Coded Aperture Imaging

Cooperative Agreement (CA) Partnerships with Universities and NASA Centers
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This document has been reviewed and determined not to contain export controlled technical data.

The Team

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The Technology

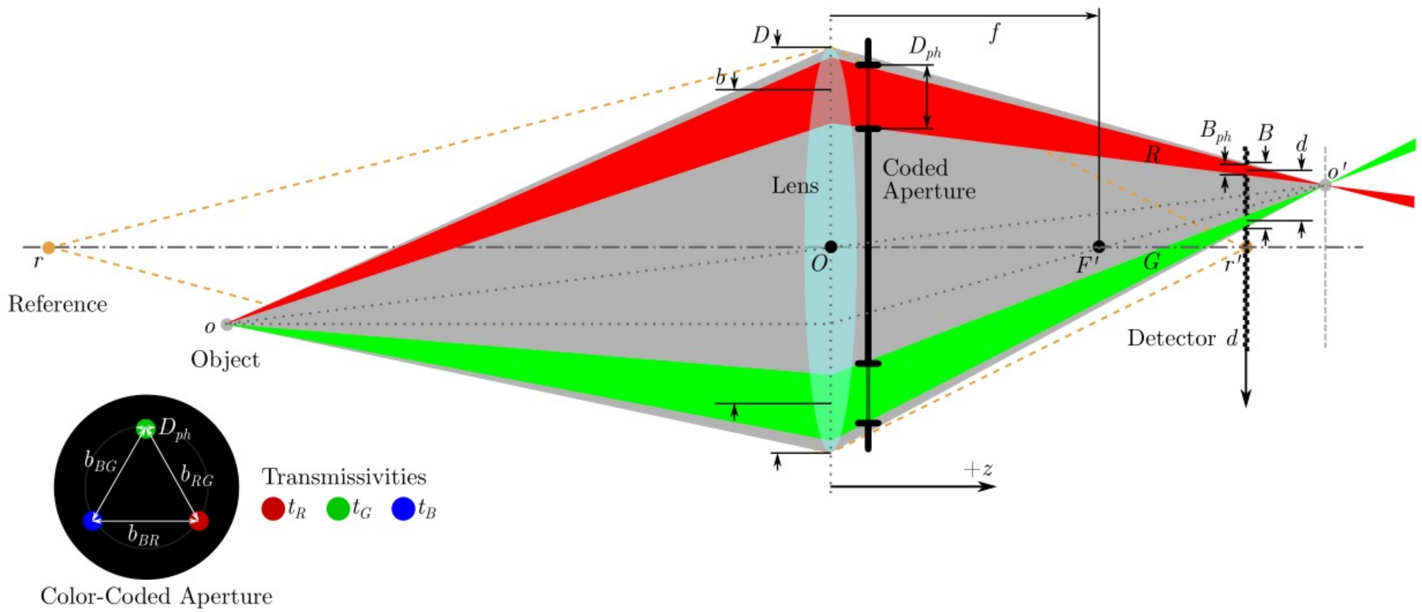
- MIT Investigation
  - Development of a time-windowed, efficient smoothing software for incremental estimation of relative poses and velocities between multiple, small, differently instrumented spacecraft.

- JPL Investigation
  - A compact depth sensor based on coded aperture imaging capable of sensing other spacecraft in the formation or at close proximity.

- Collaborative Investigation
  - Installation of a color-coded aperture on the SPHERES ground testbed.

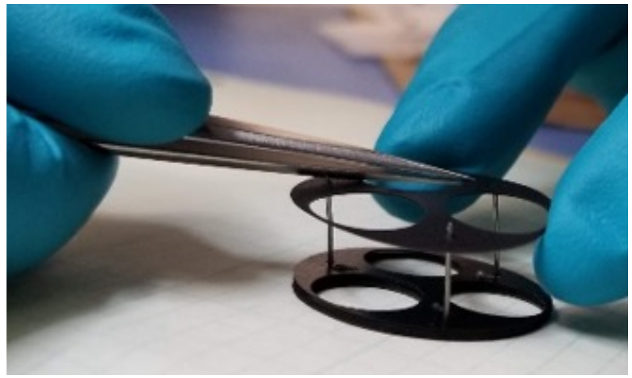
Principles of Operation

- Conventional aperture replaced with a “color-coded aperture”
- Lens deliberately defocused to induce depth-dependent “disparity” between color channels
- Equivalent to narrow-baseline stereo vision in a single camera
  - Block matching stereo algorithms are used for image processing
- Investigated as a compact / low-power alternative to LiDAR / stereo cameras for formation flight and proximity operations
- TRL: 3 → 4

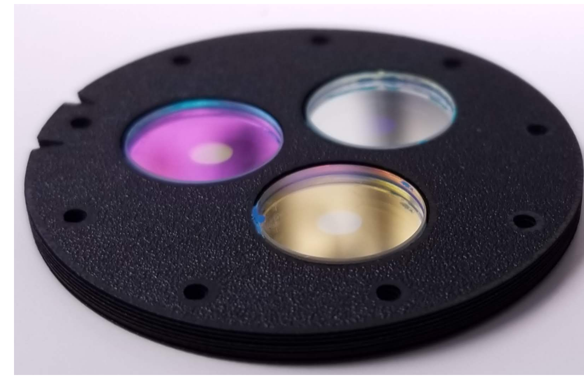


Assembling Hardware Prototype

Glass color filters

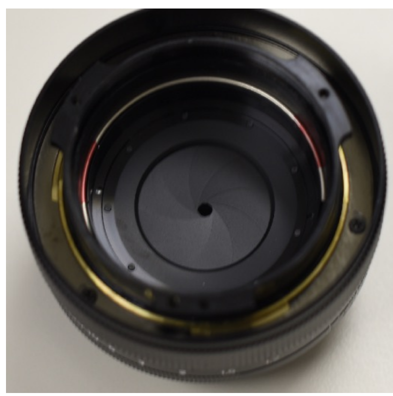


Stacking laser-cut styrene



Assembled aperture

Zeiss 50 mm lens



Original aperture

50 mm lens w/ cc ap

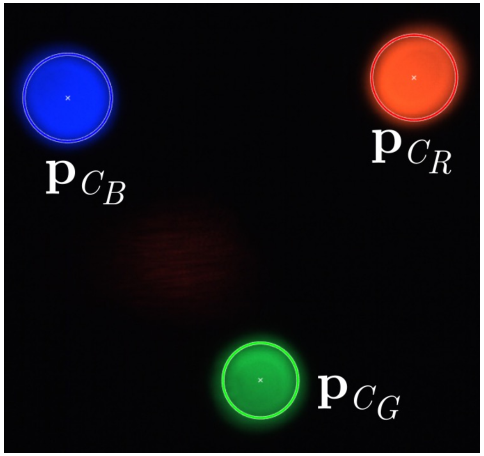
85 mm lens w/ cc ap

Calibration

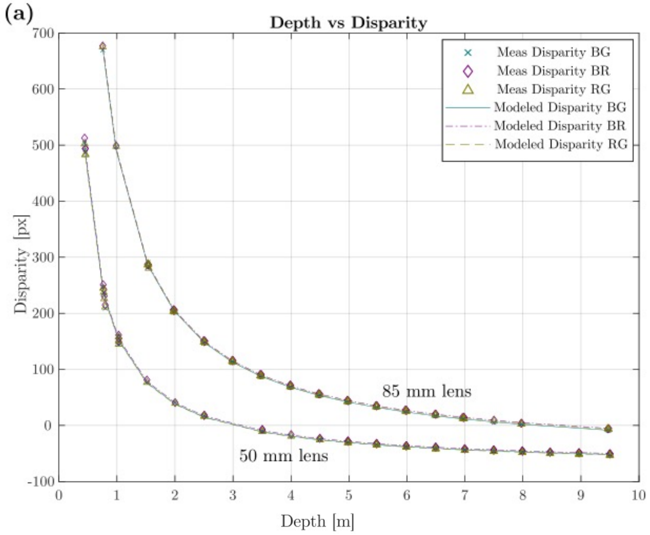
- Point light sources imaged with camera
- Point-spread function related to depths measured by Leica Total Station Laser Rangefinder

Calibration setup

- Distance between centroids in image (disparity) is related to distance between camera and point light sources (depth)



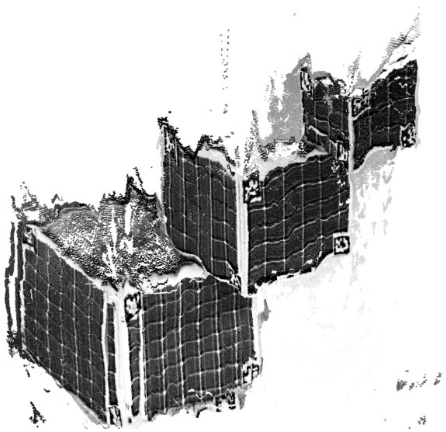
Point spread function and centroid extraction



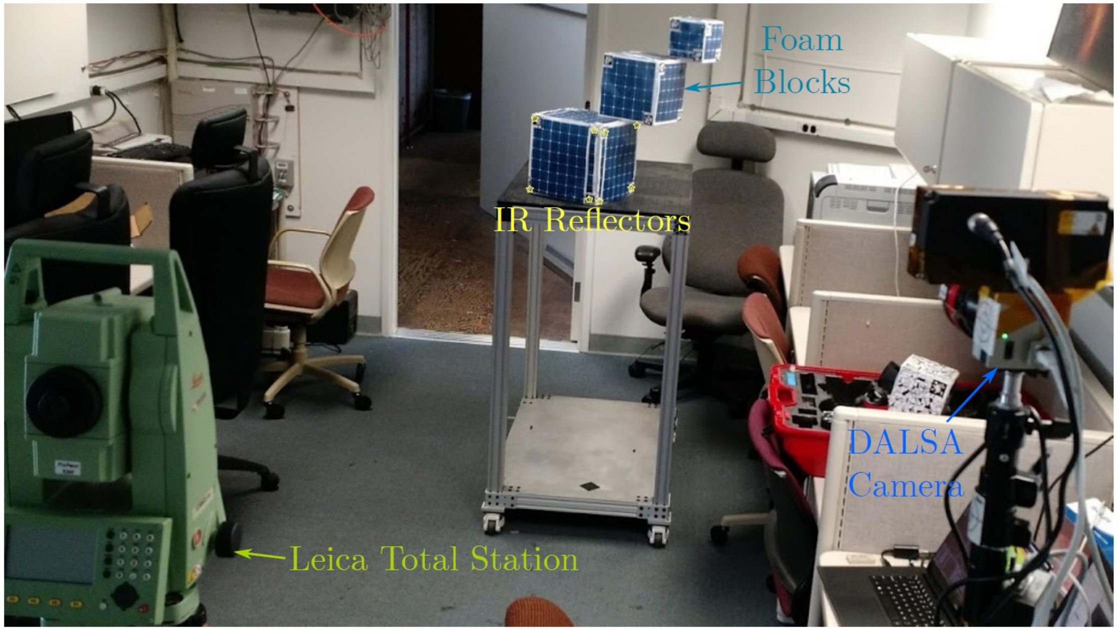
Calibrated depth vs. disparity

Dense Depth Sensing

- Conventional stereo block matching algorithms used to determine disparity
- Foam blocks with solar panel texture were imaged from 2-8.5 m
- Leica Total Station measurements were taken to IR reflectors at face corners, allowing for “ground truth” plane interpolation

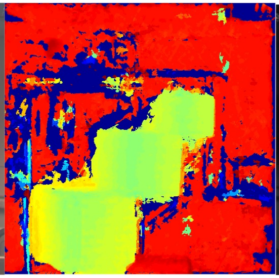


Example point cloud

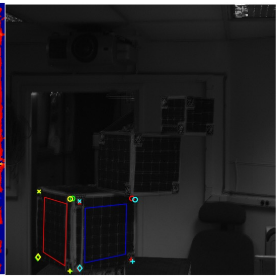


Evaluation setup

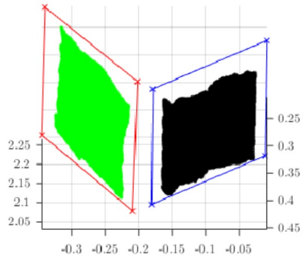
Raw image



Depth results



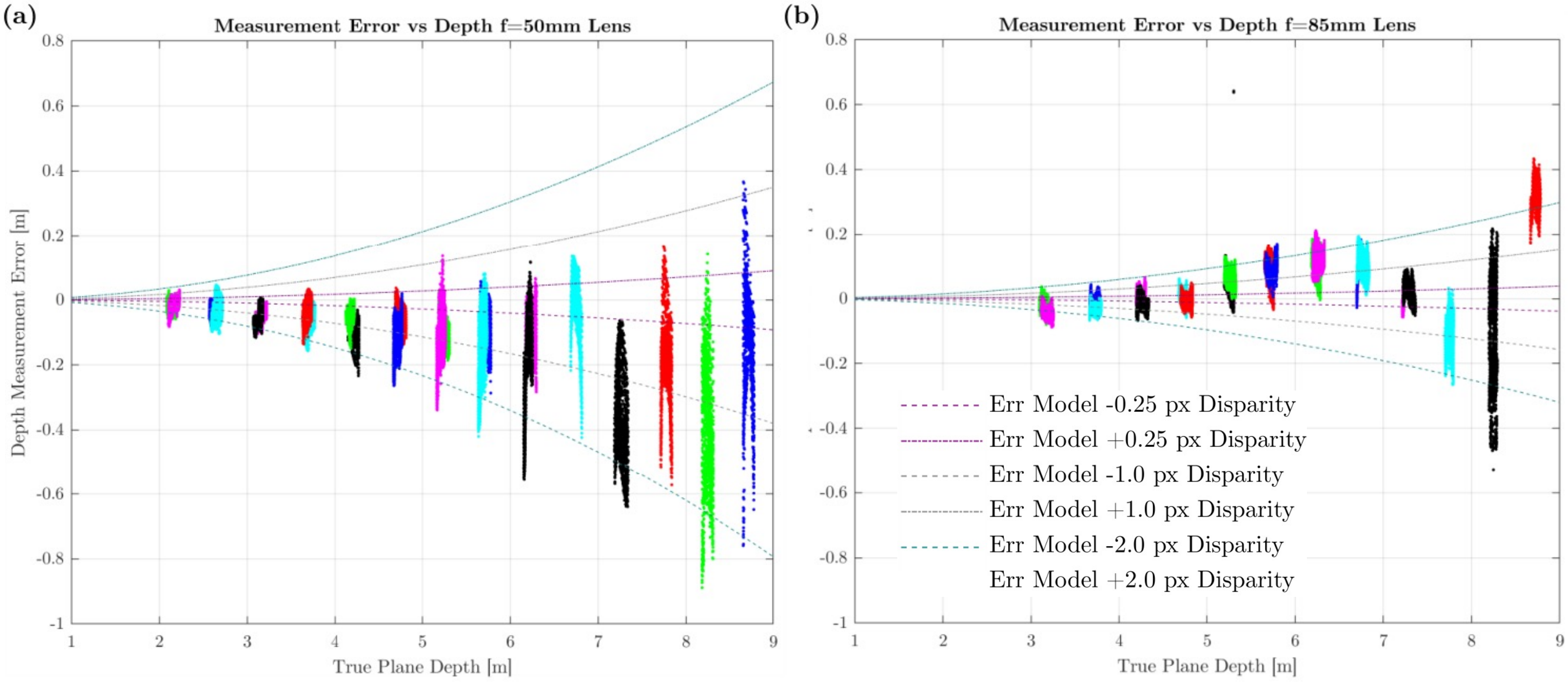
IR reflectors



Point cloud vs ground truth plane

Results

- The f=50mm lens has a wide field-of-view but is not suited for long range
- The f=85mm lens has a narrow field-of-view but is better suited for long range
- Both lenses nearly follow the +/- 2px disparity error model



Resultant error vs distance, compared with disparity error models

Discussion & Conclusions

- Publications
  1. Teran, A. and Setterfield, T. (2019) Point-to-CAD 3D Registration Algorithm for Relative Navigation Using Depth-Based Maps, IEEE Aerospace Conference
  2. Setterfield, T. et al (2019) Depth from a Calibrated Color-Coded Aperture Camera using Disparity, NASA JPL NTR 51096

- Principal of operation is similar to three camera stereo-vision with vergence
  - As a result, ranging over long distances requires a large baseline, and thus a large aperture, or large focal length
- Advantages
  - At short ranges, provides a solution for passive, compact, depth sensing (low SWaP)
  - Less likely to fall out of calibration than stereo cameras, which depend on structural rigidity
  - Applicable to small satellites at short ranges (i.e., proximity operations)
- Disadvantages
  - Long-distance ranging requires impractically large apertures

- Currently at TRL 4, and not packaged for space
- Applicability of technology to potential demonstration missions
  - Small satellite missions requiring low SWaP dense depth sensing over < 10 m

Thank You!

Questions?

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