Prototype of Image Acquisition and Storage System for SHINE

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Outline

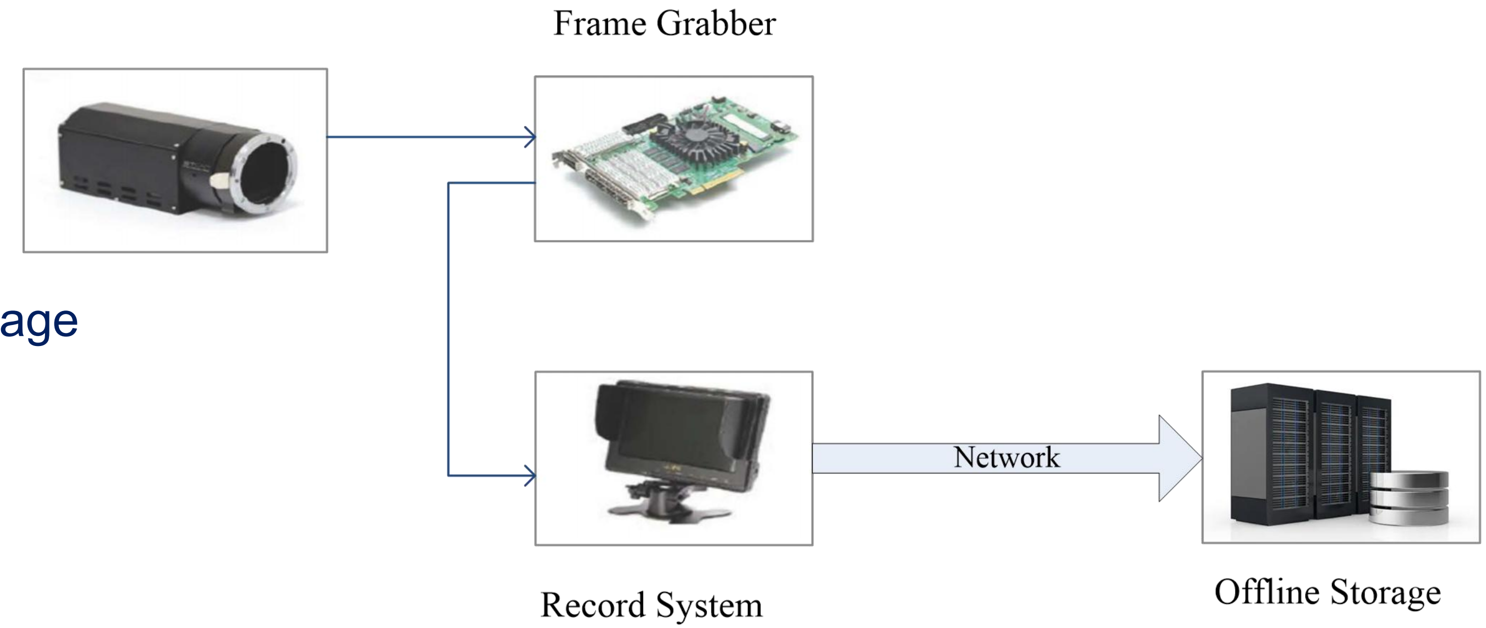
- Motivation
- Image Acquisition and Storage System Architecture
  - Image Acquisition
  - Image Transmission
  - Image Storage
  - Image Retrieval
  - Online display
- Testing
- Summary

Motivation(1)

- SHINE is a quasi-continuous wave hard X-ray free electron laser facility
- A myriad of image data generated by the beam monitor system, the optical diagnostics system, the laser system, etc.
- High-speed frames of image data (1000MB/sec) to be acquired and stored for analysis

Commercial camera storage:

- <1min ,local record system
- transferring the images to offline storage
- take the next acquisition



Motivation(2)

- Most of the high-speed image acquisition systems are built for beamlines, e.g. LCLS, European XFEL, SNS
- A dedicated system with DAQ readout, traffic, cache, online analysis, offline storage, high-speed network, etc.
- Our goal is to build a general image system which is less expensive, using regular commercial hardware.

- A prototype system with Camera Link cameras
- ZeroMQ protocol for transferring
- HDF5+MongoDB for data storage

Image Acquisition and Storage System Architecture

- Image Acquisition
  - Camera Link interface choosed
  - CCD × 2
- Image Transmission
  - Fiber extender, single mode fiber cables, no distance limited
  - ZeroMQ protocol
  - 10 Gb/s network
- Image Storage
  - receive data frame by frame
  - unpack data package, then storing

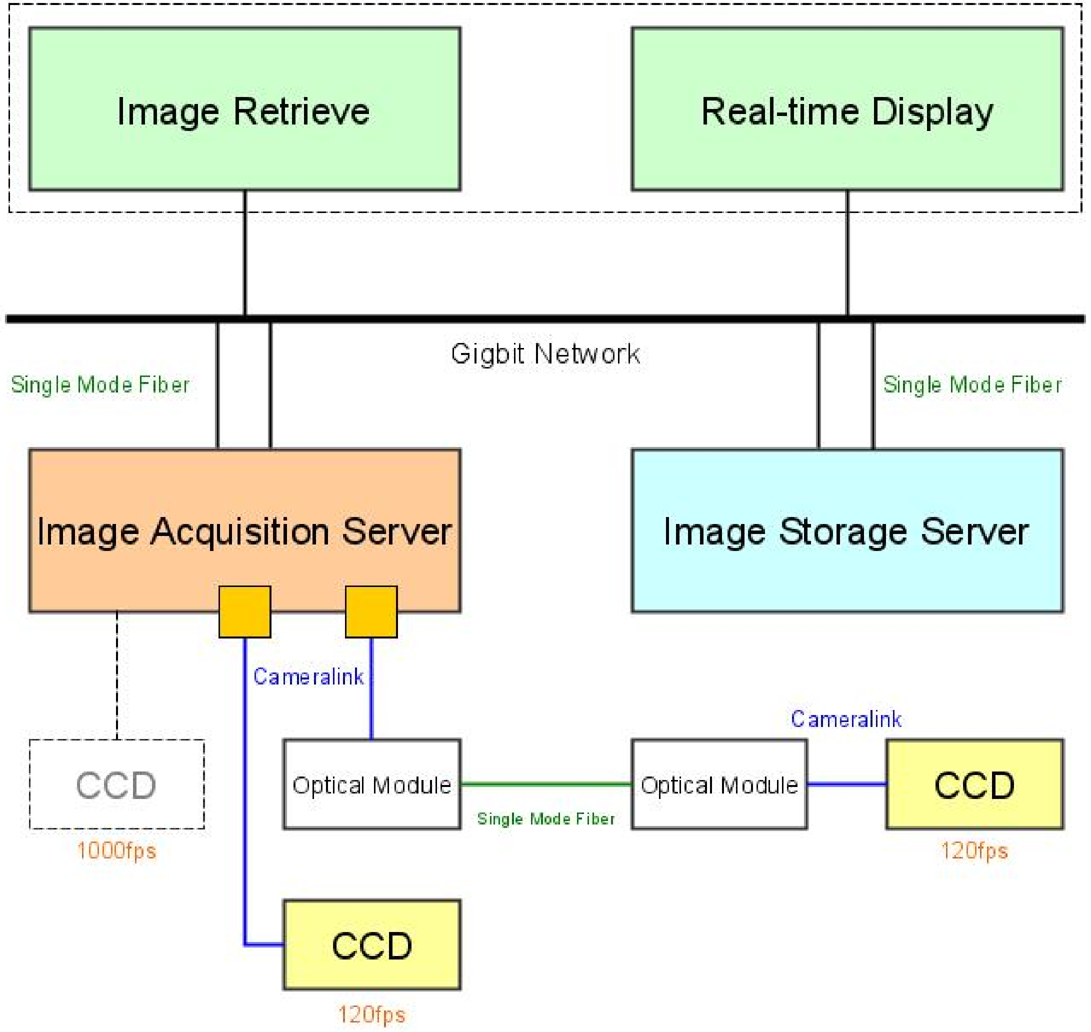


Image Acquisition and Storage System Architecture

- Image Retrieval
  - Web based,following J2EE architecture
  - Remote queries
  - Querying saved records
- Real-time display
  - display image with other related metadata in real time

Image data are transmitted through 10 GigaBit Ethernet for acquisition, storage and on-line display, using ZeroMQ protocol for communication.

Image Storage Servers

10 GigaBit Network

Image Acquistion Server

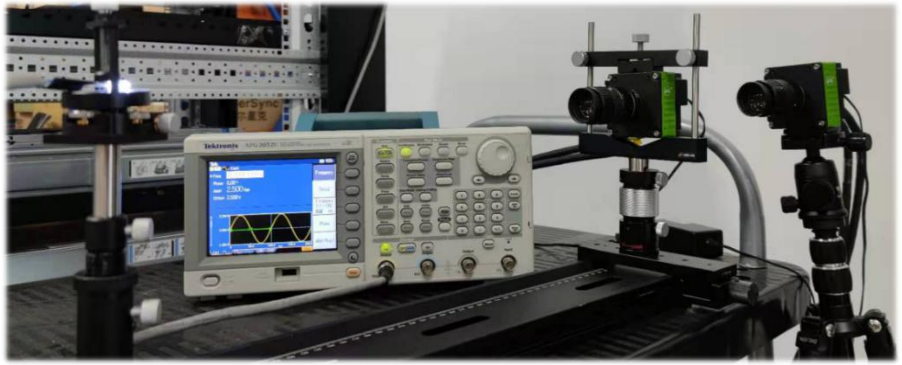
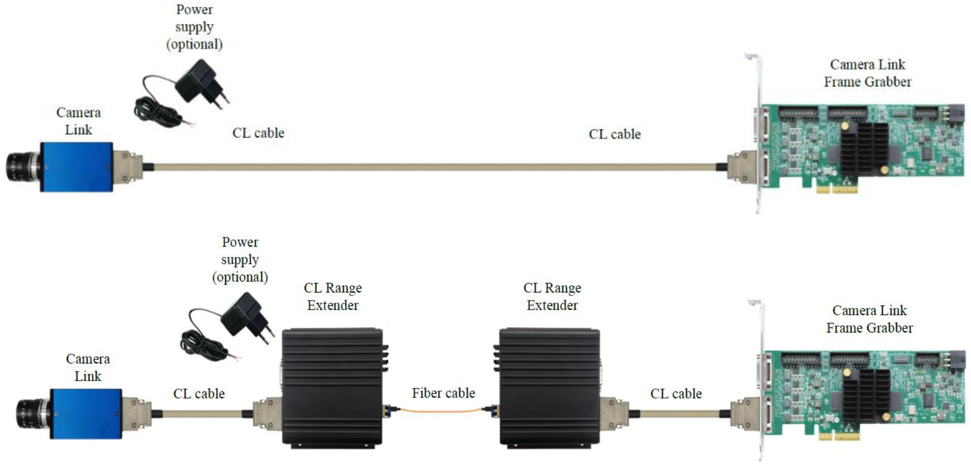


Image Acquisition

Camera Data Interface	
GigE Vision	slower speeds, 100m cable length
Camera Link	5.4Gbps, short cable length, cost effective
CoaXPress	6.25Gbps, short cable length, expensive



MATROX API <-> Ubuntu 14.04

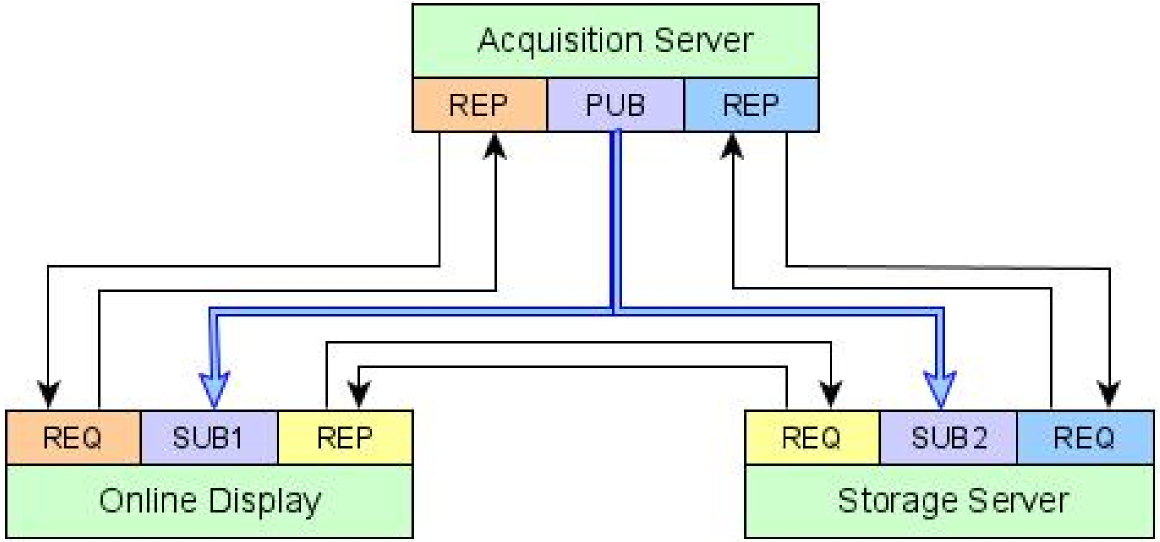
- Camera #1: connected to Camera Link Frame Grabber through CL cable (~10 meters)
- Camera #2: connected to CL Range Extender over Fiber, solves distance limitation of Camera Link

Camera Link Frame Grabber： PCI Express-based device, high bandwidth

Image Transmission——ZeroMQ

- request-reply pattern :
  - implement handshaking
  - one shakes hands with each other
- publish-subscribe pattern :
  - one-to-many
  - acquisition server publish a stream of image data
  - the other two servers consume the stream

TCP

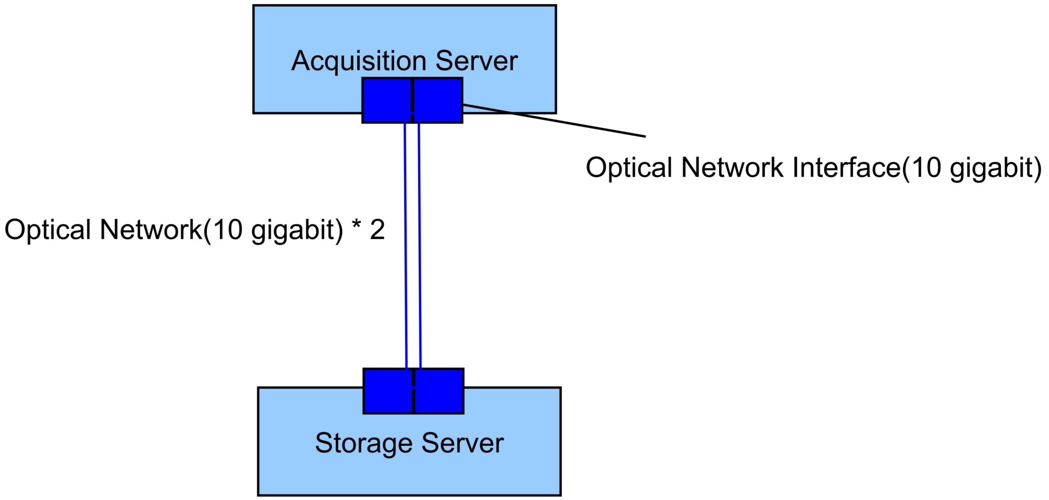


Request-Reply + Publish-Subscribe

Note:The connection will be interrupted if the sender does not receive the answer.

- ✓ modify configuration parameters
- ✓ even if the sender does not receive a reply, it can continue to ask

Image Transmission——ZeroMQ


Acquisition Server
Optical Network Interface(10 gigabit)
Optical Network(10 gigabit) * 2
Storage Server

- ✓ Two network interfaces --> a single logical ‘bonded’
- ✓ increases the network throughout and bandwidth

600MB/sec ——>1200MB/sec

Problem #1: Network bonding increases CPU consumption

Solution: transmit data through two networks

Problem #2: two network ports transmit simultaneously,

lost + duplicate

Solution:

- ✓ optimize the execution order of threads
- ✓ add several mutex locks

SHINE

Image Storage——Schemas

image data: represents an image

metadata : details relevant to the image, organized to facilitate searchability

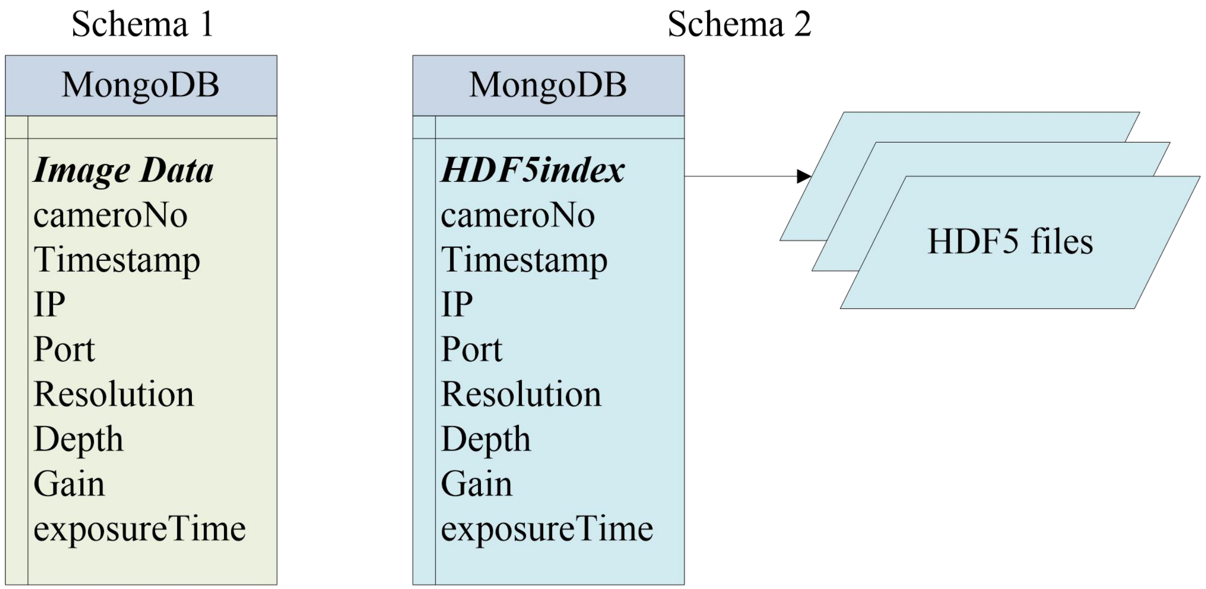
Storage Schema 1: Both stored in MongoDB (image:2-D array uint8)

Storage Schema 2: HDF5+MongoDB

Storage Schema 3: HDF5+Cassandra

Storage Schema 4: HDF5 DIRECT CHUNK

WRITE



Schema 1

MongoDB

Image Data
cameroNo
Timestamp
IP
Port
Resolution
Depth
Gain
exposureTime

Schema 2

MongoDB

HDF5index
cameroNo
Timestamp
IP
Port
Resolution
Depth
Gain
exposureTime

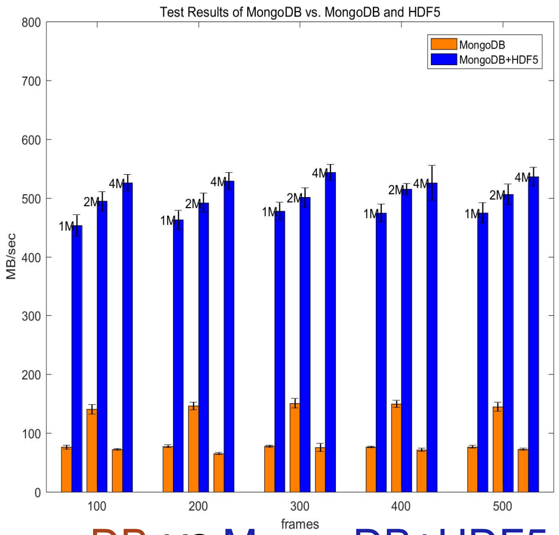
HDF5 files

Image Storage——Performance

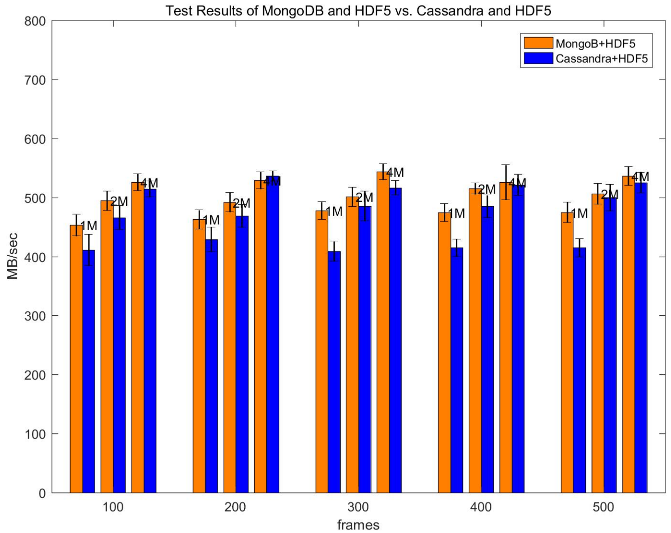
Rank-mounted Server			
Hard Disk	RAM	CPU	OS
960GB SSD	512GB	2 physical (6 cores/CPU)	Linux/CentOS 7

three different sizes of gray level image
- 1024×1024 bytes (1MB)
- 1024×2048 bytes (2MB)
- 2048×2048 bytes (4MB)

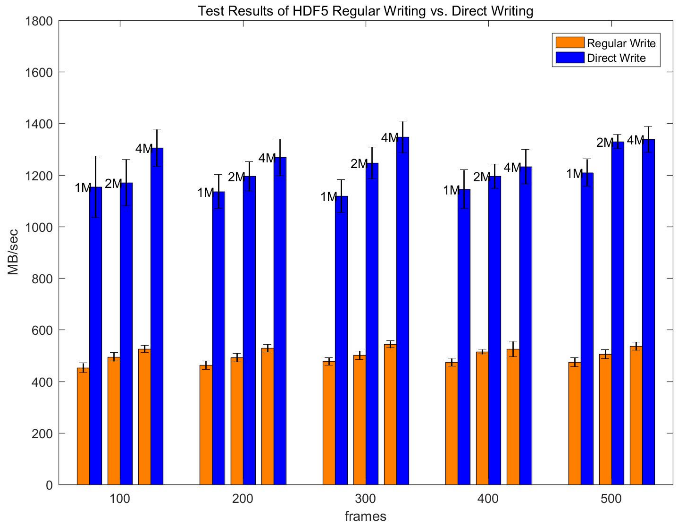
- record the time consumed to store 100, 200, 300, 400 and 500
- perform the same store operation 50 times constantly
- mean value + error bars



MongoDB *vs* MongoDB+HDF5



MongoDB+HDF5 *vs* Cassandra+HDF5



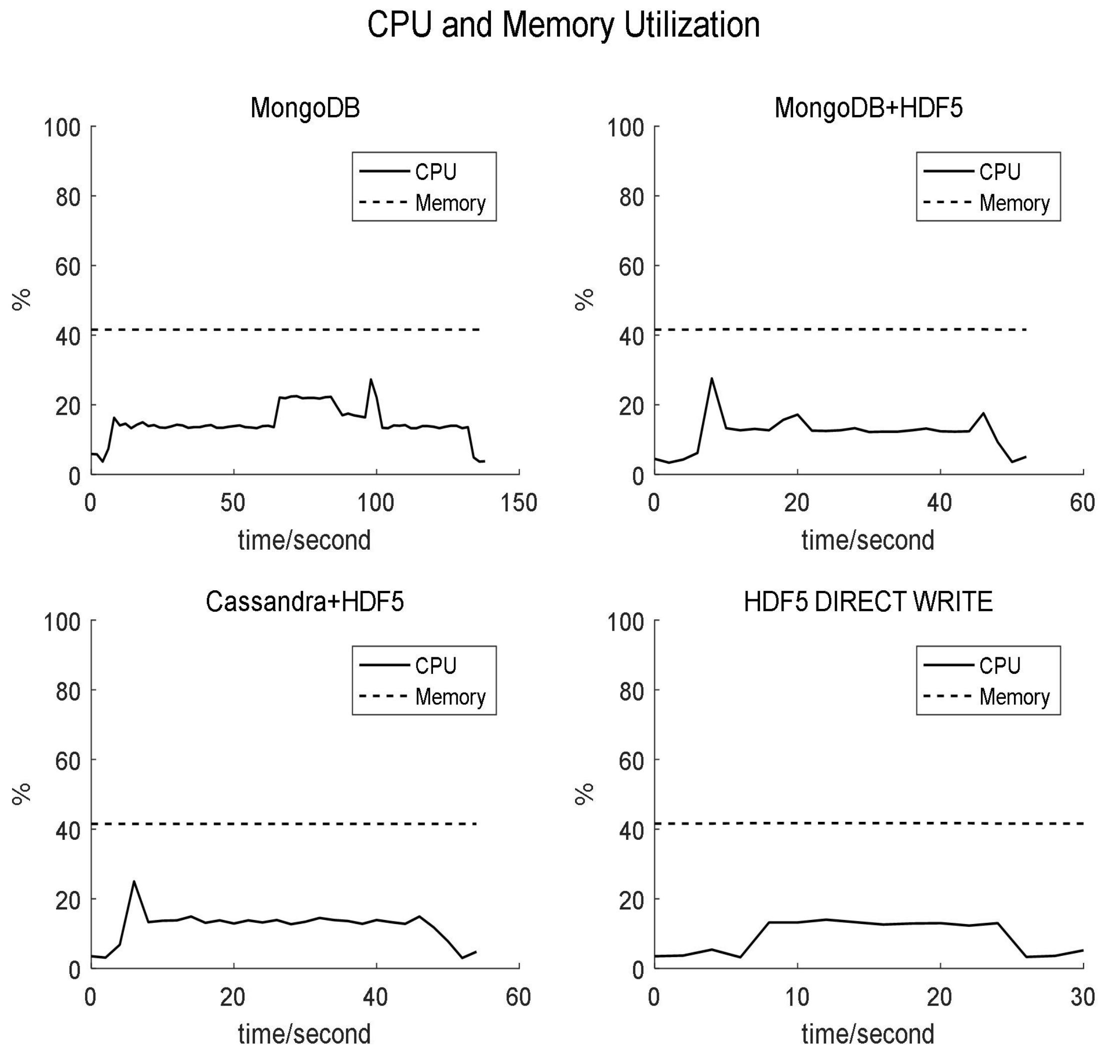
MongoDB+HDF5 *vs* MongoDB+HDF5 Direct Chunk Write

Image Storage——Performance

- ➢ monitor CPU and memory utilization
- ➢ before, during and after
- ➢ 200 frames, 2M

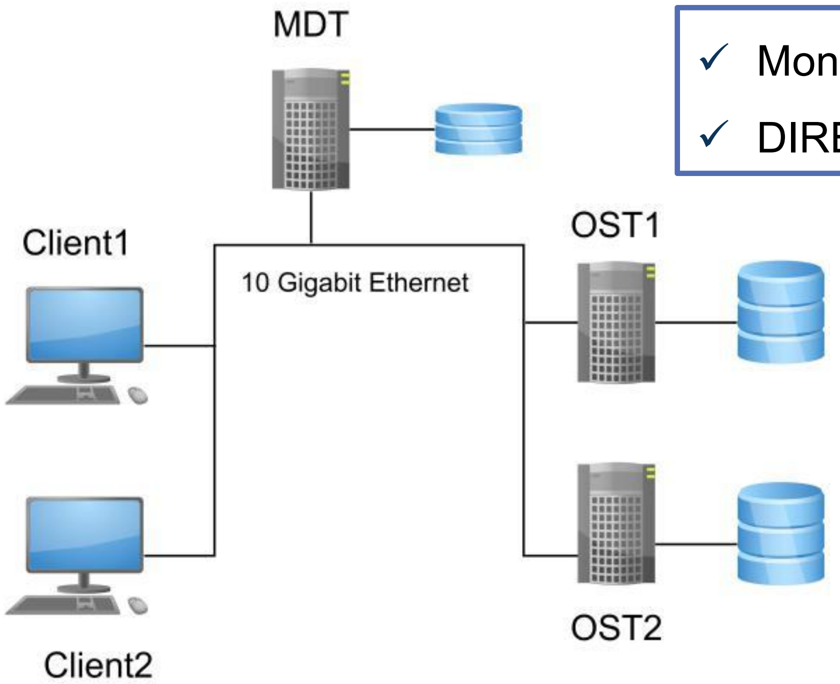
- ✓ CPU load? —— NO
- ✓ memory load? —— NO

The storage performance is greatly influenced by the hard disk

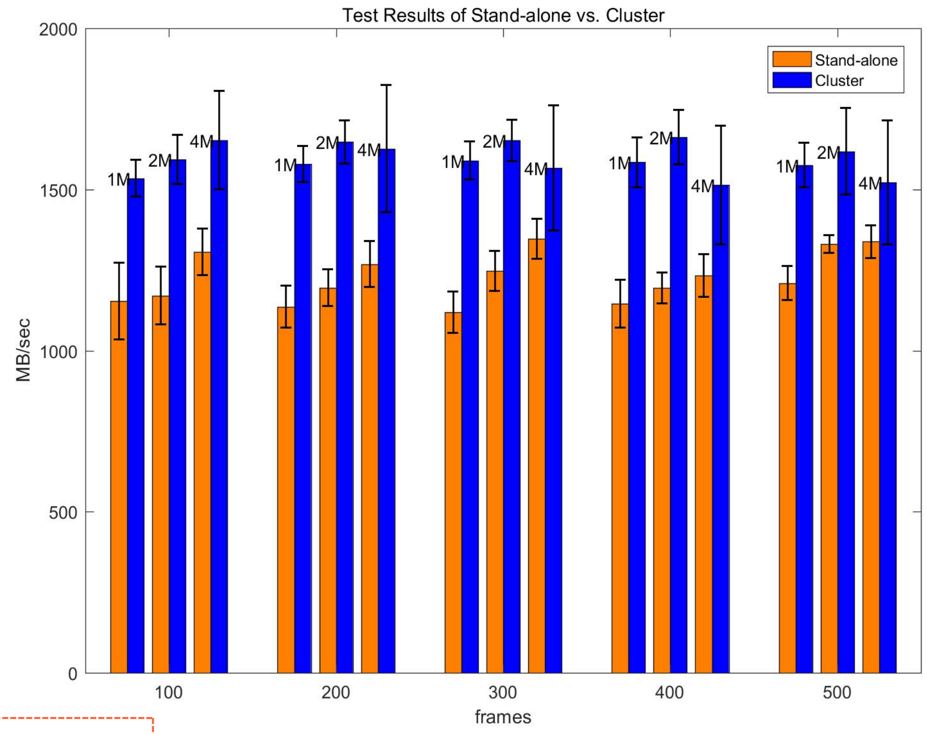


SHINE

Image Storage——Lustre



- ✓ MongoDB+HDF5
- ✓ DIRECT CHUNK WRITE



	Memory	Hard Disk	CPU	Operation System
MDT	128GB	600GB(SSD)	2 CPUs (12 cores)	Linux/CentOS7
OST1	128GB	1200GB(SSD)	2 CPUs (12 cores)	Linux/CentOS7
OST2	128GB	1200GB(SSD)	2 CPUs (12 cores)	Linux/CentOS7

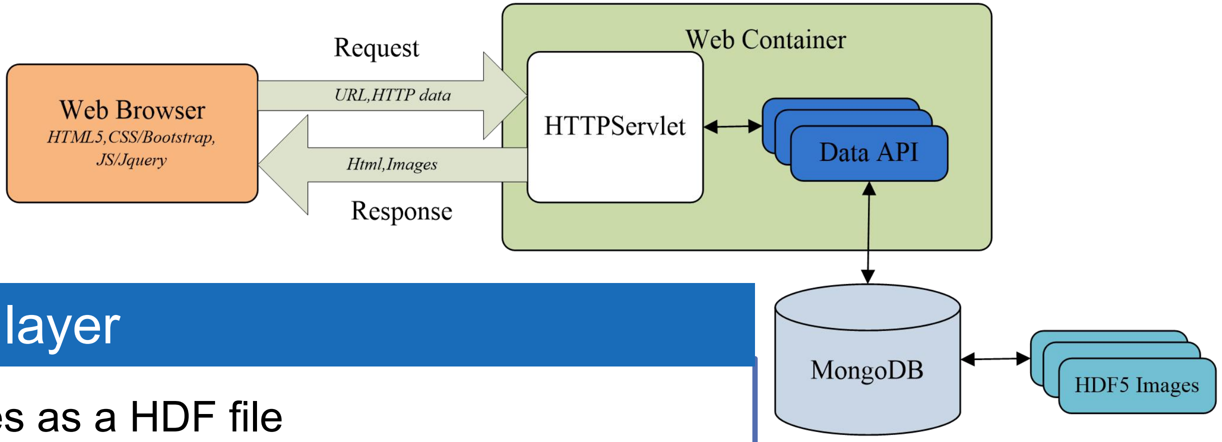
Lustre: 1500MB/sec

Stand-alone server:1200MB/sec

“The Data Storage System for SHINE”,Huihui Lv ,Yingbing Yan ,Heyun Wang. doi: 10.1016/J.NIMA.2021.165285

Image Retrieval

- ✓ Based on Maven J2EE Glassfish
- ✓ MongoDB +HDF5 storage



The persistence layer

- ➢ HDF5：store the image data, N(100,200,...) frames as a HDF file
- ➢ MongoDB：store metadata, timestamp, cameroNo,index,...

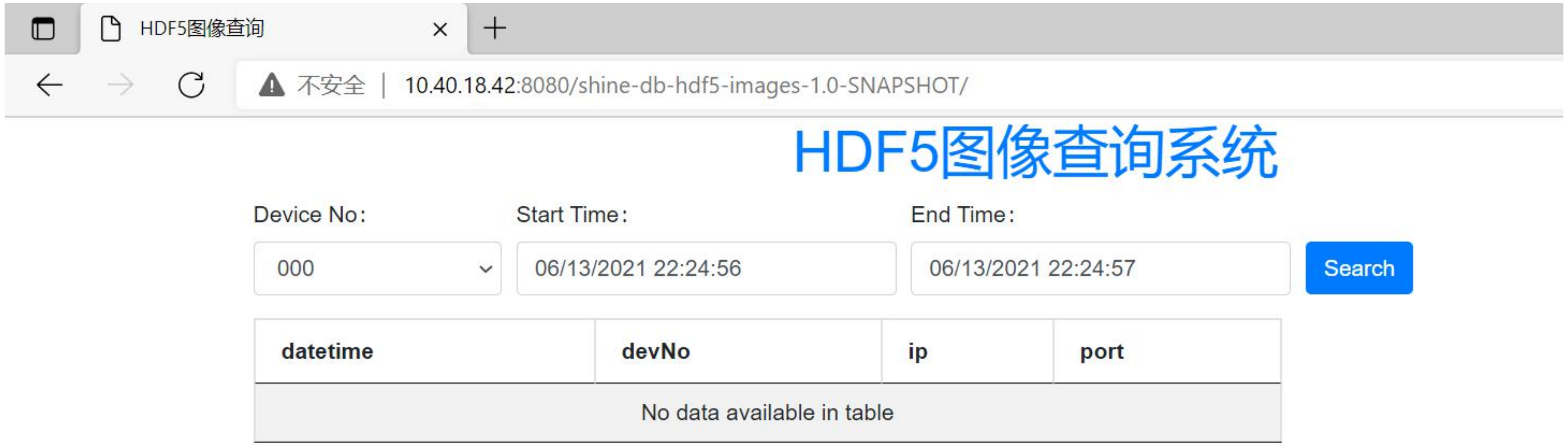
The business logic layer

- ➢ DataAPI：JDBC，Java HDF5 Interface（JHI5), hyperslab
- ➢ Servlet：process demand to the data carried by the web client, return data in JSON format

The client layer

- ➢ HTML5 Canvas to draw pixel-level image
- ➢ Bootstrap to style responsive websites
- ➢ JQuery：timepicker，Datatables，Bootstrap-select/selectpicker

Image Retrieval



HDF5图像查询
不安全 | 10.40.18.42:8080/shine-db-hdf5-images-1.0-SNAPSHOT/

HDF5图像查询系统

Device No: 000

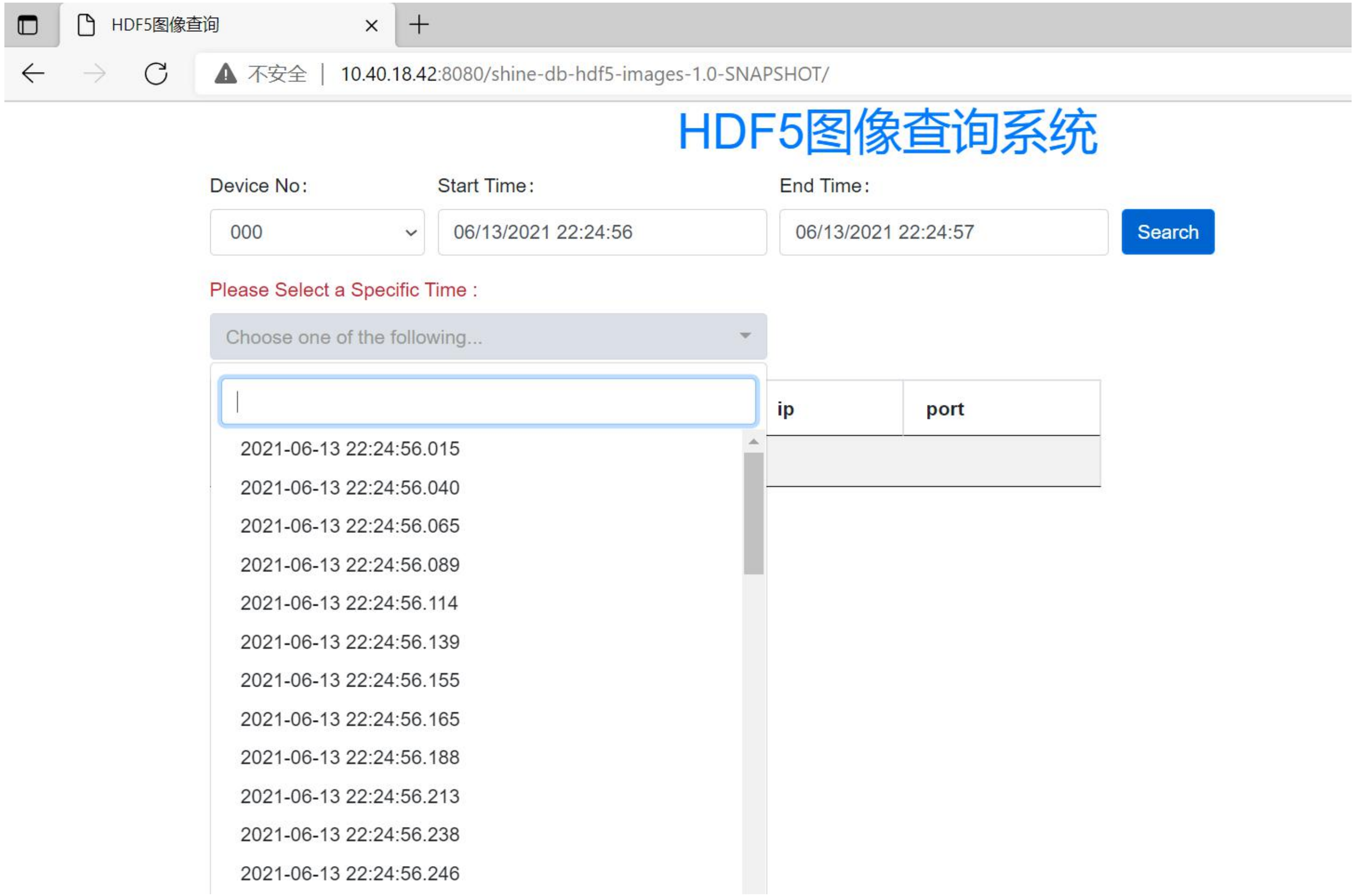
Start Time: 06/13/2021 22:24:56

End Time: 06/13/2021 22:24:57

Search

datetime	devNo	ip	port
No data available in table			

Image Retrieval



HDF5图像查询系统

Device No: 000

Start Time: 06/13/2021 22:24:56

End Time: 06/13/2021 22:24:57

Search

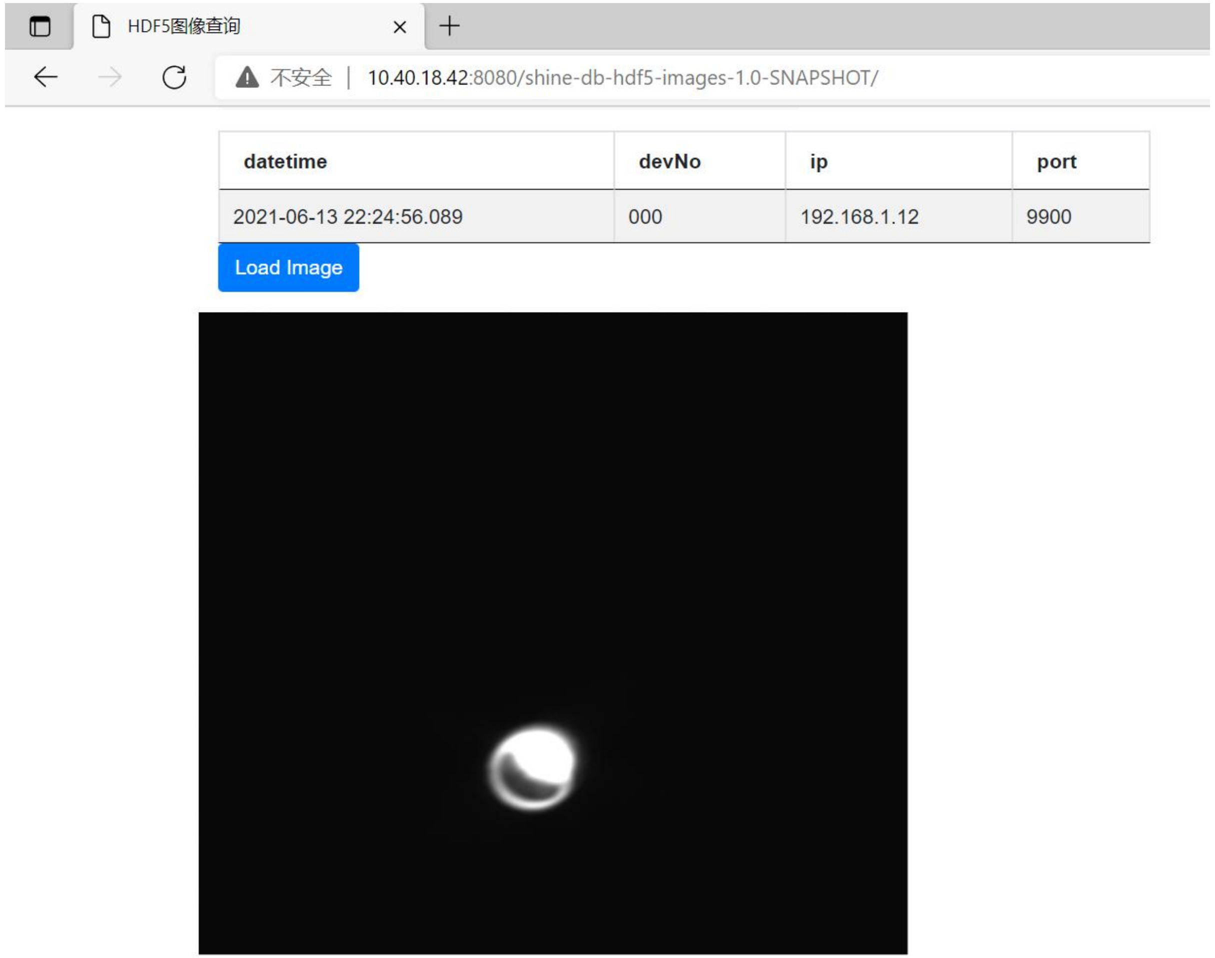
Please Select a Specific Time :

Choose one of the following...

```
2021-06-13 22:24:56.015
2021-06-13 22:24:56.040
2021-06-13 22:24:56.065
2021-06-13 22:24:56.089
2021-06-13 22:24:56.114
2021-06-13 22:24:56.139
2021-06-13 22:24:56.155
2021-06-13 22:24:56.165
2021-06-13 22:24:56.188
2021-06-13 22:24:56.213
2021-06-13 22:24:56.238
2021-06-13 22:24:56.246
```

ip	port

Image Retrieval



HDF5图像查询
不安全 | 10.40.18.42:8080/shine-db-hdf5-images-1.0-SNAPSHOT/
Load Image

datetime	devNo	ip	port
2021-06-13 22:24:56.089	000	192.168.1.12	9900

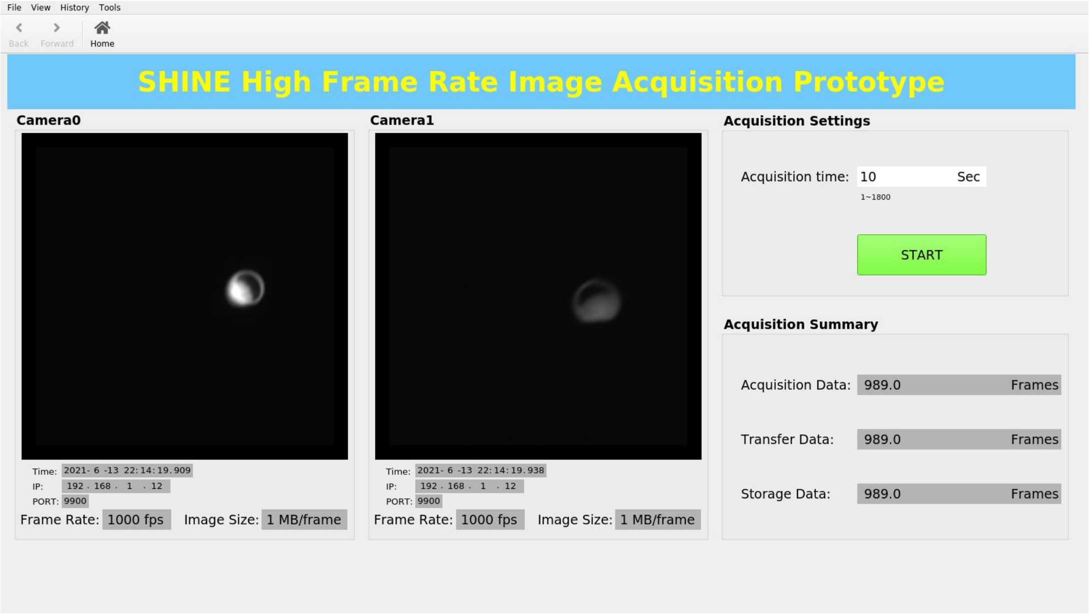
Online Display

ZMQ + PCASpy + PyDM

ZMQ: transmit images and messanges

PCASpy: EPICS API

PyDM: graphic user interface



SHINE High Frame Rate Image Acquisition Prototype

Camera0

Time: 2021- 6 -13 22:14:19.909
IP: 192 . 168 . 1 . 12
PORT: 9900
Frame Rate: 1000 fps Image Size: 1 MB/frame

Camera1

Time: 2021- 6 -13 22:14:19.938
IP: 192 . 168 . 1 . 12
PORT: 9900
Frame Rate: 1000 fps Image Size: 1 MB/frame

Acquisition Settings

Acquisition time: 10 Sec
1~1800

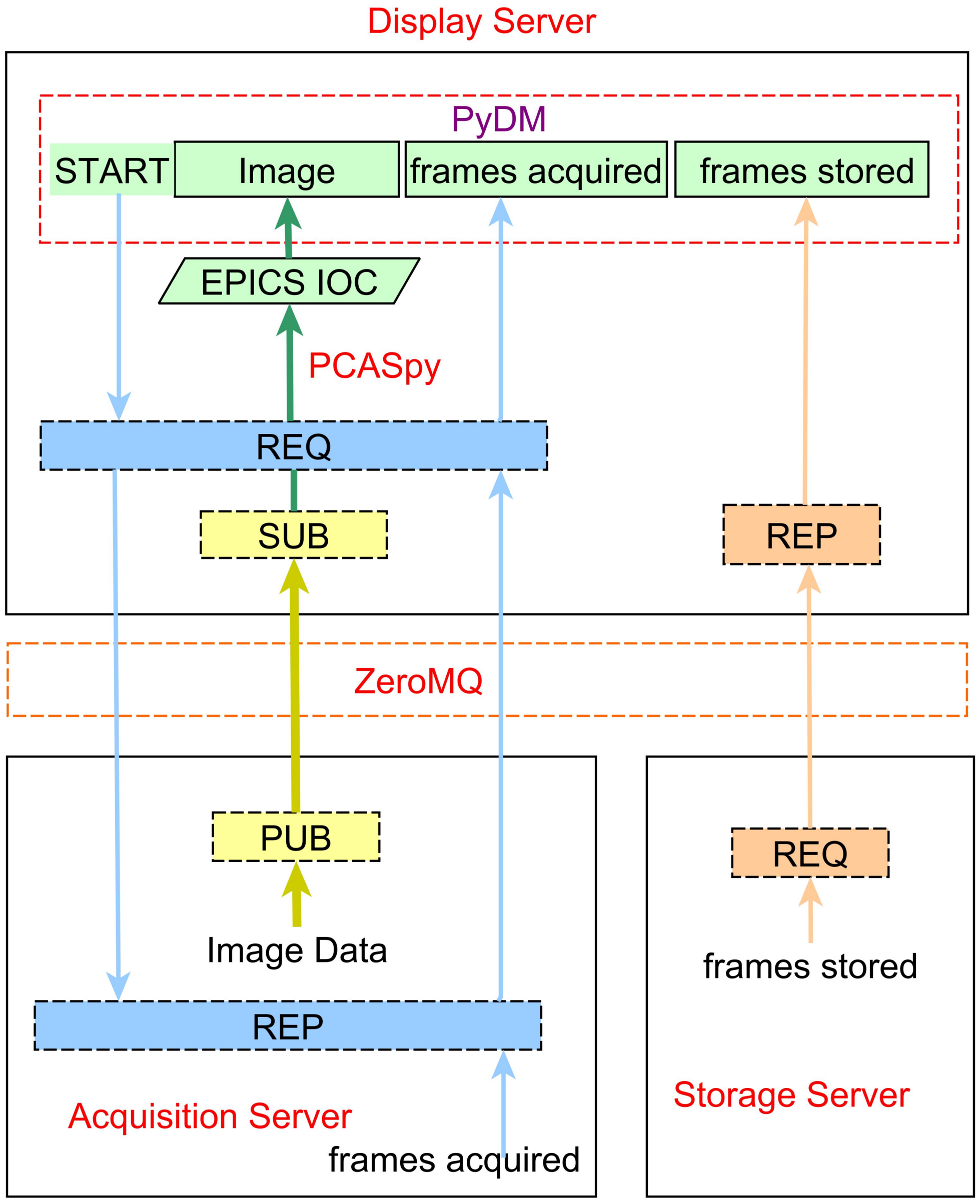
START

Acquisition Summary

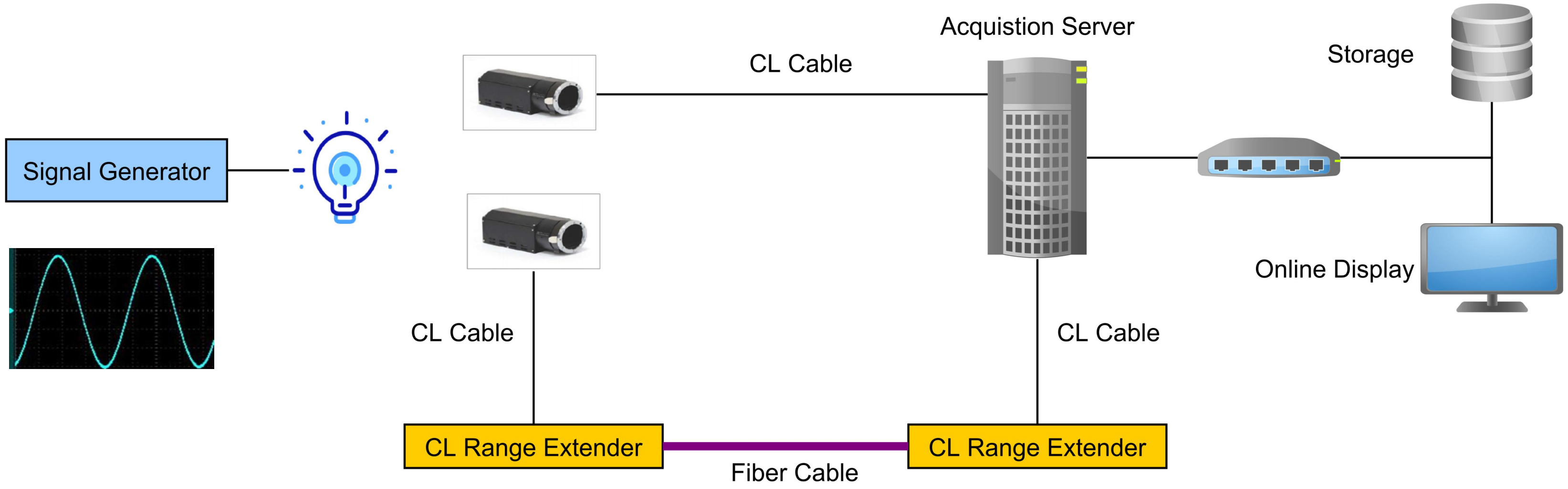
Acquisition Data: 989.0 Frames

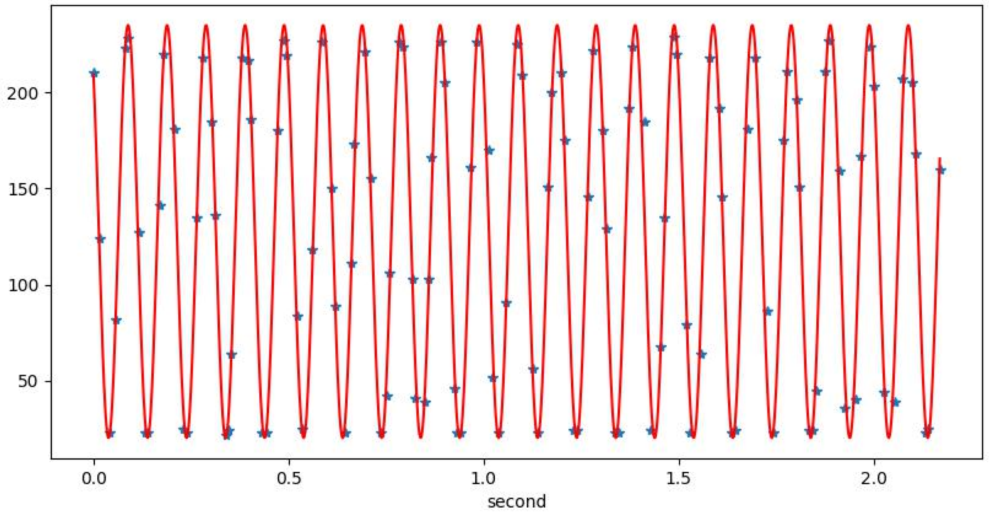
Transfer Data: 989.0 Frames

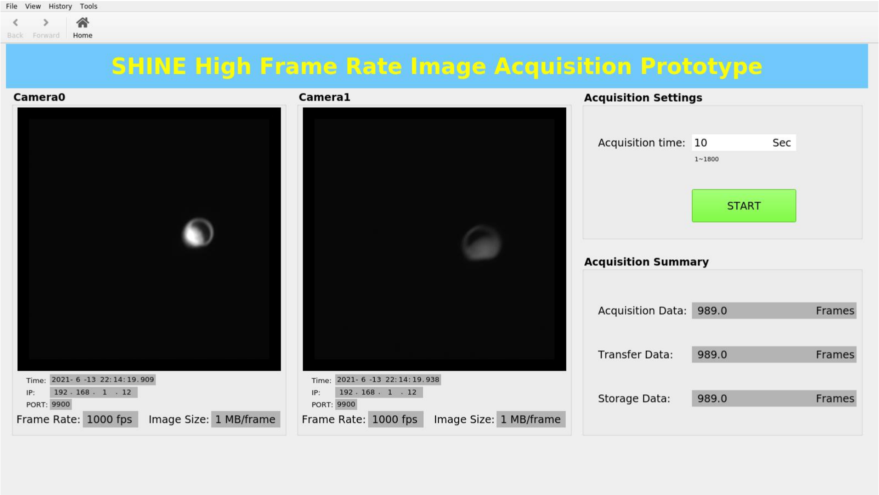
Storage Data: 989.0 Frames



Testing







SHINE High Frame Rate Image Acquisition Prototype

Camera0

Time: 2021- 6 -13 22:14:19.909
IP: 192 . 168 . 1 . 12
PORT: 9900
Frame Rate: 1000 fps Image Size: 1 MB/frame

Camera1

Time: 2021- 6 -13 22:14:19.938
IP: 192 . 168 . 1 . 12
PORT: 9900
Frame Rate: 1000 fps Image Size: 1 MB/frame

Acquisition Settings

Acquisition time: 10 Sec
1~1800

START

Acquisition Summary

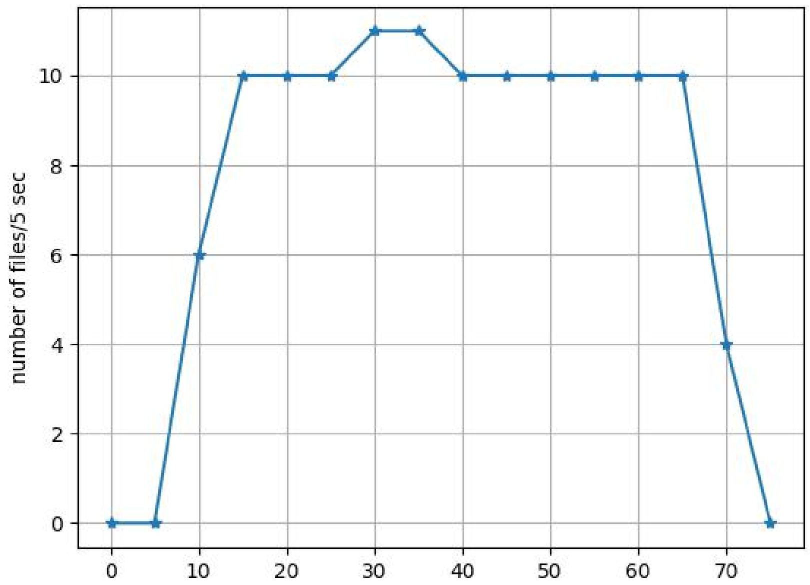
Acquisition Data: 989.0 Frames
Transfer Data: 989.0 Frames
Storage Data: 989.0 Frames

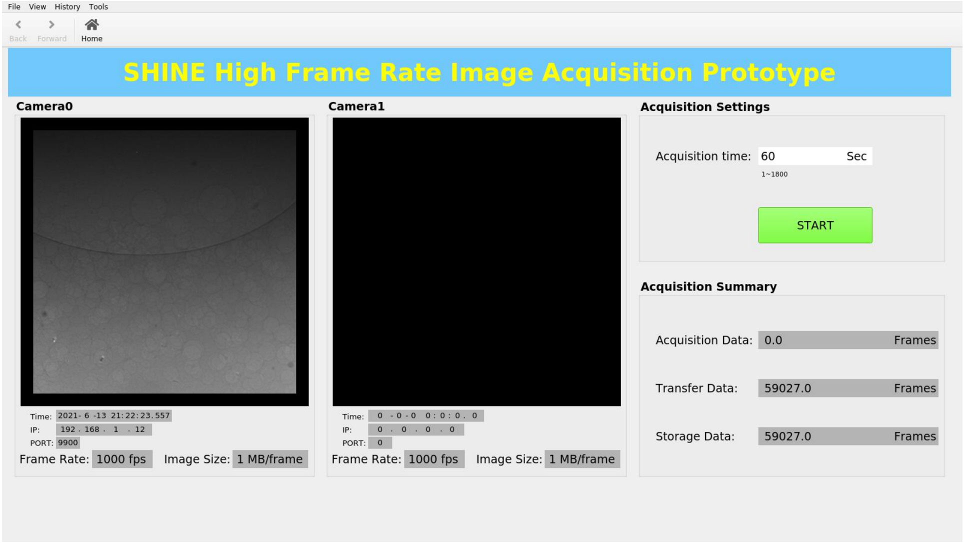
Testing

1000frames/sec

- image size: 1MB, from beamlines
- transmission speed: 1000 frames/sec
- number of HDF5 files generated
- watch -n 5 "ls |wc -l |tee -a num.log"
- storage speed:

500MB * 10 / 5sec = 1000 MB/sec





SHINE High Frame Rate Image Acquisition Prototype

Camera0

Time: 2021- 6 -13 21:22:23.557
IP: 192 . 168 . 1 . 12
PORT: 9900
Frame Rate: 1000 fps Image Size: 1 MB/frame

Camera1

Time: 0 - 0 - 0 0 : 0 : 0 . 0
IP: 0 . 0 . 0 . 0
PORT: 0
Frame Rate: 1000 fps Image Size: 1 MB/frame

Acquisition Settings

Acquisition time: 60 Sec
1~1800

Acquisition Summary

Acquisition Data: 0.0 Frames
Transfer Data: 59027.0 Frames
Storage Data: 59027.0 Frames

Summary

- The system is able to acquire, transmit and store the image data at speed of 1000MB/sec stably without loss.
  - Camera Link interface
  - ZeroMQ
  - HDF5 and MongoDB storage
  - multi-thread programming
  - multi-network ports
  - one-to-many transmission
- The hardware architecture and software design is not limited to image data. It could also manipulate the waveform data for SHINE.

Thank You for Your Attention！

SHINE