Unmanned Aircraft Systems, Machine Learning and Polarimetric Imaging for Enhanced Marine Debris Detection and Removal

Presentation to the NOAA UAS Program Office Mission Concept Review

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Principle Investigator(s)

Tim Battista
NOAA Marine Spatial Ecology Division (MSE)

Amy V. Uhrin
NOAA Marine Debris Program (MDP)

Co-Investigators

Chris Parrish & Richie Slocum
Oregon State University

Peter Murphy
NOAA Marine Debris Program
Overall Objectives

- ID suitable UAS system/payload for Marine Debris Program.
- Determine optimal data acquisition parameters.
- Automate detection & material type classification.
- Develop and implement operationally-efficient workflows & deployable algorithms.
Mission Goals & Objectives

• Two study sites: 1) controlled testing & training site and 2) validation site with persistent high density marine debris.

• Compare sensors & platforms including polarimetric imaging.

• Develop operational procedures.

• Develop auto-detection & material-type identification via machine learning

• Evaluate concentration & material type products

• Training and initial Transition to MDP & partners.
Heatmaps Representing Concentrations of Marine Debris

*Proof-of-concept: mock-up created through hand digitization*

Focus on macro-debris (>1 m size) which is most typical debris for MDP-supported cleanup.

Level of accumulation informs removal/remediation decisions.
• Goal: auto detection and classification of marine debris
  – Hierarchical classification
    • Binary: belongs at beach vs. doesn’t belong at beach
    • Material type classification: plastic, wood, foam, metal
    • Identification: bottle, fishing net, nylon line, buoy/float, crab trap, flipflop, etc.

• Not inventing new ML algorithms
  – Utilize existing ML frameworks
    • Tensorflow, Pytorch

• Research focus areas
  – Size of training database
  – Performance of various models
    • Performance metrics: precision, recall, and receiver operating characteristic (ROC) curves

• Potential collaboration with Ross Winans, NOAA OCM and University of Hawai‘i at Mānoa MS student
Polarimetric Imaging

- Polarimetry = measurement and interpretation of the polarization state of transverse light waves reflected by object
- Useful for identification of human-made objects within a scene

Combination of spectral and polarimetric imaging info can facilitate both detection and recognition

(1) Aluminum bowl
(2) Glass mason jar
(3) Acrylic panel
(4) Plastic trash bag
(5) Toothbrush
(6) Plastic broom handle
Investigation of PI Cameras

- Will be conducting market research for procurement
- Key specs
  - Cost
  - Resolution
  - Chip size (pixels and microns)
  - Lens
  - Frame rate
  - Spectral bands
  - Polarimetric info
  - Size, weight, power requirements

FLIR Blackfly S USB3: https://www.flir.com/products/blackfly-s-usb3/?model=BFS-U3-51S5PC-C

PolarCam G5: https://www.4dtechnology.com/products/imaging-polarimeters/
sUAS Platforms

• 3 OSU owned airframes operated by OSU team members

• Solo : Lightweight custom mapping system
• S900 : Heavy lift custom mapping system
• P4P : COTS mapping system

• Algorithms and research aims to be platform agnostic
Two study sites:

1. Controlled testing and training site
   - Debris items will be placed, accurately surveyed, and flown with range of parameter settings
   - Identified location: Neptune State Scenic Viewpoint, south of Yachats, Oregon
     - Encompasses range of shoreline types/features: rock outcrop, sand, vegetation, cliff, and creek outflow

2. Validation site
   - Test procedures operationally in site known to have persistently high densities of macrodebris

3. *Opportunistic data collection opportunity @ Netarts Bay, OR
CONOPS Florence, OR
Testing Site

- Neptune State Park in Class-G airspace. OPRD Scientific Research Permit Required
- Flights: surface to 400 ft AGL, operations 150-400 ft
- Flights under Part 107, OSU UAS policies and procedures, NOAA UAS Handbook, & AOC-approved

▲ = Neptune State Scenic Viewpoint test site
CONOPS Oahu, HI* Validation Site

- James Campbell Wildlife Refuge in Class-G airspace.
- Site selected due to persistent high concentrations of debris.
- Same operational approval and CONOPS process as for testing site.

*Tentatively planned site
All proposed operating areas are in Class G airspace and do not require special airspace access requests.
Required Assistance

• No assistance is required from AOC.
# Project Personnel

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>LOE (mo)</th>
<th>Role</th>
<th>Qualification(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tim Battista</td>
<td>NOAA NCCOS</td>
<td>7</td>
<td>Project management, technical guidance</td>
<td>sUAS operation planning, remote sensing</td>
</tr>
<tr>
<td>Amy Uhrin</td>
<td>NOAA ORR</td>
<td>2</td>
<td>Project management, technical guidance</td>
<td>MDP expert</td>
</tr>
<tr>
<td>Chris Parrish</td>
<td>OSU</td>
<td>4.5</td>
<td>Pilot, system integration, sUAS field testing</td>
<td>sUAS pilot, system engineer</td>
</tr>
<tr>
<td>Richie Slocum</td>
<td>OSU</td>
<td>10</td>
<td>Pilot, system integration, sUAS field testing</td>
<td>sUAS pilot, system engineer</td>
</tr>
<tr>
<td>Kyle Herrera</td>
<td>OSU</td>
<td>12</td>
<td>Pilot, system integration, sUAS field testing</td>
<td>sUAS pilot*</td>
</tr>
<tr>
<td>Peter Murphy</td>
<td>Genwest</td>
<td>2</td>
<td>Technical guidance &amp; evaluation, sUAS system testing</td>
<td>MDP Developing Technologies Expert</td>
</tr>
</tbody>
</table>
Project Risks

Project Management Risks and Mitigation

Risk: Project funding transferal  
Probability: unlikely.  
Potential Impact: moderate.  
Mitigation: NCCOS will pre-initiate the contract mechanism through existing contract vendor mechanisms to ensure success.

Risk: Cost overrun  
Probability: unlikely.  
Potential Impact: moderate.  
Mitigation: In the event that project cost estimates are inaccurate, cost overruns will be mitigated by cost trimming in other portions of the budget.

Risk: Key personnel leaving the project  
Probability: unlikely.  
Potential Impact: moderate.  
Mitigation: In the event that key personnel (Parrish/Slocum) leave the project, the alternate pilot will conduct UAS flights, and an alternative engineer will be substituted for integration tasks.
Mission Operational Risks and Mitigations

Risk: Inclement Weather
Probability: low
Potential Impact: moderate.
Mitigation: Time windows specified for fieldwork include realistic-to-conservative budgets for inclement weather. Fieldwork can be suspended on a daily basis, as necessary, if short-term weather events occur.

Risk: NEPA permitting failure
Probability: unlikely.
Potential Impact: moderate.
Mitigation: Operations will be rescheduled in the event additional NEPA review/clearance is necessary. However, ample lead-time submitting documentation for NEPA approval and close coordination with the AOC oversight authorities should mitigate any delays.
Flight Safety Risks and Mitigations

Risk: Failure of a quadcopter UAS engine  
Probability: unlikely  
Potential Impact: moderate.  
Mitigation: Preflight inspection of engines and props. We will not fly the drones over people or vessels.

Risk: Collision with a manned aircraft  
Probability: Rare  
Potential Impact: Catastrophic  
Mitigation: UAS operations will conform to all FAA policies and flight restrictions.  
- We will remain below 400 feet MSL at all times  
- Use Flightradar24 to track aircraft to give us early alerts including distance, and altitude of nearby manned aircraft.  
- Use a visual observer to monitor the UAS and visually search for nearby manned aircraft  
- Maintain radio contact with nearby control tower, if available
Flight Safety Risks and Mitigations (contd)

Risk: Loss of Drone GPS navigation
Probability: unlikely
Potential Impact: moderate.
Mitigation: Switch pilot control mode to control the UAS to use only the augmented stability mode without GPS, and manually fly the UAS to the designated landing zone and land.

Risk: Loss of Drone ground control signals
Probability: unlikely
Potential Impact: moderate.
Mitigation: Each drone will be configured to “Return to Home” in the event of a loss of control signals. The Return to Home location will be updated and verified as part of the preflight checklist before each takeoff. We will advise the nearest control tower of the loss of control.

Risk: Interference with UAS control signals causing loss of control.
Probability: Rare
Potential Impact: moderate.
Mitigation: When onsite, examine the radio frequency (RF) spectrum used by each UAS for interference by using an RF spectrum analyzer to insure clear channel operation.
Risk Assessment

X, Y

Technical: 2,2

Cost: 1,1

Schedule: 3,4
# Milestones

## Period of Performance: 01 June 2020 – 31 May 2022

<table>
<thead>
<tr>
<th>#</th>
<th>Deliverables (D) &amp; Milestones (M)</th>
<th>Estimated Completion Date</th>
<th>Success Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(D) Quarterly Project Report Briefings</td>
<td>Quarterly</td>
<td>Completion</td>
</tr>
<tr>
<td>2</td>
<td>(D) Initial Technical Review with UASPO</td>
<td>2 months from date of award (est. August, 2020)</td>
<td>Completion</td>
</tr>
<tr>
<td>3</td>
<td>(M) NEPA documentation</td>
<td>7 months from date of award (est. January, 2021)</td>
<td>Signed document</td>
</tr>
<tr>
<td>4</td>
<td>(M) Procure or fabricate sensors and platforms</td>
<td>4 months from date of award (est. October, 2020)</td>
<td>Proof of purchase</td>
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<tr>
<td>5</td>
<td>(D) Development of Transition Plan</td>
<td>6 months from date of award (est. December, 2020)</td>
<td>Completion</td>
</tr>
<tr>
<td>6</td>
<td>(M) Conduct flight tests at OSU UAS test facility</td>
<td>7 months from date of award (est. January, 2021)</td>
<td>Written Documentation</td>
</tr>
<tr>
<td>7</td>
<td>(M) Conduct tests of PI at OSU testing facility</td>
<td>7 months from date of award (est. January, 2021)</td>
<td>Written Documentation</td>
</tr>
<tr>
<td>8</td>
<td>(M) Train machine learning (ML) algorithm and develop beta version of workflow</td>
<td>11 months from date of award (est. May, 2021)</td>
<td>Written Documentation</td>
</tr>
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## Milestones

### Period of Performance: 01 June 2020 – 31 May 2022

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</thead>
<tbody>
<tr>
<td>9</td>
<td>(M) Conduct flights at testing &amp; training site Neptune State Scenic Area, OR</td>
<td>12 months from date of award (est. June, 2021)</td>
<td>Trip Report</td>
</tr>
<tr>
<td>10</td>
<td>(M) Refine ML algorithms and workflows</td>
<td>14 months from date of award (est. August, 2021)</td>
<td>Completion</td>
</tr>
<tr>
<td>11</td>
<td>(M) Conduct validation tests in HI</td>
<td>15 months from date of award (est. September, 2021)</td>
<td>Trip Report</td>
</tr>
<tr>
<td>12</td>
<td>(M) Develop SOPs</td>
<td>22 months from date of award (est. April, 2022)</td>
<td>Written Documentation</td>
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<tr>
<td>13</td>
<td>(D) Conduct training for MDP staff</td>
<td>22 months from date of award (est. April, 2022)</td>
<td>Written Documentation</td>
</tr>
<tr>
<td>14</td>
<td>(D) Complete system performance and technology transfer document</td>
<td>23 months from date of award (est. May, 2022)</td>
<td>N/A</td>
</tr>
<tr>
<td>15</td>
<td>(D) Deliver Final Project Report</td>
<td>23 months from date of award (est. May, 2022)</td>
<td>Completion</td>
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<tr>
<td>16</td>
<td>(M) End of Project Technical Review</td>
<td>23 months from date of award (est. May, 2022)</td>
<td>Completion</td>
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## Technical Readiness

<table>
<thead>
<tr>
<th>Project Component</th>
<th>Current RL</th>
<th>Anticipated Final RL</th>
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</thead>
<tbody>
<tr>
<td>Observing System Application (Platform + Sensor Combination)</td>
<td>RL 5 (Concept Demonstrated in Relevant Environment)</td>
<td>RL 8 (Final System Demonstrated in Operational Environment)</td>
</tr>
<tr>
<td>Machine learning approach to auto-detection of debris</td>
<td>RL 3 (Proof of Concept Developed)</td>
<td>RL 7-8</td>
</tr>
<tr>
<td>Polarimetric imaging (PI)</td>
<td>RL 2</td>
<td>RL 6-7, pending findings of this portion of project</td>
</tr>
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Questions?