Drifter Sensor Network for Environmental Monitoring

Daniel Boydstun*, Matthew Farich*, John McCarthy III*, Silas Rubinson*, Zachary Smith*, and Ioannis Rekleitis†
*Computer Engineering, University of South Carolina, Columbia, SC, USA
†Computer Science and Engineering, University of South Carolina, Columbia, SC, USA
Email: yiannisr@cse.sc.edu

***Abstract*—This paper presents the design, development, and deployment of a sensor network of drifter nodes. The target domain is coastal water monitoring, and study of Lagrangian water dynamics. The nodes are equipped with a camera, inertial measurement unit (IMU), GPS, WiFi, and a computing unit. Each unit is water resistant, with buoyancy characteristics that enable it to float in a vertical position. The sensors are capable of recording geolocated visual data at variable rates. They collect Lagrangian current observations as they move along the water surface. In addition to the current measurements, the drifters are also recording image data that provide insights about the health of the marine life below the surface. We propose, to utilize the motion generated by the wave action in order to record wider field of view images from the ocean floor. Results from a successful deployment of the coast of Barbados are presented together with a discussion on lessons learned.**

***Keywords*-Sensor network; Image stitching; Underwater Vision**

I. Introduction

This paper presents a drifter sensor network designed for collecting information in coastal environments. The drifters were designed to be low cost, to enable the deployment of several units, easy to construct, and build from commercial off the self (COTS) components. Each node is capable of recording information from several sensors including an Inertial Measurement Unit (IMU), GPS, and a camera facing the ocean floor. The data is stored locally on the computing unit, low cost embedded system. Each node is also equipped with a 802.11n WiFi capabilities. The nodes are placed inside a PVC tube, one side is sealed by a permanently attached acrylic window, and the other one sealed with a removable cap. The nodes are battery powered with duration up to ten hours. The final design will be made available open source at the Autonomous Field Robotics Lab's website[1].

Tracking a body of water as it moves through the ocean by following it with a sensor, is called tracking using Lagrangian measurements, in contrast to measuring the waters velocity at a fixed point which is termed tracking based on Eulerian measurements[2]. The developed nodes are capable of floating on the surface and following the upper layer of water as it moves from the joint forces of currents and wave action. The GPS sensor provides adequate information to track the motion of the node over time. Preliminary experiments demonstrate this capability. In addition the IMU data can be further used to characterize the motion patterns from the inertial information, and is considered as future work.

Figure 1. Deployment of three drifters over the coral reef off the Bellairs Research Center, Barbados.

The visual data recorded during our experiments demonstrates the benefit of unstabilized motion as it resulted in a much wider field of view. Obtaining vision data of a coral reef is quite valuable to marine biologists [1], [2], however, it is a tedious task. Deploying a collectve of drift nodes over an area of interest at regular intervals will result in comprehensive coverage at minimal cost. In addition the drift nodes are non-intrusive as they passively float at the surface not affecting the marine life below. In addition, the sensor nodes can be easily mounted on surface vehicles e.g. the kingfisher ASV[3] to provide plug and play underwater camera capabilities. By attaching two of them a fixed distance apart, stereoscopic data can be recorded.

The next Section II provides an overview on related work on drifter nodes and monitoring. Section III discusses the design choices made. The experimental setup for the 2015 Field Trials is outlined in Section IV. The experimental results on Lagrangian measurements is presented in Section V. Visual data collected from a drifter node deployment are in Section VI. The paper concludes with a discussion on lessons learned and directions for future research.

[1]http://www.afrl/cse.sc.edu/drifters/

[2]http://secoora.org/classroom/flowing_ocean/tracers

[3]http://www.clearpathrobotics.com/kingfisher/

II. Background

The problem of tracking ocean currents was very important, in the past, for navigation, sailors off the Marshal Islands utilized twig maps to record the direction of different currents and swells [3]. As early as 1953, floating devises were used to record the Lagrangian motion of the currents [4]. Around the same time, Laughton [5] developed a deep sea underwater camera to obtain additional information. Neutrally buoyant drifters were modified to follow the isopycnal boundaries performing experiments of hundred of kilometers [6]. Many different floats have been deployed over the years, many of which operated at depth [7] measuring currents as they vary over time.

A low cost drifter was proposed as early as 2003 [8] with a special design to operate in surf zones. The SECOAS project proposed a self organizing network of floats [9] In [10] an overview of different systems, including drifters, AUVs, and gliders is presented. An analysis of the different sampling domains and which vehicle is suitable for which domain is discussed. Oroza et al. [11] proposed the use of active vehicles for collecting Lagrangian measurements for tracking currents in order to improve the efficiency.

Tinka et al. [12] developed an actuated floating sensor network for estimating water flow. Drift nodes have been used in collaboration with Autonomous Surface Vehicles (ASVs) to estimate current motion [13] and to study a property of interest in the water body frame of reference [14]. Research on robotic monitoring of Lagrangian Coherent Structures was proposed in [15] with an emphasis to control strategies for distributed sensing from a swarm of robots. The work was extended to relay only on local information allowing for extending the number of robots and the area covered [16]. AUVs have been also used to track the movement of water masses that act as larval transport [17].

III. Drift Node Design

The primary goal of the design was to create an inexpensive sensor which can still collect quality data. The node had to be easily transportable and robust to casual handling; Fig. 2 presents a schematic of the electronics. First the hardware components and the shell construction is going to be discussed and then an outline of the software components will be presented.

A. Hardware design

The brain of each sensor node is a Raspberry Pi computer, which is low cost, low power, but still capable of running a Linux variant. In the current implementation the model B+ was used. We are currently considering upgrading to the newest model that has a multi-core processor. The Raspberry Pi camera was used, even though it is a low cost camera the images recorded, as can be see in Fig. 7, were very clear. The Adafruit Ultimate GPS Breakout, with an external GPS antenna was used to record the position of the node. The Pololu MinIMU-9 V3 IMU was used to provide information about the orientation of the node at 10Hz. Finally, the Edimax EW-7811Un 150Mbps 11n Wi-Fi USB Adapter was used to broadcast an adhoc network and also to record WiFi signal strength. All the electronics were powered by a RAVPower Element 10400mAh battery, which provided more than ten hours of continues operation.

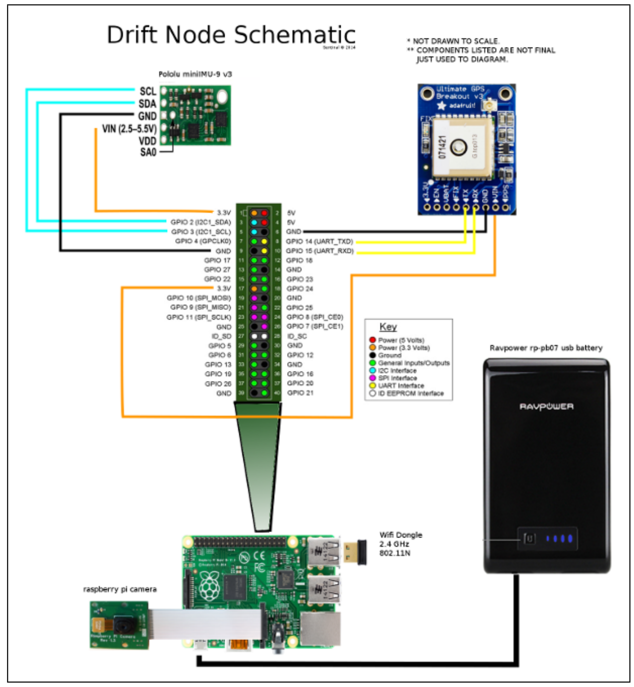

Figure 2. Schematic of hardware components and their connectivity used in the deployed drifters.

All the electronic components were mounted on one side of a rectangular piece of acrylic; see Fig. 3, and the battery was mounted on the opposite side. At the bottom side a circular piece was attached (via epoxy glue) and the camera was attached with two screws. The top side had another disk attached on which the GPS antenna was fixed with a velcro strip. The electronics assembly fit snugly inside a PVC tube with a diameter of three inches. The bottom part of the tube was permanently sealed with an acrylic window that allowed the camera to record from the bottom. The top part had a removable cup that ensured the inside was water tight.

B. Software design

The Raspberry Pi is capable of supporting a variant of Linux called Raspbian, we loaded each node with the Raspbian Wheezy OS[4], which enabled them to run the ROS framework[5]. With the drift nodes being ROS enabled their functionality expanded and drivers for the different sensors became accessible. In addition, data logging was facilitated

[4]http://www.raspbian.org/
[5]http://www.ros.org/

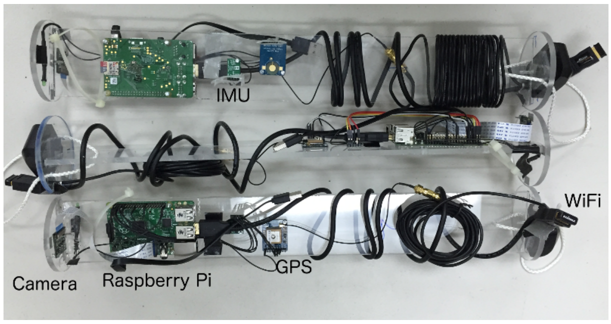

Figure 3. The assembled electronics for the three drift nodes.

by the ROS rosbag mechanism[6], then the data could be played in a timely fashion, like they were just acquired live. The GPSd[7] was used to monitor the GPS and then the data was served as a ROS message. The minimu9-ahrs driver[8] was used to communicate with the IMU, and the data were published as a standard ROS message. The advantage of using the standard ROS format is that standard tools such as rviz[9] and rqt[10] can be used to visualize the data; see Fig. 4.

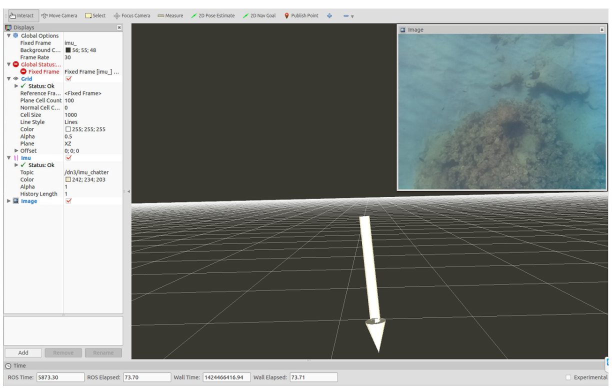

Figure 4. The IMU data played back and visualized in sync with the camera footage using the rviz software package.

During testing and also during deployment the GPS delayed for a random interval to acquire a fix. In the startup scripts of each node we placed a test condition that blocked the activation of the IMU and the camera drivers and consequently the logging process in the form of a rosbag, until the GPS had acquired a fix.

IV. Experimental Setup

Three drift nodes were created using the above described hardware/software configuration. Preliminary test were performed on land and at Lake Murray, SC. The nodes were further tested during the field trials at the Bellairs Research Institute, Holetown, Barbados, in January 2015. Ballast was adjusted to compensate for salt water, and tests were performed for the water resistance of the design; see Fig. 1. During the tests it was discovered that the GPS device of one of the nodes was not functioning, as such during the final deployment only two of the three nodes were deployed.

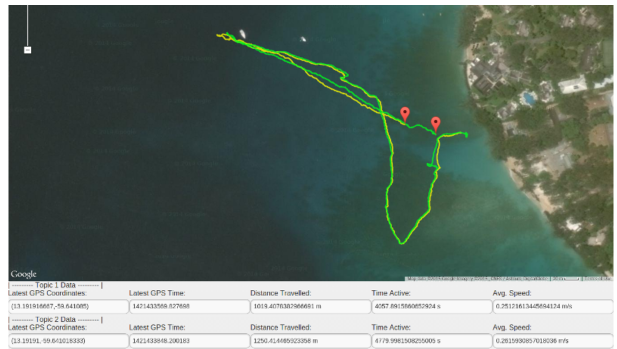

Figure 5. The GPS trails of two drift nodes as they moved off the coast of Barbados. During the experiment different behaviors were studied. Free drifting; constrained drifting near an anchor point; moving a single node and towing the other; moving both nodes with fixed orientation and at a fixed distance between them.

The experiment was divided in four phases, first the two nodes were left to float by themselves starting from the two pin locations in Fig. 5 until they reached the top left corner; see Fig. 6 for only this part of the experiment. Then the two nodes were connected with a string of length 9.2 m, one node was kept in vertical position and moved up to the bottom part of the trail in Fig. 5, while the second node was dragged behind. Looking over the IMU data in rviz, the first node indicates a nearly vertical pose for this part of the experiment, while the second node holds an approximately forty-five degrees inclination of the vertical. The third part of the experiment consisted of holding both nodes in a vertical position at a fixed distance apart simulating long-baseline stereo. Finally the nodes were left to float near the shore for a short period of time. The difference between drifting undisturbed and forced to maintain fixed distance and orientation can be seen in the recorded footage from the two cameras: Fig. 9a presents a mosaic from a long sequence of images from a single node drifting; Fig. 9b,c are two mosaics, one from each node during the same time frame; finally, Fig. 9d presents a composite demonstrating the overlap between the two cameras.

V. Current Estimation

Using the GPS trail over time we can estimate the combined wave and current action as a Lagrangian measurement. Figure 6 shows the paths of the two nodes, they floated approximately for 40 minutes, and the cumulative distance travelled by each node was approximately 500 m. The

[6]http://wiki.ros.org/rosbag
[7]http://www.catb.org/gpsd/
[8]https://github.com/DavidEGrayson/minimu9-ahrs
[9]http://wiki.ros.org/rviz
[10]http://wiki.ros.org/rqt

straight line distance was around 300 m. The velocity of the nodes was 0.2 m/s on average.

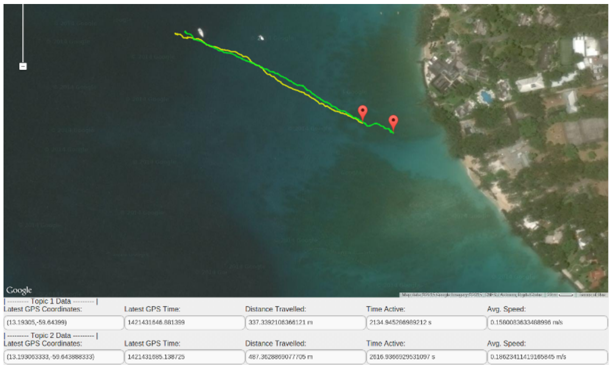

Figure 6. The GPS trails of two drift nodes as they moved off the coast of Barbados by the combined effect of wave and current action.

VI. Underwater Vision

As mentioned earlier, the drift nodes use a camera mounted at the bottom of the enclosure to capturing images at 2Hz. The images, together with the GPS, IMU, and WiFi signal strength data are stored locally and they can be played back later in a timely manner. Post-experiment, selected subsets of the images were stitched together in a single larger image so that the entire path each drifter took can be viewed as a single large image; see Fig. 7. If other nodes took a similar path the images captured can be used in conjunction to give a larger picture of the ocean floor. In this manner multiple drifters can be used to map shallow coral reefs.

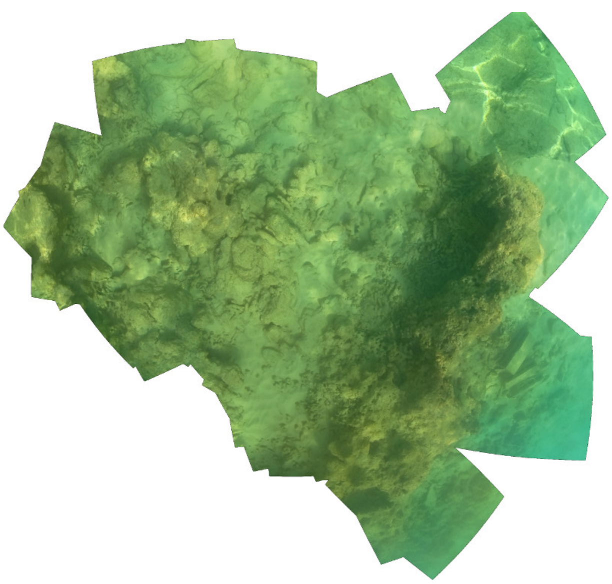

Figure 7. A mosaic from several images collected from a single drift node floating over a coral head.

The area of image stitching [18], [19] is well developed, for this work we utilized the Image Composition Editor[11] from Microsoft Research.

A. Wave Actuated Vision

Using ocean waves to actuate the drifters allows the camera a wider field of vision as the camera's field of view is shifting. The cameras field of view can be modeled as wondering about a hemisphere. When combined with the linear motion imparted by ocean currents or wind this gives the camera field of view hemispherical view of the ocean floor. Figure 8 presents a composite from several images collected while the drifter was floating at the surface constantly changing orientation. At the top of the image is an illustration of the drifter in various orientations.

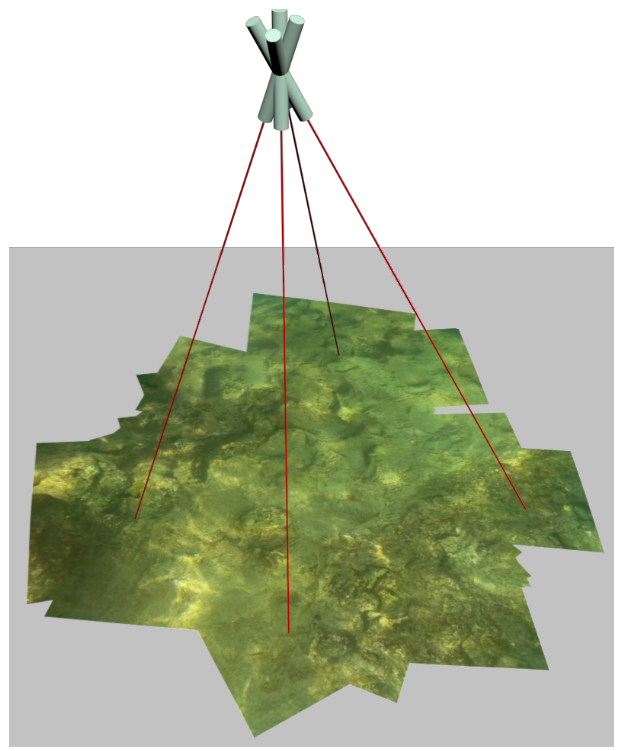

Figure 8. A schematic of a single drift node at different orientations over a short period of time and the images collected stitched together under it.

B. Transect Mapping

In the area of marine biology, a common tool is to record data from a straight line, termed a transect. During our experiment we collected visual data in two modes, when the drifters were floating unconstrained, and when they were moving with fixed orientation. When free floating the wave action generated a wider field of view as can be see in Fig. 9a, compared to the fixed orientation data from Fig. 9b,c. Even at a low frame-rate of 2Hz, enough images were collected to produce detailed panoramas. The resolution in

[11] http://research.microsoft.com/en-us/um/redmond/projects/ice/

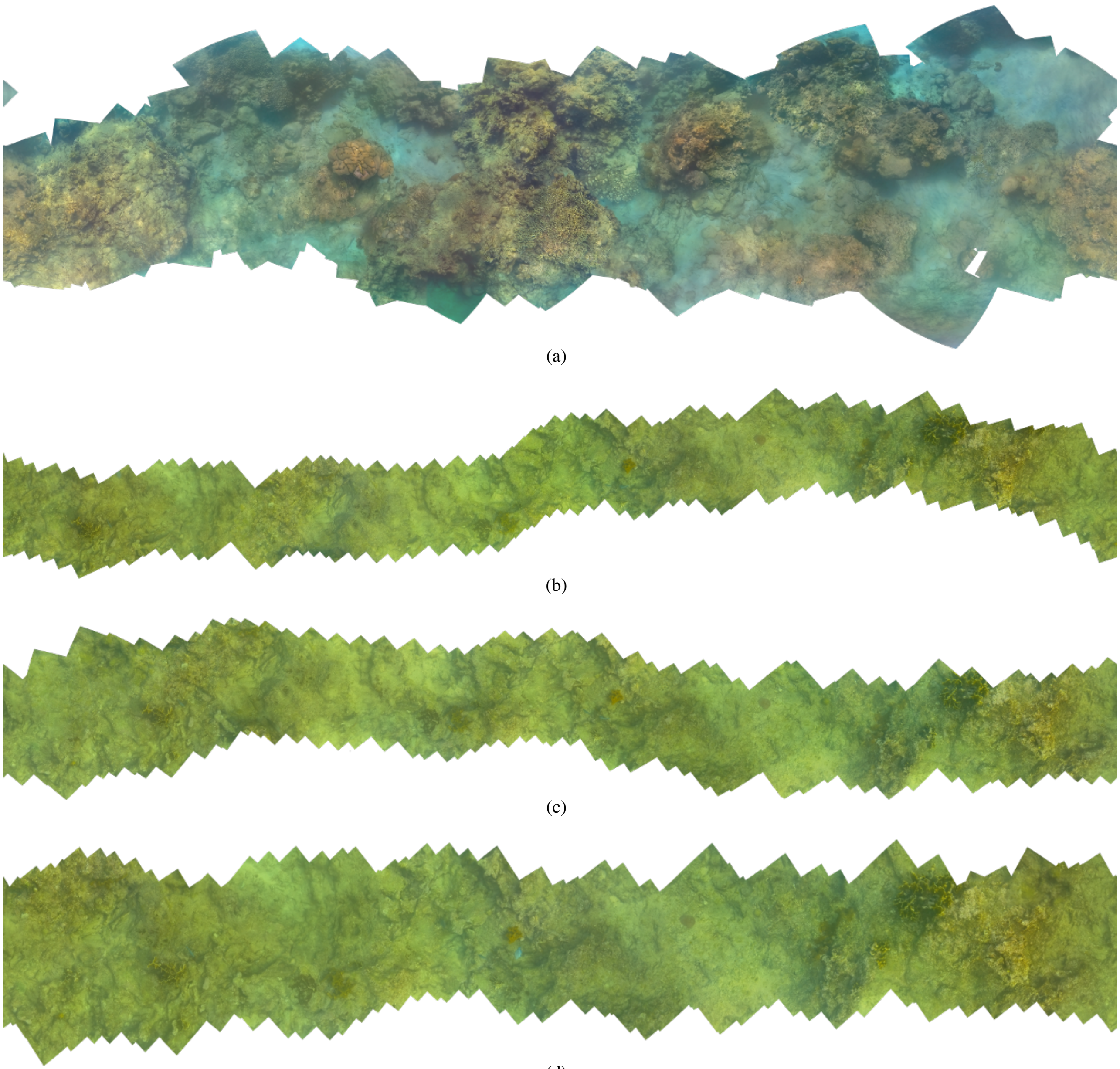

Figure 9. (a) Mosaic from a drift node while drifting freely. (b,c) Mosaic from the two drift nodes while drifting with fixed orientation and at a fixed distance apart. (d) Mosaic from the two transacts, indicating the overlap between the two fields of view.

the images included in the paper is heavily reduced due to size constraints; for example, the original image from the transect in Fig. 9a was 7680 by 2372 pixels, and the image in this paper is 1280 by 395 pixels, a reduction of 6 times in each dimension.

VII. Conclusion

We presented the design of a drifter camera sensor network and its deployment in a coastal waters environment. With a low budget of $250 of COTS components the proposed design can be realized in large number of drifters enabling the measurement of water dynamics in coastal areas and the inexpensive recording of the seafloor. The design is extensible and can accommodate the addition of new sensors such as SONAR rangers, conductivity, temperature, and depth (CTD) sensors, salinity sensors, and turbidity sensors.

Utilizing the inertial and visual data in a probabilistic state estimation framework similar to the ones proposed in [20]–[23] will augment the GPS position estimation for higher accuracy in the recording of seafloor structures which will be beneficial to marine biologists. Preliminary results using the Image Composition Editor indicate that the recorded data can produce high fidelity models of the underwater environment. In addition to stitching the images together, the GPS/IMU data will also provide scale in the visual data, enabling the construction of photorealistic 3D models.

During the deployment, the WiFi strength from the two nodes was recorded reciprocally. As expected the signal was very noisy with very little correlation with the separation distance between the two nodes. During future deployments we are planning to use several drifters and to examine whether the signal strength from multiple nodes can be utilized as a range measurement in a cooperative localization [24] framework.

Future plans include the mechanical design modification in order to add a steering mechanism. While still passive, by controlling partially the angle of motion, we expect to steer a team of drifter nodes actively to maintain the inter-node distance inside specific bounds. These bounds will be specified by the communication capabilities of the nodes, ensuring the team maintains communication among all members and also to ensure enough separation to maximize coverage.

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