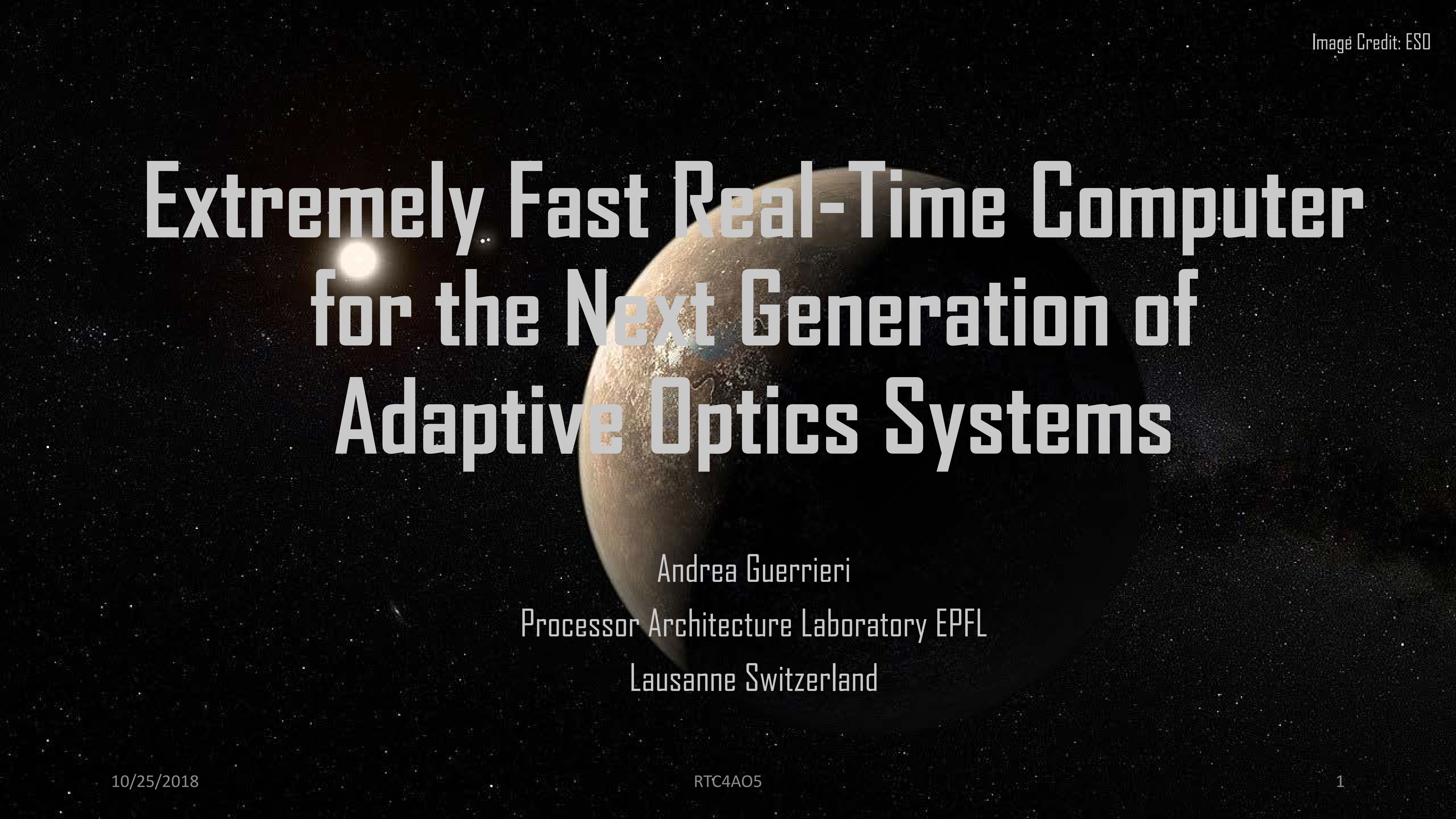

Image Credit: ESO

Extremely Fast Real-Time Computer for the Next Generation of Adaptive Optics Systems

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Introduction

In 2016, a rocky exoplanet has been discovered in the habitable zone of Proxima Centauri, the closest star from our solar system. This may represents our best current opportunity to search for life outside the Solar System.

The Observatory of Geneva has started a feasibility study for an instrument that would allow direct detection of Proxima Centauri b in visible reflected light, and characterization of its atmosphere [1].

The Exoplanet Proxima Centauri B
Image credit:ESO

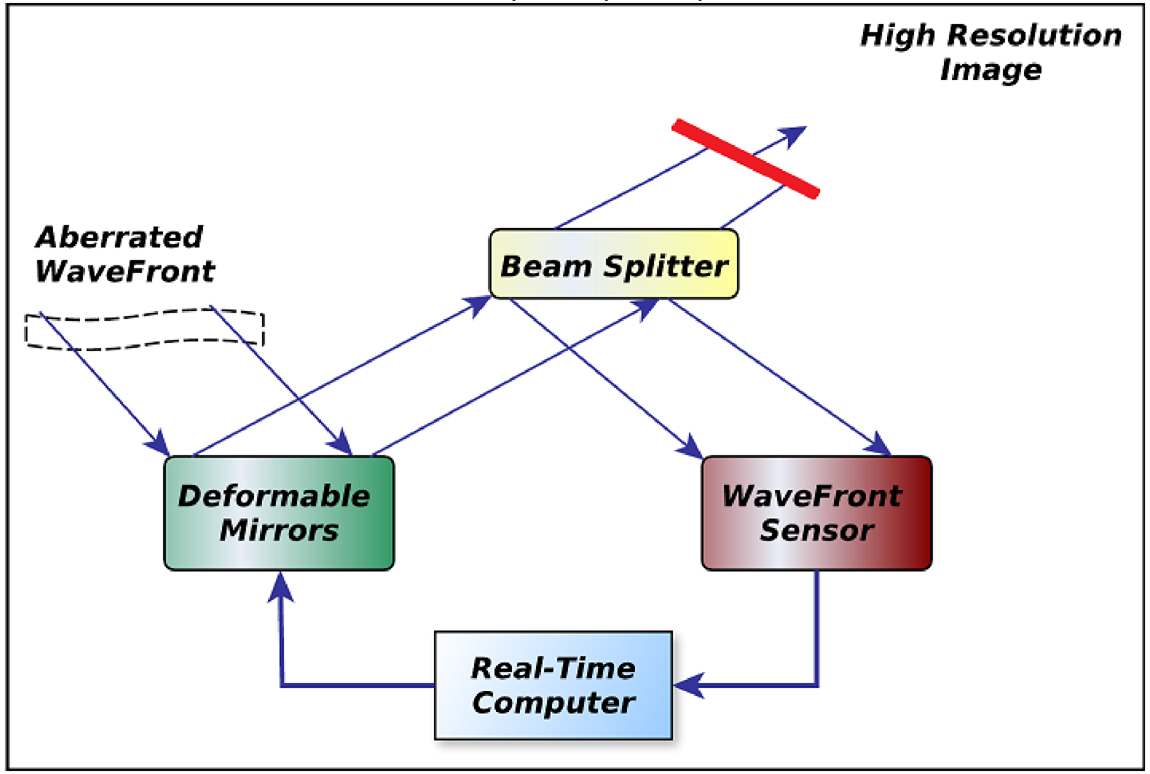
This instrument includes a powerful **Adaptive Optics (AO)** system capable to run at **4KHz** in closed loop.

[1] "Atmospheric characterization of Proxima b by coupling the Sphere high-contrast imager to the Espresso spectrograph", Lovis et al. 2016, url: https://arxiv.org/abs/1609.03082.

Adaptive Optics System

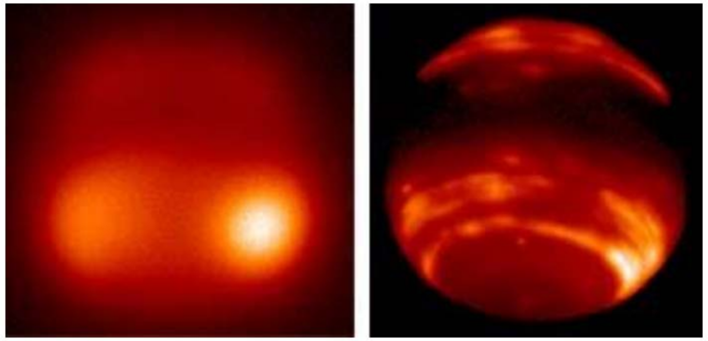
The Adaptive Optics System corrects the blurring of the image due to the presence of the turbulent atmosphere

Adaptive Optics System



Adaptive Optics Components

- WaveFront Sensor (WFS)
- Deformable Mirror (DM)
- Real-Time Computer (RTC)



The planet Neptune seen from the ground without Adaptive Optics (Left) and with Adaptive optics (Right)

Target System Specification

WaveFront Sensor (WFS)

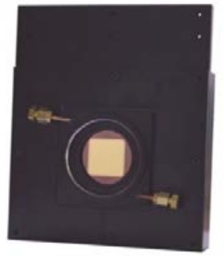
- Pyramid WFS with OCAM2K camera
- 1'500 fps of 240x240 / 3'000 fps of 120x120 (14 bit depth)
- CameraLink interface

OCAM2K Camera

Image Credit: Axiomoptics

Deformable Mirrors (DM)

- Boston Micromachines MEMS
- Up to 4K actuators



4K-DM

Image Credit: Boston Micromachines

Real-Time Computer (RTC)

- WFS acquisition rate: **250μs**
- Computation latency: **< 50μs**

Control Algorithm

The control algorithm is based on the concept of modes. These modes are the result of spatial decomposition of the shape of the wavefront into a set of functions orthogonal in the space of the pupil.

Stage 1 *Preprocessing*

Extract the slopes

$$s_1(x,y,k) = \frac{p_A(x,y) + p_B(x,y) - p_C(x,y) - p_D(x,y)}{\sum_{A,B,C,D} p(x,y)}$$

$$s_2(x,y,k) = \frac{p_D(x,y) + p_B(x,y) - p_C(x,y) - p_A(x,y)}{\sum_{A,B,C,D} p(x,y)}$$

$$s(k) = \begin{bmatrix} \bar{s}_1(k,..) \\ \bar{s}_2(k,..) \end{bmatrix}$$

Stage 2 *Modal Decomposition*

Compute the amplitude of the modes from the WFS signal

$$\bar{r}(k) = D_+ \bar{s}(k)$$

$$D_+ \text{ of size } [n,m] \text{ with } m < 400$$

Stage 3 *Optimal Controls*

IIR (Infinite Impulse Response Filter) using 36 coefficient for the first 5 modes

$$c_{1..5}(k+1) = a_{0,1..5} r_{1..5}(k) + a_{1,1..5} r_{1..5}(k-1) + ... + a_{18,1..5} r_{1..5}(k-18)$$

$$-b_{0,1..5} r_{1..5}(k) - b_{1,1..5} r_{1..5}(k-1) - ... - b_{18,1..5} r_{1..5}(k-18)$$

for the other modes

$$c_{6..m}(k_1) = a_{0,6..m} r_{6..m}(k)$$

Stage 4 *Actuators Command*

Mapping the command to the mirror

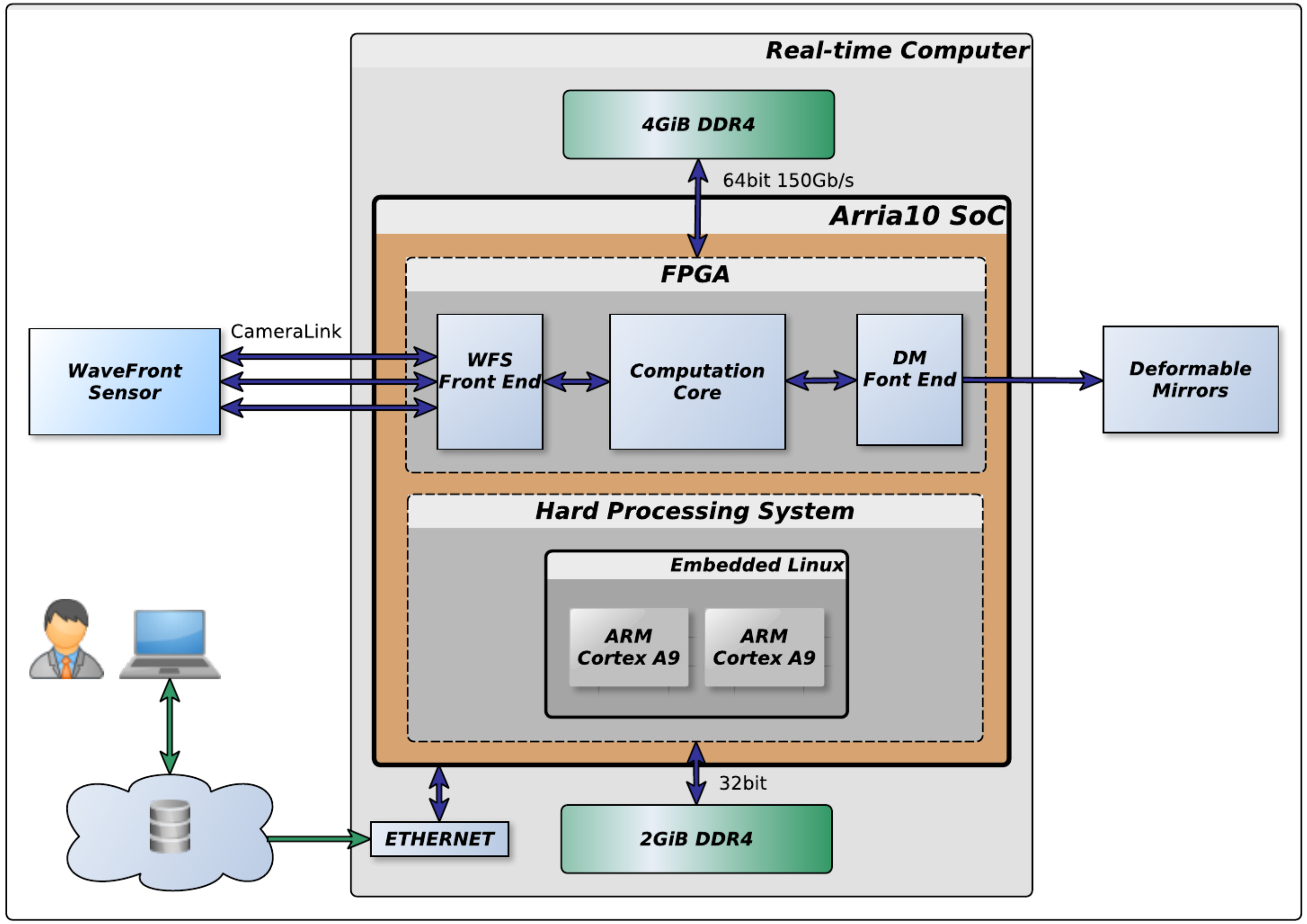
$$\bar{c}^*(k+1) = M\bar{c}(k+1)$$

Real-Time Computer

Architecture

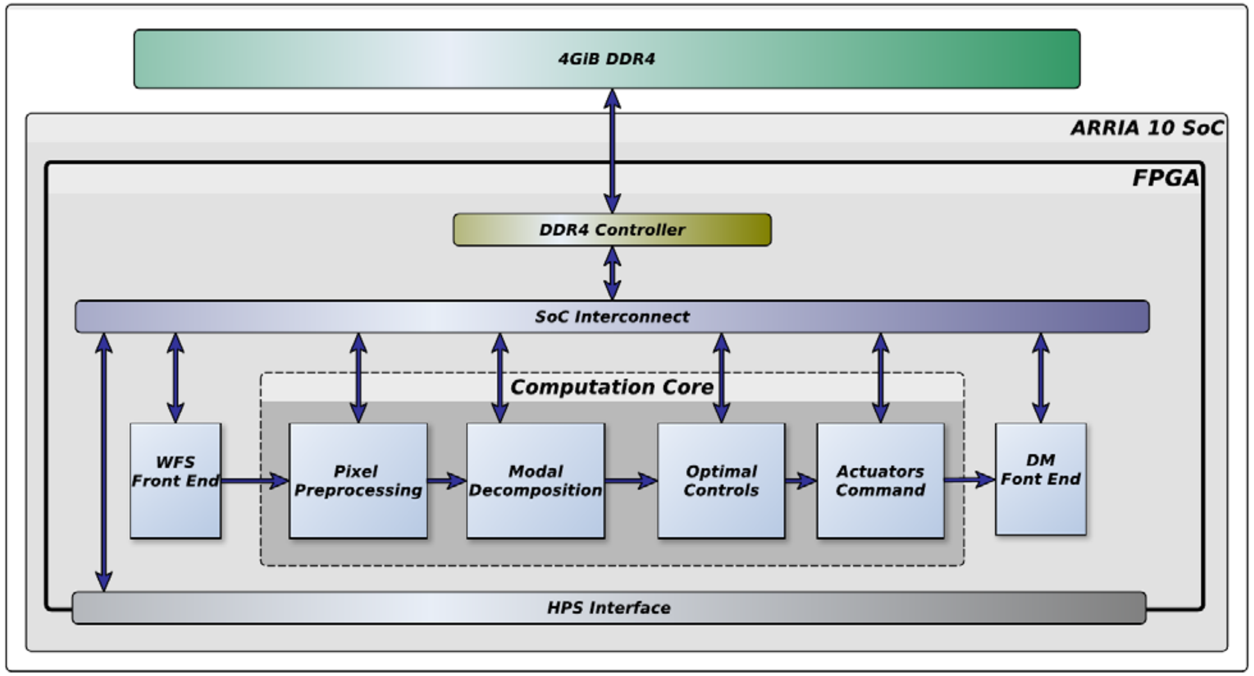
- Intel Arria10 SX660
- 20nm SoC: HPS+FPGA 250MHz
- Hard floating point DSP blocks
- 4GiB DDR4 64bit 1.2GHz FPGA
- 2GiB DDR4 32bit 1.2GHz HPS
- Dual ARM Cortex-A9 MPCore 1.5GHz
- Embedded Linux

Block Diagram



Real-Time Computer

Hardware Pipeline

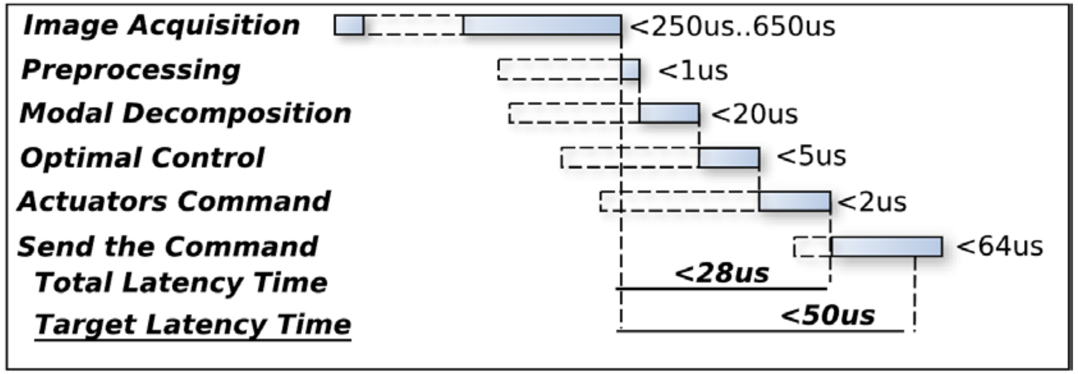


Estimated Resource Utilization

Hardware Unit	*DSP blocks*
Preprocessing	13
Modal Decomposition	800*
Optimal Control	56
Actuators Command	800*

- 250MHz FPGA op. freq. (up to 450MHz)
- Use of resource sharing techniques*
- High speed memory interface 150Gb/s

Processing Pipeline



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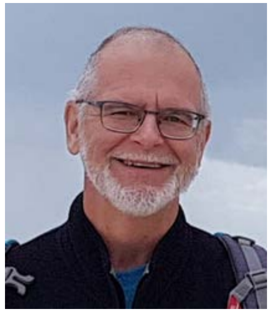

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Interested to the project?

Don't hesitate to get in touch with us!

Thank you for your attention