Université de Bordeaux - LOMA UMR5798 CNRS

Master 2 Internship proposal
Time-frequency analysis of the non-stationary rheology of living systems: from continuous wavelet transforms to fractional wavelet transforms

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Thesis possibility after internship: YES Funding: YES If YES, which type of funding: ANR

Abstract
The wavelet transform is a mathematical time-frequency (time-scale) decomposition method introduced in the early 1980s. It has been applied to a number of fields including physics, physical chemistry, biology, signal and image processing, differential and integral equations, material engineering, mechanics, economics, epidemics, ... Real experimental signals (for instance creep or relaxation signals on living cells and tissues which are produced by the partner team of this project) are very often non-stationary (they contain transient components), and involve a rather wide range of frequencies. Exponential relaxation functions have been generalized with Mittag-Leffler functions to better fit frequency dispersive (fractional) rheology of biomaterials. Standard Fourier analysis is indeed inadequate in these situations since it provides only statistical information about the relative contributions of the frequencies involved in the analyzed signal. The possibility to perform simultaneously a temporal and frequency decomposition of a given signal was first proposed by Gabor [Gabor1946] for the theory of communication. Later on, two distinct wavelet transform methods were developed in parallel: (i) a continuous wavelet transform (CWT) and (ii) a discrete wavelet transform. For singular (self-similar or multifractal) signals or images, the CWT transform rapidly became a predilection mathematical microscope to perform space-scale analysis and to characterize scale invariance properties. In particular, it was used to elaborate a statistical physics formalism of multifractals [Bacry1993, Arneodo1995]. During the past 30 years, the CWT was used for biological applications, on both one-dimensional (1D) signals and two-dimensional (2D) images.

Each wavelet component used for such time-frequency decompositions is usually constructed as a scalable bandpass filter in the frequency domain, and therefore remains limited to a bounded frequency interval. Recently, researchers have come up with new mathematical transforms to analyze such signals, namely, fractional Fourier transforms (FrFT), short-time fractional Fourier transforms (STFrFT), Radon-Wigner transforms (RWT), ridgelet transforms (RT), …. In order to analyze non-stationary signals whose FrFT spectral characteristics change with time, in the same line as Gabor transform, short-time FrFT were proposed to provide a joint representation of a signal in both time and FrFT domains, rather than just a FrFT domain representation. Although STFrFT has rectified almost all the limitations of FrFT, it remains limited in the case of real signals having high spectral components for short durations and low spectral components for long durations. This limitation can be circumvented with the Fractional Wavelet Transform (FrWT) [Mendlovic1997]. The FrWT inherits the excellent mathematical properties of wavelet transform and FrFT along with some fascinating properties of its own. These properties make FrWT a useful mathematical tool in signal and image processing with numerous advantages over conventional wavelet transform.

The purpose of this internship is to compare the performance of CWT (real and complex continuous wavelets) and FrWT for the analysis of model signals with a time-varying frequency content. Several fractional wavelets which have been proposed in the literature will be tested on model signals to discriminate time-invariant additive noise from non stationary components. The model signals will be constructed from fractional differential or integral stochastic equations, so as to mimic real rheological signals recorded from living cell samples. In particular, the transition from a quiescent state (arrest in the cell division cycle) to an active state (non stationary) will be studied. The objective of this project is to propose a non-intrusive, real time tool (as compared to intrusive fluorescence staining) to track temporal phase transitions during the cell cycle interphase (growth of the cell volume and mass) in both health and disease.

References:

A. Arneodo, E. Bacry, J. Muzy, The thermodynamics of fractals revisited with wavelets, Physica A 213, 232-275 (1995).
E. Bacry, J. F. Muzy, A. Arneodo, Singularity spectrum of fractal signals from wavelet analysis: Exact results, J. Stat. Phys. 70, 635-674 (1993).
D. Gabor, Theory of communication, J. Inst. Electr. Eng. 93, 429-457 (1946).
D. Mendlovic, Z. Zalevsky, D. Mas, J. Garcia, C. Ferreira, Fractional wavelet transform Appl. Opt., 36, 4801-4806 (1997).