Ground-based Hardware for Optical Space Tracking

Project Manager: Jack Toland

Hardware: Kira Altman, Lucas Calvert, Seth Hill, Duncan McGough, Jacob Vendl

Software: Ginger Beerman, Connie Childs, Blaine Covington, Rachel Mamich, Connor Ott

Sponsor: The Aerospace Corporation

Advisor: Marcus Holzinger
Motivation

• Increasing number of space objects
  • CubeSats
  • Mega Constellations
  • Debris

• International dependence on space
  • Communication
  • Weather
  • National Security

Solution

Design a low-cost, ground-based, optical tracking system for space situational awareness (SSA) and space traffic management (STM).
Specific Objectives

**Scheduler:** Propagate multiple space objects and create an imaging task list based on visibility and operator prioritization.

**Actuation Hardware:** Articulate the imaging system to capture multiple observations per pass for LEO, MEO and GEO space objects.

**Imaging System:** Image space objects in Earth orbits with relative visual magnitudes equal to or brighter than 10 under ideal conditions.

**Image Processing:** Process images for the boresight and target object right-ascension and declination.

**Orbit Determination:** Perform an orbit determination using standard advanced filtering methods using angular observations.
CONOPS

Captured Image

Recorded Measurements

\((\alpha_1, \delta_1, t_1), (\alpha_2, \delta_2, t_2)\)
\((\alpha_3, \delta_3, t_3), (\alpha_4, \delta_4, t_4)\)
\((\alpha_5, \delta_5, t_5), (\alpha_6, \delta_6, t_6)\)
Baseline Design

- Chassis with Leveling
- Dual-Output Power Supply
- Computer and GPS
- Actuation Mount
- Camera and Lens
Critical Project Elements

- Structure
- Actuation Hardware
- Imaging Hardware
- Electronics
- Software

- Chassis
- Actuation mount
- Camera & Lens
- GPS
- Scheduler

- Critical Element
- Non-Critical Element

- Onboard Processor
- Image Processing
- Power Supply
- Orbit Determination
Project Schedule
Work Breakdown Structure

### Chassis
- **WP 1.1**: 80/20 Superstructure Assembly
- **WP 1.2**: Manufacture and attach Electronics Boxes
- **WP 1.3**: Manufacture, weld and attach Imaging Pedestal

### Imaging Assembly
- **WP 2.1**: Assemble camera + lens w/ adapter
- **WP 2.2**: Assemble actuation mount and counterweight
- **WP 2.3**: Integrate camera + lens with actuation mount

### Electronics
- **WP 3.1**: Configure UDOO for software install and operation
- **WP 3.2**: Mount electronics components to chassis
- **WP 3.3**: Install power distribution wiring
- **WP 3.4**: Install data transfer wiring

### Software
- **WP 4.1**: Develop primary automation script
- **WP 4.2**: Complete Scheduler script
- **WP 4.3**: Complete Image Processing script
- **WP 4.4**: Complete Orbit Determination Script

**Status:**
- Complete
- In Progress
- Not Started
Work Breakdown Structure

**WP 4.1: Automation Script**
- Implement comms between UDOO and hardware
- Develop event-based hardware commands
- Organize into event-based structure
- Continuously develop error handling for each component
- Integrate with Automation Script

**WP 4.2: Scheduler**
- Develop propagator to locate space object in local sky
- Develop constraints to remove non-visible and conflicting passes
- Develop hardware command interface
- Integrate with Automation Script

**WP 4.3: Image Processing**
- Implement matched filtering
- Develop Astrometric calibration process
- Map pixel locations to \((\alpha, \delta)\)
- Integrate with Automation Script

**WP 4.4: Orbit Determination**
- Develop Non-Linear Batch Filter
- Implement perturbations in model (SRP, Drag, J2)
- Move Filter from MATLAB to Python
- Integrate with Automation Script

Status:
- Not Started
- In Progress
- Complete
Project Schedule

GHOST - Spring

Manufacturing and Integration
- Component Purchase
- Component Receiving
- Hardware - Chassis
- Hardware - Imaging Assembly
- Hardware - Electronics
- Software - Scheduler (MVP)
- Manufacturing Status Review
- Initial System Test Deadline
- Software - Image Processing
- Software - Orbit Determination
- Software - Scheduler (Refined)
- Test Readiness Review

Test
- Initial System Test (Scheduler + Har...
- Full System Test (Software + H...
Manufacturing
Example Streaks

Unprocessed images with dim and bright space object streak
Astrometry

NGC-2500
*Barred Spiral Galaxy*

Apparent Mag = 12.2

*NASA Extragalactic Database*
# Hardware - Future Work

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Description</th>
<th>Progress</th>
<th>Anticipated Difficulties</th>
<th>Initial Test Critical?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actuation</td>
<td>Cable wrap management 3D printed</td>
<td>CAD model completed</td>
<td>Precision of 3D printing and effectiveness of solution</td>
<td>No</td>
</tr>
<tr>
<td>Chassis</td>
<td>Monitor mount 3D printed</td>
<td>No design completed</td>
<td>Containing all of the electrically sensitive components</td>
<td>No</td>
</tr>
</tbody>
</table>
## Interfaces - Future Work

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Description</th>
<th>Progress</th>
<th>Anticipated Difficulties</th>
<th>Initial Test Critical?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imaging</td>
<td>UDOO interfacing with Zwo camera</td>
<td>INDI driver installed and working on PC</td>
<td>Installing INDI driver on UDOO</td>
<td>Yes</td>
</tr>
<tr>
<td>Actuation</td>
<td>UDOO interfacing with iOptron mount</td>
<td>INDI driver installed and working on PC</td>
<td>Installing INDI driver on UDOO</td>
<td>Yes</td>
</tr>
<tr>
<td>GPS</td>
<td>UDOO interfaced with Adafruit GPS module</td>
<td>USB connection established, but digital pin I/O desired.</td>
<td>Correct drivers installed; Resolving hard-port wiring errors</td>
<td>No</td>
</tr>
</tbody>
</table>
Data Wiring

- **NORAD IDs & TLE’s**: Complete
  - USB 3.0 (M)

- **Imaging Hardware**: Not Tested
  - USB 3.0 (F)

- **Data Protocol: INDI Driver**
  - UDOO Processor
    - USB 3.0 (F)
  - Arduino
    - Digital 2
    - Digital 3
  - GPS Receiver
    - Tx
    - PPS

- **Actuation Hardware**
  - LCD Monitor
    - HDMI (F)
  - RS-232 (M)

- **Data Driver: CircuitPython**
  - USB 3.0 (M)
  - RS-232 (F)

Legend:
- Digital I/O
- USB
- RS-232
- HDMI
**WP 4.1: Automation Script**

**Status: Behind Schedule**
- Some oversight in planning for the main structure of software pipeline.
- Not necessary for initial testing.

**Future Work**
- Finish design of main structure and implement.

**Plans to Complete Task**
- Once scheduler in viable state, reallocate software team.
- Allocate resources from hardware team once manufacturing is complete.
WP 4.2/3/4: Software Modules

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Status</th>
<th>Description</th>
<th>Known Difficulties</th>
<th>Initial Test Critical?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scheduler</td>
<td>Close to Minimum Viable Product</td>
<td>Provides times and locations of objects for imaging</td>
<td>Conflict resolution, optimizing for maximum observations</td>
<td>Yes</td>
</tr>
<tr>
<td>Image processing</td>
<td>Prototype created with assumed single object</td>
<td>Extracts measurements from images</td>
<td>MF thresholding and eliminating neighboring objects</td>
<td>No</td>
</tr>
<tr>
<td>Orbit Determination</td>
<td>Prototype Complete in MATLAB</td>
<td>Provides orbit estimate from batch of measurements</td>
<td>Upgrading dynamics, quantifying measurement uncertainties</td>
<td>No</td>
</tr>
</tbody>
</table>
Budget
# Procurement Status

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Procurement Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chassis</td>
<td>IN PROGRESS</td>
</tr>
<tr>
<td>Actuation</td>
<td>COMPLETE</td>
</tr>
<tr>
<td>Imaging</td>
<td>COMPLETE</td>
</tr>
<tr>
<td>Processing</td>
<td>COMPLETE</td>
</tr>
<tr>
<td>GPS</td>
<td>IN PROGRESS</td>
</tr>
<tr>
<td>Power</td>
<td>IN PROGRESS</td>
</tr>
</tbody>
</table>
## Budget/Account Update

<table>
<thead>
<tr>
<th>Component</th>
<th>Actual Cost</th>
<th>Budget Allocation</th>
<th>Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chassis</td>
<td>$498.52</td>
<td>$600</td>
<td>16.9%</td>
</tr>
<tr>
<td>Actuation</td>
<td>$1,118.88</td>
<td>$1500</td>
<td>25.4%</td>
</tr>
<tr>
<td>Imaging</td>
<td>$1,947.06</td>
<td>$2000</td>
<td>2.6%</td>
</tr>
<tr>
<td>Processing</td>
<td>$304.89</td>
<td>$400</td>
<td>23.8%</td>
</tr>
<tr>
<td>GPS</td>
<td>$55.39</td>
<td>$100</td>
<td>44.6%</td>
</tr>
<tr>
<td>Power</td>
<td>$218.35</td>
<td>$400</td>
<td>45.4%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$4,200.80</strong></td>
<td><strong>$5000</strong></td>
<td><strong>16.0%</strong></td>
</tr>
</tbody>
</table>
Questions?

Thank you to:
- Professor Marcus Holzinger
- Aerospace Corporation, Daniel Pachura
- ASEN 4028 – TA
Backup Slides
Operator Input

On boot, autorun:

```
./Schedule.py
./Main.py
```
• Prototype in MATLAB
  • Equations of motion including two-body and J2
• Research
  • Found python equivalents to built in MATLAB functions used
    • Skyfield Github repository
  • Researched SRP and drag models
    • Cannonball model for SRP
    • Jacchia-Roberts for atmospheric density
    • Drag will rely on B* drag coefficient estimate
**Software Architecture**

**Event-Driven programming**

Actuation/Imaging Hardware listens to clock, executes as scheduled.

IP listens for available images, processes from queue.

OD listens for batches of measurements, processes from queue.
Hardware Command and Control

Instrument Neutral Distributed Interface is a protocol designed for astronomical equipment control.
- Compatible with imaging sensor and mount

For Each line in .cmd file

<table>
<thead>
<tr>
<th>Satellite ID</th>
<th>Move Time</th>
<th>Begin Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>00:00:00</td>
<td>00:00:10</td>
</tr>
<tr>
<td>2</td>
<td>00:00:40</td>
<td>00:00:50</td>
</tr>
<tr>
<td>3</td>
<td>00:01:00</td>
<td>00:01:25</td>
</tr>
<tr>
<td>4</td>
<td>00:01:30</td>
<td>00:01:56</td>
</tr>
</tbody>
</table>

If Current Time > Move time
- Command slew to RA/DEC

If Current Time > Begin Time
- Command exposure
# Software Status

<table>
<thead>
<tr>
<th>Software Component</th>
<th>Priority for Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scheduler</td>
<td>High</td>
</tr>
<tr>
<td>Hardware integration/commands</td>
<td>High</td>
</tr>
<tr>
<td>Image Processing</td>
<td>Low</td>
</tr>
<tr>
<td>Orbit Determination</td>
<td>Low</td>
</tr>
<tr>
<td>Main Script</td>
<td>Low</td>
</tr>
</tbody>
</table>