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3D DIARIZATION OF A SPERM WHALE CLICK COCKTAIL PARTY BY AN ULTRA HIGH SAMPLING RATE PORTABLE HYDROPHONE ARRAY FOR ASSESSING INDIVIDUAL CETACEAN GROWTH CURVES

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ABSTRACT

Passive acoustics allow us to study groups of animals and obtain information that could not be gathered by other means. In this paper we demonstrate a method using an ultra high velocity portable recorder, and apply it to a set of audiovisual recordings of a Sperm whale pod. We thus localise and segregate nearly all the clicks emitted by the animals that are filmed. To our best knowledge, this is the first characterization of these vocalizations correlated to visually identified individuals. This approach allows the construction of growth curves of the biggest toothed cetacean and opens avenues to possible acoustic individual signatures.

1. INTRODUCTION

Passive acoustics allow us to study groups of animals and obtain information that could not be gathered through other methods. In this paper we study a set of audiovisual recordings of a Sperm whale pod, acquired with a specific ultra high-frequency and small aperture antenna, shown in Figure 4. This antenna is equipped with a Go-Pro video camera and the JASON DAC [1, 2], capable of recording up to 5 channels at a 2 MHz sampling rate. In this experiment it was set to record at 300 kHz. In 2018, the antenna had 3 hydrophones, thus increasing the number of cases that can be distinguished. This high velocity recording allows to reduce the size of the array, while keeping a good angle of arrival resolution. We then demonstrate how Time Difference of Arrival (TDoA) and a nonlinear solver can produce the localisation of nearly all the clicks emitted by the animals that are filmed. To our best knowledge, this is the first characterization of these vocalizations correlated to individuals that have been identified visually. It allows the construction of growth curves for individual whales, and opens avenues to possible acoustic individual signatures.

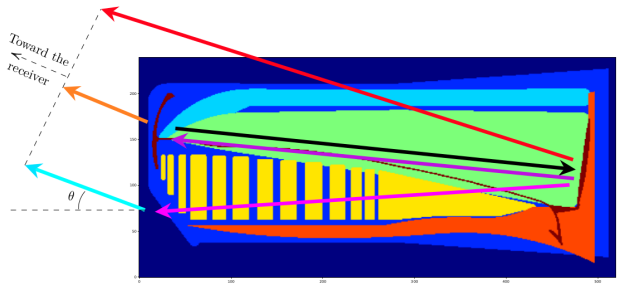

Figure 1. Pulse path in the head of the Sperm whale in the leaky bent horn model. The spermaceti is in the green volume.

2. SPERM WHALE CLICK EMISSION

When a Sperm whale emits a click, it propagates through the water and reaches each hydrophone at a different time. By inverting the propagation equation, it is thus possible to obtain the location of a Sperm whale relative to an acoustic antenna [3]. The difficulty of this task resides in the estimation of the various times of arrival, and having good measurements of the speed of sound and of the shape of the antenna. Once the positions are obtained, the clicks can be clustered by individuals when locations of multiple individuals are sufficiently spaced. Note that this is the case when Sperm whales are foraging. While passive acoustics alone can obtain some degree of individual labeling with this technique, the obtained labels cannot keep the association with one individual over multiple dives. The association between multiple encounters being out of the question. The use of a video channel solves this issue since an expert can identify the same Sperm whale over multiple years using visual cues. The use of the video thus allows us to study the variation of an acoustical individual feature, such as the inter pulse interval (IPI) over the years, or perform behavioural studies.

Figure 1 shows the acoustic paths that a pulse follows. After being emitted at the base of the black arrow, the pulse will bounce back and forth in the spermaceti (light green in Fig.1) according to the bent horn model [4–6]. This bounc-

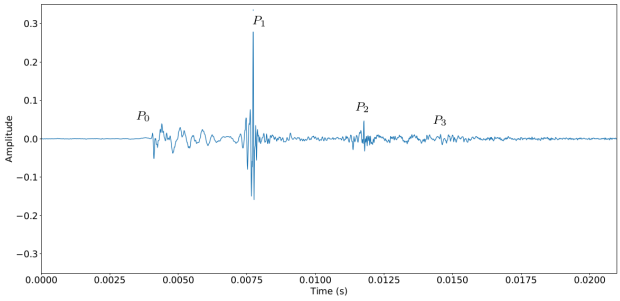

Figure 2. Example of a Sperm whale click demonstrating its multipulsed structure P0, P1, P2. The nominal IPI is the time lapse between P1 to P2.

Figure 3. François Sarano holding the 2018 antenna near *Physeters m.*

ing generates the multiple pulses that form a Sperm whale click as seen in Fig.2. The nominal IPI is the time difference of arrival between P2 and P1. The difference between P1 and P0 depends on the angle θ (see [7, 8] for details on the automatic estimation of the IPI and the effects of the angles). The nominal IPI is related to the length of the head of the individual, thus related to its body length. The length of the head function of IPI is linked to the sound celerity in the spermaceti. The extrapolation to the body size has been studied in [9–11].

3. CLICK DETECTION

The collected recordings include a cocktail party of various types of click trains from several animals as shown in Fig.5.

For this study, the clicks were detected using the Teager-Kaiser energy operator [12] after a bandpass filter. Local maxima in sliding windows of 20 ms are then extracted. Only the maxima that are above a threshold, set by a rolling median, are kept. This rolling median is used to estimate the noise level.

4. TDOA ESTIMATION AND SOURCE LOCATION

In order to estimate the time difference of arrival (TDoA), we use a technique called geometric steered response power [13]. This technique improves the TDoA estimation by combining all the possible cross correlations. Since this technique does not use the shape of the antenna, some spurious clicks can be filtered out by using the constraints for the antenna shape [14]. Finally, using the shape of the antenna seen in Fig.3 and Fig.4, the TDoA and the position of the source are estimated.

5. DOA PLOTTING

Since we have the position of the source, we compute the Direction of Arrival (DoA) of the click at the position of the GoPro and compare it to its optical axis. Thus, we were able to plot the position of the source in the video [8], allowing us to know if the Sperm whale that emitted the click is present in the video or not, and which one it is (Fig.6). Some of these videos can be viewed at `http://sabiod.univ-tln.fr/pub/Sarano_2018/`. The whales are then identified by François Sarano's team, leading to a database of Sperm whale clicks with individual labels over multiple years. However, some parts of this data flow are still to be fully automated, and a large part of our database still lacks this labeling.

6. CONCLUSION

This database led to multiple studies. Here we present the measurements of the nominal IPI growth of young Sperm whales over four years. To our knowledge this is the first time that IPIs are followed over four years for the same individuals.

The IPIs in Fig.7 are identified using the video recording where the youngs are present (Fig.6). Then for each click linked to the right individual, the IPIs were manually measured [15]. We then estimate the size of the heads from these estimated nominal IPIs, for a sound celerity of $1405m/s$, by assuming *spermaceti* temperature of 30°C [16], (see the right axes Fig.7).

Because we know their birthdates (Tache Blanche: June 2011 ; Eliot: March 2011 ; Zoé: December 2013), we notice they have different sizes at 5 years old, and that Tache Blanche grows faster than Eliot whereas they have the same father, and their mothers are of the same size (respectively Delphine and Adélie [17]). These differences might be due to individual and environmental conditions, such as the quality of the milk they still drink at 5 years old. Following this method, we are currently adding other individuals, juveniles and adults, that we recorded over the following years with our system. These growth curves will help to better understand the growth of Sperm whales, the biggest toothed predator at the top of the trophic chain. 1

7. ACKNOWLEDGEMENTS

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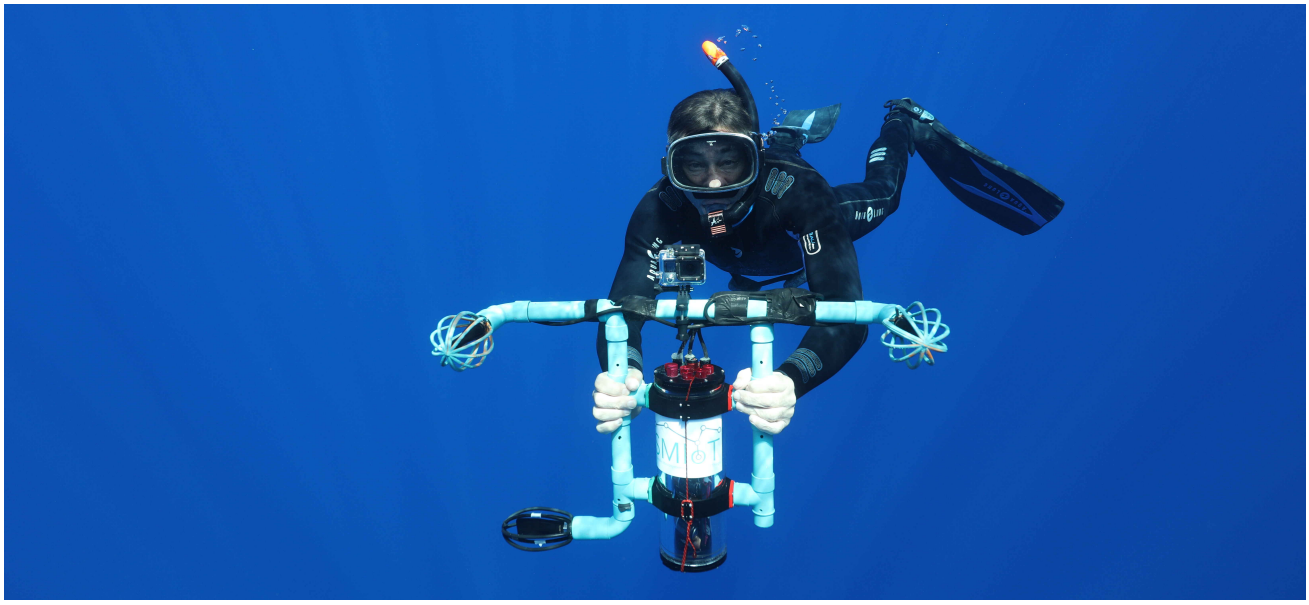

Figure 4. F. Sarano holding the antenna, version 2018, designed and built by H. Glotin (Image: F. Guerin). The hydrophones are three Cetacean Research, at the top two CR55 spaced by 60 cm, at the bottom a CR305.

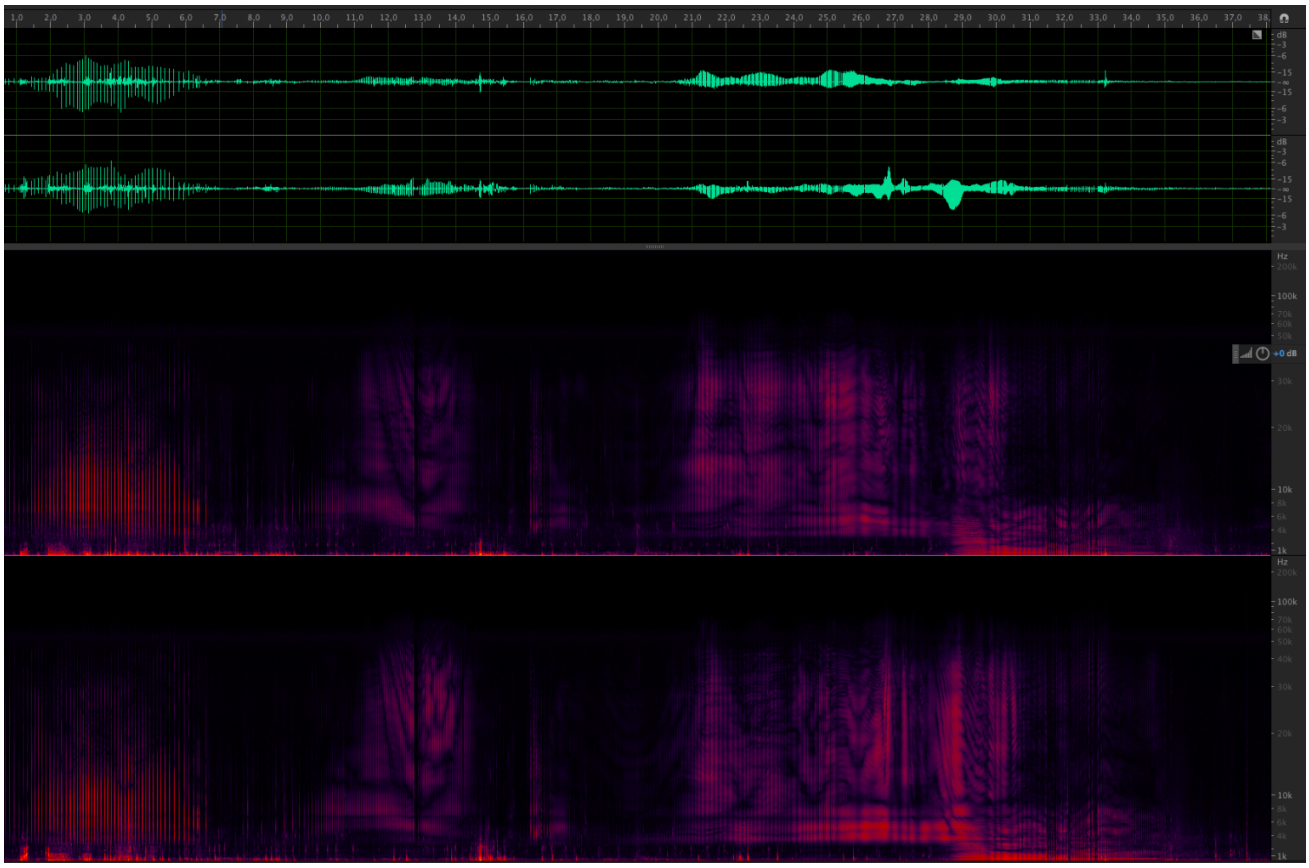

Figure 5. Spectrogram of *Physeter macrocephalus, P.m.* in near field measured by our system showing click trains up to 50 kHz. Stereo recording of the 14th of April 2018, at 300 kHz Sampling Rate, 16 bits, hydrophones CR57 (Cetacean Research Tech., USA). Graphic with the help of M. Mercier (TripinLab).

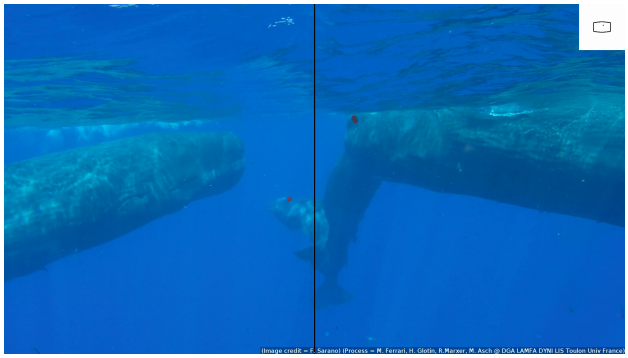

Figure 6. Group of four Sperm whales recorded in 2019, with two sources being pointed out (red dots): from Tache Blanche at the right, and from Alexander at the center (3 months old). Chesna is at the back-right (born 2018), Eliot is at the left (born 2011). Note that for visibility the dot stays on for 7 frames (at 25 frames per sec.). Hence two sequential click trains can be seen on the same frame, as in this example. Videos are available for viewing–see text.

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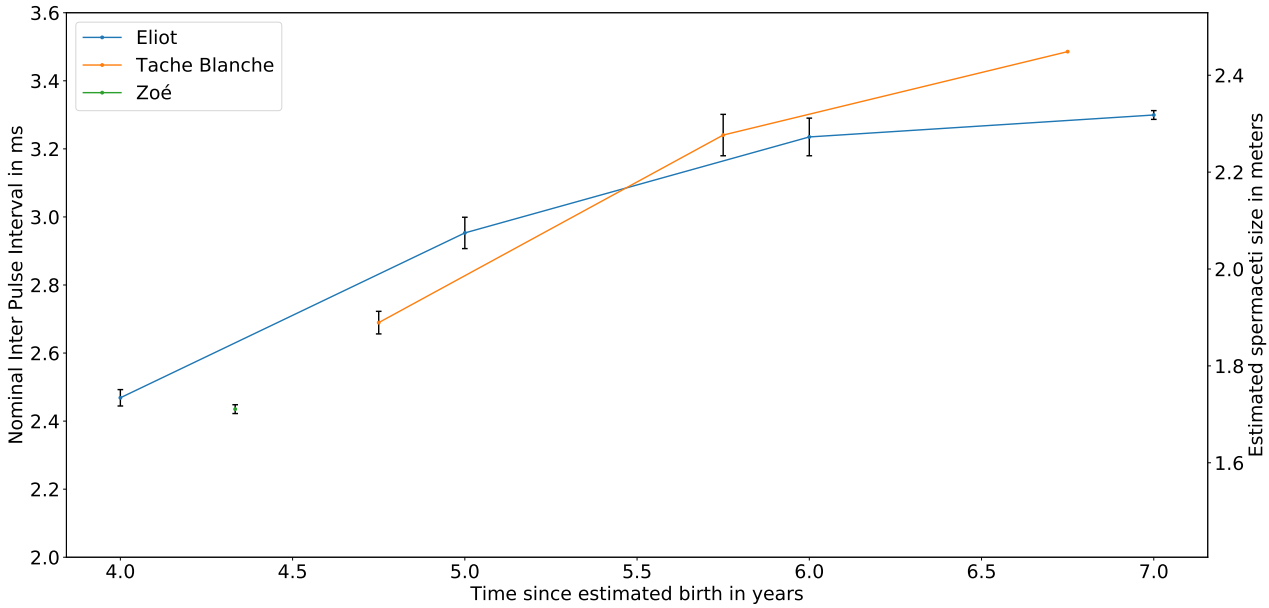

Figure 7. Measurements of the nominal IPI of three youngs, over 3 years for two of them, showing their growth. Respective birth dates are: Tache Blanche June 2011; Eliot March 2011; Zoé December 2013.

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