The ASTRI-Horn Telescope Control System
Federico Russo – INAF OAS Bologna
for the ASTRI Project
TEchnologies for Telescopes and Instruments control Software
The ASTRI-Horn Cherenkov telescope, installed at Serra La Nave on the Mount Etna (Italy), has been developed by INAF in the context of the "Astrofisica con Specchi a Tecnologia Replicante Italiana" (ASTRI) Project.

INAF proposed a prototype for the Small Size class of Telescopes of the future Cherenkov Telescope Array (CTA), and for the INAF Mini-Array which will be installed at the Observatory of Teide in Tenerife (Spain).

Astri-Horn uses a dual-mirror configuration and a Cherenkov camera having a detector composed of an array of monolithic silicon photomultiplier sensors (SiPM), coupled with a specifically designed front-end and back-end electronics.

The Astri-Horn telescope represents a successful innovative solution for the detection of very high energy gamma-rays with ground-based atmospheric Cherenkov telescopes, as was demonstrated by the detection of the Crab Nebula during the Science Verification phases.
The first point to be addressed for a control software is that of its architecture since it is made up of several subsystems.

That is, it must be able to orchestrate the flow of data between heterogeneous structures and computer programs, allowing them to communicate despite the diversity of protocols or operating systems used.
ASTRI-Horn Telescope Control System

An intuitive description for the TCS...
ASTRI-Horn Telescope Control System

An intuitive description for the TCS...

- **Graphical User Interface used for:**
  - Control and monitoring for
    - PMC (Pointing Monitoring Camera)
    - Telescope Mount
    - Active Mirrors Control
    - DataBase queries
    - …..
An intuitive description for the TCS...

- **Graphical User Interface used for:**
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- **Local Control systems for the management of Hardware devices**
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Alma Common Software (ACS)

- A middleware software infrastructure
- Based on distributed Components
- C++, Java, Python Containers
- Logging services
- Errors and alarms management
- Configuration database
- Lifecycle management
- OPC-UA libraries
ASTRI-Horn Telescope Control System
ASTRI-Horn Telescope Control System

ACTUAL Telescope Control Architecture

- Camera GUI
- Telescope GUI
- Telescope Control System
- Bulk Archive
- Camera Controller
- Camera Server
- OPC-UA
- Telescope Local Control Systems
- ACS Components
- AMC
- TCU
- THCU
- PMC
- UVScope
- Engineering Archive
- ACS Monitoring System
- Conditioning Monitoring
- Safety/Interlocks/Networking/Power
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An intuitive description for the TCS...

- TCU ACS Component
- THCU ACS Component
- AMC ACS Component
- DB ACS Component

ALMA COMMON SOFTWARE
ASTRI-Horn Telescope Control System

ACTUAL Telescope Control Architecture

- Telescope GUI
- Camera GUI
- Bulk Archive
- Camera Controller
- Camera Server
- ACS Components (AMC, TCU, THCU, PMC, UVScope)
- OPC-UA
- Telescope Local Control Systems (Camera, AMC, TCU, THCU, PMC, UVScope, Conditioning Monitoring, Safety/Interlocks/Networking/Power)
- Engineering Archive
- ACS Monitoring System

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The ASTRI-Horn GUI
ASTRI-Horn Telescope Control System

ACTUAL Telescope Control Architecture

Bulletin Archive

Camera GUI

Telescope Control System

Telescope GUI

Camera Controller

AMC

TCU

THCU

PMC

UVScope

Camera Server

OPC-UA

Telescope Local Control Systems

Camera

AMC

TCU

THCU

PMC

UVScope

Conditioning Monitoring

Safety/Interlocks/Networking/Power
The ASTRI-Horn GUI
ASTRI-Horn Telescope Control System

ACTUAL Telescope Control Architecture

Telescope Control System

Camera GUI

Telescope GUI

Bulk Archive

Camera Controller

 ACS Components

AMC TCU THCU PMC UVScope

Camera Server

OPC-UA

Telescope Local Control Systems

Camera AMC TCU THCU PMC UVScope Conditioning Monitoring

Safety/Interlocks/Networking/Power

Engineering Archive

ACS Monitoring System
ASTRI-Horn GUI
The software that implements the local control systems has more stringent requirements regarding performance, reliability and safety.

This software level is where the real handling logic, for the hardware management, resides.

The software have to provide a reliable industry standard for programming numerically controlled systems.
TwinCAT

BECKHOFF TWINCAT

- **TwinCAT** (The Windows Control and Automation Technology) is a platform that meets all the above requirements by transforming a Windows PC into a real-time controller with a multi-PLC system, **NC axis control** PID (Proportional-Integral-Derivative) controls, **programming environment**, operating station and integration of the **Safety system**.

- Performance similar to a real-time controller: to ensure that pointing and tracking meet accuracy requirements. In particular, the interaction between the encoders and the actuators can reach a frequency of the order of milliseconds.
TwinCAT Safety integration

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ASTRI-Horn Telescope Control System

- HOW HIGH LEVEL SOFTWARE INTERACTS WITH LOW LEVEL SOFTWARE?
A trip among the TCS software levels

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A trip among the TCS software levels
A trip among the TCS software levels

- Alma Common Software
- AmcComponent (ACS)
- AMC Opc-Ua Client
- AMC Opc-Ua Server
- Low Level PLC and C++ software
- TELESCOPE Active Mirror
A trip among the TCS software levels

AmcComponent (ACS)

Alma Common Software

AMC Opc-Ua Client

AMC Opc-Ua Server

Low Level PLC and C++ software

TELESCOPE Active Mirror

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A trip among the TCS software levels

Alma Common Software

AmcComponent (ACS)

AMC Opc-Ua Client

ICD

AMC Opc-Ua Server

OPC-UA

Low Level PLC and C++ software

TELESCOPE Active Mirror

HARDWARE

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ASTRI-Code Generator

ICD Document
  • Document already produced: no extra work is needed.

Excel File
  • Document to be produced: it is not a big task and will provide a big time saving for ACS modules development.
  • Please note that exists a tool in the InterfaceGenerator in order to change arrays (not yet supported) in to single variables.

Interface Generator
  • Java Tools and libraries used to create interfaces and other modules for ACS framework.

Interfaces and codes for ACS
  • The files that have been created are ready to be integrated in the ACS modules.
A trip among the TCS software levels

- AMC Opc-Ua Client
- AMC Opc-Ua Server
- Low Level PLC and C++ software
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- AmcComponent (ACS)

BECKHOFF TWINCAT

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A trip among the TCS levels... (Twincat)

- OPC-UA Global Variables!
  that match the ICD variables names
• The commands received trigger the twincat project internal logic that calculates the parameters for required movement.

• The PLC routines apply the calculated positions to the axis module (Numeric Control) and manage their executions by an interpolated mode.

• Error management, running always in background, takes care of all the unexpected behaviour of both hardware and software

• All the monitored data received from the hardware device update the corresponding opc-ua variables in every cycle.
A trip among the TCS levels... (Twincat)
A trip among the TCS levels... (Twincat)

TWINCAT ENGINEERING GUI

TELESCOPE
Active Mirror

Low Level PLC
and C++ software

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A trip among the TCS levels... (Twincat)

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ASTRI-Horn Telescope Control System
Cherenkov Camera:

- Innovative design based on SiPM (Silicon Photo Multiplier) sensors and specifically designed front-end electronics for signal capture
- Fully compliant with the CTA requirements

<table>
<thead>
<tr>
<th>Cherenkov Camera</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera opening Angle</td>
</tr>
<tr>
<td>Sensors</td>
</tr>
<tr>
<td>Number of Pixels</td>
</tr>
<tr>
<td>Pixel size</td>
</tr>
<tr>
<td>Pixel rate</td>
</tr>
<tr>
<td>Dynamical range</td>
</tr>
<tr>
<td>Photon Detection Efficiency</td>
</tr>
<tr>
<td>FoV</td>
</tr>
<tr>
<td>Weight</td>
</tr>
<tr>
<td>Dimensions</td>
</tr>
<tr>
<td>Power consumption</td>
</tr>
</tbody>
</table>
Camera Electronics

- 37 (21) Photo Detection Module (PDM) units containing:
  - SiPM board with 9 embedded temperature sensors
  - Front End Electronics (FEE) board with 2 CITIROC ASIC
  - PDM FPGA Board (*Xilinx Artix 7*)

- Back End Electronics (BEE) unit
  - Custom built solution based on the *Xilinx Zynq-7000* All Programmable SoCs.
  - Dual ARM® Cortex™-A9 Processing System and FPGA Programming Logic.
  - Custom built Linux distribution Debian Wheezy

- PDM Voltage Distribution Box (PDM VDB)
  - Custom built boards (2 mainboards with 19 daughterboards for each) to provide power (Low and Hi Voltages) to the PDMs with real-time control and monitor functionalities

- Set of auxiliary devices like GPS for synchronization, Fiber Pulser and Energy Meter for calibration, Motor Lid and Thermal controllers (provided by several vendors)
All the devices and systems are interconnected by the BEE, which is the main elaboration unit of the camera, managing all its functions:

- Receive commands from the camera control client
- Control and monitor the auxiliary devices
- Manage and acquire data from the PDMs
- Prepare and send packets to the Camera Data Acquisition Server

**Diagram:**

- **ASTRI Camera**
  - PDM
    - SiPM Board
    - CITIROC Board
      - ASIC 1
      - ASIC 2
    - FPGA Board
  - PDM Voltage Distribution Box
  - Back End Electronics
    - Processing System
    - Programmable Logic

- **Auxiliary Devices**
  - GPS
  - Thermal Controllers
  - Motor Lids Controllers
  - Fiber Optic Calibration System
    - 4CH LED Driver
    - LED Pulser Controller
    - Energy Meter

- **Instrument Control System**
  - Camera Control Client
  - Slow Control

- **Camera Server**
  - Camera DAQ Server
  - Data Product
Camera Logical View

ASTRI CAMERA CONTROL SOFTWARE

SERVER COMPONENT
Deployed on board (inside the BEE)
Directly manage all the hardware

CLIENT COMPONENT
Deployed on the control client in the control room
Manage the interaction with the user

Communication stack managed by the industrial standard protocol OPC-UA

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Camera Architecture

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Camera Architecture

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Camera Architecture

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• Every high level commands (GET, SET, CMD) must be accessible from the Engineering GUI
• Lots of controls and information for expert users, but must be user friendly
• One single Main GUI with information and commands frequently useful
Camera Eng. GUI (Devices Configuration)
Camera Engineering GUI (HK Viewer)

A dedicated window shows in real-time all the HK information in different graph types.
Camera Eng. GUI (Variance Viewer)

Integrated real-time viewer of Variance data (that measures the fluctuation of the signal acquired by the SiPM)

Allow us to evaluate:
- Effective Pointing of the telescope
- Presence of clouds
- Mirror alignment
- Electronics Health Status

Example animations (15 fps) created using three different pointing:

a) Orion’s Belt  
b) Capella (bg suppression)  
c) Fixed point at Az, El (bg suppression)
Detection of the Crab Nebula!

We started the engineering test at the astronomical site of Serra La Nave (Mount Etna) in Sicily...

...spending cold nights around bugs and lots of hard work, pizza and beer

25 and 26 May 2017: the ASTRI camera recorded its first ever Cherenkov light...

So... it works!
ASTRI-Horn

...Questions?