On the importance of measurement system calibration for underwater passive monitoring

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Abstract. The underwater passive acoustic monitoring of sound in oceans is growing in recent years and has served as a source of information on marine life and the interference of human activities on the environment. The recordings are used for species identification and prevention of potential adverse effects of vessel traffic, sonar and offshore activities as a whole. However, not much attention is given to the calibration of the hydrophone used to ensure the validity of the information collected. The resulting sound depends on the input audio, and the transfer function of the intensity of the input signal. This paper presents an assessment of how the lack of calibration of hydroacoustic systems might compromise the evaluation of the marine environment.

1. Introduction

Hydroacoustic, also known as underwater acoustics, studies the sound behavior in water and the influence of the environment on its propagation. A high quality hydroacoustic system is essential for a sound recording, and it can be used for evaluation purposes. Many echo sounders and depth probes are commercially available, but few have the desired quality for scientific and quantitative collection of acoustic data.

Currently there are few standards published in the field of underwater acoustics, such as [1,2,3], and some are being developed within the ISO (International Organization for Standardization) and IEC (International Electrotechnical Commission). This demonstrates how there is a growing concern about the quality of the performed measurements and the requirement of compliance with rules for possible use in regulatory measurement purposes.

The hydroacoustic systems should have stable electronic characteristics and are designed to maintain constant its inherent sensitivity properties, acoustic beam pattern, and transmission power, through a variety of conditions and for a prolonged period. This stability allows the system, once calibrated, to collect quantitative observations, including the repeatability within acceptable error limits. This paper presents and discusses some implications of metrology in the quality of the data used to assess the marine environment through the acoustic monitoring.

2. Acoustic monitoring

The acoustic monitoring is increasing by the scientific community to research marine mammals, especially cetaceans (whales, dolphins, etc.), many of which are easier to hear than to see. The
acoustic monitoring is also used to support efforts to mitigate potential negative effects of human activities such as ship traffic, sonar and offshore. Most cetaceans produce sounds regularly, making the use of hydrophones (underwater microphones) to detect and monitor the presence of marine mammals by the sound they emit, or its "vocalization".

An important step in acoustic monitoring is the classification or the process of determining which species are making sounds. For its realization, it is necessary to know the vocalizations characteristics of the target species. Although the vocalizations of some cetaceans such as sperm whales and humpback whales are already well described, this is not the case for many other species of marine mammals. Many researchers are actively involved in the development of new techniques to improve the classification of animal sounds, plus the development of a marine audio library of sounds.

Currently there are three approaches to hydroacoustic detection system [4]:

2.1. **Passive acoustic monitoring**
In this approach a hydrophone monitors vocalizations or signals emitted by marine wildlife. This system does not allow the precise determination of the distance from the signal source and also has ambiguity in determining the direction of the source, i.e., you cannot determine which side comes the sign.

2.2. **Active acoustic monitoring**
In this case a focused pulse sonar "ping" is transmitted in the water and the system waits for a return signal when it finds a target. This system is used to locate schools, and military case, underwater targets. As it depends on a sound beam area that is covered at one time is small. In addition, the probe itself can cause environmental effects, albeit at a low level.

2.3. **Daylight acoustic monitoring**
This sonar class is new and based on the detection of existing background noise being scattered from an object. Have significant potential advantages, including wide area coverage, does not require acoustic emission and the ability to also act as passive sonar. However, it is the "cutting edge" technology and the limits of feasibility.

3. **Electric transduction**
The function of the hydrophone acoustic monitoring is transduction of cetacean’s vocalization to electrical signals that can be recorded and analyzed. The main differences between a general measurement hydrophone and other special purpose are the characteristics of sensitivity and frequency response. Having a high sensitivity over a wide frequency range is desirable in transducers.

The hydrophone calibration consists in determining the system output (Volt) into a constant and known beep (Pascal). This ratio usually employed in the analysis of analog electronic circuits single input and single output is known as the transfer function. The audible signal when passing through the hydrophone undergoes changes and the recorded sound depends on the transfer function characteristics.

The transfer function modifies the original waveform modifying its characteristics, such as their pitch. As a result, waveform, duration, spectrum, and vocalizations level source cataloged animals, especially those with high-frequency components cannot be reliably determined from the recordings [5,6] if not well known to its transfer function. A system without calibration does not allow the correct identification of the species, and can generate a false classification [7].

4. **Methods**
An experiment was designed to demonstrate qualitatively as the calibration of a hydrophone and the environment can influence the recording of hydroacoustic signals. In this experiment, an acrylic tank filled with water was used, inside which were placed a sound source and a microphone. The sound source used was a speaker encased in a latex sheath to prevent water from entering the paper cone.
The hydroacoustic transducer used was an electret microphone mounted on a nylon carrier and insulated by PVC film as the scheme Figure 1, below:

![Simulated hydroacoustic system](image)

**Figure 1 - simulated hydroacoustic system**

The experiment was conducted in the audible frequency range (~100 Hz up to ~16 kHz). For playback and recording of the sounds we used the line-in and line-out interfaces to a PC and the software Cool Edit Pro aid (Syntrillium Software Corporation, 2003).

The acoustic signal used was the vocalization of a whale available in audio gallery of http://www.dosits.org/ website.

The experiment is to determine the difference in the frequency responses of the signals measured by the propagation on the water and in the air. This difference highlights the care that must be taken when using recorded signals to assign them to the vocalization of different sea creatures or other applications in passive monitoring.

The signals were recorded in 3 cases, namely:

- a) Original signal, $s(t)$;
- b) Propagation in water, $s_{ag}(t)$;
- c) Propagation in air, $s_{ar}(t)$;
- d) Propagation in water with interposition of a barrier (absorbent material), $s_{bar}(t)$.

To determine the frequency responses of various situations, it was applied to Fast Fourier Transform (FFT) on each sign up, define, respectively, $RF_s(t)$, $RF_{ag}(t)$, $RF_{ar}(t)$ e $RF_{bar}(t)$. The influence of water on the transmission compared with the transmission in air, is defined as the ratio:

$$\text{RatRF}_{ar} = \frac{RF_{ag}}{RF_{ar}}$$

5. **Methods**

A Figure 2 shows the results obtained for the recording of the same sign in different conditions. The signal is reproduced in the time domain and frequency (spectral representation).

Figure 3 shows the ratio between the frequencies responses of the situations described below:

- RatRF$_{ag}$  
  $s$  \Rightarrow  \text{ratio of the RF signal transmitted in the water compared to the original signal;}
- RatRF$_{ar}$  
  $s$  \Rightarrow  \text{ratio of the RF signal transmitted in the air in relation to the original signal;}
- RatRF$_{ag}$  
  $ar$  \Rightarrow  \text{ratio of the RF signal transmitted in the water in relation to the spread in the air;}
- RatRF$_{ag}$  
  $bar$  \Rightarrow  \text{ratio between the RF signals transmitted on water in relation to the signal with the interposition of the barrier.}
6. Methods

Using a graphical analysis of Figure 2 is not possible to conclude that it is the same signal in all cases. The signal suffers changes due to propagation medium, air or water, as well as changes in the propagation path (sound barrier). The hydroacoustic system used can input harmonics and reverberations that are not present in the original signal.

The use of signal processing techniques and compensation hydroacoustic system, knowing the transfer function (hydrophone calibration) would make it possible to recover the original signal, but it should be an uncertainty associated with this conversion. Identification of software and classification of automatic signals that do not use information about system calibration may incur false positives or negatives to previously recorded patterns.

Analyzing Figure 3 in details, one could observe that the water influence on the frequency response of the recorded signal (green line) has its most remarkable effect in the frequency range between 1.5 kHz and 2.5 kHz. This frequency range corresponds to the less efficient for this particular system to propagate in water regarding the propagation in air.
Another remark to be outlined can be depicted observing the cyan line in Figure 3. Regarding line corresponds to the relation between the propagation in water with and without the insulation barrier, it is easy to find that the insertion loss is more effective in the frequency range around 500 Hz.

Finally, it is worthy emphasizing that a proper frequency response characterization is fundamental for a complete understanding of how a signal recorded can be analyzed. Moreover, it is clear that different propagation media could led to different frequency response behavior of the system, once the propagation medium itself is an important part of the propagation system. It is particular true for underwater long path propagation, such as those expected in wild life monitoring.

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