Mid-Term Internship Report : Implementation of an optical sensor on "QHB" and viability tests in Toulon and Concepcion, Chile

End-of-study internship
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Matthieu JUNG

Julie Patris, Hervé Glotin, Valentin Gies, Iván Hinojosa, Franck Malige, Lyudmyla Yushchenko

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Abstract

This paper presents the design and implementation of an autonomous, open-source, low-cost, and low-power optical sensor developed to complement acoustic studies, particularly in the context of monitoring NBHF (Narrow-Band High-Frequency) species using instruments deployed off the Chilean coast. The system enables continuous image capture over periods ranging from 2 to 4 days, depending on the available onboard energy capacity.

Initial laboratory tests were conducted to characterize the optical distortions of the system, followed by sea trials near Toulon. The sensor was then deployed under real-world conditions during medium-duration scientific missions off the coast of Concepción. The module was mechanically integrated into the QHB acoustic instrument developed by the SMOIT laboratory at the University of Toulon. Each unit provides a 180° field of view, allowing full 360° coverage when used in pairs. The estimated cost per module is approximately €400, depending on component pricing.

This simple, reproducible, and cost-effective system offers a promising complementary tool for extending the temporal and spatial scope of underwater observations, with potential applications in scientific research, education, and citizen science.

Keywords

Underwater video – Medium-term monitoring – Open source hardware – Species monitoring – Bio-acoustic

Glossary

NBHF Narrow-Band High-Frequency

UWOS Underwater Optic Sensor

IHM Human Machine Interface

CdC Specifications

LIS Computer Science and Systems Laboratory

CIAN International Center for Artificial Intelligence in Natural Acoustics.

FFMPEG FFmpeg is a collection of free software for processing audio and video streams.

PAM Passive Acoustic Monitoring

IA Artificial Intelligence

IRP International Research Project

PLA Polylactic acid $(\mathrm{C_3H_4O_2})_\mathrm{n}$, is a polymer that is biodegradable in industrial composting.

UART universal asynchronous receiver-transmitter, device-to-device communication protocols

RTC Real Time Clock

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Contents

1 Introduction

The observation of marine ecosystems is a major scientific and environmental challenge in the context of climate change and increasing material and acoustic pollution. Among the most widely used non-invasive tools today, passive acoustic monitoring (*PAM*) enables the detection and recording of species' sounds and vocalizations over varying durations, without disturbing their environment. In recent years, passive monitoring of marine ecosystems has greatly advanced thanks to technological progress in sensors and automated analysis Boom et al. [1]. Combined with artificial intelligence algorithms, PAM now allows for the detection, classification, and tracking of certain species with growing efficiency, and even for spatial localization Giraudet and Glotin [2].

However, acoustic analysis alone has limitations in several contexts. It does not always enable reliable species identification, particularly when multiple species produce similar acoustic signatures, as is the case with NBHF (Narrow-Band High-Frequency) species found in Chilean waters Patris et al. [3]. Moreover, acoustic analysis does not provide visual information about size, morphology, abundance, or non-vocal behaviors, and is not well suited for direct observation of interspecies interactions or anthropogenic disturbances.

In this regard, the addition of a visual sensor represents a significant advancement, as suggested by Reyes et al. [4]. By combining imagery and sound, it becomes possible to enrich datasets to validate acoustic classifications, estimate population sizes more precisely, and better understand observed behaviors. This kind of multimodal approach—still rare in field deployments due to technical, energy, and cost constraints—is now more accessible thanks to recent innovations in open-source, low-cost embedded systems Mouy et al. [5], Purser et al. [6].

The present work is part of this dynamic and aims to design, test, and integrate an autonomous, low-cost, low-power image capture module to be coupled with an existing acoustic recorder (QHB, developed by the SMIoT laboratory at the University of Toulon), as part of observation missions targeting *NBHF* species off the coast of Chile.

1.1 Description of the Department Where the Internship Took Place

My internship took place within the LIS's Toulon branch, specifically within the team of the International Center for Artificial Intelligence in Natural Acoustics (CIAN). This department is specialized in the analysis of natural soundscapes, with a particular focus on marine bioacoustics. Researchers study sounds emitted by wildlife (especially cetaceans) in their natural environments using advanced artificial intelligence techniques (deep learning, signal processing, automatic classification, etc.).

CIAN also leads interdisciplinary projects at the crossroads of ecology, AI, and engineering. It benefits from international collaborations and access to unique datasets gathered during sea expeditions, via acoustic buoys, or from sensor networks deployed in protected areas. Within this context, I had the opportunity to contribute to an applied research project, under the guidance of experts in bioacoustics and environmental data processing.

1.2 Partners and Scientific Collaboration

During this internship, I had the chance to work closely with several key stakeholders, including:

SMIoT

The Scientific Microsystems for Internet of Things (SMIoT) is the electronics development platform of the University of Toulon. They are in charge of designing and manufacturing the QHB recorder Barchasz et al. [7] used in Patris et al. [3]. This ultra low-power board enables the recording of up to six audio channels at $256kHz$, with an overall power consumption of about $2W$.

COSMER

The COSMER Laboratory (Mechanical and Robotic Systems Design) at the University of Toulon specializes in eco-design and optimization of mechanical systems as well as marine, underwater, amphibious, and terrestrial autonomous robotics. I previously completed my final year project with COSMER on the development of an autonomous sailboat, MARIUS Jung, Caudron, and Autet [8]. The lab was therefore a valuable resource during this internship for validating mechatronic systems, rapid prototyping, and 3D printing.

University of Concepción

The Catholic University of Concepción (UCSC) is a private university connected to LIS through a CNRS International Research Project (IRP), dedicated to the study of NBHF species as mentioned earlier.

1.3 What About Chile?

The Chilean coast is of particular interest for the study of marine species that use Narrow-Band High-Frequency (*NBHF*) acoustic signals Patris et al. [3], Reyes et al. [4], Reyes et al. [9]. This area lies along one of the most productive upwelling systems in the world (the Humboldt Current), and hosts exceptional marine biodiversity, including many odontocete cetacean species, some of which are endemic or poorly studied. Human activity in this highly sensitive region may add stress to species already at risk of extinction Jaramillo-Legorreta et al. [10], Silva et al. [11]. Among these, several species have evolved highly specialized acoustic communication modes, characterized by the emission of *NBHF* signals (>100 kHz), enabling efficient echolocation in complex or shallow environments.

This phenomenon is one of the most striking examples of evolutionary convergence in the animal kingdom: different odontocete lineages, living in similar environments, independently developed NBHF signals. These signals are thought to serve multiple adaptive functions: enabling fine prey detection at short ranges and potentially reducing the risk of detection by predators such as orcas, whose hearing does not cover such high frequencies.

2 Methodology and work

2.1 Bibliography

The first stage of this internship was obviously to get to grips with the subject and its challenges. This involved an in-depth review of scientific literature on underwater video sensors, signal processing, and NBHF species monitoring. I was also given an introduction to the bibliography manager, and in particular the use of *MENDELEY*. The main benefit of this bibliographical study was to learn about the latest scientific advances in the field of PAM and mid-term video recorders.

2.2 Technical specifications & project planning

Once the bibliographical study has been carried out, we can move on to drafting the specifications to define the project's goals and objectives.

In our case, due to the limited timeline (less than 3 months of R&D), the design, manufacturing, and operational phases are likely to overlap. Indeed, the developed solution may remain at the prototype stage during this project.

The specifications include the following elements: Objectives, analysis of existing situation, target audience and project scope, life cycle analysis, APTE and inter-actor diagrams, technical focal analysis, failure mode, project planning and follow-up...

This phase was the subject of several deliverables to the laboratory:

- Specifications (English)
- Specifications (Spanish)
- A component comparison book (French)

> ***Note***
>
> The various deliverables are available on request.

Task Name	Start Date	End Date
Project Familiarization	03/03/2025	04/03/2025
Drafting of Functional Specification	05/03/2025	13/03/2025
Drafting of Technical Functional Analysis	14/03/2025	24/03/2025
Mechanical Design	25/03/2025	02/04/2025
Electronic Design	25/03/2025	02/04/2025
Component Ordering	03/04/2025	03/04/2025
Electronic Prototyping	04/04/2025	10/04/2025
Software Prototyping	11/04/2025	21/04/2025
Prototype Fabrication	22/04/2025	28/04/2025
Laboratory Testing	29/04/2025	01/05/2025
Field Testing (Real Conditions)	02/05/2025	15/05/2025
Debugging and Improvements	07/05/2025	15/05/2025
Prototype Validation	16/05/2025	16/05/2025

Table 2.1: Tasks scheduled over the first 3 months

Due to the delay in manufacturing QHB, the real-life tests will be much shorter than planned. Instead of the planned two weeks, only two days will be devoted to them, on May 14 and 15, 2025.

2.3 Design, Modeling and 3D simulation

After selecting our components, it was essential to carry out a 3D design to validate the solution and mechanical integration. The UWOS system consists of a raspberry PI Zero 2W, a Witty Pi 4 power and RTC management board, and an S13V15V5 voltage regulator that delivers a5V DC output voltage, whatever the input voltage between $2.8V$ and $22V$. Two sensor options are available: an IMX708 and an IMX462. Power is supplied by batteries located in the QHB tube. The 2" waterproof case comes from Blue Robotics.

The CAD of the system includes the internal components (rail and rack), the clamps and the mounting bracket on the QHB tube. A partial static pressure study was carried out on the support part.

An experimental design based on Tagushi's tables was carried out to determine the system's average power consumption and the impact of each factor on power consumption and detection capacity. A deliverable is currently being written on this subject.

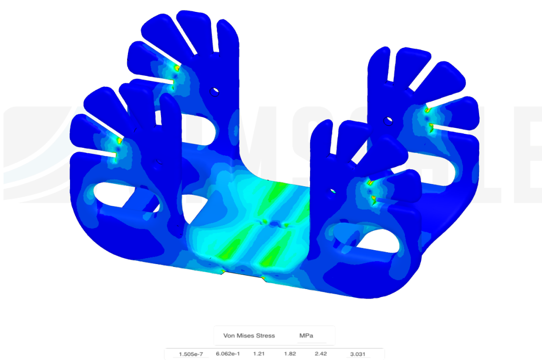

Figure 2.1: Static pressure test

Figure 2.2: 3D printing of flanges + support

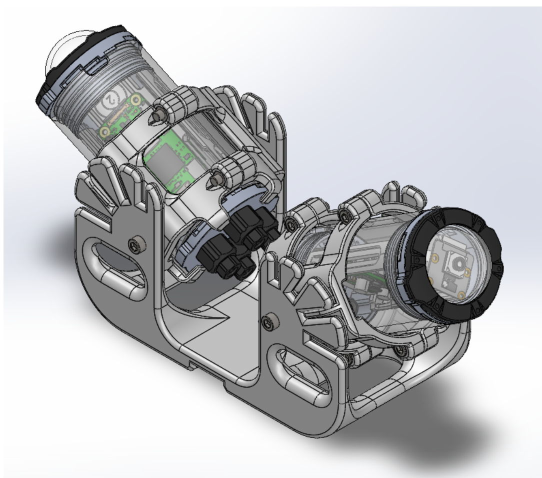

Figure 2.3: CAO UWOS

Figure 2.4: Pre-assembly of a module

On the software side, the first stage of installing the various drivers and configuring the solution has been completed and tested. However, the human-machine interface (HMI) still needs to be finalized. Video conversion software has been developed to convert videos into .h264 and .mp4 formats. The purpose of the HMI is to enable system configuration (video configuration and power management), video file import and conversion from a single wireless interface. It must also be able to inform the user of the estimated rec time depending on the configuration, and therefore, if applicable, the limiting factor.

3 Intermediate conclusion

At the half-way stage of this internship, the ambitious objectives have been met, despite certain time and hardware constraints. A first functional version of the UWOS (UnderWater Optical Sensor) module has been designed, modeled, assembled and tested in the laboratory. It is now ready to be tested in the field, notably in Chile, as part of the continuation of the study under real conditions.

Close collaboration with partner laboratories (SMIoT, COSMER, UCSC) has been essential for rapid progress on the hardware and software aspects of the project. Nevertheless, a number of elements remain to be finalized or improved, notably the precision of audio/video synchronization, the versatility of the system and its ease of use. The second half of the internship will therefore be devoted to optimizing the prototype, deploying it in the field, collecting data and analyzing the system's performance in a real environment.

Programming language used :

- Python
- Shell
- C++
- Bash
- ...

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