

Feasibility Study on Unmanned Aerial Vehicle-Based Undersea Acoustic Sensing

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ABSTRACT

An unmanned aerial vehicle (UAV) system with hybrid air-water quadcopter platform, named AquaQuad, was developed in the Department of Mechanical and Aerospace Engineering, Naval Postgraduate School. It can land on ocean surface with different sea-states for communication and provide undersea passive acoustic sensing. This study shows that the AquaQuad is an alternative equipment to sonobuoy in undersea acoustic sensing and detection.

Keywords: Aerial vehicle; Hybrid air-water; AquaQuad

INTRODUCTION

Sonobuoy is approximately 0.9 m long and 13 cm in diameter with a radio transmitter to send signals. After deploying into oceans from either aircraft or ship, it receives undersea sounds (passive), or operates as acoustic sources (active). A passive acoustic sonobuoy uses a hydrophone to listen from a target. Then, the directional hydrophone gives bearings to where the acoustic signal originated. It can detect an acoustic signal with frequencies ranging from 5 to 2,400 Hz and operate up to eight hours at depths of about 305 m [1]. Interested readers are referred to the website: <http://www.dosits.org/technology/locatingobjectsbylisteningtotheirsounds/directionalfrequencyandrangingdifarsonobuoy/>. The AN/SSQ-86 data link communication sonobuoy is an expendable, non-repairable, and limited one-way acoustic communications from buoy to friendly submarines. To advance the undersea acoustic sensing technology, new platform and instrument should be developed with long endurance, wide range of communication, on board processor utilizing pre-programmed historic sound speed profiles, and easy deployment of array with advanced acoustic sensors [2].

A prototype of long-endurance Unmanned Aerial Vehicle (UAV) system with hybrid air-water quadcopter platform, called the AquaQuad, was developed in the Department of Mechanical and Aerospace Engineering, Naval Postgraduate School [3]. It has advanced characteristics such as long endurance (staying on station longer than eight hours), continuous communication with ships and air assets, and deployment of passive array at depths to increase the probability of detection [4]. However, the AquaQuad for

undersea acoustic sensing has not been investigated. In this study, we conducted a field experiment in the Monterey Bay to illustrate the feasibility of using AquaQuad for continuing undersea acoustic sensing.

DESCRIPTION OF AQUAQUAD

The AquaQuad is an energy-independent, long endurance, hybrid-mobility unmanned system with its diameter just a little over 1 m. The prototype is a quad-rotor air vehicle with a 20-cell photovoltaic array distributed around the four propeller disks. These four water-tolerant propeller disks are 35.6 cm in diameter and made of carbon fiber. The 20-cell array uses monocrystalline Si SunPower E60 cells with roughly 24% efficiency. These cells are the sole source of energy for all operations of the AquaQuad and they must power avionics and sensors all the time, as well as energy for flight a few times per day. Outside of the quad-rotors and solar panels, a watertight enclosure holds all of the electronics including processor and power board. This enclosure must provide necessary buoyancy and stability to keep the AquaQuad afloat in rough seas. The AquaQuad has the capability to reposition itself, compensate for drift, or continue to track a moving target [4].

EXPERIMENT

An experiment was conducted on 3 November 2015 to evaluate the stability and shell integrity of AquaQuad in various sea-states with adding an acoustic sensor, i.e., Acousonde [5]. The prototype-flying model with lower enclosure removed (Figure 1). The motors and propellers were mounted to the shell along with the Acousonde

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Received: March 22, 2019; **Accepted:** April 08, 2019; **Published:** April 15, 2019

Citation: Chu PC, Cason LR (2019) Feasibility Study on Unmanned Aerial Vehicle-Based Undersea Acoustic Sensing. *J Oceanogr Mar Res* 7:192. doi: 10.4172/2572-3103.1000192

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fastened to a 10 m rod under the AquaQuad to record acoustic signal from a sound source (Figure 2).

During the experiment, the shell of the AquaQuad was used with all the four motors and propellers but no electronics on board. Equivalent weight was added to simulate the weight of the missing electronics and batteries. The AquaQuad was released in the Monterey Bay at two locations to test survivability and buoyancy limitations, with small waves (0.6-1.2 m) at the location-1 (Figure 3a), and big waves (1.8- 3.0 m) at the location-2 (Figure 3b).

The AquaQuad was deployed over the side of the rigid-hull inflatable boat (RHIB) (Figure 4) and tethered to a marine buoy (Figure 5a and 5b), to insure recovery of the prototype and to see if unseaworthy. The AquaQuad successfully stayed afloat and rode the mild swells very well with minimal water washing over the solar panels, which will be important for maintaining good solar performance while the AquaQuad stays on station for extended periods. Once the test was successful, the marine buoy was untethered from the RHIB and allowed to drift freely with the waves, but with the AquaQuad still tethered to the buoy for safety [5].



Figure 1: Prototype of AquaQuad with lower shell removed and feet attached.

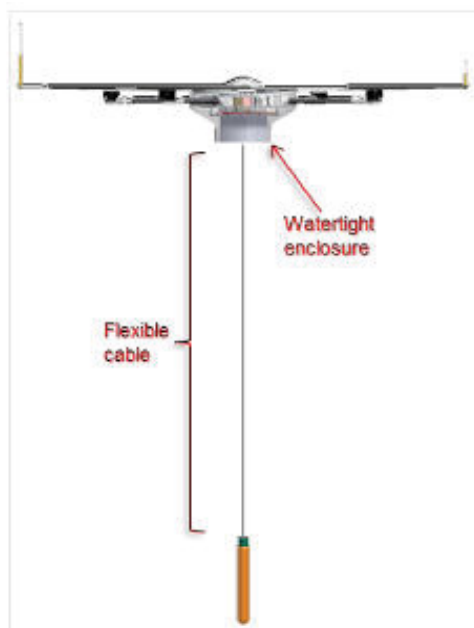


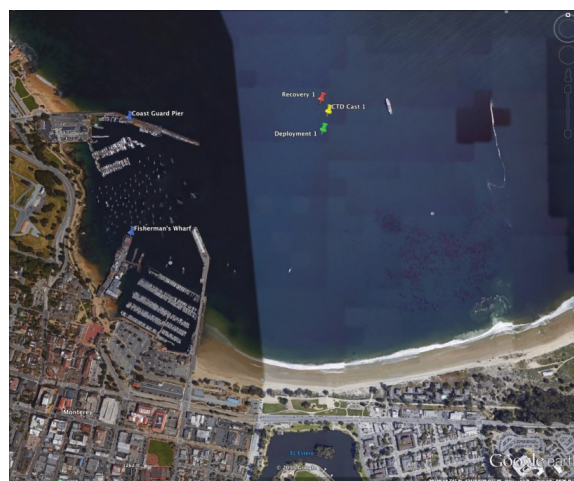
Figure 2: AquaQuad with Acousonde.

At both locations, the AquaQuad was in perfect conditions and the solar panels remained relatively dry. It was noted that the buoy and the AquaQuad, which were tethered to each other, drifted somewhat differently, and as the tether became taught, the floatation of the AquaQuad appeared to be adversely affected by the line tension. At location-1, the AquaQuad drifted north to northwest for approximately 105 m in 30 minutes after the buoy was untethered from the RHIB. After approximately 45 minutes, the buoy and the AquaQuad were retrieved. The interior of the AquaQuad shell was completely dry. At location-2, the AquaQuad drifted approximately 71 m during a time period of about 20 minutes. The distance between each deployment site was approximately 2.5 km (Figure 3a and 3b).

SOUND SPEED PROFILES

The Castaway CTD was attached to a line that could be reeled in and out of the RHIB allowing the sensor to traverse much of the water column. A weight was attached to the end of the line to counteract the buoyancy of the CTD and pull it down through the water. The description of the Castaway CTD can be found at the website: <http://www.sontek.com/productsdetail.php?CastAway-CTD-11>. It can be used in water depths of up to 100 m to achieve

(a)



(b)

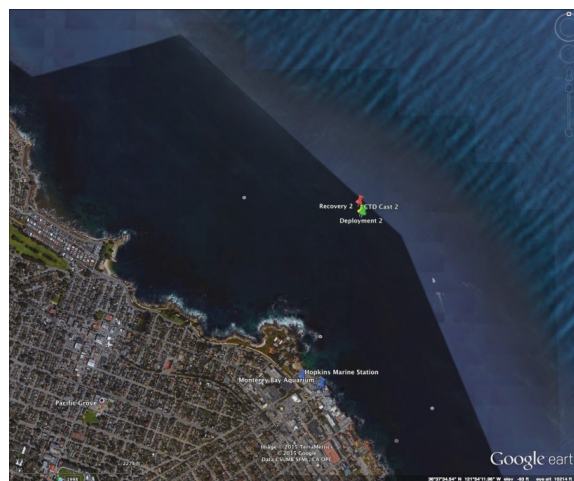


Figure 3: Locations of (a) deployment -1 and (b) deployment-2 in the Monterey Bay California with the green pin for the deployment, red pin for the recovery, and the yellow pin for the CTD measurements.

a 5 Hz response time (sample rate), fine spatial resolution and high accuracy: 0.1 psu for salinity, 0.05°C for temperature, 0.25% of full scale for pressure, and ± 0.15 m/s for sound speed [6].

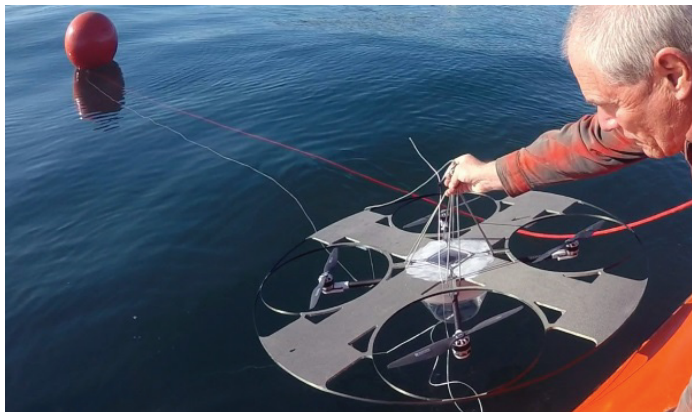
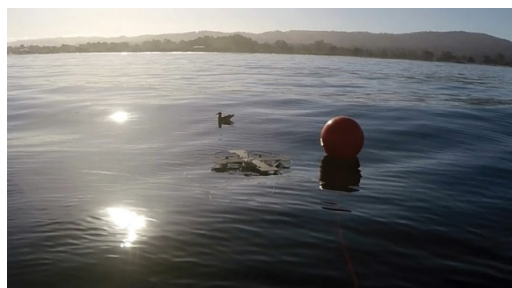


Figure 4: Deployment of AquaQuad from the rigid-hull inflatable boat (RHIB).

(a)



(b)



Figure 5: AquaQuad at the ocean surface during (a) deployment-1 and (b) deployment-2.

Figures 6 and 7 show the vertical profiles of temperature, salinity, pressure, and sound speed at location-1 (location-2). The vertical structures of temperature are quite similar at both deployment locations with a surface isothermal layer with depth of 10 m at location-1 (Figure 6) and 14 m at location-2 (Figure 7). Below the isothermal layer, there was a thermocline. These features were kept from shallower water depth of 20 m at location-1 to deeper depth of 50 m at location-2.

UNDERSEA ACOUSTIC SENSING

The Acousonde in AquaQuad collected the acoustic data during the entire experiment. The Acousonde recorded the long-term spectral averages of the acoustic waves on 1630Z and 1715Z at location-1 (Figure 8a) and on 1730Z to 1800Z at location-2 (Figure 8b). The RHIB, serving as the sound source and data collection, made several high speed passes with a closest point of approach no closer than 91 m. The Acousonde successfully picket up the low frequency sounds of the RHIB. The narrow cyan spikes correspond to the RHIB bouncing on the water. Overall, acoustic data collection by Acousonde on AquaQuad was efficient [7].

A few days after the experiment, the AquaQuad's four motors are little "crusty," however, after spinning them for a few seconds everything worked normal. Also while inspecting the AquaQuad after the rough-water operational test, there was a small amount of water inside of the enclosure. It was later determined that this was due to insufficient water sealing where the motor wires enter the enclosure. Lastly, during the experiments, the safety tether to the buoy created unrealistic forces on the AquaQuad, frequently tipping it such that the solar arrays were partially submerged some of the time. It is recommended that in future tests an alternative tether arrangement or no tether at all be utilized to avoid this.

CONCLUSION

In this study, experiments were conducted on AquaQuad-based undersea acoustic sensing with survivability including solar panels for changing sea states. The results show that the AquaQuad can not only stay on station for long time but also communicate with other assets outside a range of line of sight. Repositioning to original start location allows for continuous acoustic sensing in an area of responsibility. This makes AquaQuad an alternative equipment for continuing undersea acoustic sensing. Besides, adding active sonars to the AquaQuad makes it much more useful for the Navy even possibly being a decoy with "dipped" sonar pinging to make the contact of interest either actively engage or maneuver causing it to be tracked by an asset that can engage and destroy the contact of interest.

Furthermore, multiple AquaQuads may give better ranges and added direction capability with beam forming that the directional frequency analysis and recording sonobuoys cannot do. The AquaQuad, can lift to a sufficient altitude and pass on information about the contact such as course, speed, and even classification by RF/HF/UHF/Iridium communication.

ACKNOWLEDGMENTS

We are grateful to Dr. Kevin Jones, CDR Zac Staples, Mr. John Joseph, Mr. Tarry Rago, and Mr. Keith Wyckoff at NPS for help. The Office of Naval Research sponsored this study through NPS Consortium for Robotics and Unmanned Systems Education and Research (CRUSER).

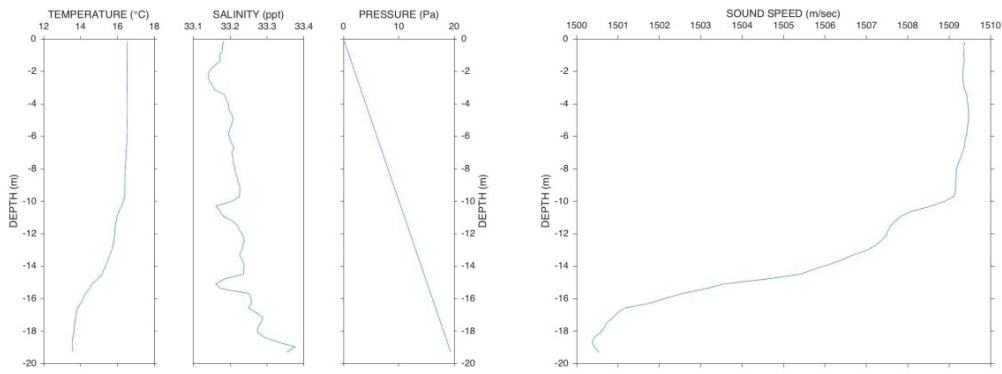


Figure 6: CTD measured profiles of temperature, salinity, pressure and calculated profile of density during the deployment-1.

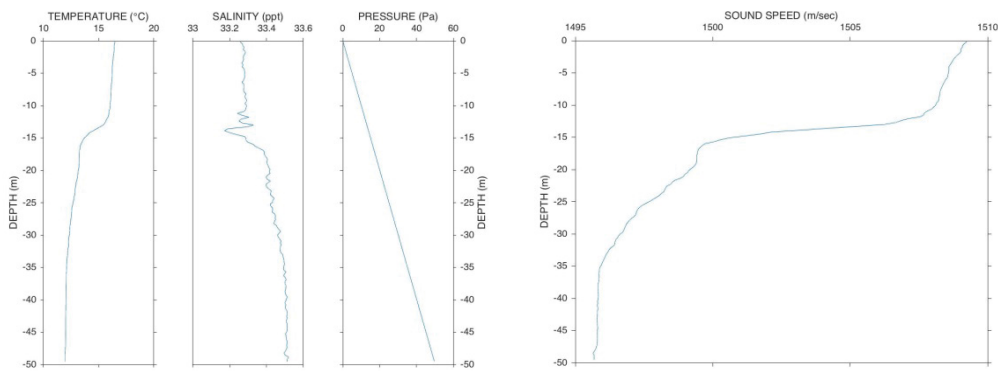


Figure 7: CTD measured profiles of temperature, salinity, pressure and calculated profile of density during the deployment-2.

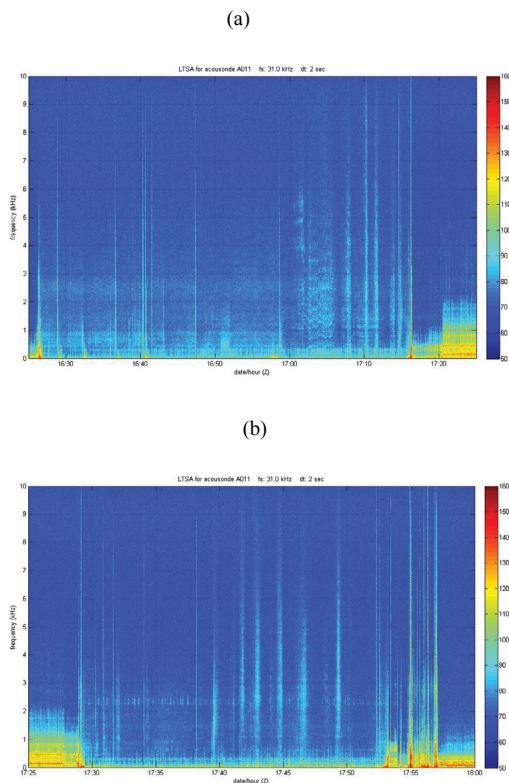


Figure 8: The long-term spectral averages of the acoustic waves during (a) deployment-1 and (b) deployment-2.

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