Tracking Tagged Fish Using a Wave Glider

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***Abstract*—In this paper, we show how using a Liquid Robotics Wave Glider can allow for a mobile and comprehensive solution for detecting tagged animals in real time and characterizing their environment. We will compare the Wave Glider based solution to more traditional buoy and boat based solutions and note the unique advantages of this novel, new technology. With its ability to follow animal migrations, change courses mid-mission, and interact with existing tracking infrastructure, the Wave Glider changes how tagged animals can be tracked. Additionally, we will discuss other sensor packages that could be added to a Fish Telemetry Wave Glider to provide complementary environmental data. Examples of existing projects and missions will be explored, including tracking great white sharks in the Pacific Ocean, various fish species off the southeast US coast and everything from salmon to crabs to eels outside of Halifax, among others.**

Keywords—Wave Glider; Fish; Telemetry; Autonomous System

I. Introduction

In its earliest incarnation, the Wave Glider was designed and implemented to be able to detect and broadcast in real-time evidence of marine life. At the beginning, the purpose was to send back to shore a real-time audio broadcast of whales in the Hawaiian Islands Humpback Whale National Marine Sanctuary. While successful, the method of using a hydrophone to capture acoustic signatures is ineffective for detecting more quiet marine life, like sharks and fishes. It's also unwieldly and reasonably power-hungry, which can be a concern when operating in cloudier regions like the Eastern shore of Canada or off the Northern California coast. Liquid Robotics, Inc (LRI), working with VEMCO, integrated acoustic monitoring receivers and modems on to the Wave Glider in order to track acoustically tagged marine life.

II. Integration

A. Wave Glider

The Liquid Robotics Wave Glider SV2 is an autonomous ocean surface glider. Propulsion of the Wave Glider SV2 is generated by wave motion acting on the two part system, while system electronics, communications and sensor payload power is powered by lithium ion batteries recharged via solar panels. The system reports back in near real-time via two-way Iridium communications. The Wave Glider can follow complex series of waypoints, fixed directions or active piloting. There are many locations for sensors to be attached, with available power and communication connections, including mast-mountings, various locations in or on the float, attached to the wave-generation section or towed behind the wave-generation section. The Wave Glider SV2 can be deployed for periods of many months, and travel great distances. Due to the passive nature of its propulsion system, the Wave Glider SV2 generates very low amounts of acoustic noise, important for detection of acoustically tagged marine animals.

B. VR2C

Initially, the VEMCO units were designed with their own battery packs, designed to be completely stand-alone units if needed. This added a lot of unnecessary weight and size for connection to the Wave Glider, a system with its own battery and solar recharging system. However, the VR2C was able to respond to real-time polling as well as have a real-time outputting mode for detected tags. As such, it was a good prototype candidate. LRI, working with VEMCO engineering, created a software driver on the Wave Glider Sensor Management Computer (SMC). This allowed detections to be timestamped, tagged with the GPS-derived location of the Wave Glider and sent back to shore via the Wave Glider's iridium satellite connection in near-real time.

Physical mounting of the VR2C was to the bottom of the wave-generating section of the Wave Glider SV2, using a modified delrin block and hose clamps (see Fig. 1). A security wire was attached in case of hose-clamp failure. The VR2C was orientated backward, though there was concern that the structure of the Wave Glider would potentially inhibit some of

Figure 1: VEMCO VR2C and VMT installed on Wave Glider SV2

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the detections.

Electrically, the Wave Glider SV2 has a power and communication connection at its rudder module, which allow wave-generating section mounted devices to draw power and have two-way communication with batteries and controls in the float section. A simple 8-pin wet-mate cable connected the VR2C to the rudder output port.

C. VMT

The VMT is a self-contained acoustic receiver with no real-time communication or battery recharging options. It's quite small (35mm diameter cylinder 180mm long), which allows for much easier and more varied mounting options. On some of the missions, a VMT was attached as confirmation and validation of the data being recorded by the VR2C unit. However, due to the lack of real-time communications it was not possible to make any comparisons till the data was post-processed.

III. Missions

Partnering with various researchers, Liquid Robotics ran a series of field-test demonstrations in various locations around the United States and Canada, including off the California Coast (primarily in the San Francisco area), near the Outer Banks in North Carolina and in the Gulf of Saint Lawrence, Canada.

Tagged and tracked animals included great white sharks, salmon, Bluefin tuna, striped bass and sturgeon. Incidental detections of other marine mammals, such as rainbow trout, eels and crabs were also detected.

A. California Coast – Dec 2011

Working with Barbara Block of Stanford and her research group at the Global Tagging Of Pelagic Predators (GTOPP), Liquid Robotics identified a fairly conservative initial path for the Wave Glider SV2 along the California coast with the goal of tracking tagged great white sharks. It was outfitted with VEMCO VR2C and VEMCO VMT receivers. Starting on December 6th of 2011, the Wave Glider SV2 was launched just south of Año Nuevo and started following a track along the 40m isobath up a stretch of 5km directly off of Año Nuevo Island (see Fig. 1).

After a few passes at this isobath (and deeper), the decision was made to move closer, to around the 25m isobath. Dr. Block had two VR4 receivers installed in 20m of water, which gave us references points to compare to.

After several more passes at the closer isobath, and many more tag detections, the decision was made to transit further up the coast to determine whether the tagged animals were venturing away from the sea lion colonies on Año Nuevo Island, and if so to what extent. While non-zero, less detections were recorded as the Wave Glider SV2 ranged ~8km up the coast as shown in Fig. 3.

After 14 days on mission, the Wave Glider SV2 was directed to return to a loiter position in Monterey Bay, where it remained for a day until conditions and boat availability were conducive to a recovery. During a range test, detections were made up to 800m. Over 250 detections were made, with at least 18 unique tags. The Wave Glider traveled over 520 km during its mission.

B. California Coast – Fall/Winter 2012

Again working with Barbara Block and her team, the Wave Glider was once again deployed from Monterey, this time with a more ambitious project goal. This mission began on August 10th, 2012, and again headed north along the coast to Año Nuevo. After running a similar course to the previous year at Año Nuevo for a period of 36 hours, the Wave Glider was tasked to circumnavigate the Farallon Islands as shown in Fig. 4, another location Dr. Block had an installed buoy receiver to compare to. At each location, hundreds of tags were recorded with many distinct animals.

After 48 hours maneuvering around the Farallon Islands, the Wave Glider SV2 was again tasked to determine whether the tagged white sharks would be found in areas other than nearby where they were originally tagged. Heading north, the Wave Glider SV2 transited to Point Reyes and then from their north along the coast as far as Patrick's Point, CA. Generally, the Wave Glider stayed along the 20m isoboath on its journey northward, and then patrolled somewhat further offshore on its southern journey. As expected, fewer tags were seen during this transit, with the vast majority being observed on the shallower path. Along with great white sharks, sturgeon, trout, salmon and squid were also detected.

Another pass of the Farallon Islands and Año Nuevo tracks were conducted on the way south on the way back down the coast as far as San Simeon, CA. This southern pass recorded more fish tags, though again less than at the actively researched areas. This is likely due to some combination of

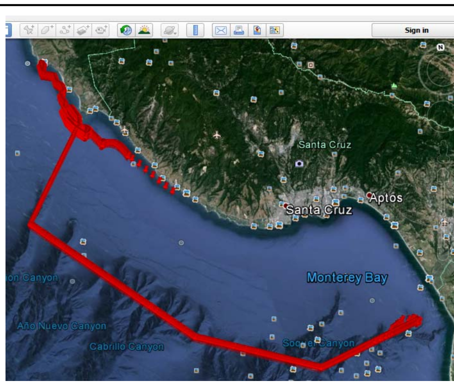

Fig 2: December 2011 Mission to Año Nuevo

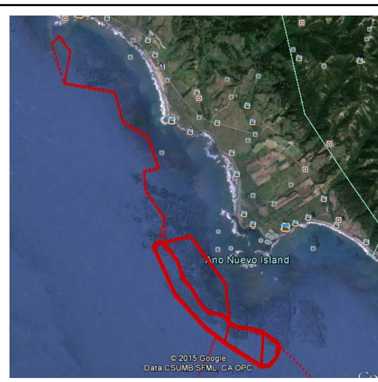

Fig 3: Close-up of path near Año Nuevo Island

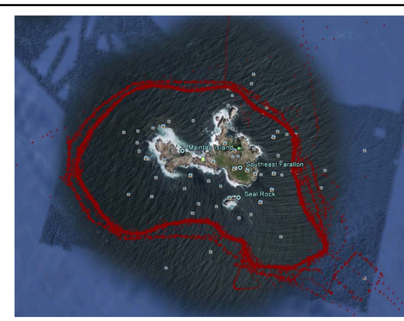

Figure 4: Path outside Farallon Islands

less shark activity along the coast along with less active tagging in those areas.

During this trip, the Wave Glider successfully navigated the major shipping lanes heading into and out of the San Francisco harbor multiple times, as well as traversing an area known for heavy seaweed, rocky shoals and fishing/crab gear without any navigational issues. The total mission was 120 days in duration and there were over 1500 total tag detections. As seen in Fig. 5, the Wave Glider traveled over 3,200km during its 118 day mission.

C. California Coast – Winter 2014, Spring 2015.

Continuing the work with Dr. Block, the Wave Glider went on two more winter missions with the primary objective to detect tagged great white sharks. Both missions were launched in Monterey Bay and then swam north to Año Nuevo and Farallon Islands. Once again, the missions successfully navigated major shipping lanes and other obstacles, detecting over 500 total tags from more than 20 unique animals. Most of the detections were great white sharks, though some were fish that had been tagged by other, unknown, researchers.

These trips totaled over 90 days and 2,500km traveled. Winter conditions did prove to be challenging to provide enough solar power for the onboard computer and VEMCO receivers to run full time, but this could possibly be alleviated with the use of the Wave Glider SV3.

D. East Canadian Shore

Working with researchers at the Ocean Tracking Network and Dalhousie University, a Wave Glider SV2 equipped with a VEMCO VR2C and VEMCO VMT was launched in the Gulf of Saint Lawrence to try to detect tagged salmon migration [1]. The trip path can be seen in Fig. 6.

The Wave Glider SV2 was launched out of Stephenville, Newfoundland on June 18th, 2012 into the Gulf of Saint Lawrence. In order to detect where in the bay the salmon smolts swam as they progressed north toward and eventually out of the Strait of Belle Isle, the Wave Glider crossed from east to west across the bay, and then zigzagged north along with the migrating fish toward the Strait. Tagged salmon were detected during this path, providing another data point for the researchers.

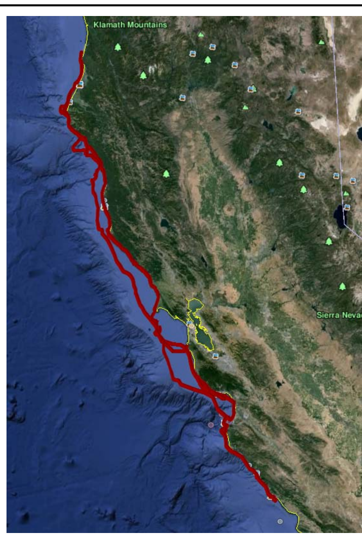

Figure 5: Wave Glider path along the California Coast

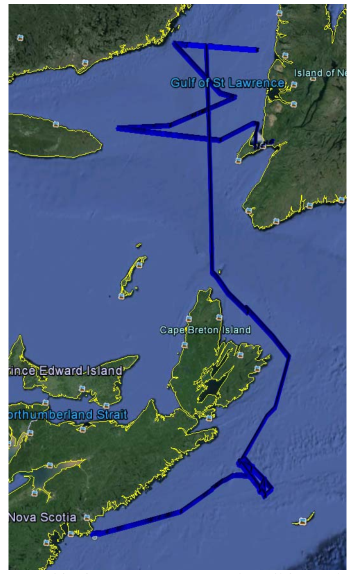

Fig 6: Gulf of St. Lawrence and Halifax Mission

After spawning season had concluded, the Wave Glider SV2 was sent south through the Gulf of Saint Lawrence, out the Cabot Strait and down to Halifax for a more convenient (and less costly) recovery. During this trip, several passes were made over installed range tags. In order to test the range of the Wave Glider, several spiral patterns were run at each tag as seen in Fig. 7.

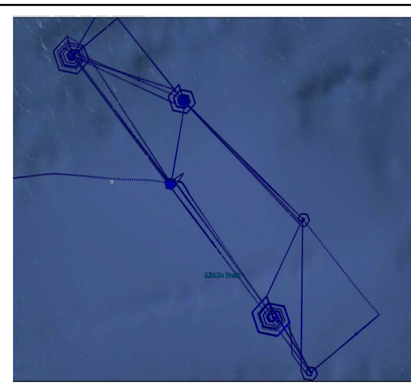

Fig 7: Close up of advanced paths outside Halifax

The Wave Glider traveled over 3300 km during its 65 day mission, detecting multiple tags. Launch delays limited the amount of salmon available to be detected, but the overall mission was still deemed a success and OTN has gone on to run their own missions in the same area with more detections.

E. Outer Banks, North Carolina

Working with researchers at Duke Marine Labs and East Carolina University, a Wave Glider SV2 equipped with a VEMCO VR2C was deployed on a mission off the Outer Banks, NC. The mobile receiver platform was looking for tagged Atlantic bluefin tuna, striped bass and Atlantic sturgeon. [2]

The Wave Glider SV2 was launched on January 7th, 2013 out of Beaufort, North Carolina. It was tasked to head north along the Outer Banks, including some pathing close to shore and in among the shallow shoals as shown in Fig. 8. One of the biggest obstacles of this mission was the near-shore presence of the Gulf Stream current, which impeded the Wave Glider on its return path southward.

Despite the challenges, the Wave Glider completed 25 days of travel, transiting over 1300 km. It recorded a total of 160 detections, from 16 distinct animals. No Atlantic bluefin tuna were recorded, but there were detections of striped bass and Atlantic sturgeon.

IV. Other Data

In addition to recording acoustically tagged fish data, the Wave Gliders on the described missions were also equipped with various meteorological sensors, allowing the researchers to record and correlate such data as air temperature, wind speed and direction, barometric pressure, wave height, sea surface temperature and salinity, among others. Unlike the ad hoc nature of fish detections, this data is recorded continuously and can give a complete temporal data set over the covered spatial area.

V. Next Steps

While the Wave Glider SV2 and SV3 have both had successful missions listening for acoustically tagged fish, there is further work to be done in order to complete and enhance the sensor integrations.

A. *Range Testing and Characterization*

While range testing was performed on several of the missions, including several of the very first integrations, it could still use further characterization. As the Wave Glider's motion is impacted by different sea states, further understanding of how that motion and speed affects receiver range is needed. Additionally, there are many different locations the various receivers may be mounted on the Wave Glider, and they may all have different impacts on range and directions. Finally, the general assumption has been that the receiver range is a sphere surrounding the sensor. Due to the Wave Glider hardware, along with flow noise and the casing of the receiver itself, it is far more likely that the actual range has some complex distortion from an ideal sphere that should be characterized.

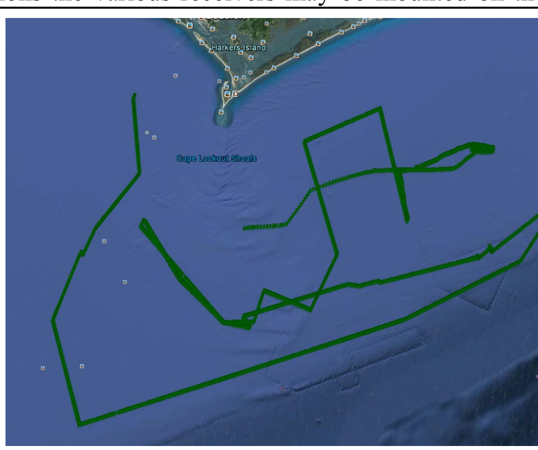

Fig 8: Close up of near-shore operations off Outer Banks, NC

These tests should be completed using an open ocean testing range. They should be conducted over a long period of time and in a variety of sea states to give the best possible characterization of the sensors.

B. *Pair With Additional Sensors*

While using receivers to acoustically tagged sensors is convenient, as they require low power, processing and space, it also comes with fairly strong limitations. The most obvious limitation is that tracking acoustic tags requires the target animals to be tagged. This requires additional expense, effort and introduces the possibility of a catch-bias into the recorded data. Possible ways to alleviate this include integrating other types and variations of sensors.

One such sensor might be an echosounder, either towed or mounted directly in the float of the Wave Glider. This sensor would be able to provide a vertical profile of fish mass in the water column. This information would give better information about everything from bait fish to their pelagic predators. It also would not require any pre-tagging of the fish in order to detect them

Another possible sensor would be a passive hydrophone that would be able to detect marine mammals or vocalizations made by the fish themselves. Several versions of a passive acoustic hydrophone have previously been integrated and used on Wave Gliders, and integrating them along with an acoustic receiver would provide a lot more information about the surrounding environment when a tag is recorded. Eventually, the passive acoustic hydrophone could be configured to also perform the tag detections, reducing the complexity of the system.

C. *Sensor Advancements*

One other limitation of the current sensor integration is the lack of ability to pinpoint the location of a detected tag. Currently, the tag is known to be in the general area around the Wave Glider, but nothing more specific is known. If the sensor had a directional capability, as some hydrophones do, the Wave Glider would then be able to not only detect the presence of an acoustically tagged fish, but would also potentially be able to follow it.

VI. Conclusions

With missions off the coast of California, the Outer Banks of North Carolina and the Gulf of Saint Lawrence and Atlantic Ocean off the coast of Nova Scotia, the Wave Glider equipped with VEMCO sensors has demonstrated its ability to act as a mobile acoustic tag receiver. While acoustic tag missions have predominantly occurred in North America, the Wave Glider has operated successfully in nearly every large body of water and the operations could be ported to nearly any area of interest. By providing a spatial receiver ability, researchers can complement and augment their existing arrays.

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