Waveforms and bio-inspired processing

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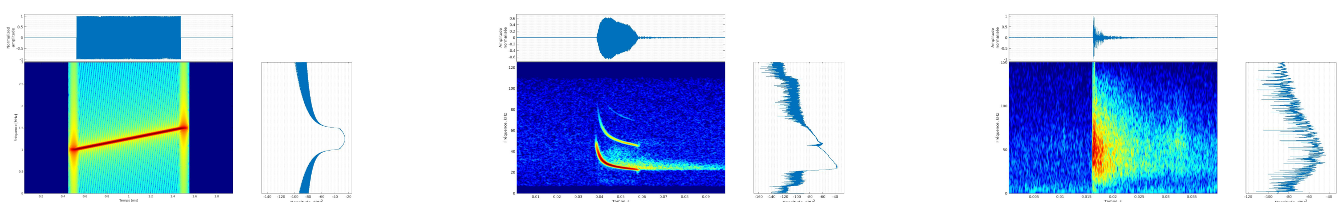
The RADAR technology is continuously evolving and the needs have been ever-growing for the last years. On one hand the spectrum management is becoming more and more complicated with the increasing need in bandwidth for communications services or the emergence of multi-user strategies. On the other hand, some requirements did not really change like the clutter processing, the heterogeneous target processing or the constant need for a better resolution. The creation and optimisation of waveforms as well as their processing are of the utmost importance to answer those needs.

The will to create new waveforms and the signal processing that goes with it drove us to the world of bio-inspired engineering and in particular the one of echolocation. The echolocation [1] also called echolocalisation is the system used by bats and dolphins to navigate through their respective environments and hunt, by the means of ultrasounds (frequency range from 20 to 100kHz and even 200kHz for some species). These mammalians have been using their biological radar for millions of years and have successfully adapted it to various types of environment and prey. Even some blind people can echolocate by emitting clicks with their tongue. Therefore, it becomes very interesting to study available waveforms and the different parameters of interest for bats and dolphins to echolocate.

Keywords: BAT, BIO-MIMICRY, ECHOLOCATION, RADAR, WAVEFORM.

Objectives

This thesis aims to propose new bio-inspired waveforms with the signal processing that goes with it. Thanks to an in-depth study of bats' (and dolphins') signals, we could improve our understanding of the construction and processing of their waveforms with mathematical tools available for time-frequency analysis like wavelets to design potentials waveforms and try to answer traditional radar issues as well as new ones.



(a) Chirp (b) Common noctule (bat) (c) Common bottlenose dolphin

Figure 1: Oscillogram (Amplitude vs Time, upper graph), Spectrogram (Frequency vs Time, main graph) and Spectrum (Amplitude vs Frequency, right graph) of a chirp compared to a call of a bat and a dolphin.

Echolocation and Perspectives

Bats use echolocation to evolve in their ecological environment. By sending ultrasounds with particular characteristics, specific to each species, they can navigate and forage in various environments (open fields, cluttered forest, above lake, etc) [2]. Figure 2 illustrates the great diversity of waveform among bats' calls. Moreover, bats adopt a particular emission scheme when approaching an eventual prey. The hunting sequence (e.g. Fig. 3) is divided in 3 phases: the search phase, the approach phase and the terminal phase/feeding buzz. During this process, bats constantly change their emission parameters (starting/ending frequency, pulse emission rate, etc). This plasticity in emission and the numerous available waveforms are the main reasons why echolocation signals are of great interest to design new waveforms for radar applications. Some properties of their signals as lower side lobe effect have already been studied [3], [4] or used for example in radar geophysical exploration [5]. Even human echolocation is a subject of interest [6]

The problem with analysing echolocation sounds lies in the overwhelming amount of parameters they carry and their various waveforms. An example of echolocation sound analysis can be found in [7], where Parsons fitted eight mathematical functions to identify different bat species according to temporal and spectral features measured on real signals. Therefore, it may be difficult to find the right parametric set of functions. Instead of focusing on very particular functions we propose to consider wavelet basis functions that are popular tools for non-stationary signal analysis.

Wavelet decomposition is a mathematical tool, capable of providing time and frequency information simultaneously, hence giving a linear time-frequency representation [8]. It has been one of the most useful digital signal processing

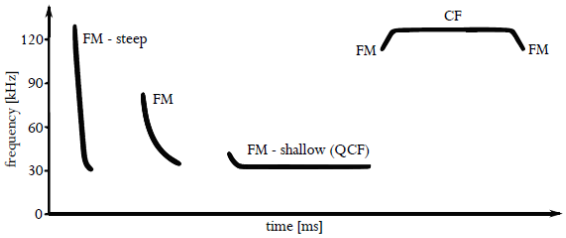


Figure 2: the main categories of bat echolocation pulses [12]

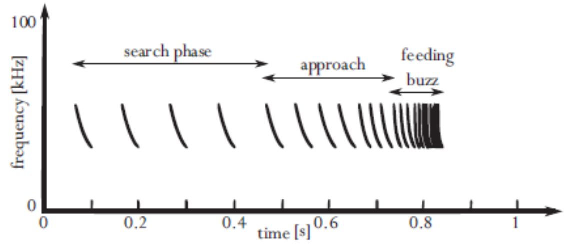


Figure 3: Echolocation sequence of FM bat [12]

tools for time-frequency analysis and the applications are numerous: earth studies, image compression or ECG and EEG (respectively ElectroCardioGram and ElectroEncephaloGram) noise removal and low level peak detection. Concerning echolocation signals, wavelets are often used to classify species ([9] and [10]) but in our case we want to find parameters to describe those signals, reconstruct them and study their response and the possibilities they offer in radar applications. Decomposing bat signals with wavelet is also a process close to the biological signal processing and the representation of frequencies in the cochlea (part of ears involved in hearing) which is important to understand. By decomposing time series into time-frequency space we could have a better understanding of the construction of bat signals and how their waveforms can be better approximated. With wavelets and the packet decomposition we can obtain several sub-bands of frequency characterizing our signals. Given a sparsest representation and the right wavelets to describe specific waveforms, we could construct a signal base for further studies, in particular these bio-inspired signals response to radar processing (matched filter, ambiguity function), or bio-inspired processing.

This first step into the comprehension of the bio-processing of echolocation signals could be carried out further with the study of the Spectrogram Correlation and Transformation receiver (SCAT) [11]. This receiver has been designed to modelize the processing of signal which takes place in bats' ear and neuronal system and seems interesting for processing studies. Once we are able to handle bats' calls correctly, we could apply a radar approach (match filter, ambiguity function) to compare and observe advantages and limits of potentials waveforms according to our objectives: clutter management, multiple targets, etc.

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