Building and operating a network of autonomous observatories with an open source software

on behalf of a large collaboration

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http://rts2.org
Historical link..

The word robot was introduced to the public by the Czech interwar writer Karel Čapek in his play R.U.R. (Rossum's Universal Robots), published in 1920.

The word robota means literally "work", "labor" or "corvée", "serf labor", and figuratively "drudgery" or "hard work" in Czech and many Slavic languages.
A question to begin with..

What you would like the observatory software to do?
You know, well, everything.
Does that include image processing?
Hm..yes, the ideal one should do it.
You named it..
Tool “make paper –journal Nature” with fancy GUI?
Yes, that will be an excellent tool!
The software

- Open source
- C++
- Running on Linux, Solaris, (Windows, Mac OS)
- Own TCP-IP communication
- Modular, hot pluggable
- Always fast interruptible
- Provides drivers for various observatory devices
  - Including switches, cryogenics controllers,..
Original goal of the software

- Gamma Ray Bursts (GRBs) optical follow-ups (~ year 2000)
  - → fully autonomous observatory operations
  - → quick observation interruptions
  - → remote operations
- Started at Ondřejov Observatory, Czech Republic, later used in Spain for BOOTES
BOOTES network

• Started in Spain 1998, PI Alberto Castro-Tirado

• Currently operating
  • BOOTES 1 (Huelva, Spain)
  • BOOTES 2 (Málaga, Spain)
  • BOOTES 3 (Blenheim, New Zealand)

• Expected
  • BOOTES 4 (Irkutsk, Russia; May 2011)
  • BOOTES IR (Granada, Spain; August 2011)
  • BOOTES 5+ (various locations considered)

• http://www.iaa.es/bootes
RTS2 locations

- Ondřejov, Czech Republic (2001, 2008)
- El Arenosillo, Spain (2002)
- La Mayora, Spain (2003)
- Bloemfontein, South Africa (2005)
- Sierra Nevada, Spain (2005)
- Blenheim, New Zealand (2009)
- CAHA, Spain (2009)
- FLWO, AZ (2010)
- CTIO, Chile (2010)
Observatory environment

- Camera
- Telescope
- Dome
- Executor
- Centrald
- rts2-xmlrpcd
- rts2-mon
- GUI
- WWW
- scripts
Software

• Scheduling
  • Human, queue, merit function, NSGA-II (Genetic Algorithm)
• Logging, events generation,
  • Disk space, dome close/open messages,
• Modular
  • LSST CCD testing lab, various strange sensors (monochromater, laser,..)
  • Network centric – modules communicates through TCP/IP.
• Open source
  • CVS (now Subversion) versioned from the beginning
Software

- Scripting
  - Simple, XML-RPC, standard input / output
- Remote access
  - ssh, web (AJAX)
- C/C++, Python, PostgreSQL
- LibNOVA
  - Celestial mechanics library
- Own communication protocol
  - SPIE 2008 poster
Software environment

- Standalone daemons
- Daemon focused on a single problem
  - Camera driver
  - Telescope driver
  - Observation execution
  - GCN (GRBs) receiver
- Hot-pluggable (restarting camera,..)
- TCP/IP communication between daemons
Software environment II

- Rich class hierarchy
  - starting from abstract classes (Object, Block)
  - Middle layer (Daemon, Device, Client, Camera, Telescope, Dome, ..)
  - The hardware (CAHA 1.23m telescope, Losmandy, Davis weather station, ..)
  - Services (Executor, Selector, ..)

- Values
  - It is possible to add new values “on-the-fly”, e.g. from the scripts
Coding philosophy

- Start from abstract code
- Develop use of the functions
- Expand use of the functions
- Catch exception, log everything (it is difficult to debug failures occurring at past without sufficient informations what failed)
- Reuse code, make abstract functions from particular implementation, ...
Requirements - scripting

• Want solution, that will be:
  • Robust
  • Platform and language independent
  • Allow quick interruptions
  • Provides rich image processing capabilities
  • Separates scripting from the observatory drivers
Solution – standard in/out control

• Solution, that is
  • Robust
    – If the script exits, next target is picked up
  • Platform and language independent
    – Any language, any platform
  • Allow quick interruptions
    – Simply shut down in/out communication with the script
  • Provides rich image processing capabilities
    – Depending on language of your choice; Python does
  • Separates scripting from the observatory drivers
    – Script is separate program, not requiring any library; can be tested outside of the observatory environment
Scripting example..

#!/bin/bash

for x in 1 2; do
    echo "value exposure = $x"
    echo "exposure"
    read exp_end
    echo "V W0 filter += 1"
    echo "V T0 WOFFS += 0.01 0.01"
    read x y
    echo "rename $y %b/test/%f"
    read renamed
    echo "log E renamed $y to $renamed"
    echo "? infotime"
    read x
    echo "G centrald sun_az"
    read y
    echo 'double test_double "[AU] double test value" 6.721'
    sleep 5
done
Requirements – weather blocking

- Want solution, that is
  - Robust
  - Simple
  - Modular, so new sensors can be added/old removed
  - Quickly identifies why is observatory closed
Solution – bad weather state

- Solution, that is
  - Robust
    - Uses system-wide states, which are used for synchronization
  - Simple
    - There are methods in API to signal bad/good weather
  - Modular, so new sensors can be added/old removed
    - Any device signaling bad weather shut down observatory; list of devices required to operate observatory is stored in central server
  - Quickly identifies why is observatory closed
    - Values outside limit are color-coded, list of failed values is provided
Lessons learned

• Replacing human observers is a complex, difficult task
• KISS (Keep It Simple S....) works
• Failures are inevitable and must be quickly dealt with (detected, reported, resolved)

• The biggest issue is synchronization and data processing
• HW control is a small piece of code
• Cheap do-it-yourself solutions are deemed to fail (sooner or later)
<table>
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<th>Column</th>
<th>Value</th>
<th>Date</th>
<th>UT</th>
</tr>
</thead>
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<td>2009/10/25</td>
<td>21:49:40.000 UT</td>
</tr>
<tr>
<td>B2 CORR_RA</td>
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<td>2009/10/25</td>
<td>21:49:40.000 UT</td>
</tr>
<tr>
<td>B2 CORR_DEC</td>
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<tr>
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<td>2009/10/25</td>
<td>21:49:40.000 UT</td>
</tr>
<tr>
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<td>andor3 CCD_SET</td>
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</tr>
</tbody>
</table>

Note: The table displays data for different columns labeled CLOUD TEMP_DIFF, B2 CORR_RA, B2 CORR_DEC, CLOUD TEMP_IN, CLOUD TEMP_OUT, andor3 CCD_TEMP, andor3 CCD_SET. The dates and times are in UT format.
Conclusions

- Mature, operational network of a fully autonomous telescopes
- Wide and growing range of system features (and functionalities)
- A decade of design, development, deployment (and failures)
Second Workshop on Robotic Autonomous Observatories
Torremolinos (Málaga) 5th - 10th June 2011

www.iaa.es/astrorob2011
e-mail: astrorob@iaa.es

Main Topics
- Robotic Astronomy: Historical perspective
- Existing robotic observatories worldwide
- New hardware and software developments
- Real-time analysis pipelines
- Archiving and data quality control systems
- Telescope and observatory control systems
- Transient detection and classification
- Protocols for robotic telescope networks
- Standards & protocols for transient reporting
- Scientific results obtained by means of robotic observatories
- Public outreach and Citizen Science
- Global networks
- Educational applications
- Future strategies

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