Underwater Electric Potential Measurements Using AUVs

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***Abstract*—Measurements of underwater electric potential (UEP) have several possible applications, including geophysical research, gas and oil exploration, and finding underwater cables and unexploded ordnance. In the present investigation, use of an autonomous underwater vehicle (AUV) to perform measurements of underwater electric potential was explored. An AUV was equipped with a spherical electric field sensor containing three pairs of Ag/AgCl electrodes. A controlled electric field source was mounted on a surface boat for testing. In a shallow saltwater test facility, tests were performed in which the UEP sensor-equipped AUV and surface boat passed one another from opposite directions. UEP measurements acquired by the AUV showed that an ac electric field source at frequencies of 5, 10, and 20 Hz on the surface boat were clearly detected.**

Keywords—AUV; underwater electric potential

I. Introduction

There are reasons to believe that measurement of underwater electric potential (UEP) would be of interest. Measurements of UEP can contribute to geophysical research [1], the exploration of oil and gas [2], and location of objects such as undersea cables and unexploded ordnance [3]. It has been demonstrated that UEP measurements can be used to determine the position and shape of nearby objects [4], and to communicate over short distances [5].

In this paper, use of an autonomous underwater vehicle (AUV) to perform measurements of UEP is described. A small AUV was equipped with a UEP sensor. The UEP sensor consisted of a polymer sphere embedded with three pairs of Ag/AgCl electrodes. The voltage signal from each electrode pair was connected to a pre-amplifier, and the output was digitized and stored. Experiments were conducted with the sensor-equipped AUV to record a signal from a controlled low-frequency ac electric field source located on a moving surface vessel. The experiments showed that the source was detected by the UEP sensor.

II. Methods

A. AUVs

The AUVs used during this testing were based on a design by Virginia Polytechnic Institute [6]. The adapted design manufactured at the University of Idaho (UI) can be seen in Fig. 1. Each AUV was 102 cm long and 10.2 cm in diameter, and powered by a 40 W brushless motor, giving a maximum speed of 1.2 m/s in still water.

Sensors on the AUV used for navigation included a pressure gauge to indicate depth, a six-axis inertial measurement unit (IMU), and a tilt-compensated magnetic compass. These sensors were accompanied by a Long BaseLine (LBL) acoustic ranging system integrated with an acoustic modem. The LBL ranging system and modem [7,8] were provided by Woods-Hole Institute. During navigation, the AUV acquired ranges from four previously-deployed

Fig. 1. UEP sensor equipped AUV.

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bottom-mounted acoustic transponders 4 times every 10 seconds, while other sensor data was sampled at 4 Hz.

Navigation was accomplished by fusing the measurements of the navigation sensors and the LBL using a Kalman filter. The states for the Kalman filter were north and east position, inertial speed and heading, and compass bias. Details of the Kalman filter are contained in [9]. Because the Kalman filter relied on a correlation of propeller speed to AUV inertial speed, ocean currents were a problem for AUV navigation.

B. UEP Sensor

The UEP sensors were custom fabricated at the UI. They consisted of three orthogonal pairs of 2 mm diameter Ag/AgCl electrodes. The electrodes were embedded in a 3.81 cm diameter spherical polymer housing molded around the electrodes. In order to mount the sensor to the AUVs, the axes of the sensor were rotated to allow a mounting rod on the back of the sensor as seen in Fig. 2. The rotation was chosen to keep each electrode pair equidistant from the mounting rod. A close-up photo of the actual sensor can be seen in Fig. 3. The sensor extended out in front of the AUV to minimize interference from the onboard electronics.

The signals from each Ag/AgCl electrode pair were amplified by a model 1010 low-noise amplifier manufactured by Dexter Research Center. A resistor voltage divider on the output of the amplifier reduced the gain to prevent overloading the data acquisition system. The overall gain of the preamplifier and voltage divider was ~250.

The data acquisition system contained in the AUV was a D.Module.C6713 DSP manufactured by D.SignT. It had a 6-channel analog to digital converter (D.Module.AD7722) and an Ethernet daughter board (D.Module.91C111) to record the data to an SD card. Digitization occurred at a rate of 16.7 kHz, with 16-bit resolution over a ±1.25 V range giving a quantization level of 0.153 µV/lsb at the sensor.

C. Field Testing

The underwater electric potential (UEP) sensor testing was performed at South Florida Ocean Measurement Facility (SFOMF). The test site was located 2.1 km offshore. The water depth at the test site was nominally 15.2 m (50’), with minimal departure. The bottom of the test area was sand and coral. Four acoustic LBL transponders were tethered to the bottom at the corners of a 260×260 m square. UEP measurements were performed by an AUV largely within the 260×260 m LBL area.

Fig. 3. Tri-axial UEP sensor

An electric field source was mounted to a 7.62 m (25’) long fiberglass-hull surface boat to serve as a known electric field to be measured by the UEP-equipped AUV. The source consisted of two conductive plates, separated by a known distance, and powered by a sinusoidal voltage. At the test site, GPS and shore-track radar was available for measuring the position of the surface boat while maneuvering.

In a typical experiment, the UEP-equipped AUV and the surface vessel containing the electric field source were positioned at opposite ends of the measurement area. The AUV and surface boat initiated collinear movements toward one another in opposite directions. AUV movements were conducted at a depth of 10 m. UEP and navigation data was recorded by the AUV. The position of the surface boat was acquired offshore. These data were used to link the AUV-acquired measurements of UEP to the relative position of the AUV and surface boat.

III. Results and Discussion

Fourteen complete repetitions of the experiment were performed. The data presented in this section is one example. Fig. 4 shows the paths taken by the AUV and the surface boat. The AUV traveled south (starting at the top of the plot) and the surface boat traveled north (starting at the bottom of the plot).

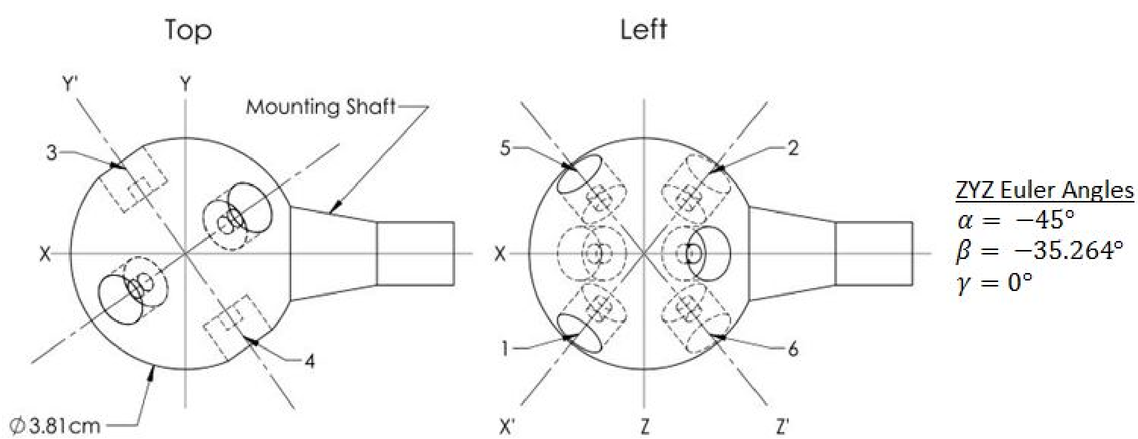

Fig. 2. Electrode orientation in 3-axis UEP difference sensor. Channel 1: Pair 1-2, Channel 2: Pair 3-4, Channel 3: Pair 5-6. ZYZ Euler Angles from AUV coordinates (XYZ) to sensor coordinates (X’Y’Z’)

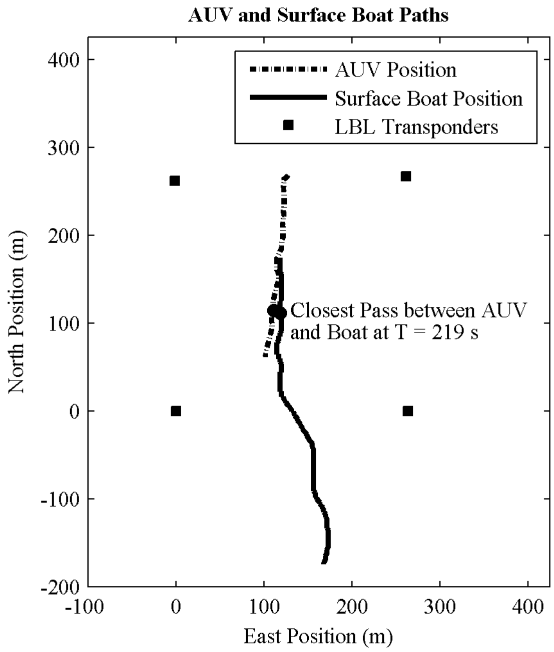

Fig. 4. Paths taken by AUV and surface boat.

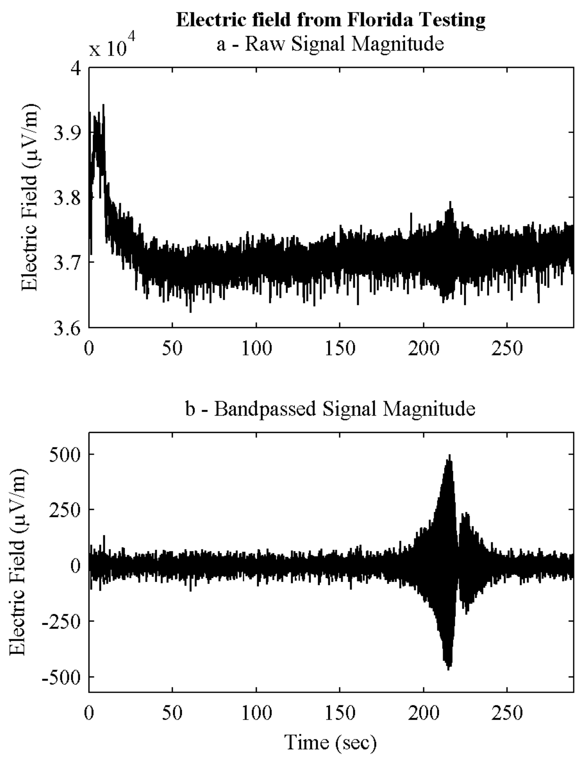

Fig. 5. AUV-acquired UEP.

At closest pass, denoted in Fig. 4, the distance between the AUV and surface boat was ~13 m at a time of 219 s into the experiment.

Three voltage signals, one from each pair of Ag/AgCl electrodes in the UEP sensor were recorded. A nominal electric field magnitude was computed as the root-sum-square from the three voltage signals. Units of electric field were obtained by accounting for preamplifier gain, the diameter of the sensor, and a shape factor to quantify the equivalent electrode separation for the sensor geometry. The raw electric field magnitude is contained in part (a) of Fig. 5. After 50 s, the raw electric field magnitude had a mean value of 37,095 μV/m. In part (b) of Fig. 5, the raw electric field magnitude has been bandpass filtered with a succession of high and low-pass Butterworth filters. The passband for this filtration was 3-25 Hz. The signal from the electric field source on the surface boat, with peak value of 415 μV/m at a time of 215 s can be seen quite clearly after removing the high and low frequency noise.

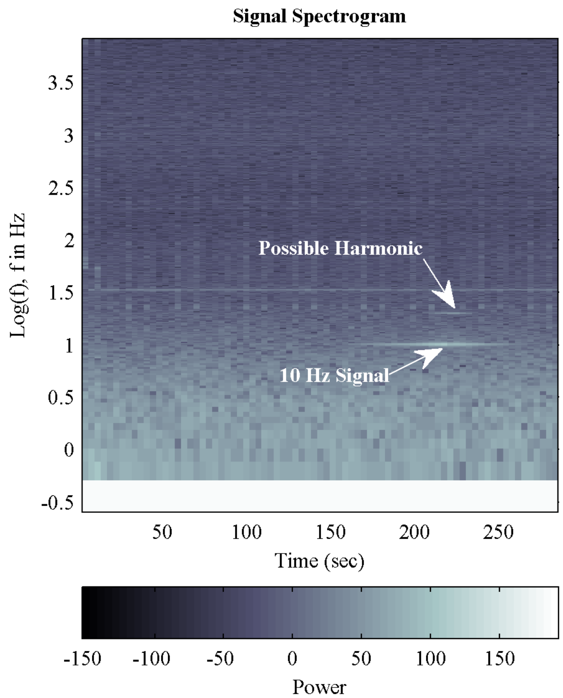

Fig. 6. Spectrogram of AUV-acquired raw electric field.

Fig. 6 shows the raw electric field signal shown in part (a) of Fig. 5 analyzed by a spectrogram. The electric field caused by the source in the surface boat can be observed in Fig. 6 at a frequency of log(10 Hz)=1 and a time of ~215 s. It is also observed that the sensor appears to have detected a harmonic of the 10 Hz ac electric field signal occurring at 20 Hz.

Regarding other experimental repetitions, similar results were obtained with the ac electric field source on the surface boat at frequencies of 5 and 20 Hz.

CONCLUSIONS

It was demonstrated that an AUV could be equipped with a UEP sensor. Experiments showed that a moving UEP-equipped AUV is capable of detecting an ac electric field at frequencies of 5, 10, and 20 Hz on a moving surface vessel.

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