ELT Tracking Local Supervisors design and development status

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ABSTRACT

The ELT Control System can be divided into the Central Control System (CCS) and subsystems Local Control Systems (LCS)[1]. At the heart of the CCS we have the High-Level Coordination and Control (HLCC) software which offers a single interface to the telescope towards the operators and instruments and coordinates the telescope subsystems. HLCC interfaces to the Local Control Systems (LCS) via the respective subsystem Local Supervisors (LSV). The LSVs are then responsible for interfacing to the different LCSs converting from the astronomical and user domains into actions and measurements in the individual device's domain.

Following celestial objects, i.e. tracking, is done on three ELT LSVs, the Main Structure (MS), the Dome and the Pre-Focal Station (PFS) LSVs. HLCC distributes the target information and the involved LSVs compute periodically the trajectory setpoints using the CCS's pointing engine for their respective devices. The tracking also considers a dynamic pointing origin, used to cope with the fact that the instruments might not have a perfectly aligned center of rotation. Pointing models that consider imperfections and physical effects are used for the MS and PFS LSVs. The timestamped setpoints are sent to the corresponding LCSs and feedback is gathered using deterministic channels.

Keywords: Telescope control software, telescope pointing, ELT.

1. INTRODUCTION

The ELT Control System can be divided into the Central Control System (CCS) and subsystems Local Control Systems (LCS). At the heart of the CCS we have the High-Level Coordination and Control (HLCC) software which offers a single interface to the telescope towards the operators and instruments and coordinates the telescope subsystems. The different LCSs provide an interface for every single telescope subsystem's actuator or sensor. HLCC interfaces to the Local Control Systems (LCS) via the respective subsystem Local Supervisors (LSV). The LSVs are then responsible for interfacing to the different LCSs converting from the astronomical and user domains into actions and measurements in the individual device's domain.

2. LOCAL SUPERVISOR DESIGN

The extensive experience and collaboration between different teams, instrumentation team for example [2], led to the following design principles for the LSVs implementation:

- Share their architecture for easier development and maintenance: Use the Rapid Application Framework (RAD), allowing event driven applications based on flexible state machines implementation and base standard behavior base classes and code templates.
- Utilize common libraries like the ELT Core Integration Infrastructure Software (CII), ELT Common Software (ECOS) tools and libraries and Common LSV libraries and tools (templates, OPCUA simulator, common commands interfaces, etc.).
- Robustness is achieved splitting the software in a distributed deployment of small specialized applications rather than large and complex applications, thus providing better testing, reliability for critical tasks and ability to execute partial functionalities.

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For each subsystem function provided by the LSVs they follow a controller-estimator-adapter design pattern. The concept is derived in principle from the JPL's State Analysis systems engineering Mission Data System methodology [3]:

- The Controller is responsible for receiving the command requests, acknowledge them, do the corresponding parameters transformations, implement the control algorithm and finally to send the commands to the LCS, subordinate function or secondary controller. The control algorithm can be a simple one step forwarding command (e.g. power on), or a more complex periodic task or control loop, which may or may not need feedback from the LCS. The Controller publishes its current action objective, e.g. set point, as Target Variable. The controller implements a common interface and basic state machine that is extended depending on the subsystem function commands and the subsystem functional and performance requirements.
- The Estimator, which reads measurements from the LCS and performs the state estimation for the corresponding subsystem function.
- The Hardware Adapter, which allows communication to the LCS, e.g., OPC UA or dedicated Fieldbus. Provides the sole interface between the LCS, i.e. the system under control, and the control system, via the corresponding ICD. Note that the LCSs are made of several devices controlled by functions. For each function, are associated several actions. Both the controller and the estimator use the hardware adapter.

The monitoring of the different subsystems is done as estimated state variables. State variables (SV) are observable pieces of information or properties of the subsystem's function over time. The collection of these state variables, e.g. device health, position, set points, temperatures, etc., or even uncontrollable but predictable (such as a planetary ephemeris) describe the state of the subsystem and can be used to define and verify its behavior.

While the state variables provided by the estimator give information about the system under control state, and by design not needing the controller or knowing its intent, we have the Target Variables (TV) that tells the current controller's goal or error. Target variables can be used to determine if a request is successfully achieved.

Both State Variables and Target Variables are published using CII's pub-sub mechanism and if required, for example to get high frequency sampled information to the Telescope Real-Time Executor (TREx), it's done using deterministic channels, i.e. ESO's multicast UDP protocol MUDPI:

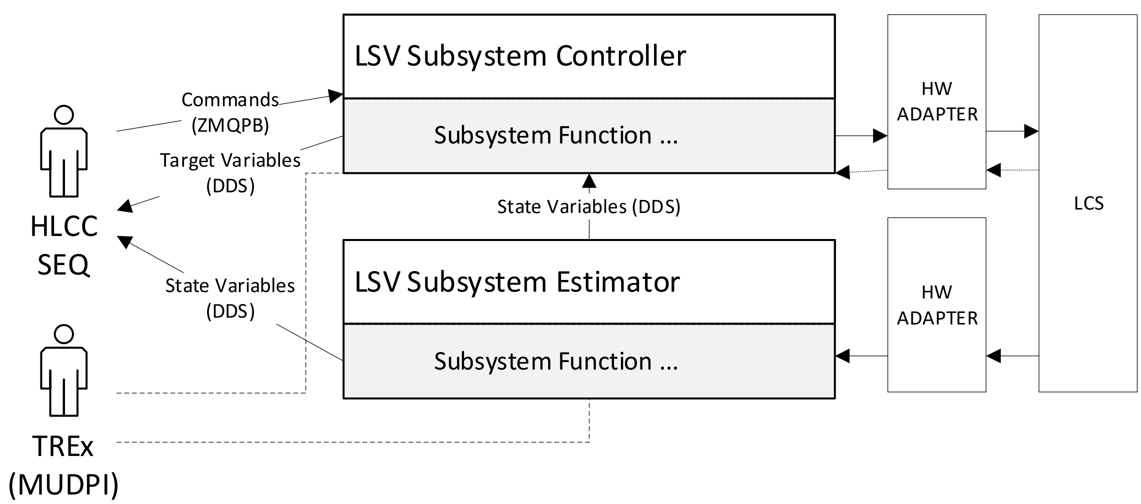

Figure 1 - Controller - Estimator - Hardware Adapter

The Local Supervisors consist of several applications which to allow scalability and depending on performance requirements are distributed on several servers. The Tracking LSVs are expected to run on Linux operating system using relying on low latency with OS preemption setting depending on the requirements. This is especially critical for the required deterministic LCS interface on the applications responsible for trajectory computation and distribution.

Tracking LSVs need precise time access to correctly compute the trajectories, and for correct operation to the deterministic channels, e.g. Profinet IRT in the case of the MS LSV, thus all Tracking LSVs servers will be synchronized with the observatory Time Reference System (TRS) using precision time protocol (PTP).

All control related applications, i.e. estimators and controllers, are written in C++ and based on the Common LSV software and the Rapid Application Development (RAD) framework.

Additionally, Fault detection and isolation (FDIR) supervisory functionalities are foreseen on some subsystems in order to detect, notify and if required react changing configuration on failure conditions.

3. TRACKING LOCAL SUPERVISORS

In simple terms we can define Tracking as the coordinated motion of different devices following a trajectory, normally corresponding to a celestial object on the sky, i.e. the target, so the target source is projected on the desired position (in the focal plane).

Following celestial objects is done on three ELT LSVs:

- Main Structure (MS) LSV, for the main axes positioning, i.e. altitude and azimuth.
- Dome LSV, for azimuth rotation and windscreen height.
- Pre-Focal Station (PFS) LSV, for the three probe arms, including their radial and angular positions plus pick-off mirror angle and trombone length.

HLCC distributes the target information and the involved LSVs compute periodically the trajectory setpoints using the CCS's pointing engine for their respective devices.

All astronomical computations are done using the ESO *eltpk* package, part of ELT ECOS, currently using the Essential Routines for Fundamental Astronomy (ERFA), based on the SOFA library published by the International Astronomical Union (IAU). The *eltpk* library provides all the functions necessary to convert from catalogue coordinates to observed local coordinates at a given time (and location). The same functions are used on the different tracking LSVs, what changes is the final step to convert device angles or positions.

The local, or observed, coordinates conversion into devices coordinates considers the application of a pointing model which compensates as much as possible for the difference between an ideal kinematic solution and the actual physical behavior. The differences are due to encoder offsets, alignment errors, flexures, etc. Such model exposes, to some extent, mechanical deficiencies as well as external effects such as gravity and temperature.

The periodic computation and application of these set points is called the Tracking loop. In the Main Structure the Tracking loop runs at 20Hz and two values are passed, one for t+50ms and for t+100ms, on every cycle:

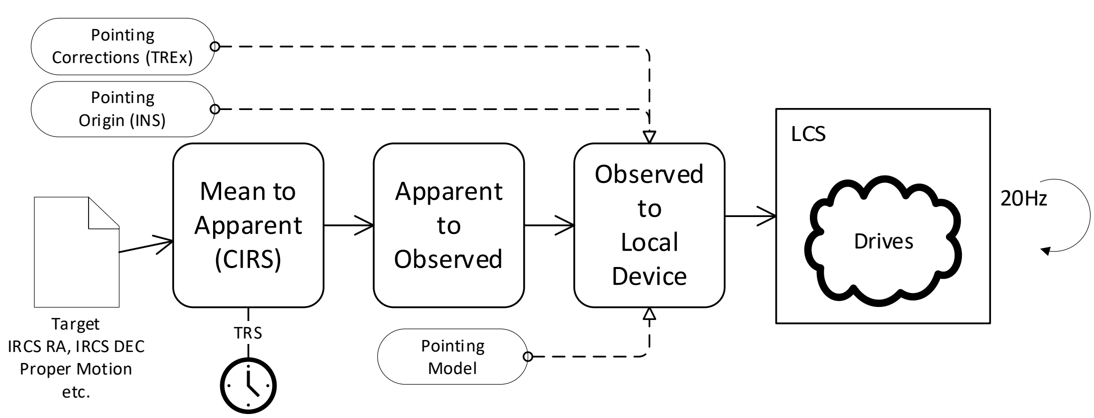

Figure 2 - Tracking Loop simplified concept

The tracking also considers a dynamic pointing origin, used to cope with the fact that the instruments might not have a perfectly aligned center of rotation. This value is received from the instruments and define the field position in the focal plane whose corresponding sky coordinates remain the same for a standard sidereal tracking trajectory, note that all other celestial objects, i.e. different coordinates, will describe arcs around the field position.

For the MS the baseline is to dynamically use the pointing terms NRX (Horizontal displacement of Nasmyth rotator) and NRY (Vertical displacement of Nasmyth rotator), which, after correcting for the currently used Nasmyth side, will correspond to a displacement of the field position. Some pointing experiments were done on sky using the VLT.

The baseline for the PFS probe arms positioning is to shift the focal sphere to be centered on the pointing origin and position the probes accordingly as shown in the picture:

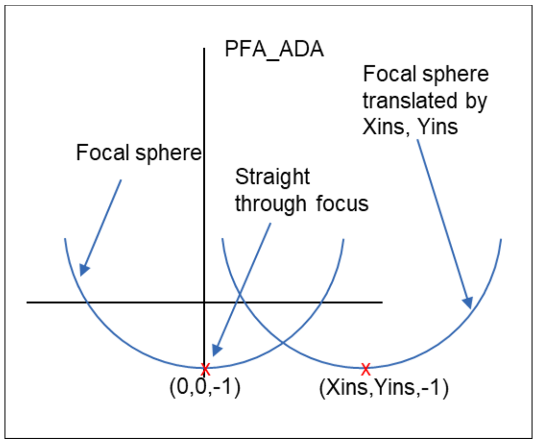

Figure 3 - Point origin focal sphere shift

4. MAIN STRUCTURE LSV

The Main Structure subsystems include all motors, encoders, drives, bearings, and electronics for its control. The MS LSV adapts high level domains like coordinates, named positions, etc. to local domain of the subsystems, e.g., angles, power state, etc. It receives commands from HLCC as well as pointing corrections from TREx.
Includes engineering user interfaces and scripts that allows for standalone operation as well as troubleshooting.

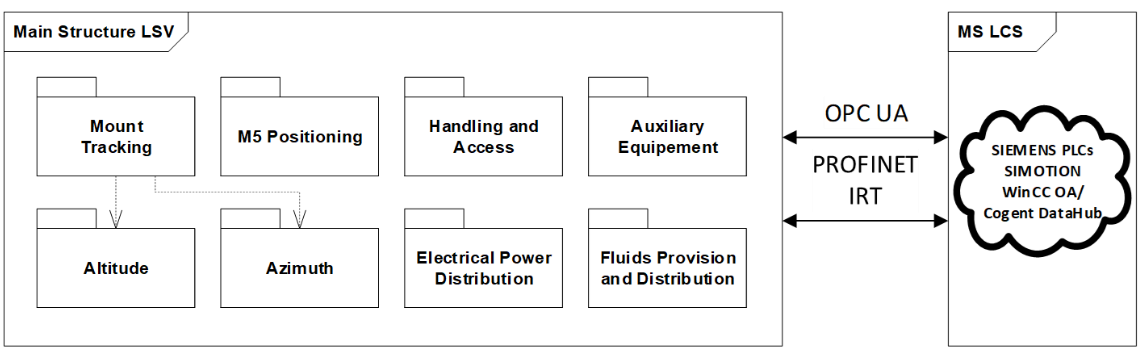

Figure 4 - Main Structure Subsystem Functions

5. DOME LSV

The Dome is the enclosure of the telescope whose main purpose is to protect the optics, mechanical and electronic components of the telescope from the external environment during the day and to provide the proper wind flow on top of the surfaces of the mirrors during observation.
The DLSV implements the following functions:

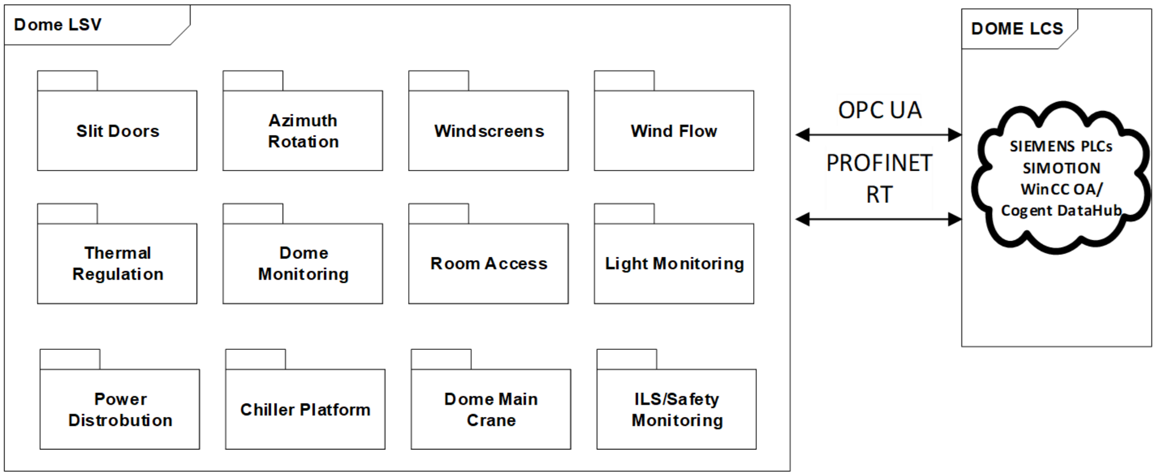

Figure 5 - Dome Local Supervisor

6. PRE-FOCAL STATION LSV

The most important function of the Prefocal Stations is to allow for the optical beam from the telescope to reach the selected instrument. The second most important task is positioning the guide probes while observing so the selected guide stars are captured by the arm optics.
The image processing, e.g. centroiding, and wavefront sensor image analysis are outside the scope of the LSV, but the cameras are controlled and monitored by the LSV.
Pixels and potential probe arm position corrections are sent and received via deterministic channels.

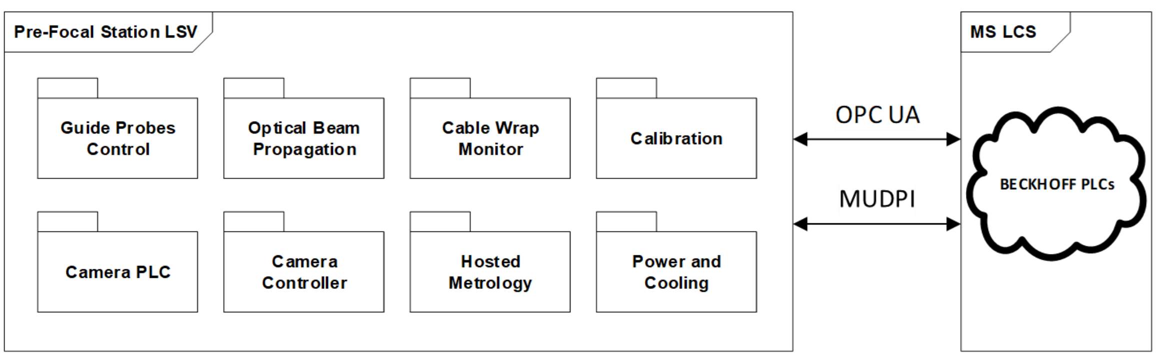

Figure 6 - Pre-Focal Station Local Supervisor

One important part of the preliminary development was to simulate and study different probe arms trajectories for special cases such as:

- Offsets. To verify the velocity and cases when the guide star goes outside the field of view or cannot be reached.
- Off-axis tracking. To verify the effect of the relative rotation speed difference between arms when tracking off-axis, i.e. for point origin away form the PFS center, and arms collision risks.
- Non-sidereal tracking. Effect of additional non-sidereal velocity on PFS probe arms.

7. CURRENT STATUS

The global ELT Local Supervisors project started back in 2021 where all major requirements, baseline architecture and design patterns were established, and the common software began to be developed. Later the project was divided into slightly different domains and performance requirements. For the Tracking LSVs the status is as follows:

- Main Structure LSV
  All software components for the different subsystem functions were created with basic functionality.
  Mount Tracking, Altitude and Azimuth functions interface with Simotion PLC and trajectories as correctly generated. Currently testing guiding corrections and pointing model application.
  Integration with HLCC commenced. LCS with some delays, to be accelerated.

- Pre-Focal Station LSV
  75% of software components for the subsystem functions were created, most with basic functionality.
  Probe controller receive target coordinates and guiding corrections. In the process of integrating the proper astronomical computations. Next steps include finishing initial implementations, startup and HLCC integration.
  Actual hardware and LCS in well advanced state and almost ready for integration.
- Dome LSV
  Not development started yet, planned for second half 2024.
  LCS with some delays.

More about ELT status in [4].

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