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# Smart embedded passive acoustic devices for real-time hydroacoustic surveys

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ABSTRACT

This paper describes cost-efficient, innovative and interoperable ocean passive acoustics sensors systems, developed within the European FP7 project NeXOS (Next generation Low-Cost Multifunctional Web Enabled Ocean Sensor Systems Empowering Marine, Maritime and Fisheries Management) These passive acoustic sensors consist of two low power, innovative digital hydrophone systems with embedded processing of acoustic data, A1 and A2, enabling real-time measurement of the underwater soundscape. An important part of the effort is focused on achieving greater dynamic range and effortless integration on autonomous platforms, such as gliders and profilers. A1 is a small standalone, compact, low power, low consumption digital hydrophone with embedded pre-processing of acoustic data, suitable for mobile platforms with limited autonomy and communication capability. A2 consists of four A1 digital hydrophones with Ethernet interface and one master unit for data processing, enabling real-time measurement of underwater noise and soundscape sources. In this work the real-time acoustic processing algorithms implemented for A1 and A2 are described, including computational load evaluations of the algorithms. The results obtained from the real time test done with the A2 assembly at OBSEA observatory collected during the verification phase of the project are presented.

## 1. Introduction

More than 70% of the earth's surface is covered by oceans and the majority of the underwater space remains unexplored. Because in-situ observation of oceans is generally difficult and costly in resources and time, the NeXOS project developed innovative, cost-effective, and compact multifunctional sensor systems for a number of domains and applications, including ocean passive acoustics, ocean optics and for an Ecosystem Approach to Fisheries (EAF). These systems were envisioned to be deployed both from mobile and fixed platforms, with data services contributing to the Global Earth Observing System of Systems (GEOSS), the Marine Strategy Framework Directive (MSFD) and the Common Fisheries Policy of the European Union [1].

Passive Acoustic Monitoring (PAM) systems are extremely valuable for long term studies of the marine environment, for example, information on species occurrence and temporal distribution can be gathered using passive acoustics before and after anthropogenic activity begins. PAM in areas of such human activities can be an effective way to monitor how noise potentially affects marine mammals by measuring how much of their acoustic habitat is being lost [2]. Generally, PAM systems include: single or multiple acoustic transducers for sound acquisition; internal electronics to control the system and for acoustic data conditioning, storage of raw audio data [3], and some may provide processing power to analyze acoustic data in real-time [4,5]. However, the majority of the available commercial passive acoustic sensors cannot perform simultaneous measurement of sound level extremes (very low and very high), and data processing has to be performed on costly and/or bulky systems, generally impractical for mobile platforms [3].

Hence, in addition to acquiring raw audio data, the NeXOS passive acoustic devices have been envisioned to enable the provision of information for the assessment of underwater noise, marine mammal

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populations, detection of fish reproduction areas, detection of Green-House Gases (GHG) seepage from pipelines and deep sea carbon storage, gasification of methane clathrates, estimation of rainfall, detection of low-frequency seismic events, ice-cracking, ocean basin thermometry and tomography, acoustic communication, etc. [6]. From a technical perspective, the focus is on improved life cycle cost-efficiency via the implementation of innovations, such as multiplatform integration, greater reliability through better antifouling management and greater sensor and data interoperability. Requirements for the sensors have been refined from this perspective through surveys and discussions with science and industry users. The feedback has then been incorporated into the engineering design process.

Within this context, we developed and implemented new, compact, low power and innovative digital hydrophones, that we describe in this paper. These passive acoustic sensors can be arranged in different configurations: as a standalone multi-channel hydrophone (named A1) or as a hydrophone array (named A2). First, an overview of the challenges for real-time hydroacoustic surveys with embedded passive acoustic devices is presented. Section 2 focuses on the design philosophy of the standalone multi-channel hydrophone (A1) and the hydrophone array (A2), including the description of the two devices, three hydrophone transducers used in the final development, and multiplatform interoperability. In Section 3 the algorithms implemented for the assessment of the underwater noise (MSFD Descriptor 11), mammal detection (MSFD Descriptor 1) and sound source localization are detailed. During the validation and demonstration phase various deployments of the A1 hydrophone have been carried out with deferent platforms such as gliders, profilers and buoys, and a deployment of A2 hydrophone array in OBSEA observatory which are discussed in Section 4. Finally, the conclusions drawn are presented in Section 5.

## 2. Passive acoustic sensors system

### 2.1. A1 hydrophone

The A1 is a dual-channel compact, low-power digital hydrophone aimed to be deployed on mobile platforms. In order to extend its dynamic range, it has two channels with different gain, sampled simultaneously enabling it to detect acoustic source levels from 50 dB to 180 dB re 1 μPa in the frequency range from 1 Hz to 50 kHz. Considering the inherent sensitivity of hydrophone transducers, the use of two amplifier stages with different gains is a cost-efficient approach in order to obtain the desired dynamic range.

As illustrated in Fig. 1, as a first step, the hydrophone signal is pre-amplified with an input stage with a gain of 20 dB. The first channel (CHA) consists of a high pass filter "equalizer", connected before the high gain stage in order to avoid saturation at low frequency caused by rough sea, ship traffic, etc. The equalizer circuit is a one-pole filter with a cut-off frequency of 3200 Hz which can be enabled or disabled through the serial interface. Furthermore, the equalizer also ensures high dynamic range at high frequency, where the ambient noise level is lower. The post gain amplifier of CHA can be set to 20 dB or 40 dB through the MCU. The second channel (CHB) does not make changes to the hydrophone's pre-amplified signal. Therefore, the two channels provide different gain:

- CHA "Hi" Gain: 40 dB or 60 dB
- CHB "Low" Gain: 20 dB

Both channels have a low pass antialiasing filter: to avoid aliasing problems, a switched capacitor filter, digitally controlled by the MCU, has been added in both the chains after the amplifier stage. The operator, through the MCU, can set the cut off frequency of the antialiasing filter, changing its control clock frequency (CLK), depending on the application and on the sampling frequency. The hydrophone signal is sampled by two 16-bit SAR converters controlled by an ARM microcontroller, which is responsible for proper data processing (mathematical operations). The working sampling frequency (SF) should be 100 Kilo Samples Per Second (KSPS) and it is controlled by the MCU timer.

The MCU processes the sampled data and transmits the results on an EIA RS-232 serial port. A1 is equipped with a Real-Time Clock (RTC) with a precision of ± 3.5 ppm and powered by an RTC battery, useful to tag temporally sampled data, but it is also equipped with a Pulse Per Second (PPS) input for the GPS link, if available. The frequency response requirement is a frequency range of 1 Hz to 50 kHz. The selected ADC can run up to 100 KSPS (50 kHz of bandwidth). Any frequency range may be selected by the MCU by changing the antialiasing filter frequency clock.

The A1 hydrophone can acquire raw acoustic data and store it in its internal memory (128 GB). However, it also has several embedded processing algorithms, which permit real-time measurements of Sound Pressure Level (SPL), click detection, whistle detection and low frequency tonal sounds detection. Regarding the transducer stage, three types of hydrophones, SQ26-01, D/70 and JS-B100 (see Table 1) have been selected for the final developments as illustrated in Fig. 2. The maximum power consumption of the A1 hydrophone is approximately 920 mW in running mode and 36 mW in sleep mode.

### 2.2. A2 hydrophone array

The A2 hydrophone array is a digital passive acoustic transducer array whose output (raw signal) is pre-processed by a master unit. The acoustic array consists of four slave acoustic devices, called A2 hydrophones, and a master unit, based on an embedded Linux computer. The A2 slave hydrophones have the same characteristics as the A1 sensor regarding the Signal Conditioning Unit (SCU), the A/D Converter (ADC) and the Micro Controller Unit (MCU), with the difference of a smaller internal memory (32 GB) and the absence of the RTC battery. Regarding the transducer stage, the JS-B100 has been selected (see Table 1) to permit high depth underwater application. The maximum power consumption of the A1 hydrophone is approximately 1.12 W in running

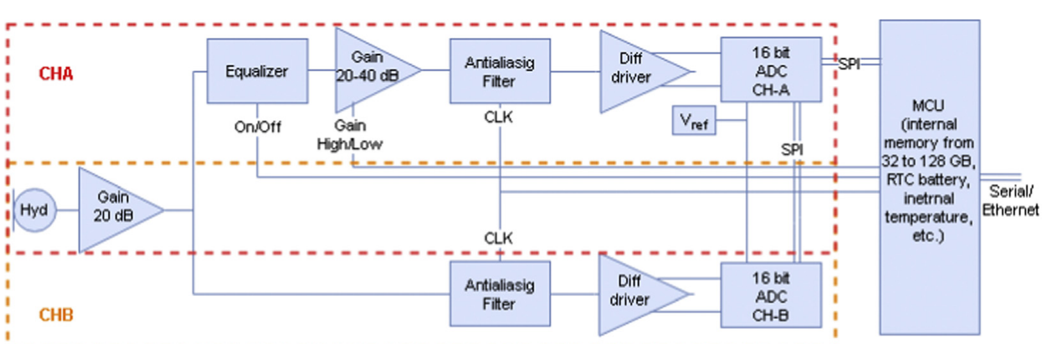

**Fig. 1.** A1 sensor block diagram. CHA is demarcated in red and CHB is demarcated in orange.