sUAS, Machine Learning and Polarimetric Imaging for Enhanced Marine Debris Detection and Removal

Research to Operations Transition Plan

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February 2, 2021

NOAA Uncrewed Systems Research Transition Office

NCCOS NATIONAL CENTERS FOR COASTAL OCEAN SCIENCE

National Ocean Service

NOAA MARINE DEBRIS PROGRAM
https://MarineDebris.noaa.gov

Approval Page

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The below parties, by providing signatures, approve of the transition plan outlined in this document, which may be periodically reviewed and updated as needed.

It is acknowledged herein that transition projects have a specific set of performance metrics, milestones, and other gate conditions that must be achieved to advance the proposed capabilities into operations. Operational implementation of these new capabilities are subject to successful completion of the described research, development, and/or demonstration, review and approval through appropriate end user NOAA Line Office governance procedures, and availability of funding. Short of meeting these conditions, the transition project could be considered for divestment. Divestment from a transition project can occur in several ways, including termination of the project or transfer of the project to an extramural partner.

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*Consult NAO 216-105B and check with relevant Line Office (LO) for appropriate transition stage signatures. Until a project matures, new R&D efforts may only require approval from a division chief or other resource manager, who may serve as both the R&D and receiving LO transition manager. R&D LO signature lines in the column to the right may be omitted if the transition activity occurs internally within a single LO.

1. Purpose for Transition Effort

The intention of this document is to guide transition efforts for the proposed capability toward operations. It is a living document and will remain valid as long as the corresponding development project is completed successfully, satisfies end user-defined Line Office metrics for success and operational constraints, and clearly surpasses each of the associated gates for transition. The ultimate decision to transition this project to operations resides with the appropriate decision maker of the receiving Line Office.

1.1 Transition Product

The quantity of marine debris in coastal waters of the U.S. is a risk to the public and marine life with substantial economic impacts on coastal communities. The success in preventing the adverse impacts of marine debris and direct critical cleanup and response functions requires the ability to accurately and quickly detect and identify marine debris. This joint project between NOS National Centers for Coastal Ocean Science (NCCOS) and Marine Debris Program (MDP) seeks to yield a set of operationally-viable procedures and workflows suitable for consistent implementation by NOAA Marine Debris Program and their partners.

1.2 Anticipated Results

The project is based on designing and demonstrating a relatively low-cost, easily deployed, and accurate marine debris detection system, so as to operationalize the approach by transferring the technological solution to existing marine debris response programs. Additionally, the procedures will enable additional periodic monitoring (unrelated to storm events), providing a repeatable, systematic method of quantifying abundance and distribution of debris in survey areas, to support policy and decision-making. A set of software tools and machine learning algorithm procedures will be developed which leverage UAS based imagery to automatically generate marine debris heat maps. The procedures will be documented in a standard operating procedures (SOP) document, and training will be provided to MDP staff to build capacity for assessment and execution of future UAS operations.

2. Research background

Since its inception in 2006, the NOAA Marine Debris Program (MDP) has been designated as the Federal lead to coordinate and implement efforts to reduce marine debris impacts in the U.S. Through the Marine Debris Act, the MDP is mandated to investigate and prevent the impacts of marine debris, collaborating with key partners to remove and prevent marine debris, and to better understand its impacts through research. This mission is benefited by the collection of data over large spatial and temporal scales to identify locations of marine debris accumulation and contribute to our understanding of debris status and trends.

Aerial imagery collection, whether via crewed or uncrewed (UAS) systems, has been the primary method for detection of marine macrodebris (>1m in size) across large areas of shoreline and open water (Veenstra and Churnside 2012, Brooke et al. 2015, Moy et al. 2017, Lebreton et al. 2018). The ability to detect and identify the composition of marine debris over a large area in a short period of time enables a comprehensive assessment of debris presence to understand its likely impacts, and can provide significant value in debris removal prioritization efforts given the ability to compare debris concentrations. While crewed systems have significant advantages over UAS in terms of longer flight duration and greater distance (providing large area spatial coverage), the cost is often prohibitive for broad usage. UAS can provide multiple advantages over crewed aircraft systems for focused small-area debris surveys, including lower operational and maintenance costs, reduced technical complexity, potentially increased flight hours, portability, rapid response, and easier pilot certification. Collectively, these benefits provide a greater opportunity to more feasibly acquire and utilize observational data that would previously have required, and been limited by access to, crewed airborne assets. UAS provide the ability to rapidly respond to severe marine debris events (e.g., hurricanes, tsunamis), to acquire high-resolution imagery over large extents of coastline, and access areas that are inaccessible by foot or small boat or where sensitive wildlife and habitats cannot be disturbed. However, the proliferation of UAS has also contributed to a confounding problem, wherein groups are operating systems with little or no coordination and in the absence of operational guidelines or recommendations.

While previous research has documented the benefits of UAS for marine debris mapping (Martin et al. 2018; Fallati et al. 2019), efforts to date have not yet yielded a set of operationally-viable procedures and workflows suitable for implementation by NOAA MDP and their partners.

3. Capabilities and Functions

3.1 Assessment of Current Capability

The current Readiness Level of the Observing System Application is at RL 3 for the Machine Learning/Algorithm and RL 4 for the Polarimetric Imager/UAS integration.

3.2 Assessment of Anticipated Operational Capability

The expected Readiness Level of the Observing System Application is anticipated to be at RL 7 for the Machine Learning/Algorithm and RL 7 for the Polarimetric Imager/UAS integration.

3.3 Acceptance Criteria for Transition

Our goal is to provide easy to follow methods that describe the use of UAS for quantitative detection of shoreline macro-size marine debris objects. UAS are not expected to replace on the ground efforts, but rather to complement them, allowing for fewer boots on the ground, observation of larger areas with greater spatial coverage, and increased temporal coverage. To be accepted, these methods will need to demonstrate accuracy that is comparable to (or better than) currently used “on-the-ground” debris monitoring methods. Additionally, these methods will need to be easily implemented (i.e. not requiring high-level expertise) and cost-effective relative to traditional monitoring methods.

4. Transition Gates and Activities

4.1 Gates toward Transition

Once the marine debris observing system has been developed in a laboratory environment, it's performance will be evaluated and tuned at an operational test site. Final performance will be evaluated at a validation site The test and validation site evaluation will provide quantitative information so as to assess Gates toward transition.

4.1.1 Gate 1: Analysis of Alternatives

Currently, the Marine Debris Program and its partners use a combination of ground-based surveys and remotely sensed observations for assessing marine debris distribution and gauging marine debris removal efforts.

On the ground monitoring: Shoreline debris monitoring is conducted by Marine Debris Program partners as part of the Marine Debris Monitoring and Assessment Project. Surveys are conducted on a monthly basis and are quite localized often covering small spatial extents and require consistent and dedicated resources. Regular shoreline monitoring is not always technically feasible in remote locations where debris accumulation can be quite high. On-the-ground efforts are also employed after extreme events to catalogue stranded debris and prioritize removal efforts..

Remotely Sensed Observations: MDP has identified strategic objectives for improved understanding of the scope, scale and distribution of marine debris in the environment through remote detection efforts. MDP will continue to assess tools and resources for partners across the Nation and world to facilitate harmonized shoreline marine debris surveys via crewed and uncrewed systems and using overhead satellite imagery. This project and the technology transition associated with it addresses MDP FY2021-2025 strategic objectives for monitoring and detection including integration of appropriate emerging remote sensing technologies and techniques to improve debris detection capabilities and outputs within the marine debris community and facilitation of the use of suitable opportunistic detection platforms and systems to increase availability of debris data (NOAA 2020).

4.1.2 Gate 2: Data Impact Assessment

Uncrewed aerial systems offer a low-cost, high-resolution option for limiting on-the-ground sampling while simultaneously increasing the extent of aerial coverage, responsiveness, spatial resolution, and accuracy of monitoring results. Because UAS allow for the collection of on-demand aerial images at user-defined frequencies, they are invaluable for detecting temporal changes, particularly those resulting from extreme events like hurricanes. As such, UAS-collected imagery using machine-learning workflows has the potential to radically improve the ability of efforts to detect debris quantis a on spatial and temporal scales that are relevant to removal efforts. The guidance produced through this effort will demonstrate how to incorporate UAS and the workflows into on-the-ground debris detection exercises for maximum impact.

4.1.3 Gate 3: Cost-benefit Analysis

Comparisons among the alternative collection methods are confounded by the fact that these alternatives and their associated products are inherently very different. Both traditional remote sensing and on the ground monitoring come with significant limitations (high cost/limited temporal resolution and limited spatial resolution, respectively) that are not associated with UAS-based approaches. While UAS based approaches involve significantly less field time, they do require significant image processing time. As a result we do not anticipate a reduction in man hours required, rather the true benefit of this approach involves the ability to collect on demand imagery with unparalleled spatial resolution (cm / pixel).

Sensor/System	**Image Resolution**	**Purchase Unit**	***Total Cost***
COTS UAS platform	< 1cm to 15 cm	Unlimited sampling frequency	*2-10 k*
Additional (multispectral)sensor	< 1cm to 15 cm	Unlimited sampling frequency	*3-5 k*
Satellite data purchase	5 – 30 m	per data set	1 k per scene
Crewed Flight	50 cm to 5 m	1 hour of image collection	1k

To provide a fairer cost-benefit analysis (cost / unit hour) based on technologies that produce relatively comparable results we further compare crewed flights and UAS-based image collection assuming the following:

- 3 image collection efforts annually, each covering a hypothetical marine debris impact area of approximately 200 acres

- equivalent time spent on image processing regardless of method of collection

- crewed flight will be billed at minimum of one hour (regardless of actual flight time)

- unit cost per hour of UAS approach reflects middle range values for platform and sensor (and pilot training)

Method	Total hours	Total cost	cost/hour/year
Crewed flight	3	$3,000	$1,000
UAS	9	$10,000	$1,111*

*Note that this includes the cost of the platform itself, which would not need to be replaced annually. If this same analysis is multiplied out over two years, the hourly cost of crewed flights remains the same, while that of UAS operations decreases by a factor of 2.

4.1.4 Gate 4: Regulations, Access, and Approvals

NCCOS and NOS scientists have and must coordinate with OMAO/UxS Operation Center for airworthiness approvals, PIC designation and flight approvals (e.g. under existing wide-area ORM and FAA part 107 regulations).

4.2 NOAA Testbeds, Proving Grounds, and Test Demonstrations

Test demonstration of this proposed system will be conducted at Oregon State University Test Facility; Neptune State Scenic Area, OR; and a validation site located on one of the Main Hawaiian Islands (TBD).

4.3 New or Existing Technology Development

The core mission of NOAA's Marine Debris Program is to investigate and prevent the adverse impacts of marine debris including response functions following severe marine debris events. However, success in that mission requires the ability to accurately and quickly detect and identify marine debris. To fulfill this mission, the MDP continues to investigate technology to improve rapid detection of debris stranded severe debris events. The incorporation of UAS-based approaches and operationally-viable procedures and workflows suitable for consistent implementation by NOAA MDP and their partners will provide greater spatial and temporal data coverage, enhanced ability to collect data after extreme events like hurricanes, easily deployed and cost-effective approach which can guide cleanup and restoration.

5. Implementation Strategy

By producing Standard Operating Protocols (SOPs) and providing training to MDP staff and partners, that complement and enhance current MDP monitoring efforts, the proposed work will facilitate the system-wide adoption and routine application of UAS methods. To encourage the transition of these methods to routine use, the project team will conduct an outreach event (described below) to MDP researchers as well as external partners. The completion of the milestones and deliverables listed below concludes NCCOS's commitments to the development and transition of the capability.

5.1 List of Milestones

- Training - Build MDP capacity to evaluate, plan, and execute future field UAS operations (April 2022).
- SOPs - Including asset and sensor selection, concept of operations, regulatory compliance, survey execution, and post processing (May 2022).

5.2 List of Deliverables

Capacity building workshop for MDP staff and partners.

SOP submitted to MDP.

6. Roles and Responsibilities

NOAA Entity	Roles and Responsibilities
NOS/NOS/ NCCOS	NCCOS will provide project management, technical oversight, and participate in on-the-ground research efforts to ensure that the developed methods adequately address the intended observation needs defined by MDP.
NOS/ORR/ MDP	MDP will participate in on-the-ground research efforts to ensure that the developed methods adequately address their observation needs and ensure that the resulting methods are widely distributed and available to all MDP researchers and partners.
OAR / UASPO	Subject to availability of funds, the NOAA Uncrewed Research Transition Office (USRTO) in OAR will fund the research, development, demonstration, and transition of the corresponding project toward RL 7 status. The USRTO will also provide management oversight for the project and serve as the UAS technology/research resource to facilitate these activities.
OMAO / UxSOC	As needed, the Office of Marine and Aviation Operations, UxS Operations Center (OMAO UxSOC) will coordinate airspace access and review UAS operations to ensure that safety and compliance with regulations and policy is maintained.

7. Budget Overview

7.1 Cost of Current Capability

Subject to availability of appropriated funds, the "pre-transition" research, development, and demonstration phase of this project is funded by the NOAA Uncrewed Systems Research Transition Office in OAR at a cost of $340,877 over two calendar years starting in June of 2020. NCCOS receives $324,129 of the OAR funds, of which $298,858 is transferred through grant mechanisms to support the technical participation of Oregon State University.

7.2 Cost of Transition Activity

The transition cost provided in this section is subject to availability of appropriated funds. This project is at Stage 1 of the transition process and therefore the transition activities, and cost, are commensurate with the current level. The project product will be initially transitioned to a set of subject matter experts in the MDP or partners. As such, we are assuming that interested user groups will need to independently own a UAS platform, observing system, and the processing software necessary to conduct deep learning image processing. We estimate the start-up cost associated with incorporating UAS into ongoing monitoring efforts to be on the order of 15k for equipment costs (platform, sensor, ground control markers, pilot training and certification) and 3k for processing software.

7.3 Cost of Operational Capability

The cost provided in this section is contingent upon NOS's decision regarding operational implementation of this capability, and is subject to availability of appropriated funds. The cost to operate and maintain the proposed capability once fully transitioned into routine operations is anticipated to be $313,000, annually. This estimate includes fully burdened labor costs for two pilots (2 x $150,000), annual training (2 x $5,000), vehicle maintenance (3 x $500), and software post-processing maintenance/ data storage (1x $1,500). Pilot costs assume that these are new hire positions, but alternatively, existing staff could be cross-trained to perform this additional duty. This estimate does not include any additional mission related operational costs (i.e., travel, per diem).

8. Risks and Mitigation

The primary risk associated with the use of UAS in marine debris monitoring programs is loss of platform due to pilot/equipment error. This risk is mitigated by maintaining standards for pilot training, platform inspection and use. Because the operations described here are conducted over uninhabited beaches, wetlands, or open water, there is little risk of personal injury associated with platform loss.

9. References

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