Distributed Sensor Signal Acquisition, Analysis, and Representation for Environmental Monitoring and Surveillance Applications

WALSAIP

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1 Problem Formulation

There is a need to explore new and efficient ways for the monitoring and surveillance of the environment.

Remote Monitoring and Surveillance (not-physical contact between sensor and phenomenon *e.g. Satellite, Aircraft, Space Craft).*

In-situ Monitoring and Surveillance (physical contact between sensor and phenomenon *e.g. Microphones, thermometers, barometers, WSN*).

Sound is an excellent carrier of information, nevertheless in the "computing world" the information extraction of acoustics signals is not that straight forward.

Can acoustic signals be used for Environmental Surveillance and Monitoring (ESM) applications? We think yes! The "how" and "why" questions are detailed next.

2 Proposed Solution

Why use acoustic signals for ESM applications?

- -Sound is an excellent carrier of information
- -Low cost hardware
- -Omnidirectional propagation
- -Light absence immunity
- -Exploit new technology (HD audio)
- -Challenging and interesting problem

How we extract information relevant to an user?

Using Signal Processing and Mathematical techniques such as:

- -Time-Frequency representation
- -Acoustical Beamforming
- -Sensor Fusion
- -Time series analysis

3 Theoretical Framework

Time-Frequency representation: The Cyclic Short Time Fourier Transform

Given a signal $x[n] \in l^2(Z_N)$ and a window function $v[n] \in l^2(Z_N)$

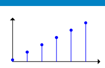
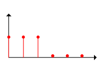
The Cyclic Short-Time Fourier Transform CSTFT is computed as follows:

$$S_{x,v}[m,k] = \sum_{n=0}^{N-1} x[n] \cdot v[<m-n>_N] W_N^{kn} \quad k,n, \in Z_N \qquad \text{Where} \quad W_N^{kn} = e^{-j\frac{2\pi kn}{N}}$$

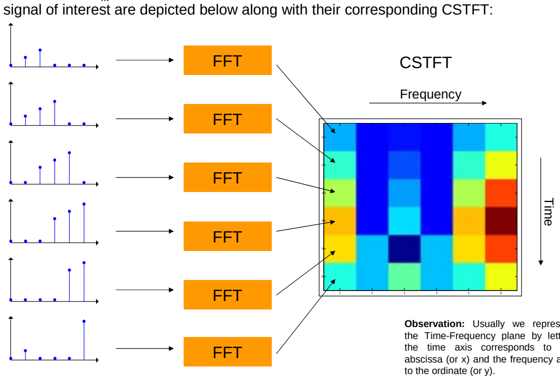
If we let $x_m[n] = x[n] \cdot v[<m-n>_N]$,Then we could write $S_{x,v}[m,k] = \sum_{n=0}^{N-1} x_m[n] W_N^{kn}$

which can be seen as $S_{x,v}[m,k] = DFT\{x_m[n]\} = X_m[k] \qquad k,n, \in Z_N$

Pictorial representation of the CSTFT

Given the signal  and  $n, \in Z_6$

The family of signals $x_m[n]$,which are obtained from the product of the moving window function and the signal of interest are depicted below along with their corresponding CSTFT:



Observation: Usually we represent the Time-Frequency plane by letting the time axis corresponds to the abscissa (or x) and the frequency axis to the ordinate (or y).

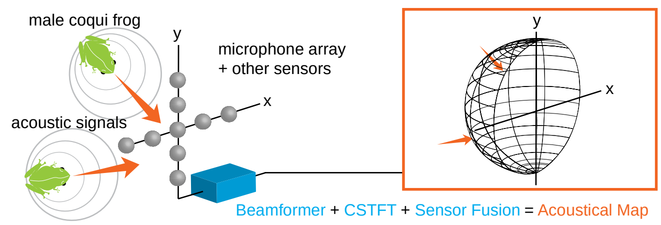
Acoustical Beamforming:

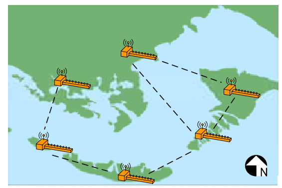
It is a Signal Processing technique which basically allows the localization of acoustic sources based upon the time delay of signals at a microphone array with known characteristics.

Sensor Fusion:

By fusing data from different type of sensors (e.g. temperature, humidity, barometric pressure, solar radiation) with the acoustical signals, measurements errors are reduced, thus the system performance to detect changes increases. For example, it is common that male coqui frogs call during the night and after rainfall, so events like a coqui calling at noon, at low humidity and high temperature should be rare!

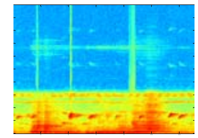
Acoustical Map:





Jobos Bay NERRS (Left), located at Aguirre, PR serves as a local Testbed.

Jobos Bay's unique characteristics have made the reserve a special part of the WALSAIP Project.



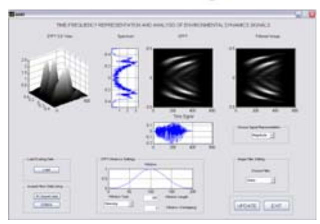
CSTFT of an acoustic signal

4 Implementation Effort

XBow MEP-SYS410 Wireless Sensor Network

Audio-Technica ATR35s Microphone

Initial Sensors deployment



MATLAB GUI for the CSTFT computation

Xilinx Virtex 4

Xilinx Virtex II Pro

5 Conclusions and Future Work

Preliminary results show the potential use of the CSTFT for detection of male coqui frogs calling. Analysis for other animals (we're also interested in birds) is mandatory!

The MATLAB-based GUI developed for computing the CSTFT have proved to be a useful tool for testing different configuration setting such as acoustic signal length, analysis window type, length, and overlapping. A stand-alone hardware implementation is being developed at the time targeting both, FPGA's and DSP's.

Beamforming and sensor fusion stages will dictate overall system feasibility, as a tool for detecting significant changes in the environment.

6 References

Richman, M.S.; Parks, T.W.; Shenoy, R.G. Discrete-Time, Discrete-Frequency, Time-Frequency Analysis. IEEE Transactions on Signal Processing. Vol. 46, Issue 6, pp.1517-1527, June 1998.

W. Sanchez, C. Aceros, D. Rodriguez, "Time Frequency Analysis using Sensors Array Based on Kronecker Products," Proceedings of the IASTED International Conference on Circuits, Signals, and Systems, Florida, USA, 2004.

A. Quinchanegua, D. Rodríguez, "DFT Multi-Beamforming Using Kronecker Computational Structures," IEEE Proceedings of the 3rd International Symposium on Image and Signal Processing and Analysis, ISPA03, Rome, Italy, Sept. 2003.

Ledeczi, A. et. al. Multiple simultaneous acoustic source localization in urban terrain. Fourth International Symposium on Information Processing in Sensor Networks, 2005. (IPSN 2005). pp.491 - 496, April 2005

Christensen, J.J. and Hald, J. Beamforming. Brüel & Kjær Technical Review. No. 1, 2004

Hall, David L. and Llinas, James. Handbook of Multisensor Data Fusion. CRC Press LLC, 2001

Rice University Time Frequency DSP:
http://dsp.rice.edu/software/tfa-background.shtml

Jobos Bay National Estuarine Research Reserve System (NERRS):
http://ctp.uprm.edu/jobos/index.html

Control of Coqui frog, University of Hawaii at Manoa:
http://www.ctahr.hawaii.edu/coqui/index.asp

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