



NI BIG PHYSICS Symposium

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Telescope Control using LabVIEW for Linux

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Observatory Sciences Ltd.



Providing software and services for large physics and astronomy projects



Observatory Sciences Ltd



UK-based company with world-side clientele, originally set up in 1998 by five scientists from the Royal Greenwich Observatory (Cambridge, UK)

We work on astronomy and other physics related projects for governmental and other organisations.

Also acts as a software partner with the suppliers of observatory and synchrotron hardware (particularly motion control)

50+ staff-years experience of operational astronomical systems, including management roles at major observatories

A track record of delivering large software projects on-time and on-budget



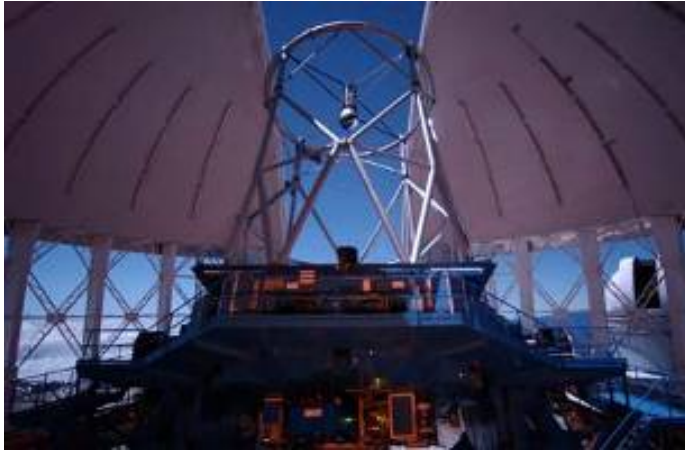
Some Observatory Sciences Clients



Astronomy	Physics
<p>North America Gemini Observatory (Hawaii) National Solar Observatory (Arizona) Large Synoptic Survey Telescope project (Arizona) Discovery Channel Telescope (Arizona) University of Hawaii University of Texas</p>	<p>Europe Diamond Light Source (UK) Delta Tau (UK) Micromech Systems Ltd. (UK) Accel GmbH (Germany) attocube GmbH (Germany)</p>
<p>South America Gemini Observatory (Chile)</p>	<p>Australia Australian Synchrotron Project (Melbourne)</p>
<p>Europe AMOS - Advanced Optical & Mechanical Systems (Belgium) <i>Working on telescopes in India & New Mexico USA</i></p> <p>UK Astronomy Technology Centre, Edinburgh (UK) <i>Working on telescope in Chile</i></p> <p>European Southern Observatory (Germany) Isaac Newton Group (La Palma, Canary Islands)</p>	
<p>Australia Australian National University (Canberra)</p>	

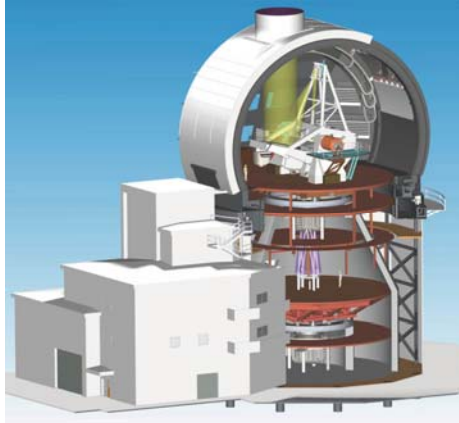


Large Telescope Control Software



Observatory Sciences staff have been involved in the Gemini **Telescope Control** and **Instrument Control Systems** software (EPICS based) for nearly 15 years. Now also involved in ...

Advanced Technology Solar Telescope



Co-development of ATST software

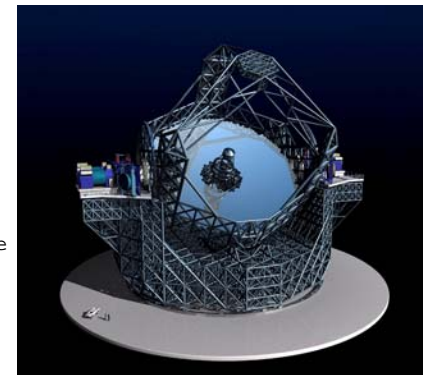
Hobby-Eberly Telescope



Large Synoptic Survey Telescope



European Extremely Large Telescope



Software studies for HET, LSST and E-ELT



Telescope Control Software



- Telescope control systems have a long history, going back to the early 1970s (e.g. Anglo-Australian Telescope 1974).
- Traditionally, entirely bespoke software written in FORTH, FORTRAN or C. More recently, using OO languages and adopting middleware and frameworks (EPICS, ACS, CORBA, ICE, DDS).



- SOAR (SOuthern Astrophysical Research) telescope in Chile was the first large telescope to use NI LabVIEW for major parts of the control system (Linux-based). Operational 2003.



- SALT (Southern African Large Telescope) adopted LabVIEW on Windows as the control software throughout its systems (NI Case Study available). Operational 2006.
- Other telescope systems using LabVIEW include GREGOR (German solar telescope), Hoku Kea (Hawaii 0.9m educational telescope)



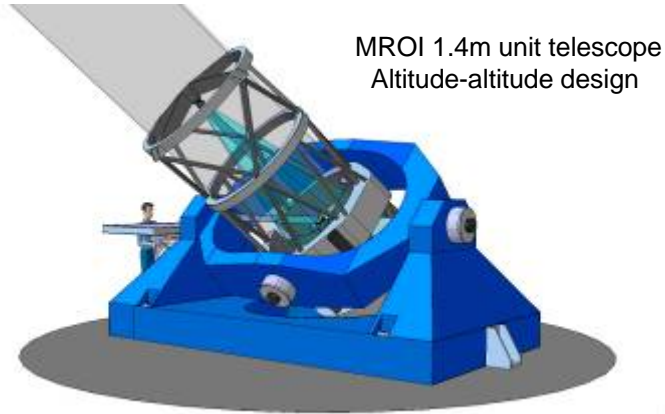
Indian Telescopes



- The **Multi-Application Solar Telescope (MAST)** is a 0.5m advanced solar telescope which will be sited at Udaipur, India.
- The **ARIES telescope** will be a 3.6 meter diameter optical telescope, the largest in Asia. It will be sited at Devesthal Peak.
- In 2007, Observatory Sciences was awarded contracts by the telescope manufacturer (AMOS Belgium) to produce both the MAST and ARIES Telescope Control System software.
- The software platform specified for these telescopes is NI LabVIEW for Linux.



Magdalena Ridge Optical Interferometer (MROI)



Proposed interferometer array at Magdalena Ridge



- The Magdalena Ridge Optical Interferometer (MROI) is a set of 6-10 1.4m advanced optical telescopes which will be operated together to form an optical interferometer.
- The telescopes will be sited on Magdalena Ridge in New Mexico, USA.
- In August 2007, Observatory Sciences was awarded a contract by the telescope manufacturer (AMOS Belgium) to produce the MROI Telescope Control System software.
- The software platform specified for the MROI TCS is NI LabVIEW for Linux



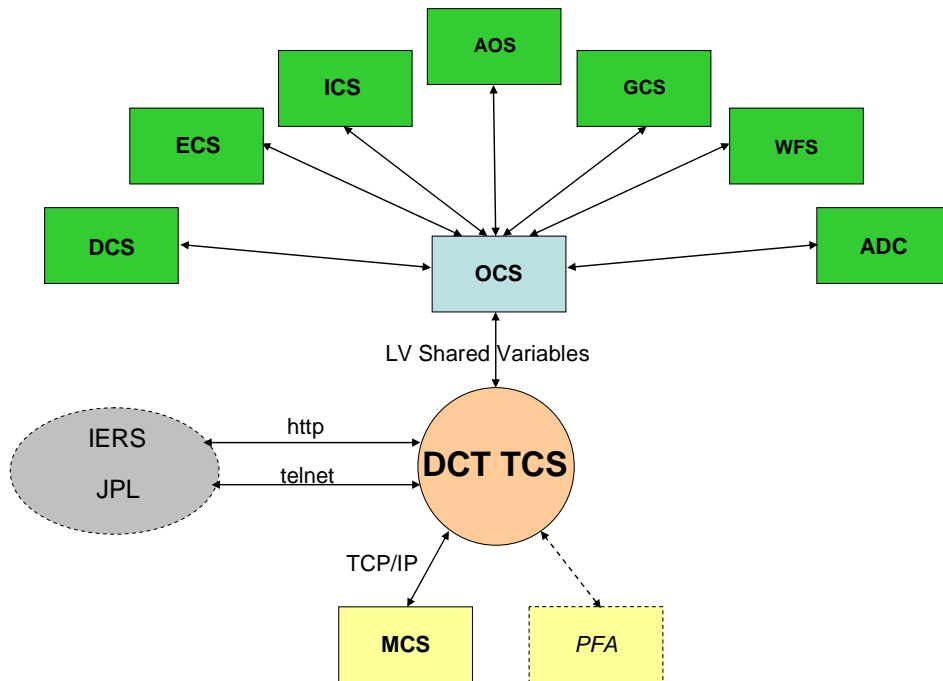
Discovery Channel Telescope



- The Discovery Channel Telescope is a 4.2 meter optical telescope being built in Arizona, USA by the Lowell Observatory. Completion date 2011.
- The scientific programme emphasises solar system studies and NEO discovery as well as astrophysics research.
- In 2008 OSL was awarded the contract by Lowell Observatory to produce the DCT Telescope Control System software.
- The software platform specified for the DCT TCS is NI LabVIEW for Windows
- TCS software Final Acceptance tests passed in December 2009.



DCT TCS External Interfaces



TCS Context Diagram

- Hardware interface
 - Mount Control System
 - (*Prime Focus Assembly, TBC*)
- Interfaces via Observatory Control System (OCS)
 - Dome Control System
 - Environmental Control System
 - Instrument Control System
 - Active Optics Control System (uses NI cRIO for M1 & M2 control)
 - Guider Control System
 - Wave-Front Sensor
 - Atmospheric Dispersion Corrector
- Internet
 - IERS (International Earth Rotation Service)
 - JPL (Horizons Solar System Ephemerides)



LabVIEW Telescope Control Software



- Consists of two major parts
 - LabVIEW
 - Rapid prototyping
 - Integrated development environment
 - Simple integration of application libraries
 - Built in debug features
 - C code: supplied in TCSpk, SLALIB libraries
 - Robust, accurate and well tested
 - Integrated with TPOINT (telescope pointing test software)

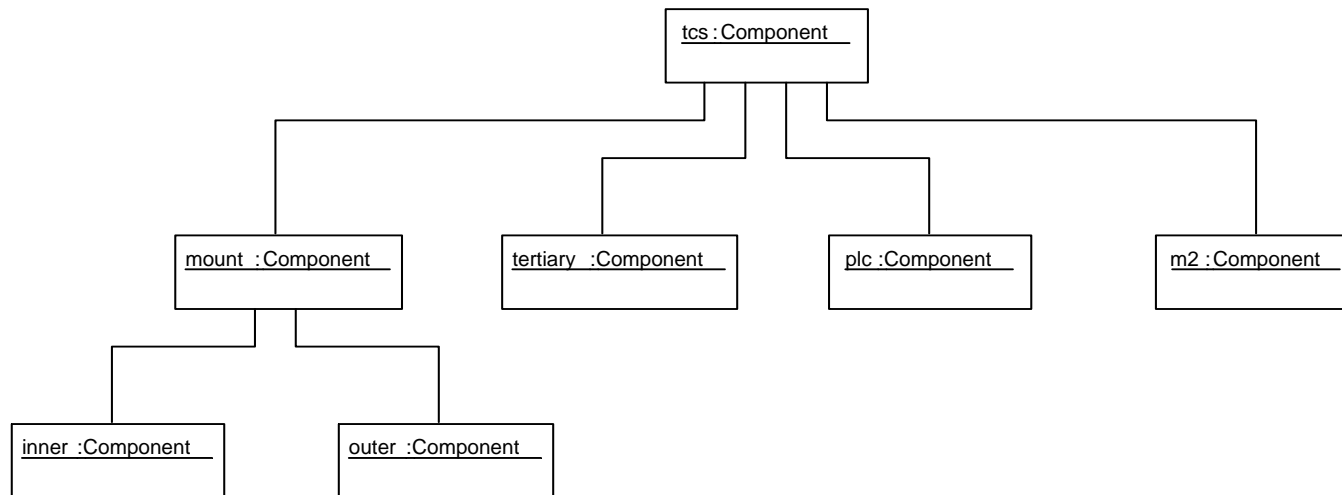


TCS LabVIEW Software Framework



- The software for four telescope control systems are being produced by OSL. The telescopes share a common core of facilities, with each one having its own unique features. Three run on the Linux OS, with (so far) one on MS Windows.
- A re-usable and portable (Linux & Windows) LabVIEW software framework has been implemented to enable sharing and re-use of software across these systems. It consists of Components and Software Services:
 - Software Components
 - Data Structures: Attributes & Attribute Tables
 - Services
 - Health
 - Events
 - Local
 - Networked
 - Logging
 - Parameter

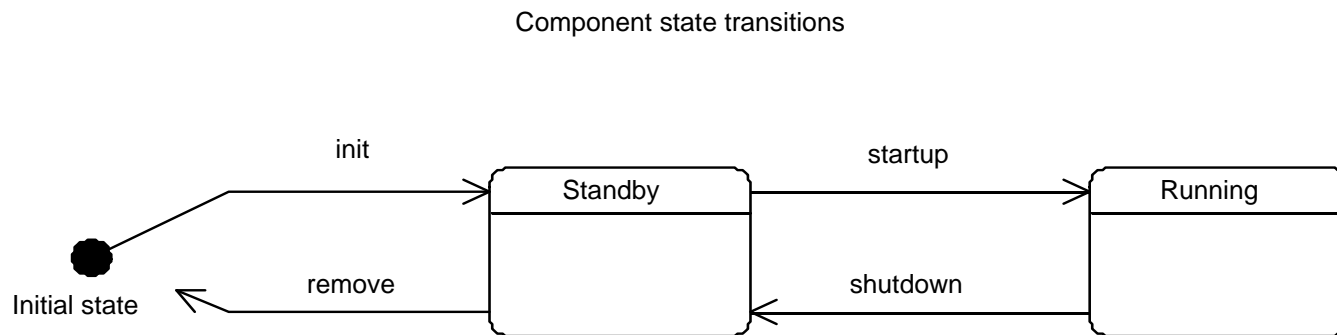
Components



- A *component* is characterized by
 - A command set
 - An overall health, activity and state
- Can be arranged hierarchically
- Command tables are built dynamically when components are loaded
- Commands receive an acknowledgement and a completion

Component State

- Standby – monitoring, house keeping etc. The state the system will be left in at end of night
- Running – responsive to commands





Internal Data Structures



- Most internal data structures in the DCT TCS are represented by Attributes and Attribute Tables, which are flexible, extensible data structures.
- An Attribute is a name-value pair, encoded as a string along with its type. Valid types are integer, double, boolean and string. One and two dimensional arrays of these types can also be stored.
- Attributes can be packaged into an Attribute Table, consisting of a name, description and array of Attributes. Methods are provided to insert or retrieve attributes or arrays of attributes in a table.
- Attribute handling is implemented in the TCS using a set of polymorphic LabVIEW VIs.



Internal Communications



- *Events* implement a publish/subscribe paradigm with one or more readers of data produced by a single publisher. Useful for rapid dissemination of general purpose data to many components. The event data items are Attribute Tables.
- *Command Queues*. Commands executed by TCS components are implemented using FIFO queues. The queued items are Attribute Tables.
- *Status Queues*. Used for transmitting status where it is important that no value change is missed (e.g. component state).



External Communication

LabVIEW Linux



- TCP/IP sockets is a general-purpose solution that enables integration into almost any software system (usually non-LabVIEW)
- Concurrent TCP server with configurable no. of connections
- Small number of server commands: do, get, monitor etc.
- Expandable number of telescope commands and status items
- ASCII protocol: should be usable by anything that can open a socket
- Good performance: Demonstrated 5000 messages/sec through single connection, dropped to 4800/sec to each client when two were connected



External Communication

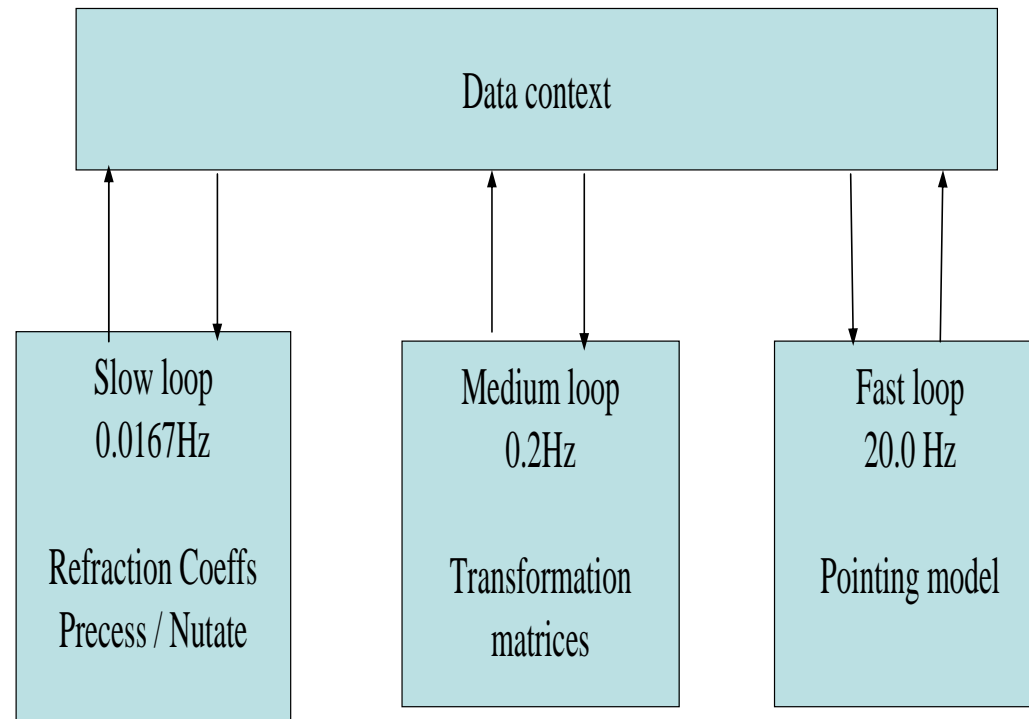
DCT TCS (LabVIEW Windows)



- Almost all the DCT subsystems are LabVIEW based, so can adopt LabVIEW-specific technology.
- Communication between DCT subsystems is implemented using LabVIEW Shared Variables and the Object-Oriented features of LabVIEW (LVOOP).
- The OCS to TCS command interface uses a LabVIEW implementation of the standard Command Pattern.
- Commands are sent from the OCS by writing the command class as a flattened string to a Shared Variable. Status is returned from the TCS using a similar process.
- Classes have been defined for all data used with the TCS to external subsystem interfaces.



TCS Pointing Kernel



Implemented in about 50K lines of C code (TCSpk and SLALIB packages) + ~5K lines wrapper code.



Screen Shots - MROI

MROI Engineering Screens

MROI Telescope Control System

TELESCOPE:

OBJECT NAME:

TARGET: RA Dec

OFFSET (arcsec): BASE:

TRACK RATE (arcsec/hr):

LST: WAVELENGTH:

UTC:

Heartbeat

Health Weather server not updating data file

Telescope: Data-Panel:

■ Elevation v local time

Use UT Red lines mark sunrise and sunset
 Blue lines mark beginning and end of astronomical twilight
 The green line marks the current time
 The red horizontal line is the elevation limit

Use local time

Name: timezone:

Telescope: Command-Panel:

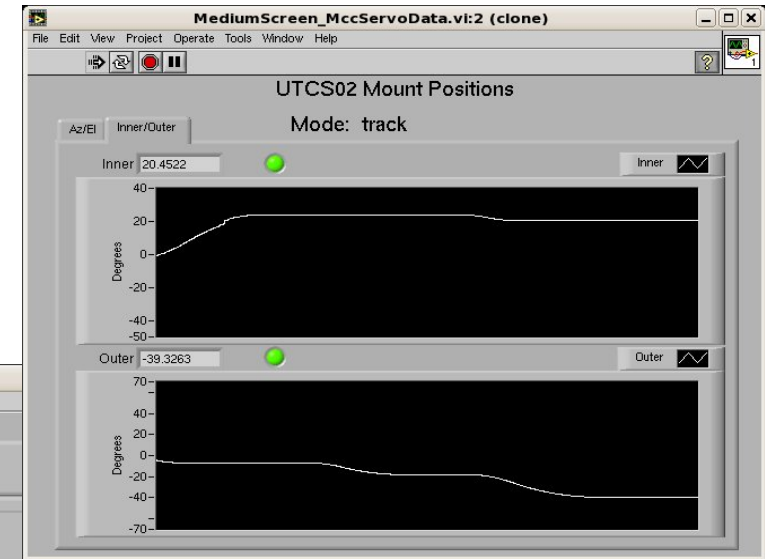
Command Response:

UTCS02 Offset Command

Offset Type:

Manual Offsets: Ra: Dec:

Offset Size:





Screen Shots - DCT

Main Display

UT 2009-Nov-20 11:39:04 LST 08:11:52 JD 2455155.985469 LOCAL 04:39:04 Mode=Operator Log in as Engineer **SHUTDOWN** **CLOSE**

Heartbeat Health System State Running Focus Cass In Position Mount Control Tracking Guiding **STOP** HealthAlerts

Object Rise/Set Airmass Zenith Blind Spot Az Wrap Rot Wrap **SUN / MOON**

Current	GUIDE TARGET Type	Sunset	Time (UT)	Time to
NAME: unspecified	RA: 00 00 00.00 X: 250.864 mm	00:18	00:18	-11:20
RA / DEC: 23:59:48.06 +80:00:00.0	DEC: +00 00 00.0 Y: -144900.121 mm	Naut. Twi. 01:16	01:16	-10:23
Diff Rates: 0.000 s/sec 0.000 "/sec	WFS TARGET Type	Ast. Twi. 01:46	01:46	-09:52
AZ / EL: +350 26 11.4 +28 59 22.5	RA: 00 00 00.00 X: 250.864 mm	Ast. Twi. 12:37	12:37	+00:58
HA: 08:11:53 W	DEC: +00 00 00.0 Y: -144900.121 mm	Naut. Twi. 13:07	13:07	+01:28
AM: 2.06	Offset (") Wavelength (µm)	Sunrise 14:05	14:05	+02:26
ParAng: -124.1	RA Dec	Moonrise 17:36	17:36	+05:57
EQ: 2000.0	Science 0.00 0.00 0.600000	Moonset 03:37	03:37	+15:59
Rot/Sky Ang: 128.0 0.0	Guide 0.00 0.00 1.000000	Phase (% full) 13		
Rot Track: TARGET	WFS 0.00 0.00 1.000000	Sun alt. -30 Moon alt. -69		
Pointing Origin (mm) X: 0.00 Y: 0.00		Sun Ecl. Long 238 Moon Ecl. Long 281		
		Sun target dist. 115.1 Moon target dist. 111.9		
		Sun Rise/Set R Moon Rise/Set R		
		Sun Proximity Moon Proximity		

TCS Command Named Presets Weather Command Target History Breakout

Am Limit M1 Cover Rot Offset

Target Config Offsets Collimation Point Origin Point Model Guide Focus Name Current Wrap

Target Configuration

TARGET: Science

Target Config Name: []

Rotator PA: 0 Degrees

Rotator Frame: Target

Wavelength: 0.6 µm

Fractional Rate: 1

Target Type: Sidereal

Set target parameters

Time to Limits

Object Rise and Set: Object Never Sets

Airmass Limit: Never Sets below Elevation Limit

Zenith Blind Spot: Does not enter blind-spot

Azimuth Wrap: Does not reach azimuth limit

Rotator Wrap: Reaches limit (270) in 10:19

mccComponentEng.vi

MCC Engineering MCC Enabled MCC Startup Checks Passed **MCC STOP** **CLOSE**

MCU Connected MCC Stopped Tracking In Guide Region Az Guide Tolerance (arcsec) 50 El Guide Tolerance (arcsec) 50

Az Pos Error (deg) 2.000000E-6 Az Wrap Demanded 5 El Pos Error (deg) -2.000000E-6 Rot Wrap Demanded 5 Az/EI Tracking Az InPos El InPos El Tolerance (arcsec) 12 El Tolerance (arcsec) 12

Rot Pos Error (deg) -1.700000E-5 Rot Stopped Rot Tracking Rot InPos Rot Tolerance (arcsec) 12 Rot Tolerance (arcsec) 12

MCC Commands MCU Commands Mount Axes Plots

Azimuth Position/Position Error Azimuth Position Time Stamp 12:17:11.788

Elevation Position/Position Error Elevation Position Time Stamp 12:17:11.788

Rotator Position/Position Error Rotator Position Time Stamp 12:17:11.797

guideComponentEng.vi

Guide Engineering

T Matrix: 1.00000 0.00000 0.00000 1.00000

Current Kp Gain 0.500000 Set Kp Gain 0.00000

Current Ki Gain 0.750000 Set Ki Gain 0.00000

Guide State On/Off

Clear Guide Corrections

AOX X Correction 0.000000 arcsec

AOX Y Correction 0.000000 arcsec

ADC X Correction 0.000000 arcsec

ADC Y Correction 0.000000 arcsec

Guide Name: Happy Jill

Az/EI Track State Track Id Match Applying Corr.

Guide X Received 1.0000 mm Guide X Received 8.021062 arcsec Guide X Accumulated 20.575177 arcsec

Guide Y Received 1.0000 mm Guide Y Received 8.021062 arcsec Guide Y Accumulated -4.119606 arcsec

Graph of Pointing Kernel Collimation Parameters GA and GB as used to apply Guide, AOS and ADC corrections.

GA 20.575177 arcsec GB -4.119606 arcsec

Graph showing GA and GB (arcsec) vs Time. GA is increasing from 0 to 20.575177, GB is decreasing from 0 to -4.119606.



Current Software Status



- DCT. Completed. TCS software final acceptance tests passed in December 2009.
- MROI. Factory tests in Belgium March 2010.
- MAST. Beta software released May 2009.
- ARIES. Alpha software released October 2009.

Effort

- *Approximately 8 FTE staff years software effort, so far*
- *About 6000 LabVIEW VIs.*