UPAL: Underwater Passive Aquatic Listener

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***Abstract*—Underwater ambient sound contains quantifiable information about the sound source. In the frequency band from 500 Hz to 50 kHz, dominant geophysical sources of underwater sound include the sound of breaking waves and rainfall. Other sound sources in the marine environment include: (1) geophysical sources such as earthquakes and volcanoes, (2) biological sources such as cetaceans, pinnipeds, fish and crustaceans, and (3) anthropogenic noises such as shipping, industrial noise and sonar. In this paper, we address the design and development of a low-duty cycle underwater passive aquatic listener (UPAL) sensor to monitor the ambient noise in marine environments. This sensor can also detect acoustic events such as rain storms, passing ships and marine animals. Further, the UPAL sensor includes real-time classification and quantification of the observed sound sources. Data from real experiments will be presented.**

***Index Terms*—Underwater Acoustic Measurements, Passive Acoustics, Underwater observations**

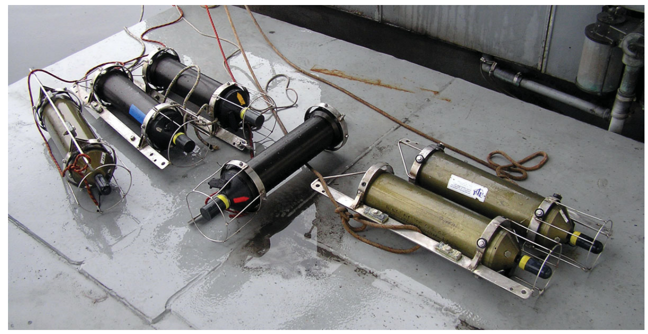

Figure 1: Predeployment of a series of UPALs

I. Introduction

The Earth's oceans provide vital resources for life on our planet. Monitoring our oceans for anthropogenic disturbances, pollution, marine life, climate change and severe weather events have been a cornerstone of learning more about our planet. One such monitoring effort involves the use of passive acoustic systems to record underwater sound events and ambient noise. These sound events can be grouped into four categories: meteorological, biological, geological and anthropogenic. Examples of sound sources could be wind-induced breaking waves, rainfall, earthquakes, underwater volcanoes, ice cracking, pinnipeds, cetaceans, ships and sonar.

Ambient underwater noise is a combination of man-made and natural sounds. Underwater sounds can be used to monitor and quantify various events such as natural processes (rainfall and wind speed), marine life that produces sound to communicate, breed or hunt, and human activities such shipping, offshore construction/operations and seismic exploration [1]–[4]. In order to understand ambient sound it is required to identify a particular source and measure the sound levels and durations associated with the sound source. This information can then be used to obtain geophysical measurements such as wind and rainfall from storms, detect and identify specific animal populations and activities and the learn about the impact of anthropogenic activities, such as who or what is producing the sound?, how loud is the sound? and is there any impact on the natural environment?

In this paper, we will introduce an underwater passive aquatic listening system known as UPAL. The UPAL system is designed to continuously acquire sound using a smart adaptive sampling strategy, classify this sound in real-time using a multi-source classification algorithm and then quantify the sound source. Due to the adaptive sampling and low-power sleep mode, UPAL can operate underwater for up to a year. UPAL data can be used to generate sound budgets for the area of observation. Such a system requires rigorous validation and improvements to the classification algorithm for smart detection and categorization of the ambient sound into multiple sources. We will present acquired data from the UPAL system as well as validation of its classifications and quantification through the use of measurements from anemometers and precipitation radar.

The rest of this paper is organized as follows. Section II outlines the related work. Section III presents the UPAL system and its hardware and software modules. Section IV discusses experimental results gathered from the UPAL system and validations. In Section V we discuss future capabilities of the UPAL sensor and in Section VI we conclude the paper.

II. Related Work

Passive acoustic systems, also known as acoustic recorders, have been an integral part of ocean monitoring activities and are not a new concept. Generally, acoustic recorders have been developed by individual research groups for their own unique needs and therefore many variations of such instrument exist. Traditionally an acoustic recorder is defined as any electronic recording system or device that acquires and stores acoustic data. Often times these devices are deployed underwater for

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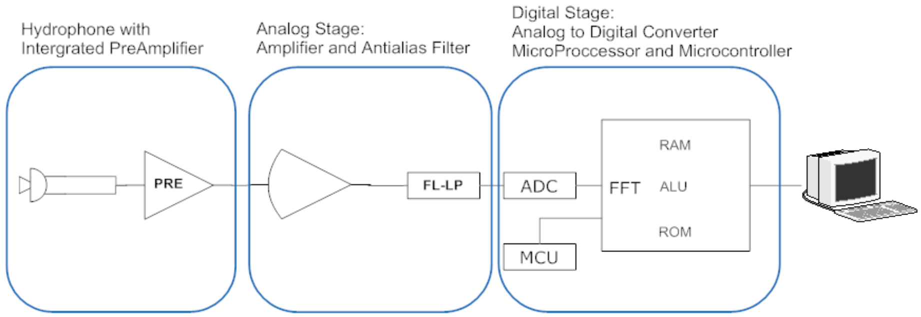

Figure 2: Block diagram of UPAL electronics

a time period of a few days to months and left unattended to record environmental sound. Once the device is recovered, the data is then processed and analyzed.

Since passive acoustic systems are not a new idea, many existing instruments exist. The work in [5] provides an inventory of autonomous recorders generated from a study conducted between 2009 and 2013. Over 40 instruments were found for recording marine mammal activities.

In addition to marine mammal activities, underwater acoustic systems have also focused on the near-real-time monitoring of natural hazards (earthquakes and volcano eruptions). Current work in these areas include the ALOHA observatory system, operated by the University of Hawai'i [6], the Perennial Acoustic Observatory in the Antarctic Ocean (PALAOA), operated by the Alfred Wegener Institute of Germany [7] and the passive acoustic system of the Integrated Marine Observing System (IMOS), lead by the University of Tasmania on behalf of the Australian marine and climate science community [8].

The difference between existing passive acoustic systems and the UPAL system being presented in this paper is that, to the best of our knowledge, the UPAL system is the only acoustic recording system that provides smart adaptive sampling and real-time classification of sound events.

III. UPAL System

The UPAL is an autonomous underwater acoustic system that can be attached to any ocean mooring, deployed as a stand alone system or integrated into other underwater systems. A real-time embedded operating and signal processing software runs on its microprocessor to detect and interpret the sound spectra and then provide sound classification and estimation of environmental (wind speed, rain rates and type, sea roughness), anthropogenic (ships, sonar) and biological (marine mammals) parameters.

A. Hardware

The UPAL instrument itself is cylindrical measuring roughly 80 cm long $\times$ 15 cm in diameter and weighs about 5kg in the water. A prototype of the UPAL sensor can be seen in Figure 3. The UPAL instrument consists of a broadband, low-noise hydrophone, a low-power microprocessor with a 100-kHz analog-to-digital (A/D) digitizer, a memory card for internal storage and a battery pack. The microprocessor contains a very low-power "sleep" mode that allows the instrument to save energy between acoustic samples, allowing for autonomous deployment for up to one year. A block diagram of the internal electronics can be seen in Figure 2.

Figure 3: UPAL Sensor

B. Sampling Strategy

The UPAL instrument is an acoustic recorder instrument designed to record data for up to one year at sea. A single data sample consists of a 4.5 second time series collected at 100 kHz. Once a data sample is recorded, it is spectrally processed to obtain a 64-frequency bin spectrum. These spectra are then evaluated individually to determine the acoustic source and stored in the instrument. In order to achieve long-term deployments, the UPAL instrument is designed to enter a sleep mode between data collections. The time period for sleep mode is variable and typically set to 5-10 minutes. The sleep

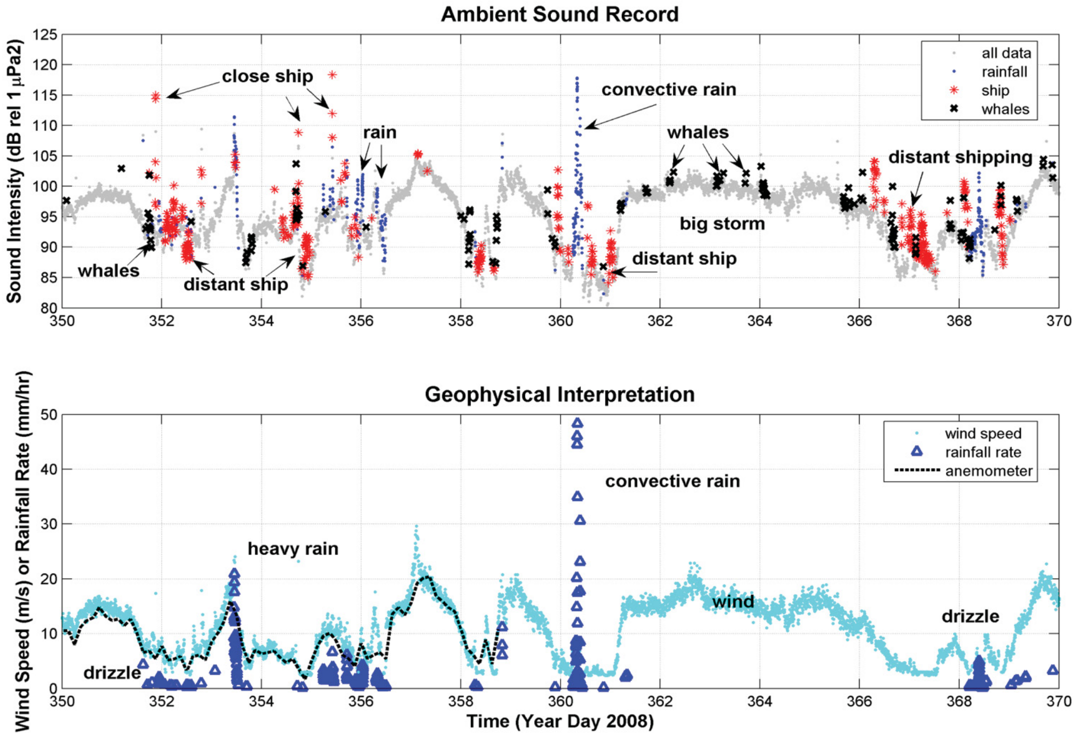

Figure 4: Ambient Sound Record and Geophysical Interpretation (from Nystuen et al. 2014)

mode interval can also be set for specific detections since the instrument is capable to distinguish sound sources through use of a detection algorithm. For example, if a researcher was only concerned with observing specific marine life, the time period could be set much shorter if it detects the acoustic source of interest. Otherwise, it would continue its normal sleep mode interval.

C. Capabilities

The UPAL sensor can be used for a variety of applications. *Climate data*: rainfall and wind speed are critical climatic variables that define atmosphere-ocean interactions and can be quantified by the UPAL sensor. *Marine mammals*: monitoring of marine mammal movements, communications, feeding process and impact from anthropogenic sounds. *Real-time operations*: monitoring of oceanic conditions (winds, precipitation, sea roughness) for off-shore platforms and industry stakeholders. *Sound budgets*: ambient noise pollution is one of the essential physical variables affecting the marine environment and ecosystem, mainly caused from excess human activities. Ambient noise levels during normal periods of the environment could be derived and used as a baseline for policy development of efficient environmental protection from anthropogenic impacts, coupled with the sustainable and effective exploitation of marine resources.

IV. Experimental Analysis

In this section we will discuss some previously recorded data from the UPAL sensor. For more complete discussion of experimental results from past deployments we refer the reader to [1], [9], [10], [12], [13].

First, we show a sample time series plot taken by the UPAL sensor [9] in Figure 4 . This time series was taken from a deployment in the northern Aegean Sea over a period of 20-days. Acoustic events detected over this time period include rainstorms (blue dots), ship passages (red stars) and whale vocalizations (black x). As some users require geophysical interpretation of the recordings, classification includes detection and removal of select noises, such as ships, and finally quantification of the physical process producing the sound. After day 358, the surface anemometer on the associated mooring failed but wind speed measurement via acoustics continued throughout the deployment.

Second, we show an example of multiple signal classifications in the frequency spectrum in Figure 5. We can observe 4 different acoustic sources in this data. There are high winds (8 m/s) that are preceding a frontal rain system, six ship passages, light rain at minutes 620-650, heavy rain from minutes 785-1000 with a strong convective cell at minute 880-900 and winds diminishing from minutes 1000-1440. Additionally, on the biological side, we can observe that whales were detected in minute 200, 950 and 1350.

V. Future Capabilities

In this section, we briefly discuss some future capabilities of the UPAL sensor.

A. Sound Budgets

The UPAL sensor is capable of obtaining sound levels, sound sources, geophysical interpretation, biological monitoring and noise pollution monitoring making it a powerful sensor. Using such information, the UPAL sensor can be used

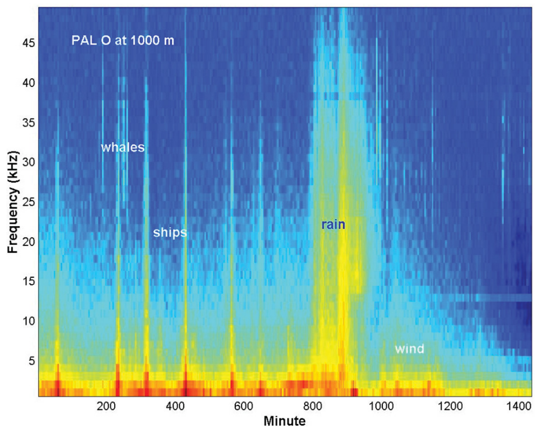

Figure 5: Multiple Signal Classifications (from Anagnostou et al. 2008)

to derive sound budgets for areas of interest and support the implementation of maritime policies particularly those relating to underwater sound pollution. Ambient noise pollution is one of the essential physical variables affecting the marine environment and ecosystem mainly caused from excess human activities. Policy decisions for the marine environment are driven by data needs with the scope of efficient protection from anthropogenic impacts, coupled with the sustainable and effective exploitation of marine resources. The UPAL sensor could be used to help develop sound budgets for normal environmental activities and then used to compare against the sound budgets for increased or additive environmental activities.

B. Underwater Wireless Networks

Underwater Wireless Networks (UWNs) are interconnected systems composed of various sensors, vehicles and devices covering large spatial areas of aquatic environments [11]. UWNs are often used for monitoring and data acquisition tasks and linked together using acoustic signals for communication and networking tasks. A series of UPAL sensors deployed in a large spatial area could be linked together using UWNs and real-time messages of detection and quantification could be sent to a base station. UWNs with active UPAL sensors has the potential to open up a variety of applications given the ability to accurately detect and classify acoustic signals. This could improve the tracking of marine life, meteorological events or anthropogenic events, such as submarines or off-shore operations.

VI. Conclusion

In this paper we have presented an underwater passive aquatic listener (UPAL) sensor. The UPAL sensor is capable of detecting underwater sound events and then classifying and quantifying each sound source. The sensor can be used for a variety of applications such as studying atmosphere-ocean interactions, marine mammal behavior and generating sound budgets for policy development and environmental protection. We have discussed the hardware and software design of the sensor and presented real experimental results recorded by the system. The sensor can be integrated into a variety of buoy systems or used as a stand alone system. In the future we wish to pair this sensor with an active communication system to make a network of monitoring sensors.

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