The Key Laboratory on Adaptive Optics,

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A Clustered Architecture of Real-Time Controller for 2.5-Meter Solar Telescope (WeHoST) GLAO System

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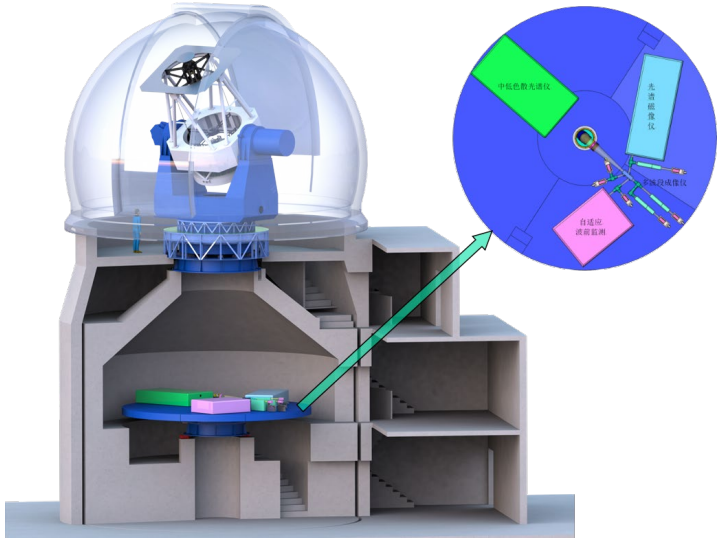
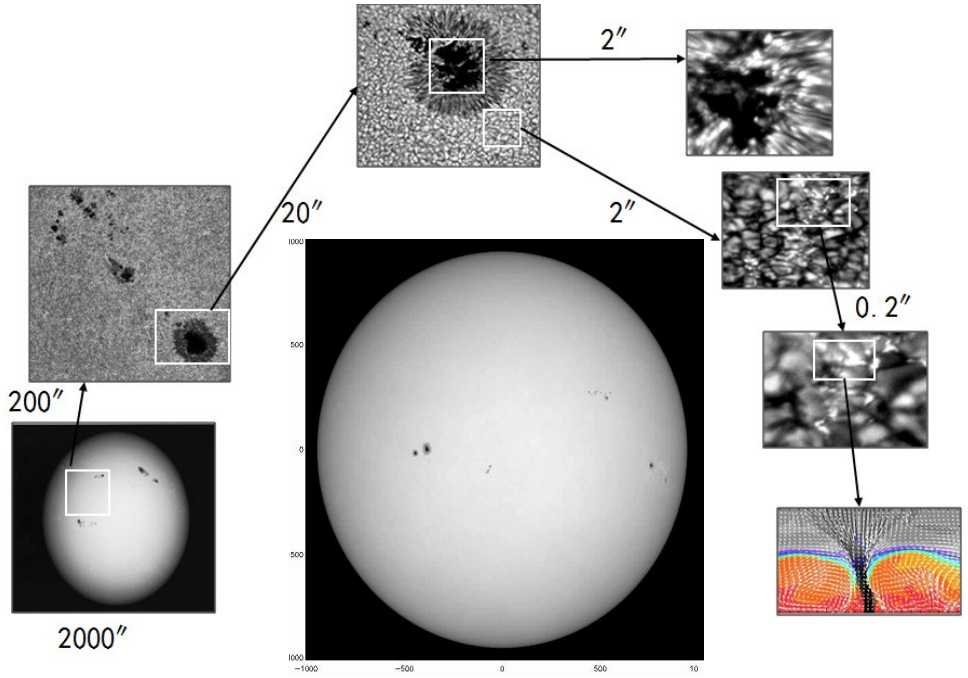
Outline

- The adaptive optics system of 2.5-meter solar telescope (WeHoST)
- The challenges involved in the real-time control of this AO system
- The clustered architecture of the RTC
- Optimization of single node in the clustered architecture
- Current performance
- Future

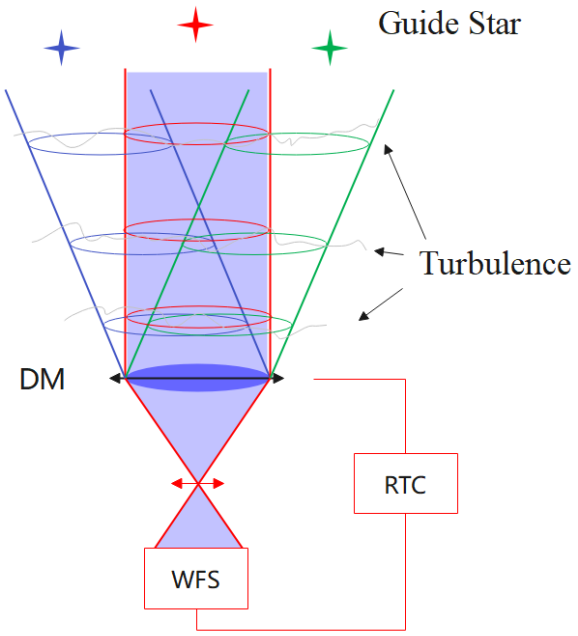
2.5-Meter Solar Telescope(WeHoST)

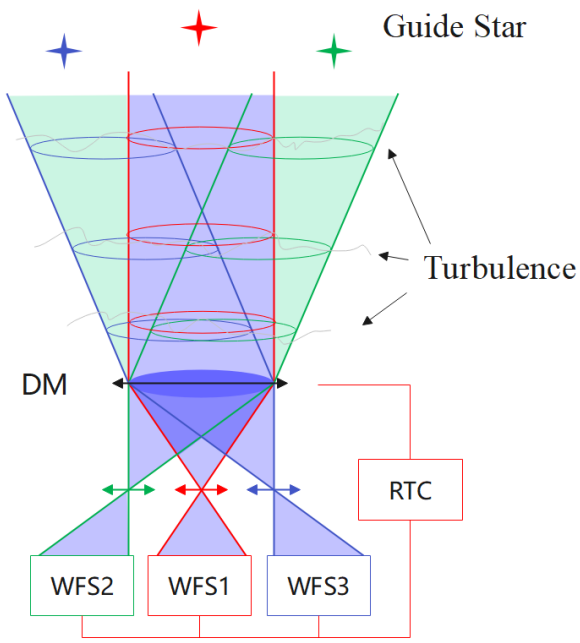




- The largest axisymmetric solar telescope in the world
- Scientific Requirements: large FoV and high resolution

AO System for WeHoST



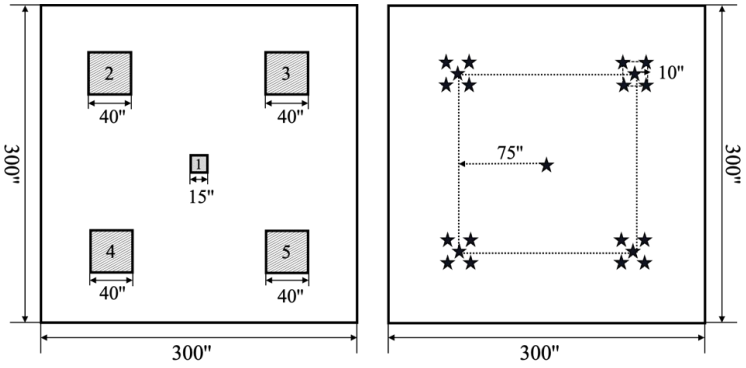


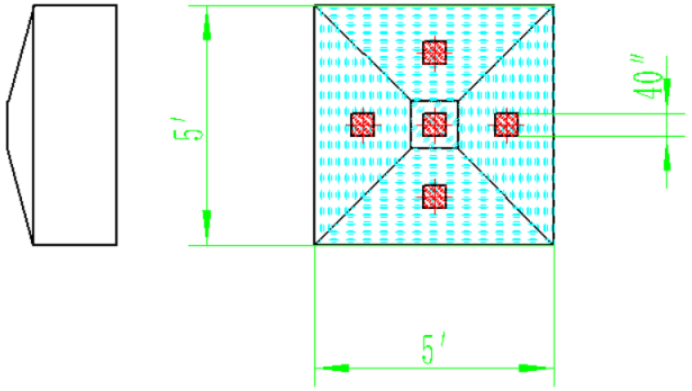
Work Mode	Correction Object	Function	Number of Deformable Mirror	Number of WFS	Typical FoV
CAO	Turbulence in one direction	Approach diffraction limit in a small FoV	1	1 small FoV WFS	10”
GLAO	Ground layer turbulence	Enhanced resolution in a large FoV	1	1 large FoV WFS or mutiple small FoV WFSs	2~10’

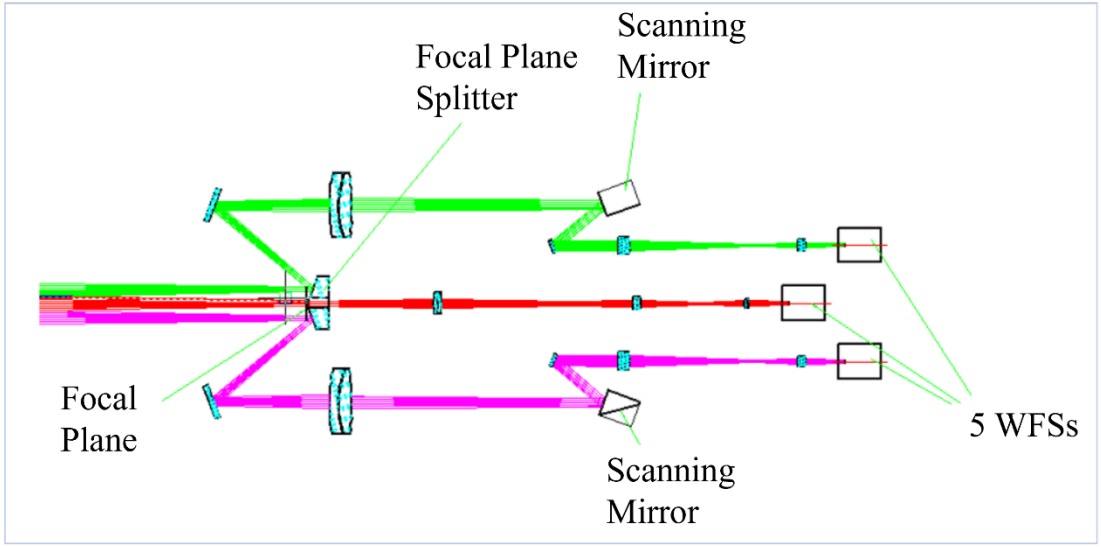
AO System for WeHoST

The Combined Wavefront Sensor System

- Number of WFS: 5, with 1 center high-order small FoV WFS and 4 off-axis low-order large FoV WFSs
- FoV of Single WFS: 15’’ / 36’’
- Maximum Detection FoV: 5’

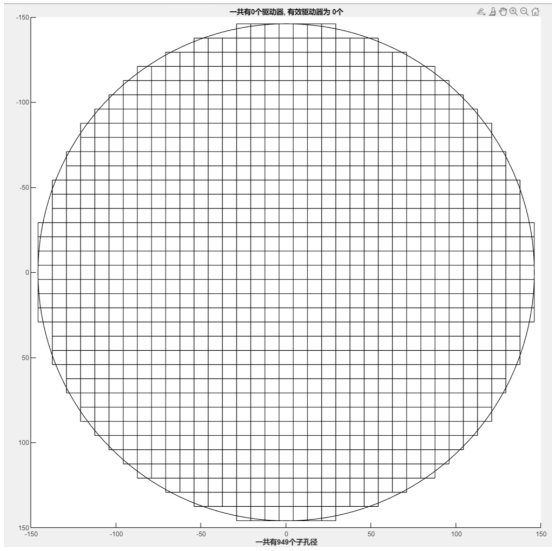


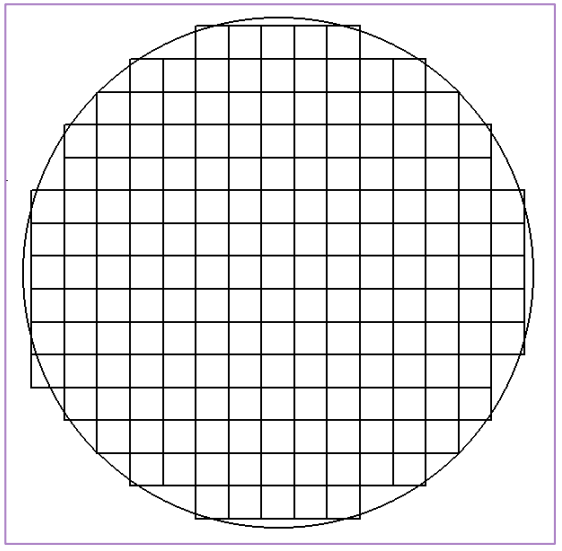




AO System for WeHoST

Parameters	High-order, small FoV WFS	Low-order, large FoV WFS
Type	Correlation Shack-Hartmann	Muti-View Correlation Shark-Hartmann (5 Views)
Numbers of Subapertures across the Pupil	35（973total）	15（177total * 5）
Frame of Rate	≥2000Hz	≥1500Hz
FoV per WFS	15 arcsec	36 arcsec
Pixels Scale	1 arcsec/pixel	0.6 arcsec/pixel
Target Size	864 * 840 pixels	900 * 900 pixels
Camera Model	Mitrokron EoSens 3CXP	

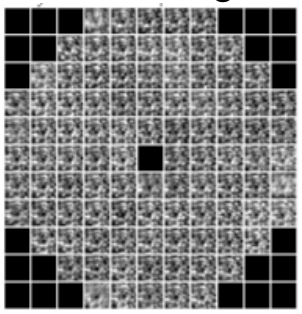


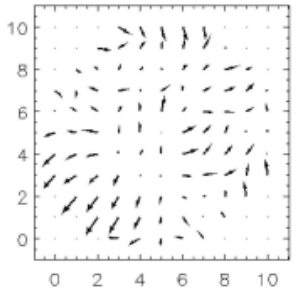


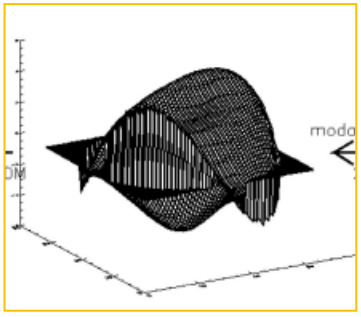
The Challenge of Solar AO RTC

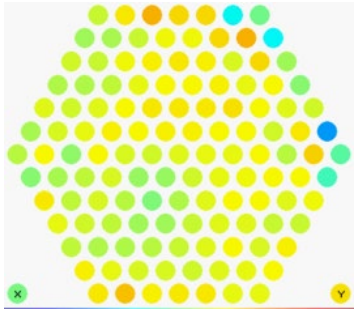
- Higher frame rate due to the worse atmosphere seeing in day times
- Synchronized detection with 5 WFS cameras
- Correlation algorithm instead of centroid algorithm is required for slope calculation and is one of the most computationally demanding operations

Image Acquisition and Processing → Slope Calculation → Wavefront Reconstruction → Actuator Commands





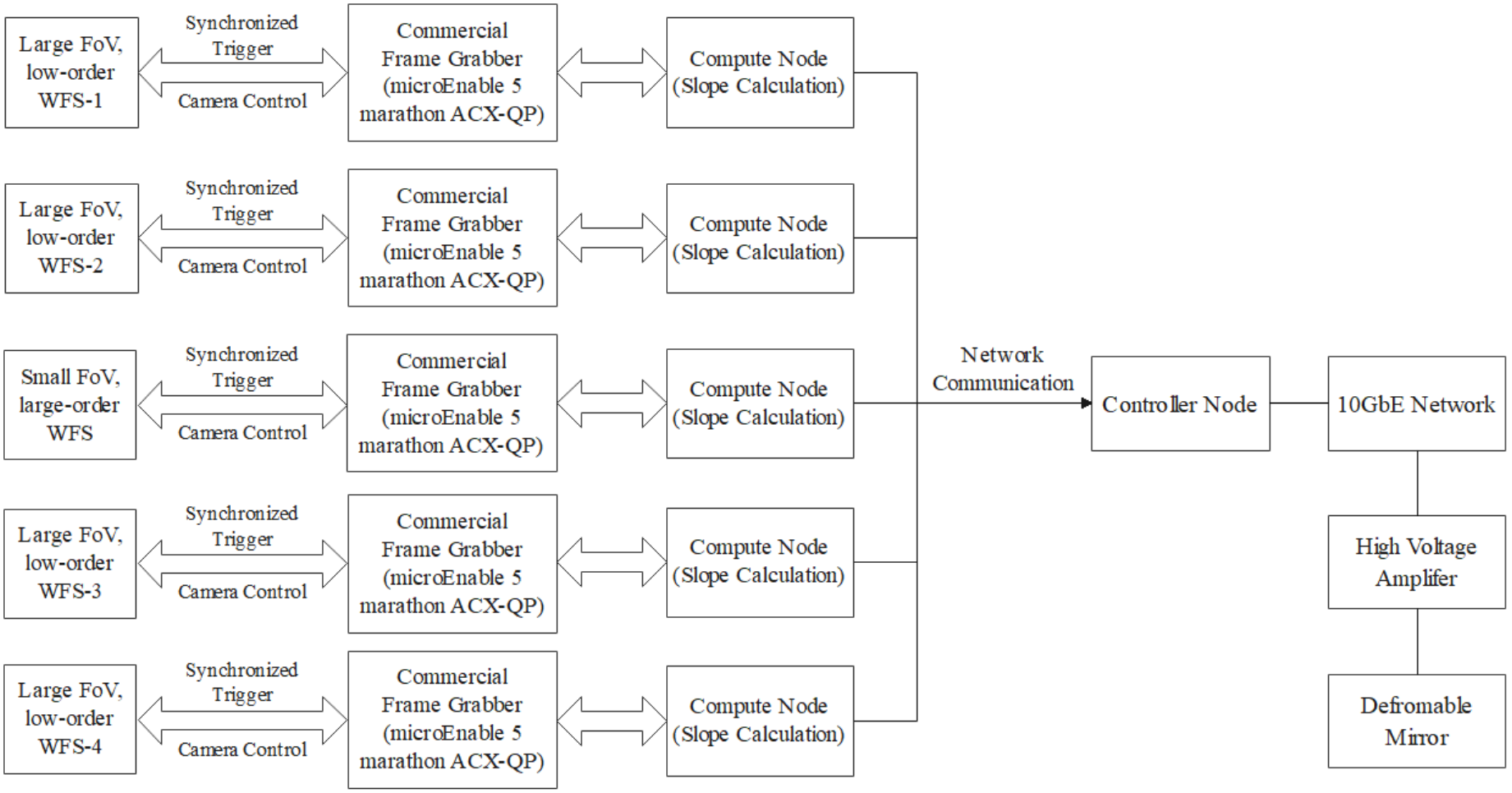




The Challenge of Solar AO

Requirements of GLAO System		Correlation Algorithm	Centroid Algorithm
Slope calculation time for one sub-aperture with a 3 GHz CPU cores		10us	1us
Total number of sub-aperture		973 + 177 * 5 * 4 = 4513	
300 us latency	Number of sub-apertures to be processed per thread	30	300
	Number of CPU cores	150	15

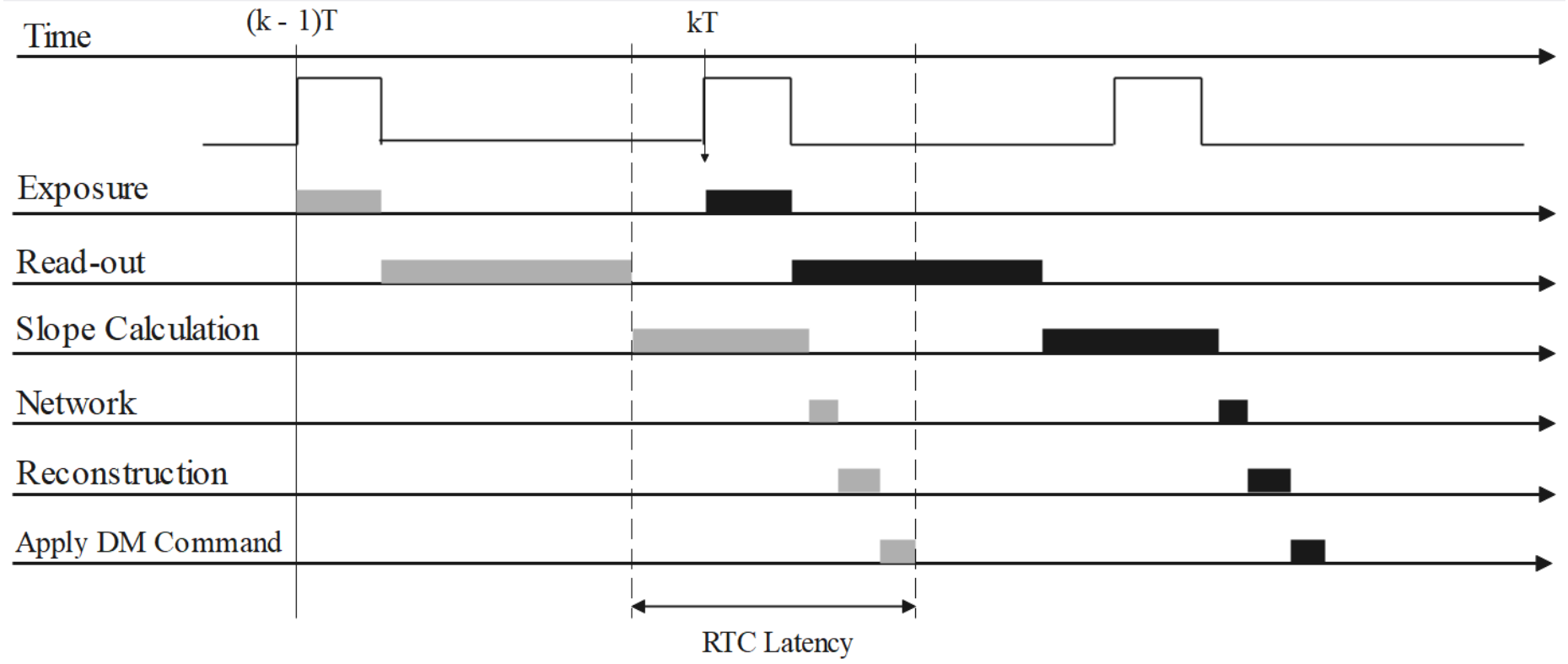
The Clustered Architecture of RTC



Optimization of Single Node

- Main optimizations of single node for muti-core CPU
  - Set up the Xenomai kernel, BIOS and OS for low-latency and low jitter performance
  - Use Intel Integrated Performance Primitives (IPP) library
  - Set the MTU size of network packets to optimize network communication between nodes

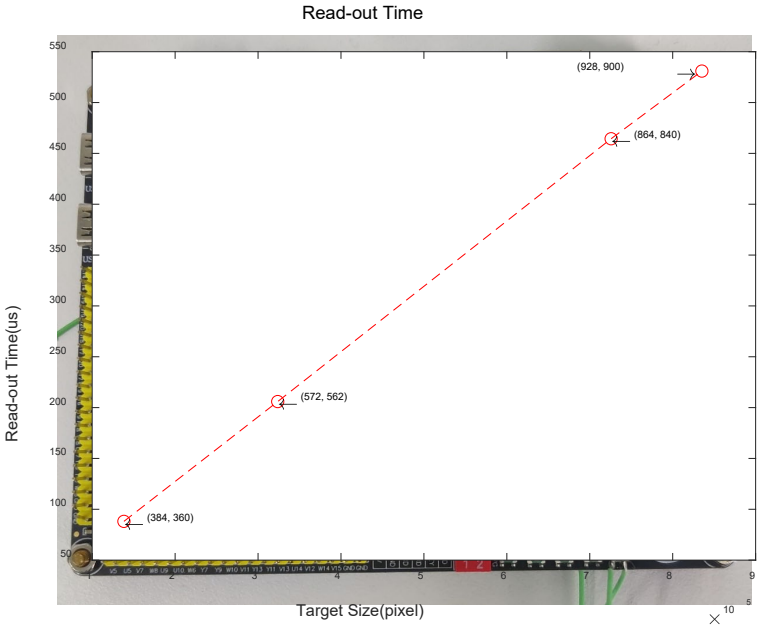
Current Performance | RTC Latency



$$\tau = Exposure\ Time + Readout\ Time + RTC\ Latency + DA\ Hold\ Time$$

CPU : Intel Xeno Gold 6248R(24 cores @3.0 GHz) * 2

Current Performance | Readout Time

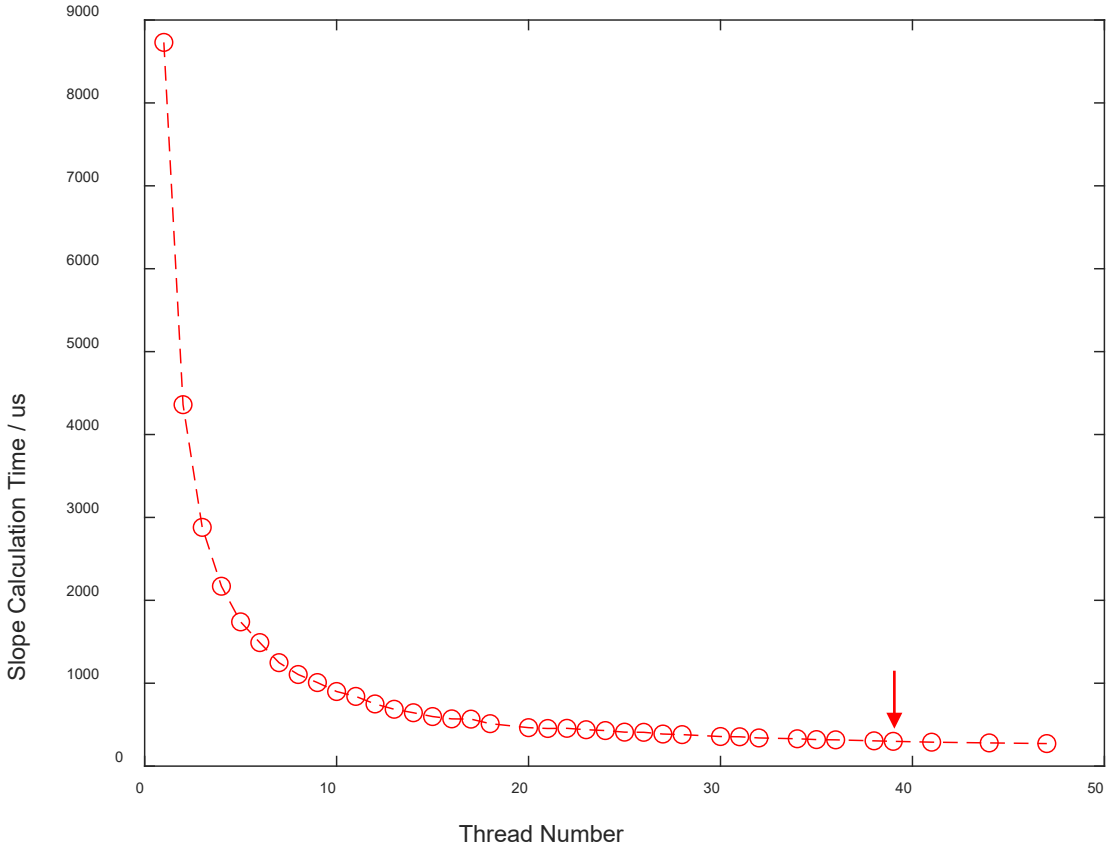


Target Size	Read-out Time(us)
384*360 pixels	88.12
576*562 pixels	205.94
864*840 pixels	464.41
928*900 pixels	530.94

- Timing starts on the falling edge of camera exposure signal
- Timing stops when it receives the network package from RTC

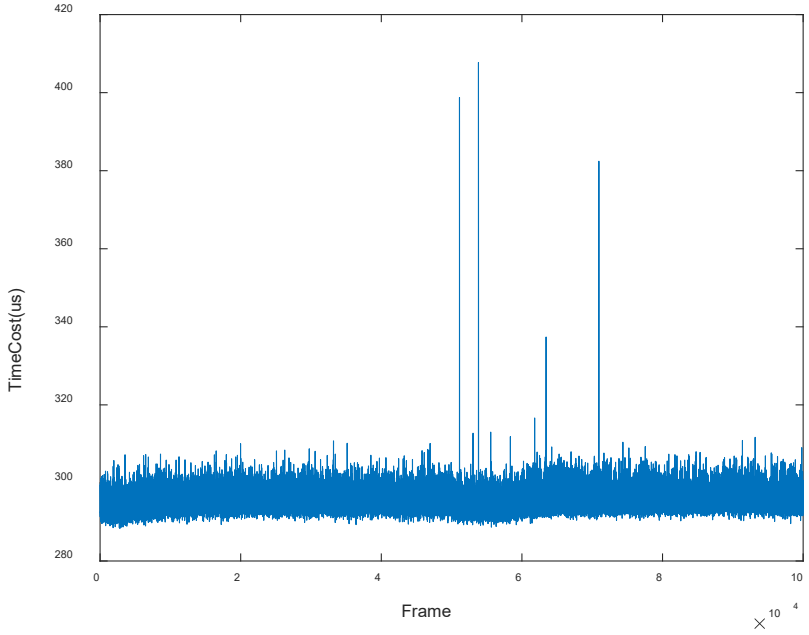
Current Performance | Slope Calculation

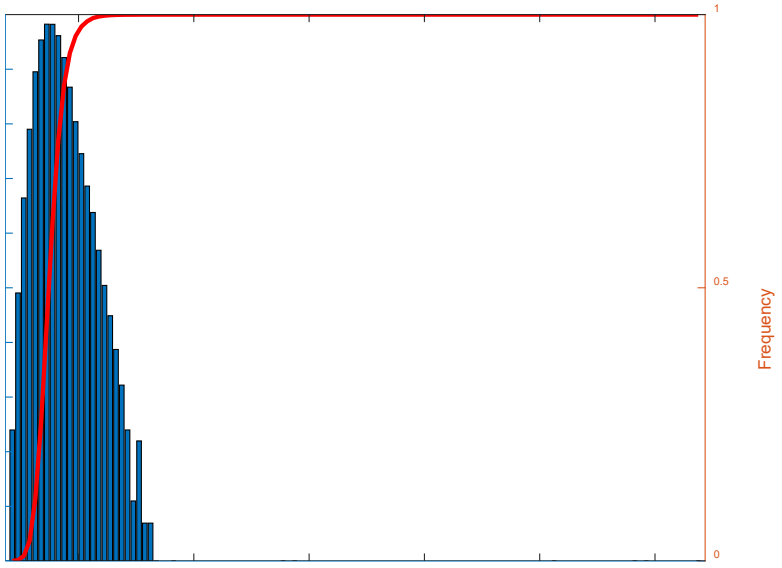
Slope Calculation Time for Small FoV, high-order WFS



Current Performance | Slope Calculation

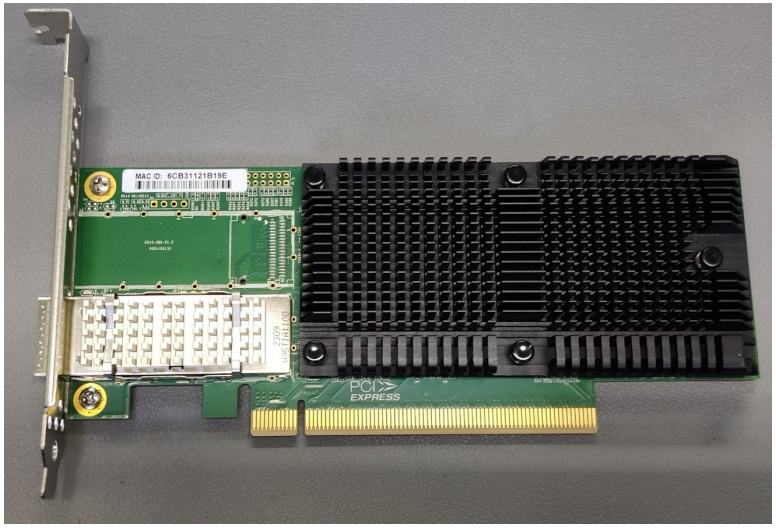
Slope Calculation Time for Small FoV, high-order WFS



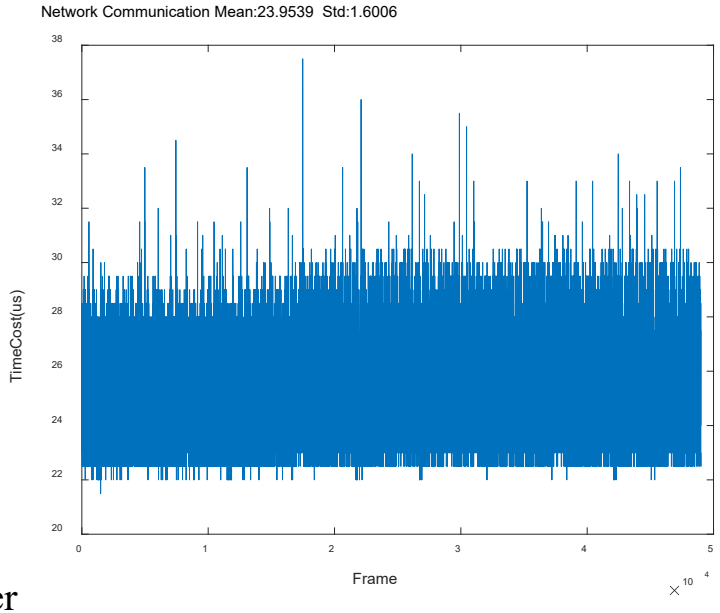


- Mean Slope Calculation Time: 295 ± 2.5 us (2.5 us rms jitter)

Current Performance | Network Communication

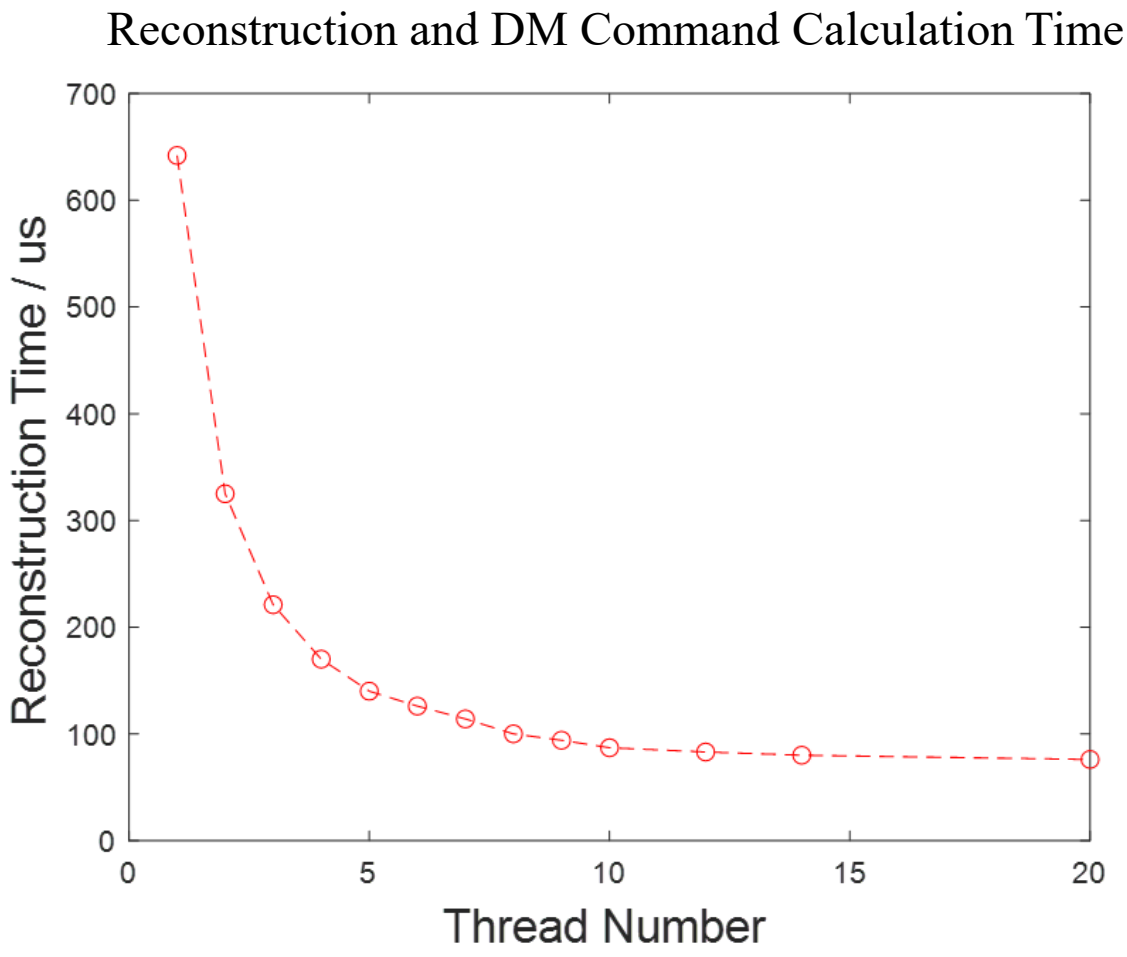


LP-Link PCIe x16 100G Single-Port Server Adapter



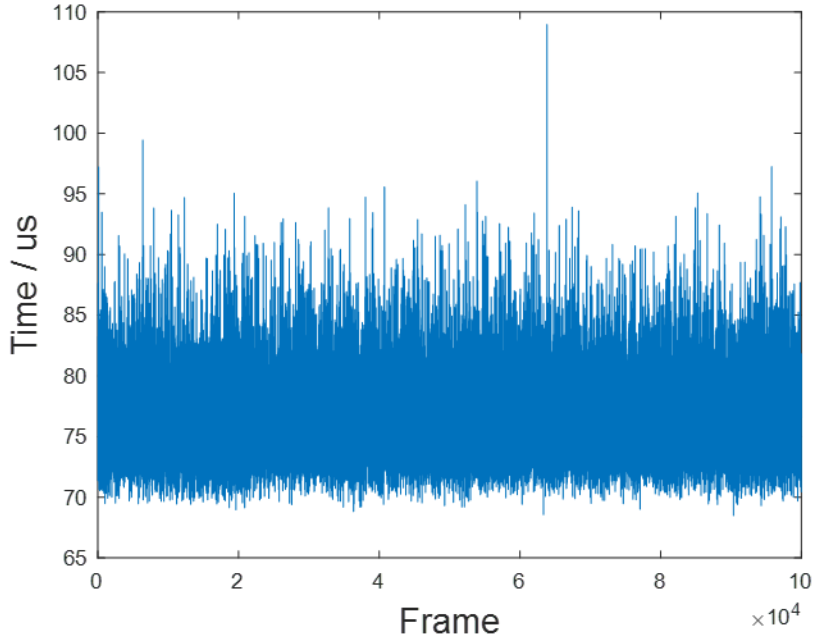
- Echo Time to send packets with 2000 floating point data(8000 bytes)
- The Maximum Transmission Unit (MTU) is set to 9000 bytes

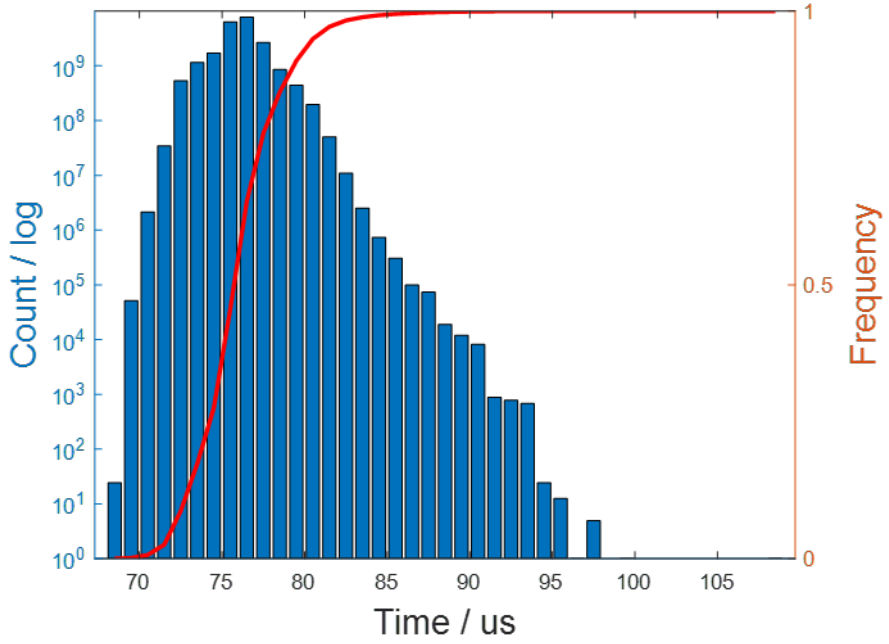
Current Performance | Reconstruction



Current Performance | Reconstruction

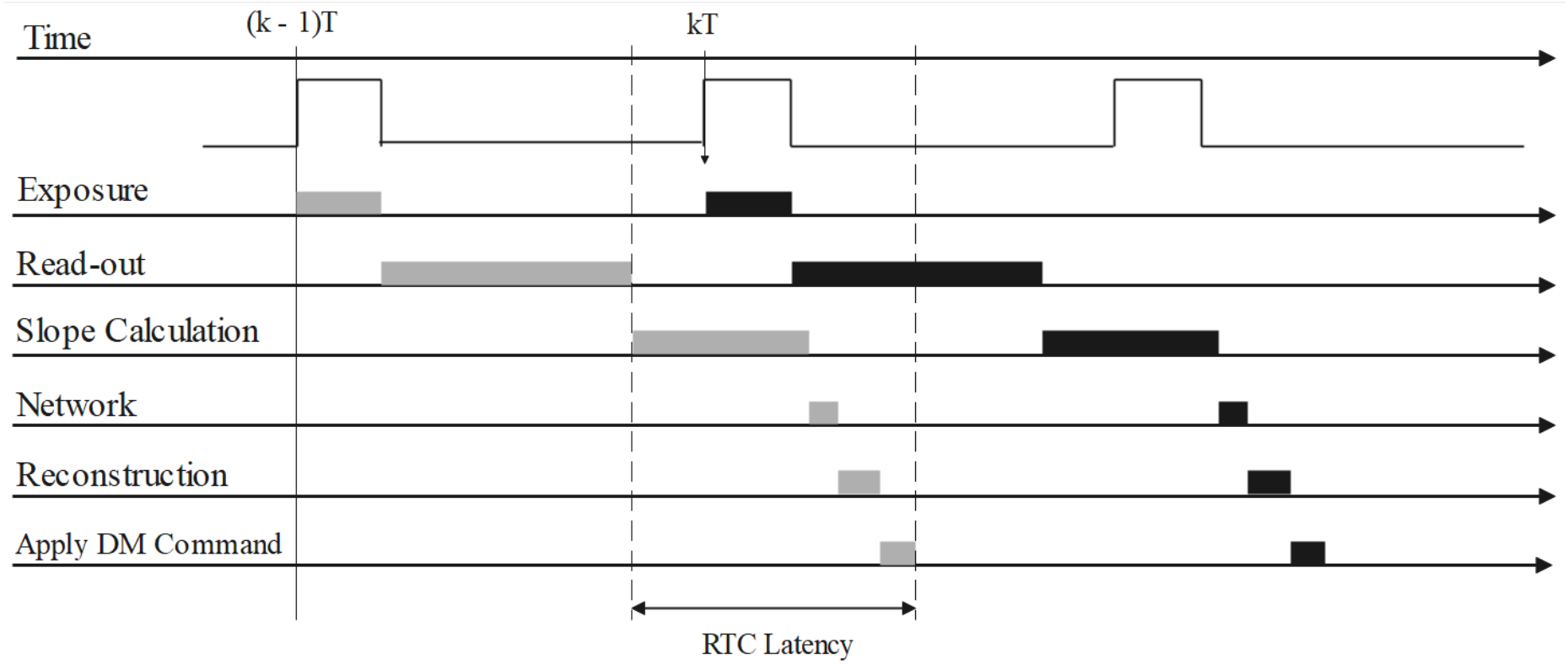
Reconstruction and DM Command Calculation Time





- Mean Time: 76 ± 2.6 us (2.6 us rms jitter)

Current Performance | RTC Latency



$$\tau = Exposure\ Time + Readout\ Time + RTC\ Latency + DA\ Hold\ Time$$

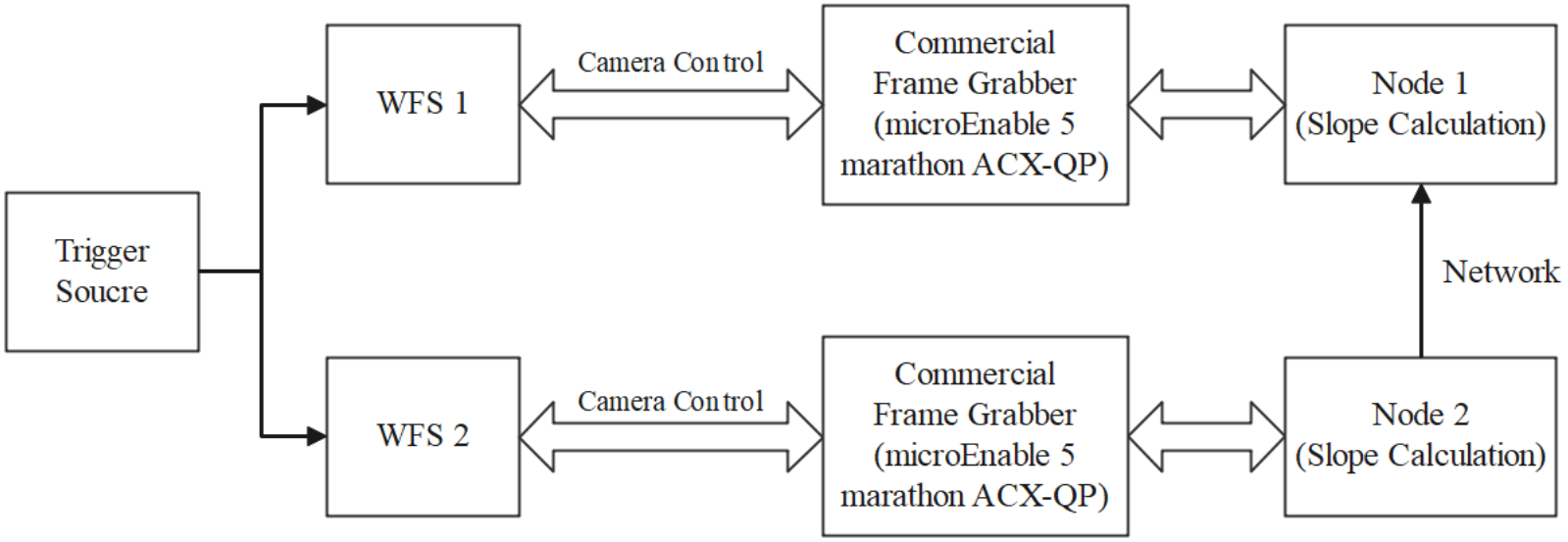
464.4 us

$$Slope\ Calculation + Network\ Communication + Reconstruction + Apply\ DM\ Command$$

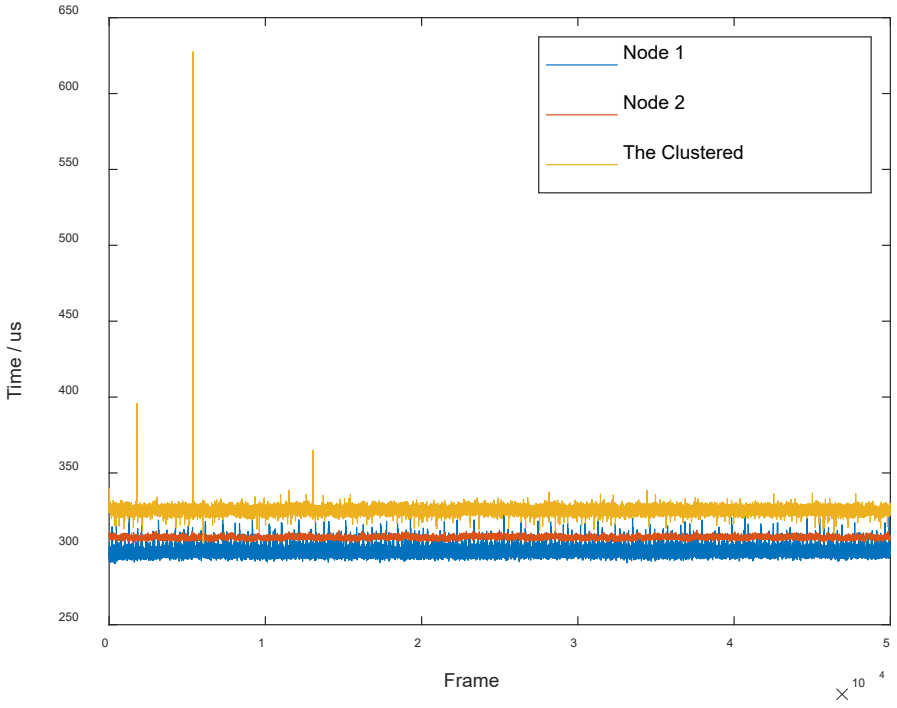
295 us 30 us 76 us 20 us

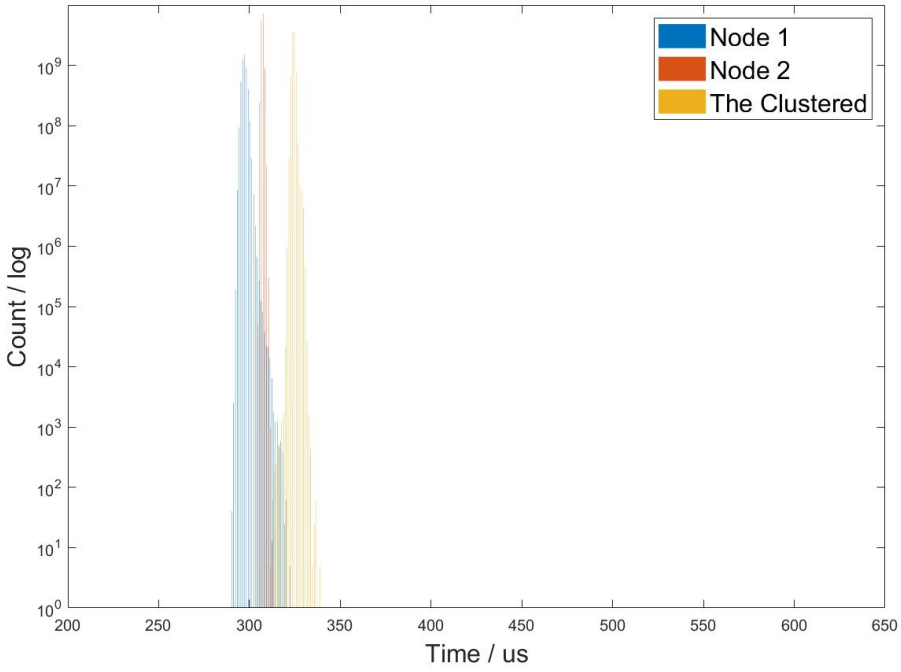
$$RTC\ Latency: 421us$$

Current Performance | Clustered



Current Performance | Clustered





- Mean Time: Node 1: 298 ± 2.7us (2.7us RMS jitter)
  Node 2: 307 ± 0.9us (0.9us RMS jitter)
  The Clustered: 325 ± 2.2us (2.2us RMS jitter)

Conclusions

- Readout time of the commercial frame grabber is measured
- Full RTC latency is ~421us, and each part of the RTC latency is measured
- RMS jitter is ~10 us, but sometimes there might be a large jitter for one frame
- Initial test of the clustered architecture is conducted with two servers and the results could meet the system requirements

Future

- Development Progress

	2022.06-2022.09	2022.09-2023.01	2023.02-2023.08	2023.09-2023.11	2023.12-2024.09	2024.10-2025.09
Plan Formulation						
Hardware Selection						
Single Node Optimization						
Hardware Purchase						
Indoor platform test						
Telescope platform test						

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Thanks for listening

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