

# EOS SPACE SYSTEMS OBSERVATORY CONTROL SYSTEM

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EOS Space Systems (EOSSS) has developed systems over many years to support research into Space Situational Awareness and Satellite Laser Ranging. These systems are based upon a software architecture that simplifies systems development with the goals of supporting multiple missions at low-cost. This software architecture is known as the Observatory Control System (OCS) and is being used at numerous installations around the world. In particular the OCS has supported local, remote and international operation of the Space Research Centre (SRC) facilities at Mt. Stromlo, Australia in both manual and automatic modes. The design objectives of this software architecture are discussed in the context of future development paths aimed at lowering systems integration costs even further, and enabling participation in international SSA networks.

## 1. INTRODUCTION

EOSSS has developed a general-purpose, distributed software architecture for control of observatories and related installations, called the Observatory Control System (OCS). The OCS is particularly suited to Space Situational Awareness and theoretically any application requiring an industrial-grade distributed control system. The OCS is operating at 8 sites internationally including installations in: Australia, China, Thailand and several locations within the United States. The OCS supports EOSSS' own SSA research and development efforts and the operational needs of customers. Current development is focused on support of cooperative international SSA efforts via remote and automatic operations.

The OCS is highly flexible and has allowed EOSSS and its customers to conduct a large number of activities and experiments. It is truly multi-mission and has supported the following activities:

- Astronomical observations
- Astrometric observations
- Satellite and space debris tracking and observation with multiple cameras / fields of view
- Satellite laser ranging (against cooperative targets)
- Debris laser ranging (against uncooperative targets)
- Variety of lasers – 1W class, 100W class, kW class; 100Hz – KHz rates
- Variety of detectors – single cell, quad cell, 32x32 cell array APD
- Variety of cameras – Andor, Princeton Instruments, Texas Instruments, Raptor Photonics, SBIG; CCD, EMCCD and thermal
- Monostatic and bi-static satellite laser ranging
- Tracking known targets
- Discovery / acquisition of previously-unknown targets via optical detection and streak analysis
- Full station automation including: scheduling, optical target search, detection, acquisition, tracking, guiding, ranging, signal detection, post-processing, data distribution
- Laser ranging safety including thermal aircraft detection camera and aircraft transponder avoidance system
- LIDAR upon orbital targets
- Adaptive Optics (coming soon)

The OCS has been developed over many years and has evolved to meet ever-increasing requirements for flexibility, extensibility and reliability.

Primary research and development of the OCS occurs at EOSSS' Space Research Centre (SRC), located on Mt. Stromlo, Canberra in the Australian Capital Territory. This facility hosts:

- a 1.8m telescope and 9m co-rotating dome
- a 1m telescope and 4m enclosure
- 300W and kW debris ranging lasers, 1064 nm wavelength
- 1W satellite ranging laser, 532 nm wavelength
- Weather monitoring station
- Multiple cameras, detectors and laser timing systems

The SRC is driven and controlled by means of the OCS, both locally and remotely and in manual and fully-automatic modes.



Fig 1. EOSSS' Mt. Stromlo SRC, driven by the OCS

## 2. ARCHITECTURAL PRINCIPLES

In order to meet its requirements the OCS has been designed according to the following principles:

**Modularity.** System components are modular, with well-defined interfaces and a separation of concerns.

**Loose Coupling.** Changes to the system are well-contained and need not affect un-related parts of the system.

**Flexibility.** System components can be easily added, removed or modified.

**Extensibility and Maintainability.** The system can be readily extended and is easily maintained. This facilitates the addition or replacement of both hardware and software functions.

**Domain and Problem-Independence.** The underlying control system is not domain or problem-specific and so is amenable to solving new problems. Problem and domain-specific concepts are provided in upper layers built upon generic, lower-level control system layers.

The Observatory Control System's immediate application is to Satellite Laser Ranging and Astronomy, but in theory it could be adapted to drive any automated industrial facility. The domain independence of the software architecture makes the OCS flexible, extensible and highly re-useable. Furthermore it has been proven via customer experience that the OCS will integrate and cooperate with existing observatory control systems in heterogeneous environments.

The OCS is based on a layered hardware and software architecture:

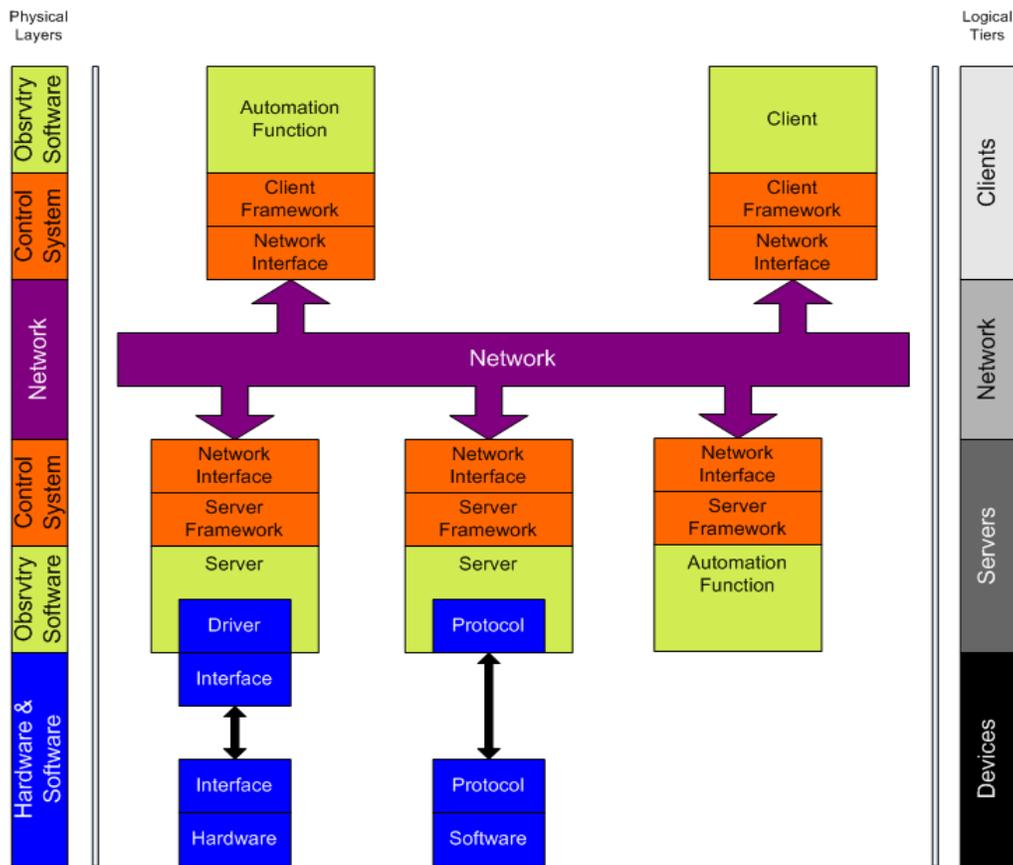


Fig 2. Layered Architecture

These architectural layers are conceptual and are as follows:

### Hardware & Software

Hardware and software include such items as: telescopes, enclosures, lasers, associated software and a variety of other equipment. A common problem with such equipment is that it is often heterogeneous, with different:

- platforms, e.g. PC
- operating systems, e.g. Windows, Linux
- interfaces, e.g. serial, CANopen, USB, Bluetooth
- protocols, e.g. sockets, CORBA, COM

A fundamental feature of the OCS is that it makes this equipment look, feel and act in a consistent manner. This is achieved by hiding the equipment behind a universal software abstraction called a *Device*.

Of particular note is that the OCS architecture allows for the quick and easy integration of new components and instruments.

### **Network**

Devices are usually accessed through an adapter card and a driver library. However there is a limit to how many devices a given computer can support; at some point a single computer will run out of capacity, or a new device will require a different operating system or computer platform. This means that most observatories require many computers and so the OCS is network-enabled.

### **Control System**

The OCS is based upon a *Client / Server* architecture. This is a network computing model based on the following concepts:

- clients connect to servers
- clients issue commands to servers
- servers respond to client commands

Within the OCS, device server applications abstract devices and make them available over the network.

Client applications connect to device servers over the network, or even over the Internet, and drive devices via commands to the relevant device server.

### **Observatory Software**

Observatory software includes client and server applications and automation functions that meet general observatory requirements and specific customer requirements. Domain and problem-specific control system functions are implemented at this level.

Like all parts of the OCS, this software is built upon a common set of software frameworks. These are code libraries that embody the most-re-useable, but complex and technical aspects of the distributed control system. These libraries facilitate software re-use and are used by EOSSS to extend its own systems. These libraries are also available to customers, who can extend their observatories over the longer term independent of EOSSS or with support from EOSSS if necessary.

The OCS provides a number of other functions, including:

**Task Scripting.** Includes the ability to write system logic in an interpreted scripting language, without the need to re-compile and re-deploy the Observatory Control System's source code;

**System Management.** Includes automatic start and shutdown of the OCS' networked computers and device servers from a single point at any local or remote location;

**Resource Management.** Includes automatic negotiation of ownership requests for system resources, enabling concurrent tasks to run correctly and safely;

**Authentication Management.** Includes user authentication and restriction of user access to device server commands based on user identities and group membership.

## Server Software

When deployed the OCS is typically customised and extended to meet the customer's specific requirements and needs. The result is a layered network of device servers that implement specific observatory functions.

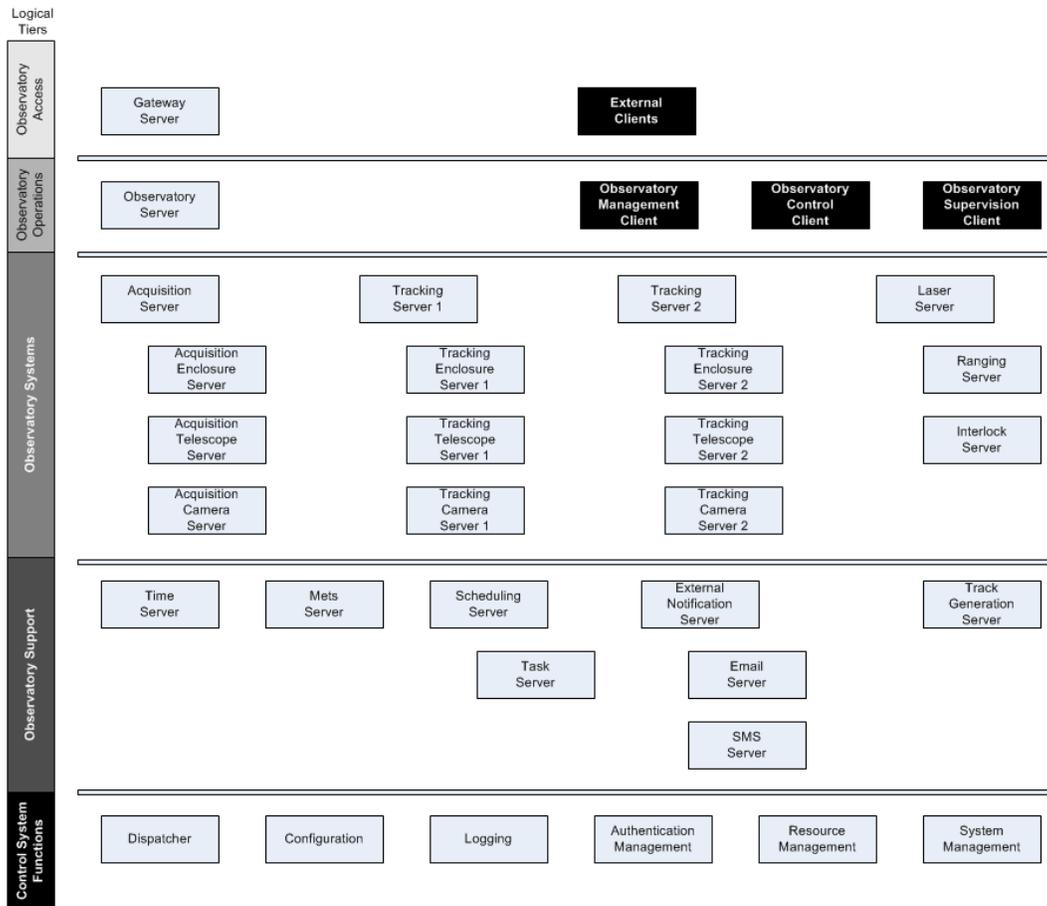


Fig 3. Example OCS Server Deployment

Note that many components are re-used between installations with most customisation occurring within the Observatory Systems layer.

The OCS is quickly and easily extended to work with 3<sup>rd</sup> party devices and instruments, giving the customer the option of sourcing components from a wider range of vendors.

## Client Software

The OCS provides a graphical user interface environment that can be configured using graphical tools. Complex user interfaces can be constructed with ease, including real-time camera imagery and asynchronous feedback.

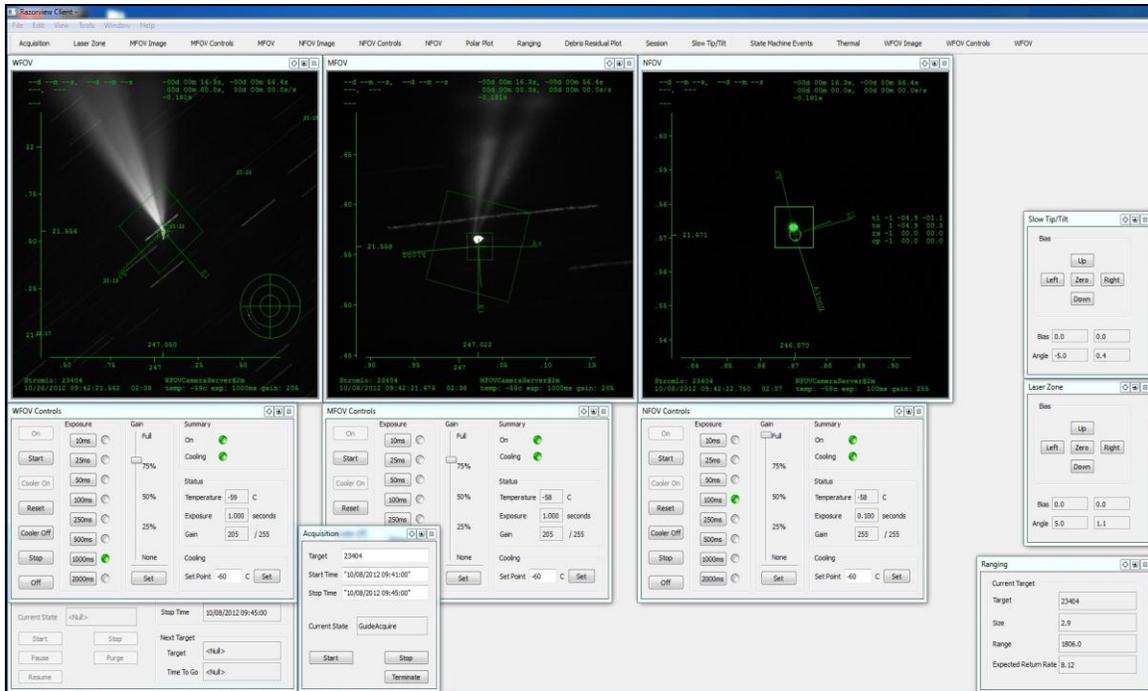


Fig 4. Satellite / Debris Laser Ranging Graphical User Interface

Such interfaces are client applications that communicate with, and display state from multiple server applications over the network or even over the Internet.

In Fig. 4 note the multiple fields of view: a wide field camera view at the left, a medium field camera view in the middle and a narrow field camera view at the right. Also note the laser beam being fired at the target, appearing as the bright spot in the centre of each view.

## Automation

The OCS provides a foundation on which complex observatory automation has been built. EOSSS has fully-automated its Mt. Stromlo SRC facility to perform both SLR and space debris ranging functions.

The Mt. Stromlo SRC facility is a world-class installation that consistently ranks among the world's best-performing SLR stations.

This facility contains two automated ranging systems: one for satellite ranging and the other for space debris ranging. These systems have common but mostly different requirements, and have shared and dedicated components. Both systems were built sharing a single instance of the OCS.

The automation includes the following features:

- Station open / close in response to scheduled tasks / weather / power failure
- Station start up / shut down in response to scheduled activity / inactivity
- Scheduling of target passes
- Target tracking, search, optical detection, acquisition, guiding and ranging
- Maximised station utilisation and throughput
- Ranging signal search, detection and analysis
- Real-time track updates from optical observations
- Automatic camera exposure control
- Automatic laser emission control (only fire laser when locked on target)
- Data collection, post-processing, distribution
- Status monitoring / error recovery
- Weather monitoring including use of Internet weather radar service
- Laser safety including system interlocks, site horizon, thermal detection of aircraft and aircraft transponder avoidance
- Satellite de-confliction (avoid illuminating satellites that are not the intended target)

All of these features are full integrated into the Mt. Stromlo system enabling autonomous and robotic operation with remote supervision, status monitoring and intervention where required.

### 3. BENEFITS

The OCS brings several benefits to the software development lifecycle. These benefits include:

**Established Patterns.** A comprehensive set of established communications and control patterns upon which network-enabled control systems are designed. This enables analysts and developers to focus on solving higher-level problems.

**Reduced Complexity.** A set of re-useable software frameworks and libraries that hide much of the technical complexity of the control system, enabling less-experienced programmers to quickly build effective applications.

**Reduced Technical Risk.** A highly-sophisticated communications and control infrastructure is easily leveraged by programmers without the need to re-implement complex functionality and services. This provides greater technical certainty in regard to control system development and enhancements.

**Eased Construction.** The use of smaller, cooperative, modular components with well-defined interfaces facilitates team-based software development, integration and testing. New devices and instruments are added with ease.

It is expected that the OCS will continue to support EOSSS' demanding technical and business requirements for many years to come.

#### 4. CURRENT DEVELOPMENT / DIRECTION

To date the OCS has integrated EOSSS' own telescopes, domes, lasers and related equipment, and other devices including cameras and detectors. But emerging industry drivers and trends require us to address several challenges, namely: smaller installations, even-cheaper, being more-cooperative.

**Smaller installations.** With constrained customer budgets it is becoming necessary to support smaller-aperture off-the-shelf telescopes and enclosures from 3<sup>rd</sup> party vendors. A great many such devices use the ASCOM interface.

**Even-Cheaper.** Out-of-the-box integration with 3<sup>rd</sup> party hardware via standard interfaces, i.e. ASCOM. EOSSS expects to reduce system costs by developing a set of standard ASCOM interfaces that can be used to integrate any compatible device without the need to write new interface or driver software.

**More-Cooperative.** Enabling external parties to access station capabilities internationally over the Internet, including Web-based means such as iLabs.

These features are a current focus with ASCOM being a 'downwards' integration and networked collaboration efforts being an 'upwards' integration.

#### 5. COLLABORATION

The OCS is a low-cost, multi-mission architectural solution being applied to *and solving* SSA problems today. The OCS supports these efforts by enabling Internet and / or international collaboration. To date the OCS at Mt. Stromlo has supported the following activities:

**ILRS Participation.** Automatic receipt of elements and provision of normal points back to the ILRS network.

**Remote Operation of a Station via VPN Connection.** Secure, *direct* access to low-level observatory services with no proxies, enabling direct interactive control and near-real time asynchronous feedback *as if the remote client were on-site*. This is not screen-scraping via Remote Desktop Protocol (RDP); it is actual control-grade integration suitable for remote manual or software control, task cueing and automation.

**Remote Scheduling.** Receipt of scheduled observation instructions from external parties for automatic batch-mode observation and results collection, complementing other SSA sensors.

**Laser Clearing House.** External (but not as yet real time) provision of laser firing windows for space debris ranging laser de-confliction.

#### 6. CONCLUSION

EOSSS continues to develop the OCS with an aim to delivering smaller and cheaper SSA installations.

EOSSS is seeking to participate in international and networked SSA efforts, and is extending the OCS to enable the Mt. Stromlo facility (or any other OCS-based installation) to participate as node in a network of stations. Such participation will enable EOSSS to promote its unique capabilities and offer specialised services that can enhance cooperative SSA at the global level. Examples of EOSSS' SSA capabilities include:

- Southern hemisphere visibility
- Large aperture telescopes and EMCCD cameras
- Real-time or scheduled operations / tracking hand-offs
- Remote passive observation and active laser tracking
- Satellite and space debris acquisition and tracking
- Orbital updates