

## **DISTRIBUTED VIRTUAL SYSTEM FOR DOLPHINS' SOUND ACQUISITION AND TIME-FREQUENCY ANALYSIS**

*Octavian Postolache<sup>1,2</sup>, Pedro Silva Girão<sup>1</sup>, Miguel Dias Pereira<sup>1,2</sup>, Mário Figueiredo<sup>1</sup>*

<sup>1</sup> *Instituto de Telecomunicações, DEEC, IST, Av. Rovisco Pais, 1049-001 Lisboa, Portugal, psgirao@ist.utl.pt,*

<sup>2</sup> *Escola Superior de Tecnologia - LabIM, IPS, 2910-761 Setúbal, Portugal, poctav@alfa.ist.utl.pt, joseper@est.ips.pt*

**Abstract:** Dolphins are mammals whose sound emitting and hearing capabilities are very important tools for their underwater life. At the same time, dolphins' life activities assessment uses dolphins' emitted sounds to localize them and to better understand their habits and behavior. The present work reports a distributed virtual instrument based solution for dolphin sounds acquisition, transmission and analysis (Dolphin Monitoring Network). The system hardware includes a set of "field listen cells" constituted by a hydrophone connected to a TCP/IP audio server. For wireless communication, a wireless bridge is connected to the audio server Ethernet port. Using tailor-made LabVIEW software, which includes several iTalk/X (ActiveX) components, the data is received by a Wi-Fi connected laptop-based monitoring base station. The recorded sounds are analyzed by a time-frequency analysis block implemented within the software associated with sound classification tasks.

**Keywords:** virtual systems, wireless network, underwater sounds, time-frequency distributions

### **1. INTRODUCTION**

Dolphin monitoring systems are able to contribute to a better understanding of the structure and dynamics of dolphins' populations, as well as to the natural and anthropogenic factors (factors of human origin) that impact them. By using different types of measurement systems, including hydrophones, it is possible to collect and analyze the data (especially acoustic signals) associated with dolphins' behavior, data that can be used also by wildlife management agencies.

Dolphin sound emissions can be classified in different categories: narrow-band-frequency-modulated continuous tonal sounds referred to as whistles, broadband sonar clicks and broadband burst pulse sounds [1,2].

Dolphins produce many different types of whistles. One of the whistle dolphins use most frequently, called a signature whistle, appears to serve as identification of individual dolphins since each dolphin develops a signature whistle that is uniquely its own. The approximate frequency range of bottlenose dolphin whistles is 5 to 15 kHz, which indicates that both data acquisition boards and audio

recording systems are possible solutions for this type of sound acquisition.

The broadband sonar clicks emitted by dolphins are thought to be exclusively used for echolocation, the dolphin's amazing ability to gather information about its world through sound. Clicks are produced in rapid sequence, called "click trains," that sound to us like a creaking door or loud buzz. The frequency range for echolocation clicks is 0.25 to 220 kHz [3].

Broadband burst pulse sounds are a general classification given to such sounds as barks, mews, chirps, and pops. Dolphins apparently make these sounds only under emotional duress, when they are angry, frightened, upset, or frustrated.

Referring to data acquisition and recording of the signals obtained from hydrophones, different solutions are reported in the literature including high quality audio interfaces such as EDIROL UA-5 or sound acquisition based on multifunction boards and programmable filters that permit to acquire broadband sounds signals including the dolphin clicks.

Sound analysis tasks are usually performed using a personal computer and commercial software such as Raven [4] that permits the analysis of the data stored in .wav format files. Data processing algorithms such as Short Time Fourier Transform (STFT) represent an important component of the time-frequency data analysis of non-stationary signals. Other techniques for acoustic signals analysis such as Wigner-Ville distribution, Choi-Williams distribution, Discrete-Wavelets or Continuous Wavelets Transform are also reported in the literature [5] and are generally associated to marine acoustic signals classification [6].

The present article presents a distributed virtual system that uses several hydrophones, audio signal based on VoIP technology, wireless communication and LabVIEW graphical programming software to acquire, store, transmit and analyze data associated with dolphins' life monitoring. Based on the designed and implemented system, it is possible to detect both temporal and spectral changes in dolphins' sound waveforms (DSW) according to the type of dolphins' sounds (whistles, burst pulse, sonar clicks)

acquired at the field listen cells level and Wi-Fi transmitted to a monitoring base station expressed by a laptop PC where Short Time Fourier Transform (STFT), Wigner-Ville distribution (WVD), Choi-Williams distribution (CWD) and cone-shaped distribution (CSD) advanced signal analysis modules are implemented. Elements of marine sound classification and dolphin sound classification are also considered.

## 2. DOLPHIN MONITORING NETWORK

Taking into account that the dolphins' population under observation is spread over a wide area (Sado Estuary), a distributed measurement system denominated Dolphin Monitoring Network (DoNET) was designed and is under implementation to acquire dolphins' sounds and to performed advanced processing tasks associated with whistle, clicks and burst dolphin' sounds. The DoNET architecture is presented in (Fig 1).

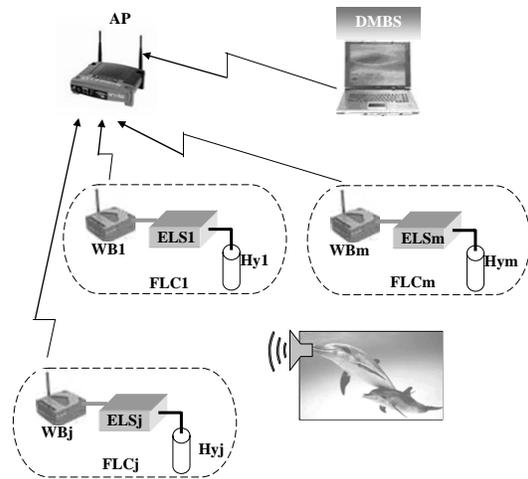


Fig.1. The DoNET block diagram (FLC-field listen cell, Hy-hydrophone, ELS- audio-Ethernet server, WB- wireless bridge, AP- access point, DMBS – dolphin monitoring base station)

### 2.1 Dolphins Sound Sensing

The hydrophone is the interface between the field listen cells and the underwater world. Composed of a piezoelectric material, it converts a sound pressure in a proportional tension. The frequency range of sensitivity of the used hydrophone (Aquarian Hydrophone AQ15) starts at 20 Hz and goes up to 100 kHz. It is almost omni-directional increasing the possibility of capturing dolphins sound. For each field listen cell the hydrophone is connected to the hydrophone conditioning circuit that is linked to the audio input of the ELS mounted on a buoy using a cable that allows the hydrophone to stay at 2 m depth. The cable is screened to avoid the interference of external signals.

Referring to the signal conditioning, a preamplifier based on a charge amplifier is included and permits to automatically regulate the gain to obtain always the optimal signal level. The first tests have been conducted on whistles and burst pulses only. Thus, and to prevent aliasing, the conditioning circuit includes also an OPA2604 based 22.05

kHz active low-pass filter, which makes possible to sample signals at a rate of 44.1 ksamples/s.

### 2.2 Data Acquisition and Wi-Fi Communication

Considering that for each FLC only one hydrophone is used, an Ethernet listen server materialized by an ii3-OEM module (Digital Acoustics) is the adopted solution. The ii3-OEM module is completely digital and 100% IP-based with endpoints individually addressed for two-way intercom communication and paging. As basic characteristics of the module can be underlined: self contained Ethernet Intercom board, integrated RJ45 10/100, 3.5mm jacks for Mic In associated with the hydrophone conditioning circuit output, static IP assignment or automatic via DHCP, integrated diagnostics and network optimization, 5 to 9 volt DC power.

The signals associated with the hydrophone channels are converted into digital format by the Ethernet listening servers. Taking into account the field operation conditions, a Wi-Fi connection between the field listen cells and DMBS was carried out. For this purpose, a set of Ethernet-wireless bridges, WBj, (D-link DWL-810+) and an 802.11-b access point were used.

Two types of Wi-Fi network architectures (Ad-Hoc and Infrastructure) were designed and tested. While the Ad-Hoc architecture includes fewer elements and is easy to adapt to the field conditions, the infrastructure architecture assures higher reliability and permits to implement an Internet connection publishing the data through client-server technology.

## 3. DoNET SOFTWARE

The DoNET software includes an FLC control and advanced dolphin sound analysis components both of them being implemented at the DMBS level.

### 3.1. FLC Control

The FLC control component permits the audio Ethernet server configuration (IP, name), performs the listen functions and data storage in \*.wav type file format. This component was developed in LabVIEW using ActiveX technology provided by the iTalk/X full edition that works properly under LabVIEW programming environment. The control of FLC was carried out using iTalk/X properties such as *LocalIP*, *LocalPort*, *SaveMicToFile*, *ListenMode* and methods such as *GetSocketNumber*, *InitializeAudio*, *ListenStart*, *ListenStop*, *CloseAudio*, *CloseConnections*,.. The files associated with marine underwater sounds are stored in the DMBS and analyzed using advanced processing software component including different time-frequency (t-f) analysis modules fully developed also in LabVIEW.

### 3.2. Time-frequency Analysis

Since classical FFT do not clearly indicate how the frequency content of a signal changes over time, the mixed time-frequency signal representation has received considerable attention as a powerful tool for analyzing a variety of non-stationary signals. In the particular case of dolphin whistles sounds (dolphin signature), burst pulse

signals, or whistles combined with clinks or other underwater sounds a high resolution in both time and frequency domains is required.

In the present case, t-f analysis modules were considered in order to extract features from dolphins acquired signals (DO(t)) expressed by dolphin whistles and burst pulse sounds. The implemented algorithms were also tested for broadband clicks (BC) obtained in a \*.wav file format from a dolphin sound database: This type of signal is not possible to be acquired by the ELS due to the sampling rate limitation (44.1 kHz maximum sampling rate).

The most common t-f analysis technique, the STFT spectrogram, involves a moving time window. This window attempts to capture a portion of the signal sufficiently restricted in time so that stationarity and LTI (linear time-invariant) assumptions are approximately met. The STFT of the acquired  $d(n)$  signal is defined by:

$$STFT_d(\omega, m) = STFT(d(n)) = \sum_{n=0}^{R-1} d(n-m)w(n)e^{-j\omega n} \quad (1)$$

where  $w(n)$  is the window function of length  $R$ . In the present case a hamming function was used with  $R$  equal to 128 and 256.

The Wigner-Ville distribution (WVD), functionally similar to a histogram, yields a better temporal and frequency resolution than the STFT. However, WVD is characterized by many artifacts and the introduction of negative values represents drawbacks of the method. For a time series  $d(n)$  corresponding to the dolphin sound the expression of discrete-time Wigner-Ville distribution  $WVD(n, f)$  is:

$$WVD_d(n, f) = 2 \sum_{k=-\infty}^{\infty} h_N^2(k) d(n+k) d^*(n-k) \cdot e^{-j4\pi f k} \quad (2)$$

where  $h_N(k)$  is a data window that performs a frequency smoothing. The distribution is negatively affected by important cross-terms, which limit its practical use. Thus, advanced versions such as smoothed Wigner-Ville and especially Choi-Williams distribution are nowadays mainly used. The discrete Choi-Williams [7] distribution is:

$$CWD_d(n, \theta; \sigma) = \sum_{\tau, \mu=-\infty}^{\infty} d(n+\mu+\tau) d^*(n+\mu-\tau) \cdot e^{-j2\tau\theta I(-2j\mu, \tau; \theta)} \quad (3)$$

$$I(\mu, \tau; \sigma) \approx \exp\left(i\xi\mu - \frac{\xi^2 \tau^2}{\sigma}\right) / 2\sqrt{\frac{\pi}{\sigma}} |\tau| \quad (4)$$

$n = n f_s$  ( $f_s$  sampling frequency),  $\theta = 2\pi f / f_s$ . The parameter  $\sigma$  controls the compromise between time-frequency resolution and level of artifacts. As  $\sigma$  increases, the resolution increases but also the artifacts. Decreasing  $\sigma$  the artifacts are reduced, although some resolution is lost. A judicious choice of  $\sigma$  will provide a clear time-frequency image of the analyzed dolphin sound signal. A study in this sense was carried out.

#### 4. RESULTS AND DISCUSSION

Based on the developed LabVIEW dolphin sound advanced data processing software, different types of dolphin sound were analyzed. Thus, and to try to extracting the dolphin signature, whistle signals from two bottlenose dolphins were processed using the above mentioned TFD algorithms. The evolution in time of the whistle signal and the corresponding power spectrum of one of the dolphins are presented in Fig. 2.

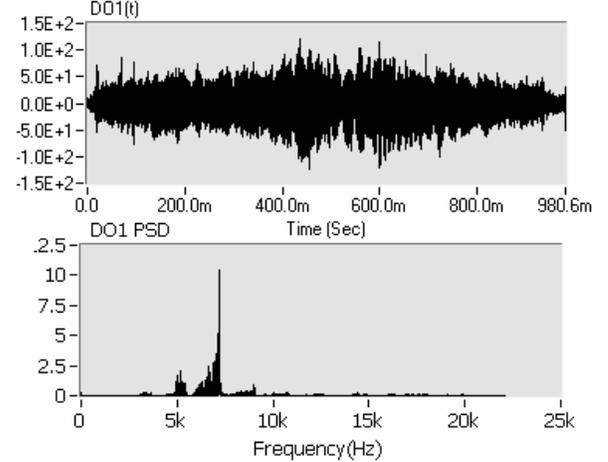


Fig. 2. Dolphin whistle analysis results: whistles signal (DO1s(t)), and associated power spectrum density

Using the acquired whistle signals and the implemented LabVIEW software calculations were performed on different categories of dolphins' sounds as well as a comparison of the spectrograms obtained with the different types of processing algorithms. Thus, the STFT based spectrogram (Fig. 3) obtained for the DO1(t) signal of Fig. 2 provides a good resolution in frequency and less resolution in time for a wide used window (hamming  $R=256$ ) and low resolution in frequency and high resolution in time for a narrower window.

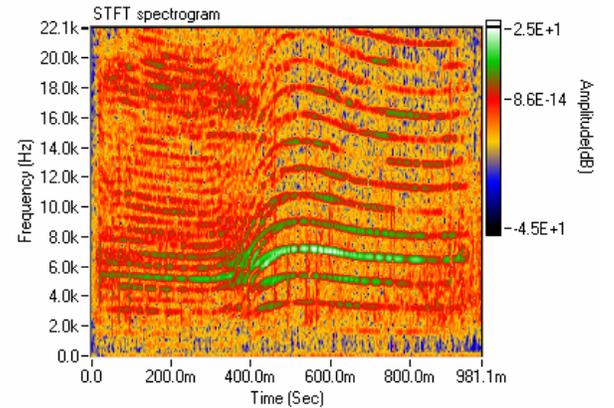


Fig. 3. The STFT spectrogram for a DO(t) whistle sound signal

In order to increase the resolution of the t-f representation the WVD was applied and the obtained results are depicted in Fig. 4. Comparing with the results obtained using the STFT, the WVD presents better

resolution in time and frequency but includes also a set of artifacts (Fig.4).

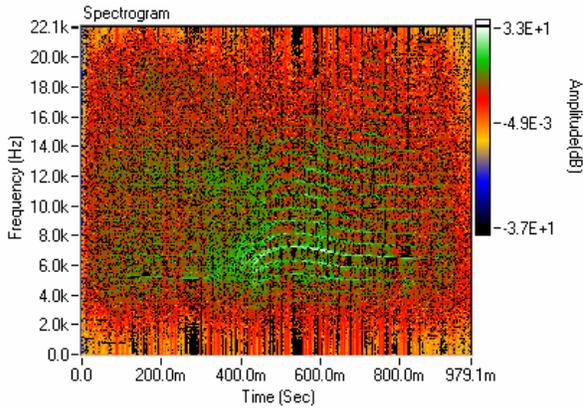


Fig.4. WVD spectrogram of DOI(t) whistles

As mentioned before, the Choi-Williams distribution is a good solution as long as the  $\sigma$  parameter is well chosen. Figure 5 shows the whistles sound spectrogram calculated using the Choi-Williams distribution. As it can be observed the obtained spectrogram permits the identification of the dolphin whistle signature considering the good resolution of the t-f representation.

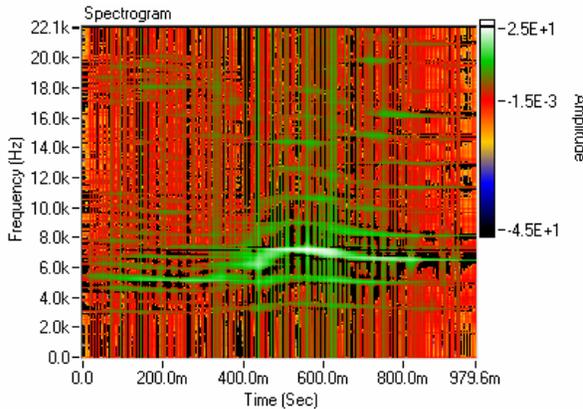


Fig. 5. CWD spectrogram for DOI(t) dolphin whistles sound ( $\sigma=1E-5$ )

Considering that the CWD seems to be a better t-f based method for dolphin whistles signal identification, a second signal DO2(t) was processed (Fig. 6).

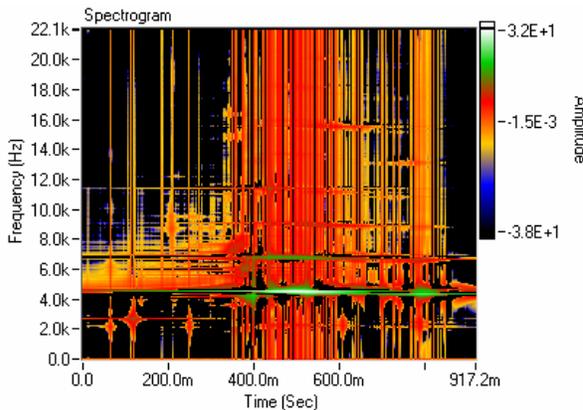


Fig. 6. CWD spectrogram for DO2(t) dolphin whistles sound

Analyzing the t-f results presented in Fig. 5 and Fig. 6 differences between the obtained patterns can be observed. Such differences can be expressed using quantities such as beginning, ending, peak, maximum and minimum frequencies, peak and center times, duration [8] and be used for whistles classification.

Results for burst pulse signals were also obtained. An example is shown in Fig. 7.

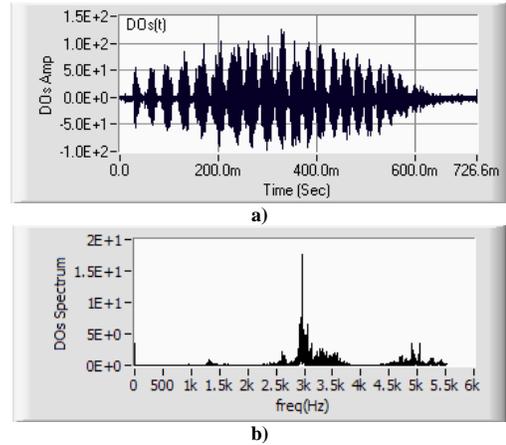


Fig. 7. Dolphin burst pulse analysis results a) the burst pulse signal (DOs(t)), and the power spectrum of the burst pulse (PS-DOs).

As for the whistles case, the t-f characteristics of the burst pulse sounds were obtained using both the STFT and the CWD. The respective spectrograms are depicted in Fig. 8.

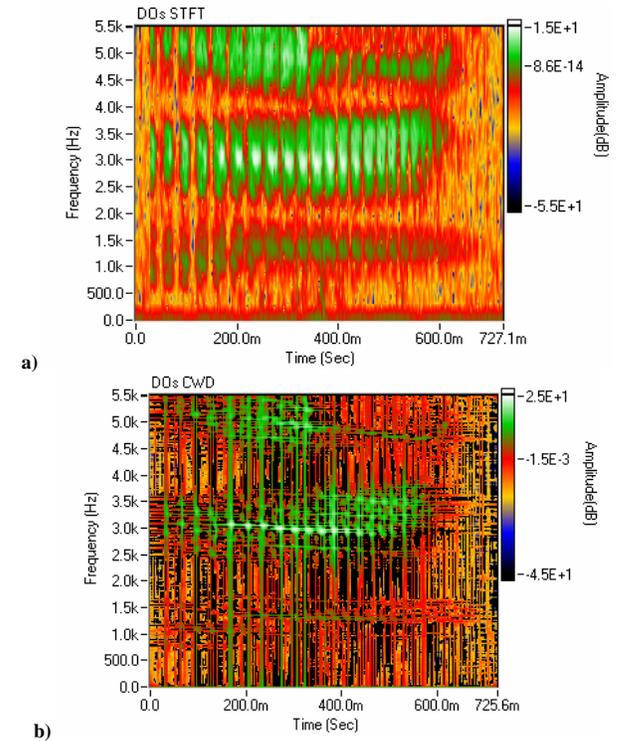


Fig. 8. Dolphin burst pulse TFD results a) STFT spectrogram b) CWD spectrogram

For the spectrogram, the time and frequency resolutions cannot be simultaneously optimized. Fig.8.a reveals lower resolution both in frequency and time domains than Fig.8.b, which means that CWD is a good option for future dolphin sound analysis.

In what the processing time is concerned, the utilization of CWD advises off-line processing. For the particular case of DO1, and using a Pentium4 - 2.8GHz based PC, the STFT computation times are less than 1.5s for 128 to 512 frequency bins while in the CWD case the computation times vary between 7.3s for 128 frequency bins to 114.5 for 512 frequency bins. To reduce the computation time a DSP based solution (e.g. AD Blackfin ADSP-BF533) will be considered in the future.

## 5. CONCLUSION

A distributed virtual system for dolphins' sound acquisition based on VoIP server technology is presented.

Several time-frequency analysis techniques are implemented as part of the system software component in order to analyze different types of sounds and to provide data for future sound classification and dolphin signature identification.

From the results obtained until now, the Choi-Williams algorithm proved to be the better suited for dolphins' whistles and pulse burst classification. Further work is required to confirm the validity of the method.

In the future, and in the context of dolphins' identification through their emitted sounds, the authors will address not only the current problem but also two more challenging issues: identification from composed sound signals and source localization.

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