

# Parameterization of the Star Tracker Measurement Process Model for CubeSats

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Aerospace Engineering Master's Thesis Proposal



CAL POLY

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# CONTEXT

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# CubeSat Technology

## Where are CubeSats in the industry?

- Developed at Cal Poly
- Cost-effective method to send things in orbit
- Technology has evolved
  - Missions have become more complicated
- OSIRISv2, PIXL
  - Intersatellite communication demos
  - Lack of affordable attitude determination sensors



Figure 1. Artist rendition of PIXL operations <sup>[1]</sup>

# Sensor Availability

## What are the options?

- Sun Sensors
  - $0.5\text{--}3.5^\circ$  @ \$10,000<sup>[2]</sup>
- Horizon Sensors
  - $0.5^\circ$  @ \$3,250<sup>[3]</sup>
- Star Trackers
  - 5 arcsec @ \$140,000<sup>[4]</sup>

Note: 3600 arcsec = 1 degree



Figure 2. Rocket Lab ST16RT2 Star Tracker<sup>[4]</sup>

# Star Trackers and CubeSats

## Can we fly star trackers?

- CubeSat missions are budget constrained
  - \$50,000 - \$200,000<sup>[5]</sup>
- Star Trackers are expensive
  - \$30,000+<sup>[6]</sup>
- Decision to make
  - Forfeit on mission opportunities
  - Work around mission requirements

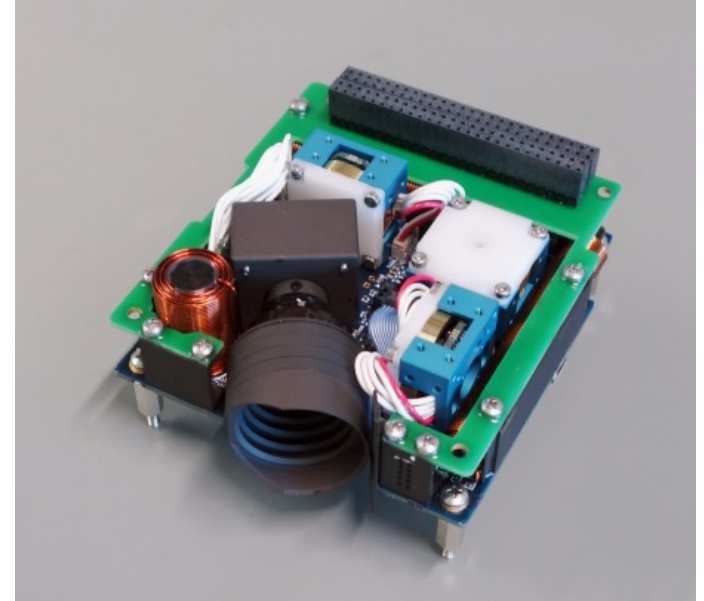


Figure 3. Berlin Space Technologies  
CubeSat star tracker

# The Guiding Question

“Are star trackers, when traded on performance, a viable solution for attitude determination in CubeSats?”

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# PROPOSED THESIS

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# Star Trackers

## What is a star tracker?

- Attitude Determination Sensor
- Uses images of “celestial sphere” and look-up catalogs
- 3 Main Processes
  - Image Capture
  - Centroiding
  - Identification

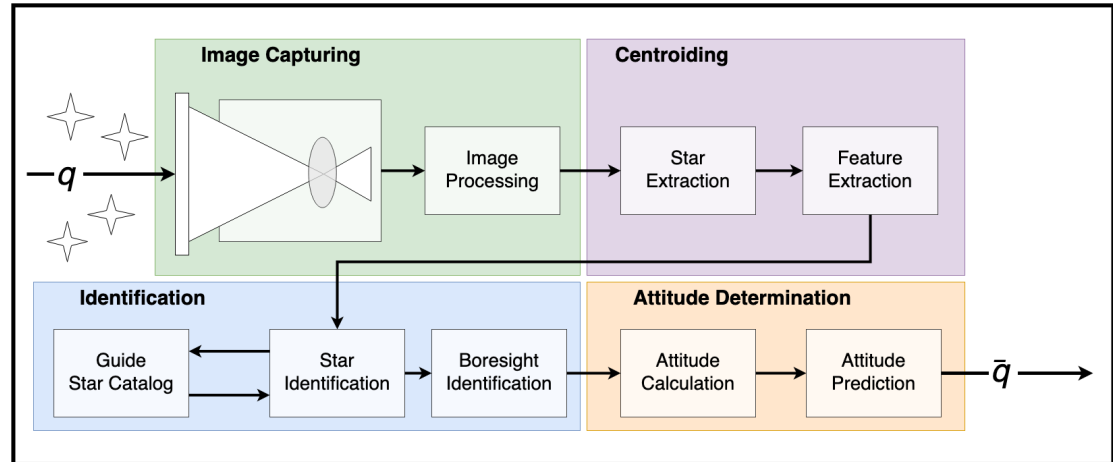


Figure 4. Star tracker operations; adapted from Y. Li, et al. (2022)<sup>[7]</sup>

# Error Propagation

“Important factors that affect star tracker accuracy include thermal drift, optical aberration, detector noise, and systematic error...” [8]

- Hardware
  - Optical Distortion
  - Focal Plane Bias
  - Noise
- Software
  - Systematic Errors
- Environment
  - Thermal
  - Radiation/Charged Particles
  - Body Rates

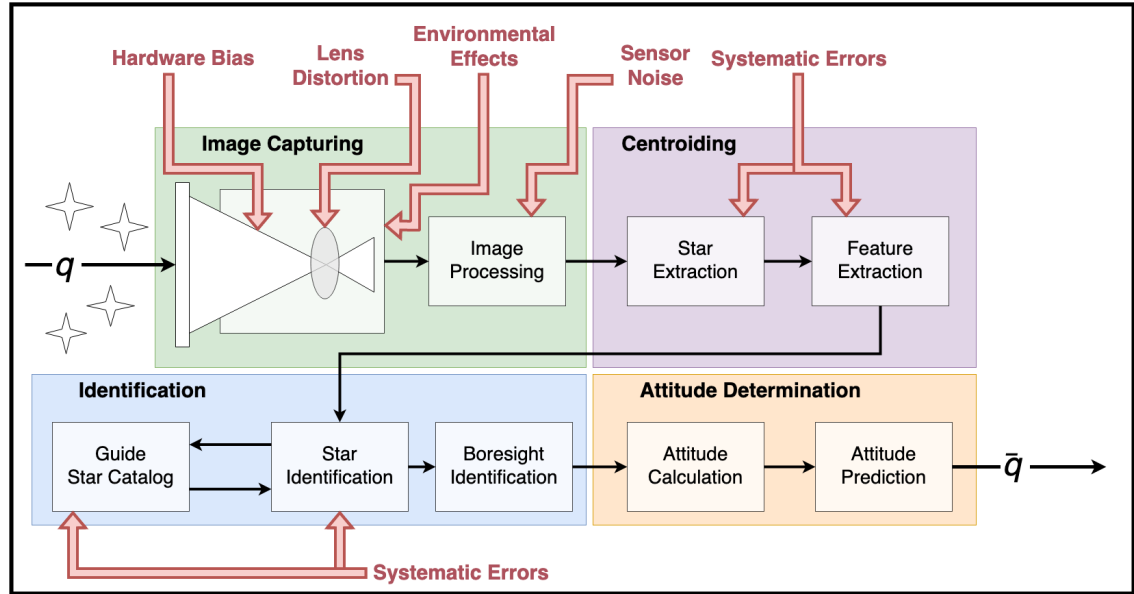


Figure 5. Star tracker error sources

# Proposed Thesis

## What will this thesis do?

- Analyze the measurement process in star trackers
- Develop a measurement process model
  - Environmental Effects
  - Hardware Effects
  - Algorithmic Effects
- Propose star tracker configurations with varying optimizations

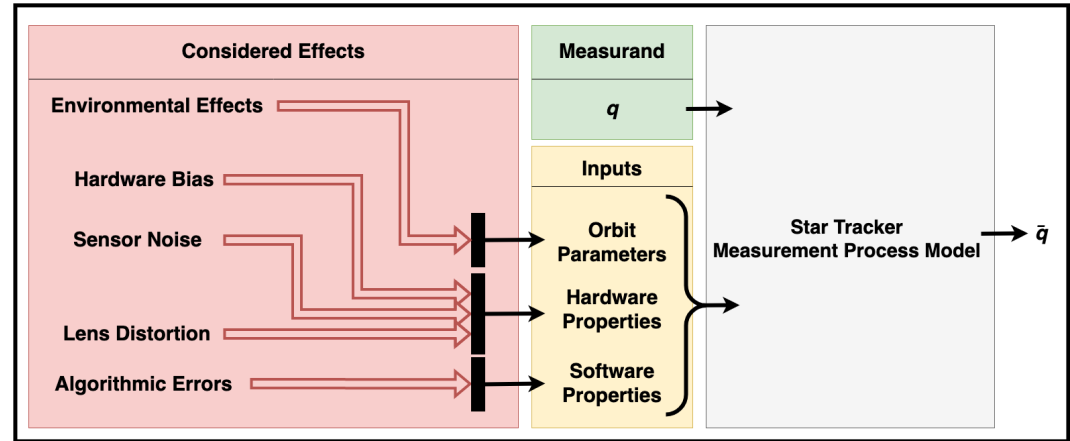


Figure 6. Star tracker errors and measurement process model

# Motivation

## Why is this thesis important?

- Filling the performance gap
  - Sun sensors and magnetometers (affordable, coarse)
  - Current star trackers (expensive, fine)
- Star Tracker Development
  - Analysis of external effects
  - Tool to provide preliminary evaluations

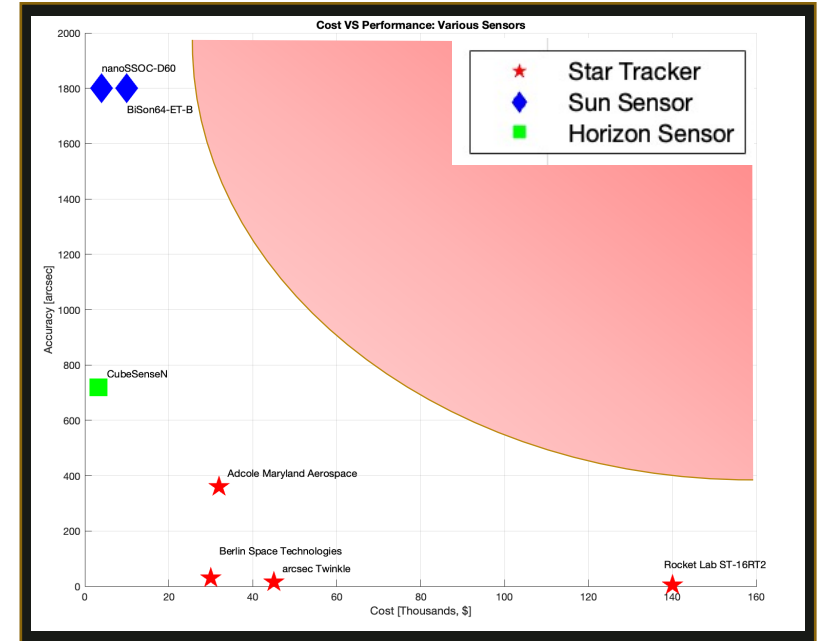


Figure 7. Cost VS performance for various sensors

# Audience

## Who's looking for a star tracker?

- CubeSat Developers
  - Stricter pointing requirements
  - Low budgets
  - Low volume
- Star Tracker Developers
  - Analysis of process optimizations
  - Inform on important considerations
  - Provide guidance on relating effects and performance



[9]

# Contribution

## What will this thesis provide?

- Measurement Process Model
  - Enable the community to develop hardware
- Inform Star Tracker Developers
  - Signify important considerations to minimize error propagation
- Identify areas to trade on performance for cost
  - Help close the gap in sensor availability

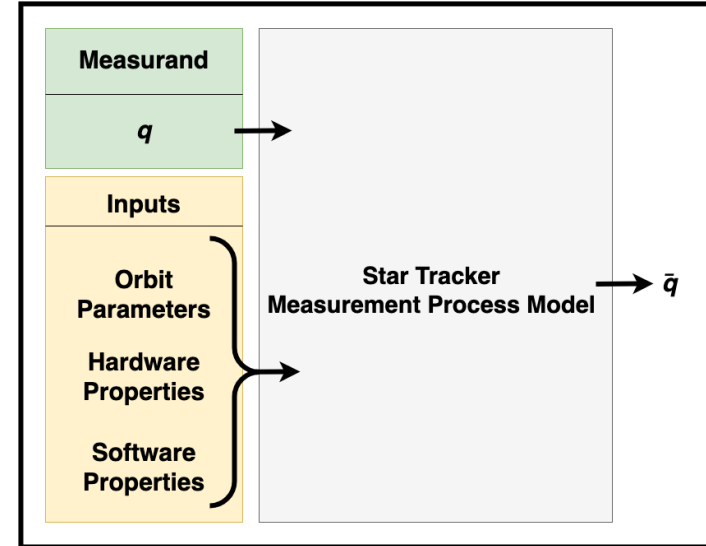


Figure 8. Star tracker measurement process model information diagram

# Scope

## What will this thesis consider?

- Focus on key concepts and effects
  - Hardware
    - Bias
    - Noise
  - Software
    - Algorithmic Errors
  - Environment
    - Thermal Environment
    - Radiation
- Finding models
- Develop Measurement Process Model

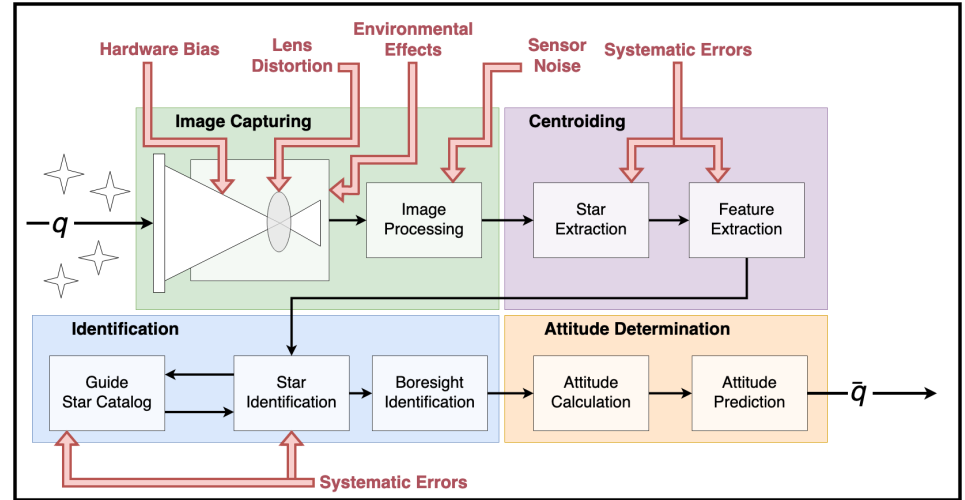


Figure 9. Star tracker error sources

# Methodology

## What strategies will this thesis employ?

- Research
  - Finding models
  - Determining Codependence
- Experimental Research
  - CPCL Star Tracker work
- Monte Carlo Analysis
  - Model combination
  - Measurement Process Model development
  - Derive accuracy and precision

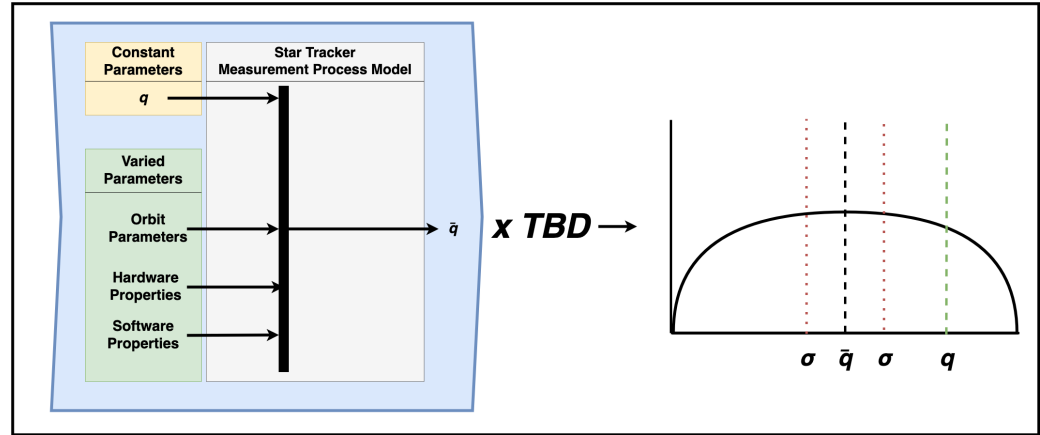


Figure 10. Monte Carlo Analysis Diagram



# Schedule

## Fall Quarter

- Literature Review
  - Understand current state
- Maintain catalog of models
  - Physics of different phenomenon
- Document work informally

## Winter Quarter

- Continue to catalog and combine models
- Develop Measurement Process Model
  - Continually validate model
  - Monte Carlo Analysis
- Document work informally

## Spring Quarter

- Finish Measurement Process Model
- Final Model validation
- Write thesis based on notes from Fall/Winter

# Success Criteria

## What is considered a successful thesis?

- Measurement Process Model has been developed
- Identified key areas of improvement
- Identified areas to trade performance for cost
- Case study of CPCL hardware/software for real life case

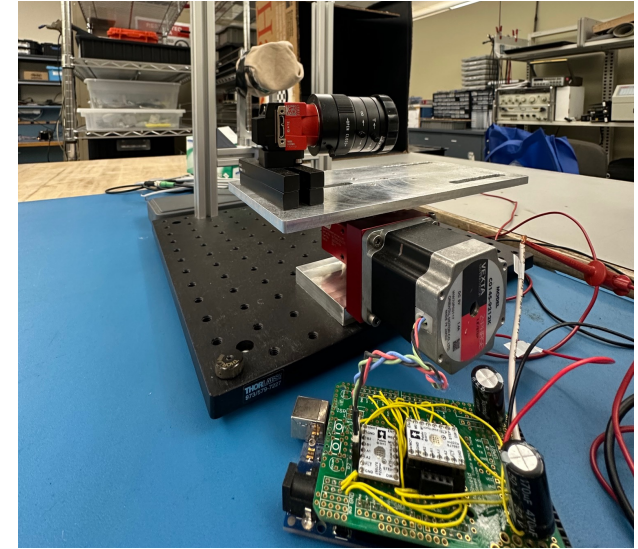


Figure 11. Cal Poly CubeSat Lab star tracker testbed

# Expected Challenges

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## What challenges are expected?

- Model Discovery
  - Literature may be sparse on affects specific to star trackers
- Model Combination
  - Co-dependence between parameters
- Model Validation
  - Little to no feasible experimental work for validation

# Challenge Mitigation

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## What challenges are expected?

- Model Discovery
    - Literature may be sparse on affects specific to star trackers
  - Model Combination
    - Co-dependence between parameters
  - Model Validation
    - Little to no feasible experimental work for validation
- Model Discovery
    - Research
    - Derive from first principles
  - Model Combination
    - Research
    - Monte Carlo Analysis
  - Model Validation
    - Research
    - “Heart Checks”
    - Informed assumptions
    - Consider single effects at a time

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<https://www.cubesatshop.com/product/bison64-et-b/>

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[3] SatSearch, "CubeSense N Horizon Sensor,"  
<https://satsearch.co/products/cubespace-cube-sense-n>

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[4] RocketLab USA, "Star Tracker ST-16RT2 Datasheet,"  
<https://www.rocketlabusa.com/assets/Uploads/RL-ST16RT2-Data-Sheet.pdf>

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[5] Anders Nervold, Joshua Berk, Jeremy Straub, and David Whalen. A pathway to small satellite market growth. *Advances in Aerospace Science and Technology*, 01:14–20, 01 2016.

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[7] Y. Li, X. Wei, J. Li and G. Wang, "Error Correction of Rolling Shutter Effect for Star Sensor Based on Angular Distance Invariance Using Single Frame Star Image," in *IEEE Transactions on Instrumentation and Measurement*

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[8] Hui Jia, Jiankun Yang, Xiujuan Li, Juncai Yang, MengFei Yang, YiWu Liu, and YunCai Hao. Systematic error analysis and compensation for high accuracy star centroid estimation of star tracker. *Science China Technological Sciences*, 53:3145–3152, 11 2010.

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[9] Scale, Target, Dollar figures from Creazilla  
<https://creazilla.com/>

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# Questions?

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