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

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PlanetS

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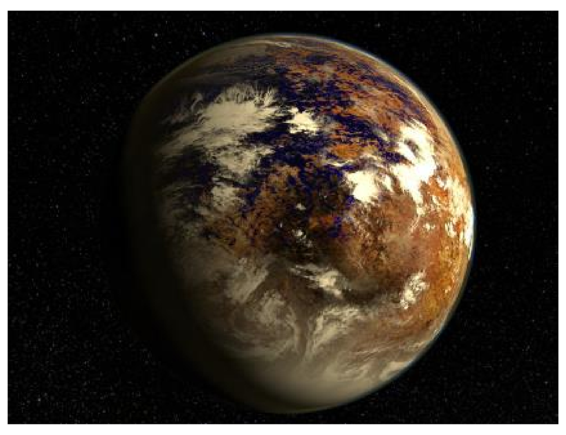
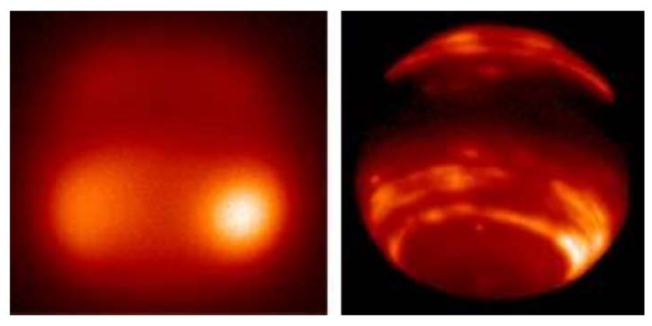
Introduction

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 Exoplanet Proxima Centauri B
Image credit:ESO

The Observatory of Geneva has started a feasibility study for an instrument that would allow direct detection of Proxima Cen b in visible reflected light, and characterization of its atmosphere, by spatially resolving the planet to feed a high-resolution spectrograph. This instrument includes a powerful Adaptive Optics (AO) system to provide wavefront correction at visible wavelengths, capable to run at 4KHz in closed loop.

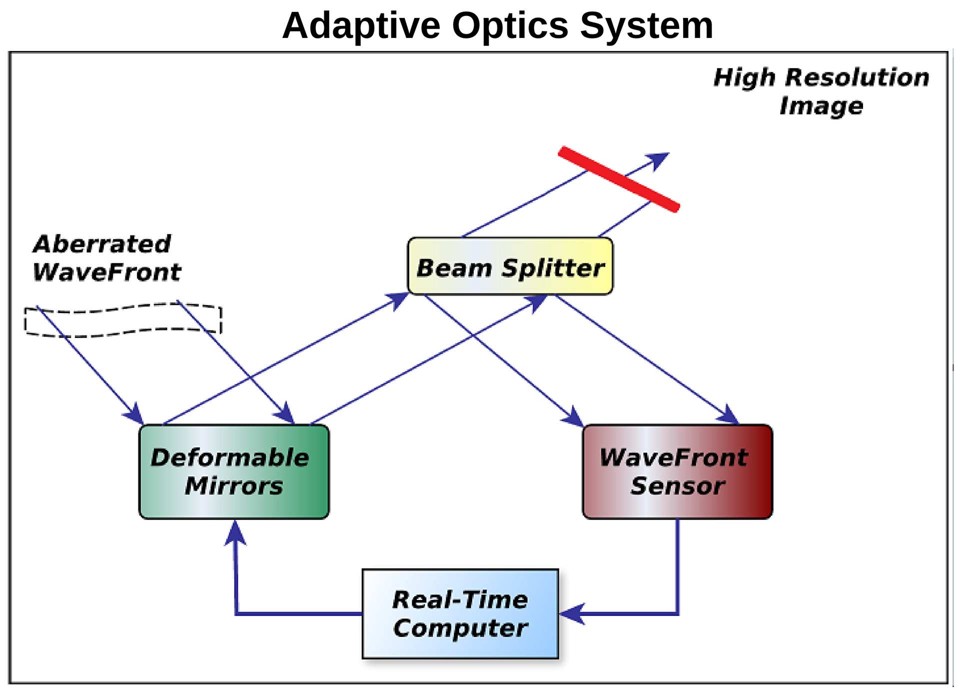


The planet Neptune seen from the ground without Adaptive Optics (Left) and with Adaptive optics (Right)

Adaptive Optics System Overview

The Adaptive Optics System is what corrects the blurring of the image due to the presence of the turbulent atmosphere between the light sources in the sky and the telescope on the ground.

Adaptive Optics System



AO Components

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

Target System Specifications

WaveFront Sensor

- OCAM2K Camera
- 240x240@1500fps or 120x120@3700fps 14bit depth
- CameraLink Interface

Deformable Mirrors

- Boston Machine MEMS
- 500-4000 actuators

Real-Time Computer

- Up to 4KHz in closed loop
- Acquire images from WFS
- Compute the control algorithm in < 50μs
- Send the command vector to DM

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.

Preprocessing

Extract the slopes

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

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

$$s(k) = \begin{bmatrix} \bar{s_1}(k,..) \\ \bar{s_2}(k,..) \end{bmatrix}$$

Modal Decomposition

Compute the amplitude of the modes from the WFS signal

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

Optimal Controls

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

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

While for the other modes

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

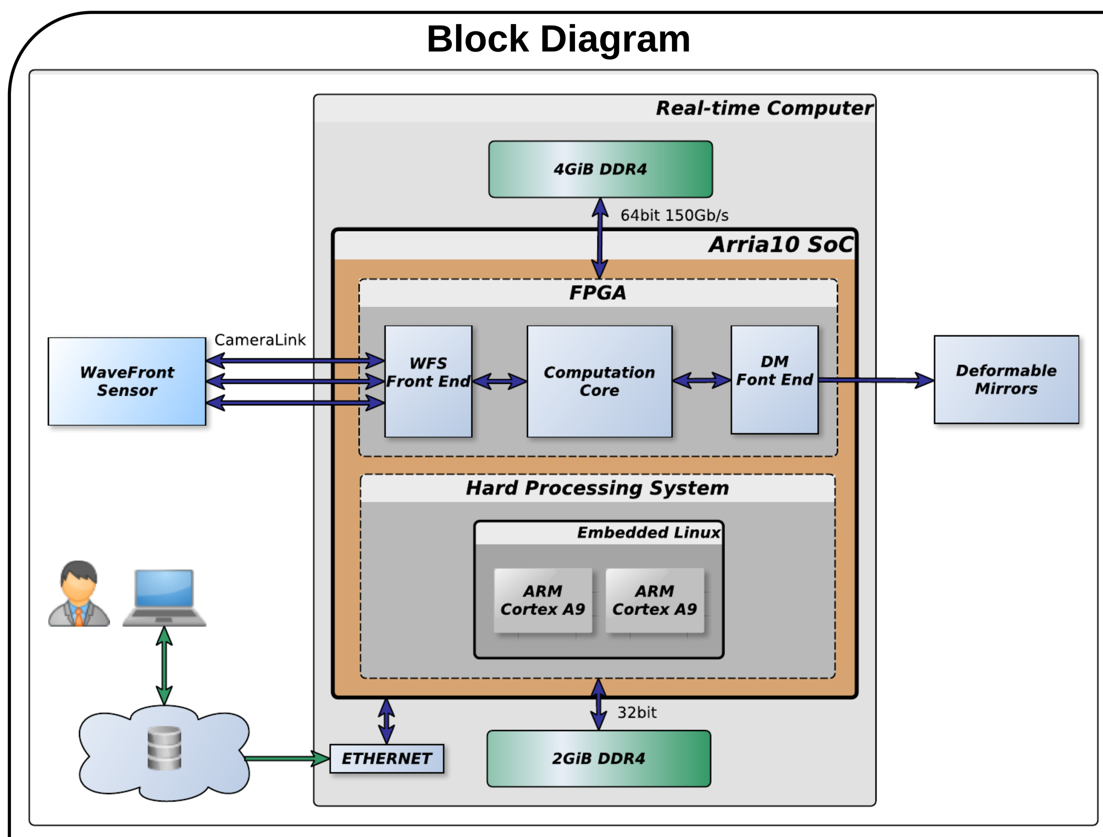
Actuators Command

Mapping the command to the mirror

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

Real-Time Computer

Block Diagram



Architecture

- Intel Arria10 SX660
- 20nm SoC: HPS+FPGA@250MHz
- Hard floating point DSP blocks (1600)
- 4GiB DDR4 64bit @1.2GHz FPGA
- 2GiB DDR4 32bit @1.2GHz HPS
- Dual ARM Cortex-A9 MPCore @1.5GHz
- Embedded Linux

Functions

- Acquire the images from the WFS
- Pre-process the raw images
- Compute the wave front shape
- Compute the correction
- Send the command vector to the DM
- Control the system through Web Interface

Required Performance

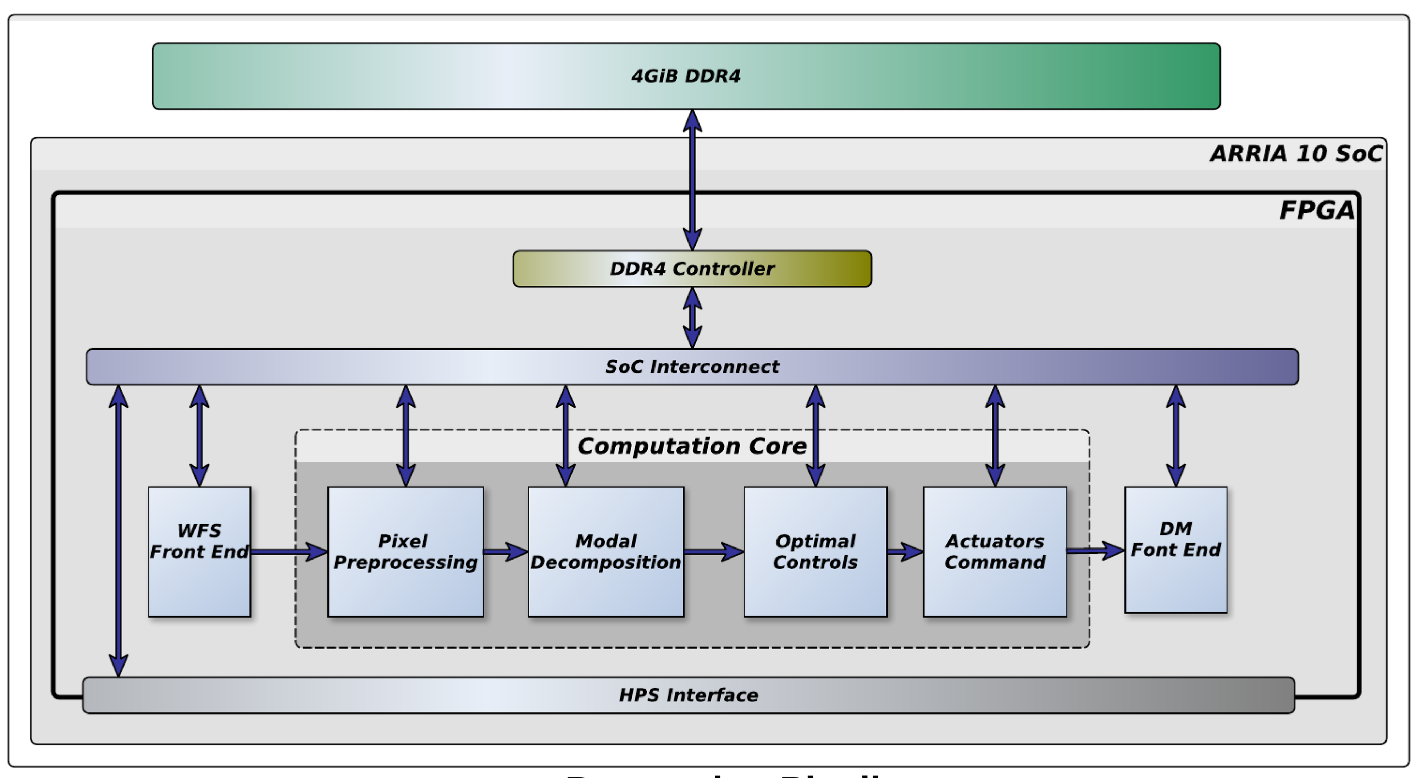
- WFS Bandwidth < 1.4 Gb/s
- DM Bandwidth < 2.5 Gb/s

Estimated Resource Utilization

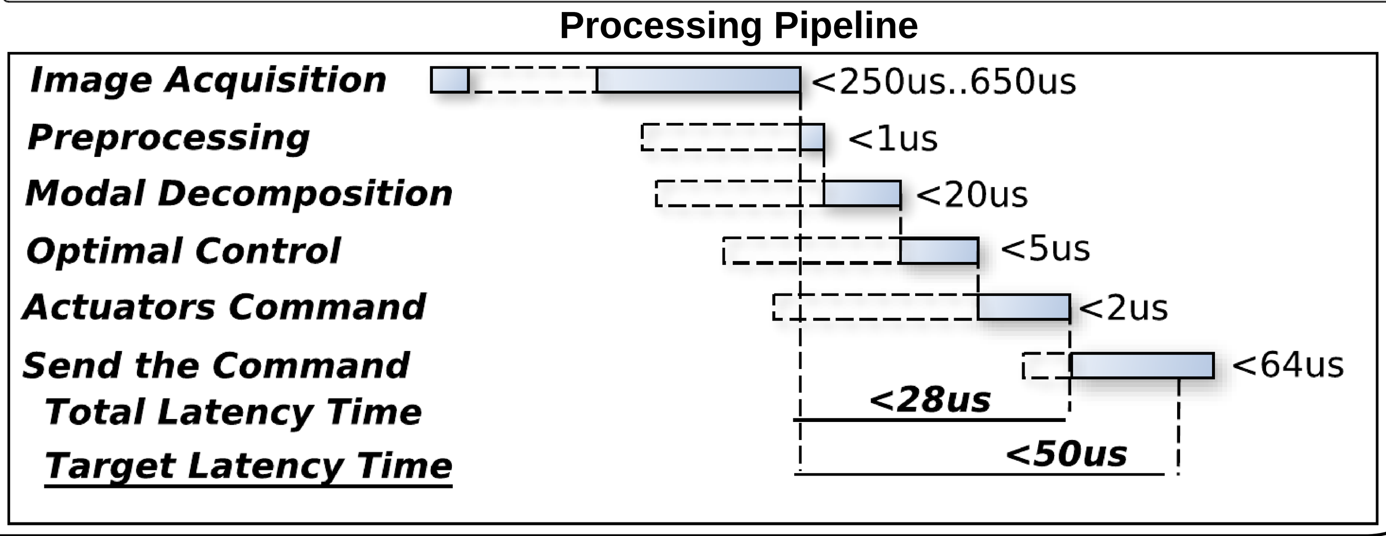
Hardware Unit	*DSP blocks*	*%*
Preprocessing	13	1
Modal Decomposition	800*	50
Optimal Control	56	3
Actuators Command	800*	0

***Shared resources**

Hardware Pipeline



Processing Pipeline



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