MACE TELESCOPE

Observation, Data Acquisition & Monitoring

*A. Jain, S. Srivastava, P. Mahesh, J. Deshpande and S. Padmini

MACE is a large telescope comprising multiple subsystems, which operate in a synchronized manner to perform successful observations. The paper introduces a robust, concise and autonomous Operator Console (OC) to operate, control and monitor the entire process, providing workflow management autonomous schedule based observation, orchestration of data acquisition and monitoring of telemetry data, while maintaining safety of subsystems. The highly-automated OC conducts entire observation on a single click from both local and remote geographic locations using multiple geographically distributed clients. This included telescope operation, generation of observation schedule, setup of system and experimental parameter, generation of alarms, application of interlocks between various subsystems and date & time synchronization. The facility of remote operation of the telescope from BARC, Mumbai allows operation, testing, troubleshooting and upgrade of the system.

The system is operational with telescope tracking, mirror alignment, camera imaging and LID control, LED calibration, weather and sky monitoring, archival of observation & monitoring data with local and remote Ocs. Various subsystems, respective controllers and their major responsibility are covered in this article. To ensure maximum availability of Control System, retry procedures are incorporated in case of failure to achieve recovery online whenever possible.

Challenges

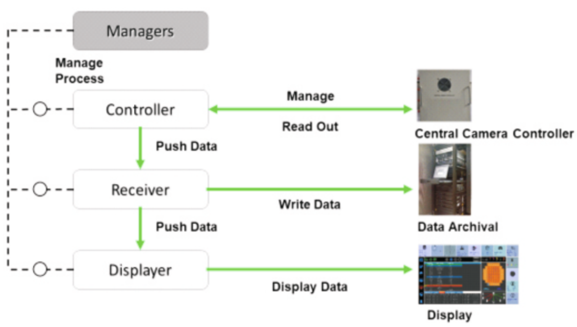
Data acquisition, Control and Monitoring system was challenging to design and build due to its unique requirements, to interface with custom designed electronics, to handle large data volumes generated by large-scale physics experiments with limited resource available at remote geographical location. Also features such as fully automated observation support and provision for remote operation, upgrades and troubleshooting require advanced design considerations. The system should be able to take care of safety, security of all the subsystems and manage the synchronization for a successful observation run. It should provide features for fault tolerance, recovery, security, reliability and availability. Also, it should support continuous system deployment and evolution over a long lifetime, making maintenance and scalability significant. An integrated OC should provide concise information in the form of a dashboard to blend data from multiple sources into a holistic view for operator convenience. Separate consoles should provide elaborate information to configure, schedule, control and monitor the experiment.

The remote operation must take place over shared satellite network with a limited allotted bandwidth of 256 kbps. Hence, it becomes crucial to optimize communication mechanisms to avoid any delay in communication chain to and from remote OC. The possibility of multiple OC clients operating simultaneously requires synchronization to assume Controller and Observer roles.

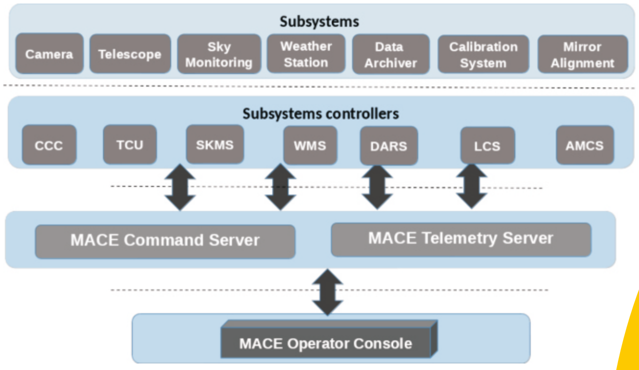
System Architecture

A modular architectural design is adopted for scalability at subsystem and telescope level. Specification of well-defined interfaces allows for easy accommodation of subsystem changes. At the highest level, there are separate managers for control and telemetry.

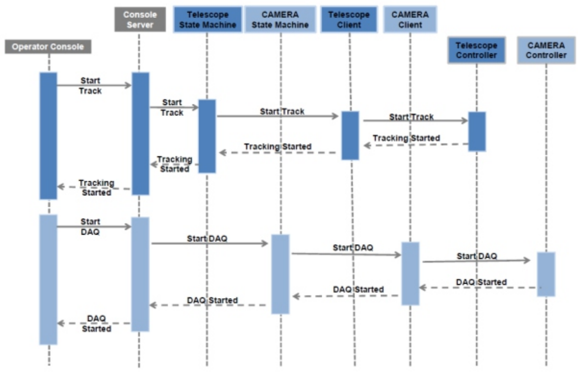
Managers orchestrate with subsystem controllers to manage required performance and functionality of the subsystems; subsystem receivers to push/pull experimental and monitoring data and archive it for long terms storage; and subsystem displayers to display monitoring and observation data to the astrophysicists in the Control Room. Control action for each subsystem takes place in the local controller, but the OC has detailed status of all systems.



▲ SYSTEM ARCHITECTURE.



▲ SYSTEM CONTEXT diagram.



▲ SEQUENCE DIAGRAM.

Subsystem	Subsystem Controller	Responsibility
Camera	Central Camera Controller (CCC)	High resolution imaging camera for recognition and acquisition of Cherenkov events.
Telescope	Telescope Control Unit (TCU)	Moving the telescope towards specific sources at proper orientation.
Sky Monitoring System	Sky Monitoring System (SkMS)	Quantifying the sky transparency level and checking the tracking accuracy during observation.
Mirror Alignment System	Automatic Mirror Control System (AMCS)	Focusing the Cherenkov light onto the camera by aligning the mirrors
Weather Station	Weather Monitoring System (WMS)	Monitoring of wind speed and weather parameters during observation.
Calibration System	LED Calibration System (LCS)	Relative gain calibration of the imaging camera.
Data Archiver	Data Archiving System (DArS)	Archival of event and monitoring data.

The Command and Telemetry Server of MACE acts as centralized control and data server interacting with various subsystems to perform subsystem-wide control and monitoring tasks. MACE OC, which acts as a client to both the servers, is responsible for overall control, monitoring and error handling of the telescope.

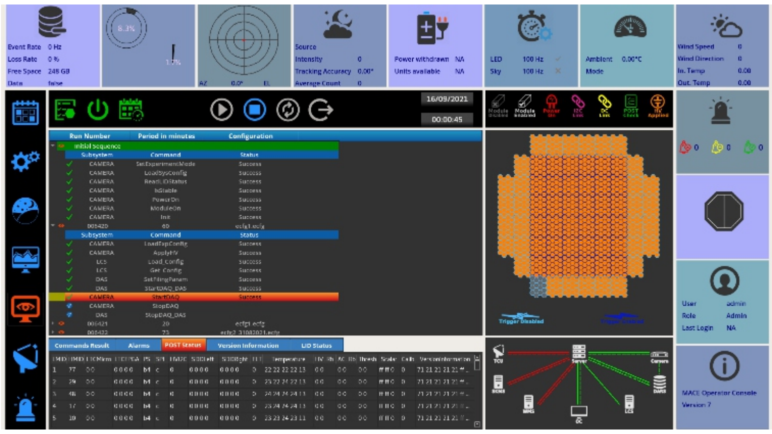
Separation of Control and telemetry path and having separate manager helps in segregating responsibilities and provide redundancy and fault tolerance making system robust. Decoupling of command and Data interface with OC provides room for concurrent command and data processing.

State Based Control: MACE OC allows sequence-based observation run which is pre-created based on the order in which commands are to be executed. Safety interlocks across subsystem are checked before sending it to command server for execution. MACE Command server maintains a state machine for each of the subsystem as per their functionalities. All functionally diverse subsystems of MACE telescope operate in recognized definable states only. As a command is received from MACE's OC, it is validated in corresponding state machine to ensure its safe execution in the present state of the subsystem before sending it to the subsystem controller. Since, behavioural functionality of subsystems changes along with its state, a unique State pattern has been used to provide a systematic and loosely coupled way to achieve this, allowing the behavior to be changed at run-time depending on its current state.

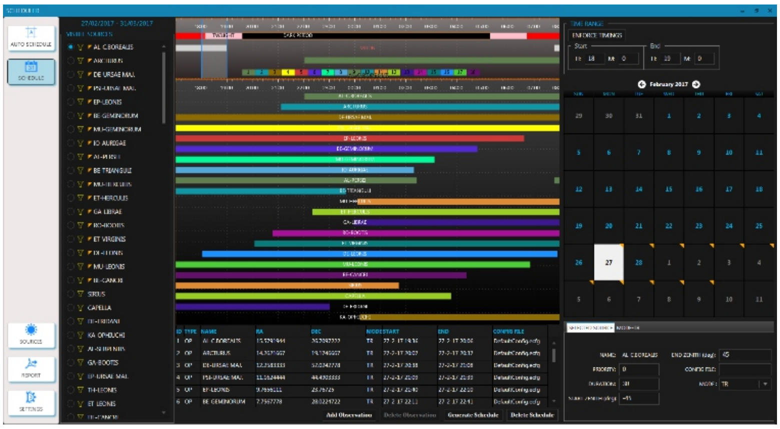
Efficient Communication Mechanisms: The two servers communicate with geographically distributed multiple OC clients and a large number of subsystems. The server implements reactor pattern based non-blocking, robust and optimized communication mechanism for performing IO, facilitated by a single threaded event loop blocking on resource-emitting events and dispatching them to corresponding handlers and call-backs.

MACE Run Control and Monitoring Dashboard

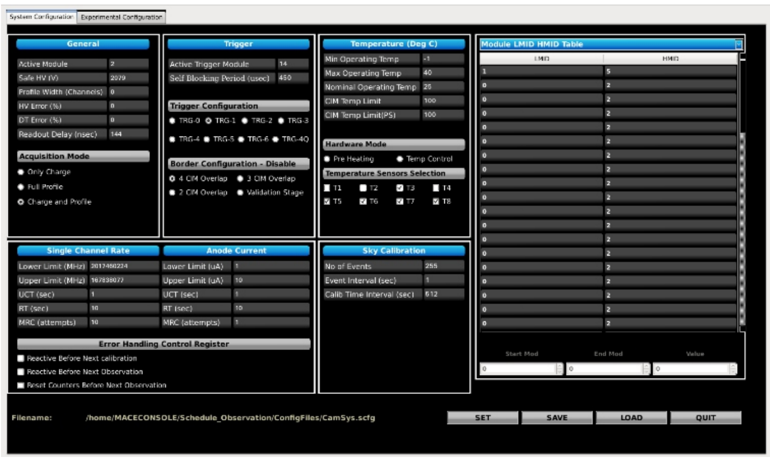
MACE OC provides a concise, robust and self-sufficient dashboard that runs on multiple displays for simultaneous



▲ MACE TELESCOPE Operator console dashboard.



▲ MACE TELESCOPE Scheduler.



▲ MACE TELESCOPE Configuration Manager.

control of operation and monitoring of the telescope parameters. This includes display of the control and configuration parameters, status of all subsystems, detailed display of command execution status, system health status, and display of online analysis data. Date and time of all subsystems are synchronized periodically with centralized GPS clock.

Role-based access with authorization is provided to prevent the intrusion into the system by unauthorized users. Multiple operational modes are supported to perform observation, subsystem test, calibration run and trigger efficiency checks.

Workflow Management: The dashboard provides complete workflow for operating the telescope including selection of mode, configuration and connection establishment of the subsystems, incorporation of the schedule, automatic start of observation, run and monitoring support during the observation.

Pre-observation Support: The dashboard allows launching of separate consoles to prepare schedule and configuration for the experiment. The Scheduler generates automated schedule for the observations based on a database of high energy gamma-ray sources. For each night, visibility plots of each star are available such as the zenith angle of each source versus time. The schedule generation for a specific period is automated.

The sources are picked up for scheduling by applying a set of customizable user defined filters like source visibility, priority etc. The software also provides a tree-map visualization to represent hierarchical multi-dimensional schedule information for the selected time period.

The Configuration Manager facilitates configuration of system parameters related to number of active and trigger modules, safe operating temperature limits, anode current and SCR limits; and experimental parameters related to LED and sky calibration, high voltage and discrimination threshold etc.

Run Control: Automatic operation of the telescope is based on a pre-defined schedule. The schedule for the night is retrieved from a centralized storage, the operations listed in sequence are timelined, and time required for pre/post operations is taken care of in order to start the data acquisition for particular observation run at desired time.

In addition to providing one-click experiment run, the run console provides the operator option to pause, abort, and stop data acquisition. In test modes operator can select the set of commands from a given task list required for execution of given observation run, including the pre/post operations as well as initialization tasks. Once a run is started, progress of each observation run and overall progress for the observation scheduled for that night is periodically updated.

The console implements various interlocks across subsystems. If any interlock is violated, the console generates warnings/alarms and displays them over a common interface for prompting Operator to carry out necessary emergency measures.

Telemetry Monitoring: There are subsystem monitoring widgets for detailed and periodic health & status monitoring. The camera monitoring widget displays single channel rates, high voltage applied, anode current and temperatures etc. Telescope and Mirror alignment widget provide tracking status of the telescope and status of individual mirrors actuators.The sampled experimental data is displayed to operator for data quality monitoring. The console provides for charge and profile data display at a configurable frequency.

Remote Operation: The MACE telescope is remotely operated from BARC Mumbai using ANUNET, over satellite network through GSAT 18. There is no conceptual difference between software working on site and remotely. It has provision for remote upgradation, troubleshooting, configuration and data transfer.

The software also has provision for multiple OCs, operating concurrently, for coordinating control and monitoring activities, thus allowing multiple researchers from different geographical locations to control or observe the experiment simultaneously. New clients can be inserted into this system dynamically. Only one OC can assume the role of controller, rest all the clients remain observers.

In order to create an effective interface, with capability of remote operation, client server architecture has been adopted. The command and data servers run on site in Hanle and Clients can connect to the server from remote geographical locations.

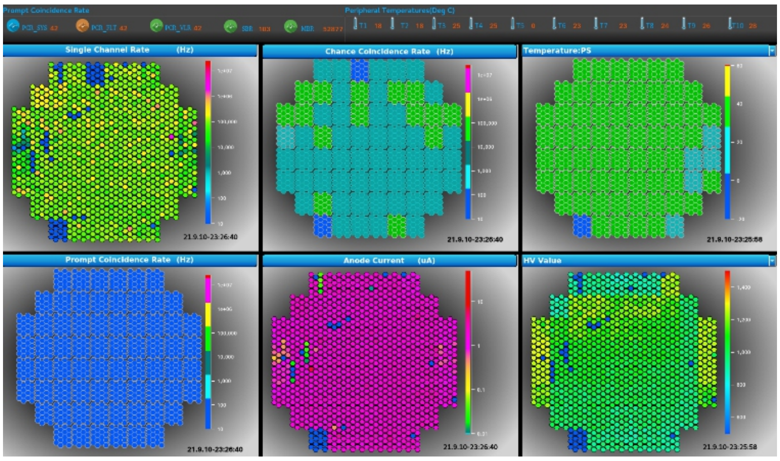
Results

MACE Data acquisition system achieved sustained event acquisition rate of 2k in only charge mode and 1.6k in charge plus profile mode. The critical telemetry data is acquired at 5sec interval and routine at 1 min in both remote and local setup. System is built as fault tolerant with various recovery mechanisms. Retrial of commands is done before a component is declared faulty and sufficient timeout is provided for network delays. Fault isolation is done to avoid cascade of failure from subsystem to many subsystems. All errors, warnings are reported using a common console.

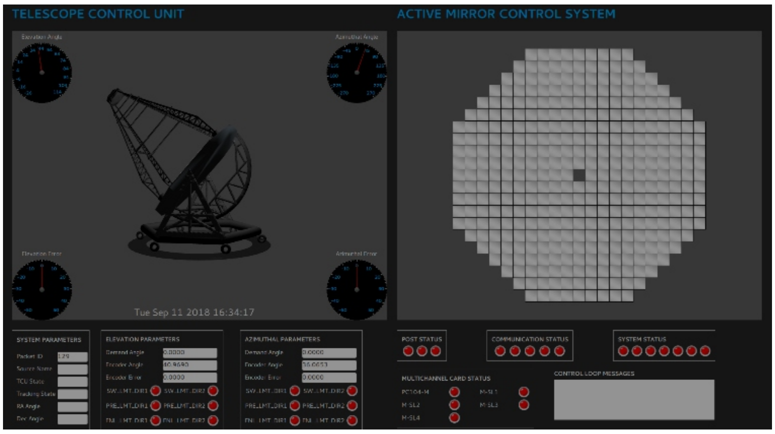
Optimization is carried out to make system responsive during remote operation by segregating the desired event data to be displayed online and data that can be saved on site and retrieved later for data processing. In remote operation setup, only charge data is provided for online data quality monitoring due to constrained bandwidth requirements.

Software unit testing and Interface testing with various subsystems was carried out in MACE Lab, BARC Mumbai. Integration testing with Camera and Telescope subsystem was performed in ECIL, Hyderabad. Validation and acceptance testing with all the subsystems was carried out at site.

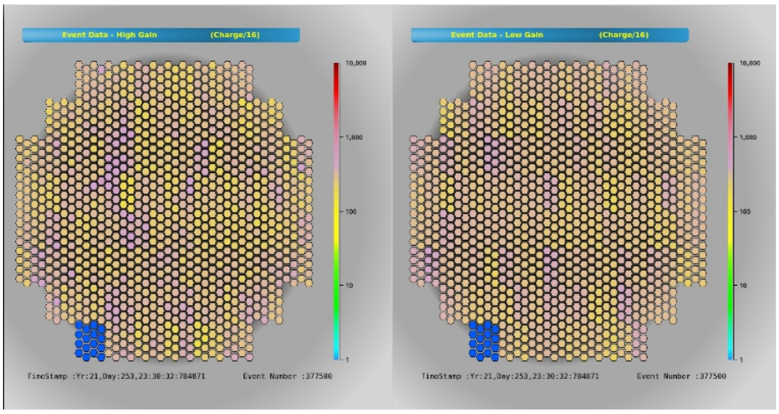
Various design principles and design patterns were followed during software design and development. The developed software is scalable to any number of subsystems and employs multithreaded architecture for concurrent execution of tasks for enhancing run time performance. The benefits gained by incorporating various design principles make software robust and scalable. Usage of design patterns has made software scalable, robust, fault tolerant and efficient. The enhancement in software design has helped in achieving maximum performance.



▲ MACE TELESCOPE Camera Telemetry Monitoring.

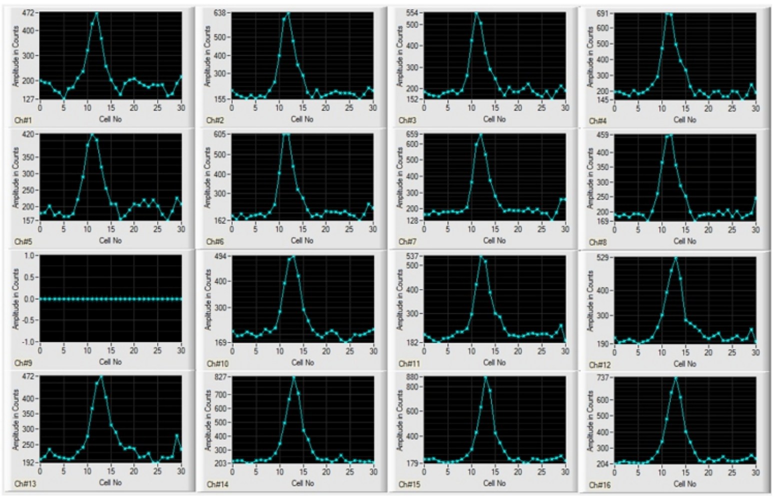


▲ MONITORING of Telescope and Mirrors.



▲ MACE TELESCOPE Event Data Display: Charge data.

▲ MACE Control Room Setup at Hanle.



▲ MACE Event Data Display.

Conclusion

MACE Data Acquisition, run control and monitoring software is tested with all the subsystems and commissioned at site. Currently it is operated through both remote and local interfaces. The operator console framework is generalized and is scalable to multiple telescopes with little modifications and extendable to other high energy physics experiment of similar scale.

Acknowledgement

Sincere thanks to every member of the DAPS, ED and ACS, CnID for their support during testing and integration. Authors are grateful to Anita Behere, Director, E&IG Group for her continuous support and encouragement. Sincere thanks to users from ApSD for their constructive feedback and support at site. We also acknowledgement to CD for providing ANUNET infrastructure and timely support.

The authors are from Electronics Division
Bhabha Atomic Research Centre
Trombay, Mumbai-400085.

*anushri@barc.gov.in**