Introduction

Shallow water environments inherently contained variable oceanographic zones where human interaction due to commerce, fishing, and transportation reasons have been increasing steadily. These zones are important for many reasons such as commerce, fishing, and oil, but they are also environmentally very sensitive and fragile. Coastal oceans are also important regions because of high biological production due to strong freshwater-seawater mixing that nourishes marine life. Littoral waters, coastal zones, and estuaries, and rivers are also transition zones between freshwater and seawater, and the interaction between two water bodies and the tidal dynamics can significantly impact underwater acoustic transmissions. Therefore, these environments deserve long-term monitoring and protection for ecosystem health and sustainability. Advance technologies such as robotics need a thorough understanding of the oceanography and acoustics techniques can provide that. These techniques can be used in variety of ways, such and survey, communication for command and control, and to retrieve collected in-situ data. However, in shallow waters sound propagation has complicated multipath structure, and environmental variability due to coastal processes makes the acoustic problem more complicated. Currently, a few acoustic studies have explored these regions, and future practical underwater applications call for more detail investigations into environmental variability in these particular regions.

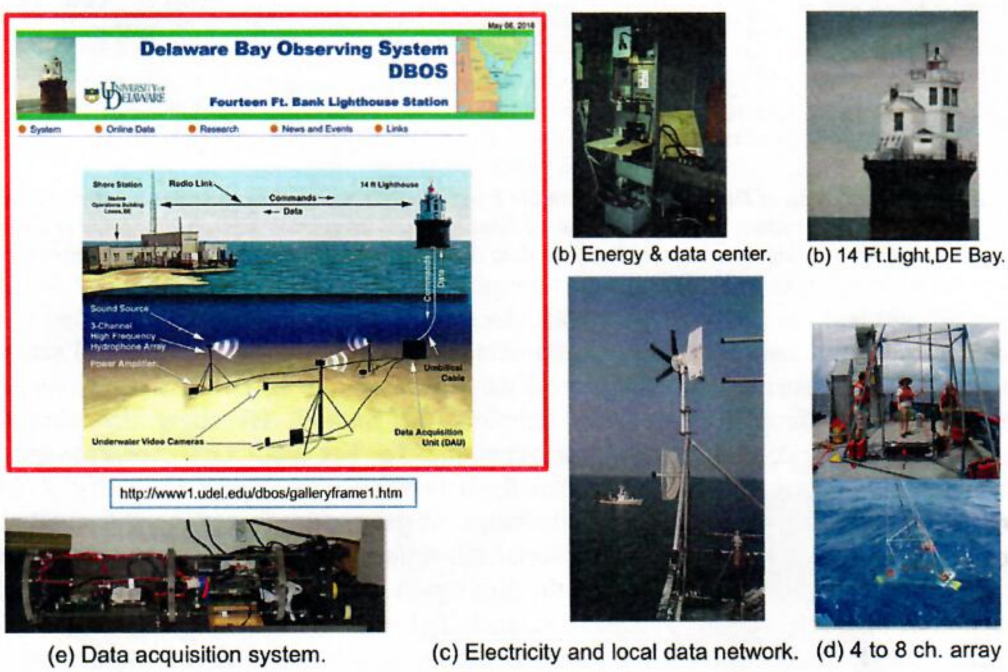


Figure 1. Overview of High Frequency Acoustic experiment 1997-2000 and formation of Delaware Bay Observing System (DBOS). (a) design and fabricated Data Acquisition system, (b) Energy and data center inside Fourteen Ft. Light house, (c) 14 Ft. Light house inside DE Bay, (c) Wind powered electricity generator and data transfer antenna to Lewes, DE, (d) Acoustic tripod equipped with 4 (or 8) element vertical line array.

Background

In late 1990's Ocean Acoustics Laboratory at the University of Delaware launched a research program to study the environment during low intensity acoustic signal propagation in a relatively controlled environment where detectible changes of the environment could be measured and quantified. The system was called Delaware Bay Observing System (DBOS) [1,2].

These experiments were conducted for few weeks at a time starting from summer of 1997 through the end of 2000. During this period, a thorough understanding of the physical oceanography of the Bay and the ecological aspects of fish and soundscape provided a rich experience enhancing acoustical oceanography and underwater communications at University of Delaware.

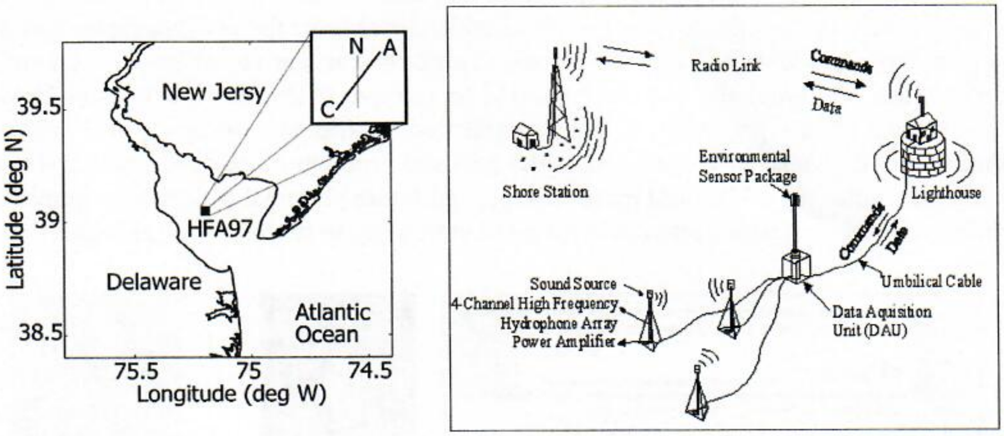


Figure 2. (left) Map of DE Bay estuary with the location of HFA experiments in center. A and C are source receiver locations. (right) Schematic of three acoustic transceiver tripods connected to the 14 Ft. Lighthouse during operation. Subsurface data acquisition system and environmental sensors are also shown.

Figure 2 shows the location of these experiments and the schematic of the tripod setup for the reciprocal acoustic transmissions. In Figure 3 we show a sample data set collected over one week period from 9/23 through 9/28/1997. Subplots (a) through (f) show the environmental measurement in water column as a function of geotime Tg. The subplot (g) shows the arrival of an acoustic pulse that was transmitted repeatedly between points A and C in Fig. 2 while the environment was going through substantial change. Surface winds mixed the upper water column while the ebb and flood tides pumped the ocean salt water inside the Bay. Acoustic transmissions went through substantial changes, in fact, the direct path between source and receiver suffered 20 dB loss at some specific periods of geotime, such Tg1 and Tg2 shown in Fig. 3(g). Analysis of these data reveals direct interaction between the broadband acoustic signal and the environment caused by tidal straining and the shear flow that occurs between ebb and flood periods causing the sound speed profile to refract the bottom bounce signal to switch from reflection to refraction mode and hence causing a shadow zone near the bottom where the acoustic signal suffers a major intensity drop. This is due to tidal straining and that occurs between ebb and flood tides causing the sound speed profile to become upward refracting hence creating a shadow zone near the bottom where salty water arrives from the open ocean. During a few hours per day, the salt water intrusion into the estuary caused this condition and hence a major shift in the values of the direct path. There is about 20 dB difference in the value of direct path between these two geotimes.

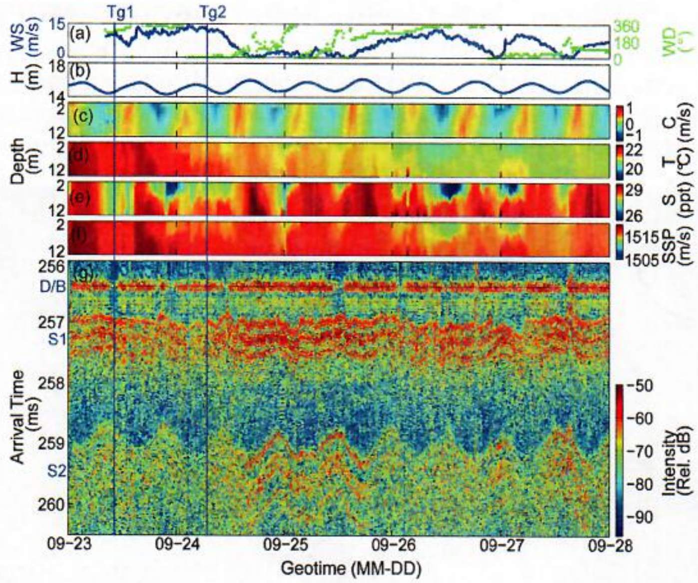


Figure 3. (a) Wind speed (blue) and wind direction (green); (b) tide height; (c) current profile along the acoustic track; (d) salinity profile; (e) temperature profile; (f) sound speed profile, (g) channel impulse response as a function of geotime showing arrival of pulse from point A to C (Fig. 3) from 9/23 through 9/28/1997.The responses at Tg1 and Tg2 show two different periods that direct acoustic path from source to receiver suffers 20 dB loss.

In Figure 4. We show more detailed channel response function for Tg1 and Tg2 geotimes. Where the direct path and its vanishing behavior is clearly shown for the ebb and flood tide cycles.

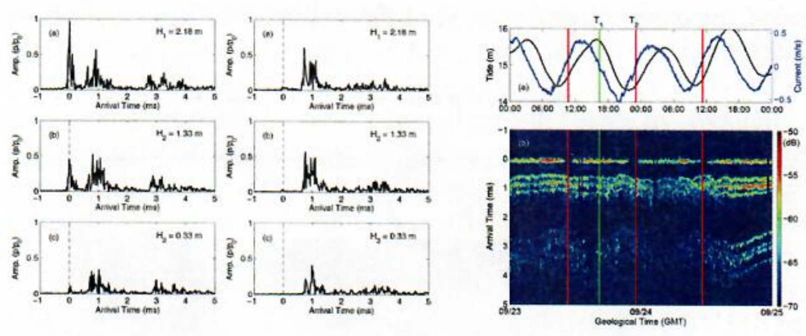


Figure 4. (left) Channel impulse response function at T1 and T2 showing major drop in amplitude of signal in T2 where the surface bounced paths are not showing a big change.

During the High Frequency Acoustic, HFA97 and HFA2000 experiments it was also mandated by the State of New Jersey to place "real-time" camera monitoring for fish activities during the sound transmissions. The movies obtained during the experiment showed the fish were not affected during the transmission of acoustic signals. Figure 5. shows a frame of one of the videos recorded during the HFA2000 experiment. In this video, the sound projector transmits chirp signals at specified intervals at a source level of about 160 dB re 1 μ PA and shows clearly that fish are not affected by the sound transmission (Videos are available for discussion upon request). These data have provided a chance to revisit the idea of using sound and video together to conduct in-situ analysis of fish hearing and behavior.

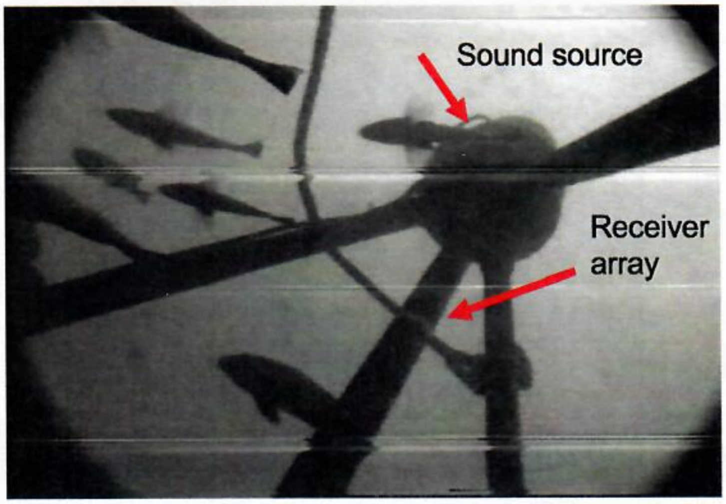


Figure. 5. A frame of a movie recorded during transmission of chirp signals in HFA2000 experiment showing fish does not get affected by the sound transmissions [movie is available upon request].

Figure 6. shows the recorded sound using a passive recorder in Delaware Bay in 2014. Although no video camera was used in passive recording during 2014 experiment, the recorded sound could be identified as Croaker fish and a loud Cusk Eel that appears after around 7 seconds in Figure 6. Now, combined and simultaneous underwater sound and video recordings can be made in high resolution to study the behavior of fish in their natural habitats while the oceanography and the sound scape is changing.

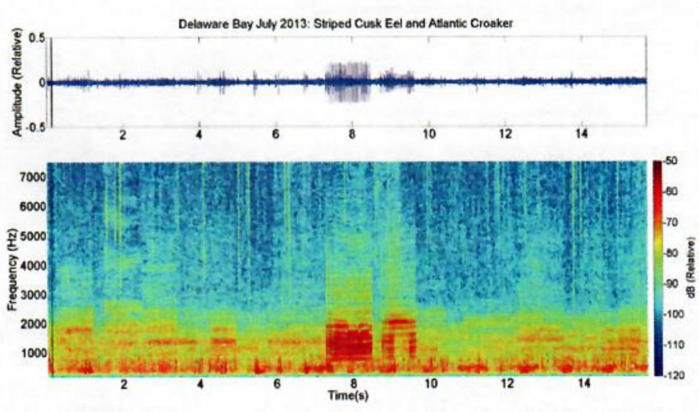


Figure 6. Measured sound in Delaware Bay in 2014 showing Cusk eel and croaker sounds in the background of many other sounds.

Recently it was shown by Pepper and Hawkins that fish mechanism of hear is beyond using the sound pressure and it related to the particle motion [3]. Figure 7 is copied exactly from Reference [3] by Popper and Hawkins showing possible ways that the sound and vibration may contaminate the soundscape and could affect the marine life.

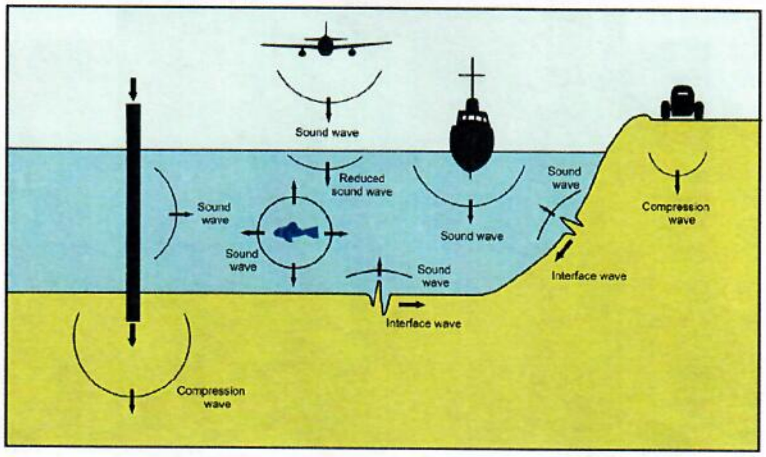


FIG.7. (Color online) Sounds may be generated in water by natural and human sources located at different positions. The sources may include pile drivers, marine animals, aircraft, ships, and vehicles on adjacent land. The ratio of sound pressure to particle motion may vary greatly depending on the source and its location, the depth, and the distance from the source. Copy of Figure by Anthony D. Hawkins, in JASA paper "Popper and Hawkins, J. Acoust. Soc. Am. 143 (1), page 470, January 2018.

Technical Approach

We propose to fabricate a system to record underwater sound and vibration of the soundscape and simultaneous video of the objects in the near field. This system will work for shallow water, littoral waters, estuarine environment, and rivers. We propose to use state of the art instrumentation that exist today. These instrumentations include, a) sound pressure using hydrophones, b) fluid particle motion in three access using a vector sensor, c) seabed particle acceleration measurements using three axis accelerometers, and d) videos similar to what we have recorded during the HFA97 and HFA2000 experiments [2]. We wish to simultaneously study marine life behavior in their natural habitats. In addition to passive recording of the above parameters, we will equip this instruments with a programmable sound source that can transmit variety of sound signals to accurately control and generate sound and use it in a controlled experimental setting. While the passive and active recordings are being conducted, we record all the environmental parameters, including temperature and salinity profiles at each measurement position, the current profile, and surface waves using an existing wave rider buoy in our laboratory.

This system will be placed on a bottom lander plate with small penetrable cone shape tip that can go into soft seafloor sediments. A prototype model of this package would look like the unit displayed in Figure 8. In this figure, a seismometer sensor placed on the bottom plate records the vibration of the seafloor while the vector sensor in the center of the tripod measures the particle motion in the water column. The reference hydrophone in yellow cover (to reduce drag induced noise and an underwater camera with extended battery life and disk space will be mounted on the base in looking up position.

Figure 8. Tripod configuration housing instruments a) through e) using G4 data acquisition system.

Vector sensor

The Acoustic Vector Sensor is capable of measuring acoustic particle velocity as well as pressure at a single point in space. It has advantages for source localization problems compared with the standard pressure sensor arrays. Our goal is to use three of these vector sensors in three tripod configurations to study the partitioning of energy between the water column and the seafloor and the energy that is coupled into water where fish are able to feel. These are done while the fish will be filmed using a long-term video capability that we will develop into the design. Series of experiments will be proposed once the equipment is designed and fabricated. Two hydrophones will be placed inside the tripod above the seafloor to measure the reference sound pressure level.

Billboard array to localize fish position and record backscattered signal

In addition to the sound, vibration, high resolution video recording and particle motion measurements we propose to use the concept of "Acoustic Camera" to localize on the fish position while they are in their natural habitat. We are also planning to use active source, to obtain high resolution back scattered signal from fish in near range. The concept of acoustic camera for visualization of sound sources has become widespread in the industrial settings of sound and vibration measurements. Figure 9 shows an example of localizing the source position in air using a billboard type array in air. We propose to use the same concept using a 28 or 64 element hydrophone billboard array laying horizontally on the base of the tripod with aforementioned instrumentation to provide a recording device and an "Acoustic Camera" to record images similar to what is shown in Figure 5 from the bottom of tripod looking up into the water column.

Figure 9. Acoustic camera in air showing localization of a sound transmitted by a person standing a few feet from the billboard array in vertical plane. Picture taken during the Acoustical Society meeting in May 2018.

Minimum redundancy array design

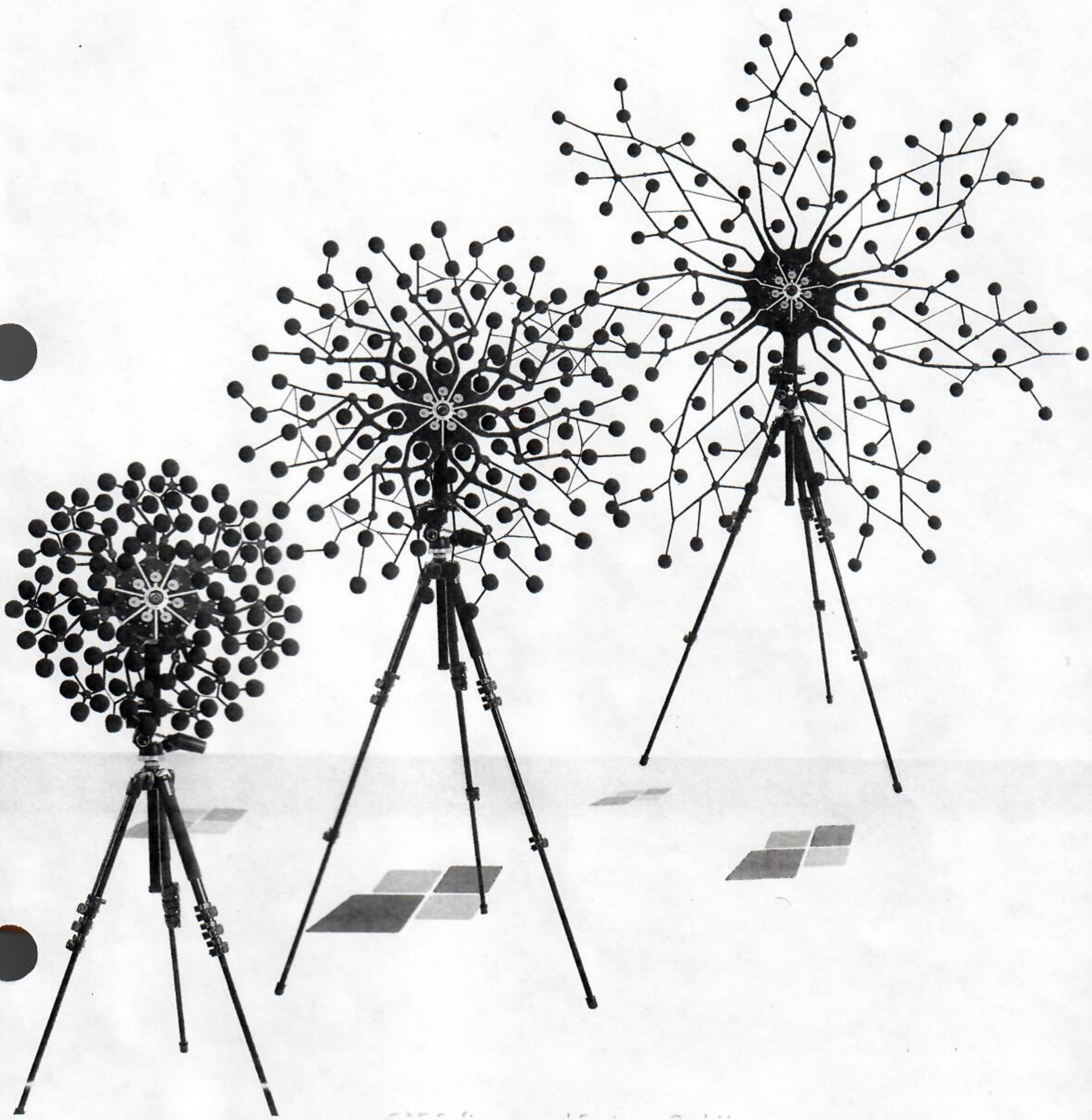
We will use the concept of minimum redundancy array design to conclude the task of monitoring and recording fish sounds simultaneously. The concept of minimum redundancy arrays is one of the most important types of multi-element antennas, that has played an important role in communications and in radio astronomy. Here we propose to use the similar concept in underwater acoustics in order to beamform and localize the source of a generated sound using the spatial diversity and enhancing the signal to noise ratio by elimination noise. The problem of interest is mainly concerned with spatial resolution and aliasing of signals where feeding many elements of the array with tapering the illumination of the aperture to obtain a desired beam shape or degree of side lobe suppression.

Educational benefits to US Navy

Ocean Acoustics laboratory at the University of Delaware has contributed to the Naval needs by educating and producing working members of the operation science and technology in the Navy and other ocean science agencies (e.g. Dr. J. Senne at NAVOCENO, Robert Heitsenrather, NOAA). We are also working closely with educators at the U.S. Naval Academy (USNA) (e.g. Prof. Joe Smith). There exists a MOU for educational collaboration between UD and USNA. We will be involving USNA faculty and midshipmen in field and/or analysis work of this proposal. Furthermore, PI will contribute to USNA teaching as guest lecturer in the spring of 2015. This exposure serves as a first step towards collaboration in both teaching and research to train and mentor the next generation of engineers and scientists in both civilian and military sectors at UD and USNA.

Noise Inspector

Innovation leader in acoustic cameras

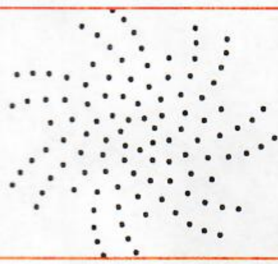


Array Technology - The Key for good Results

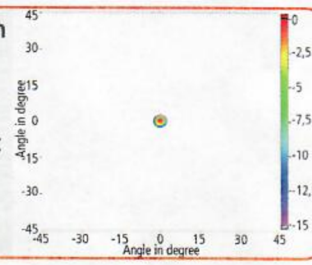
Because the influence of the array designs is that significant, we created a portfolio of good microphone distributions (see below). Furthermore it is absolutly possible to create customized array designs to fulfill the customers needs.

Our array designs

Bionic L-112 Array
Microphones: 112
Diameter: 1.7 m

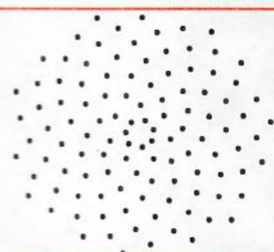


Beampattern
-3dB width: ±1.33044 °
max side lobe: -15.4284 dB

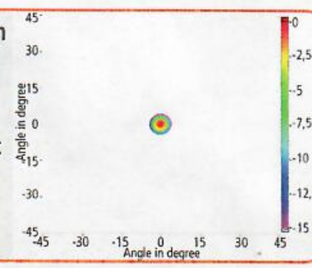


Simulation at 5 kHz

Bionic M-112 Array
Microphones: 112
Diameter: 1 m

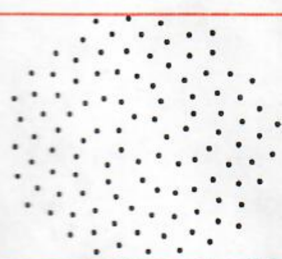


Beampattern
-3dB width: ±2.13321 °
max side lobe: -21.7749 dB

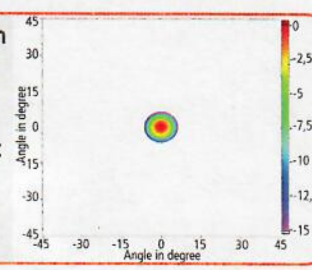


Simulation at 5 kHz

Bionic S-112 Array
Microphones: 112
Diameter: 0.6 m

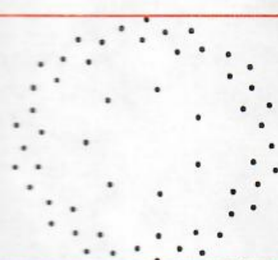


Beampattern
-3dB width: ±3.30846 °
max side lobe: -16.2920 dB

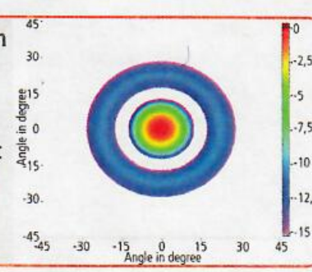


Simulation at 5 kHz

Bionic XS-56 Array
Microphones: 56
Diameter: 0.27 m



Beampattern
-3dB width: ± 6.6501 °
max side lobe: - 10.4825 dB



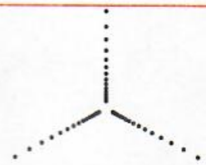
Simulation at 5 kHz

Common Arrays

The array design is an important physical property to deliver very high resolution results. Therefore we put a lot of engineering know-how into the shape of the arrays. Standard designs give results with poor resolution and/or poor dynamic range.

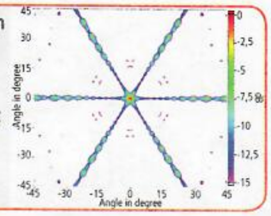
Common array designs

Star Array
Microphones:
48
Diameter:
1.6 m

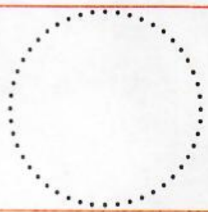


Beampattern
-3dB width:
±1.07414 °
max side lobe:
-5.53551 dB

Simulation at 5 kHz

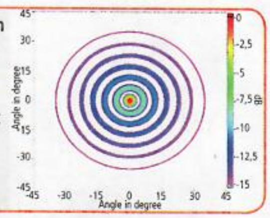


Ring Array
Microphones:
48
Diameter:
0.75 m

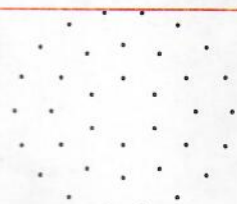


Beampattern
-3dB width:
±1.92012 °
max side lobe:
-7.89909 dB

Simulation at 5 kHz

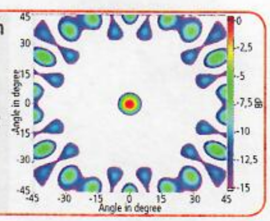


Concentric ring Array
Microphones:
36
Diameter:
0.6 m



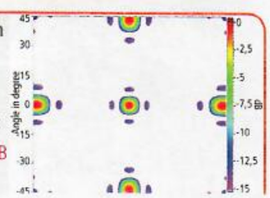
Beampattern
-3dB width:
±2.96055 °
max side lobe:
-5.49043 dB

Simulation at 5 kHz



Chess Array
Microphones:
49
Diameter:
0.6 m

Beampattern
-3dB width:
±2.59681 °
max side lobe:
-0.0001821 dB

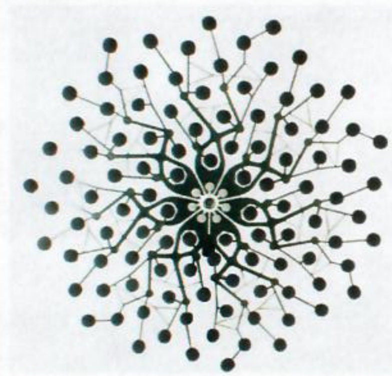


Product Finder - Acoustic Imaging

	SoundCam	Bionic XS	Bionic S	Bionic M	Bionic L	Wind-Array	Intensity Array	Acoustic Compass	3D
Measurement in Far Field	X	X	X	X	X	X		X	X
Microphones	62	112	112	112	112	40	40	8	112 - 448
Array Width (m)	0.3	0.47	0.6	1.0	1.7	5.0			
Frequency range from (Hz)	900	800	400	250	150	50	40	40	
Nearfield Holography (from 40 Hz)			X	X					
Surface scanner (Intensity)							X	X	
Expandable to different sizes		X	X	X	X				X
Handheld device with real-time localization	X	X	X	X				X	

3D Systems

SoundCam



Bionic Systerms XS, S, M & L

Acoustic Intensity Systems

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SOUNDCAM

The First Handheld Sound Camera for Everyone

What is SOUNDCAM?

SOUNDCAM is the first camera that images sound and is affordable for everyone. The system is intuitive and as easy to use as a smartphone. SOUNDCAM locates sound sources in realtime and immediately displays the results on the screen.

Human beings best process information in a visual way. SOUNDCAM visualizes complex acoustic information and creates a connection between hearing and seeing. Analyzing and understanding sound has never been easier!

Hardware

Physical Properties	Dimensions	34 x 34 x 9.5 cm (13.4 x 13.4 x 3.8 inch)
	Weight	appox. 3 kg (7 lb)
	Waterproof	IP54
	Anti-theft system	Kensington lock
	Battery life	min 2.5 h
	Tripod socket	1/4 inch
	Buttons	4 + power on/off
	Base	4 rubber nubs
	Temperature range	-40°C to +60°C (-40°F to 140°F)
Display	Size	7 inch / 15.5 x 8.6 cm
	Resolution	800x480
	Touch	10 finger capacitive touch
Embedded Controller	Processor	ARM A53 4x1.2 GHz
	RAM	1 GB
	OS	Linux for ARM
Interfaces	USB	for data export or keyboard/mouse
	Ethernet	LAN (for running software on laptop/PC)
	Audio	3.5 mm for headphones, etc.
Sensors	Microphones	64 digital MEMS
	Frequency range	10 Hz - 24 kHz
	Sound pressure	max. 120 dB
	Sample rate	48 kHz
	Resolution	24 bit
Optical Camera	Type	digital
	Resolution	320x240 (50fps) or 640x480 (16fps)
	Lighting	4 LEDs
	Aperture angle	± 38°
	Shutter	global shutter
Power	Supply	power adapter
	Battery	Li-ion battery
	Power Path Management	work and charge simultaneously (charger + PPM is integrated; no external charger unit necessary)

Software features

OS	Linux (Windows software also available)
HMI	Touchscreen or mouse and keyboard, Headphone
Online Performance	Up to 100 acoustic fps, up to 50 optical fps
	Acoustic pictures, optical pictures, sonogram and spectrum
	Listen to local sound
	Place marker while measuring
	Recording 10s./30s./60s. buffer or manual
Offline Features	Offline mode for analysis
	View acoustic results picture by picture
	Save and reload
	Replay
	Listen to local sound
Export	mp4 (video)
	wav (sound)
	jpg (picture)
Intuitive Usability	Distance settings
	Frequency filter
	Dynamic filter
	Different scaling modes (off, auto and smart)

It is now your turn to analyse sound and make the world a calmer, better place.

CAE Software & Systems

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