INITIAL FIELD TRIALS OF THE NOISESPOTTER: AN ACOUSTIC MONITORING AND LOCALIZATION SYSTEM

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INTRODUCTION

In support of monitoring technologies to evaluate the potential environmental effects of marine and hydrokinetic (MHK) energy devices, this project attempts to ultimately improve upon traditional acoustic sensing techniques by developing a cost-effective compact array of acoustic vector sensors that characterizes, classifies, and provides accurate location information for anthropogenic and natural sounds.

Acoustic sensing techniques typically involve the use of hydrophones that measure acoustic pressure, a scalar quantity that provides no directional information as to the location of the source of sound. As a result, localizing the source of sound is typically achieved by large arrays consisting of multiple time-synchronized hydrophones. Further, for most deployments of acoustic instruments, data are stored on board for the entire duration of the deployment. Data analysis following instrument recovery provides soundscape characterization, including information about the source of sound.

An acoustic vector sensor measures three-dimensional (3D) acoustic particle velocity in addition to acoustic pressure on a single sensor. This vector measurement inherently provides directional information (acoustic bearing) regarding the source of sound. A vector sensor array (VSA) can therefore triangulate individual measured bearings to provide sound source localization, and thereby help characterize sound specific to a source. This localization ability is key to characterizing sounds from MHK devices, which have been found to emit low intensity sounds on the order of 106-109 dB re 1 μPa in the frequency band 125-250 Hz and undetectable above the ambient noise outside this band.[1] with other sources of sound likely to be present in the vicinity, including boats, industrial activities, and natural sources such as marine mammals, precipitation, breaking surface waves, and fish choruses.

In addition to providing the ability to localize and characterize sounds from MHK devices, the NoiseSpotter will enable the ability to process acoustic data in near real-time. Processed data metrics, such as source location, peak sound levels, signal to noise ratios, and ambient noise levels will be compiled into a compact data digest for relay to a land-based shore station. This paper sets forth three goals: (1) to provide updates on an ongoing Department of Energy (DOE) funded project to characterize and localize sound from MHK devices, (2) to describe recent field results using a controlled acoustic source and (3) to demonstrate the utility and feasibility of vector sensors to geolocate an acoustic source. Section 2 describes the initial system design of the NoiseSpotter. Section 3 describes a recent field experiment, while Section 4 details results obtained. Section 5 summarizes the results and discusses future directions.

NOISESPOTTER SYSTEM DESIGN

A key principle of long-distance underwater acoustic propagation is that sound travels along discrete paths between a source and a receiver. Given the uniqueness of the acoustic field between a source and receiver, a variety of techniques can be employed to determine the location of a sound source.[2] These techniques vary in hardware complexity, accuracy, and computational efficiency based on the underlying physical assumptions.

The NoiseSpotter is a platform that can improve upon the method of direction of arrival estimation by using acoustic vector sensors that measure triaxial particle velocity in addition to acoustic pressure. Each vector sensor has the ability to determine the bearing of an acoustic source. With multiple time-synchronized vector sensors located on the array, the essential principle of the proposed technology is that the source can be geo-located by triangulation of particle velocity vectors measured across the array[3,4].

The NoiseSpotter V1 consisted of an array frame designed to house three acoustic vector sensors that formed the VSA, and a surface float that housed the data acquisition unit (Figure 1). The VSA consisted of three M20 vector sensors from Geospectrum Technologies Ltd.: two model M20-40s and one M20-100. The M20-040 features a single wet-connect underwater cable that relays the four measurement fields (tri-axial particle velocity, and omni-directional pressure) to an external amplifier circuit board. Pressure and particle velocity channels are sensitive to the frequency range 50 Hz-5 kHz. Power to the sensor is supplied via an amplifier circuit board connected to a rechargeable battery pack (32 Ahr; Sartek Industries Inc.), and relayed to the sensor via the above mentioned wet-connect underwater cable. The M20-100 operates similarly to the M20-040, but is augmented with a second wet-connect underwater cable and digital amplifier circuit board to receive the digital compass output from the sensor. Logging data from the analog sensor output therefore requires conversion to a digital format, followed by storage on a solid state drive. A multi-channel off-the-shelf data acquisition unit was purchased from MCCDAQ Inc. (Model LGR5327). This low-cost data logger can simultaneously record 16 single-ended or 8 differential-ended data streams, at a synchronous sampling rate of up to 500 kHz, with a sampling depth of 16 bits per sample. The logger is easily configurable where segment sizes can be modified, and the input voltage range can be user-specified.

The VSA frame was built using a lightweight anodized aluminum angle and consists of a 93 × 45 x 45 cm rectangular cage, with a 10-cm-tall triangular subframe above and below the rectangular cage (Figure 1). The tapered triangular subframe provides a mounting point for the mooring line. Direct contact between the steel eye-bolt and the aluminum frame, which can lead to rapid corrosion when exposed to saline water, is avoided by using nylon bushings through which the eye-bolt is inserted. Additionally, every joint where various members of the frame are bolted together is padded with rubber to minimize the potential for noise from metal-on-metal contact.

The NoiseSpotter is moored with a mid-water column inverse catenary mooring (Figure 2). Stability of the cage is maintained by means of flotation balls above the mooring, and bottom anchors to help keep the mooring line taut. Surface motions are decoupled using a system of smaller weights and floats to form an ‘accordion’ shaped mooring between the surface Spotter and the subsurface flotation balls. The effect of horizontal currents on noise measurements is achieved by means of a 50 Hz high-pass filter built into the acoustic sensors that effectively filters out lower frequency effects on sound from horizontal motions. The mid-water column array also consisted of a broadband acoustic recorder (BAR), the microMARS manufactured by Desert Star Systems, and an off-the-shelf IMU.

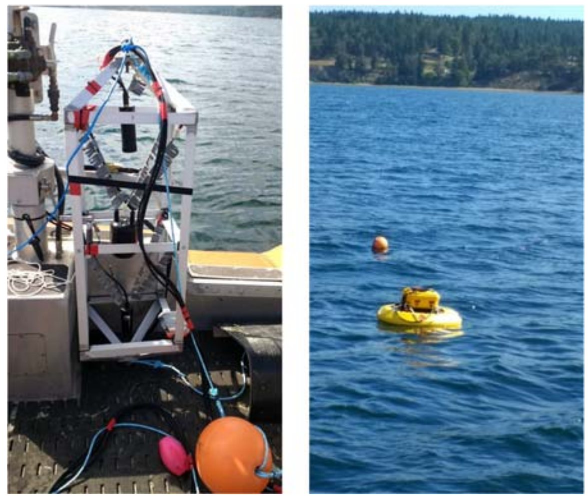

FIGURE 1 (LEFT) VSA FRAME WITH SENSORS. GRAY FAIRING WAS USED TO MITIGATE ACOUSTIC STRUM. (RIGHT) SURFACE BUOY WITH PELICAN® CASE (HOUSING THE DATA LOGGER, VSA AMPLIFIER BOARDS, AND BATTERY PACK) STRAPPED ON.

IN-WATER TESTING IN SEQUIM BAY, WASHINGTON

The VSA was deployed on July 11 and 12, 2017, in Sequim Bay, Washington, in collaboration with the Pacific Northwest National Laboratories (PNNL). The water depth at the deployment location was 26 m, with the array located 15 m above the bottom. The bathymetry at the test location was almost uniformly flat over a 1 km distance, and the bottom composition was primarily soft mud. Repeated acoustic transmissions were made using a low- and high-frequency acoustic source using 3-second-long pulsed sinusoids over 100 Hz to 5 kHz (source level 120 dB re 1 μPa, low-frequency source), and 10 kHz to 33 kHz (source level 127 dB re 1 μPa , high-frequency source). Each set of pulsed sinusoid transmissions were repeated three times at each transmission distance. The acoustic source was deployed over the side of a small boat, the R/V Desdemona, owned by PNNL. Transmissions were conducted at distances of 10 m, 50 m, 100 m, 200 m, 500 m and 1 km from the VSA mooring. Low-frequency transmissions were simultaneously received on vector sensors. The vector sensors are not sensitive to frequencies greater than 5 kHz, which were only received on the BAR.

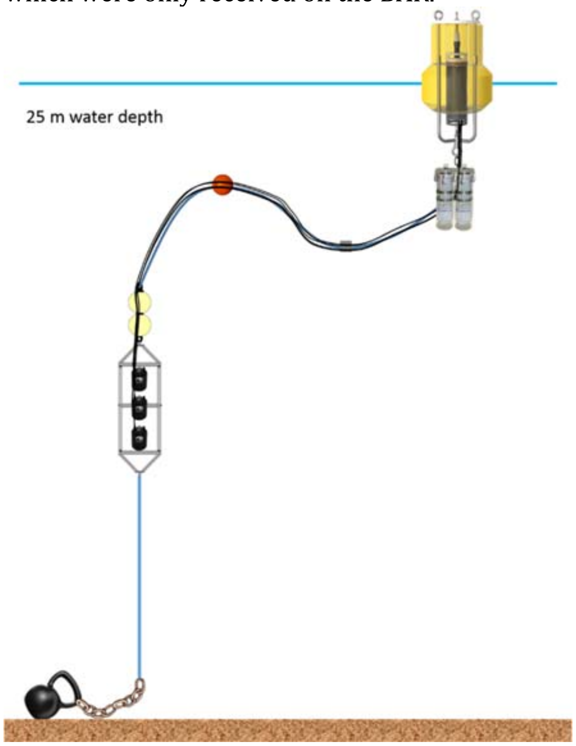

FIGURE 2 VSA MOORING SCHEME WITH ALUMINUM ARRAY FRAME ENCLOSING THREE VECTOR SENSORS AND THE BAR (NOT ILLUSTRATED). AN OFF-THE-SHELF DATA LOGGER AND EXTERNAL BATTERY PACK WAS MOUNTED TO THE SURFACE BUOY.

RESULTS

The first step in processing and analyzing the vector sensor data was to verify that measured pressure levels are consistent with those measured on the calibrated BAR. This effort effectively serves as a sensor intercomparison that takes into account potential signal losses on the cables, the frequency response of the line amplifier, and any artifacts introduced by electronic noise from the data acquisition system.

Shown in Figure 3 are the received signals on the vector sensors (labeled GTI), and the BAR, at a variety of source-receiver separations, and a number of frequencies. Both systems show a good comparison in received levels, except at 200 Hz at a 1-km separation. An increase in pressure at 2 kHz (200m separation) and 200 Hz (500 m separation) is likely due to constructive interference effects in acoustic propagation. There is no discernible signal at 1 km, so received levels of 85 dB is likely electronic noise.

Figure 4 shows vertical particle velocity measurements made on the M20-100. Particle velocity measurements are calibrated using the manufacturer-provided calibration curves, and show the received stepped frequency pulses.

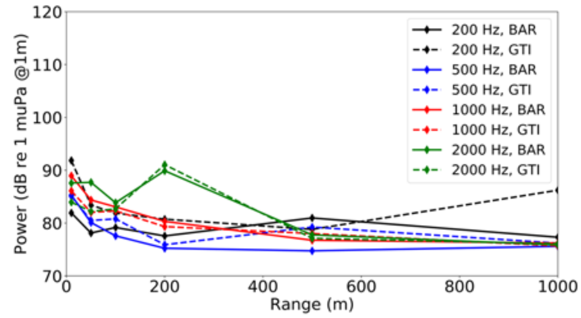

FIGURE 3 RECEIVED SIGNAL LEVELS ON THE BAR COMPARED TO THE M20-100 VECTOR SENSOR AT VARIOUS FREQUENCIES. SIGNALS RECEIVED ON THE VECTOR SENSOR ARE COMPARABLE IN MAGNITUDE TO THOSE RECEIVED ON THE BAR, LENDING CONFIDENCE IN VSA DATA QUALITY.

While data logger-induced self-noise is also apparent in the measurements, signals of interest are clearly visible, allowing for the further development of location estimation algorithms using the acquired time-synchronized pressure and particle velocity data.

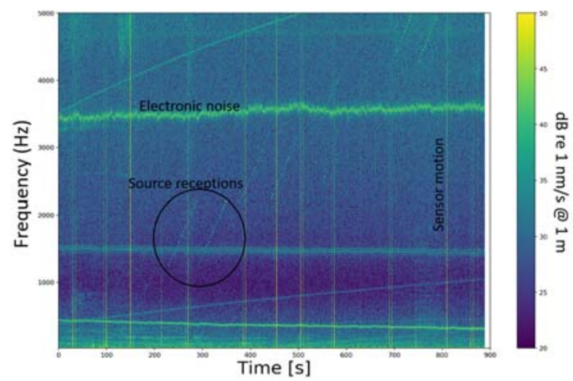

FIGURE 4 PARTICLE VELOCITY IN THE Z-DIRECTION, MEASURED BY THE M20-100. THE LOW-FREQUENCY PULSED SINUSOIDS BETWEEN 100 HZ AND 5 KHZ AS TRANSMITTED BY THE CONTROLLED LOW-FREQUENCY SOURCE ARE VISIBLE. ALSO SEEN ARE BROADBAND STRIATIONS (VERTICAL LINES), INDICATIVE OF ARRAY MOTION AND ARTIFACTS FROM DATA LOGGER SELF-NOISE (HORIZONTAL STRIATIONS).

Also visible in the Figure 4 are regular broadband striations in the particle velocity data, which are not visible in the omni-directional pressure measurements. These striations are most prominent in the z-velocity measurement. This indicates that these striations are array-motion induced (swaying/yanking of the array), providing impetus for mooring redesign, e.g., to lower the array onto a stable bottom platform in future efforts.

Having established adequate data quality of the vector sensor data, bearing estimation of the acoustic source is demonstrated. While time-synchronized measurements were available during the initial field testing in Sequim, the x-velocity and pressure channels were not functioning on each of the M20-040s respectively. As a result, bearing estimates are demonstrated using the M20-100, following the methodology of Thode et al.[2]. The technique for bearing estimation calculation involves segmenting the time series into discrete one second-long segments. Data were band-pass filtered between 1-3 kHz to avoid the self-noise bands. The cross spectral density matrix is then calculated using 1024 point fast Fourier transforms that are overlapped by 512 points. The result is that a bearing estimate is obtained every 1 second of a time series.

Bearing estimation was conducted for fifteen minute-long time series of controlled acoustic source transmissions that were obtained at various source receiver separations (10 m, 50 m, 100 m, 500 m and 1 km) during BP1 field testing in Sequim, WA.

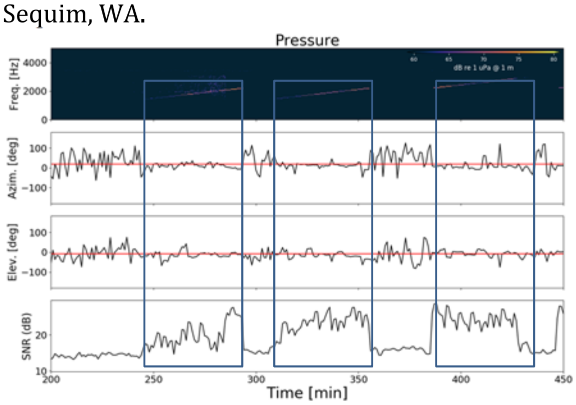

FIGURE 5 SPECTROGRAM OF RECEIVED PRESSURE LEVELS ON THE M20-100 (UPPER PANEL), AZIMUTH ANGLE (MIDDLE PANEL) AND ELEVATION ANGLE (BOTTOM PANEL).RED LINES INDICATE TRUE AZIMUTH AND ELEVATION ANGLES. BLUE BOX SHOWS WINDOWS OF ACTIVE TRANSMISSION.

Figure 5 shows an example of elevation and angle estimates obtained for an approximately 7 minute time series. Shown in the upper panel is a spectrogram of the received signal, which shows the evolution of the frequency content of received signals.

Receptions of the controlled source transmissions are seen as the step-like progression in energy across frequency as an evolution of time. Estimates of azimuth and elevation angle during these periods are seen to closely track the true bearing of the source. Outside of these periods where the source was transmitting, the bearing angles exhibit significantly larger deviations from the true bearing, consistent with isotropic ambient noise. Also seen is a strong dependence of bearing angle accuracy on the received signal intensity. For example, the period around the 260 minute mark, where the signal level drops in intensity, shows increased error in estimated bearing angles. Similar behavior in the accuracy of the bearing estimate is seen at the 420 minute mark.

SUMMARY

Results from an initial field test for the NoiseSpottter indicate that vector sensors are a suitable candidate for noise characterization and geo-location of MHK devices. The M20-100 data were found to be sufficient for developing the bearing estimate algorithm. Bearing estimates were found to be within 10% of true azimuth and within 25% of true elevation when signal to noise ratios exceeded 25 dB. The higher threshold for elevation angle estimates is primarily due to the sensitivity of the vertical velocity measurement to sensor motion. Nonetheless, this analysis indicates that the vector sensors are suitable for location estimation. Tests of a bottom-mounted platform with a rigid frame containing the array are forthcoming which will provide stability in moderate to high currents. A flow noise shield will enclose all of the vector sensors which will minimize flow noise by providing a low-flow environment around the vector sensors.

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