

FLYEYE TELESCOPE CONTROL SYSTEM: SOFTWARE DESIGN OF A MODULAR ARCHITECTURE TELESCOPE

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ABSTRACT

The Near Earth Object Survey Telescope (NEOSTEL) is an innovative project of the NEO segment of the ESA's Space Safety programme and will in particular focus on the survey and tracking of Near Earth Objects (NEOs).

This paper describes the software (SW) design of the Flyeye Telescope together with a brief explanation of the Telescope components.

The Flyeye Telescope can be considered as a distributed control system composed of more than 50 items. All SWs elements that compose the Flyeye will be described, from the top-level control SW down to the subsystems control software.

1 INTRODUCTION

The NEO Survey Telescope Deployment (NEOSTED) project has the goal to develop, accept and deploy on site the first Flyeye prototype NEOSTEL (NEO Survey TElescope). The NEOSTEL telescope main aim is the Survey and Tracking of Near-Earth Objects (NEOs), part of the European Space Agency (ESA) Space Safety programme (S2P). The Flyeye telescope can also be tailored for Space Surveillance and Tracking (SST) application. OHB Italia is the prime contractor for this project, and the technical coordinator of a multinational consortium. [1]

The telescope is based on a patented technology, named Flyeye, that splits the Field of View (FoV) into sixteen sub-FoV, granting high accuracy in an extremely wide Field of View (FoV=44 sq. degrees) [2].

The NEOSTED Telescope is therefore composed of 16 astronomical cameras, the equatorial mount, 16 camera focusing motors, 4 chillers, the time distribution system, 16 camera workstations, the primary mirror, the Switched Rack PDU, the emergency PLC. Each of these subsystems has its own control software developed in distinct Operative Systems (OS) using different programming languages. At the same time, all these different subsystems need to work together in a coordinated and synchronized manner to ensure efficient operation. All parts of the system are therefore networked together, with the goal to provide coordinated control and feedback from a central control room and even remotely over the internet.

The Telescope Control System (TCS) is the software dedicated to the local control and monitoring of all the subsystems that compose the Telescope, remote control of the telescope will be performed by the Enhanced Site Equipment Control (ESEC).

The SWs that compose the telescope are developed both on Windows and Linux OS and are integrated together using the EPICS framework. The design follows a modular architecture that allows to monitor and control the Telescope from the very first phase of the project. Each telescope component is integrated in the TCS by means of a dedicate software module that monitors and controls the subsystem, integrating it seamlessly in the framework. A Finite State Machine (FSM) coordinates all the subsystems and implements a set of high-level commands that allows both to perform observation campaigns and to implement safety functions, hiding the complexity of the system to the users.

2 SOFTWARE ARCHITECTURE

The control and monitoring of the Fly Eye Telescope is managed by several SW working in a distributed system of hierarchical type with precise subdivision of tasks.

The SW involved in the system are the following:

- Scheduler: system dedicated to planning the observations
- ESEC: interface between Scheduler and observatory, it allows remote monitoring, control of the telescope and observatory management
- Data processing and archiving: software dedicated to data archiving and image processing for NEOs detection
- TCS: telescope control system and associated subsystems
- Subsystems: are divided into Telescope and Observatory subsystems; it includes low-level SW for the management, control, and implementation of the single subsystem.

The physical location of the SWs is depicted in Figure 2-1, the involved sites are:

- Observatory, physical place where the telescope is installed with all its subsystems together with the ESEC server and the data processing system

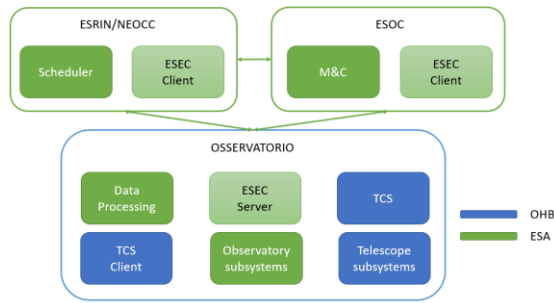


Figure 2-1 Flyeye architectural design

- ESRIN/NEOCC, centre where the Scheduler is run, and the status of the telescope is monitored via the client
- ESOCC, centre from which monitoring and control of the telescope is performed

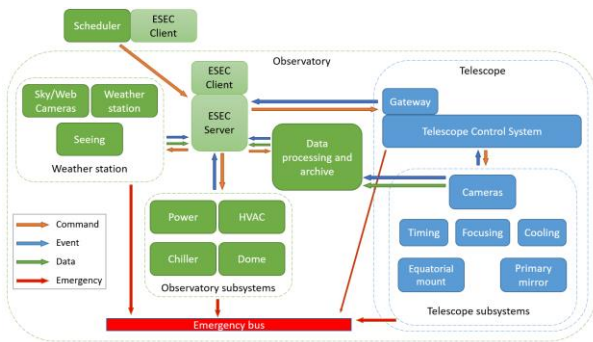


Figure 2-2 Flyeye detailed architecture and interface

Figure 2-2 shows the detailed architecture and the interfaces between the various systems that compose the Flyeye Telescope. In particular, the arrows identify the flow of commands, events, data, and emergencies. This distributed architecture is coordinated and managed by the ESEC which monitors and coordinates all the observatory subsystems and the telescope subsystems to execute the observing campaign.

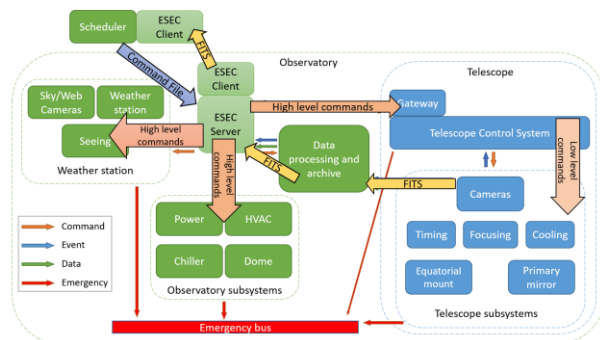


Figure 2-3 Flyeye detailed interface

The detailed interfaces between the various systems are shown in Figure 2-3. ESEC receives from the Scheduler a file containing the commands sequence to be executed during the observations. The list of commands is

converted by the ESEC into high-level commands to be sent to the observatory subsystems and to the TCS. The commands sent from the ESEC to the TCS are high level commands. The TCS is in charge to receive and translate the high-level command in low level commands to be sent to the Telescope subsystems. The images collected during the observation campaigns are instead sent from the cameras to the data processing system which stores, processes, and makes them available to ESEC.

In a SW hierarchical decomposition of the observatory, the TCS is the link between the ESEC and the subsystems that compose the telescope, see Figure 2-4.

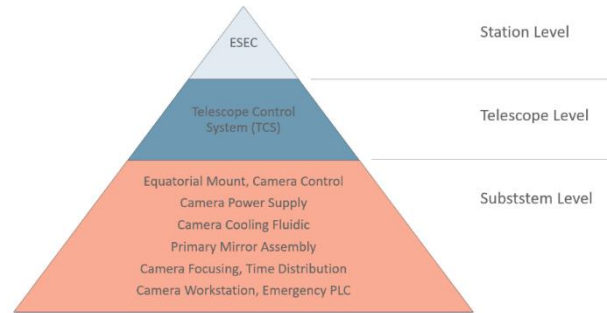


Figure 2-4 SW hierarchical decomposition

The component breakdown of the Flyeye Telescope (ESEC and TCS) is described in Figure 2-5. The components can be divided into three levels as follows:

- System Level: includes functional independent components and the coordination of the high-level operations.
- Subsystem Level: includes the components controlled by the TCS. The TCS coordinates and manages the complex telescope level operations.
- Component Level

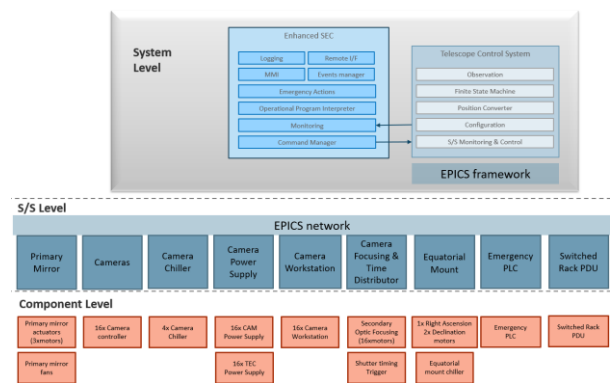


Figure 2-5 TCS and ESEC component breakdown

2.1 Communication protocol

The communication protocol of Flyeye Telescope is based on the EPICS framework [3].

EPICS is an architecture that provides a wide range of functionality, rapid application development and modification, and extensibility at all levels to meet the demands of complex systems. The software architecture developed was selected to meet these requirements.

EPICS uses Client/Server and Publish/Subscribe techniques to communicate between process. The EPICS architecture can be divided in several subsystems: the Distributed Database, the Display Manager, the Alarm Manager, the Sequencer, and the Channel Access.

The Distributed Database is used to provide local control. The database provides data acquisition, data conversion, alarm detection, and close loop control. A portion of the distributed database is loaded in each Input Output Controller (IOC). The IOCs are more complex entities, which basically consist of a Channel Access Server and a database containing different interconnected records called Process Variable (PV). Each record performs a specific task or maps a specific hardware device and exposes to the environment its value and attributes (limit, engineering unit, alarm status and severity).

The Display Manager provides an interface between the operator and the control system. The display manager is capable of monitoring or modifying any field in any database distributed throughout the network via the channel access communication bus. The display manager allows the application engineer to build display hierarchies that use the windowing capabilities of workstation.

The alarm manager is used to create fault trees for alarm presentation to the operator. The warning and alarms are configured in the database. The alarm manager monitors and groups these alarm conditions into a fault tree for presentation to the operator.

The Sequencer executes Finite State Machine (FSM), which run inside an IOC, allowing the creation of simple programs written in a State-Notation Language, which is suitable for handling FSM.

The Channel access is a “software bus” provided to communicate between various EPICS subsystems. All the communication issues that in a traditional environment have to be taken into account by the program, are demanded to the Channel Access protocol. It allows the system components and user extended components to perform channel connections, gets, puts and monitors on any field of the distributed database using the TCP and UDP protocols. Channel connections are performed by connecting a unique channel name to the IOC containing the channel. Channel access provides notification to its clients when a connection is broken and

another notification when it reconnects. This connection management is used to keep all subsystems informed of the status of the other IOCs, on which it may depend for parameter information.

3 SOFTWARE COMPONENT

3.1 Enhanced Site Equipment Control (ESEC)

The ESEC is the monitoring and control system of the entire observatory.

The architecture of the ESEC system falls into the family of server-client systems, see Figure 3-1. The server is a local (located at the observatory) monitoring and control (M&C) system. It interfaces to the TCS and all subsystems of the observatory. It provides a standardized access interface to clients connect to.

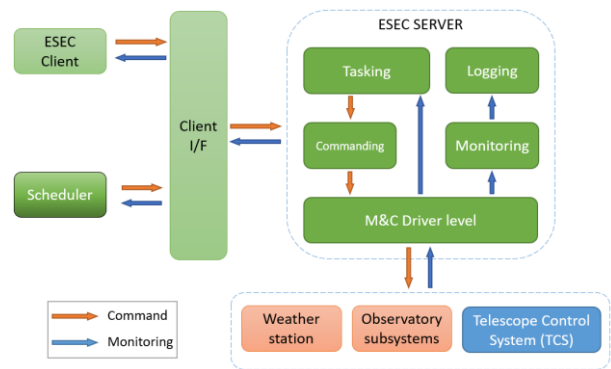


Figure 3-1 ESEC detailed architecture

The ESEC server receives commands from the client which in turn (through a driver level M&C module) translates into the protocol required by the TCS.

The ESEC client is an application that acts as a client for the ESEC server. It displays monitoring data and provides the means to control devices and execute high-level commands, see Figure 3-2.

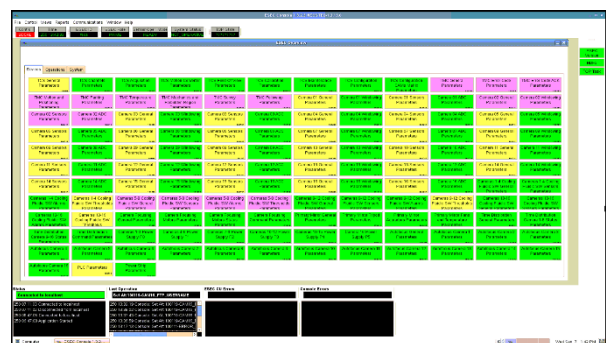


Figure 3-2 ESEC client

3.2 Telescope Control System (TCS)

TCS Software runs under VMware ESXi environment on an HPE ProLiant server. The TCS is composed by four virtual machines (see Figure 3-3):

- Telescope Control System IOCs
- Telescope Control System MMI
- PV Gateway
- Telescope NTP Server

All the virtual machines use Linux OS. Three virtual machines (all except the Telescope NTP Server) are based on EPICS.

Telescope Control System IOCs virtual machine hosts several EPICS IOCs used to control all the telescope subsystems. The IOCs perform real-world I/O and local control tasks and publish this information to clients using the Channel Access (CA) network protocol. CA is specially designed for the kind of high bandwidth, soft real-time networking applications.

The Telescope Control System MMI virtual machine hosts the MMI running under the Control System Studio environment. The MMI through the CA finds the IOCs information and gives to the user the ability to monitor and control the IOC. The IOC monitoring and control is allowed through the EPICS PVs. The MMI objects like LEDs, text box, buttons are directly connected to the EPICS PVs, the user changing the PVs value change the IOC behaviour.

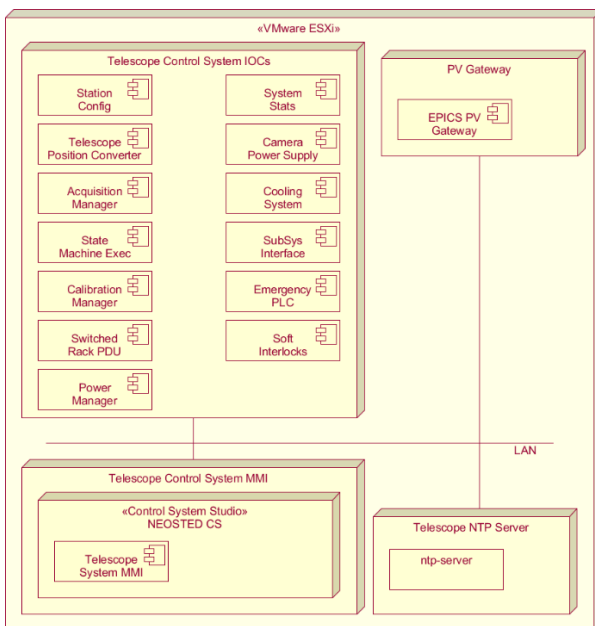


Figure 3-3 : TCS deployment diagram

The PV Gateway virtual machine hosts the PV Gateway EPICS component in charge of exposing a selection of PVs to higher layers (ESEC) and controlling the access. A Channel Access Gateway allows user to examine the

current state of the IOCs but prevents them from making unauthorized adjustments to the running system.

The Telescope NTP Server virtual machine hosts the NTP SERVER component in charge of generate the NTP clock.

3.2.1 TCS IOCs

Telescope Control System IOCs virtual machine hosts several IOCs, in Figure 3-4 each IOCs is modelled as a package. Following the complete list of all the IOCs:

- State Machine Exec: it identifies the possible modes to operate the telescope, it coordinates the Telescope subsystem and interfaces with the ESEC
- Station Config: its function is to load parameters from configuration file related to the observatory site
- Telescope Position Converter: its purpose is to convert celestial coordinates to raw motors positions and vice versa

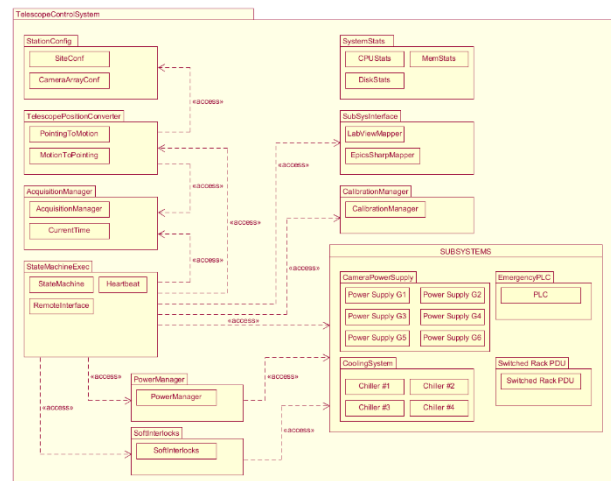


Figure 3-4 TCS IOCs package diagram

- Acquisition Manager: it collects parameters specific to an acquisition session
- System Status: its scope is to monitor the percentage of system CPU and memory usage
- Subsystems Interface: it is used for controlling the Primary mirror, Camera Focusing, and Time Distribution subsystems
- Calibration Manager: it collects parameters specific to a calibration session
- Camera Power supply: it is intended for monitor and configure the power supplies parameters
- Cooling system: it is intended for monitor and configure the camera chillers parameters
- Emergency PLC: its scope is to monitor and control the PLC lines
- Switched Rack PDU: it is intended for monitor and control the Switched Rack Pdu outlets
- Soft Interlocks: its function is monitoring the

- subsystem PVs and set the system emergency
- Power Manager: its scope is to power-off, restart and power-on via Wake on LAN the workstation/subsystems of the systems.

Components interact each other by exposing EPICS PVs and consuming EPICS PVs exposed by other components or subsystems.

Of particular interest is the State Machine Exec IOC, it oversees the management and coordination of all the subsystems of the TCS through a Sequencer which implements the state machine depicted in Figure 3-5.

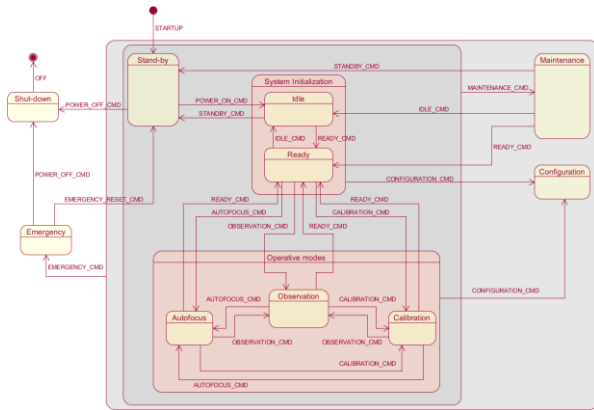


Figure 3-5 TCS Finite state machine and commands

At each state is assigned a particular task, below is the explanation of each state:

- Stand-by: it is the initial state of the TCS when the system is started.
- Idle: it is the daytime preparation mode; in this state the primary mirror ventilation is started to ensure that the operating temperature is reached. This command is performed several hours before the start of observations; the scope is to minimize thermal effects due to the temperature difference between the primary mirror and the environment.
- Ready: after the daytime preparation phase, the equatorial mount and cameras cooling system are turned on, and it waits until all the operational temperatures are reached. Only at the end of this phase the telescope is ready to be used.
- Maintenance: mode used for maintenance procedures.
- Configuration: in this mode it is possible to configure the subsystems parameters.
- Observation: operational mode used during the observation campaign.
- Calibration: Operational mode used for calibration data collection.
- Autofocus: automatic procedure used to set the mirrors in order to reaches the best focus position.

- Emergency: state of emergency that interrupts normal use of the system; it can be triggered by alarms or subsystem emergencies or by user request.
- Shut-down: Final state in charge of shutting down the telescope subsystems.

Furthermore, the TCS provides to the user (ESEC) several high-level commands to be used during the observations. These commands are dedicated to the acquisition with the cameras and the movement of the equatorial mount.

3.2.2 TCS MMI

The TCS MMI is a set of graphical user interfaces used to monitoring and control the telescope and its subsystems.

Components requiring operator interaction include a dedicated MMI made by one or more windows. TCS MMI running under the Control System Studio (CSS) environment [4].

CSS is a collection of tools that deal with PVs, these tools are specialized for access to the PVs values, alarm handler as well as several operator interface and control system diagnostic tools.

The TCS MMI allows a full operability of the telescope through several windows. There is a window for each telescope subsystems plus a group of windows dedicated to the TCS. Figure 3-6 is the main windows of TCS MMI.



Figure 3-6 TCS MMI main windows

3.2.3 PV Gateway

The PV Gateway virtual machine hosts the PV Gateway EPICS component [5]. The Gateway is both a server (like an EPICS IOC) and a client (like the EPICS CSS studio MMI). Normal clients connect to the Gateway server side, and the Gateway client side connects to IOCs and other servers, possibly other Gateways. The reasons for using the Gateway in TCS SW are to provide convenient access from one subnet to another and to provide extensive additional access security.

Only a selection of PVs are exposed in write mode to the ESEC software. These PVs are the ones used for command the TCS FSM. All the other PVs can be accesses in read only mode, to prevent unauthorized changes to the PVs values.

In the TCS two separated sub-networks are foreseen:

- System sub-network
- Control sub-network

System sub-network is used by TCS to operate the system. Control sub-network is used by the ESEC to control the TCS. The PV Gateway connects the two networks.

3.2.4 TCS NTP

The TCS NTP Server virtual machine is in charge of generate the Network Time Protocol (NTP) clock for the Telescope network. Usually, the linux NTP daemon is configured for use the public server, in the TCS NTP Server VM the NTP daemon is configured to distribute the time from the system clock synchronized by the PTP protocol distributed by the GPS antenna present in the Time Distributor subsystem.

3.3 Telescope subsystems

3.3.1 Astronomical Cameras

The SW of the sixteen astronomical cameras run on a SoC that integrate CPUs with high-level operating systems, and FPGAs that guarantee the required digital performances. The SoC used is the Xilinx ZYNQ-7030.

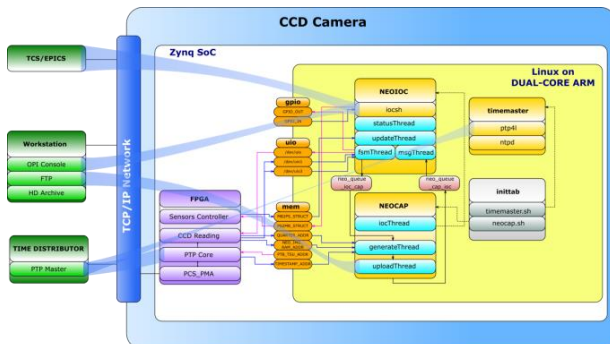


Figure 3-7 Camera SW design

The Zynq SoC's Arm Dual Core is dedicated to run the

customized version of the Xilinx Linux Kernel distribution, which has been built by applying Petalinux Tools.

In the SW run two main applications: one dedicated to the FITS image generation and image upload to the data archive; the other dedicated to EPICS interface and internal FSM handling.

3.3.2 Equatorial mount

The Equatorial mount SW run on two Siemens components the Simotion RT and the Windows RT both.

The Simotion RT runs the main TMC software itself has no hardware input/output capability, therefore it uses its Profinet interface to interface with a decentralized I/O system of the type ET200S, the safety PLC, the HMI and the drives. The main duty is the actuation of the Right Ascension and Declination motors.

The Windows RT hosts the OPC server, the EPICS/OPC bridge, the logging database, the plot tool for the logged data and allows access to the logging dump files.

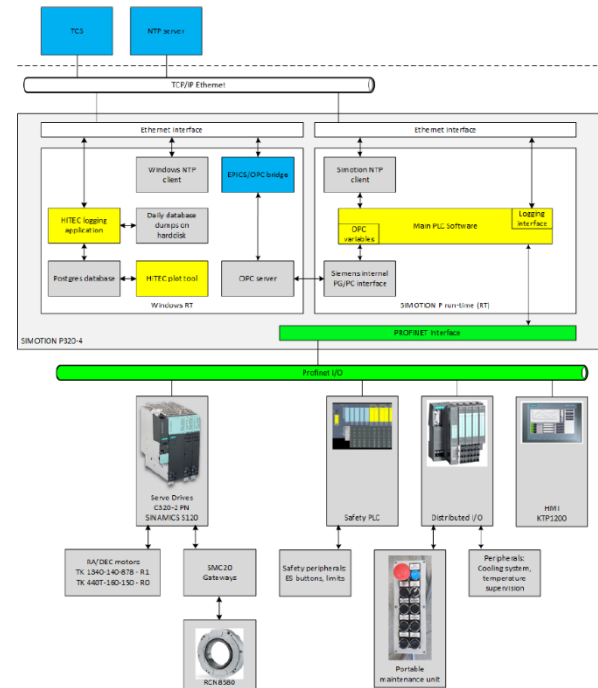


Figure 3-8 Equatorial mount components

3.3.3 Primary mirror

The control of the entire PMC system is demanded to the Beckhoff Industrial PC equipped with a quad core Atom processor. The PC is a windows machine that runs: a software written in C# (using .Net framework) that controls all the devices installed on the PMC, and an EPICS IOC. The SW actuate three primary mirror actuators that allow to tip, tilt and piston the primary mirror.

3.3.4 Focusing motors and Time distribution

The Focusing motors (FOC) and Time distribution (TMD) SW is developed on the same hardware, the NI PXI of the National Instrument.

The goal of the FOC is to position the camera optics in a specific position. The actuation is done using stepper motors with NI drivers to provide the direction and the pulse train; position readings are performed by HEIDENHAIN encoders that transmit data via EnDat.

The TMD's purpose is twofold: distribute to the telescope systems the reference time received by the GPS and control the cameras shutter to take the pictures at a schedule time. The precision of timing and the synchrony between cameras are two basic requirements.

On the same machine run an EPICS IOC.

3.3.5 Camera chillers

The camera chillers SW runs on an ASCOM PLC. The software is in charge to control the inverter process pump, the compressor, and monitor the ventilator, liquid pressure, and the flow meter. The communication protocol used to command and monitor the chillers is the Modbus. The EPICS IOC Cooling system that run on the TCS IOC machine allow to integrate the chillers in the telescope system.

3.3.6 Camera power supplies

The power supplies are x32 TDK Power supplies. The Power supplies are grouped 6 by 6; for each group, the first TDK-Lambda Z36-12 is set as Master, is LAN connected and reachable by TCP/IP, the other five power supplies are configured as Slaves and connected in RS485 daisy chain to the Master, that thus acts as a gateway for its slaves Monitoring and Control.

The EPICS IOC Camera Power Supply that run on the TCS IOC machine is intended for monitor and configure the power supplies parameters. There are six Camera Power supply IOCs that run in the TCS.

3.3.7 Camera workstation

There are sixteen camera workstations with Linux operative system. The workstation run an EPICS IOC developed in python that coordinate the phases of the autofocus procedure. The procedure counts the following steps: sky subtraction, source extraction, figure of merit computation. The result of these processing is used as input to decide the best focus position.

3.3.8 Switched Rack PDU

The Switched Rack Pdu is an APC AP7921B, its scope is power-on and power-off the camera ethernet switches.

The EPICS IOC Switched Rack Pdu that run on the TCS IOC machine is intended for monitor and control the eight outlets. Communication with the Switched Rack

Pdu is done using the telnet protocol.

3.3.9 Emergency PLC

The PLC installed in the telescope is of the Siemens S7 family. It is used for monitor and control hardware lines. There are fourteen digital input lines and ten digital output lines. The EPICS IOC Emergency PLC that run on the TCS IOC communicates with the PLC using the OPC-UA protocol.

4 CONCLUSIONS

The Flyeye components and relative SW has been presented and discussed in this paper. Particular attention has been dedicated to the SW architecture and the system communication protocol.

The factory acceptance tests (FAT) were performed in the second semester of the past year by using the entire system without the equatorial mount (equatorial mount will be integrate directly on site). The obtained results are in line with the expectations.

The on-site acceptance tests (OSAT) will be performed on Observatory Site that will be implemented at Monte Mufara in Sicily.

5 REFERENCES

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