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

Minsong Wei, Jingyu Bao, Fei Xing, Zengyi Liu, Ting Sun, Zheng You

Department of Precision Instrument, Tsinghua University, Beijing, China
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3  Real-time image processing approach
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Introduction

The star trackers

\[ \mathbf{v}_i = \begin{bmatrix} \cos \alpha_i \cos \delta_i \\ \sin \alpha_i \cos \delta_i \\ \sin \delta_i \end{bmatrix} \]

Celestial coordinate

\[ \mathbf{w}_i = \mathbf{A} \mathbf{v}_i \]

Attitude matrix

\[ J(A_q) = \frac{1}{2} \sum_{i=1}^{n} \alpha_i \| \mathbf{w}_i - A_q \mathbf{v}_i \|^2 \]

Star tracker coordinate

\[ \mathbf{w}_i = \frac{1}{\sqrt{(x_i-x_0)^2 + (y_i-y_0)^2 + f^2}} \begin{bmatrix} -(x_i-x_0) \\ -(y_i-y_0) \\ f \end{bmatrix} \]
## Introduction

### Typical Star Tracker

<table>
<thead>
<tr>
<th>Jena-Optronik Astro 15</th>
<th>Jena-Optronik Astro APS</th>
<th>EADS Sodern SED 36</th>
<th>EADS Sodern HYDRA</th>
<th>BALL CT-602</th>
<th>Galileo A-STR</th>
<th>DTU ASC</th>
</tr>
</thead>
</table>

### Miniature Star Tracker

<table>
<thead>
<tr>
<th>Sinclair ST-16/ST-16RT</th>
<th>BCT Nano Star Tracker</th>
<th>BST ST-100</th>
<th>Sodern AURIGA</th>
<th>Azmerit ASTC-1</th>
<th>Tsinghua Nano Star Pico Star Tracker</th>
<th>Tsinghua Tracker</th>
</tr>
</thead>
</table>
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

- 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**

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### Nano Star Tracker vs. Pico Star Tracker

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Nano Star Tracker</th>
<th>Pico Star Tracker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>7.0″, 70″ (3σ)</td>
<td>7.0″, 70″ (3σ)</td>
</tr>
<tr>
<td>Size</td>
<td>50 × 50 × 113 mm³</td>
<td>32 × 32 × 45 mm³</td>
</tr>
<tr>
<td>Mass</td>
<td>245g</td>
<td>50g</td>
</tr>
<tr>
<td>Power consumption</td>
<td>0.7W</td>
<td>&lt;0.5W</td>
</tr>
<tr>
<td>Slew rate</td>
<td>2°/s (4°/s Optional)</td>
<td>1° /s</td>
</tr>
<tr>
<td>Data update rate</td>
<td>10Hz (20Hz Optional)</td>
<td>5Hz</td>
</tr>
</tbody>
</table>

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**Nano star tracker** (with baffle)  
**Pico star tracker** (optical head only)
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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:

- Line image exposure
- Line image readout
- De-noise
- Line image processing
- Background analysis
Real-time image processing approach

Implementation

Morphology based image processing approach

Tsinghua University

Real-time image processing approach

Implementation

Morphology based image processing approach

Tsinghua University
Real-time image processing approach

➢ Simulation

Simulation result

- 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

Tsinghua University
Performance experiments

- In-flight Performance

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

Attitude information

Function monitor parameter from telemetry data
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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.
Thank you!

xingfei@mail.tsinghua.edu.cn
xingfei@ty-space.com
Department of Precision Instrument, Tsinghua University, Beijing, China
www.ty-space.com