Opto-Acoustic Intensity Probes for Fused Video and Vector Acoustics Measurements in Undersea Monitoring

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Abstract- **Acoustic intensity probes are readily available commercial assets often found in the automobile industry. Pairing of vector mechanics based readings of acoustic output coupled with video allow users to quickly observe visually where a noise source exists on a target of interest. The advent of undersea acoustic vector sensor technology in the last few decades has allowed for the possibility of compact low frequency measurement tools on the order of hand-held for diver use size applications. By coupling the relative omni-directional beam patterns of an acoustic vector sensor with the relative field of view of a hand-held camera, it becomes possible to map acoustic wavefront estimations to the pixelated video output of the camera. An example using variable drive motors in a remote operated vehicle is presented.**

I. INTRODUCTION

Hand-held video cameras are ubiquitous in commercial availability, typically providing comprehensive specifications on performance specifications such as Filed of View (FoV). AVS typically include a reference hydrophone with three collocated accelerometers, measuring all axes spatially to within some fidelity of accuracy within some number of relative degrees. When the acoustic intensity is measured, two dimensions (bearing and elevation) can be extracted from a point sensor and coupled with the optical output by mapping the estimated acoustic bearing and elevation with the observed optical bearing and elevation. This opto-acoustic fusion allows for a relatively compact (hand-held) capability that could be employed by divers or unmanned systems to quickly assess acoustic and visual data simultaneously.

Vector based intensity probes have been proposed with conventional Directional Frequency and Ranging (DiFAR) systems [**1**]**.** AVS have also been used in previous experiments in the tracking of whales in open-ocean [**2, 3**]. For the purposes of this document, the beamforming methods applied in [**2**] will be used with respect to the intensity model for a representative mechanical target meant as a surrogate for fish. Recent advances in piezo-electrics allow for true particle velocity measurement directly through the accelerometer, and a Wilcoxon AVS 205 model is used in place of DiFAR sensors. Many camera systems – in our use case the FujiFilm FinePix XP85 model camera with a 1/2.3" CMOS image sensor recording in 1920 x 1080 60p – can be readily used to generate high quality recordings.

Detection and Sensing of Mines, Explosive Objects, and Obscured Targets XXIII
edited by Steven S. Bishop, Jason C. Isaacs, Proc. of SPIE Vol. 10628, 106280Y
 · doi: 10.1117/12.2302810

II. TEST SETUP

For demonstration, a Seabotix LBV 300 Remote Operated Vehicle (ROV) with a variable drive motor is used. The ROV was operated using two rear thrusters as well as one vertical operated intermittently to maintain depth. The ROV is also equipped with a TrackLink 1500LC acoustic tracking system operating between 31.0-43.2 kHz.

Figure 1: Seabotix LBV 300 Remote Operated Vehicle (ROV). This vehicle was used as a test target for the proposed system.

Figure 2: A Fujifilm 85XP camera system on the left was paired with the Wilcoxon Acoustic Vector Sensor (AVS) model 205 on the right to generate an opto-acoustic data fusion algorithm.

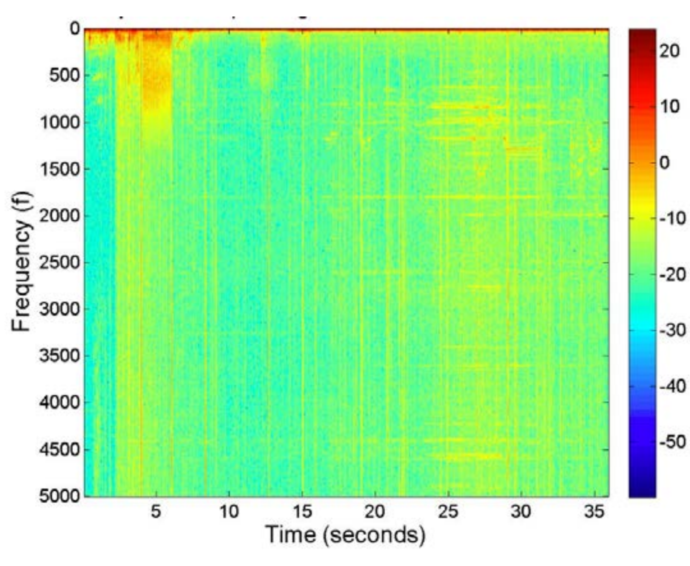

Figure 3: spectral content of the target ROV variable drive outputs. The ROV was placed into the water and driven into position at approximately the 5 second mark. Note variation and gear mesh rates observable in 25 to 30 second window in the 500 to 1500 Hz band of the record. Color mapping is set to $20*\log_{10}(V/Hz)$ dB Re 1μPa.

In water observations show strong gear meshes and variable drive frequencies primarily centered on the 1100 Hz region within several hundred Hertz of bandwidth. Operating on the equations of acoustic intensity as described in [**4**] and applying beamforming methodologies as described in [**3**], the equations for deriving bearing and elevation are as follows:

$$I_{\{x,y,z\}} = \mathrm{Re}\{\frac{1}{2}\hat{p}u^{*}_{\{x,y,z\}}\} \tag{1}$$

Where Intensity (*I*) is the time averaged intensity for a given dimension vector (*x, y, z*) as calibrated relative to the AVS with reference pressure $\hat{p}$,

$$I_{mag} = \sqrt{I_x^2 + I_y^2 + I_z^2} \tag{2}$$

I_{mag} represents the magnitude of the time averaged intensity. Using vector trigonometry,

$$\tau = \arccos(\frac{I_z}{I_{mag}}) \tag{3}$$

τ is derived as the angle of incidence relative to the 0º position of the calibrated sensor in the *z*-axis (depth for the purposes of this paper), and

$$\theta = \arctan(\frac{I_y}{I_{mag} * \sin(\tau)}, \frac{I_x}{I_{mag} * \sin(\tau)}) . \tag{4}$$

Where θ represents the bearing argument relative to the 0º position of the calibrated sensor in the *x* and *y*-axis (latitude and longitude bearing for the purposes of this paper). Taking these relationships into account for a pair of collocated AVS on a registered plane relative to the seafloor and surface, it is possible to derive range, track and speed in the *x, y,* and *z* dimensions as well. The following cartoon depiction describes such a system relative to a source being tracked and how to derive the aforementioned solutions.

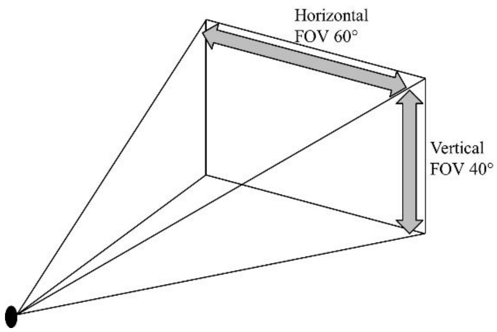

Figure 4: Approximation of the optical field of view captured by the Sony FujiFilm FinePix XP85's image sensor used for this experiment.

The optical output of the Fujifilm camera approximates 60 degrees horizontally and 40 degrees vertically. Approximating omni-directional wavefronts in shallow water as cylindrically spreading plane waves, the operational window for the acousto-optic intensity probe becomes +/- 30 degrees of horizontal acoustic data and +/- 20 degrees of vertical acoustic data from nadir on the calibrated AVS.

III. RESULTS ON FIELD DATA

An example dataset collected at the NOAA NMFS pier in Panama City, FL is considered. The uncalibrated source ROV was driven from an off-sight (out of filtered bearing and elevation readings) position and into general viewing range of the camera. Sources were set approximately 14 feet at a depth of approximately 3 feet from one intensity probe that was situated at 2 feet of depth in 4 feet of water off of the pier. Data is consistently sampled into the time-frequency domain for spectral analysis of the intensity in 1 Hz steps with overlap of +/- 1 Hz starting at 1 Hz and ending at 2500 Hz. The time constants for overlap (similar to a spectrogram) are 0.1 second samples for frequency content analysis with 50% (.05 second) overlap between time slices. Three sub-bands were analyzed, with emphasis on the 400 to 800 Hz region where strong drive frequencies were observed.

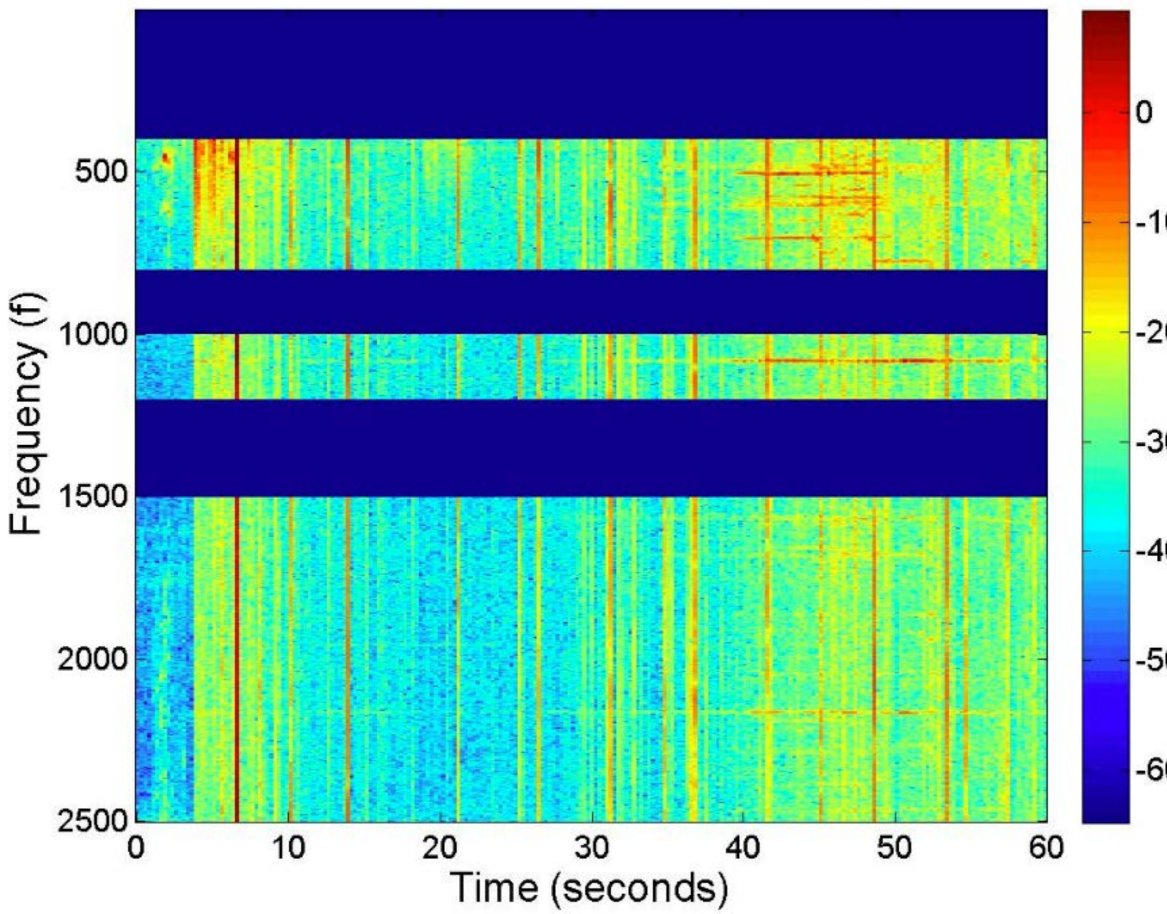

Figure 5: Intensity-gram mapping of the spectrum shown in Figure 1. Color mapping is set to $20*\log_{10}(V/Hz)$ dB Re 1μPa. Frequencies of interest are filtered to show regions of interest for potential sound mapping. Note strong impulses observed as full-band “streaks” are the acoustic transponder on the ROV.

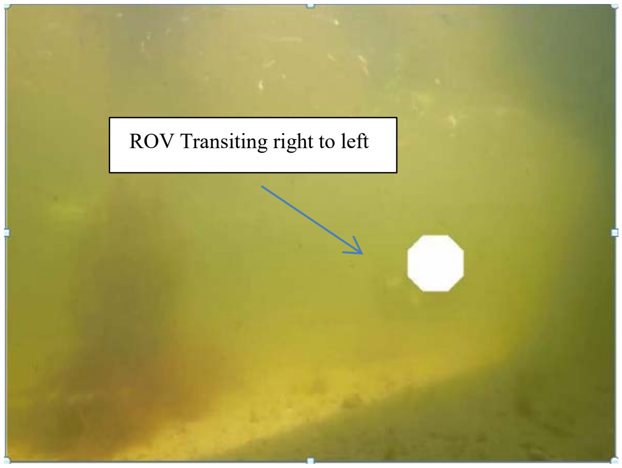

Figure 6: Example Screen grab from the fused opto-acoustic probe output. Note large octagon placed to denote strong bearing elevation readings of the mixed regions in the vicinity of the ROV's rear thrusters for the band-limited intensity measurements at Time 23 seconds. The ROV is visible just to the bottom left of the intensity marker.

The resulting outputs were developed using Matlab software routines generated for this experiment. To co-register the imagery with the intensity measurements, the optical output pixels were allocated to sub-degree markings from nadir in each video frame, and each acoustic vector reading was subsequently registered to a pixel. The white octagon was used as an equally weighted marker for the three sub-bands noted, with peak intensity measurements used as source position estimates and grouped to form a centroid about which the octagon marker was placed.

IV. SUMMARY

Development of the opto-acoustic intensity probe for detection, classification and localization of various fish species presents opportunities for acousticians to more accurately determine real fish population sizes and observe very precisely where the output of individual animals is occurring. The ability to transition from a statistics-based estimate of the rough order of magnitude of the biomass to a discrete estimate of each fish vocalizations' point of origin and species could greatly enhance the ability of fisheries and military interests to assess environmental impacts. The ability to paint spatial features of the acoustic work of a source as defined by the intensity suggests that undersea intensity probes coupled with optical cameras are feasible.

ACKNOWLEDGEMENT

The authors would like to thank Dr. Robert Barton of Naval Undersea Warfare Center Newport (DIVNPT) for his support in developing beamforming methods for the AVS and Dr. Gerald D'Spain for the AVS equipment used in this experiment.

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