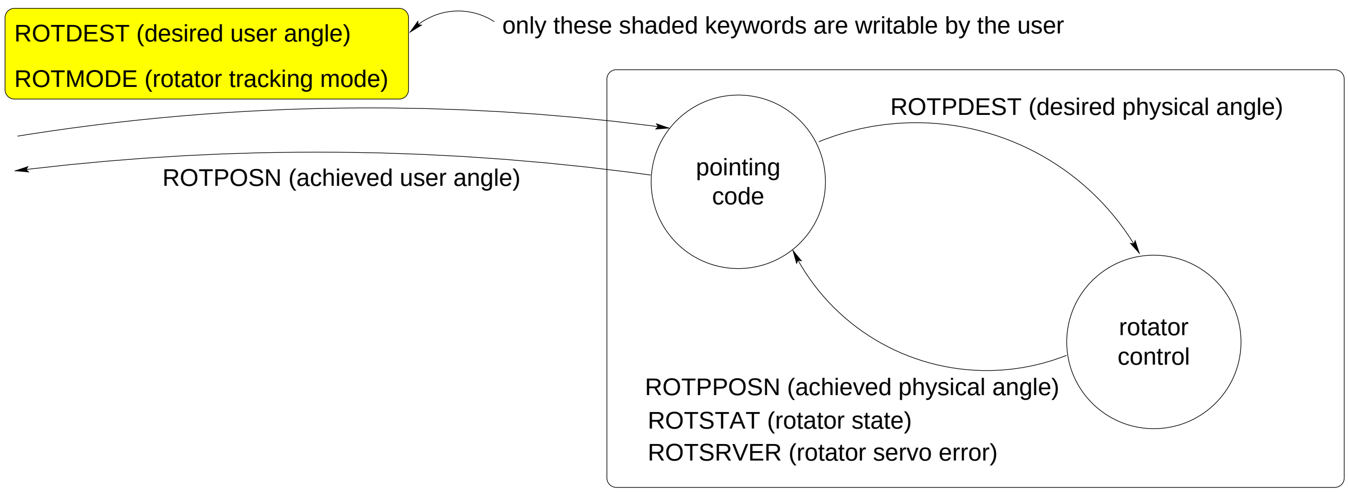

Figure 6. DCS rotator-related tasks and keywords.

The instrument-supplied rotator control task for HIRES is called watch_hirot. This task runs on the HIRES instrument control computer. Watch_hirot is run within the context of a shell script wrapper called watch_hirot_monitor which is started when the instrument control computer is booted. Watch_hirot_monitor insures that watch_hirot is always running and will automatically restart watch_hirot should it terminate abnormally for any reason.

The watch_hirot task running on the instrument computer communicates with keyword server tasks on the HIRES instrument control VME crate (which houses the servo motor controller hardware for the image rotator) by means of HIRES keyword reads and writes that are transmitted over a conventional 10 Mbit/sec private Ethernet link connecting the instrument computer and the HIRES VME crates. The watch_hirot task also communicates with several DCS EPICS-based VME control crates (where the pointing task and ancillary telescope and dome control tasks run) by means of DCS keyword reads and writes that are transmitted over a separate 10 Mbit/sec public Ethernet link connecting the instrument computer to the DCS crates (see Fig. 7).

Users can use either the *xhires* GUI (see section 3.2.4) or the *dcsgui* (see section 3.2.5) to specify the two DCS keywords, ROTMODE and ROTDEST, that determine the rotator's target position angle. Based on the settings of ROTMODE and ROTDEST, along with the current telescope position, the DCS pointing task computes (at a 20 Hz rate) the desired rotator physical angle, ROTPDEST. The DCS broadcasts a time-tagged version of this angle at a 2 Hz rate using the keyword triplet ROTDETS1, ROTPDSTS, ROTDETS2, where the first and last keywords provide time tags and the middle keyword the desired physical angle.

The watch_hirot process at startup expresses interest in these and other related DCS keywords using the KTL operation ktl_read/continuous and specifies associated callback routines for each keyword. Whenever the DCS broadcasts updated values for these keywords, the corresponding callback functions are invoked. The delivery of the ROTDETS1, ROTPDSTS, ROTDETS2 triplet every 0.5 seconds triggers a callback routine that implements an adaptive PID servo loop which computes a velocity update that is written to the HIRES instrument control VME crate via the IROTTVEL keyword. This PID loop is closed by reading back the instantaneous rotator physical angle from the HIRES crate via the IROT2ANG keyword. Watch_hirot uses this value to compute the rotator servo error which is transmitted back (via the DCS keyword ROTSRVER) to the DCS pointing task along with the

[§]This figure is derived from a similar figure in Keck Software Document 46a.

achieved rotator physical angle (via the DCS keyword ROTPPOSN) in order to close the telescope pointing servo loop. Watch_hirot also returns various rotator status conditions (e.g., slewing, tracking, in position) to DCS (via the DCS keywords ROTSTAT, ROTSTST and ROTERRS) for use by the various DCS GUIS, and to HIRES (via the HIRES keyword IROTMSG) for use by the HIRES GUI *xhires*.

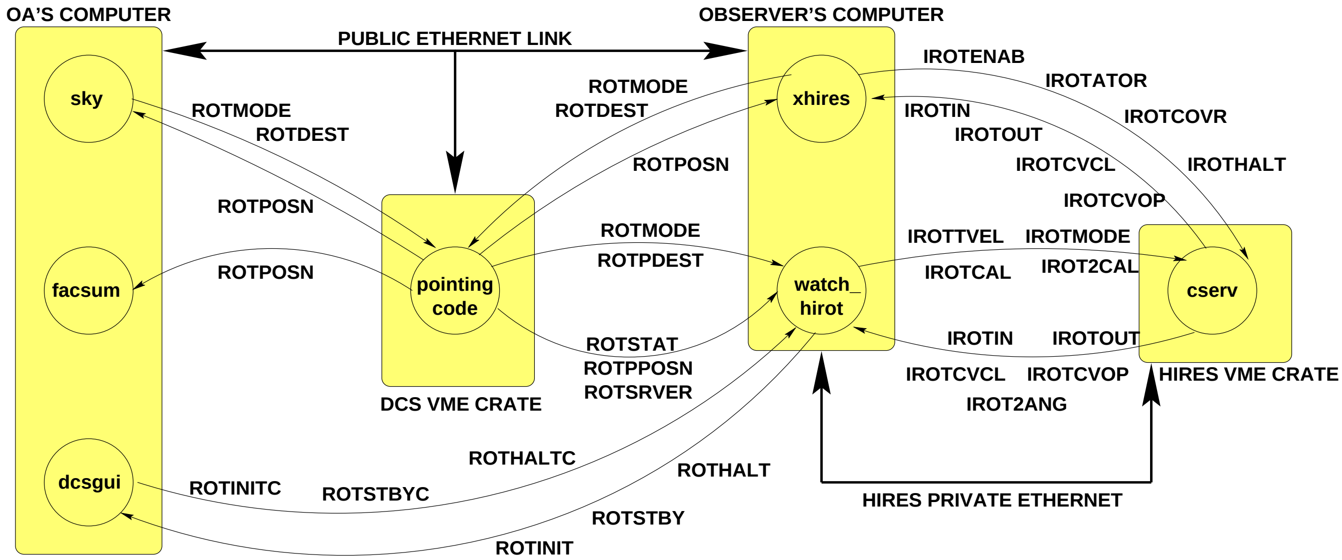

Figure 7. The watch_hirot task replaces the DCS rotator control task.

Since the image rotator has no cable wrap constraints or other physical limits on its rotation, it can rotate continuously. This allows watch_hirot to employ shortest-path-routing when slewing to new positions. Watch_hirot also performs the conversions required to map the DCS angles, which are expressed in terms of radians on the sky, to the HIRES rotator angles, which are expressed in terms of prism rotation angles in degrees. Recall that one degree of prism rotation results in two degrees of optical rotation on the sky.

XNTP protocol is used as the base-level mechanism for synchronizing time between the HIRES instrument control computer and the DCS VME crates. However, watch_hirot implements its own internal mechanism to insure more precise synchronization of its time with that of the DCS VME crate that runs the pointing task. Accurate time synchronization is needed to insure proper interpolation of the various time-tagged demanded and actual position angles transmitted between the various HIRES and DCS tasks.

3.2.4. Modifications to the HIRES GUI *xhires*

The top-level window for the HIRES GUI, *xhires*,[7] is shown in Fig. 1. This window provides a simplified schematic of the instrument and uses a graphical representation of the light path to concisely display the state of all the major opto-mechanical elements of the instrument. This representation provides a clear and unambiguous display of the position of any optical elements that can be moved in or out of the light path, thus alerting observers to common errors in instrument setup. Cooperating copies of *xhires* can be run at multiple sites, facilitating cooperative local/remote observing.

Fig. 8 shows the portion of this top-level window which was modified for the image rotator. The image rotator is graphically depicted by an icon which represents the dovetail prisms that comprise its main optical element. When the rotator is positioned in the beam and its covers are open, the converging light beam from the telescope (coming into the instrument via open hatch at the left of edge of the figure) is shown entering the transparent prism icon and being internally reflected within the prism before emerging rotated and continuing towards the spectrograph slit at the right edge of the figure. Fig. 9 illustrates the appearance of the graphical light path when the rotator is moved out of the beam with its covers open and Fig. 10 illustrates the appearance with the rotator out of the beam and its covers closed. Fig. 11 shows the display with the rotator in the beam and its covers closed. Since this most likely represents either an error in instrument setup or a failure of some mechanism to respond to a move request, the color of the prism icon changes to red to alert the observer.

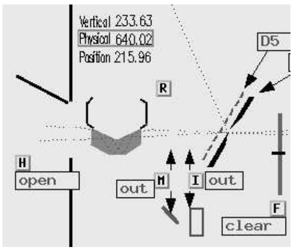

Figure 8. In / open

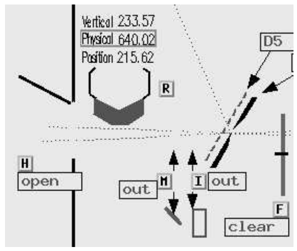

Figure 9. Out / open

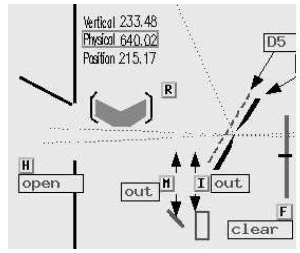

Figure 10. Out / closed

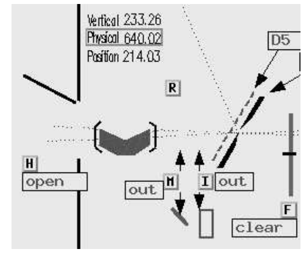

Figure 11. In / closed

The other elements that are shown to the right of the prism icon in Figs. 8 to 11 are the comparison lamp pick off mirror "M" and the iodine cell "I" (both shown out of the beam) followed by the movable decker plates (shown with aperture D5 selected), the slit, and the first filter wheel (shown set to the "clear" position). In the upper left of each these figures are three numbers that display the current rotator position angle as measured with respect to three different references frames, one for each of the three rotator modes: vertical, physical, and position angle. The currently selected rotator mode (in this case, physical) is highlighted with an enclosing box.

The status display for each element is decoupled from the control mechanism for that element by means of pop-up control windows. Devices in the instrument can only be moved from these pop-up windows. An element cannot be moved accidentally simply by clicking in the top-level status display window. These control pop-up windows are brought up by clicking the mouse on a small control button located adjacent to the graphical icon for the element to be controlled. In the case of the rotator, the control pop-up window (see Figs. 12 and 13) is activated by clicking on the small button labeled "R" that is located above and slightly to the right of the rotator prism icon (see Figs. 8 to 11). Unlike most of the *xhires* graphics (which were built using the Motif Toolkit), the rotator control pop-up window was built using the DataViews graphical development environment.

The rotator control pop-up (see Fig. 12) contains several sets of radio buttons. The first pair (labeled "MOTION") enables or disables all image rotator functions, the second pair (labeled "ROTATOR") moves the rotator in or out of the beam, and the third pair (labeled "COVERS") is used to open and close the dust covers at each end of the prism. Underneath these toggle buttons are three pushbuttons. The "HOME" button drives the rotator to the home position (see section 3.1), thus initializing the incremental encoders used to measure the rotator physical angle. The "PARK" button drives the rotator to a stow position and closes the dust covers, while the "HALT" button is used to immediately halt the rotator and prevent further rotation until the HALT button is popped back out. Three other pushbuttons select various engineering modes. "SPIN LEFT" cause the rotator to spin continuously counter-clockwise at high-speed, while "SPIN RIGHT" causes similar clockwise rotation. These modes are used for aligning the rotator and in calibrating the reference pointing origin. The "SEQUENCE" button selects a sequence mode which is not yet operational but which will provide a means of having the rotator follow a custom trajectory as defined in a time-tagged sequence-mode file. The "HELP" button brings up an on-line help window, and the "DISMISS" button makes the rotator control pop-up window disappear.

The remaining buttons on the control pop-up are located under each of three dials and are used to select between the three primary rotator modes: vertical angle, position angle, and physical angle. The mode is first selected by pushing in the button under the dial corresponding to the desired mode. The desired angle (in decimal degrees) for that mode is then entered into the text box adjacent to the "SET" button. The "SET" button is pressed to activate the selected parameters. When the rotator is in motion, the graduations on the two larger dials (the vertical and position angle dials) rotate about their respective images of the HIRES slit, which remain fixed. Thus, the orientation of these two dials matches the guide camera image. The smaller, physical angle dial behaves differently in that its graduations remain fixed while its inner arrow rotates to indicate the current physical angle.

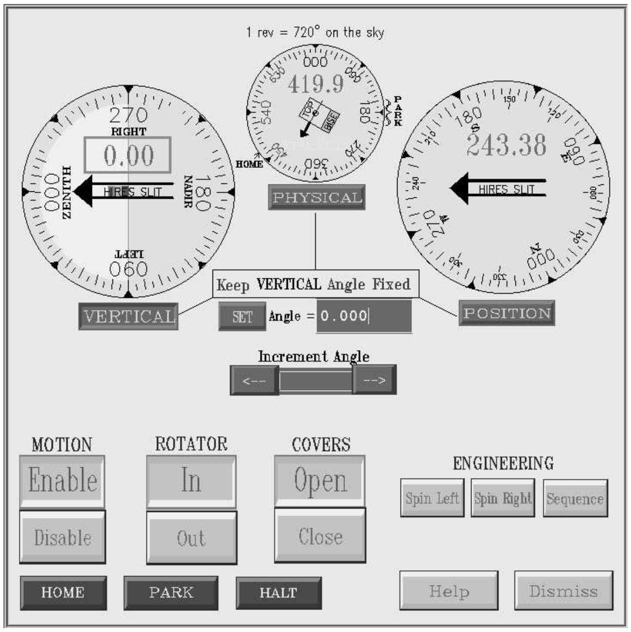

Figure 12. Vertical angle mode

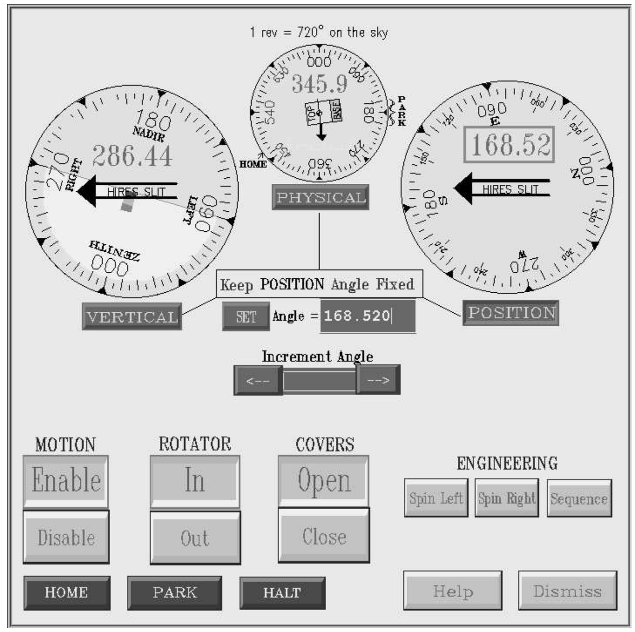

Figure 13. Position angle mode

Figure 12 shows the appearance of this pop-up when the vertical angle rotator mode has been selected. This is the mode is which the rotator is most commonly used. When the vertical mode position angle is set to 0, the atmospheric dispersion vector will be maintained in alignment with the HIRES slit. This is shown graphically by a small rainbow that aligns with the HIRES slit icon that appears in the center of the vertical mode position angle dial at the left edge of the pop-up screen. While the vertical mode angle is normally left at zero when operating in vertical angle mode, it can be set to small non-zero values should the need arise to keep a nearby non-target object out of the slit. Figure 13 shows how the pop-up looks when the position angle mode has been selected. In this mode, the specified position angle on the sky will be held fixed relative to the slit.

When physical angle mode is selected (not shown in either Figs. 12 or 13), the rotator will be driven to the specified physical angle and held fixed at that position. This mode is not astronomically useful but is provided for engineering purposes. Note that the range of the physical angle dial runs from zero to 720 degrees. This is because one degree of prism rotation yields two degrees of optical rotation on the sky. During commissioning, it became apparent that rotator angles always need to be expressed in consistent units (i.e., degrees on the sky) regardless of what rotator mode was currently selected. Since one revolution of the physical angle dial corresponds to 720 degrees on the sky, the physical angle dial was labeled accordingly.

3.2.5. Interactions with the DCS GUIs

There are three GUIs for the DCS that run on the workstation used by the observing assistant (OA) and which interact with the rotator: *sky*, *facsum*, and *dcsgui* (see Fig. 7). The *sky*[8] program is both an observation planning tool and a telescope control GUI. As a planning tool, it processes target lists, locates guide stars, and previews their locations in the guider frame for various instrument orientations. As a telescope control GUI, it can command moves of the telescope and rotator. Accordingly, the rotator mode (ROTMODE) and destination angle (ROTDEST) can either be set by the OA using *sky* or by the observer using *xhires*. Changes made by one are instantly visible to the other. The *facsum* program is the facilities summary display and it displays both telescope and rotator positions and status. The *dcsgui* program is used to initialize and display the overall status of the various telescope subsystems, including the rotator. It is used whenever the telescope systems are re-started. This set of GUIs for the DCS allows the OA to perform those rotator functions needed at telescope startup, as well as those needed for target acquisition. Once the OA has acquired the target specified by the observer, rotator operation is implicitly handed off to the observer, who uses *xhires* to establish the rotator settings appropriate for the particular science observation.

3.2.6. Interactions with the DCS and autoguider

The motion of the HIRES rotator into and out of the optical beam requires two forms of special processing to avoid confusing the DCS and autoguider. Whenever the image rotator is in the beam, it optically flips the handedness of the image that is delivered to the slit. This effect would be extremely confusing to observers when comparing the guide camera image to their finding charts and it would also be confusing to the autoguider. To compensate for the effect, if HIRES is the selected instrument and its image rotator is in the beam, the guide camera software inverts the order of the image rows as they are read from the HIRES guide camera so that the handedness of the guide camera image remains the same regardless of whether the rotator is in or out of the beam.

In addition, whenever the rotator is retracted out of the beam, it no longer rotates the image delivered to the guide camera or the spectrograph slit. In this case, if the actual physical rotator angle were transmitted to the DCS pointing task, then pointing, offsetting, and guiding errors would occur. To avoid such confusion when the rotator is retracted, the watch_hirot task forces the rotator mode (ROTMODE) to "physical" and zeroes out the desired rotator position angle (ROTDEST) and the rotator servo error (ROTSRVER). It also reports the achieved rotator position angles (ROTPPOSN and ROTPOSN) as zero, regardless of their actual values. The image rotator physical angle zero point is carefully calibrated so that when the rotator is in the beam and rotated to this zero point the row-inverted image displayed on the guide camera will be identical to the guide camera image that is displayed when the rotator is retracted out of the beam.

4. CONCLUSION

User interface and control software have now been successfully commissioned with the HIRES image rotator. Use of the HIRES image rotator while observing with HIRES is now routine. Its design provides cooperative access to rotator functions for both the OA and observer while permitting stand alone operation of the rotator when the DCS is not available. Future instrument-supplied rotators for Keck-2 instruments will likely be modeled on this design.

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