Liverpool Telescope

Robert Smith
Liverpool John Moores University

http://telescope.livjm.ac.uk/
A Robotic Telescope

• One that can operate without night-time supervision.
• Not “remote controlled”.
• Software is responsible for the safety of the telescope and observatory.
Our Vision for a Robotic Telescope

- Robotic “National facility class” telescope
- Diverse instrumentation
- Common user – scheduled by TACs. Not devoted to or dominated by any one project.
- Software decides what (and how) to observe. No “queue”.
- Flexible operations responsive to changing needs of time-domain astrophysics
Advantages of Robotic (as opposed to remote)

- **Unstaffed**
  - Cheaper to run? (space, facilities, accommodation, food, water)
  - No night working
  - Reduced travel (also true for remote operations)

- **Flexibly scheduled**
  - Both better and qualitatively new science
  - Shared facility for diverse monitoring timescales (minutes - months)
  - Respond rapidly to changing conditions
  - Painless Targets of Opportunity

- **Standardized data taking procedures**
  - Homologous data quality
  - Allows automated pipeline data reduction to scientifically useful quantities

- **Simplifies inter-observatory collaboration and hand-offs between telescopes**
Operational Challenges for a Robotic Telescope

• Real-time observer interaction
  – Can be automated in very many cases

• Management and being fair to all
  – Traditional block schedules are cleaner

• Reliability
  – When time lost, typically in large chunks
  – Avoid fragile instruments (Can still be innovative)
Cumulative technical downtime for 2010
Talk Outline

• Robotic
• Hardware: Telescope & Instruments
• A User’s Perspective
• Operations Staff Perspective
• Our current user community
LT Specifications

- 2m primary (f/3), f/10 at Cass
- Designed and built by TTL (now LCO)
- Alt-Az (hydrostatic bearings)
- Image quality < 0.6” on-axis
- Pointing < 10” rms
- Integrated autoguider
- Closed loop tracking < 0.2” over 1hr
- Max slew rate > 2° per sec
- Zenith blind spot < 2°
- Clamshell enclosure
- Science Operations Jan 2004
- Sited on La Palma, Islas Canarias

Science Operations Jan 2004

Sited on La Palma, Islas Canarias
Requirements for an automatic telescope

Remote & Robotic
• Automated startup and shut down procedure.
• Very reliable weather information.
• High degree of reliability
• Fault recovery/logging/management procedures.
• Failsafe operation - make sure it is protected if it does fail.

Additional for Robotic
• Well defined sequence of observations including calibration observations.
• Autonomous scheduler for robotic operation.
Instrumentation

Iain Steele, Chris Mottram, Alan Scott, Stuart Bates, Steve Fraser, Robert Smith (JMU)
John Meaburn, Dan Harman (Manchester)
Phil Charles, Luisa Morales (Southampton)
Peter Meikle (ICSTM)
David Clarke (Glasgow)
Don Pollacco, Ian Todd (QUB)
Sue Worswick (Optical design)
Acquisition & Guidance Box

- 1 straight-through port
- 18 side ports
- Off axis frame transfer autoguider (limit V=17)
- Retractable, folding mirror gives instrument change time < 30 seconds
RATCam

- 2048 x 2048 pixels
- 0.135 arcsec/pixel
- Read noise < 8e
- On-chip binning
- Automated reductions
- FoV 4.6 x 4.6 arcmin
- Cooled to 163K
- Readout < 10 sec

ugriz BV Hα
RATCam Calibrations & Pipeline

• Every night
  – Automated twilight flat fields
  – Photometric standards every 2 hours.
  – Quicklook reductions in 2 – 3 min

• End of night pipeline
  – Debiases and trims the overscan region
  – Flat fields based on latest flats
  – Solves WCS against catalogues
  – Data distributed following business day

• Data provided to allow user to
  – Defringe
  – Apply a bad pixel mask
FRODOSpec

- Dual beam
  - Dichroic at 5750Å
  - Blue Arm 3800 – 5750Å
  - Red Arm 5750 – 9000Å
- Two gratings
  - VPH, $R = 5500$
  - Transmission grism, $R = 2300$
- IFU 11x11 lenslet array (0.9 arcsec “pixels”)
- Fixed central wavelengths
- Ar, Xe and W lamps
- 4k x 2k detectors cooled to -100 degC
- Commissioned Autumn 2008.
A big black box
Example: A PTF supernova
Unprocessed 2D spectra available within ~2 minutes.
Pipeline extracted spectra

Currently available next day, but working on speeding up the software to allow inclusion in Quicklook
RISE
Fast imager / photometer

- Rapid Imaging Search for Exoplanets
- Frame transfer CCD (no shutter) camera (Andor)
- 1024 x 1024 pixels
- Fore-optics give 10x10 arcmin FoV
- 0.6 seconds minimum exposure time

- Developed with QUB for specific project but available as a common user facility.
Exoplanets - SuperWASP

SuperWASP telescope on La Palma
Exoplanets - Transit timing

Routinely delivering few-millimag photometry for transit studies.

Typical depth of transit 0.01-0.03 magnitudes and duration 1-4 hours.

An “Earth” in the same system would perturb the orbit timing by about 10 seconds a year.

WASP discovery data

E. Simpson, S. Barros, QUB
THOR
Even faster imager

- Primarily the tip-tilt camera but can be deployed scientifically too.
- Integrated into the user phase 2 system
- EMCCD (no shutter) camera (Andor)
- 512 x 512 pixels (but frequently windowed)
- ~5 msec minimum exposure time
- High time resolution or “lucky” shift-and-add

Lunar occultation timing. 6msec exposures
RINGO2

- Upgrade to RINGO polarimeter
- EMCCD has read-noise <1e^- and read out approx. 8 fps.
- Gain 2 mag sensitivity
- Time resolution ~ 1sec

Can stack data post acquisition to trade sensitivity vs. time resolution
Instrument for 2011: IO (“Infrared-Optical”)

- Optical FOV 10 x 10 arcmin
- IR FOV 6 x 6 arcmin
- Tip-tilt feeds for both cameras
- Dichroic feed to both cameras
- Wavefront sensor (THOR) is EMCCD that can be used as very fast (10ms) timing camera and for lucky imaging.
O camera

- Fairchild CCD486 BI array
- 4096 x 4096 15 micron pixels
- Dark current < 0.02 e^- /sec
- Read noise < 10 e^- 

- Modifications to the telescope are complete
- Camera to be installed 2011
I camera

• HAWAII-2RG
  – 2048 x 2048 18 micron pixels
  – 1.8 micron cutoff
  – Substrate removed
    • QE>70% 0.4 - 1.0 microns
    • QE>80% 1.0 - 1.8 microns
  – Dark current < 1 e⁻ / sec
  – Guide window functionality to generate tip-tilt signal
Instrumentation

• Current
  – RATCam: CCD imager
  – RINGO2: Polarimeter
  – FrodoSpec: Spectrometer
  – RISE: Fast readout CCD
  – THOR: Very fast readout CCD

• Near Future (this year)
  – IO:O: CCD Imager

• Later
  – IO:I: NIR Imager
  – Tip-Tilt

• Decommissioned
  – SupIRCam: NIR imager
  – RINGO: Polarimeter
  – Meaburn(John): Spectrometer
Common Features Between Instruments

- Completely independent
- Common command set (e.g. CONFIG, DAY_CALIBRATE, NIGHT_CALIBRATE, TWILIGHT_CALIBRATE, WAVELENGTH_CALIBRATE, EXPOSE)
- Knowledge of calibration procedures built into the instrument control system
- Electrical power kept running 24/7
- Few servo mechanisms – obtain precision via mechanical means
- Housekeeping: Single data transfer, reduction software, archiving
- Problems with cooling
- PSU failures are most common fault
How Users See Robotic Operation

<table>
<thead>
<tr>
<th>Observer</th>
<th>TAC</th>
<th>Support Astronomer</th>
<th>Automated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1 application (&quot;paper&quot; forms)</td>
<td>Time allocation</td>
<td>Technical Secretary</td>
<td></td>
</tr>
<tr>
<td>Group specification</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upload to Telescope</td>
<td>phase2ui</td>
<td>User support</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Scheduling</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Observing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Data transfer to Liverpool</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pipeline processing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Archiving</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Data Distribution</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Quality checks</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Quality Checks
Phase2 Data Entry

Observing Requests entered at any time. Available immediately to the scheduler.

- Phase 2 GUI (for humans)
- RTML document (for software)
Phase2ui

- A conventional menu driven GUI
- Java 5 and Swing executable runs locally at user
- Launched from browser by Java Webstart
- Accesses phase2 db at telescope via Web Services
  - SOAP (XML documents) over HTTP
  - Widespread compatibility and minimal system requirements. (Browser + JVM)
    - If web browser works, this should too.
- User has single sign-on for all their proposals
- When internet fails, requests cannot be changed. Observations continue using existing database.
Observation Definition Wizard

For straightforward observation groups. Most programs use the conventional pre-packaged sequences.

Specify **what** you want, not how.
Modular Definition of Sequences

User defines observation as an explicitly ordered list of commands
The Validator

Sequence in editor
FAILURE: An Instrument Config is required before an Exposure.
FAILURE: An Instrument Config is required before an Exposure.
The validation completed with 2 failures.
Validator Rules

- **DANGER**: “injury to life or equipment”
  - Cannot occur!

- **FAIL**: “telescope software will reject”
  - E.g., no PI, no TAC, no timing constraint, missing instrument config, sky PA specified but no target coordinates

- **WARN**: “telescope accepts, but it looks wrong”
  - Should almost never be ignored
  - E.g., missing focal plane configuration, no target

- No approval required by support astronomer
- No “mild warning” for uncommon configs
Real time status of LT

Pipeline reduced data within 2–3 minutes
If you have javascript available on your browser, we strongly recommend turning it on.
Should you decide not to, the 'Refresh form' button can be used to force the dynamic updates which would have been automated by javascript.

Instructions for using this form

**Target Position**
- Target Name
- Right Ascension
- Declination
- J2000
- 'Radial' search mode: Circle
- Resolve name
- using resolver

**Observational Criteria**
- Date
- Integration
- Seeing
- Airmass
- Instrument
- RATCam
- Ringo
- SupIRCam
- Meaburn

**Imaging Configurations**
- Optical
- IR
- Clear
- Sloan u'
- Sloan g'
- Sloan r'
- Sloan i'
- Sloan z'
- Bessell B
- Any of these filters

**Spectroscopic Configurations**
- Wavelength (Å)
- Resolution (Å)
- Dispersion (Å pix⁻¹)
Timing Constraints

- **Flexible**
  - Any time after a start date the conditions are met. Once only.

- **Monitor**
  - Repeat at an interval with regularity precision defined by a window fraction.
    Interval typically hours to months.

- **Ephemeris**
  - Once only, at a specified phase.

- **Interval**
  - Observe repeatedly with a fixed minimum interval.

- **Fixed**
  - At a specific time (e.g. occultation or simultaneous with a spacecraft)

- **Target of Opportunity modes**
Targets of Opportunity

- Client script running at the telescope (e.g., GRB followup)

- Intelligent agent submitting Robotic Telescope Markup Language with the appropriate priority flag (e.g., exoplanet microlensing)

- Make it as simple or as complex as you like…
Software Processes
Night Operations Staffing

• Capable of totally unsupervised operations.
• Duty Officer on rota doing one week shifts.
• Principally role is coordinating safety officer
  – Always someone on call at a single phone number.
• Can prevent operations at their discretion.
• Most errors occur at start-up, so frequently helpful to have a witness even if the automated fault recovery fixes things for itself.
• No observers means no observer support
Night Operations Staffing

• Almost all staff on this rota.
• Reduces out-of-hours working by the classically “operations” staff (aka astronomers)
• Allows software engineers to see their own code running.
• One staff hour per day
Science with the LT

- Target of Opportunity follow-up
  - GRBs
  - Extragalactic Supernovae
  - Novae
  - Solar system objects – Comets and asteroids

- Regular monitoring
  - Variable stars: CVs, YSOs
  - AGN and Quasars
  - Doppler mapping with a spectroscopic capability
  - Gravitational lensing
  - Solar system objects – Comet orbits
Current Time Allocations

- PATT (UK) 40%
- Liverpool JMU 30%
- CAT (Spain) 20%
- CCI (International) 5%
- Schools/Education (UK) 5%
- OPTICON (International) up to 2%

- LT has 40-50 observing programs from 30 different institutes, allocated by 6 TACs
Summary

• Common User Facility – adds cost!
• Comprehensive instrumentation suite
• Can react to triggers (manually or automatically) within seconds
• Data products available promptly
• Always happy to work with people to make “special” modes and/or instrumentation to enable new science

http://telescope.livjm.ac.uk/