COE CST Third Annual Technical Meeting:

Autonomous Rendezvous and Docking

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COE CST
Center of Excellence for Commercial Space Transportation

Overview

- Team Members
- Purpose of Task
- Research Methodology
- Results or Schedule & Milestones
- Next Steps
- Contact Information

Team Members

- PI: Dr. Penina Axelrad, University of Colorado Boulder
- Dr. Jay McMahon
- Students: Aerospace Engineering Sciences
  Steve Gehly (PhD student)
  Heather LoCrasto (MS student)
- Industry Partner: Ball Aerospace

Purpose of Task 244

- **Purpose:** To develop overall rendezvous, approach, docking methodology
- **Objectives**:
  - Standards are required to enable the FAA to license multiple vendor vehicle systems to make orbital rendezvous and docking a routine and safe activity.
  - These standards must be established to define appropriate requirements for safe operations without specifying a particular design.
  - Increase autonomy, improve flexibility, robustness, reduce cost
- **Goals**: The goals of this project are to develop a draft set of standards and to fill key technology gaps for automated rendezvous and docking of vehicles in LEO/GEO encompassing approach trajectories, sensing, estimation, guidance and control, and human interaction.
  - Systems engineering analysis for draft standards
  - Feasibility of Flash LIDAR based relative position and attitude

Target Missions

Increasing Challenge →

Knowledge	Marked	Drawings	None	
Controlled	Active	Passive Stable	Tumbling	
Cooperative	Maneuvers	Measurements 2-way Comm	2-way Comm	None

Configuration	Knowledge	Controlled	Cooperative
Refuel/Material Delivery	Marked	Active	2-way Comm
	Drawings		None
Repair/Retire	Marked	Passive Stable	None
	Drawings		
Debris Disposal	None	Tumbling	None

Mission Phases

Phase	~Range	Objective	Sensor	Safety
Launch	>10,000 km	• Insert chaser into orbit in same orbit plane, below target	GPS	Resume mission on nav failure
Phasing	>5 km	• Reduce range to target • Chaser acquires initial aimpoint for approach	GPS	
Homing/Closing	5000-250 m	• Relnav • Reach then enter approach ellipsoid	Radar, Lidar, RGPS	• Preclude collision • Maintain target sensing
Final Approach	0-250 m	• Chaser achieves docking capture conditions • Interfaces within docking range	Optical, RF, LIDAR	• Preclude collision • Low velocity • Keep-out zone • Avoid plume impingement

Key Technology – Flash LIDAR

Motivation

- Flash LIDAR may be a key sensor that makes ARD more practical
- Provides range measurements to a variety of points on target object, allowing the relative position and attitude to be estimated
- As an active sensor, LIDAR is robust to poor lighting conditions and offers an advantage over traditional optical measurements

Study Objectives

1) To generate a realistic model of flash LIDAR measurements and determine the levels of accuracy and uncertainty anticipated in ARD scenarios

2) To understand how sensor noise and errors in calibration affect predicted performance

3) To evaluate the information/measurement profile and maneuver accuracy required to achieve specific position and attitude accuracy

Flash LIDAR for Relative Navigation - Overview

- Actively illuminates target spacecraft
- Combination of pulsed laser with flash focal plane array returns both a range and intensity measurement (3D image)
- High frame rates (up to ~30 Hz)
- Instruments made by Ball and ASC have flown on space shuttle missions
- Does not require target cooperation
- Reduces slewing/pointing requirements and search algorithms with respect to single beam systems
- ASC chosen to provide a flash system for OSIRIS-Rex mission
- Challenges: systems are new and still being developed; each pixel must be characterized/calibrated

Ball’s VNS system for Orion

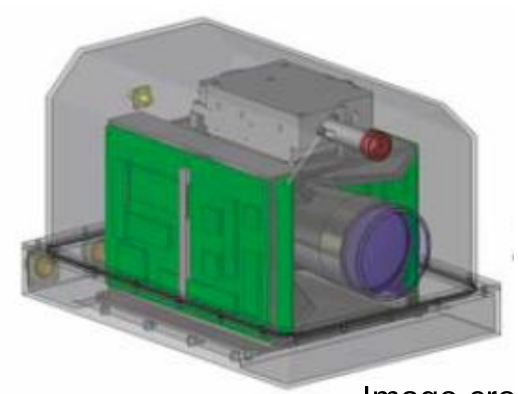


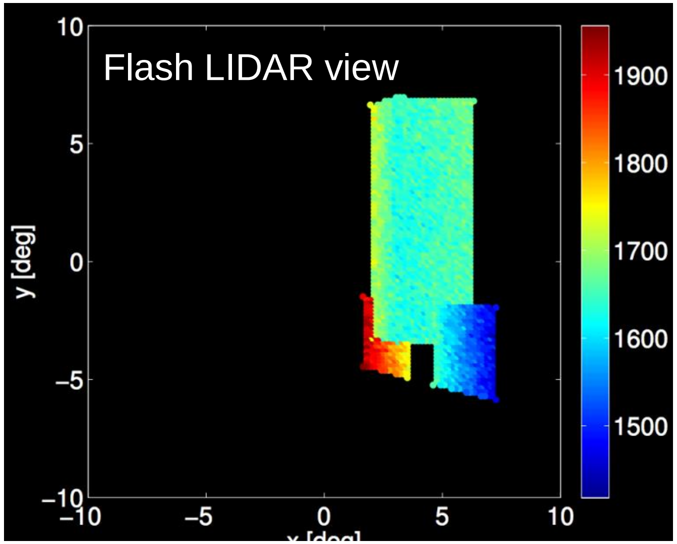
Image credit: R. Craig & P. Earhart, Ball Aerospace & Technologies Corp.

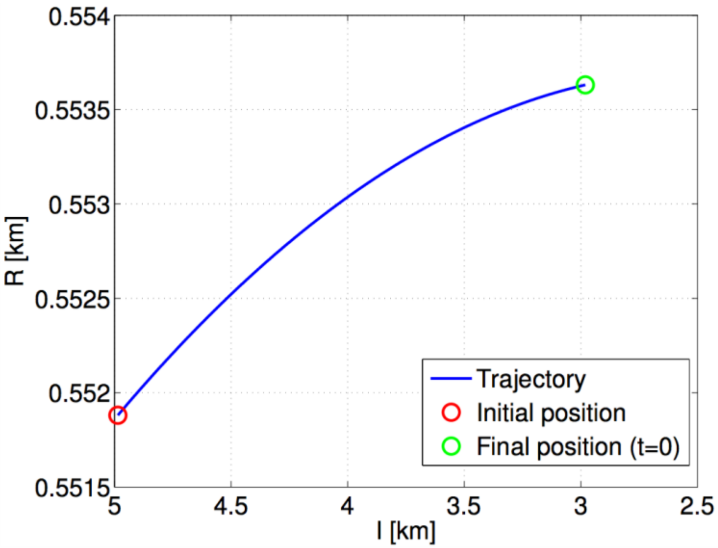
ASC’s DragonEye system on the Shuttle

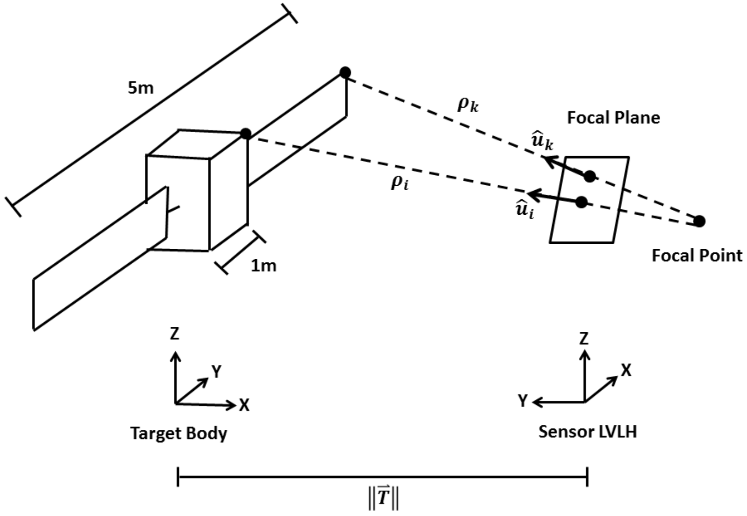
Image credit: R. Stettner, Advanced Scientific Concepts, Inc.

Flash LIDAR for Relative Navigation - Modeling

- Instrument Characteristics: 256 x 256 array, 20 deg FoV, random range errors with 1-sigma of 1% added, pointing errors due to finite pixel size
- For phasing stage, measurements are averaged, knowledge of target shape not required, creates errors in estimates on the order of size of target
- Modeled an ISS type approach to an Iridium style satellite: phasing catches up from below/behind, burn to transfer to slow approach



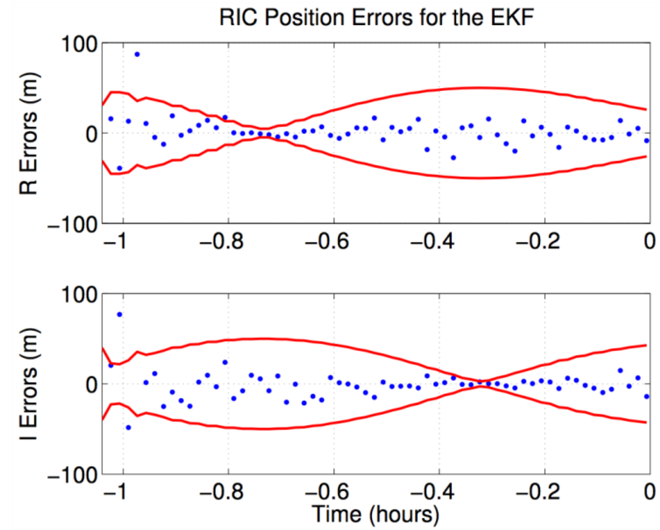




Flash LIDAR – Phasing Results

Phasing Orbit Determination

Target acquisition at 5 km (at -1.2 hours)
Initial errors [radial, in-track directions]:
  [1 -1] km, [1 -1] m/s
Measurement taken every 60 seconds
Start updating state with EKF after 10 measurements
Process noise added

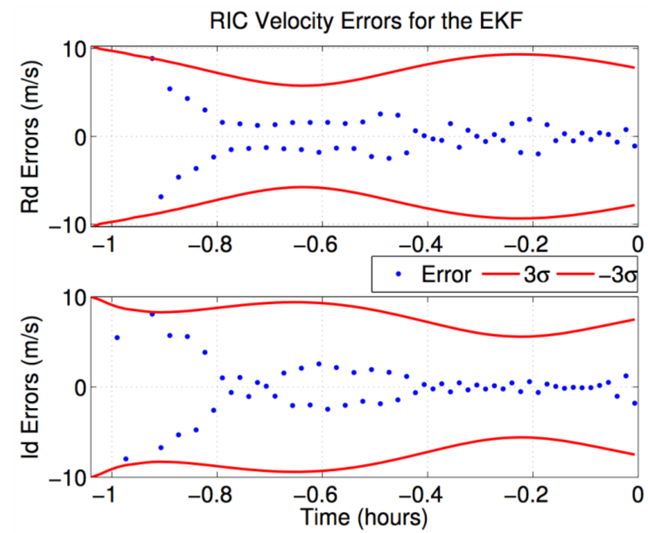


Results:

Post-fit residuals:
 range = 0.32 meters , angle in plane = 1.0e-05 deg

<u>Measurement interval 60 sec</u>
  Position RMS = [70.9, 58.7] m
  Velocity RMS = [5.78, 3.956] m/s

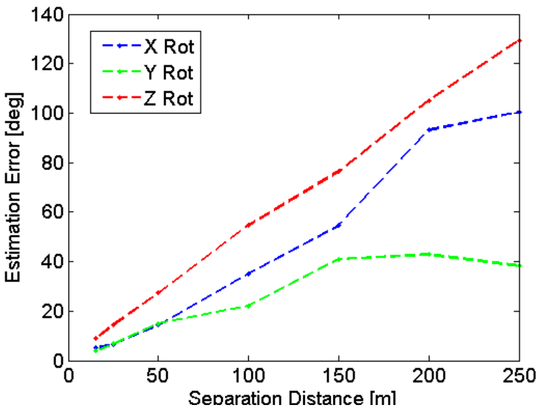
<u>Measurements interval 10 sec</u>
  Position RMS = [9.82, 15.0] m
  Velocity RMS = [1.02 2.85] m/s



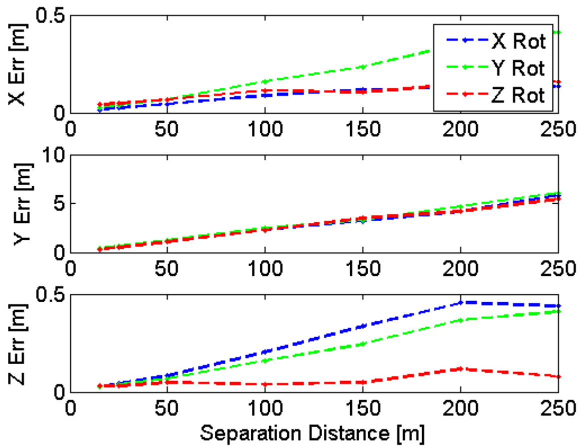
Flash LIDAR– Final Approach Results

250 to 15 meter separation

RMS errors computed for rotations from 1-90 deg about each axis as a function of separation distance



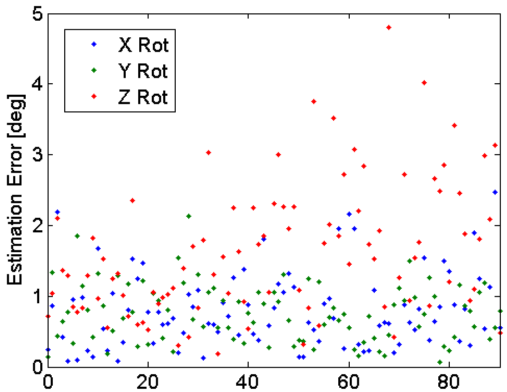
Attitude errors grow quickly with distance



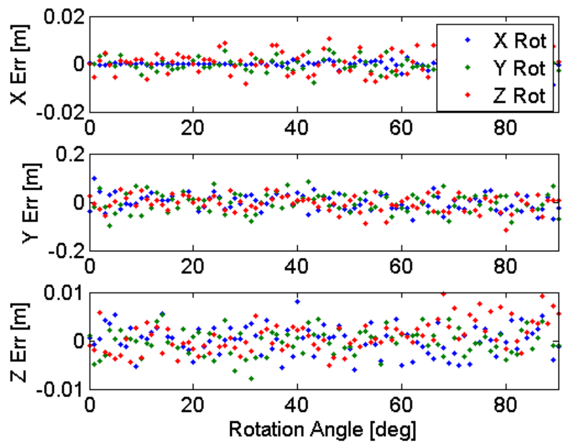
Position errors worst in along-track (y)
~ 5m at 250m

15 meter separation

Attitude and position estimation errors for rotations from 1-90 deg



Attitude errors under 5 deg for all cases



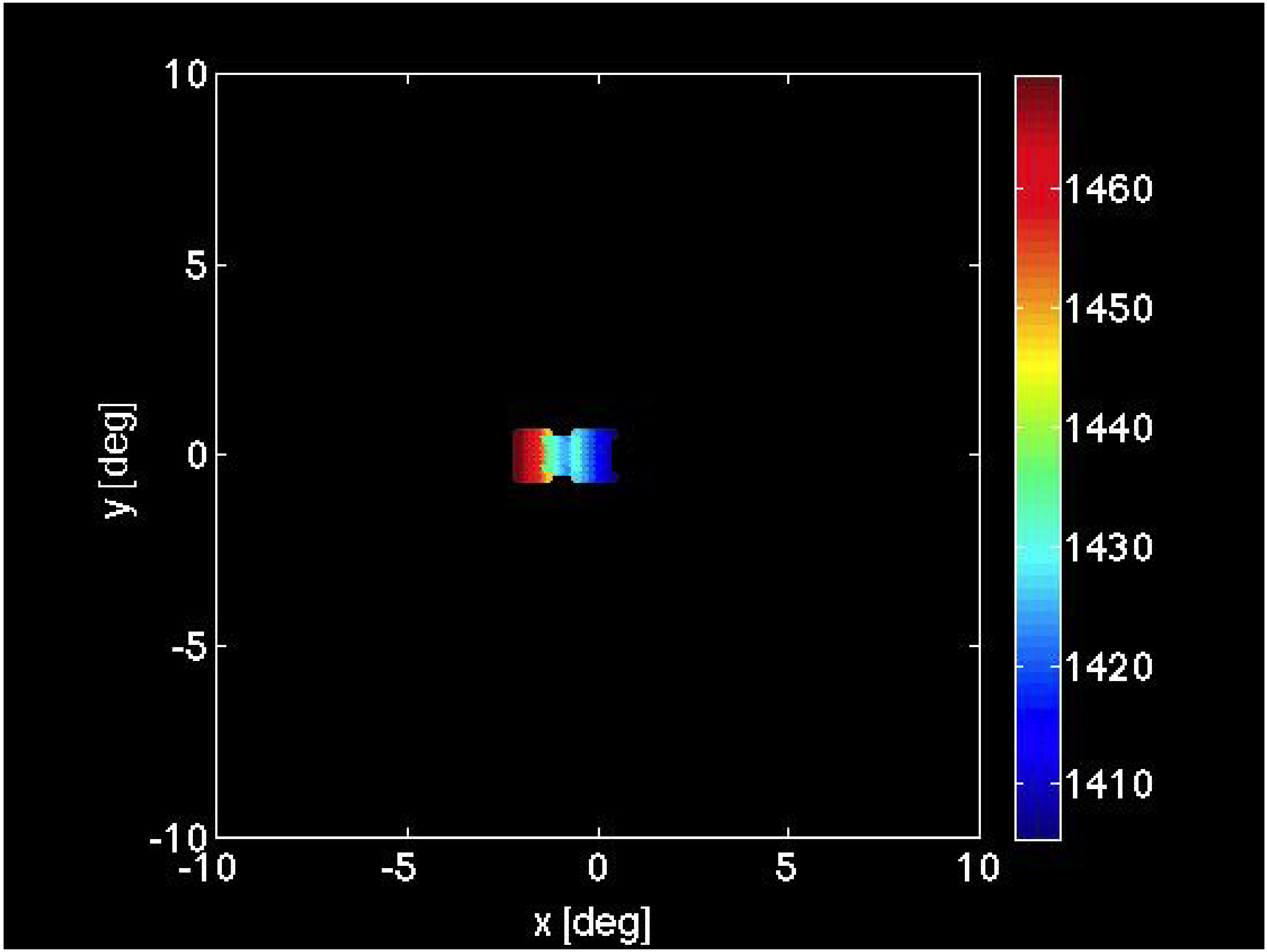
Position errors worst in along-track (y) direction, due to noise in range measurements

Next Steps

- Research and analyze US and ISO regulations, standards and guidelines for ARD
- Identify critical requirements and determine if existing approaches support these requirements without overconstraining design
- Describe common/good ARD architecture options and perform trade-offs

- Implement feature identification algorithm
- Use Flash LIDAR simulation to quantify uncertainty for position and attitude under various approach trajectories & vehicles
- Develop/implement algorithms for unknown target configuration in Flash LIDAR simulation
- Incorporate models for calibration errors

Questions?



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