MORFEO
Real Time Computer

Italo Foppiani on behalf of the whole team
MORFEO

M12

NGS MODULE

M11 FLIP MIRROR

M10

Correcting plate ENTRANCE WINDOW

DEFORMABLE MIRRORS (M9, M10)

Dichroic

M7

LGS MODULE

MICADO
Control Requirements

- 6 LGS probes
- 1100×1100 px images
- 68×68 sub-apertures
- 500 fps

- 3 NGS probes with 2 cameras each
- Low Order WFS:
  - 256×256 px images
  - 2x2 sub-apertures
  - up to 1000 fps

- Telescope M4 DM:
  - 2.4m flat
  - 5300 actuators

- Reference WFS:
  - 240×240 px images
  - 10x10 sub-apertures
  - 0.1 -100 fps

- Post focal DMs:
  - 0.9m diameter convex spherical
  - 1000 actuators
  - Post focal DMs:
    - 1.2m diameter concave spherical
    - 1150 actuators
High level control scheme: HRTC

\[ e^j = PR \cdot s^j + \left( PR \cdot ID \sum_{i=0}^{m} p^i c^{j-i} - \sum_{i=0}^{m} p^i c^{j-i} \right) \]

- \( s \) measured slope
- \( e \) error term DM space
- \( PR = P \# R \) Projector \# Reconstructor (8k \times 42k coeff.)
- \( ID \) DM interaction matrix
- \( c \) DM shape
- \( p \) weighting coefficients

Computational complexities:
- 672 MFLOP for \( PR \cdot s^j \)
- 128 MFLOP for \( PR \cdot ID \sum_{i=0}^{l-1} a^i c^{j-(d+i)} \)
High level control scheme: SRTC

- **PR update**

\[ R = C A^T \begin{pmatrix} A & C & A^T + C N \end{pmatrix}^{-1} \]

\[ A = IP \cdot ML^{GS} \]

\[ P = \begin{bmatrix} \sum_{i=1}^{N_{Opt}} \left( \sum_{j=1}^{N_{Opt}} \left( MD_{opt}^i \right)^T MD_{opt}^j \right) \\
\sum_{i=1}^{N_{Opt}} \left( \sum_{j=1}^{N_{Opt}} \left( ML_{opt}^i \right)^T ML_{opt}^j \right) 
\end{bmatrix} \]

- Computational complexity: ~700 TFLOP
- Minimum updating period: 6 min

- 40 data tasks at least
- telemetry storage

\( IP \) pupil interaction matrix
\( C \) Atm Turbulence covariance
\( CN \) WFS noise covariance
\( ML^{GS} \) Atm layers projections along GS
\( MD_{opt} \) DM projections along optimization
# Telemetry Requirements

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• **Herzberg Extensible Adaptive optics Real-time Toolkit** (HEART) has been shown in the previous presentations (by Malcom, Jennifer, Ed) about CPU based systems:
  • Key features:
    • modular structure of generalized control code and utilities easily configurable
    • distributed architecture (internal UPD/IP real-time communication)
    • CPU-based architecture for off-the-shelf hardware
    • Implemented in C for Linux with real-time patch

• MORFEO RTC feasibility/preliminary study based on HEART was carried out during phase B.

• **NRC Herzberg Astronomy and Astrophysics institute** is joining the MORFEO consortium as responsible of final design and build of the HRTC
MORFEO HRTC based on HEART

One server for each

6 High Order Processing servers

WFS

HOP Servers

LGS WFS Processing
High Order Reconstruction

LGS/HO gradients (x6)

High Order NGS WFS Processing
High Order Truth Reconstruction

REF/HOT gradients (x3)

Low Order NGS WFS Processing
Low Order Reconstruction

LO gradients (x3)

Combination & Temporal Filtering

DM error vector
DM shape

Closed Loop Wavefront Correction

- processes NGS WFS data
- combines DM and NGS commands vector

Wavefront Corrector Controller

WCC Server
MORFEO HRTC based on HEART

6 High Order Processing servers

Each HOP server:
- receives data stream from una camera
- processes data stream to get pixels (possibly unpacking)
- calibrates and arranges pixels to get images
- computes slopes
- computes a slice of the MVM to get DMs commands from slopes using coefficients stored into CPUs cores cache
HRTC Timing

**Requirements**

- Max Comp. time 2400 µs
- Max Latency 700 µs

**HEART estimated comp. time**

- 2150 µs
Soft-RTC subsystem main functionalities

• interface towards the Instrument Control System for supervisory and monitoring purposes

• coordinates the RTC in response to commands (setup AO modes, open/close loops, ...)

• carries out AO related co-processing (such as loops optimisations, calibrations, measurements, data recording, ...)
The Morfeo SRTC follows the ELT RTC reference architecture and is based on the ESO RTC Toolkit.

Its main components are:
- Supervisor node
- Telemetry Gateway
- Computing nodes: to perform the required co-processing requirements
  - Number cruncher
  - Pixel processor
  - Storage node
  - Atmospheric parameters estimation
MORFEO SRTC Co-processing

Main computational functionalities

- Control matrices updates (PR)
- Mis-registration
- Pixel maps (sub-ap. weights, dark, background, …)
- Atmospheric parameters estimation
- Telemetry and metadata recording

SRTC Nodes

- Number cruncher
- Pixel processor
- Auxiliar node
- Storage node
Total of about 40 datatasks distributed among 4 computing nodes optimized for computing power or connectivity or storage.

The telemetry gateway will be deployed in a ESO standard IT server in accordance with architecture requirements and preliminary benchmarks.
Number cruncher node

- High performance node w/GPU
- Computes:
  - PR updates
  - DMs mis-registrations

Computation requirements
- PR update for LGS (the most demanding one) requires ~700TFLOP.
- Benchmarks show that a CPU system needs several minutes for this computation.
- A GPU offload foreseen for these (mostly algebraic) computations to increase timing margins.
Pixel processor node

- High performance CPU node
- Computes Pixel based computations (e.g. background map optimization, dark map optimization, threshold map optimization, slope offset optimization, ...)
- Computations I/O bound

### Computation requirements

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<tr>
<th></th>
<th>#streams</th>
<th>#pixels</th>
<th>(max.) framerate [Hz]</th>
<th>(min.) sub-sampling</th>
<th>operations per pixel (estimate)</th>
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Resulting total computational power is ~3.8 GFlops