A. COVER PAGE

Project Title: Machine Learning for Automated Detection of Shipwreck Sites from Large Area Robotic Surveys	
Grant Number: NA21OAR0110196-T1-01	**Project/Grant Period:** 07/01/2021 - 06/30/2024
Reporting Period: 07/01/2021 - 06/30/2024	**Requested Budget Period:** 07/01/2021 - 06/30/2024
Report Term Frequency: Final	**Date Submitted:** 09/27/2024
Program Director/Principal Investigator Information: KATHERINE SKINNER , BS MS PHD **Phone Number:** 7346150312 **Email:** kskin@umich.edu	**Recipient Organization:** UNIVERSITY OF MICHIGAN AT ANN ARBOR 3003 SOUTH STATE STREET 1st Floor Wolverine Tower ANN ARBOR, MI 481091276 **UEI:** GNJ7BBP73WE9 **EIN:** 38-6006309 **RECIPIENT ID:**
Change of Contact PD/PI: NA	
Administrative Official: JOSEPH BURNS 3003 S. State Street Wolverine Tower Ann Arbor, MI 48109 **Phone number:** 734-763-5710 **Email:** jrburns@umich.edu	**Signing Official:** JOSEPH BURNS 3003 S. State Street Wolverine Tower Ann Arbor, MI 48109 **Phone number:** 734-763-5710 **Email:** jrburns@umich.edu
Human Subjects: NA	**Vertebrate Animals:** NA
hESC: No	**Inventions/Patents:** Yes **If yes, previously reported:** Yes

B. ACCOMPLISHMENTS

B.1 WHAT ARE THE MAJOR GOALS OF THE PROJECT?

This project developed new technology and innovative methods to advance autonomous capabilities of marine robotic systems for search and survey of shipwreck sites. The main goal of this work was to increase efficiency and decrease cost for these missions. To achieve this goal, we proposed the following objectives: (i) to develop novel machine learning algorithms for online detection and ranking of potential targets of interest from sonar data collected through large area robotic surveys, (ii) to develop novel methods for efficient path planning of robotic surveys to collect high resolution imagery from potential sites of interest, and (iii) to validate proposed methods through large area robotic search and survey of shipwreck sites in the Thunder Bay National Marine Sanctuary (TBNMS) in Lake Huron.

B.1.a Have the major goals changed since the initial competing award or previous report?

No

B.2 WHAT WAS ACCOMPLISHED UNDER THESE GOALS?

File Uploaded : NOAAOER21_FinalRPPR2024-Accomplishments.pdf

B.3 COMPETITIVE REVISIONS/ADMINISTRATIVE SUPPLEMENTS

For this reporting period, is there one or more Revision/Supplement associated with this award for which reporting is required?

No

B.4 WHAT OPPORTUNITIES FOR TRAINING AND PROFESSIONAL DEVELOPMENT HAS THE PROJECT PROVIDED?

File Uploaded : NOAAOER2021_FinalRPPR-Training.pdf

B.5 HOW HAVE THE RESULTS BEEN DISSEMINATED TO COMMUNITIES OF INTEREST?

Results were disseminated to communities of interest through several public outreach activities. PI Skinner developed and led a workshop including a lecture and hands-on activity on "Underwater Robotics for Marine Archaeology" for the Kelsey Museum of Archaeology "Family Day" focused on "Archaeology and Technology". "Family Day" is a 3-hour event that takes place biannually and is open to the public. The event focuses on hands-on family-friendly activities to engage a broader population in archaeology topics. PI Skinner organized and led a 75-minute workshop on "Underwater Robotics" for the University of Michigan (UM) Center for Engineering Diversity and Outreach (CEDO) Engineering Summer Camp. The workshop leveraged data and experience from this project. CEDO Engineering Summer Camps invite UM faculty and students to engage with K-12 students to foster excitement in their field. PI Skinner also developed and presented a 60-minute lecture on "Underwater Robotics" for the Michigan-Louis Stokes Alliance for Minority Participation (MI-LSAMP) Robotics Workshop. The lecture leveraged data and experience from this project. MI-LSAMP aims to increase the number of underrepresented minority students earning undergraduate degrees in STEM fields with a focus on graduate school preparation. PI Skinner presented a public lecture titled “Deploying Robots and Artificial Intelligence to Search for Shipwreck Sites” at the Great Lakes Maritime Heritage Center. Additionally, this work resulted in two features through coordination with the Michigan College of Engineering Communications & Marketing team: (1) Featured as a YouTube video titled “Artificial Intelligence Trained to Find Shipwrecks” on the Michigan Engineering YouTube channel, and (2) Featured in an article titled “Building Curious Machines” on the Michigan Engineering News webpage and print. Lastly, results from this project were used to create curriculum materials for ROB 572: Marine Robotics at the University of Michigan.

B.6 WHAT DO YOU PLAN TO DO DURING THE NEXT REPORTING PERIOD TO ACCOMPLISH THE GOALS?

Not Applicable

Accomplishments

This project involved the following activities:

1. We developed novel machine learning methods for detection and segmentation of shipwreck sites from sidescan sonar imagery collected onboard marine robotics platforms.
2. We developed novel methods for robot path planning to enable autonomous surveys of shipwreck sites.
3. We demonstrated machine learning and motion planning algorithms for shipwreck detection and survey in Thunder Bay National Marine Sanctuary (TBNMS).
4. We released a benchmark dataset for machine learning for shipwreck segmentation from sonar imagery to improve accessibility to data and software tools for advanced technology for ocean exploration.

Accomplishments under these activities are detailed further below.

Machine Learning for Detection and Segmentation of Shipwreck Sites from Sidescan Sonar Imagery: One challenge of working with sonar imagery in machine learning applications is that there is limited labeled data available for supervised approaches. To overcome this challenge, we developed a novel method, STARS, for segmentation of shipwreck sites from sonar imagery with no real labeled data required for training. We compare the performance of our framework to state-of-the-art segmentation solutions operating under the same restrictions. Our main contributions are i) a synthetic shipwreck generation method for sidescan sonar images, and ii) a novel network architecture that leverages anomaly detection and deformation prediction to better segment shipwrecks and debris fields found at shipwreck sites without requiring real examples of shipwrecks for training. Figure 1 shows an overview of the STARS network architecture. Figure 2 shows sample qualitative results for input sidescan sonar images to provide comparison between the ground truth, STARS, and baseline methods.

This work is detailed in the following publication: A. Sethuraman and K. A. Skinner. “STARS: Zero-shot Sim-to-Real Transfer for Segmentation of Shipwrecks in Sonar Imagery” in Proceedings of the *British Machine Vision Conference*, November 2023.

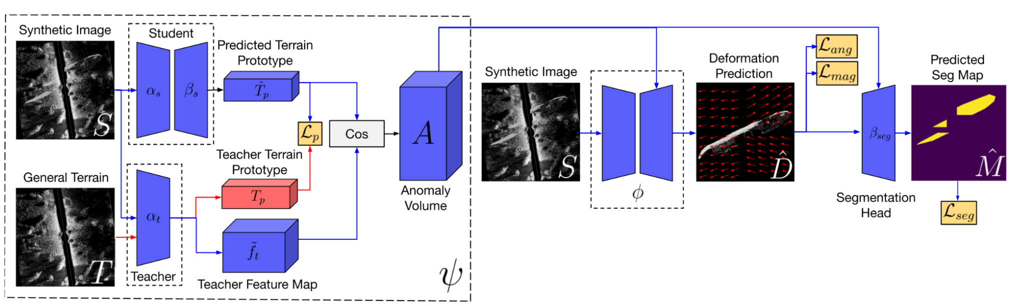


Figure 1. STARS network architecture. STARS leverages real terrain data with synthetic shipwrecks for training to predict shipwreck segmentation. During test time, STARS can take in a real sonar image containing a shipwreck to perform shipwreck segmentation. Note that STARS does not require any real examples of shipwrecks for training.

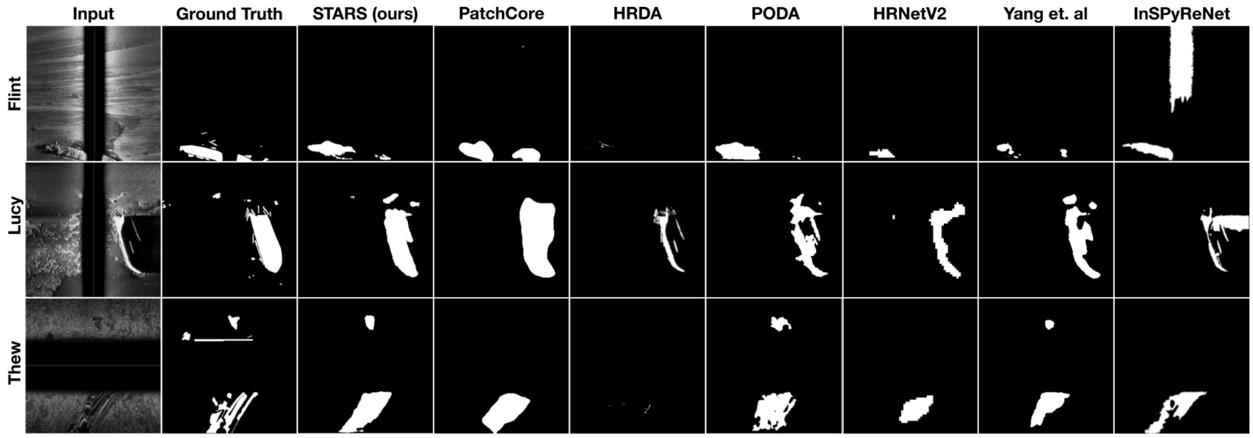


Figure 2. Selected qualitative results from our method compared to baselines. Some methods have a tendency to inaccurately over-segment or fail to segment debris from shipwrecks, resulting in lower performance. However, STARS consistently produces more accurate segmentation outputs.

Motion Planning for Autonomous Shipwreck Surveys: To collect optical images in close proximity of the shipwreck, this project has supported development of an obstacle avoidance path planning algorithm specifically designed to create smooth, collision-free trajectories for underwater robotic systems operating in dynamic environments. The proposed approach begins with the generation of an initial path based on the system's kinematics, which is then refined through optimization that accounts for both the system's constraints and the presence of obstacles. The optimization process incorporates the correlation between path states into a kernel, enhancing the planner's ability to adaptively adjust the path to avoid obstacles while maintaining smoothness. However, leveraging these correlations can result in significant computational demands for systems with high dimensionality. To address this, the proposed method, named AmaxGPMP, employs a strategy to reduce the amount of information required to construct these kernels while still accurately capturing the state correlations, thereby reducing computation time. The proposed approach has been first tested in simulation and its performance compared to classical approaches such as A* and RRT (Fig. 3). After that it has been deployed on a small hybrid ROV/AUV and optical data has been collected (Fig. 4). This has also been coupled with coverage path planning algorithms to ensure all the area detected in the sonar images is covered (Fig. 5).

This work is detailed in the following publication: M. Pesson, E. Morgan and C. Barbalata, "Collision Free Path Planning for Underwater Vehicles in Rapidly Changing Environments," 2024 *IEEE International Conference on Advanced Intelligent Mechatronics (AIM)*, Boston, MA, USA, 2024, pp. 1524-1530, doi: 10.1109/AIM55361.2024.10637062.

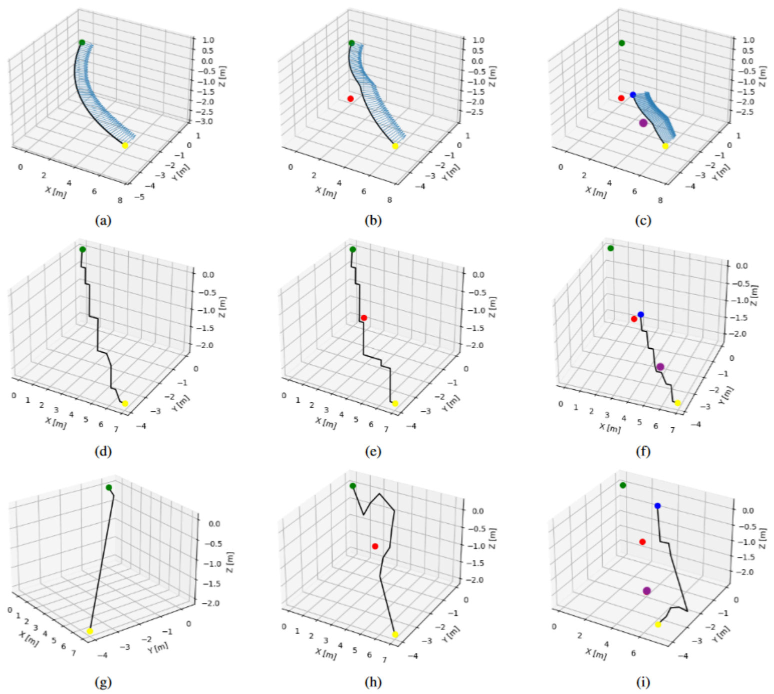


Figure 3. Simulation results where the green sphere represents START position, the yellow sphere is the GOAL, and the red spheres represent OBSTACLES: (a - c) proposed approach results, (d - f) A* results, (g - i) RRTConnect results. For all cases; no object in the environment (first column figures), one object in the environment known from the start of the mission (second column), one object known from the start and a second object is emerging after the start of the mission (third column).

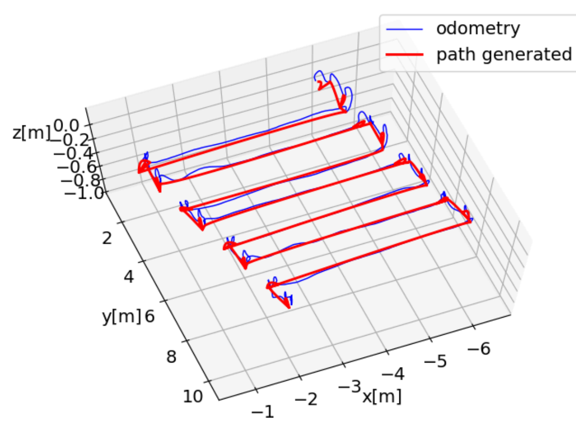


Figure 4. Path taken by the real vehicle to collect data using AmaxGPMP over *Monohansett*.

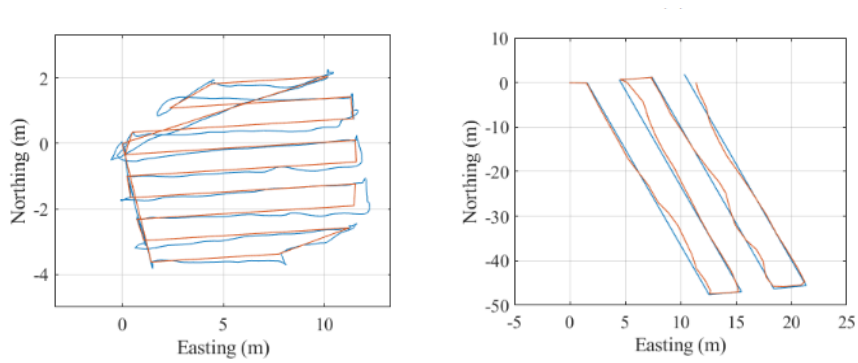


Figure 5. Survey of *W. P. Rend* (left) and of *Barge No. 1* (right) using the hybrid ROV/AUV with coverage path planning and AmaxGPMP.

Imagery collected from ROV and AUV surveys was used to produce 3D reconstructions, with a focus on the *Monohansett*, *J. Davidson*, and *Barge No. 1* sites. The team used Meshroom Software and Neural Radiance Fields (NeRFs) for this task. The team also experimented with color correction using classical approaches that have been first used to improve the quality of the images. Figure 6 shows a sample 3D reconstruction generated from data collected from field surveys.

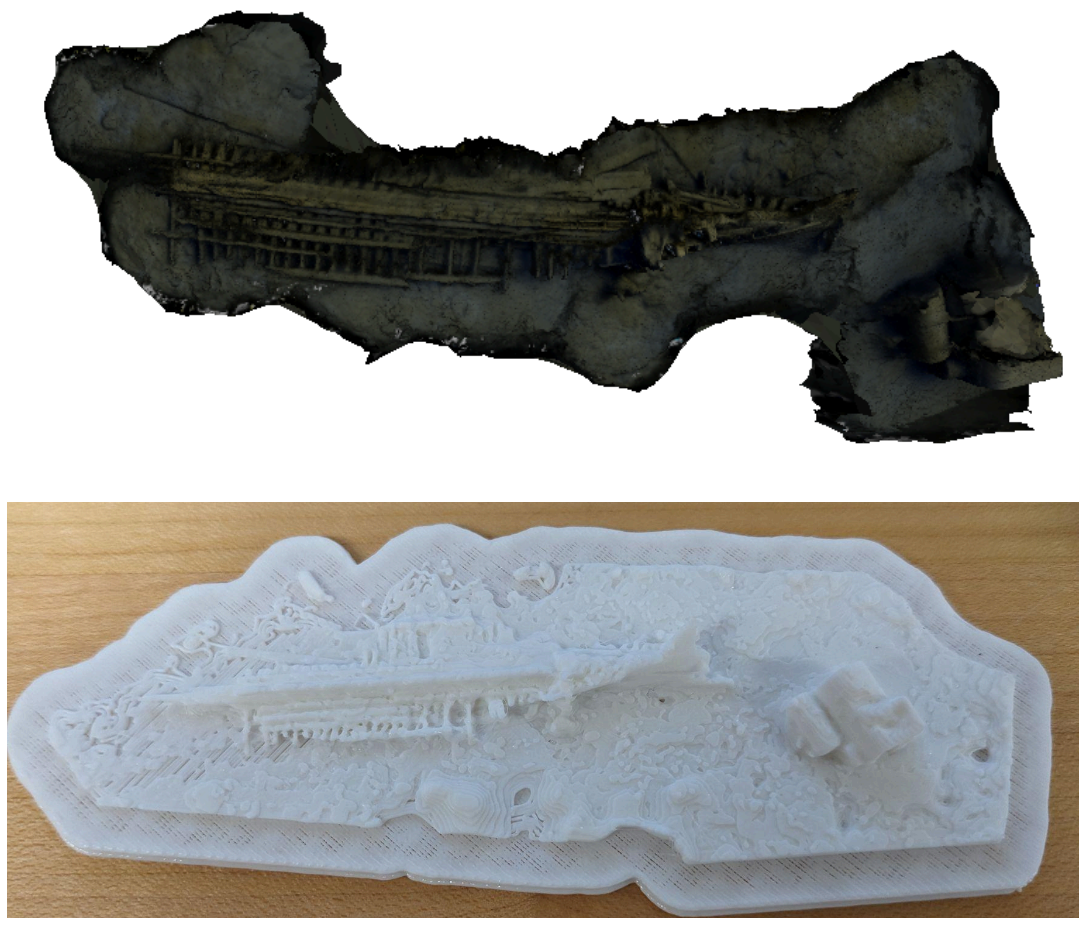


Figure 6. 3D reconstruction of *Monohansett* and 3D print based on the reconstruction

AI4Shipwrecks: Benchmark Dataset for Shipwreck Segmentation from Sidescan Sonar Imagery: With data collected during field trials, we compiled a dataset consisting of PNG images and corresponding labels for segmentation of sidescan sonar imagery of shipwrecks. We released this dataset, AI4Shipwrecks, along with supporting software tools, for the research community. The dataset and software tools can be found here: https://umfieldrobotics.github.io/ai4shipwrecks/. The AI4Shipwrecks dataset consists of 28 distinct shipwrecks totaling 286 high-resolution labeled sidescan sonar images, provided in PNG format. We consulted with expert marine archaeologists at TBNMS to produce segmentation labels for each sonar image. We also present benchmark experiments for comparison of state-of-the-art supervised segmentation methods to demonstrate the current state of the field and to provide insights on opportunities and open challenges for future research. Figure 7 shows the distribution of sites included in the AI4Shipwrecks dataset.

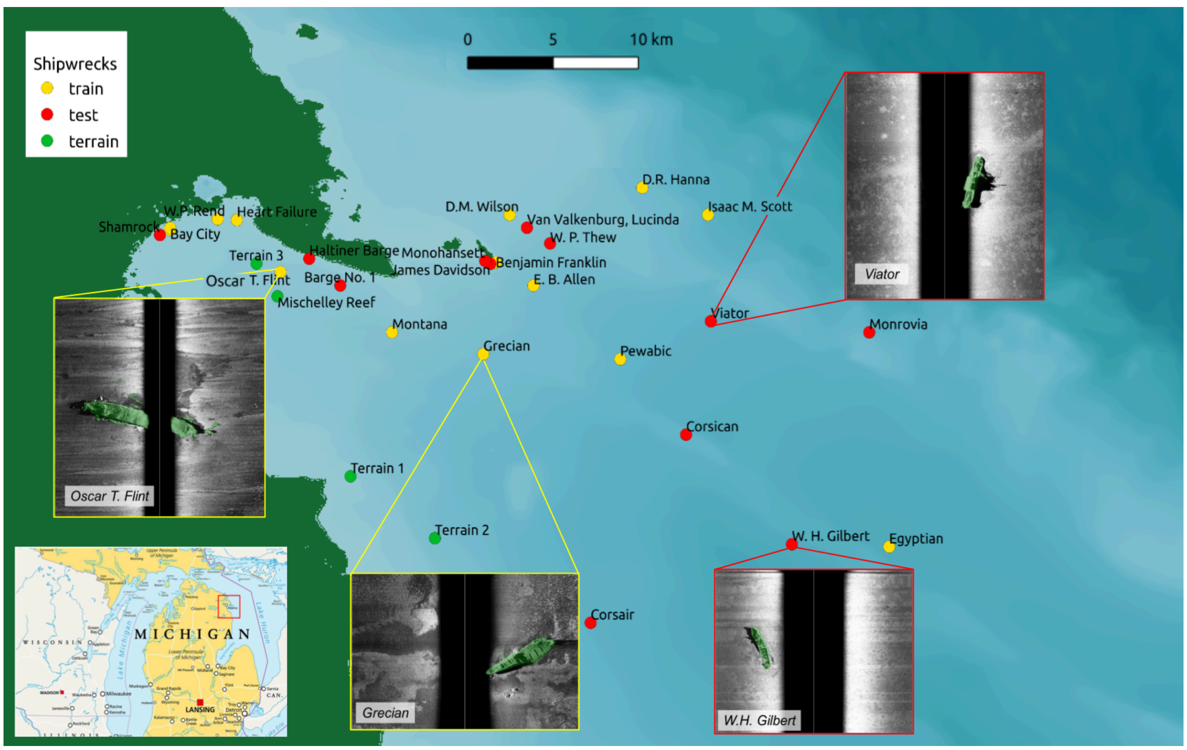


Figure 7. Map of survey sites in TBNMS, Lake Huron, MI included in the AI4Shipwrecks dataset. Callouts include example sonar data overlaid with ground truth labels. Color indicates sites that are included in testing (red) and training (yellow) splits, and locations of additional terrain surveys (green).

This work is detailed in the following publication: A. Sethuraman, A. Sheppard, O. Bagoren, C. Pinnow, J. Anderson, T. Havens, and K. A. Skinner. “Machine Learning for Shipwreck Segmentation from Side Scan Sonar Imagery: Dataset and Benchmark.” *International Journal of Robotics Research*, 2024. doi:10.1177/02783649241266853.

Training and Professional Development

This project supported training and professional development activities for undergraduate and graduate students. From the University of Michigan, 4 graduate students and 1 undergraduate student participated in this project throughout the project duration. At Louisiana State University, 2 graduate students and 1 undergraduate student participated in this project. Student engagement on this project provided critical training and professional development opportunities for graduate and undergraduate students to engage in state-of-the-art research including in data collection, data processing, and development and implementation of algorithms for marine robotics applications. Students also gained experience in technical communication through assisting with preparation of conference and journal papers, and preparing and presenting poster and oral presentations at conferences and workshops.

C. PRODUCTS

C.1 PUBLICATIONS

Are there publications or manuscripts accepted for publication in a journal or other publication (e.g., book, one-time publication, monograph) during the reporting period resulting directly from this award?

Yes

Publications Reported for this Reporting Period

Public Access Compliance	Citation
N/A	E. Morgan, I. Carlucho, W. Ard, and C. Barbalata, 2022. “Autonomous Underwater Manipulation: Current Trends in Dynamics, Control, Planning, Perception, and Future Directions.” Current Robotics Reports, pp. 1-12.
N/A	W. Ard and C. Barbalata. "Sonar Image Composition for Semantic Segmentation Using Machine Learning." In Proceedings of the IEEE/CVF Winter Conference on Applications of Computer Vision, pp. 248-254. 2023.

C.2 WEBSITE(S) OR OTHER INTERNET SITE(S)

Category	Explanation
Data or Databases , Software	https://umfieldrobotics.github.io/ai4shipwrecks/

C.3 TECHNOLOGIES OR TECHNIQUES

NOTHING TO REPORT

C.4 INVENTIONS, PATENT APPLICATIONS, AND/OR LICENSES

Have inventions, patent applications and/or licenses resulted from the award during the reporting period? Yes

If yes, has this information been previously provided to the PHS or to the official responsible for patent matters at the grantee organization? Yes

C.5 OTHER PRODUCTS AND RESOURCE SHARING

NOTHING TO REPORT

D. PARTICIPANTS

D.1 WHAT INDIVIDUALS HAVE WORKED ON THE PROJECT?

Commons ID	S/K	Name	Degree(s)	Role	Cal	Aca	Sum	Foreign Org	Country	SS
KASKIN	Y	Skinner, Katherine	BS,MS,PHD	PD/PI	1.0	0.0	0.0			NA
	Y	Meadows, Guy		Co-Investigator	0.6	0.0	0.0			NA
	N	Anderson, Jamey		Marine Operations	0.2	0.0	0.0			NA
	N	Sheppard, Anja		Graduate Student (research assistant)	0.7	0.0	0.0			NA
	N	Ard, William		Graduate Student (research assistant)	2.0	0.0	0.0			NA
	N	Pesson, Mason		Graduate Student (research assistant)	12.0	0.0	0.0			NA
	N	Naresh Babu Amutha, Nibarkavi		Graduate Student (research assistant)	0.9	0.0	0.0			NA
	N	Sethuraman, Advaith		Graduate Student (research assistant)	7.0	0.0	0.0			NA
	N	Bagoren, Onur		Graduate Student (research assistant)	0.5	0.0	0.0			NA
	N	Arnold, James		Undergraduate Student	5.0	0.0	0.0			NA
	N	Du, Allison		Undergraduate Student	1.4	0.0	0.0			NA
	Y	Havens, Timothy		Co-Investigator	1.5	0.0	0.0			NA
	Y	Barbalata, Corina		Co-Investigator	2.0	0.0	0.0			NA
	N	Pinnow, Christopher		Electrical & Computer Engineer	0.9	0.0	0.0			NA
	N	Kocher, Erik		Research Engineer	0.1	0.0	0.0			NA

Glossary of acronyms:
S/K - Senior/Key
Cal - Person Months (Calendar)
Foreign Org - Foreign Organization Affiliation
SS - Supplement Support
RS - Reentry Supplement
DS - Diversity Supplement

Aca - Person Months (Academic)	OT - Other
Sum - Person Months (Summer)	NA - Not Applicable

D.2 PERSONNEL UPDATES

D.2.a Level of Effort

Not Applicable

D.2.b New Senior/Key Personnel

Not Applicable

D.2.c Changes in Other Support

Not Applicable

D.2.d New Other Significant Contributors

Not Applicable

D.2.e Multi-PI (MPI) Leadership Plan

Not Applicable

E. IMPACT

E.1 WHAT IS THE IMPACT ON THE DEVELOPMENT OF HUMAN RESOURCES?

Not Applicable

E.2 WHAT IS THE IMPACT ON PHYSICAL, INSTITUTIONAL, OR INFORMATION RESOURCES THAT FORM INFRASTRUCTURE?

This project involved extensive data collection from field trials in Thunder Bay National Marine Sanctuary. With data collected during field trials, we compiled a dataset consisting of PNG images and corresponding labels for segmentation of side scan sonar imagery of shipwrecks. We released this dataset, AI4Shipwrecks, along with supporting software tools, for the research community. The dataset and software tools can be found here: https://umfieldrobotics.github.io/ai4shipwrecks/. The expected impact of this dataset is to improve accessibility to data and software tools for advanced technology for ocean exploration. Data collected during field trials will also be archived through the National Centers for Environmental Information (NCEI).

E.3 WHAT IS THE IMPACT ON TECHNOLOGY TRANSFER?

Not Applicable

E.4 WHAT DOLLAR AMOUNT OF THE AWARD'S BUDGET IS BEING SPENT IN FOREIGN COUNTRY(IES)?

NOTHING TO REPORT

G. SPECIAL REPORTING REQUIREMENTS SPECIAL REPORTING REQUIREMENTS

G.1 SPECIAL NOTICE OF AWARD TERMS AND NOTICE OF FUNDING OPPORTUNITIES REPORTING REQUIREMENTS

NOTHING TO REPORT

G.2 RESPONSIBLE CONDUCT OF RESEARCH

Not Applicable

G.3 MENTOR'S REPORT OR SPONSOR COMMENTS

Not Applicable

G.4 HUMAN SUBJECTS

G.4.a Does the project involve human subjects?

Not Applicable

G.4.b Inclusion Enrollment Data

NOTHING TO REPORT

G.4.c ClinicalTrials.gov

Does this project include one or more applicable clinical trials that must be registered in ClinicalTrials.gov under FDAAA?

G.5 HUMAN SUBJECTS EDUCATION REQUIREMENT

NOT APPLICABLE

G.6 HUMAN EMBRYONIC STEM CELLS (HESCS)

Does this project involve human embryonic stem cells (only hESC lines listed as approved in the NIH Registry may be used in NIH funded research)?

No

G.7 VERTEBRATE ANIMALS

Not Applicable

G.8 PROJECT/PERFORMANCE SITES

Not Applicable

G.9 FOREIGN COMPONENT

No foreign component

G.10 ESTIMATED UNOBLIGATED BALANCE

Not Applicable

G.11 PROGRAM INCOME

Not Applicable

G.12 F&A COSTS

Not Applicable

I. OUTCOMES

I.1 What were the outcomes of the award?

This project developed new technology and innovative methods to advance autonomous capabilities of marine robotic systems for search and survey of shipwreck sites. We developed novel machine learning methods for detection and segmentation of shipwreck sites from side scan sonar imagery collected onboard marine robotics platforms. We also developed novel methods for robot path planning to enable autonomous surveys of shipwreck sites. We demonstrated both machine learning and motion planning algorithms for shipwreck detection and survey in Thunder Bay National Marine Sanctuary (TBNMS). Lastly, we released a benchmark dataset for machine learning for shipwreck segmentation from sonar imagery to improve accessibility to data and software tools for advanced technology for ocean exploration.

J. MISCELLANEOUS DOCUMENTS

J.1 Other Documents

Please upload any additional attachments needed for your award that do not have a specific upload field in another section of the RPPR.

FY21 Grantee Final Report

I. Overview

1. Grant Number (Not applicable for federal PIs): NA21OAR0110196
2. Principal Investigator (name, address, contact information):
Dr. Katherine Skinner
3244 Ford Robotics Building
2505 Hayward Street, Ann Arbor, MI 48109
kskin@umich.edu
734-615-0312
3. Total Award from NOAA Ocean Exploration: $433,366
4. Project Title: Machine Learning for Automated Detection of Shipwreck Sites from Large Area Robotic Surveys
5. Area of Operation (include a map and/or coordinates): Thunder Bay National Marine Sanctuary (45.0034°N, 83.253°W). Figure 1 shows a map of TBNMS, highlighting the proposed area of operation. Figure 2 shows the original proposed survey regions (Regions A-D).

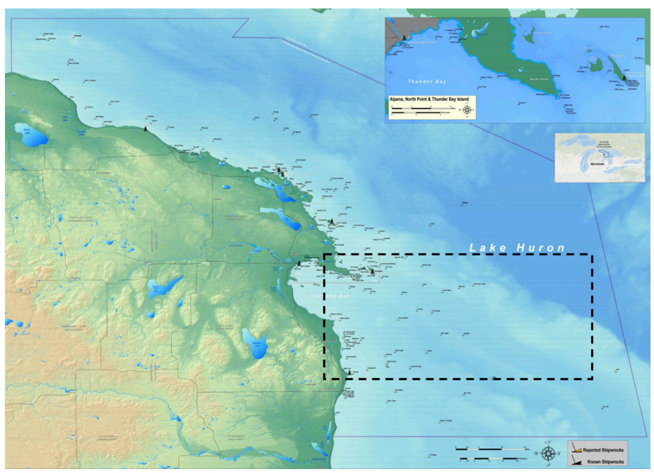


Figure 1. Map of Thunder Bay National Marine Sanctuary (TBNMS) highlighting the boundaries of the proposed survey region.

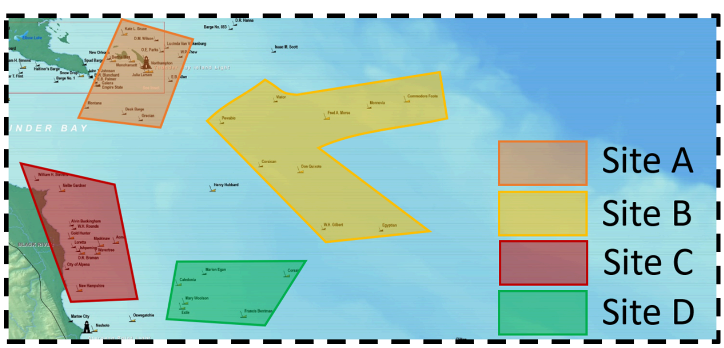


Figure 2. Proposed survey regions A-D.

6. Co-PI(s), Participating Institutions, and Personnel:
Corina Barbalata, Louisiana State University
Timothy Havens, Michigan Technological University (from July 1st, 2022 to June 30th, 2024)
Guy Meadows, Michigan Technological University (from July 1st, 2021 to June 30th, 2022)
7. Award Period: From July 1st, 2021 To June 30th, 2024

II. Summary

1. Abstract
This final report details the project goals, approach, findings, outreach activities, diversity activities, and evaluation for "Machine Learning for Automated Detection of Shipwreck Sites from Large Area Robotic Surveys" (NA21OAR0110196) between the period of July 1st, 2021 to June 30th, 2024.

2. Purpose of Project
   a. *Describe topic and/or questions that were addressed*
   This project developed new technology and innovative methods to advance autonomous capabilities of marine robotic systems for search and survey of shipwreck sites. The impact of this work is to increase efficiency and decrease cost for these missions. The technology developed was demonstrated in Thunder Bay National Marine Sanctuary (TBNMS), which contains almost 100 known shipwreck sites and over 100 undiscovered sites. Data collected and software developed throughout this project was made publicly available as a benchmark dataset to encourage and enable future research at the intersection of machine learning and ocean exploration. While the developed technology was immediately applied to search for shipwreck sites in TBNMS, it is widely applicable to enabling new discovery of submerged maritime assets in deep ocean water.

   b. *Describe/list the project objectives*
   This project achieved the following objectives:
      i. Developed novel machine learning algorithms for detection and ranking of potential targets of interest from sonar data collected through large area robotic surveys,
      ii. developed novel methods for efficient path planning of robotic surveys to collect high resolution imagery from potential sites of interest, and
      iii. validated proposed methods through large area robotic search and survey of shipwreck sites in the Thunder Bay National Marine Sanctuary (TBNMS) in Lake Huron.

3. Approach
   a. *Describe the work that was performed*
   This project involved the following activities:
      i. We developed novel machine learning methods for detection and segmentation of shipwreck sites from sidescan sonar imagery collected onboard marine robotics platforms.
      ii. We developed novel methods for robot path planning to enable autonomous surveys of shipwreck sites.
      iii. We demonstrated machine learning and motion planning algorithms for shipwreck detection and survey in Thunder Bay National Marine Sanctuary.
      iv. We released a benchmark dataset for machine learning for shipwreck segmentation from sonar imagery to improve accessibility to data and software tools for advanced technology for ocean exploration.

   Accomplishments under each of these activities are detailed further below in Section II.4.a.

   b. *Describe how the project was organized and managed (e.g., roles and responsibilities of participants)*
   PI Katherine (Katie) Skinner led the overall project with focus on development of machine learning methods. Skinner supervised undergraduate and graduate student research at the University of Michigan (UM). The students' roles were to assist in data processing, development of machine learning methods, and production of the benchmark dataset for machine learning from sonar imagery.

   Co-PI Corina Barbalata led path planning development. Barbalata supervised undergraduate and graduate student research at Louisiana State University (LSU). Students at LSU assisted with the development of adaptive motion planning algorithms for underwater vehicles, including autonomous underwater vehicles (AUVs) and remotely operated vehicles (ROVs). Students at LSU also assisted with image collection and 3D model reconstruction

   Co-PI Guy Meadows (between July 2021-June 2022) and Co-PI Tim Havens (between July 2022-June 2024) were responsible for management and coordination of field expeditions with the Michigan Technological University IVER-3 AUV.

c. *Describe how data were organized, processed, and archived to meet NOAA data management requirements*
Sensor data collected during field trials included sonar data (*.jsf), optical still imagery (*.png), video (*.mp4), and data from proprioceptive sensors (Robot Operating System (ROS) *.bag files). Navigation data refers to data from proprioceptive sensors including IMU and DVL data.

As data was collected during field testing, it was downloaded and stored on portable SSD drives as a safeguard to prevent loss of data. Throughout field trials, data was uploaded to an on-site Synology DiskStation network-attached storage (NAS) server. Multiple local copies were maintained as backup. Full data copies were provided on portable hard drives to the UM (PI: Skinner) and LSU (Co-PI: Barbalata) teams. The MTU team (Co-PI: Havens) has a full copy of the IVER-3 data. ROV data can be shared with the MTU team upon request. A data copy was also transferred to the TBNMS sanctuary scientists. Upon completion of field work, all data was copied to a RAID storage system maintained by the PI at the University of Michigan. Data stored at the University of Michigan has been backed up on Michigan's Data Den Research Archive, a data storage solution managed by the University of Michigan Library to enable access, back-up, and maintenance of digital data collections. A portable hard drive will also be maintained as a local backup copy at the University of Michigan. To meet NOAA data management requirements, data collected and generated during this project will be archived with NCEI.

Software developed at the University of Michigan is in a private Github repository. Github offers version control for tracking updates and changes to software across the project team. The software developed at Louisiana State University is currently held in a password protected Github account, to which all members of the LSU team have access.

4. Findings
   a. *Describe actual accomplishments and findings (provide maps, graphics, and images)*
      i. **Machine Learning for Detection and Segmentation of Shipwreck Sites from Sidescan Sonar Imagery.** One challenge of working with sonar imagery in machine learning applications is that there is limited labeled data available for supervised learning approaches. To overcome this challenge, we developed a novel method, STARS, for segmentation of shipwreck sites from sonar imagery with no real labeled data required for training. We compare the performance of our framework to state-of-the-art

segmentation solutions operating under the same restrictions. Our main contributions are i) a synthetic shipwreck generation method for side scan sonar images, and ii) a novel network architecture that leverages anomaly detection and deformation prediction to better segment shipwrecks and debris fields found at shipwreck sites without requiring real examples of shipwrecks for training. Figure 3 shows an overview of the STARS network architecture. Figure 4 shows sample qualitative results for input side scan sonar images to provide comparison between the ground truth, STARS, and baseline methods.

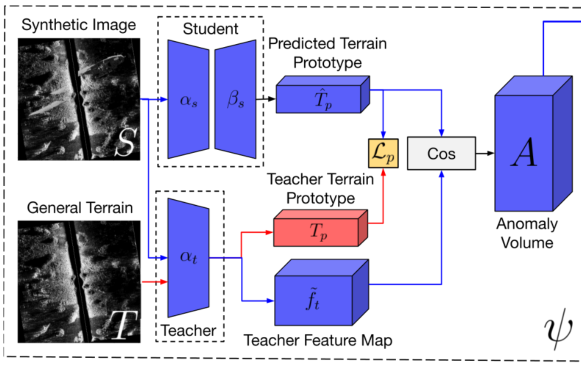


Figure 3. STARS network architecture. STARS leverages real terrain data with synthetic shipwrecks for training to predict shipwreck segmentation. During test time, STARS can take in a real sonar image containing a shipwreck to perform shipwreck segmentation. Note that STARS does not require any real examples of shipwrecks for training.

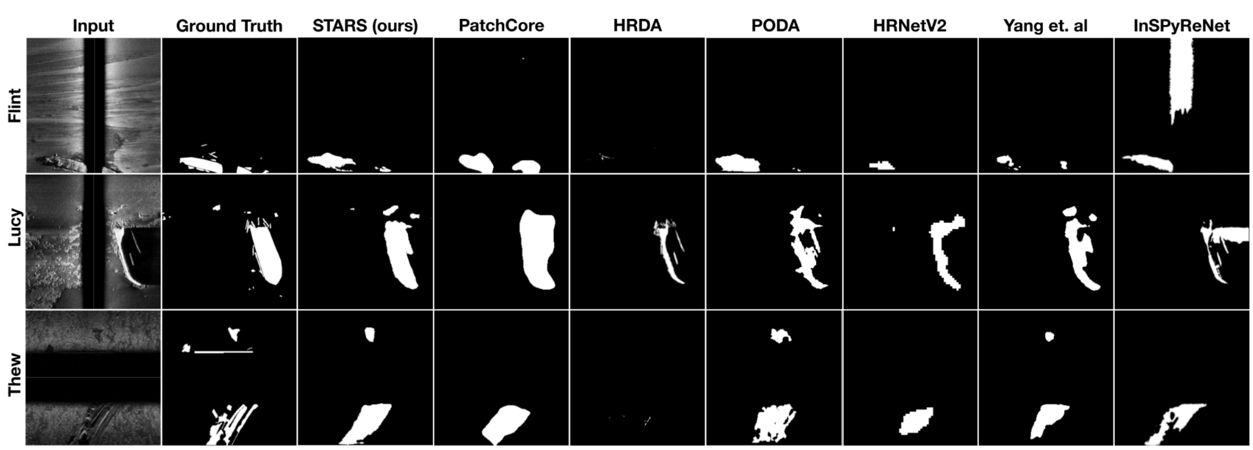


Figure 4. Selected qualitative results from our method compared to baselines. Some methods have a tendency to inaccurately over-segment or fail to segment debris from shipwrecks, resulting in lower performance. However, STARS consistently produces more accurate segmentation outputs.

This work is detailed in the following publication: A. Sethuraman and K. A. Skinner. “STARS: Zero-shot Sim-to-Real Transfer for Segmentation of Shipwrecks in Sonar Imagery” in Proceedings of the *British Machine Vision Conference*, November 2023.

ii. Motion Planning for Autonomous Shipwreck Surveys.

To collect optical images in close proximity of the shipwreck, this project has supported an obstacle avoidance path planning algorithm specifically designed to create smooth, collision-free trajectories for underwater robotic systems operating in dynamic environments. The proposed approach begins with the generation of an initial path based on the system's kinematics, which is then refined through optimization that accounts for both the system's constraints and the presence of obstacles. The optimization process incorporates the correlation between path states into a kernel, enhancing the planner's ability to adaptively adjust the path to avoid obstacles while maintaining smoothness. However, leveraging these correlations can result in significant computational demands for systems with high dimensionality. To address this, the proposed method, named AmaxGPMP, employs a strategy to reduce the amount of information required to construct these kernels while still accurately capturing the state correlations, thereby reducing computation time. The proposed approach has been first tested in simulation and its performance compared to classical approaches such as A* and RRT (Fig. 5). After that it has been deployed on a small hybrid ROV/AUV and optical data has been collected (Fig. 6). This has also been coupled with coverage path planning algorithms to ensure all the area detected in the sonar images is covered (Fig. 7).

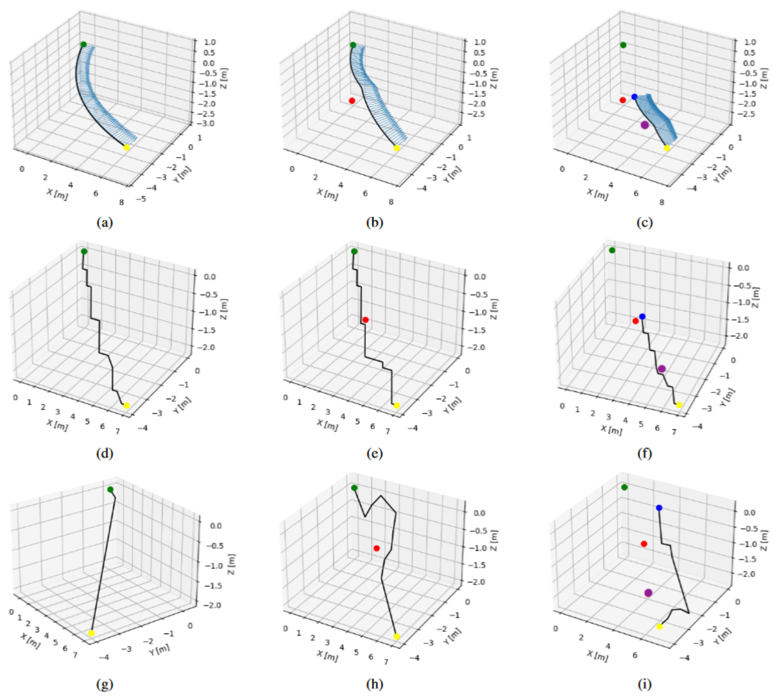


Figure 5. Simulation results, where the green sphere represents START position, the yellow sphere is the GOAL, and the red spheres represent OBSTACLES: (a - c) proposed approach results, (d - f) A* results, (g - i) RRTConnect results. For all cases; no object in the environment (first column figures), one object in the environment known from the start of the mission (second column), one object known from the start and a second object is emerging after the start of the mission (third column).

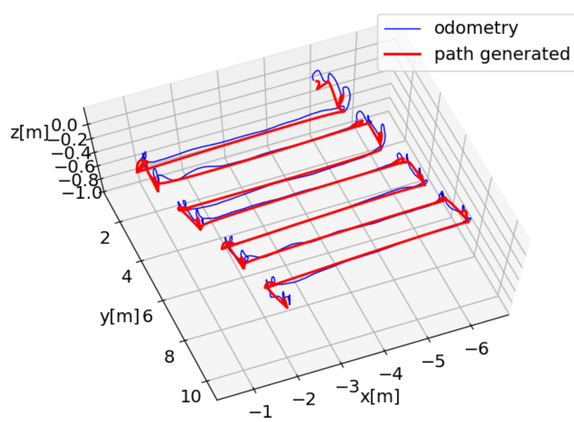


Figure 6. Path taken by the real vehicle to collect data using AmaxGPMP over *Monohansett.*

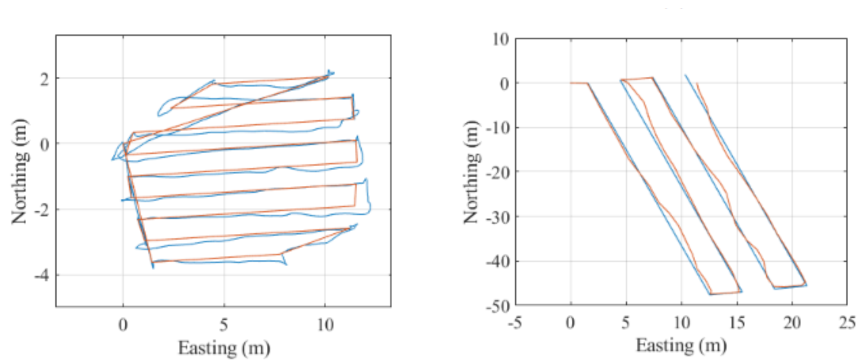


Figure 7. Survey of *W. P. Rend* (left) and of *Barge No. 1* (right) using the hybrid ROV/AUV with coverage path planning and AmaxGPMP.

This work is detailed in the following publication: M. Pesson, E. Morgan and C. Barbalata, “Collision Free Path Planning for Underwater Vehicles in Rapidly Changing Environments," *2024 IEEE International Conference on Advanced Intelligent Mechatronics (AIM)*, Boston, MA, USA, 2024, pp. 1524-1530, doi: 10.1109/AIM55361.2024.10637062.

Imagery collected from ROV and AUV surveys was used to produce 3D reconstructions, with a focus on the *Monohansett*, *J. Davidson*, and *Barge No. 1* sites. The team used Meshroom Software and Neural Radiance Fields (NeRFs) for this task. The team also experimented with color correction using classical approaches that have been first used to improve the quality of the images. Figure 8 shows a sample 3D reconstruction generated from data collected from field surveys, and a 3D print based on the reconstruction.

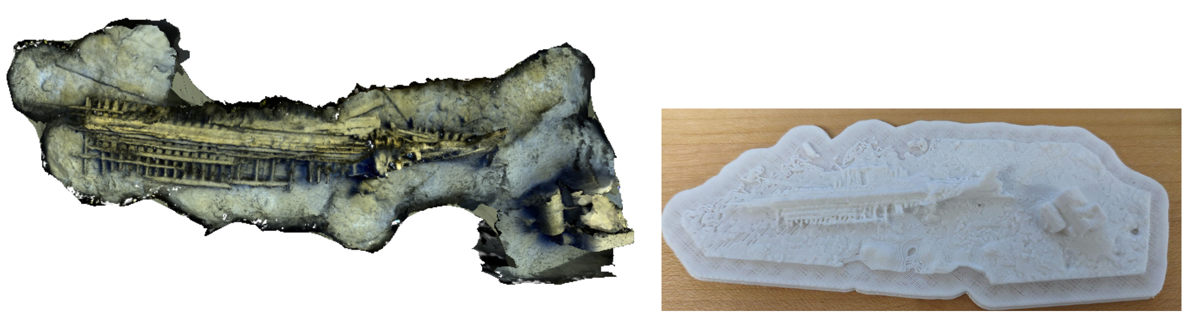


Figure 8. (left) 3D reconstruction of *Monohansett* and (right) 3D print based on the reconstruction. Note: Brightness of the 3D reconstruction has been enhanced for improved visibility.

iii. **AI4Shipwrecks: Benchmark Dataset for Shipwreck Segmentation from Side Scan Sonar Imagery.** With data collected during field trials, we compiled a dataset consisting of PNG images and corresponding labels for side scan sonar imagery of shipwrecks. We released this dataset, AI4Shipwrecks, along with supporting software tools, for the research community. The dataset and software tools can be found here: https://umfieldrobotics.github.io/ai4shipwrecks/. The AI4Shipwrecks dataset consists of 28 distinct shipwrecks totaling 286 high-resolution labeled side scan sonar images, provided in PNG format. We consulted with expert marine archaeologists at TBNMS to produce segmentation labels for each sonar image. We also present benchmark experiments for comparison of state-of-the-art supervised segmentation methods to demonstrate the current state of the field and to provide insights on opportunities and open challenges for future research. Figure 9 shows the distribution of sites included in the AI4Shipwrecks dataset.

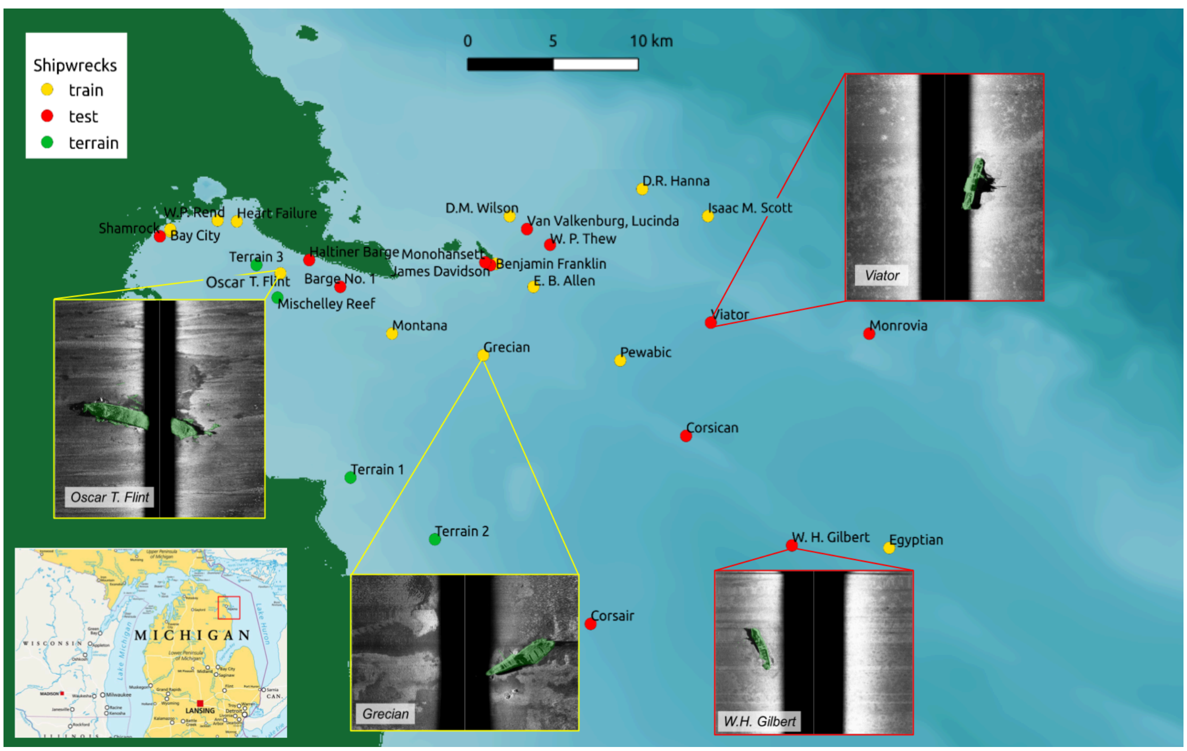


Figure 9. Map of survey sites in TBNMS, Lake Huron, MI included in the AI4Shipwrecks dataset. Callouts include example sonar data overlaid with ground truth labels. Color indicates sites that are included in testing (red) and training (yellow) splits, and locations of additional terrain surveys (green).

This work is detailed in the following publication: A. Sethuraman, A. Sheppard, O. Bagoren, C. Pinnow, J. Anderson, T. Havens, and K. A. Skinner. "Machine Learning for Shipwreck Segmentation from Side Scan Sonar Imagery: Dataset and Benchmark." *International Journal of Robotics Research*, 2024. doi:10.1177/02783649241266853.

b. *Inventory of activities (number of submersible/ROV dives, CTD, net tows, square kilometers mapped in the U.S. Exclusive Economic Zone, technology development milestones, etc.), including maps and/or coordinates*
Table 1 provides an inventory of activities during Year 1 field trials, which took place between May 23, 2022 and June 3, 2022. For AUV missions, we report the approximate area covered from side scan sonar surveys (in km^2). The total estimated area covered is 8.04 square kilometers. For ROV missions, we report the number of ROV deployments. We had a total of 13 ROV deployments with three different ROV platforms.

Table 1. Inventory of activities during Year 1 field trials.

Date	**Mission**	**Site**	**Site Waypoint (Latitude, Longitude)**	**Vehicle**	**Approx. Site Depth (ft)**	**AUV Area Coverage (km^2)/Number of ROV Deployments**
5-23	I-1	*E.B. Allen*	45.0162666667, -83.1649833333	IVER-3	100	0.066
5-23	I-2	*E.B. Allen*	45.0162666667, -83.1649833333	IVER-3	100	0.066
5-23	I-3	*E.B. Allen*	45.0162666667, -83.1649833333	IVER-3	100	0.0264
5-23	I-4	*W.P. Thew*	45.0450833333, -83.1534166667	IVER-3	84	0
5-23	I-5	*W.P. Thew*	45.0450833333, -83.1534166667	IVER-3	84	0.072
5-23	I-6	*W.P. Thew*	45.0450833333, -83.1534166667	IVER-3	84	0.036

5-24	I-1	*Lucinda Van Valkenberg*	45.0563333333, -83.1696666667	IVER-3	60	0.06
5-24	I-2	*Lucinda Van Valkenberg*	45.0563333333, -83.1696666667	IVER-3	60	0.07344
5-24	I-3	*D.M. Wilson*	45.065333, -83.182133	IVER-3	40	0.072
5-24	I-4	Terrain *(near Lucinda Van Valkenberg)*	45.055234, -83.173974	IVER-3	40-60	0.42462
5-24	I-5	*Montana*	44.98375, -83.2668833333	IVER-3	63	0.07344
5-27	I-1	*Viator*	44.9913333333, -83.03715	IVER-3	188	0.384
5-27	I-2	*Viator*	44.9913333333, -83.03715	IVER-3	188	0.64
5-27	I-3	*Monrovia*	44.9836666667, -82.923	IVER-3	140	0.832
5-27	I-4	*Haltiner Barge*	45.035, -83.3267167	IVER-3	13-17	0.1963
5-28	D-1	*Monohansett*	45.033267, -83.1998	*Dory*	18	2
5-31	I-1	*Oscar T. Flint*	45.0261333333, -83.3473833333	IVER-3	30	0.384
5-31	I-2	*Oscar T. Flint*/Terrain	45.0261333333, -83.3473833333	IVER-3	15-30	0.672
5-31	I-3	*Oscar T. Flint*	45.0261333333, -83.3473833333	IVER-3	30	0.672
5-31	I-4	*Heart Failure*	45.0621, -83.37755	IVER-3	18	0.26
5-31	D-1	*Oscar T. Flint*	45.0261333333, -83.3473833333	*Dory*	30	1
5-31	N-1	*W.P. Rend*	45.062367, -83.392583	*Nemo*	17	1

6-1	I-1	*Barge No. 1*	45.015317, -83.303967	IVER-3	42	1.092
6-1	I-2	*Haltiner Barge*	45.035, -83.3267167	IVER-3	13-17	0.168
6-1	I-3	*W.P. Rend*	45.062367, -83.392583	IVER-3	17	0.168
6-1	I-4	Artificial Reef	45.061054, -83.387030	IVER-3	5-10	0.3408
6-1	I-5	*Heart Failure*	45.0621, -83.37755	IVER-3	18	0.168
6-2	I-1	*Grecian*	44.9683166667, -83.19985	IVER-3	75-100	0.325
6-2	I-2	*Pewabic*	44.9648333333, -83.1039333333	IVER-3	165	0.768
6-2	N-1	*Monohansett*	45.033267, -83.1998	*Nemo*	18	2
6-2	O-1	*Monohansett*	45.033267, -83.1998	*Outlander*	18	1
6-2	D-1	*Bay City*	45.05615, -83.42675	*Dory*	11	2
6-2	N-2	*Bay City*	45.05615, -83.42675	*Nemo*	11	1
6-3	D-1	*Harvey Bissell*	45.05615, -83.42675	*Dory*	15	2
6-3	N-1	*Haltiner Barge*	45.035, -83.3267167	*Nemo*	13-17	1

Table 2 provides an inventory of activities during Year 2 field trials, which took place between June 5, 2023 and June 23, 2023. For AUV missions, we report the approximate area covered from side scan sonar surveys (in km^2). The total estimated area covered is 10.7 square kilometers. For ROV/AUV missions, we report the number of ROV/AUV deployments. We had a total of 20 optical ROV/AUV deployments with two different ROV/AUV platforms.

Table 2. Inventory of activities during Year 2 field trials.

Date	**Mission**	**Site**	**Site Waypoint (Latitude, Longitude)**	**Vehicle**	**Approx. Site Depth (ft)**	**AUV Area Coverage (km^2)/Number of optical ROV/AUV Deployments**
6-5	I-1	*Egyptian*	44.834867, -82.908583	IVER-3	230 ft	0.720
6-5	I-2	*Egyptian*	44.834867, -82.908583	IVER-3	230 ft	0.832
6-5	I-3	*W.H. Gilbert*	44.83658, -82.9787	IVER-3	235 ft	0.104
6-5	I-4	*W.H. Gilbert*	44.83658, -82.9787	IVER-3	235 ft	0.512
6-6	I-1	Region C	44.884157, -83.296527	IVER-3	15-20 ft	0.240
6-6	I-2	Region C	44.883745, -83.295347	IVER-3	15-20 ft	0.252
6-7	I-1	*Monohansett Davidson Franklin*	45.033267, -83.1998	IVER-3	15-20 ft	0.240
6-7	I-2	Mischelley Reef	45.008614, -83.349146	IVER-3	21-35 ft	0.240
6-7	I-3	Mischelley Reef	45.009808, -83.348910	IVER-3	21-35 ft	0.064
6-7	I-4	*Bay City Bissell Alpena Steamer*	45.05615, -83.42675	IVER-3	14 ft	0.180
6-8	I-1	*D.R. Hanna*	45.08417, -83.08655	IVER-3	135 ft	0.900
6-8	I-2	Region A	45.03064, -83.36473	IVER-3	35 ft	0.640
6-9	I-1	*Corsican*	44.97126,	IVER-3	160 ft	0.480

			-83.055			
6-9	I-2	*Corsican*/Region D	44.97126, -83.055	IVER-3	160 ft	0.630
6-9	I-3	*Corsair*	44.782033, 83.12377	IVER-3	182 ft	0.600
6-9	I-4	Region C	44.84081, -83.23598	IVER-3	82-92 ft	0.640
6-9	B-1	*W.P. Rend*	45.062367, -83.392583	*Bruce*	17 ft	2
6-14	I-1	*W.P. Rend*	45.062367, -83.392583	IVER-3	17 ft	0.128
6-14	D-1	*W.P. Rend*	45.062367, -83.392583	*Dory*	17 ft	1
6-14	B-1	*W.P. Rend*	45.062367, -83.392583	*Bruce*	17 ft	1
6-14	I-2	*Monohansett*	45.033267, -83.1998	IVER-3	15-20 ft	0.042
6-14	B-2	*Monohansett*	45.033267, -83.1998	*Bruce*	15-20 ft	2
6-14	I-3	*J. Davidson*	45.0324, -83.192717	IVER-3	20 ft	0.118
6-14	B-3	*J. Davidson*	45.0324, -83.192717	*Bruce*	20 ft	1
6-15	I-1	*Isaac Scott*	45.05153, -83.03922	IVER-3	175 ft	0.720
6-15	I-2	*Isaac Scott*	45.05153, -83.03922	IVER-3	175 ft	0.240
6-15	I-3	*D.M. Wilson*	45.065333, -83.182133	IVER-3	40 ft	0.504
6-15	I-4	Terrain (near *Lucinda Van Valkenburg*)	45.055234, -83.173974	IVER-3	60 ft	0.114
6-16	B-1	*Bay City*	45.05615,	*Bruce*	14 ft	1

			-83.42675			
6-16	I-1	*Shamrock, J.F. Warner*	45.051283, -83.4342	IVER-3	15 ft	0.108
6-16	I-2	*Shamrock*	45.051283, -83.4342	IVER-3	15 ft	0.168
6-16	I-3	*Barge No. 1*	45.015317, -83.303967	IVER-3	42 ft	0.264
6-16	I-4	Terrain (near *Barge No. 1*)	45.01952, -83.30122	IVER-3	42 ft	0.720
6-16	D-1	*Barge No. 1*	45.015317, -83.303967	*Dory*	42 ft	1
6-16	I-5	Terrain (near *Haltiner Barge*)	45.035, -83.3267167	IVER-3	17 ft	0.252
6-16	D-2	*Haltiner Barge*	45.035, -83.3267167	*Dory*	17 ft	1
6-16	I-6	*Haltiner Barge* (bilge only)	45.035, -83.3267167	IVER-3	17 ft	0.015
6-20	D-1	*D.M. Wilson*	45.065333, -83.182133	*Dory*	40 ft	3
6-20	B-1	*D.M. Wilson*	45.065333, -83.182133	*Bruce*	40 ft	2
6-21	D-1	*Monohansett*	45.033267, -83.1998	*Dory*	15-20 ft	2
6-21	D-2	*J. Davidson*	45.0324, -83.192717	*Dory*	20 ft	1
6-21	B-1	*Barge No. 1*	45.015317, -83.303967	*Bruce*	42 ft	1
6-21	D-3	*Barge No. 1*	45.015317, -83.303967	*Dory*	42 ft	1

c. *Inventory of samples collected*
Nothing to report.

d. *List resulting publications, presentations, websites, etc. All publications must acknowledge NOAA Ocean Exploration funding and be submitted to the NOAA Institutional Repository. Abstracts, publications, and other materials must be appended or linked to this report.*

i. Publications

- E. Morgan, I. Carlucho, W. Ard, and C. Barbalata, 2022. "Autonomous Underwater Manipulation: Current Trends in Dynamics, Control, Planning, Perception, and Future Directions." *Current Robotics Reports*, pp.1-12. Available at: https://link.springer.com/article/10.1007/s43154-022-00089-2
- W. Ard and C. Barbalata. "Sonar Image Composition for Semantic Segmentation Using Machine Learning." In Proceedings of the *IEEE/CVF Winter Conference on Applications of Computer Vision*, pp. 248-254. 2023. Available at: https://openaccess.thecvf.com/content/WACV2023W/MaCVi/papers/Ard_Sonar_Image_Composition_for_Semantic_Segmentation_Using_Machine_Learning_WACVW_2023_paper.pdf
- A. Sethuraman and K. A. Skinner. "STARS: Zero-shot Sim-to-Real Transfer for Segmentation of Shipwrecks in Sonar Imagery" in Proceedings of the *British Machine Vision Conference*, November 2023. *selected for oral presentation. Preprint available at: https://arxiv.org/abs/2310.01667
- E. Morgan, W. Ard, and C. Barbalata. "A probabilistic framework for hydrodynamic parameter estimation for underwater manipulators." Proceedings of *OCEANS 2023-MTS/IEEE US Gulf Coast*. IEEE, 2023. Available at: https://ieeexplore.ieee.org/document/10337120
- A. Sethuraman, A. Sheppard, O. Bagoren, C. Pinnow, J. Anderson, T. Havens, and K. A. Skinner. "Machine Learning for Shipwreck Segmentation from Side Scan Sonar Imagery: Dataset and Benchmark." *International Journal of Robotics Research*, 2024. Preprint available at: https://arxiv.org/abs/2401.14546
- M. Pesson, E. Morgan, and C. Barbalata. "Collision Free Path Planning for Underwater Vehicles in Rapidly Changing Environments" in the *2024 IEEE/ASME International Conference on Advanced Intelligent Mechatronics*. Available at: https://ieeexplore.ieee.org/document/10637062

ii. Presentations

- "Towards Sim2Real for Shipwreck Detection in Side Scan Sonar Imagery" by A. Sethuraman and K. A. Skinner at the Sim2Real Workshop at *Robotics: Science and Systems*, June 2022.
- "Leveraging Marine Robotic Systems for Data-Driven Shipwreck Detection" by K. A. Skinner at the Lakebed 2030 Conference, September 2023.
- "Leveraging Synthetic Data for Learning-Based Marine Robot Perception" by K. A. Skinner. Invited keynote presentation at the First Workshop on Photorealistic Image and Environment Synthesis for Robotics (PIES-Rob) at the *IEEE International Conference on Intelligent Robots and System*s, October 2023.
- "Emerging trends in sensing capabilities and their integration with underwater robotics" by C. Barbalata and K. A. Skinner. Invited tutorial at the Combined IEEE 2023 Symposium Sensor Data Fusion and International Conference on Multisensor Fusion and Integration (SDF-MFI), November 2023.
- "Integrating Machine Learning with GIS Tools for Automated Shipwreck Detection from Sonar Imagery", by A. Sethuraman, A. Sheppard, O. Bagoren, and K. A. Skinner at the Society for Historical Archaeology 2024 Conference on Historical and Underwater Archaeology, January 2024.

iii. Websites

- University of Michigan Field Robotics Group, "AI4Shipwrecks Dataset". Available at: https://umfieldrobotics.github.io/ai4shipwrecks/

e. *List the final data inventory, including a complete list of all data types collected (e.g., CTD, MBES, images). Describe the location and status of the data archive and/or sample storage and the plan for timely public access. If the data are/will be archived at an approved facility outside of NCEI, the URL link(s) to the data should be provided to NOAA Ocean Exploration*

Final data products produced during this project included: raw sensor data, processed sensor data, and software. Sensor data includes sonar data (*.jsf), optical still imagery (*.png), video (*.mp4), and data from proprioceptive sensors (ROS *.bag files). Processed data includes processed sensor data, navigation data derived from sensor fusion, additional data products including 3D models derived from optical imagery, segmentation labels, and output from the developed deep neural network including pretrained models for replicating network output. Note that the *.jsf format is a proprietary EdgeTech format. Open source software is available to read this format and convert it to another format as necessary for enabling open access to the data. Navigation data refers to data from proprioceptive sensors including IMU and DVL data. Software refers to code for the developed deep neural networks and adaptive path planning algorithms. Note that the original data plan included collection of environmental data, including temperature and pressure, as well as ship tracks for the support vessel. We did not collect ship tracks, but instead report a site waypoint for each visited site. We also did not collect independent environmental data, although the *.jsf files do contain temperature information.

Software developed at the University of Michigan is in a private Github repository. Github offers version control for tracking updates and changes to software across the project team. The software developed at Louisiana State University is currently held in a password protected Github account, to which all members of the LSU team have access.

A benchmark dataset and software tools have been publicly released through the following website: https://umfieldrobotics.github.io/ai4shipwrecks/. This release includes processed side scan sonar data (*.png) and segmentation labels (*.png). The *.png format was selected for ease-of-use by non-expert users. The raw sensor data and remaining processed sensor data products will be released through NCEI. If data formats are not compatible with NCEI, the data will be released through Mendeley Data.

f. *Note any major changes/adjustments to activities, expenditures, results, etc. reported in previously-submitted documents (e.g., Cruise Report, Semiannual Report)*
Nothing to report.

g. *Equipment inventory procured with grant funds and final disposition by NOAA on ownership*
Nothing to report.

5. <u>Highlights from outreach and education and diversity and inclusion activities</u>
    a. Public outreach
        - PI Skinner presented a public lecture titled “Deploying Robots and Artificial Intelligence to Search for Shipwreck Sites” at the Great Lakes Maritime Heritage Center on June 22, 2023
        - PI Skinner developed and led a workshop lecture and hands-on activity on “Underwater Robotics for Marine Archaeology” for the Kelsey Museum

of Archaeology "Family Day" focused on "Archaeology and Technology" (Fall 2023). "Family Day" is a 3-hour event that takes place biannually and is open to the public. The event focuses on hands-on family-friendly activities to engage a broader population in archaeology topics.

b. Media
- The field expedition was shared on the NOAA Ocean Explorer Instagram account. The PI also coordinated with the UM media team to share content on social media through the University of Michigan Robotics Department Twitter and Instagram accounts.
- The project team coordinated with NOAA for a feature of the field expeditions on The Ocean Explorer website.
- Featured on WBKBTV: "Scientists travel to the Thunder Bay National Marine Sanctuary", WBKBTV on June 1, 2022
- Featured in *Alpena News*: "Research team uses robots to search for shipwrecks" by Darby Hinkley on June 6, 2022
- Featured in *Alpena News*: "Researcher to present on sonar data collection in Thunder Bay tonight" by Zipporah Abarca on June 22, 2023
- Featured in *Alpena News*: "Researchers deploy autonomous vessels in Thunder Bay" by Darby Hinkley on June 21, 2023
- Featured on WBKB TV "NOAA Funded Project Uses AI to Detect Shipwrecks" on June 20, 2023
- Featured on 1057 The Bird Radio on June 22, 2023
- Featured on WCMU Public Radio on June 21, 2023 by Zipporah Abarca: "How artificial intelligence is making new discoveries in the Great Lakes"
- Featured on the Michigan Engineering YouTube channel: "Artificial Intelligence Trained to Find Shipwrecks." *Winner of 2023 Michigan Emmy Award for Technology - News category (Marcin Szczepanski and Gabriel Cherry)
- Featured on the Michigan Engineering News webpage and print: "Building Curious Machines", May 2023.

c. Education
- Results from this project were used to create curriculum materials for ROB 572: Marine Robotics at the University of Michigan.

d. Diversity and inclusion activities
- PI Skinner organized and led a 75-minute workshop on "Underwater Robotics" for Center for Engineering Diversity and Outreach (CEDO) Engineering Summer Camp (Summer 2023). The workshop leveraged data and experience from this project. CEDO Engineering Summer Camps invite UM faculty and students to engage with K-12 students to foster excitement in their field.

- PI Skinner developed and presented a 60-minute lecture on "Underwater Robotics" for the Michigan-Louis Stokes Alliance for Minority Participation (MI-LSAMP) Robotics Workshop (Summer 2023). The lecture leveraged data and experience from this project. MI-LSAMP aims to increase the number of underrepresented minority students earning undergraduate degrees in STEM fields with a focus on graduate school preparation.
- An undergraduate research assistant was recruited through the University of Michigan Undergraduate Research Opportunity Program (UROP) to participate in this project. UROP offers research opportunities and support for freshmen and sophomores, which can improve retention of undergraduates from underrepresented backgrounds in STEM fields.

III. Evaluation

1. Accomplishments - *Explain special problems and discrepancies between scheduled and accomplished work*
   There were several discrepancies between planned and accomplished surveys during field expeditions. These discrepancies did not have a significant impact on meeting the overall project objectives. The discrepancies are detailed in the Field Reports for 2022 and 2023 field expeditions.

2. Expenditures
   a. *Describe original planned expenditures*
      Original planned expenditures included: Salary and fringe benefits for 0.5 summer months per year of PI effort; salary, fringe benefits, and tuition for 1 Graduate Student Research Assistant; domestic travel for field work; boat rental for field work; subcontracts with Louisiana State University and Michigan Technological University; and indirect costs.

   b. *Describe actual expenditures*
      Actual expenditures align with the categories that were originally planned.

c. *Include a final budget expenditures table (NOAA Ocean Exploration template provided) with a column of original planned expenditures and a column of actual grant expenditures*

	*** Funds Available**	**Actual Expenditures**	
	For This Reporting Period	**For This Reporting Period**	**Balance Remaining**
Salaries & Wages	$ 47,264.00	$ 51,699.34	$ (4,435.34)
Staff Benefits	$ 10,713.00	$ 9,883.34	$ 829.66
Travel	$ 3,946.00	$ 6,926.77	$ (2,980.77)
Subk <25K	$ 50,000.00	$ 50,000.00	$ -
Supplies	$ 39,000.00	$ 38,150.00	$ 850.00
Subk > 25K	$ 167,818.00	$ 167,808.73	$ 9.27
Other - Tuition	$ 30,109.00	$ 21,504.42	$ 8,604.58
Indirect Cost	$ 84,516.00	$ 87,729.31	$ (3,213.31)
Total	$ 433,366.00	$ 433,701.91	$ (335.91)

d. *Explain special problems and discrepancies between planned and actual expenditures*
Nothing to report.

3. Next steps
   a. *Planned or expected outcomes (professional papers, presentations, etc.)*
   Nothing to report.

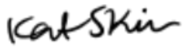
   b. *Brief description of how project deliverables and outcomes contribute to societal and/or ecosystem well-being*
   This work developed new technology in machine learning and marine robotics for detection and survey of shipwreck sites. The developed machine learning methods improve efficiency of shipwreck detection missions, allowing initial sites of interest to be detected onboard the boat within minutes of downloading data. This increased efficiency will in turn lead to decreased costs required to carry out search missions. The robotic planning methods developed enable repetitive, yet adaptive, autonomous robotic surveys for consistent monitoring of shipwreck sites on an annual basis. While the methods developed were demonstrated in TBNMS for shipwreck search and survey, these methods are also applicable to other regions, including deep ocean waters, and can be extended beyond shipwrecks to detection and survey of other maritime assets of interest. Lastly, this work led to release of a benchmark dataset for shipwreck detection from side scan sonar

imagery. Datasets for training and testing and code for evaluation were made open-source. Increasing accessibility to data and software tools will enable future research in advanced technology for ocean exploration.

c. *Brief description of needs and/or plans for additional work, if any (next project phase, new research questions, unaccomplished work, etc.)*
Data will be archived through NCEI.

Prepared by: PI Katherine Skinner with input from Co-PIs Corina Barbalata and Timothy Havens

Signature of Principal Investigator:



Date: 09/23/2024

BUDGET EXPENDITURES REPORT

EXAMPLE FOR PLANNED EXPENDITURES VERSUS ACTUAL EXPENDITURES FOR REPORTING PERIOD

NOAA Grant No.: NA20OAR01104XX
Institution Name: University of Michigan
Lead PI Name: Katherine Skinner
Award Period: 07/01/2021-06/30/2024
Reporting Period: 07/01/2021-06/30/2024

Total Award Amount: $433,366

	* Funds Available For This Reporting Period	Actual Expenditures For This Reporting Period	Balance Remaining
Salaries & Wages	$ 47,264.00	$ 51,699.34	$ (4,435.34)
Staff Benefits	$ 10,713.00	$ 9,883.34	$ 829.66
Travel	$ 3,946.00	$ 6,926.77	$ (2,980.77)
Subk <25K	$ 50,000.00	$ 50,000.00	$ -
Supplies	$ 39,000.00	$ 38,150.00	$ 850.00
Subk > 25K	$ 167,818.00	$ 167,808.73	$ 9.27
Other - Tuition	$ 30,109.00	$ 21,504.42	$ 8,604.58
Indirect Cost	$ 84,516.00	$ 87,729.31	$ (3,213.31)
Total	$ 433,366.00	$ 433,701.91	$ (335.91)

Please Explain Any Significant Differences (Plus or Minus 5%)

*** Funds Available** — **This should be the funds awarded: If a one-year award, this should reflect the entire award amount.**
Multi-year awards: If a two-year award, this should reflect funds allocated for Year 1 PLUS Outyear 2