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SONIFICATION OF UNDERWATER ACOUSTIC DATA : AN ART-SCIENCE INITIATIVE TO EXPLORE AQUATIC LIFE

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ABSTRACT

The project aims at better understanding the functioning of aquatic ecosystems by using the most advanced 3D sound technologies (Wave Field Synthesis, binaural synthesis...) to design a spatialized audio representation of underwater active acoustics data. This so-called "sonification" process will enable to benefit from the excellent temporal and frequency acuity of the auditory system for the exploration and analysis of echosounder data, whose quantity and complexity still constitute a major challenge. Sonification has initially been tested in artistic contexts, with an emphasis on pedagogy and mediation for the general public: creation of electronic music by students in Hydrography/Oceanography/Acoustics, digital art installations, composition of a string quartet, musical conferences, etc. These various experiments will participate in the elaboration, in a second time, of a tool for sound analysis of underwater active acoustics data, whose scientific relevance and complementarity to traditional analysis methods will have to be validated (signal processing, statistics, data classification algorithms, multi-frequency approaches, visual representations such as echograms, etc.).

Keywords: *arts & sciences, underwater ecology, active acoustics, spatial audio, sonification*

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1. INTRODUCTION

Fisheries acoustics is a science that relies on the emission of ultrasound in water to detect and study aquatic life (organization of marine biodiversity, distribution and behavior of species, interaction with temperature, salinity and currents, evaluation of stocks for sustainable fishing, etc.). The principle is simple: an echo-sounder emits ultrasound; the ultrasound propagates and reflects on the obstacles it encounters (fish and plankton in particular); the echo-sounder captures the reflected ultrasound (called echoes); the strength of the echoes and their delays provide information on the depth of the obstacles, their nature (seabed, fish, crustaceans, plankton, wreckage, etc.), and sometimes even make it possible to identify a species (mackerel, sardines, whiting, krill, etc.) and to estimate its population density.

The strength of the echoes sent back by the organisms gives a lot of information on their size and nature: possible presence of a hard shell (reflecting the sound), of a gas bubble (resonance effects), etc. For example, layers of zooplankton will give a strong echo at 200 kHz, but will go unnoticed at 38 kHz; krill (small cold-water crustaceans) will give a moderate to strong echo at 70 kHz, 120 kHz and 200 kHz, but much weaker at 18 kHz or 38 kHz. It is therefore important to use several frequencies to be able to detect and identify all types of organisms, by comparing the strength of the echoes obtained for each frequency with the frequency responses of marine organisms modeled in the literature [1]. The greater the number of frequencies used, the better the chances of accurately identifying the type of organisms or even the species.

This method of observing underwater environment, called active acoustics, has the advantage of being nondestructive for the environment and of operating at great depths (>1200 m). However, the interpretation of data is sometimes complex because of the mixture of a large diversity of organisms in the same region or depth layer, despite the use of signal processing tools, statistics or data classification algorithms. The amount of data to be processed, especially with multi-frequency or broadband signals, is also a technical challenge for these analyses.

2. THE CHALLENGE OF VISUALIZING UNDERWATER ACTIVE ACOUSTIC DATA

To guide them in their exploration of data, researchers often use visual representations (in real-time or not) of the ultrasonic signals received by the echo-sounder, like the echogram presented in Fig. 1.

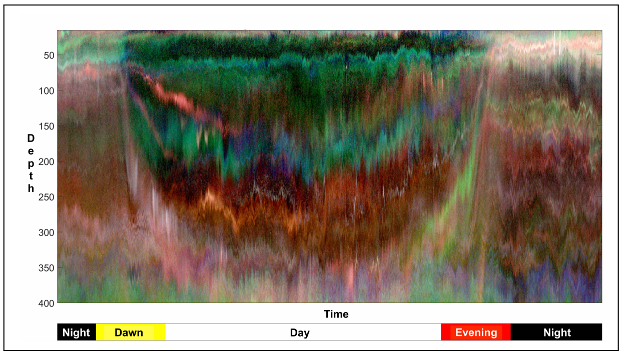

Figure 1. Echogram showing echo strength as a function of time and depth (in meter). Red, green and blue intensities correspond to the intensity of echoes measured at 18, 38 and 70 kHz respectively.

Unfortunately, the poor spectral acuity of the eye minimizes the quantity of information which can be represented on this type of graphs. Having only three different types of sensors on the retina (called cone cells) to distinguish colors, the eye is sometimes unable to differentiate between very different light signals. For example, if one decides on Fig. 1 to represent a fourth ultrasonic frequency using yellow coloring (assuming there is access to a display screen with 4 types of pixels: red, green, blue and yellow), it will be impossible to determine whether the yellow areas on the echogram correspond to the presence of this fourth frequency or to a “mixture” of “red” and “green” frequencies. As echo-sounders often use 5 frequencies (or more), or sometimes even broadband signals, the scientists therefore have to compare and cross-check information from different echograms, complicating the overall understanding of the data.

3. WHY NOT LISTENING TO THE DATA INSTEAD OF LOOKING AT THEM ?

Several studies have highlighted the limitations of visual representations for data exploration and interpretation when the number of dimensions to be processed is high [2].

On the other hand, the human ear is excellent at detecting very thin spectro-temporal variations [3] and shows an astonishing capacity to separate several sound sources and then focus on one source in particular [4]. This so-called ”cocktail party effect” (in reference to the ability of the ear to focus attention on a particular stimulus while filtering out a range of other stimuli such as noise), is particularly effective when the sources are spread out around the subject in different directions: this is called *spatial unmasking*. These performances of detection and separation of multiple sources even in complex and/or highly noisy environments seem to be adapted to the exploration and interpretation of underwater echo-sounder acoustics data.

Although hearing is less precise in localization than vision, advances in 3D sound allow to optimize spatial auditory performance: Ambisonic or Wave Field Synthesis (WFS), for example, allow to place sound sources precisely in space using a network of speakers, while binaural technology enables to create a 3D sound space using headphones only [5].

4. GOAL OF THE PROJECT

Our aim is to transform underwater acoustic data into spatialized audible signals, in order to take advantage of the spectro-temporal acuity of the ear while relying on 3D sound technologies to optimize spatial acuity: the ear’s remarkable ability to analyze complex scenes would allow the superposition of information obtained for several ultrasound frequencies, and perhaps even add other types of information such as temperature, salinity, currents, or even the phase of echoes (rich in information for the detection of artifacts), thus offering the operator a unified and global perception of data. The use of 3D sound technologies to precisely place data around the operator would allow not only to use the position of sound objects (azimuth, elevation, distance) as information, but also to achieve spatial unmasking and benefit from the cocktail-party effect.

It will then be necessary to verify whether the analysis by listening to these "sonified" data can increase our knowledge of the underwater world compared to traditional methods. Previous studies have already shown the potential of sonification for the analysis of complex data (in many fields such as seismography [6], solar wind [7], stem cells [8], stock market values [9], trees [10]). In their study on sonification of salmon migration, Hegg *et al.* point out the limitations of traditional statistical methods for analyzing complex spectro-temporal data and see sonification as a promising complementary tool [11] while Holtzman *et al.* explain in a study on tectonic that they used previous studies on the perception of sonified seismic data to train their Machine Learning algorithm, which subsequently revealed important spectro-temporal properties of seismic signals [12].

5. PRELIMINARY EXPERIMENTS THROUGH ARTS & SCIENCES PROJECTS

Sonification of echograms was initially tested through several artistic creations, with an emphasis on pedagogy and mediation for the general public.

5.1 Immersive sound installation "Hydrofaunie"

"Hydrofaunie" was an immersive sound installation designed by Master Students in Hydrography/Oceanography (ENSTA Bretagne) and in Sciences & Technologies of Sound (Image & Sound Brest - University of Brest), which was presented during the Ressac Festival (Arts & Sciences festival organized by the university of Brest in march 2022). The installation consisted of a corridor made up of five pairs of speakers, each representing a certain range of depths (see Fig. 2). The original ultrasonic frequencies were represented by sine waves at audible frequencies, which modulated more or less with sine waves of close frequencies depending on the strength of the echoes. As visitors moved through the corridor of speakers, they could navigate between the different depth levels and discover the distribution, diversity and movements of subaquatic life through the variations in sound content.

Figure 2. Immersive sound installation "Hydrofaunie" during the Arts & Sciences Ressac Festival (Brest, 2022).

5.2 Immersive and interactive audiovisual installation "Under the Sea"

"Under the Sea" was an immersive audiovisual installation designed by Master Students in Sciences & Technologies of Sound (Image & Sound Brest - University of Brest), which was presented during the Art'Pulseurs Festival (Arts & Sciences festival organized by the marine science discovery park Océanopolis in October-November 2022). The installation was very similar to "Hydrofaunie", except that the visitors could this time navigate between different depth levels and times of the day by piloting a small submarine projected on a screen using a joystick (see Fig. 3).

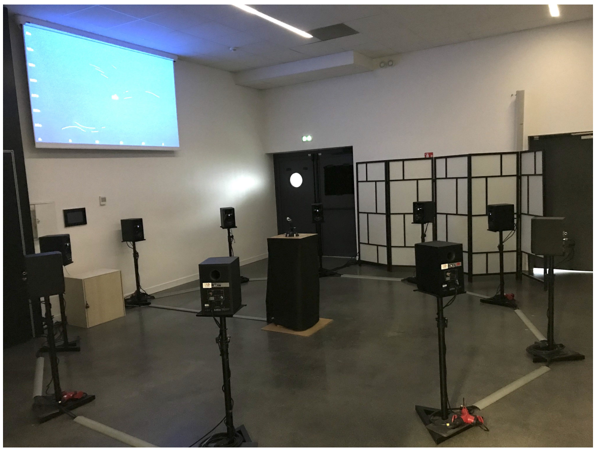

Figure 3. Immersive and interactive sound installation "Under the Sea"

5.3 String quartet “Picogramme”

In their study on sonification of salmon migration, Hegg *et al.* explain that they had worked with composers “with the objective of meaningfully representing juvenile salmon movement as sound [...] in a pleasing way” [11]. As one of the researcher of our project was also a professional composer, he tried to explore several ways of transforming the echograms into “meaningful” (and hopefully pleasing) music. Depth, intensity and colour of the echogram presented in Fig. 1 were mapped to musical parameters such as pitch, dynamic, rhythm or timber, resulting in a 7-minute string quartet, “Picogramme”, which was created during the 2023 RESSAC meetings (see Fig. 4).

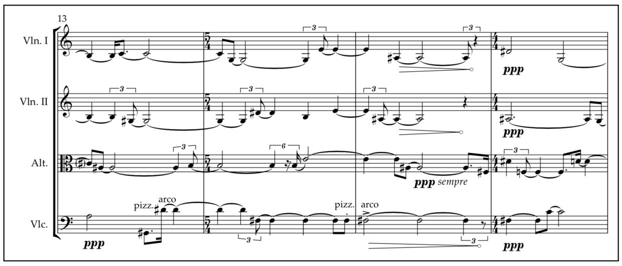

Figure 4. String quartet “Picogramme”

5.4 Future projects

A new version of the “Hydrofaunie” installation will be presented during the next edition of the Ressac Festival (March 2024). A duet for cello and accordion, exploring other ways to convert echograms into music, will also be created by the internationally renowned contemporary music ensemble Sillages.

6. CONCLUSION

These different “Arts & Sciences” projects have been an exciting way of opening a new research theme around the spatialized sonification of underwater acoustic data. We wish to continue to develop this ”Arts & Sciences” approach as it allows not only to communicate on our research activities but also to inspire the development of a scientific tool for sound analysis of underwater active acoustics data.

7. ACKNOWLEDGMENTS

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