A Mobile Communications Gateway for AUV Telemetry

Global Command, Control and Navigation Aiding for REMUS AUVs

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***Abstract*— Autonomous underwater vehicle (AUV) operators rely on underwater acoustic telemetry for monitoring and control during mission sorties. This requires operators to maintain acoustic communications by remaining nearby, or deploying a moored gateway buoy and remaining within radio frequency (RF) communications range. An autonomous mobile communications and navigations gateway system has been developed by Hydroid and Woods Hole Oceanographic Institution, to extend telemetry capabilities with REMUS AUVs over the horizon, for situations where deploying moored resources is impractical.**

Hydroid gateways rely on the Micro-modem acoustic modem, developed by the Acoustic Communications Group at Woods Hole Oceanographic Institution. The modem has been designed with signaling characteristics for reliable communication in the challenging shallow water horizontal propagation path, along with a small physical size and low-power electrical requirements, making it an ideal choice for installation in AUVs.

This new mobile "Smart Gateway" is carried as a payload on the Liquid Robotics Wave Glider SV2, an autonomous surface vehicle (ASV), which provides significant energy with long endurance and mobility to allow deep water station keeping, and potentially AUV-coordinated transit.

Traditional Gateway systems offered by Hydroid and others typically provide a simple serial interface to the deployed acoustic modem, over RF link. The autonomous gateway system described here manages RF and acoustic links without user intervention, using data caching and AUV link discovery to provide disruption tolerant telemetry services to multiple AUVs. In addition to caching data when links are down, the gateway can monitor the acoustic communications link performance, to adjust acoustic modem data rate, when REMUS AUVs are in range.

In addition to telemetry services, the system can provide navigation assistance, by means of a moving long-baseline transponder. This paper provides a detailed system description, along with results from recent at-sea testing.

Keywords—autonomous underwater vehicle; underwater acoustic communications; autonomous surface craft; telemetry; command and control; long baseline acoustic navigation; moving baseline acoustic navigation; system description

I. Introduction

This paper presents motivation and system design description information for the recent development of a novel mobile communications system with Hydroid REMUS autonomous underwater vehicles (AUV) co-operating with a Liquid Robotics Wave Glider SV2 autonomous surface vehicle (ASV), to provide improved telemetry and localization services to the REMUS AUVs as they perform their survey missions.

II. Concept of Operations

Fig. 1 below shows a sketch of the concept of operations.

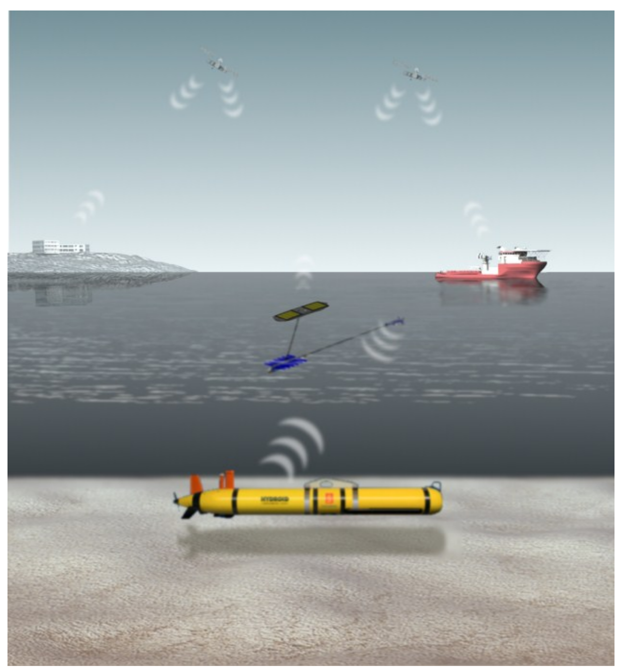

Fig. 1 – a rendering of the Concept of Operations for an ASV-hosted AUV communications and navigation aiding payload, showing Hydroid REMUS 600 AUV in acoustic communications with a Liquid Robotics Wave Glider SV2, which is acting as an acoustic-RF gateway, communicating via satellite to ship-based or shore-based operators.

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A Liquid Robotics Wave Glider ASV is provisioned with a REMUS RF-acoustic communications gateway payload, so that it can relay communications between REMUS AUVs as they perform their missions. All vehicles are programmed with partially co-located missions so that they may communicate acoustically during some part of their missions.

A. Telemetry Links

To receive mission telemetry, the communications gateway polls in-range AUVs, at the best acoustic data rate for each link. Received messages are stored locally on the gateway, and forwarded via Iridium modem or 802.11 wireless Ethernet (Wi-Fi) link to the operator.

B. Command Links

To command an AUV, the operator submits messages to the communications gateway via RF (either Wi-Fi or Iridium). The gateway accepts commands on behalf of submerged AUVs, and queues them. When vehicles come into acoustic range, the gateway establishes a communications link to the vehicle, and transmits pending messages. If the operator requests acknowledgment, the message will be repeated until the vehicle acknowledges reception, and the acknowledgment is cached and forwarded to the operator, as with telemetry described above.

C. Discovery

Once deployed, the gateway autonomously attempts to establish and maintain acoustic links to all AUVs identified in the gateway configuration. Each AUV is discovered by short-duration acoustic modem ping signal. If an AUV modem replies to the ping signal, the gateway polls it for mission status telemetry, and transmits commands and navigation data to it, until the link fails.

D. Link Management

Each acoustic link is monitored by observing poll replies, as well as essential modem reported receiver input signal-to-noise ratio, and decoder mean square error metrics [1]. For each link, average throughput is measured, as well as current packet data rate. The gateway will change data rates for each link using user-configurable SNR thresholds, and drop an acoustic link after several successive unsuccessful polls.

E. Localization Service

Survey class REMUS AUVs are equipped with real-time aided inertial navigation system (AINS): the Kongsberg NavP system. These vehicles are capable of using any number of underwater acoustic transponder ranges, tightly integrated with the INS to improve the navigation solution [2]. Such a vehicle can use bottom mounted transponders, and also moving transponders whose position and position uncertainty are known. The REMUS mobile gateway carries a transponder and relays transponder position measured using integrated GPS and 3-axis orientation sensor, via acoustic link.

F. GPS Sensor Data

The gateway payload logs raw GPS receiver data suitable for Precise Point Positioning processing. This data is post-processed on a daily basis, and may provide good estimates of ellipsoid-referenced sea water level, at the Wave Glider location [3]. This data may be used to generate ellipsoid-referenced survey data from REMUS AUV hydrographic surveys.

III. System Description

A. Overview

An autonomous RF-acoustic communications and navigation-aiding payload has been developed to be installed on a Liquid Robotics Wave Glider SV2.

RF communications systems, localization sensors and embedded controller are designed to be integrated in a standard Wave Glider forward payload housing. Acoustic components are mounted on the subsea glider frame.

Fig. 2 shows the system block diagram for the Wave Glider payload systems. The payload electronics installed in the Wave Glider forward payload housing in the surface float, along with acoustic components installed on the Wave Glider subsea glider frame.

The system includes a Texas Instruments OMAP 3530-based Gumstix™ computer-on-module (COM) running embedded Debian Linux. The processor controls sensors and communications devices using RS-232 serial ports, and communicates to the operator via on-board 802.11 Wi-Fi module.

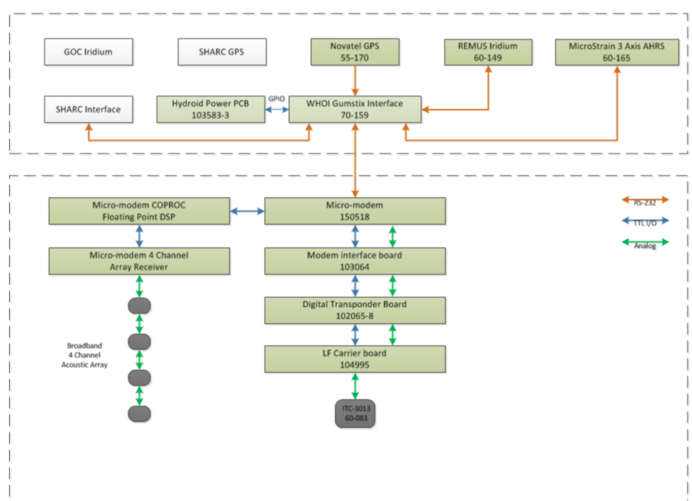

Fig. 2 – Smart Gateway Payload system block diagram, showing surface float payload housing subsystems including GPS, Iridium Modem, 3-axis heading reference, and Gumstix Overo computer-on-module (COM); also shown is the subsea electronics module developed by Woods Hole Oceanographic Institution (WHOI) including Micro-modem, Micro-modem PSK Coprocessor, 4 channel acoustic array, REMUS Digital Transponder, and ITC-3013 transducer.

Fig. 3 - Engineering sketch showing Wave Glider float modules, including forward payload (left, red) where the REMUS Smart Gateway RF and controller electronics are integrated [4].

B. Wave Glider

Fig. 3 above shows an exploded view of the modular Wave Glider float. All REMUS Smart Gateway surface float electronics are housed in the forward payload, shown in red. The payload is standard, and can be integrated on any Wave Glider SV2.

Fig. 4 below shows the extensively modified Wave Glider subsea frame. The acoustic electronics are integrated in a cylindrical housing which is mounted along with ITC-3013 transducer and 4 channel acoustic array inside an acoustically transparent plastic fairing.

The electronics housing has a high capacitance power supply, to facilitate high current acoustic transmissions, fed from the relatively low current (~1A limit) Wave Glider power supply.

The transducer location is not optimal for acoustic communication due to the mechanical noise of the glider platform, and the surface noise of the float. A baffle has been added to the ITC-3013 transducer mount, to reduce noise heard from the direction of the glider and surface.

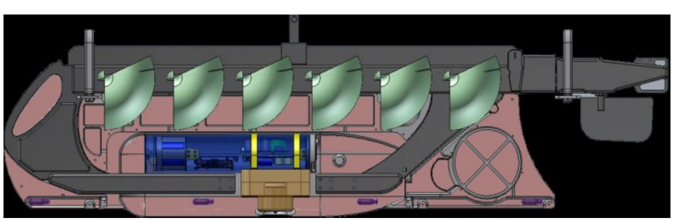

Fig. 4 – Engineering model of the Wave Glider subsea glider frame, showing watertight housing (in blue) along with hydrophone array(purple), transducer and acoustic baffle(orange), encapsulated in a low drag acoustically transparent housing(pink).

C. REMUS Link Management Processor

The REMUS Link Management (RLM) processor is used in several Hydroid communication products. A Gumstix Overo COM is hosted on a custom carrier board which provides additional RS-232 and RS-485 serial ports, a real-time clock, 100baseT Ethernet, additional microSD storage interface, USB and user-programmable FPGA.

1) Embedded Linux

The RLM runs Embedded Debian Linux operating system, which allows the processor to act as a server, allowing users to connect using many popular Linux and UNIX services such as SSH and SFTP.

2) Polling MAC

The Smart Gateway controller maintains link state for the acoustic link to each AUV served. As vehicles are discovered, they are added to the polling schedule. As links fail, they are removed. Scheduled events include navigation data to the AUVs, commands to the AUV (when present), and telemetry from the AUVs.

D. Data Rate Switching

The RLM uses the rich communications receiver performance metrics to establish link quality. The RLM decide which data rate is appropriate, based on the link quality over several most recent packets. The four data rates used by the RLM are shown below in Table I.

TABLE I. SMART GATEWAY MICRO-MODEM DATA RATES[7,9]

	Micro-modem Packet Types		
Data Rate #	***Acoustic Packet Description***	***Data Payload***	***Burst Rate***
0	FH-FSK	32 bytes	80 bps
1	QPSK, BCH(128:8)	192 bytes	498 bps
4	QPSK, BCH(64:10)	512 bytes	1301 bps
5	QPSK, BCH(9:14)	2048 bytes	5388 bps

Traditionally, REMUS AUVs rely on Rate 0 FSK packets for mission telemetry. A rich message set called the Compact Control Language (CCL) has been developed [6], to efficiently use the 32 byte data frame that Rate #0 provides.

The higher throughput available with PSK rates 1, 4 and 5 make richer telemetry possible. The telemetry content possible with each data rate is shown below in Table II.

TABLE II. REMUS TELEMETRY CONTENT BY MODEM DATA RATE

Data Rate #	***Telemetry Content Description***	***Data Payload***
0	1 CCL Message	32 bytes
1	6 CCL Messages	192 bytes
4	Sidescan Imagery, Sidescan Raw Pings, Mutlibeam ranges.	512 bytes
5	Sidescan Imagery, Sidescan Raw Pings, Mutlibeam ranges.	2048 bytes

E. WHOI Micro-modem

The WHOI Micro-modem provides a packet based acoustic communications solution which allows the user to implement media access control (MAC), and control data rate on a per-packet basis [7]. The RLM uses this flexible interface to manage both MAC and acoustic packet data rate autonomously, as described above. A photo of the WHOI Micro-modem is shown below in Fig. 5.

Fig. 5 - A photo of the WHOI Micro-modem showing the TI-6713 DSP floating point coprocessor board, which is required to receive PSK packets. The board set has a physical footprint of 4.5” x 1.75”.

F. Diversity Array

A 4 channel array of hydrophones has been added to improve PSK communications performance. It has been shown that adding spatially distributed receiver channels exploits spatial multi-path diversity, to improve receiver performance [8]. The Micro-modem has a multi-channel decision feedback equalizer (DFE) which can improve receiver performance in the presence of multi-path interference.

IV. TESTING

At the time of writing this paper, the REMUS Smart Gateway has been tested twice in local water. Tests were short, due to unfavorable acoustic conditions, but validated the design, and demonstrated basic functionality.

A. Test Locations

Testing was performed in late June and early July at two locations in coastal Massachusetts: first in Cape Cod Bay, then later in Buzzards Bay. In both locations, unfavorable propagation conditions were found.

B. Environment

A Conductivity Temperature (CT) cast was made to determine the sound speed profile. Fig. 6 shows an estimated Sound speed profile, derived from the CT measurements.

This profile represents an extremely challenging acoustic propagation channel. Sound speed varies greatly throughout the water column, with downward refraction throughout, and a thermocline boundary near 6m depth.

The REMUS AUV was operating near 9.5m depth, while the Wave Glider tow body operates at a depth near 7m. This possibly puts transmitter and receiver on different sides of the thermocline boundary, each in a downward refracting layer.

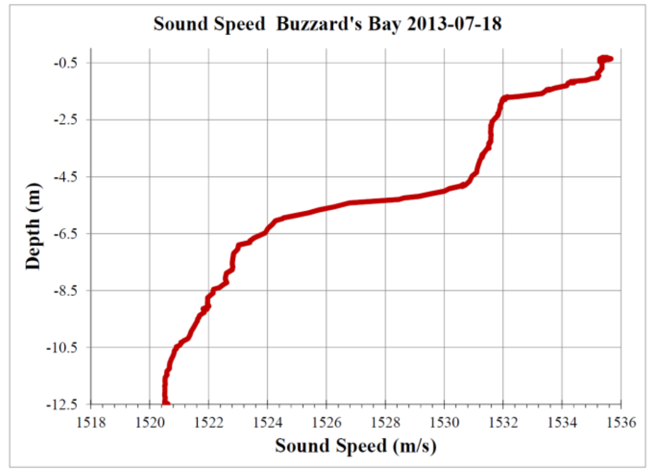

Fig. 7 - Sound Speed profile versus depth, measured using a CTD lowered from the ship during vehicle operations. Note that the sounds speed is extremely fast (>1520), with a small amount of mixing at the surface, and downward refracting throughout. Also notice the extreme change in propagation speed from 5m to 6m depth. During the test, the vehicle flew at 9.5m depth, and the Wave Glider tow body was a bit less than 6m depth.

These conditions prove to be extremely challenging, with reliable communication ranges of less than 1 km. Better conditions may only be found locally by waiting for fall weather, or moving to deeper waters offshore.

C. Test Operations

For each test, we launched the Wave Glider into a small 400m x 400m box, programmed to navigate from corner to corner, repeatedly.

A REMUS 600 AUV was programmed for a sidescan and multi-beam survey, near this box. The REMUS began within

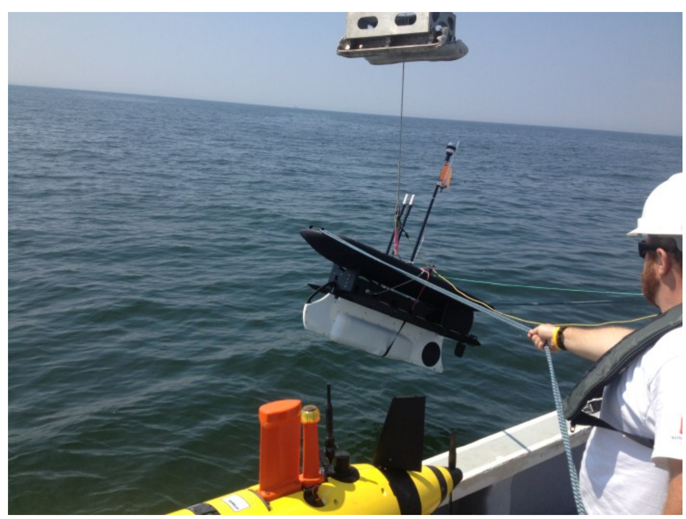

Fig. 6 - Photo showing the launch of Liquid Robotics Wave Glider with REMUS Smart Gateway modifications. In the launch configuration, the glider tow body is attached to the surface float with a quick-release strap. This photo shows the WHOI-designed low drag fairing, in white. A REMUS 600 AUV is also visible in the foreground.

500m of the Wave Glider box, and worked away from the Gateway, in raster fashion. AUV mission was aborted as soon as acoustic communications failed. A better test for these conditions would have operated the communications platforms at all ranges.

D. Test Results

With challenging acoustic propagation conditions less than 200 telemetry packets were received in each test. This small sample was inadequate for quantitative analysis, but a few observations were made.

1) PSK communications worked

At the beginning of both tests, high rate PSK packets were received. The test saw mostly low-rate PSK packets, out to about 1.2 km maximum range. Communications worked *reliably* to about 1 km. This performance is explained by the poor propagation conditions discussed above.

There was possible aspect dependence observed on both platforms, which needs to be investigated further.

2) Rate-changing Algorithm worked

After setting the rate thresholds properly for this environment, the Gateway adapted data rate for conditions, although only a small number of high-rate packets were ever received.

3) Telemetry relay worked

Traditional REMUS CCL and high-rate test data was relayed to the REMUS Vehicle Interface Program (VIP), and displayed.

4) Gateway Link Monitor worked

Throughout the deteriorating conditions, acoustic link quality metrics were reported to VIP and displayed.

E. Test Conclusions

More testing is required with either better acoustic propagation conditions, or smaller programmed platform ranges. Aspect dependence of acoustic receiver performance needs to be investigated.

ACKNOWLEDGMENT

The described Smart Gateway technology is currently under contracted development by Hydroid, Inc., a Kongsberg Company. Two early prototypes have been developed.

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