RYERSON UNIVERSITY

Calibration Techniques for Low-Cost Star Trackers

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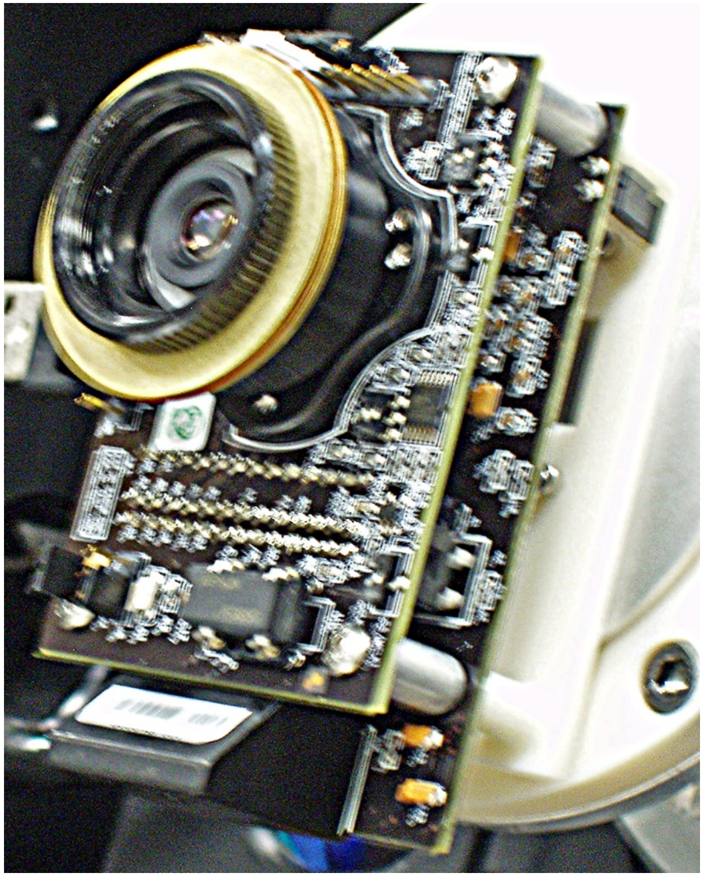
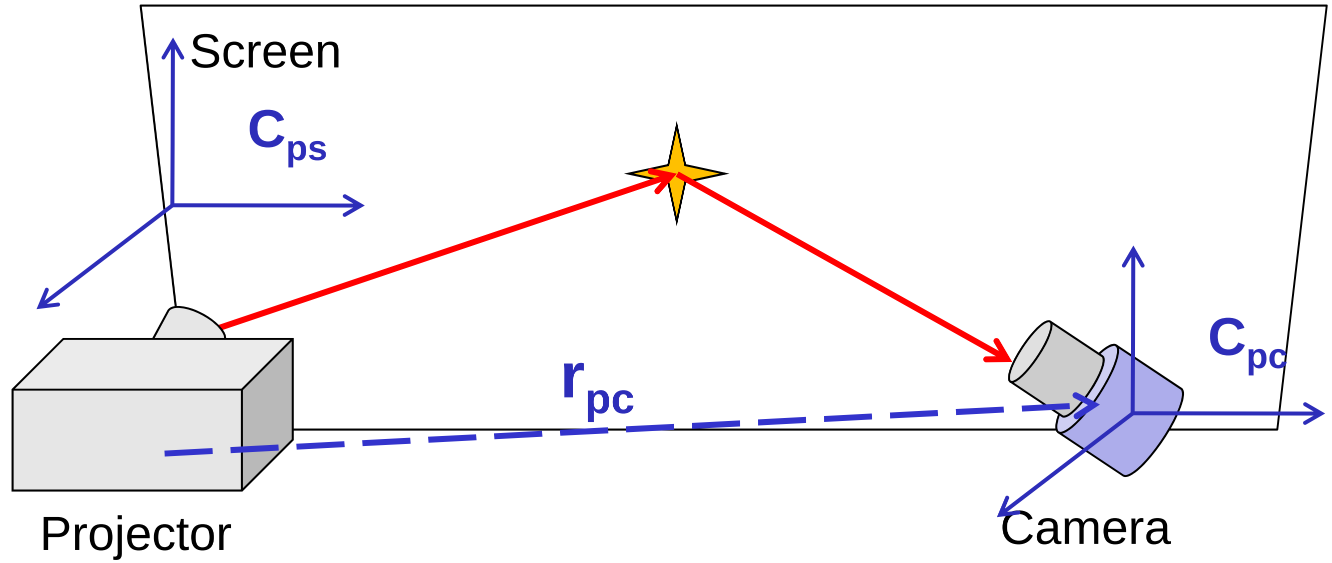
Motivation

- Lots of interest in nanosatellite-class star trackers
  - 3-axis, single-instrument solution.
- We've been working on concept at Ryerson University
  - Commercial 5 MP, Color, CMOS detector
  - 2592 x 1944, 7.13mm (diag) detector
  - F/2.0 Lens
- Cost-Effectiveness Challenges
  - Recurring Costs
  - Test Equipment/Fixturing
  - Labor Skill-Set
  - Shared facilities
- Techniques themselves aren't particularly earth-shattering.
  - Robust performance, modest accuracy, low cost.



Lab Calibration



Problem Characteristics:

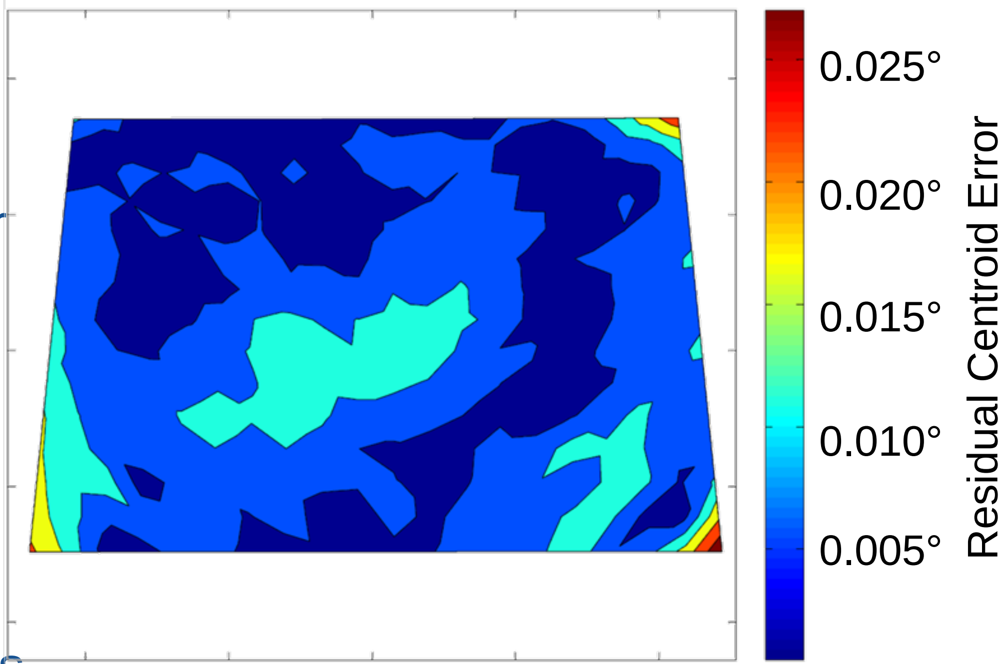
- Need accurate star-field projection for pattern matching tests.
- Algorithm Validation
- Challenges
  - Unknown tolerances
  - Poor registration

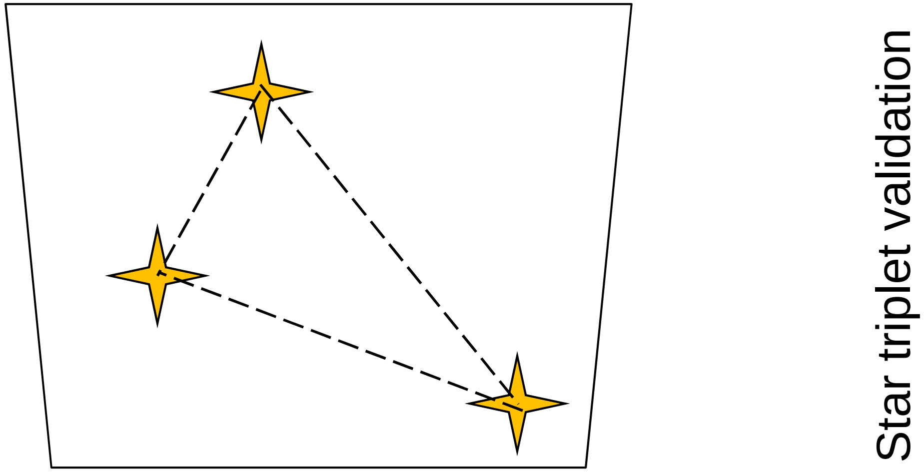
Solution Elements:

- Digital 'pre-blur' (centroid control)
- Ray model of light path (11 parameters), Distortion coefficient
- Test pattern projection, least-squares model optimization.
- Geometry Correction during testing

Lab Calibration Results

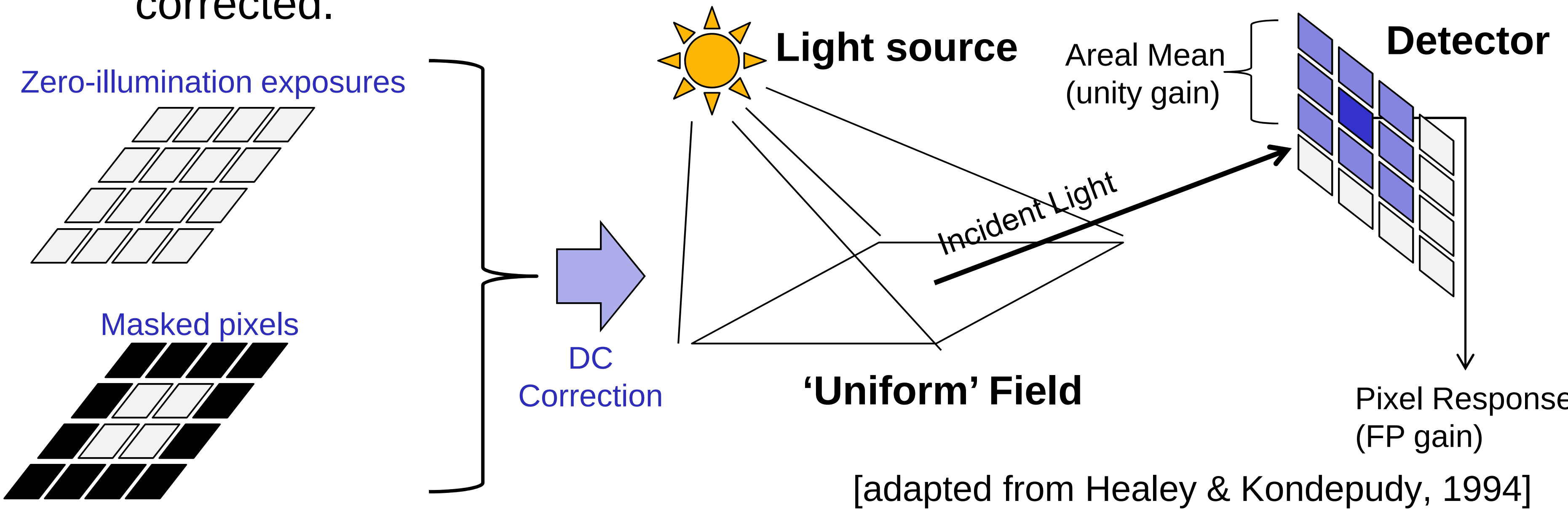
- Good optimization convergence
  - Mean error 0.007°, Max. error 0.031°
  - Projector resolution is limiting factor (0.033° pixel size)
- Modest calibration time
  - Few minutes of labor
  - 10-15 min. automated process
- Validation using mock star triplets
  - Measure arc-lengths and dihedral angles
  - Accuracy agrees with model residuals





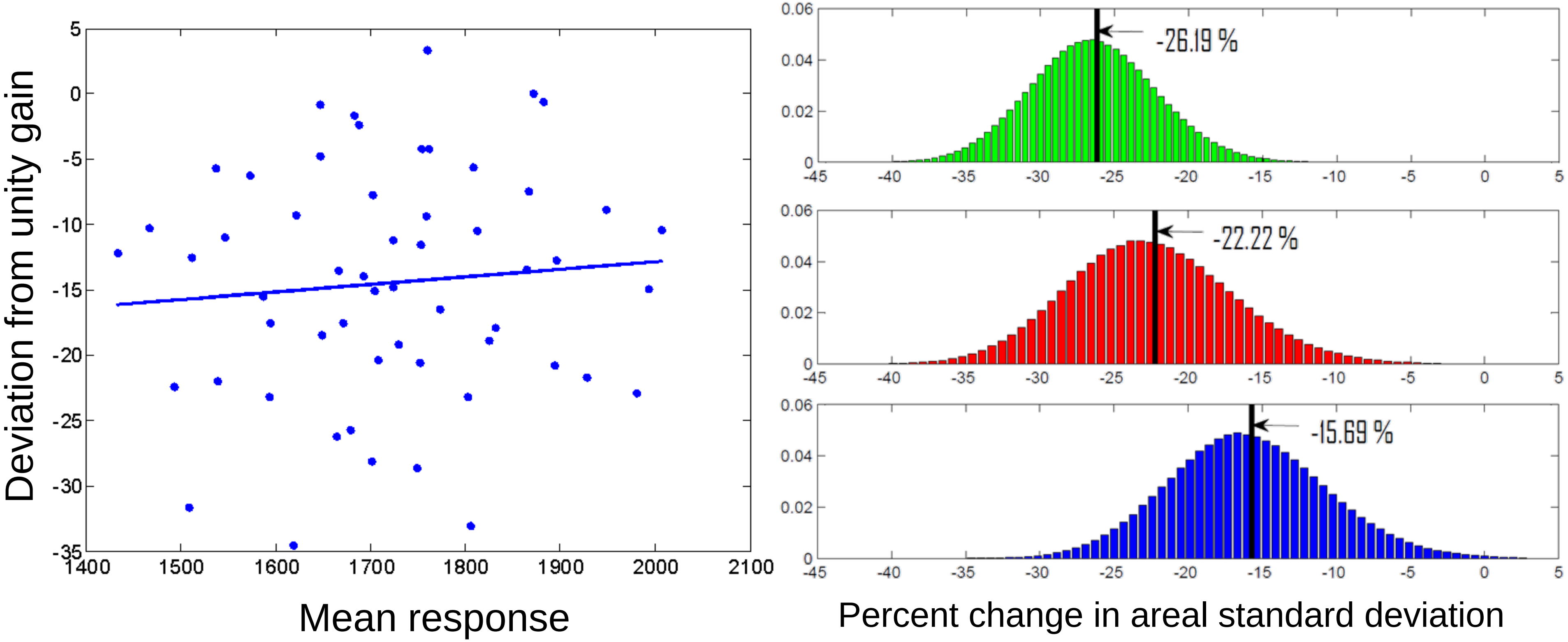
Detector Noise Calibration

- Priorities for successful inexpensive star tracker:
  - Need to see stars (Reliable low-SNR detection)
  - Need to estimate star location (Centroid estimation accuracy)
- Noise sources affect star detection and centroid estimation accuracy
  - Particularly important for dim stars
- Dark Current (DC) and Fixed-Pattern (FPN) noise can be (partially) corrected.



[adapted from Healey & Kondepudy, 1994]

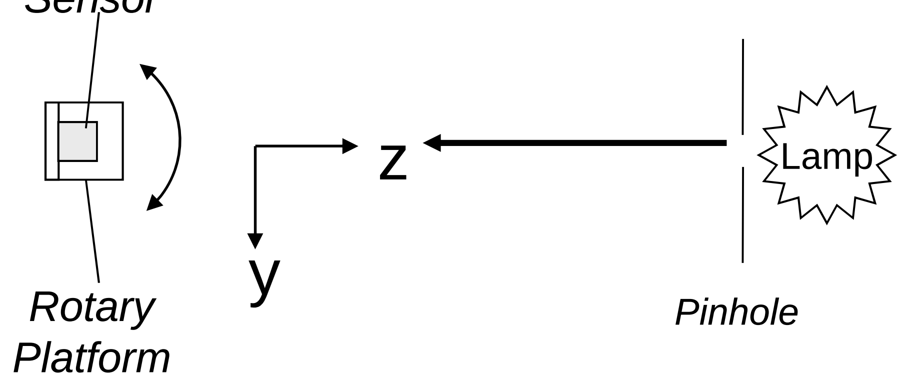
FPN Results

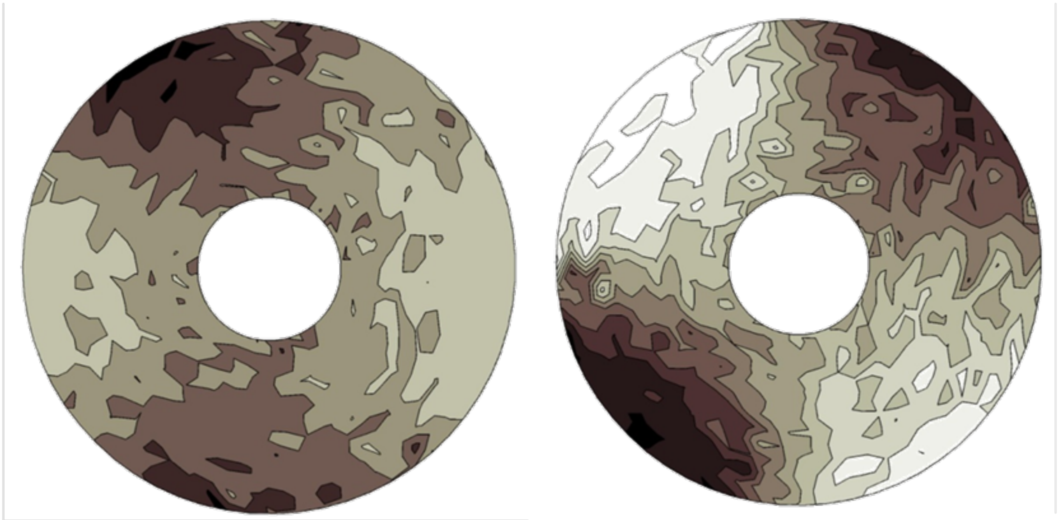


- Reasonable (but not extraordinary) improvement in FPN variability.
- Currently looking at effect on detection
- Tradeoff between offline/online DCN correction
- FPN correction can be storage-intensive (at least 1 byte/pixel)

Aberrations

- Optical aberrations present in most systems
  - Difficult to correct in simple optical designs.
  - Leverage SW to supply corrections.
- Rotary test stand plays large role.
  - May be costly, but greatly simplifies test process.
- Calibrate from source to star **shape** and **position**
- Storage requirements depend on calibration representation





σ_x variation $\qquad$ ρ variation

Conclusions

Method	Labor Time	Total Time	Storage or Computation
Lab	Few Minutes	~15 min.	N/A
FPN	~15 min	~20 min.	High
Aberrations	~5 min	~30 min.	High/Low

- Clear, if local, results in all calibrations
  - Work continues on assessing impact on detection thresholds
- Minimal reliance on expensive test hardware.
  - Some degree of aberration mapping will be needed.
  - Infrastructure investment.
- Labor requirements pretty modest.
- One hidden challenge
  - Detector/Optical alignment not easily observable