Mapping of Coastal Reef Systems Using an Autonomous Surface Kayak

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Abstract

Coral reefs in coastal environments are ecologically important systems that are subject to natural and anthropogenic change. In order to study, monitor, and map coastal reef systems, scientists and managers need affordable autonomous platforms that are versatile, rugged, and can operate in shallow environments where these reefs are found. In this collaborative study with the Robotic Discovery Laboratories (RDL) at the University of Delaware (UD) and the Remote Sensing Division, U.S. Naval Research Laboratories (NRL), Washington, DC, an autonomous Coastal Kayak system outfitted with conventional off-the-shelf sensors and equipment was used to map coral reef systems in Kaneohe Bay, Oahu, Hawaii. Results will evaluate the utility of using this versatile, rugged, and low-cost platform for reef mapping applications in coastal environments. Additionally, this study will evaluate the capacity for integration of externally-mounted or towed sensor packages with the Coastal Kayak system to collect additional data for use in studying and monitoring reef ecosystems.

Methods and Approach

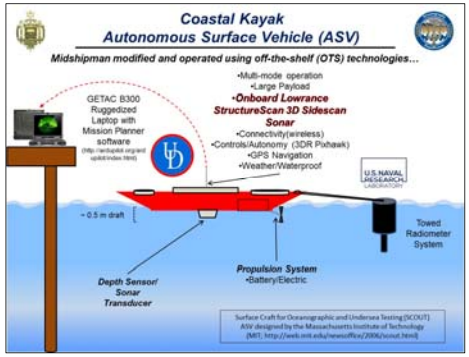

Figure 1. Conceptual diagram of the USNA Coastal Kayak Autonomous Surface Vehicle (ASV) used in this study.

The Coastal Kayak ASV (**Fig. 1**) was developed in collaboration with RDL, UD based on a SCOUT ASV platform on loan to USNA from the Naval Undersea Warfare Center, Newport, RI. The Coastal Kayak is powered by a 12 VDC AGM marine battery. Propulsion is through an electric trolling motor. Autonomous control is through a 3D Robotics Pixhawk auto-controller and GPS using Mission Planner software. For this study, the Coastal Kayak was equipped with a Lowrance StructureScan 3-D side-scan sonar and depth finder and was outfitted to tow a custom-made radiometer sled developed by Dr. Steve Ackleson of NRL (**Fig. 2**). Side-scan imagery was processed into geo-referenced mosaics using Sonar TRX software.

Figure 2. The Coastal Kayak being set-up for operation, the ASV underway, and a close-up of the towed radiometer sled.

Reef Surveys, Kaneohe Bay, Oahu, Hawaii

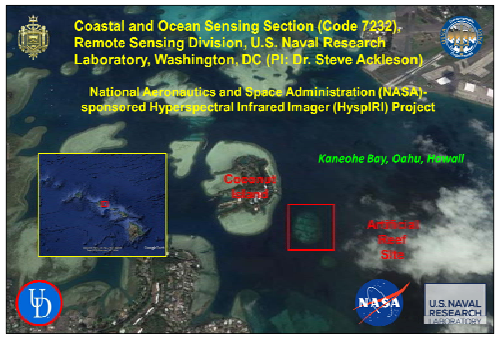

Figure 3. Map showing study area on an artificial reef in the vicinity of Coconut Island, Kaneohe Bay, Oahu, Hawaii (Google Earth).

Kaneohe Bay is a large embayment on the northeast coast of Oahu, Hawaii that has extensive coral reef systems. Coconut island is a private research island in Kaneohe Bay run by the Hawaii Institute of Marine Biology. The Coastal Kayak conducted surveys of an artificial reef off Coconut Island in collaboration with Dr. Steve Ackleson (NRL) as part of the NASA HyspIRI Project (**Fig. 3**).

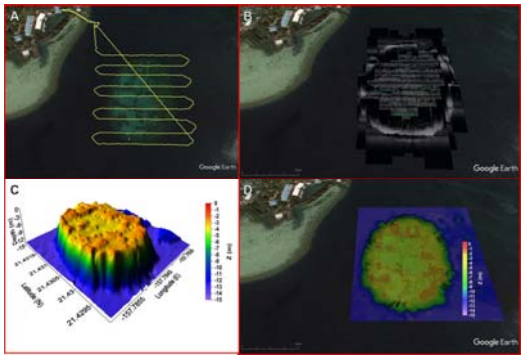

Figure 4. Results of a Coastal Kayak survey (no towed sled) of the artificial reef on 12 FEB 2017: (**A**) survey/mission track; (**B**) Side-scan mosaic (Sonar TRX); (**C**) 3-D bathymetry, and (**D**) 2-D bathymetric contour plot. 3-D bathymetry and 2-D bathymetry contours plots were constructed in Surfer v.10 using a Kriging interpolation method.

A side-scan mosaic from a reef survey with no towed radiometer sled on 12 FEB 2017 captured reef features but with some patchiness and distortion due to swath width variability plus wind and wave induced motion of the ASV (**Fig. 4A&B**). Interpolated 3-D and 2-D bathymetry (**Fig. 4C&D**) matches well with 2009-10 NOAA gridded 4-m bathymetric data (https://www.coris.noaa.gov/metadata/records/html/kaneohe_bathy_4m.html). Data from the towed radiometer sled during other surveys generated useful results (**Fig. 5**).

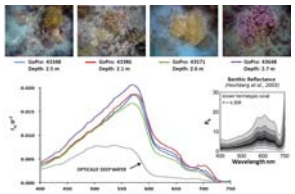

Figure 5. Reflectance measurement results and GoPro imagery over the surveyed artificial reef from the NRL towed radiometer sled. These data were presented by Ackleson et al. (2017) at the 2017 American Society of Limnology and Oceanography (ALSO) Aquatic Sciences Meeting, 26 FEB - 03 MAR 2017, Honolulu, HI (*used with permission*).

Discussion

Figure 6. Survey mission track and compiled side-scan mosaic (Sonar TRX) for a Coastal Kayak survey of the artificial reef on 07 FEB 2017. Note: During this tow, the ASV towed the NRL radiometer sled (Google Earth).

During a north-south survey mission on 07 FEB 2017 with the towed radiometer sled, winds increased from 1-2 m/s (2-4 mph) to 5-6 m/s (11-14 mph) and shifted from the southwest to the northwest. The Coastal Kayak struggled in the wind/wave field especially with the added towed radiometer sled causing an erratic survey track and significantly patchy and distorted side-scan mosaic (**Fig. 6**). Winds during the survey on 12 FEB 2017 were also from the west-northwest and variable from 1-4.5 m/s (2-10 mph) but the east-west survey track and absence of the towed radiometer sled resulted in better side-scan survey results (**Fig. 4**).

Table 1. Cost estimate for the Coastal Kayak (ASV) used in this study.

Item	Approx. Cost
Wilderness Systems Pungo Kayak	$900
Lowrance HD	$1500
West Marine 12V AGM battery	$350
3DR Pixhawk controller and GPS	$600
Electrical Propeller System	$500
Miscellaneous Materials	$2000
Total:	**$5850**

Figure 7. USNA EcoMapper (Iver-3) Autonomous Underwater Vehicle (AUV) (YSI Integrated Systems/Ocean Server Technology; *Credit: RDL*).

The results of coral reef surveys conducted in Kaneohe Bay met the requirements for the NRL/NASA HyspIRI project but also highlighted the current strengths and weakness of the Coastal Kayak platform. Stability in moderate wind/wave conditions was an issue especially when towing an instrument package. The installed off-the-shelf side-scan sonar provided adequate data but results could be improved with a more capable instrument USNA EcoMapper AUV (**Fig. 7**). Operations over shallow reefs can be risky with AUVs. The Coastal Kayak is inexpensive (**Table 1**) when compared to advanced autonomous platforms like the EcoMapper (~$200K). Its draft allows it to operate in waters as shallow as 0.5 m. Its large payload and surface area allows for customized sensor expansion. Engineering improvements can be made in the future to the Coastal Kayak to improve stability and maneuverability, increase thrust, and better integrate sensor systems to make it a capable, affordable autonomous platform for coastal reef mapping.

Conclusions

- ***The Coastal Kayak ASV was able to successfully survey a coral reef in Kaneohe Bay and tow a custom toward sensor package over the reef in support of the NRL/NASA HyspIRI project***
- ***The Coastal Kayak ASV configuration needs improvements to stability, maneuverability, thrust and sensor integration to make it a more capable platform for coastal reef mapping.***

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