Laser Doppler flowmetry signals: pointwise Hölder exponents of experimental signals from young healthy subjects and numerically simulated data

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Abstract — **We analyze the complexity of laser Doppler flowmetry (LDF) signals which give a peripheral view of the cardiovascular system. For this purpose, experimental and numerically simulated LDF signals are processed. The experimental signals are recorded in young healthy subjects. The numerically simulated LDF data are computed from a model containing six nonlinear coupled oscillators reflecting six almost periodic rhythmic activities present in experimental LDF signals. In the model, the oscillators are coupled with both linear and parametric couplings in order to represent cardiovascular system behaviors. To our knowledge this modeling has never been proposed yet. The complexity of all the experimental and simulated signals is studied by the computation of pointwise Hölder exponents. The latter identify the possible multifractal characteristics of data. The pointwise Hölder exponents are determined with a parametric generalized quadratic variation based estimation method first calibrated from white noise measures. The results of our signal processing analysis show that experimental LDF signals are weakly multifractal for young healthy subjects at rest. Furthermore, our findings together with another recent work of our group show that pointwise Hölder exponents of the simulated data do not describe the ones of the young healthy subjects but are closer to the ones of elderly healthy people. This paper provides useful information to go deeper into the modeling of LDF data, that could bring enlightenment for a better understanding of the peripheral cardiovascular system.**

Keywords — **Laser Doppler flowmetry, multifractality, Hölder exponent, nonlinear oscillator, biomedical engineering**

I. Introduction

Laser Doppler flowmetry (LDF) is commonly used in clinical research for monitoring microvascular perfusion. LDF signals are generated by the interaction between photons of a laser light and moving scatterers, mainly red blood cells. Both concentration and velocity of the moving scatterers affect the LDF perfusion estimate [1].

In this paper, we analyze the complexity of LDF signals which give a peripheral view of the cardiovascular system. For this purpose, experimental and numerically simulated LDF signals are processed. The experimental signals are recorded in young healthy subjects. Recent works have shown that LDF signals, recorded in young healthy subjects at rest, are weakly multifractal [2], but that aging can lead to a reduced multifractality [3]. This information is important as it could help in the modeling of the peripheral cardiovascular system: an accurate modeling should behave in the same way as the system it aims to reproduce. For LDF signals, a set of five nonlinear oscillators coupled with linear couplings has recently been proposed as a theoretical model [4]-[6]. We propose herein to numerically simulate, for the first time, LDF signals with *six* nonlinear oscillators (reflecting six almost periodic rhythmic activities present in experimental LDF signals) coupled with a combination of *both* linear and parametric couplings (in order to represent cardiovascular system behaviors). To analyze the multifractality of these simulated signals, a computation of their pointwise Hölder exponents is done in comparison with the ones of experimental LDF signals. For the computation of the Hölder exponents, we propose to use the parametric generalized quadratic variation (GQV) based estimation method as the latter, being applied on microvascular data, has proved to give interesting results [2], [4]. Moreover, in order to have a better interpretation of the results, the GQV based estimation method is first calibrated with a measure of white noise.

Our paper is organized as follows: we first introduce the theoretical model of LDF signals. Then, the theory of the GQV method is presented, as well as the tool used for calibration. We then apply the GQV method on simulated and experimental LDF data and present the results that we comment. Finally, we end with a conclusion.

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