Mission Design and Concept of Operations of a 6U CubeSat Mission for Proximity Operations and RSO Imaging

Overview

• Introduction
• Mission success criteria
• Concept of operations
• 6U Cubesat design
• Conclusions
University NanoSat Program

Air Force Office of Scientific Research: funding
Air Force Research Lab: management

Hardware demonstration
Hands-on experience
Funding
Mission military relevance
Aerospace Industry
Department of Defense

Advancing capabilities in U.S. space superiority
Team

- Embry-Riddle Aeronautical University
  - “Prime Contractor”
  - Overall design procurement and integration
  - PI: Bogdan Udrea
- University of Arkansas
  - Nanosat propulsion system
  - Co-I: Adam Huang
- Red Sky Research LLC
  - Science
  - Co-I: Mikey Nayak
Addresses 3 of 15 prioritized USAF space capabilities:

4. Space situational awareness
8. Satellite operations
10. Offensive space control

Advances Rendezvous & Proximity Ops (RPO) technology

XSS-11 autonomous proximity operations.
(Image from spacetoday.org)
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Science Problem Statement

- Perform relevant space-based SSA with a nanosat
- Without a priori knowledge of RSO shape or attitude:
  - Assess the capability of the visual and visual-aided navigation algorithms to:
    1. Extract 3D shape knowledge of the RSO
    2. Estimate the attitude state of the RSO
  - Perform infrared radiometry science
- Execute near-optimal trajectories to maximize space-based surveillance of the RSO in low earth orbit
- Validate on-board autonomous relative trajectory
  - Planning
  - Control
  - Execution
Mission Success Criteria

• **Minimum success**
  Take an unresolved image of the RSO and downlink it to the ground station.

• **Full success**
  Maneuver into the proximity of the RSO, with preloaded commands, and take an image in which the RSO occupies at least 15% of the pixels of the visible and IR spectrum cameras.

• **Extended mission success**
  On-board planning and execution of maneuvers to acquire a relative orbit with respect to the RSO and use the LRF to generate a 3D point cloud.
Imaging Results - Simulation

Unknown RSO: Upper stage with attachment of interest

Results of Autonomous Proximity Imaging
With robust RSO attitude solution, LRF-only sensor can recover shape knowledge of unknown RSO.

LRF-only point clouds: 89,000 / 11,000 / 3,500 strikes

Shape reconstruction after: 32 / 12 / 4 hours of surveillance
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Overall Concept of Operations

1. Launch
   - 500km
   - Orbit: LEO
   - LV: TBD

2. Ejection from CSD

3. Partial solar panel deployment

4. Detumble and sun acquisition

5. Complete solar panel deployment and uncovering of payload

6. Early orbit and systems checkout
   - Minimum mission success

7. RSQ approach
   - ADCS and propulsion systems have been verified
   - RSQ: TBD

8. Science operations and downlink
   - See science CONOPS for more detail

9. Deorbit
Relative Orbit Acquisition (1/2)

Propellant optimal trajectories for acquisition of a circular relative orbit. (Each color represents a different initial in-track distance.)
ARAPAIMA prior to maneuver to 250m relative orbit
Science Concept of Operations

LV release

10x10x10x100 km NMC insertion
(ground-based SSA)

Systems checkout

Guidance checkout
(Imaginary RSO)

NMC, SK

Waypoint

Trim burn

EOL

Prove rendezvous, dock with asteroids, non-cooperative RSOs

Refine matching maneuvers

Seed error model

"Hover" over RSO feature

"Hover" over RSO feature

IDVD guidance:
Fast circumnavigation

SSA material recognition

LRF-only point cloud survey

10x10x10x25 NMC insertion
(ground-based SSA)

Transition to Angles Only Nav

Drifting spiral NMC
10x10x10x±10

Waypoint guidance
1, 2 km teardrops

3D RSO shape reconstruction

Verify AON solution

Establish 250 m relative orbit

Pose estimation
(Bounded Hough x-form)

Mono stereovision
(structure from motion)

Extract RSO attitude solution

Decision Point

Guidance

Navigation
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ARAPAI MA CubeSat

- Double-deployable 3U solar panel
- Deployable 2U solar panel
- S3S startracker
- GPS patch antenna
- Computer stack
- GA640C-15A SWIR camera
- MLR-3K laser rangefinder
- S3S startracker
- Reaction wheels
- Body-fixed 3U solar panel
- Orbital Maneuvering Engine
**Conclusions/Project Timeline**

<table>
<thead>
<tr>
<th>Review</th>
<th>Months from Kickoff</th>
<th>Date</th>
<th>Expectations (Mechanical, Electrical, Software)</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Concept</td>
<td>1-2</td>
<td>12 Mar 13</td>
<td>Mission concept</td>
</tr>
<tr>
<td>System Requirements</td>
<td>4</td>
<td>30 Apr 13</td>
<td>CAD model, electrical board concept, software/hardware identified</td>
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<tr>
<td>Preliminary Design</td>
<td>8</td>
<td>10 Aug 13</td>
<td>Physical model, breadboards, high-level block diagram</td>
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<tr>
<td>Critical Design</td>
<td>12-15</td>
<td>Jan 14</td>
<td>Refined CAD, elegant breadboard, software 1.0</td>
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<tr>
<td>Proto-Qualification</td>
<td>20</td>
<td></td>
<td>Engineering unit, flight-ready configuration board, software 2.0</td>
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<tr>
<td>Flight Competition</td>
<td>24</td>
<td>Jan 15</td>
<td>Flight CAD, flight-ready configuration board tested, software 3.0</td>
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</tbody>
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**Demonstrating flight hardware gives competitive edge**
Vielen Dank!