Monitoring Marine Mammal Acoustics Using Wave Glider

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Abstract – **The Wave Glider, a wave-powered unmanned maritime vehicle (UMV), represents a novel and unique approach to persistent ocean presence. Wave Gliders harvest the abundant energy contained in ocean waves to provide essentially limitless propulsion. The Wave Glider can operate as a vessel, covering long distances in the ocean, or as a station-keeping platform. Wave Gliders have demonstrated long open-ocean transits and extended deployments of up to one year.**

The High-frequency Acoustic Recording Package (HARP) is an autonomous data logging system optimized for long-term, broad-band marine mammal monitoring. The HARP system includes low-power electronics, high-speed data sampling, large capacity data storage, and batteries for self-contained power. In addition to housing the data logger, a hydrophone was designed to be towed behind the Wave Glider.

Together, Scripps Institution of Oceanography and Liquid Robotics combined these two technologies to demonstrate a new approach to marine mammal monitoring. Providing a mobile, long-endurance and fully connected platform for acoustic monitoring, the Wave Glider with HARP enables new scientific results and improved economics. Over a series of engineering and scientific evaluations, the HARP system has proven effective for monitoring marine mammals when deployed on the Wave Glider.

In this paper, we give an overview of the Wave Glider platform and integrated HARP system, and present results from the extensive engineering sea trials conducted with several prototype and production versions of the vehicle and data logger.

I – INTRODUCTION: WAVE GLIDER

The Wave Glider is a new class of wave-propelled, persistent ocean vehicle (Fig. 1). [1, 2] The key innovation of the Wave Glider is its ability to harvest the abundant energy in ocean waves to provide essentially limitless propulsion. The Wave Glider is a hybrid sea-surface and underwater vehicle comprised of a submerged "glider" attached via a tether to a surface float and is propelled by the conversion of ocean wave energy into forward thrust, independent of wave direction. The wave energy propulsion system is purely mechanical; no electrical power is generated nor consumed by the propulsion mechanism. There is substantial power available in ocean waves, and the Wave Glider harnesses this power to maintain an average forward speed of 1.5 kts in seas with 0.5m - 1m wave height.

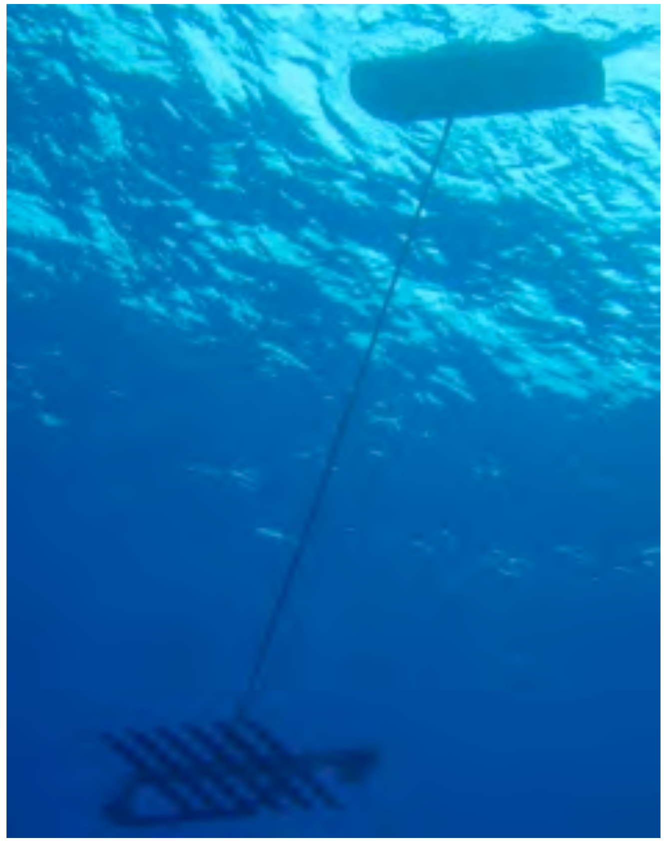

Figure 1: Wave Glider photo, showing the sea-surface vehicle tethered to the submerged glider by an electro-mechanical cable.

The Wave Glider vehicle has been designed to withstand large open-ocean waves and strong winds with its low-profile surface float, high-strength tether and robust submerged glider. In 2007 during Hurricane Flossie, the Wave Glider demonstrated an ability to operate in seas with wave heights over 3m and winds greater than 40 kts. More recently, while surveying along the Alaska coast, the Wave Glider successfully operated in waves over 6m high and winds greater than 50 kts. The robustness of the Wave Glider design has led to many successful missions over long periods in strong and weak seas with many different deployment configurations. [2, 3]

Wave Gliders have completed many engineering sea trials including endurance tests and long voyages. For

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example, its longest mission used two Wave Gliders to transit from Hawaii to San Diego during the summer of 2009 (Fig. 2). Later that year, a single vehicle transited from Monterey to Alaska. [3]

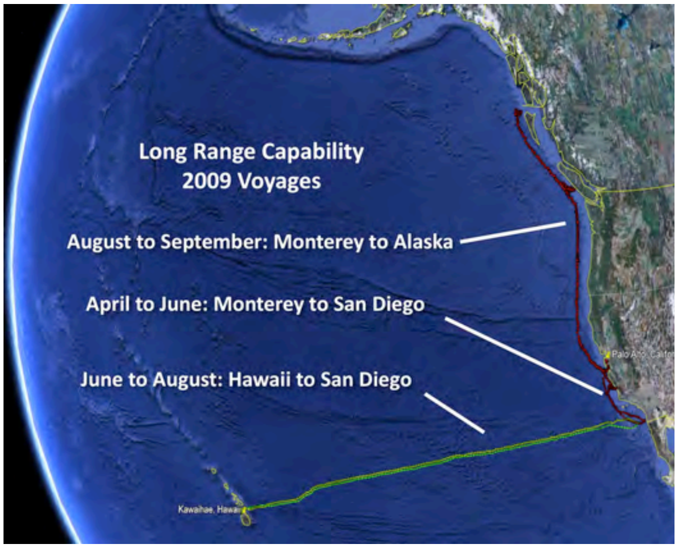

Figure 2: Map of the Wave Glider's long range expeditions in the northeastern Pacific during 2009.

In addition to traveling long distances over a few months, the Wave Glider has demonstrated exceptional persistence over longer time spans. The longest running individual Wave Glider began a customer sponsored 120 day endurance demonstration in December 2008. After 169 consecutive operating days, the customer requested the vehicle briefly return to dock so their payload could be removed. The vehicle immediately resumed operation and remained at sea off Hawaii until December 2009 when it was briefly recovered to remove some modest biofouling. Immediately, it was returned to operation until May 2010 when it was recovered to shore for minor maintenance followed by a return to testing. As of July 2010, this Wave Glider remains operating at sea. This vehicle has been operating at sea for more than 550 days, exceeding the target specification of a one year operational period.

II – THE HARP SYSTEM

Liquid Robotics collaborated with the Scripps Institution of Oceanography (SIO) to integrate the High-frequency Acoustic Recording Package (HARP) onto a Wave Glider. [4, 5, 6] The HARP was designed for long-term (up to one year) deployments as an autonomous broad-band acoustic recorder primarily for marine mammal monitoring. The HARP includes low-power electronics (1/2W continuous data acquisition and 3W 20% duty cycle data storage), high-speed data sampling (200 kSamples/s, 16-bit), 16 laptop disk drives (2TB), and 12V batteries for self-contained power. SIO repackaged the HARP electronics into one of the Wave Glider's modular payload housings (Fig. 3).

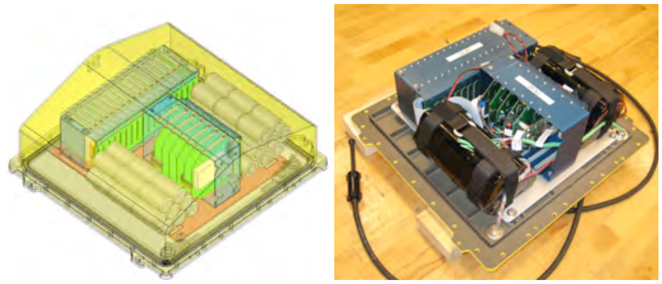

Figure 3: Computer-aided design model and photo of HARP data logger integrated in a Wave Glider payload box.

A hydrophone was designed to be towed behind the Wave Glider and to have a small cross-sectional area (25.4mm diameter) with a small diameter (6.3mm) electro-mechanical cable to minimize drag while towing (Fig. 4). The hydrophone consists of two transducers: Benthos AQ-1 cartridge for 10Hz - 2kHz and Sonar Research HS-150 for 2kHz - 100kHz. These two sensors are amplified and filtered with electronics inside the oil-filled hydrophone tube. The conditioned analog signals are digitized and stored to disk by the HARP data logger. The hydrophone cable was about 10 m long and was attached to the wing glider system, approximately 8m beneath the surface vehicle. [6]

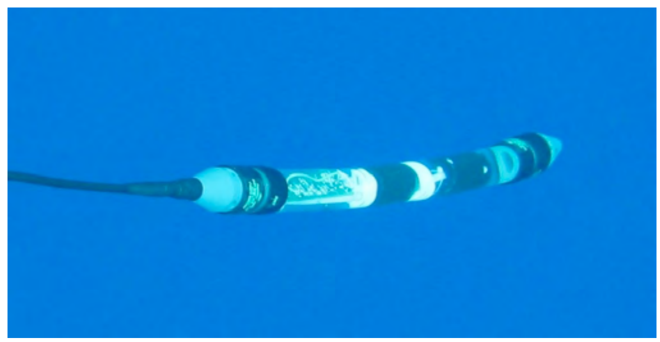

Figure 4: Photo of the hydrophone and tow cable as it is towed behind the Wave Glider at sea.

III – TEST RESULTS

A. October 2009 Trials

The Wave Glider with HARP was deployed twice during October, 2009 in the Liquid Robotics test range offshore of Puako Beach, Hawai'i and was programmed to travel along the perimeter of a square about 300m along each side. The first test showed that the Wave Glider could successfully tow the hydrophone and cable in low sea state conditions overcoming the array's drag forces. The second test on 9 October recorded approximately 75 hours (3 days, 3hours) of acoustic data almost filling one 120 GB hard drive. Many different sounds over a wide frequency band were recorded during this test including vehicle and towed hydrophone self-noise, propeller cavitation and echosounder noise from passing vessels, and sounds from biological sources such as dolphin whistles and echolocation clicks.

Characterizing self-noise is important to provide feedback to vehicle engineers with the goal of reducing these noises to increase signal-to-noise (SNR) ratios and improve data quality to better monitor marine mammals. At low frequencies around 10 Hz, the predominate noise source was cable strum from the towed hydrophone as no cable fairing was employed for this first test.

To evaluate low frequency (<1000Hz) sounds, the original 200kHz data were decimated (low-pass filtered and re-sampled at a lower rate) providing smaller data files for faster processing and easier evaluation. During the 75 hours of deployment, periods of both high and low noise levels were observed. These differences in low frequency noise are likely related to differences in sea state which affects the dynamics of the Wave Glider including surface splashing and bubble generation. Both broad-band transient events and longer periods of increased low frequency (<200Hz) noise were present.

Analysis of higher frequencies showed both anthropogenic noise and vehicle self-noise. For example, 50 kHz echo sounders from nearby vessels are clearly seen as narrow-band pulses in spectrograms (time-frequency) plots (Fig. 5). Also, broadband pulses about 2 seconds long and occurring throughout the data set are presumed to be caused by servo motors used to adjust the rudder. These 2 second bouts of noise often included click-like pulses (Fig. 5).

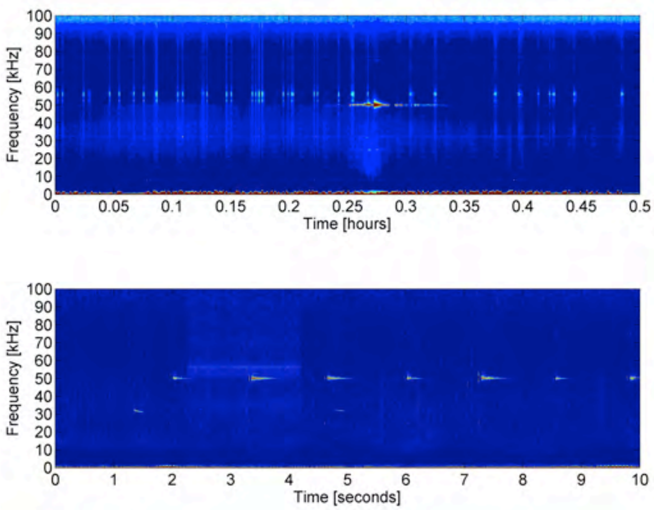

Fig 5: Long duration (1/2 hr) spectrogram (top) and shorter duration (10 s) spectrogram (bottom) show 50 kHz echo sounder and broad-band, 2 second pulsed self-noise.

While vehicle self-noise was present during the first test, these noises did not appear to cause masking of any biological sounds. Mechanical impulsive sounds can be differentiated from dolphin clicks by noting click temporal patterns and coincident occurrence with dolphin whistles. Typical frequency modulated dolphin whistles were recorded, often with higher frequency harmonics, as were broad-band clicks (Fig. 6).

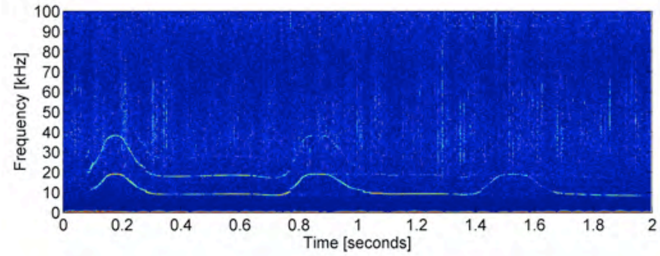

Fig 6A: Spectrogram of dolphin whistles shows frequency modulated tones around 10khz along with harmonics.

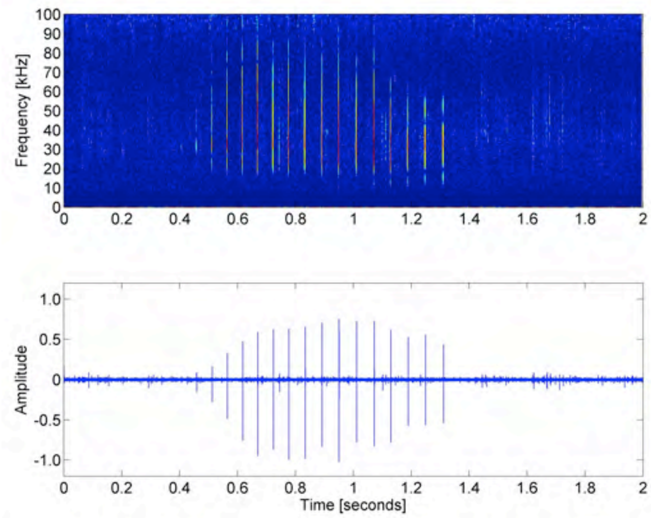

Fig 6B: Spectrogram and waveform of dolphin broad-band clicks show the received amplitude ramp up and then down suggesting the echolocation click beam direction changed rapidly.

B. March 2010 Trials

On 11-12 March 2010, a Wave Glider with HARP was deployed offshore of Hawai'i to record singing humpback whales. Improvements to the towed hydrophone system were made to decrease low frequency self-noise while underway. A fairing was attached to the cable reducing low frequency strum and a flexible coupling attaching the cable to the wing reduced shock impulses from wing motion.

A comparison of relative spectrum levels between the October 2009 and March 2010 deployments for frequencies 1 to 100 Hz shows a significant improvement to lower noise levels when using a cable fairing and flexible coupling configuration (Fig. 7). The October 2009 deployment without fairing and non-elastic line coupling is about 10-25 dB higher in self noise at frequencies less than 15 Hz, potentially causing masking of low frequency sounds.

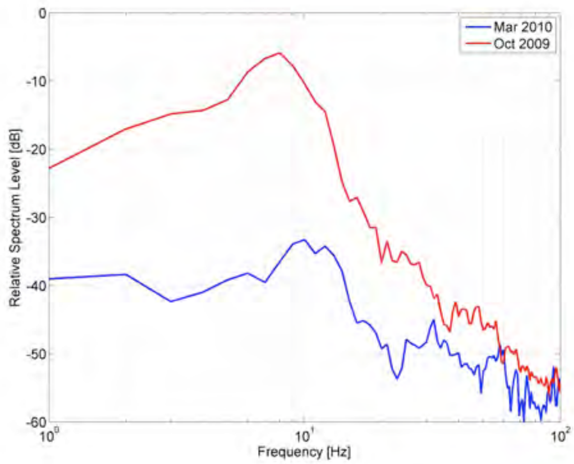

Fig 7: Relative spectrum levels between 1 and 100 Hz for the October 2009 deployment with hard mounted cable (red) and for the March 2010 deployment using a cable fairing and flexible coupling (blue) show a reduction of low frequency self-noise of around 20-25 dB below 10 Hz.

Spectrogram and a time series of humpback song recorded offshore of Hawai'i in March 2010 using the Wave Glider and HARP shows typical low frequency moans with higher frequency harmonics (Fig. 8).

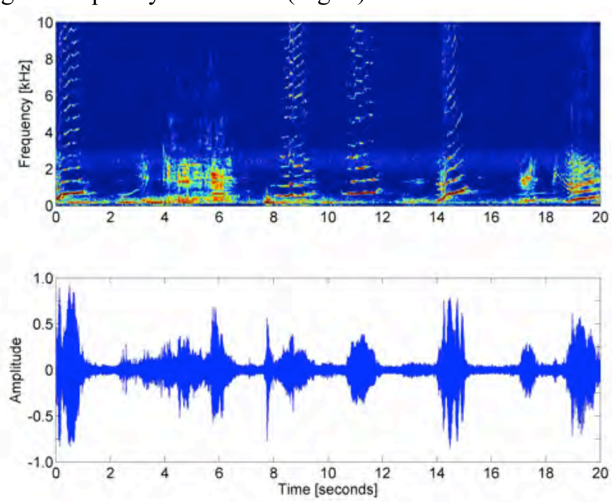

Fig 8: Spectrogram and waveform of humpback sounds show intense, low-frequency song during March 2010.

IV – CONCLUSIONS

A HARP was successfully integrated into a Wave Glider and deployed off Hawai'i in October 2009 and March 2010. A HARP hydrophone with approximately 10m of cable was towed aft of the glider wing system and did not significantly impede the mobility of the Wave Glider such that typical testing tracks were traversed over both deployments.

Very low frequency (~10Hz) noise, presumably from cable strum, is the dominate noise source at these frequencies throughout the recordings. Cable strum was reduced by including a fairing on the cable. Low frequency (<1000Hz) impulsive type noise events likewise was reduced by replacing the nylon line strain relief for the hydrophone cable with an elastic strength member. Additional tests and modifications are planned to further reduce these noises.

Higher frequency, broad-band pulses lasting 2 seconds throughout the recording are presumed to be vehicle-related based on their consistent duration, and likely may be from energized servo motors used to adjust rudder headings. Characterization and origination points of this noise source are being investigated with acoustic and engineering trials in a test tank, potentially leading to a quieter vehicle.

During the October 2009 trials, dolphin whistles and clicks were recorded showing that broad-band recordings of marine mammals can be made from a Wave Glider. A subsequent deployment of a Wave Glider with a HARP in a region with known humpback whales was completed in March 2010. In these trials, lower frequency singing humpback whales were recorded with high fidelity. Building upon these preliminary trials, long-term deployments of HARP systems on Wave Gliders should provide unique data sets with which to further our understanding of marine mammals.

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REFERENCES

[1] Hine, R., S. Willcox, G. Hine, and T. Richardson. "The Wave Glider: A wave-powered autonomous marine vehicle." *Proceedings MTS/IEEE OCEANS 2009*, Biloxi, MS.

[2] Manley, J., S. Wilcox, and R. Westwood. "The Wave Glider: An energy harvesting unmanned surface vehicle." *Marine Technology Reporter*, November/December 2009: 27-31.

[3] Manley, J. and S. Willcox. "The Wave Glider: A Persistent Platform for Ocean Science," *Proceedings of IEEE OCEANS 2010,* Sydney Australia, May 2010.

[4] Wiggins, S. M. and J. A. Hildebrand. "High-frequency Acoustic Recording Package (HARP) for broad-band, long-term marine mammal monitoring", *Symposium on Underwater Technology and Workshop on Scientific Use of Submarine Cables and Related Technologies*, 17–20 Apr 2007, IEEE, Tokyo, p 551–557.

[5] Willcox, S., J. Manley, and S. Wiggins. "The Wave Glider, an energy harvesting autonomous surface vessel." *Sea Technology,* November 2009: 29-31.

[6] Wiggins, S. "Integration and Use of a High-frequency Acoustic Recording Package (HARP) on a Wave Glider." MPL TM-528, Internal Report SIO/Liquid Robotics. October 2009 and April 2010.