Developments of next generation monitor and control systems for Radio Telescopes

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Abstract. As part of the ongoing upgrade of the GMRT observatory, the monitor and control (M&C) system is being upgraded to a modern specification driven system. The basic building block of the proposed M&C framework is a SACE node which provides command, response and event data streaming interfaces to the child and parent nodes running locally or remotely in a heterogeneous operating system environment. A prototype M&C system formed by hierarchically composing SACE nodes at different levels has been successfully tested at the GMRT. For the recently built 15m antenna at NCRA, a generic, web based M&C system has been developed which allows remote, authenticated operation. We discuss issues relevant to the development of the next generation M&C systems for radio telescopes using the lessons learned from these two systems. We also summarize flexible, reusable and cost-effective approaches using off the shelf packages and technologies used in generic frameworks, which can contribute to form the basis for M&C systems of very large radio telescopes like the SKA.

1. Introduction

The Giant Metrewave Radio Telescope (GMRT) built and operated by NCRA [1] is undergoing a major upgrade in several aspects like seamless frequency coverage from 150 to 1500 MHz, large instantaneous bandwidth of observations (maximum of 400 MHz), revamped servo system and other matching improvements in support systems. The GMRT monitor and control (M&C) system is a central supervisory system which controls and monitors telescope subsystems like analog receivers, digital signal processing back-ends and electro-mechanical subsystems like servo and feed positioning drives of the thirty antennas spread over a radial distance about 15 km from the central control building. To control and coordinate new or upgraded subsystems of the telescope, and for performing astronomical observations with enhanced automation, the GMRT M&C system is being upgraded.

In conventional monitor and control systems, as the synchronization and communication protocols are tightly coupled with individual device level controllers, adding new features in response to upgrade requirements requires significant changes and becomes a difficult task. The advent of technologies in micro-controllers like PC104, Rabbit and Labjack, allows running the embedded control software with IP based interfaces which can conveniently handle the different states of the devices, including functionalities like safety and hard real time requirements of the instrument. To exploit these advantages, next generation M&C systems are mainly based on a specifications driven framework and that provides a powerful and flexible way to implement functionalities like coordination between the telescope subsystems, handling their states (like initialization, normal, suspend, restore etc.) and providing a configurable user interface.
A prototype version of a new M&C system for the GMRT, developed in collaboration with the System Research Laboratory of TRDDC-TCS, India [2], uses a generic specifications-driven M&C framework called Sensor Actuator and Control Element (SACE). NCRA has recently built a 15m radio telescope in its Pune Campus for which, a generic, web based M&C system has been developed in collaboration with Persistent Systems Ltd., India [3]. In sections 2 and 3, we describe these M&C systems in detail. In section 4, we note the commonalities between these two systems, and also carry out a comparative study with the M&C systems of other modern telescopes, to highlight the current trends in M&C system development such as: usage of generic frameworks like EPICS, Service Oriented Architecture and SACE. We also discuss the issues relevant to the development of next generation M&C systems for large radio telescopes like the SKA [6].

2. SACE Architecture based GMRT M&C system

2.1. SACE Architecture: The basic building block of the framework is a SACE node (figure 1), that provides command, response and event data streaming interfaces to the child and parent nodes running locally or remotely on heterogeneous operating system environments. Each node provides standardized M&C functionalities like command-response validation and translation, state machine for control algorithm flow etc. At the application layer, the SACE node functionalities can be configured as required using the input files and rules appropriate to the instrument under control. The core of the SACE is nothing but the Meta model interfaces written in Java which provide wrappers around the components or plug-in modules specified in the initialization file. The SACE architecture partitions the M&C functionalities into components that can be mapped to independent tasks which can be implemented using the available or futuristic alternative technologies. For example, the desired application control logic is implemented using the UniMod java FSM framework, command validation is done using OpenRules which takes inputs in MS Excel format, open source java script engine Rhoen is used for the scripting, and Java Swing frame-work is used to auto generate the GUI using XML self-description files. The SACE engine uses config.ini file for component selection along with the Java libraries and deployment specifications or configuration XML files, to generate the project specific M&C runtime environment.

2.2. The GMRT M&C development: The SACE node is repeated at each level of the GMRT M&C system, along with specifying the application behaviour using the self-description and FSM logic to perform dedicated tasks. The SACE instance running at any antenna (called antenna SACE), receives and validates the commands from the parent SACE node running at the central building (CEB SACE) and distributes it to the individual child Subsystem SACE nodes which control analog receiver chain

![Figure 1 SACE High Level Architecture Diagram](image1.png)

![Figure 2. Web based M&C system architecture for the 15m antenna](image2.png)
systems and servo and feed positioning systems at the antenna base. Similarly, responses and events gathered from all the subsystem SACE are sent to the CEB SACE through the antenna SACE. A prototype version of this GMRT M&C system formed by hierarchically composing SACE nodes at each level of M&C, system has been successfully tested on a set of three GMRT antennas.

The SACE architecture has been proven to be based on self-description concepts, best suited for hierarchical composition on multiple devices and provides most of the functionalities required by a M&C system. SACE is a scalable, cost saving and agile solution as it provides interfaces for COTS & customized software.

3. Web based M&C system for the NCRA 15m telescope

The NCRA 15m antenna is a Alt-Azimuth mounted parabolic dish located at Pune. We have developed a web-based M&C system suitable for this antenna and for the 2m Optical telescope of ICUAA [3], based on an architecture which is sufficiently generic to cater to both types of telescopes with most of the differences in specification captured as configuration parameters.

3.1 Web based M&C Architecture and the 15m antenna M&C system implementation:

Figure 2. shows the high level architecture diagram of the M&C system for the 15m antenna. The spring framework, used along with the web container, provides runtime environment for the web functionalities like security, concurrency, life-cycle management, transaction and other services. The spring web controllers route the request from the C&M System user interface (CMS-UI) to the Core System Services. The CMS-UI display web-page consists of HTML and Flex components which handle the HTTP requests and responses from the telescope users. The core system services accept and validate the requests from the controller, and pass them to the appropriate service components like batch processing, state-machine and data layer objects. The core system also provides dynamic service level integration and implementation such as user and user-group or role management, catalog management etc. The state-manager is responsible for over-all behaviour of the M&C system and keep updates of live status of all the telescope sub-systems like servo, signal conditioning, sentinel and back-end processing units. Upon raising of alarms or exceeding the threshold levels of telescope parameters, state-machine takes corrective actions to restore the telescope to normal operations. The core-system services & state machine uses XML specifications, self-description and rule files which increase the level of configurability of the M&C system. The communication and messaging layers mainly handle the requests / responses, asynchronous events and monitoring data between the CMS and telescope subsystems wrappers using message queues and socket communication. The wrapper software is generic and configurable, and communicates to all subsystems of the telescopes. The wrapper decodes the XML packets received from the CMS, passes to hardware devices to take action, and after gathering the responses from devices, converts them to XML packets to send to the CMS.

3.2 Salient Features:

Our web based M&C frame-work is a end to end software solution for the radio and optical telescopes M&C system which has the salient features like (i) Context based web-browser interface. (ii) Modular and allow easier hardware/software upgrades. (iii) Scalable and configurable (via xml-DTD specification). (iv) Automatic state-restoration, exception handling using the batch/scripts. (v) Gives alarms notifications through the audio, visual and emails.

4. Current Trends in the M&C System Technologies

Table 1 shows a comparative study of the M&C system frameworks used in the GMRT and the 15m Antenna, along with those for other new M&C systems in upcoming radio telescopes like the Australian SKA pathfinder (ASKAP) [4] and the MeerKAT in South Africa [5]. We note the commonalities like all the M&C systems use Linux OS platform and open source software for the web-browser based UI, Java technologies, programming/scripting languages like Java, C++, python, jsleep and middleware based on the TCP/IP based protocols, activemq and ICE for the
communication. The scalable and specifications-driven framework achieved by using self-description / configuration files in .xml and .ini formats, and state-machine and command / response validation uses rule files. Most of the M&C systems use MySQL for the database.

### Table 1: Trend in technologies for the Radio Telescope M&C System

| Telescopes          | NCRA-GMRT                  | NCRA 15m Antenna | ASKAP                  | MeerKAT                  |
|---------------------|----------------------------|------------------|------------------------|--------------------------|
| **Platform**        | Linux, Solaris             | Linux            | Linux, MacOSx          | Linux MacOSx             |
| **Architecture**    | SACE (Hierarchical)       | Spring Framework, Tomcat (Service Oriented) | EPICS (Server-Client Model) | Service Oriented Architecture (SOA, Python based client library) |
| **Programming Languages & Scripting** | Java, C++, Mozilla rhino script | Java Technologies, C/C++, jsleep | C++, Java, Python | Python and C++ |
| **User Interface**  | Java Swing based          | Web based (java scripts, servlet, flex components) | Control system studio, MontiCA server, BOY | Web interface, Adobe AIR, ipython shell, stellarium soft. |
| **Middleware (Comm.)** | JMS, TCP/IP socket lib    | ActiveraMq, TCP/IP | Channel Access and ICE | Katcp-python(pypi), TCP/IP |
| **State Machine**   | UnimodFSM executor        | groovi, DRules   | IOC-State Notion language |                          |
| **Database**        | HSQDLIB 1.8, MySQL        | HSQDLIB (3.2.6), MySQL | Erics Database using PyEpics, MySQL | MySQL. |
| **Self-description** | .xml and .ini files       | .xml and .xls files | .ini and .xml files |                          |
| **Command validation** | OpenRules and MS Excel    | DRules           | EPICS-IOC             | Pythonic rules. |
| **Alarm Notification and exception handling** | Audio/Visual              | Audio/Visual/SMPT, JMS2email | CSS BEAST Component – Alarm configTool, JMS2RDB |                          |

5. Summary

Frameworks used for the M&C systems for the GMRT, the NCRA 15m antenna, the ASKAP, and the MeerKAT provide standardized functionality with important features like: (i) Cost-effective proven approach (ii) generic platform (iii) loose coupling (iv) scalable and configurable system (v) automatic state-restoration, exception handling (vi) context-based UI and reporting strategies (vii) Alarms with audio, visual and emails/SMS notification and (viii) integrated access to remote nodes and/or monitoring storage (archives). In conclusion, large resources like money, time, and man power invested during design and develop a customized M&C system and during the up-gradation of the new hardware, can be avoided by using the generic frameworks for M&C systems described here.

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