System-on-a-chip based nano star tracker and its real-time image processing approach

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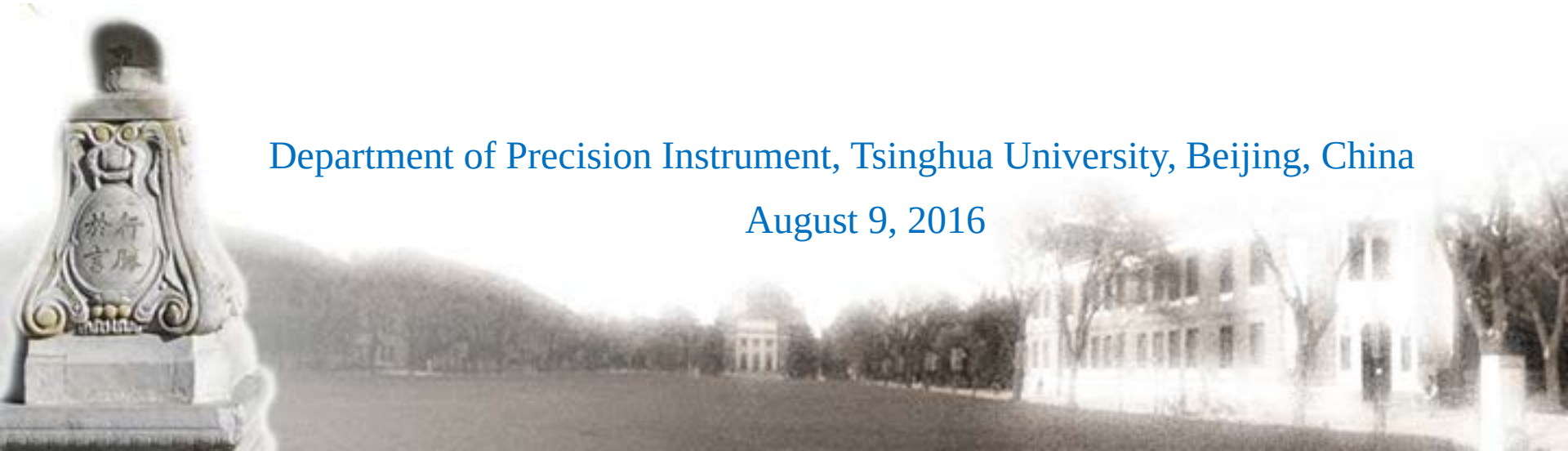

Outline

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2 SOC based star tracker

3 Real-time image processing approach

4 Performance experiments

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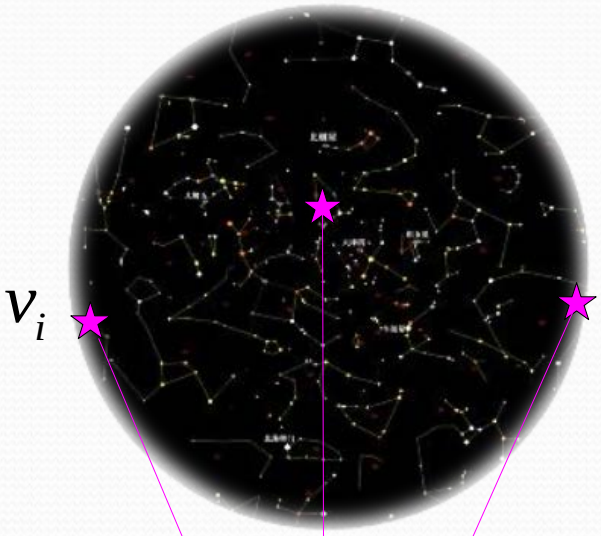
Introduction

➢ The star trackers

$$\boldsymbol{v_i} = \begin{bmatrix} \cos\alpha_i \cos\delta_i \\ \sin\alpha_i \cos\delta_i \\ \sin\delta_i \end{bmatrix}$$

Celestial coordinate



$$w_i = Av_i$$

Attitude matrix

$$J(A_q) = \frac{1}{2}\sum_{i=1}^{n} \alpha_i \left\| w_i - A_q v_i \right\|^2$$

Star tracker coordinate

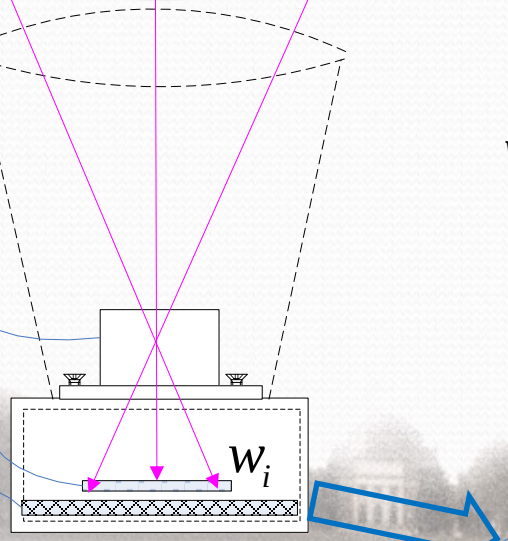
$$\boldsymbol{w_i} = \frac{1}{\sqrt{(x_i - x_0)^2 + (y_i - y_0)^2 + f^2}} \begin{bmatrix} -(x_i - x_0) \\ -(y_i - y_0) \\ f \end{bmatrix}$$

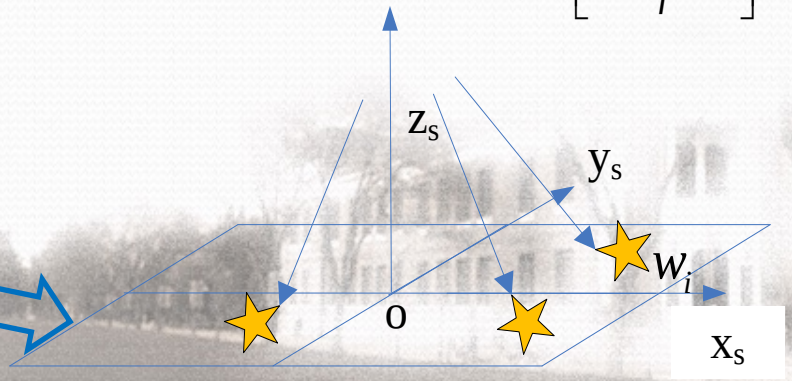
Baffle

Lens

Image detector

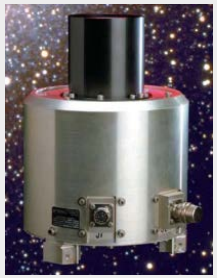
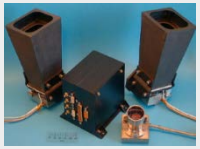
Processing unit



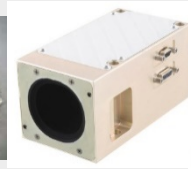
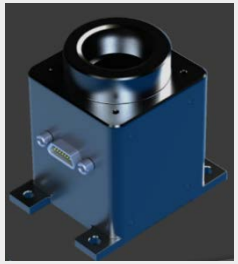


Introduction

➢ Typical Star Tracker

Jena-Optronik Astro 15	Jena-Optronik Astro APS	EADS Sodern SED 36	EADS Sodern HYDRA	BALL CT-602	Galileo A-STR	DTU ASC	Tsinghua
							

➢ Miniature Star Tracker

Sinclair ST-16 /ST-16RT	BCT Nano Star Tracker	BST ST-100	Sodern AURIGA	Azmerit ASTC-1	Tsinghua Nano Star Tracker	Tsinghua Pico Star Tracker
						

Introduction

➢ Advantages of nano star tracker

- ✓ **Small size, low weight and low power consumption**
- ✓ **High performance (accuracy and data update rate) and miniaturization**
- ✓ **Low cost for small satellites**

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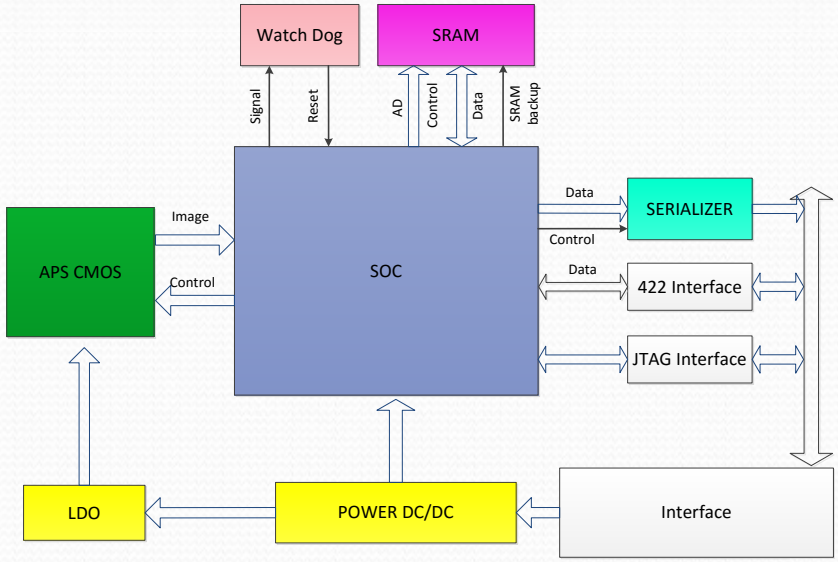
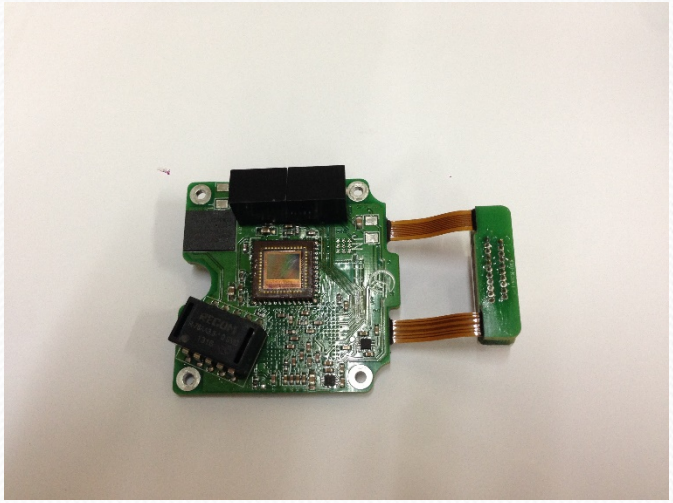
SOC based star tracker

➢ SOC based hardware



Schematic

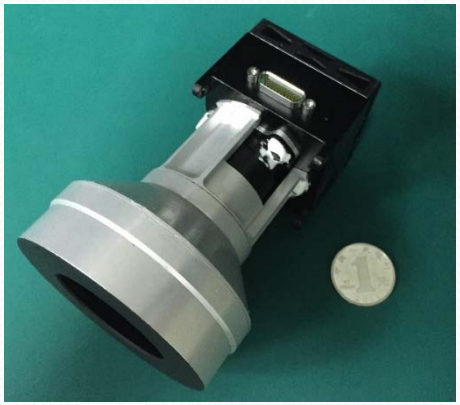


Flex-rigid PCB

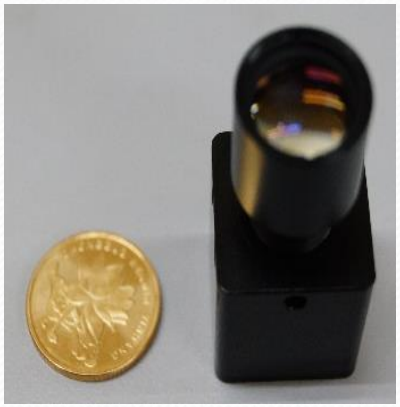
- ✓ A single SOC (system on a chip) structure : reduce unnecessary power consumption
- ✓ SOC: APS CMOS control, image processing, attitude determination and communication
- ✓ Flexible-rigid PCB: improve the reliability and isolate the main PCB from outside
- ✓ Power consumption: <0.7W

SOC based star tracker

➢ Nano & Pico star trackers



Nano star tracker (with baffle)



Pico star tracker (optical head only)

Parameter	Nano Star Tracker	Pico Star Tracker
Accuracy	7.0″, 70″(3σ)	7.0″, 70″(3σ)
Size	50×50×113 mm^3	32×32×45mm^3
Mass	245g	50g
Power consumption	0.7W	<0.5W
Slew rate	2° /s (4 ° /s Optional)	1° /s
Data update rate	10Hz (20Hz Optional)	5Hz

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Real-time image processing approach

➢ Principle

- Pipeline structure: **Almost no time delay**
  - ✓ Image processing (including background analysis and image filtering) while image capturing (including image exposure and pixel read-out)
  - ✓ Star extraction ends at the end of image read out
- Row by row: **Almost no space taken**
  - ✓ Image pixel is read out row by row
  - ✓ Image is processed row by row

- **Real-time image processing approach**

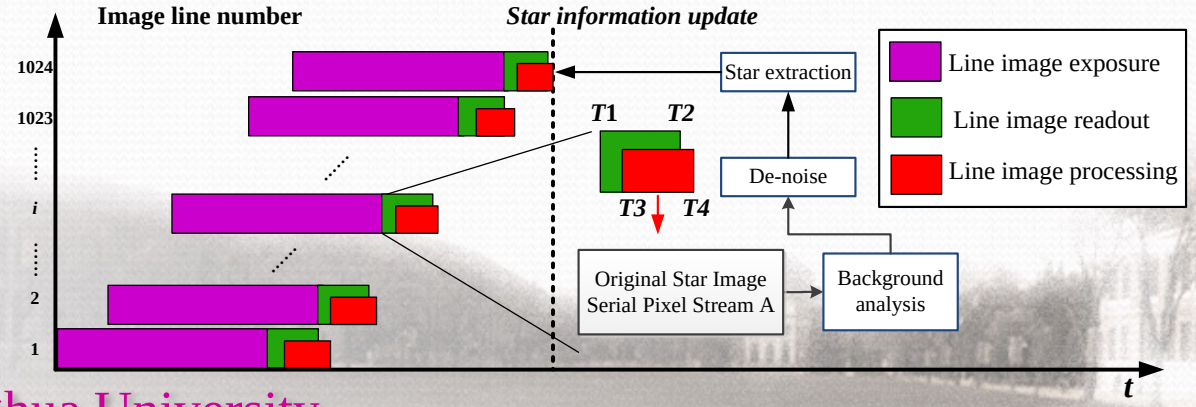
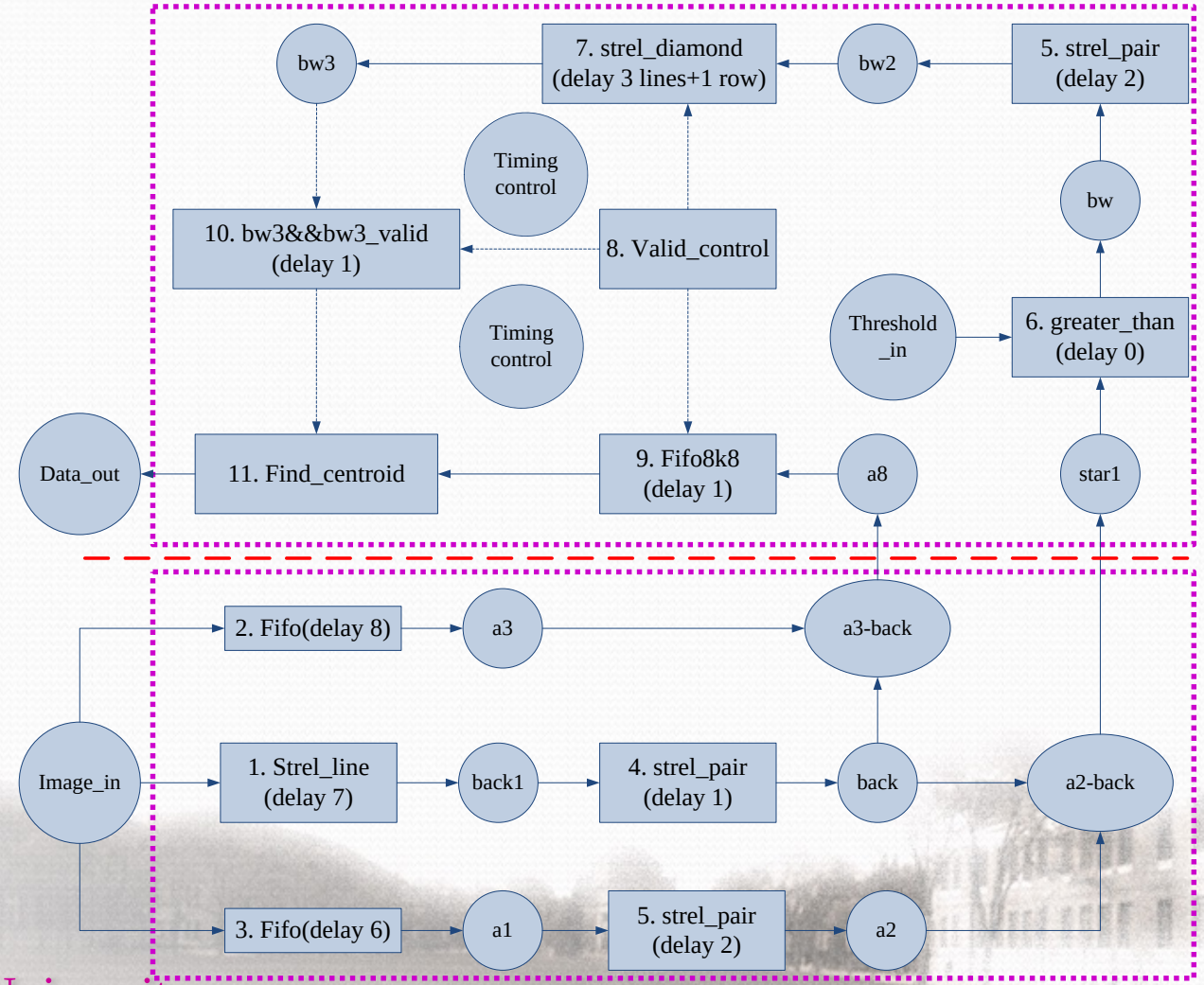


Image processing timeline

Real-time image processing approach

➢ Implementation



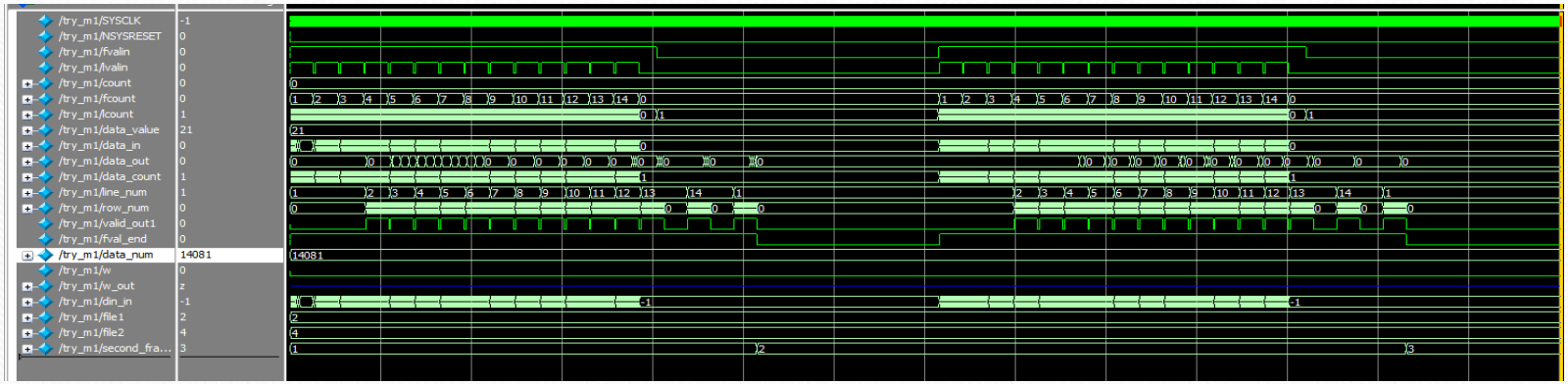
de-noise and
star extraction

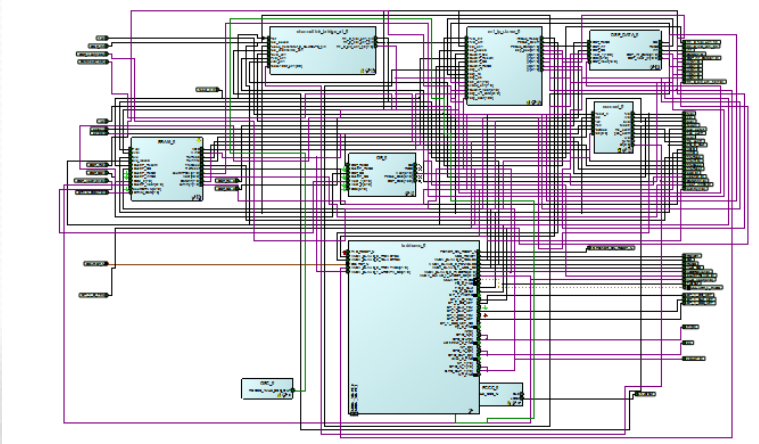
de-noise and
background analysis

Real-time image processing approach

➢ Simulation

Simulation result





Hardware implementation

- **Time delay simulation**:

3 rows delay in a total 1024 rows image (0.29% of the whole image readout time)

- **Star extraction simulation:**

All stars could be successfully extracted in a whole image

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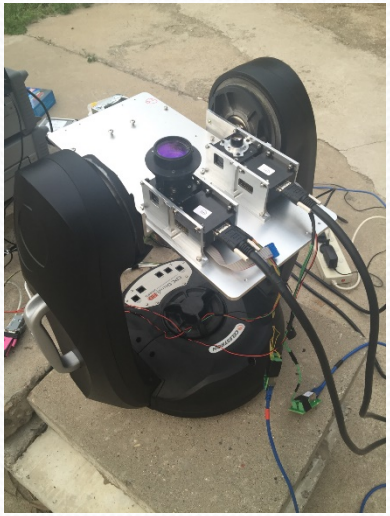
Performance experiments

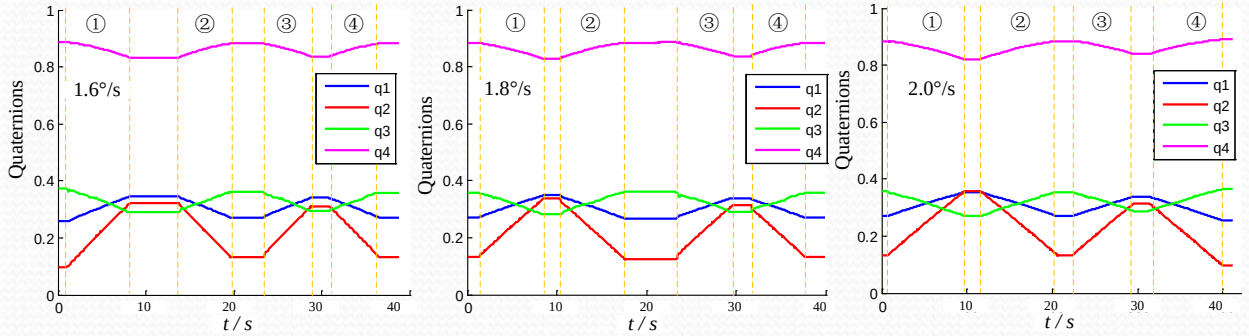
➢ Dynamic performance tests

- **Results**

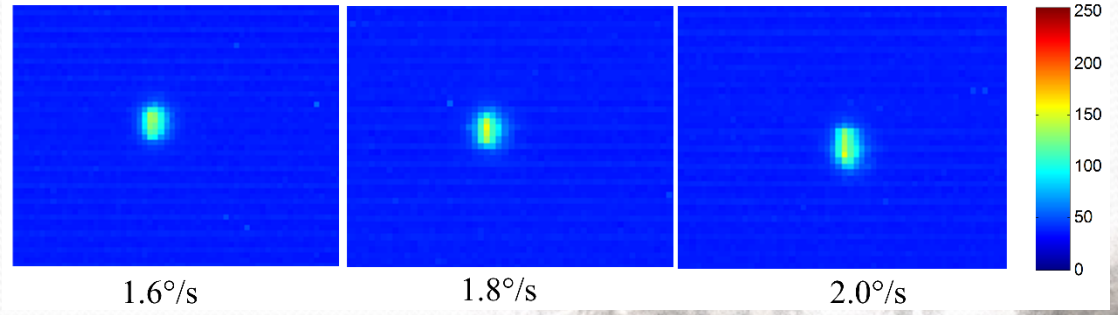
✓ Dynamic range: >2° /s



Test setup



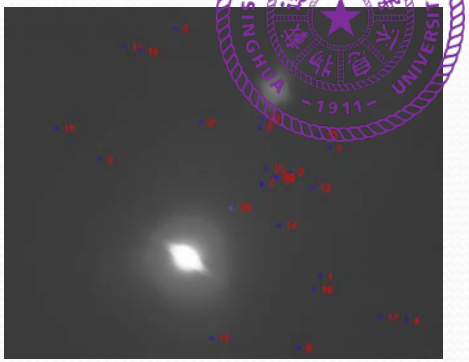
Dynamic test results of the nano star tracker at different rotation rates



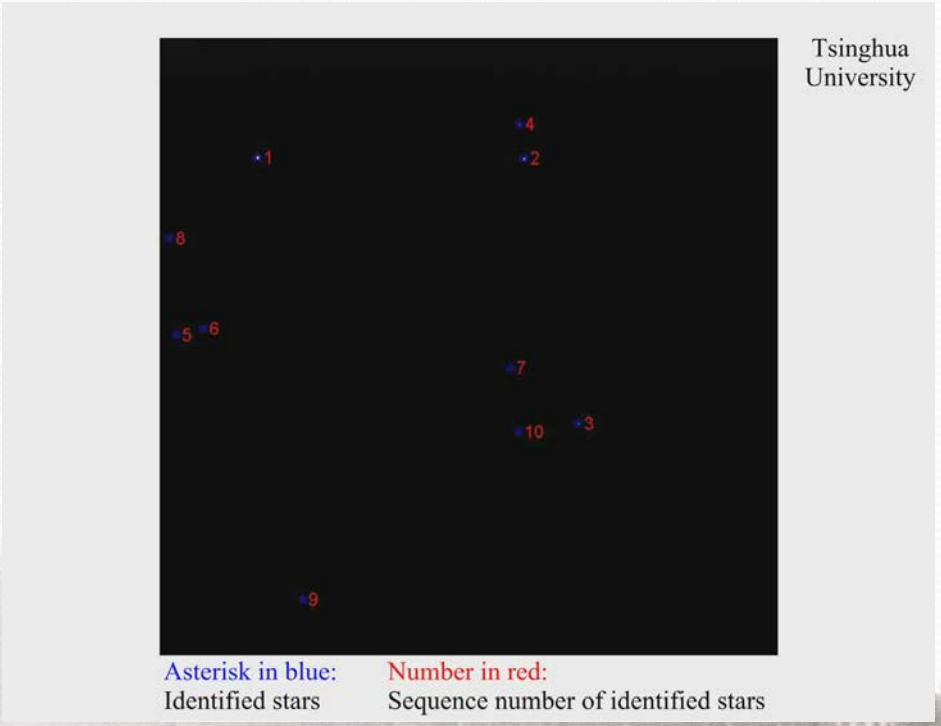
Images of a specific star at different dynamic condition

Performance experiments

- **Stray light resistance tests**



work with moonlight

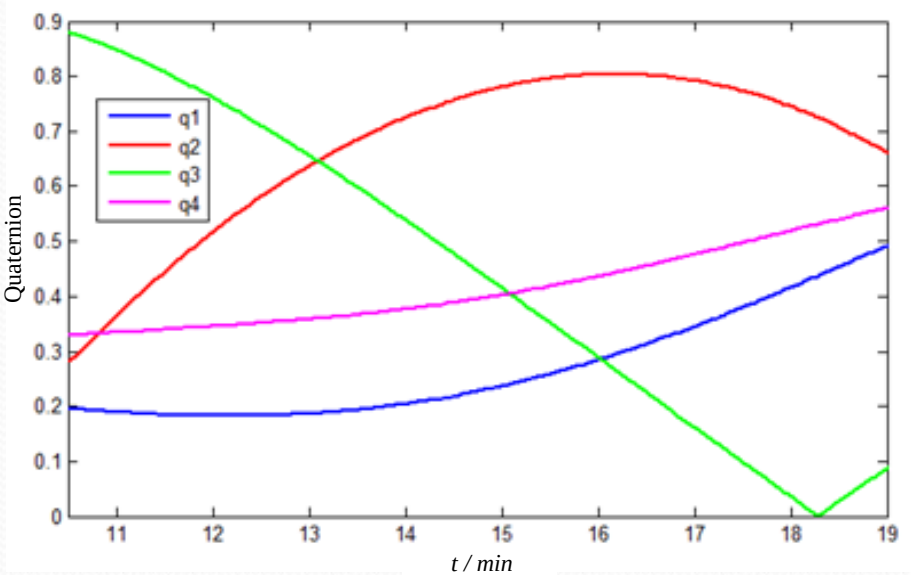


work with clouded light

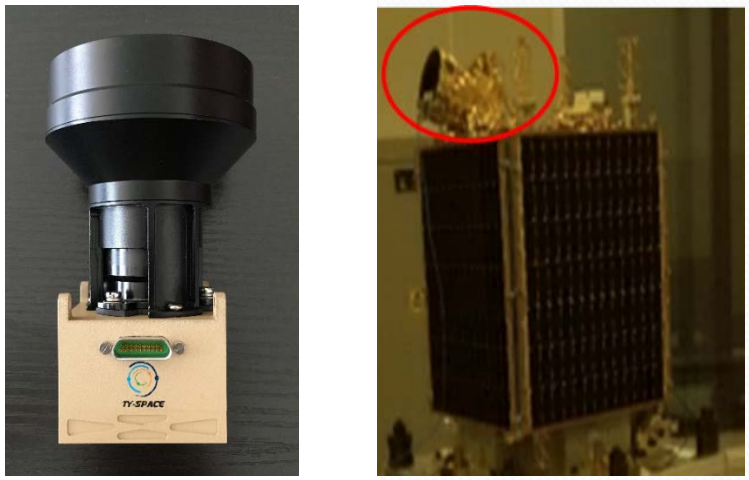
work in the early morning

Performance experiments

➢ In-flight Performance

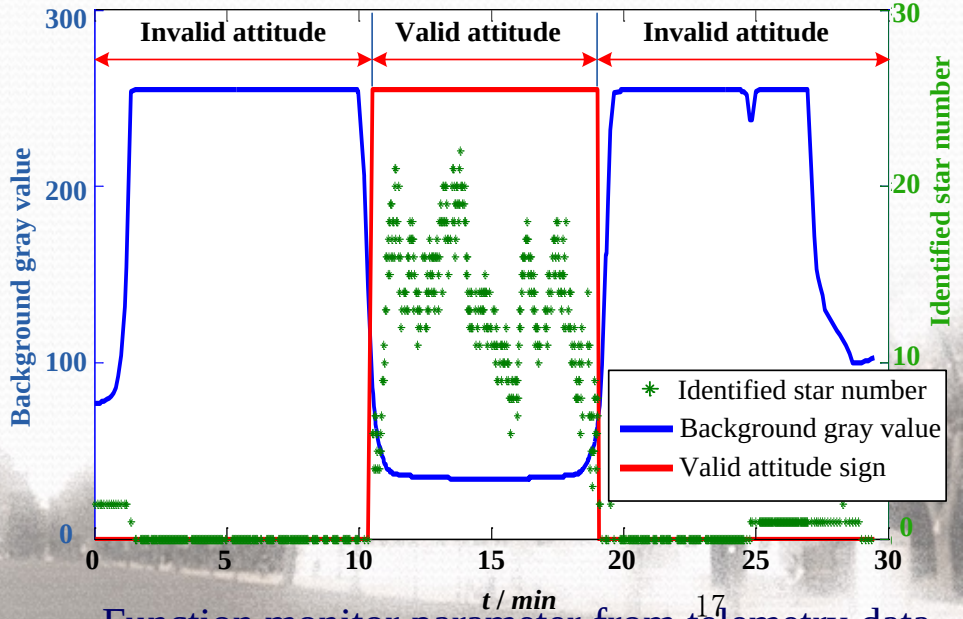


Attitude information



On board NS-2

- ✓ On board a nano-satellite NS-2 for almost one year
- ✓ Functional for attitude determination



Function monitor parameter from telemetry data

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Summary

FOV	12° × 15°
Accuracy	7.0″, 70″(3σ)
Size	50×50×113mm^3
Mass	245g
Power consumption	0.7W
Dynamic range	>2 °/s
Data update rate	>10Hz

- ✓ The SOC based nano star tracker has been achieved with in-flight experience
- ✓ A real-time image processing approach was implemented to further improve the dynamic performance of the nano star tracker
- ✓ The nano star tracker could improve the performance of small satellites, especially for application on remote sensing, or agile small satellites.

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TY-SPACE

Thank you !

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