Speckle Characterization by Fractional Parameters: preliminary results before application to the discrimination of cardiopathies from echocardiographic images

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Speckle Characterization by Fractional Parameters: preliminary results before application to the discrimination of cardiopathies from echocardiographic images

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***Abstract* - To this day, echocardiography does not allow to discriminate certain pathologies such as, Hypertrophic Cardiomyopathy (HCM) and cardiac amyloidosis. Therefore, we attempt to define new echographic markers suited for this discrimination purpose. The work presented in this paper concerns the evaluation of the ability of fractal parameters to characterize speckle properties. For this purpose, we carried out an experiment by capturing the transmission of a laser light through a layer of milk thanks to a lensless camera. The obtained images present speckle that can be changed either by modifying the milk temperature or by changing its thickness. Thus, we evaluated how two fractal parameters (Hurst exponent and Fractional Dimension) could take into account these modifications of the speckle properties. This preliminary work leads to good results that we currently adapt in order to discriminate hypertrophic heart diseases on a database of echocardiographic images under development.**

***Index Terms* - Image Processing, Ultrasound, Optical Imaging.**

I. INTRODUCTION

Cardiovascular diseases are one of the main causes of morbidity and mortality in industrial countries. Prevalence of cardiovascular diseases is increasing because of the aging population [1]. Cardiac hypertrophy can be observed in various cases, such as in sarcomeric hypertrophic cardiomyopathy (HCM) and is generally defined by cardiomyocyte hypertrophy. The main cause of these cardiac infiltrative pathologies is cardiac amyloidosis[2, 3]. Cardiac amyloidosis is clearly under-estimated in the aging population and is majorly represented by Senile Amyloidosis or wild-type transthyretin amyloidosis (WT-TTR). Two other forms of cardiac amyloidosis also exist for the aging population: transthyretin-related hereditary amyloidosis (m-TTR) and Amyloid Light-chain (AL) Amyloidosis.
Echocardiography is the routine examination to diagnose cardiac hypertrophy [4]. However, echocardiography cannot distinguish true cardiac hypertrophy from protein infiltration of the extracellular matrix leading to the increase in the left ventricular wall thicknesses [2].

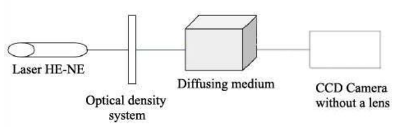

Figure 1: The experimental setup for the speckle image acquisition.

Our hypothesis is that tissues of different structures will generate different acoustic diffusion phenomena expressed by a specific "speckle" in ehocardiographic images. The fractal approach has been found to be appropriate to study a non-linear and non-stationary phenomenon, such as speckle [5]. Recently, in our laboratory, a new fractal approach was developed to characterize speckle produced by the interaction of laser with a diffusing medium [6, 7, 8, 9]. It is based on the computation of two parameters : the Hurst exponent and the Fractional Dimension.
This paper deals with verifying and validating the capability of these parameters to characterize the speckle induced by a laser light in a diffusing medium whose physical factors are controlled.
The good obtained results highlight that these fractional parameters could be used to define new echographic markers suited to discriminate Cardiac Hypertrophies.

II. MATERIALS AND METHODS

We used a database of speckle images formed in our laboratory [8]. The experimental setup consists of a laser beam that illuminates the diffusing medium, the milk layer in our case, through an optical density system to avoid saturating the CCD (Charge-Coupled Device) sensor of the camera. A camera without a lens is placed after the diffusing medium. The experimental setup for the speckle image acquisition is shown in Figure 1. An example of the captured speckle images is presented in Figure 2.
Two fractal parameters, the Hurst exponent (H) and the Fractional Dimension (D), are used to characterize the speckle captured from the observed medium. H originates from a Brownian-motion approach, while D stems from a fractal approach. H is directly related to D by the following relation: $D = 2 - H$. The Hurst [10] exponent's use

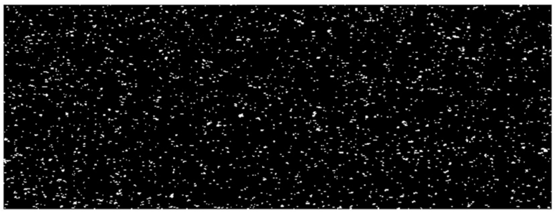

Figure 2: An example of the captured speckle images of a milk layer by a camera without a lens.

is very wide in the characterization of stochastic processes and is usually associated with auto-correlation that highlights long-term memories in signals [11]. Hurst describes a chaotic series by an exponent that represents the probability for an event to be followed by a similar event [8]. An estimate of the Hurst exponent can be made from the following diffusion function [12]:

$$F_D(\zeta) = E|X(t + \Delta t) - X(t)|^2 \propto |\Delta t|^2 H \quad (1)$$

where E stands for “mathematical expectation”. H can then be estimated from the slope of the plot of the diffusion function on the logarithmic scale [6]:

$$logF_D(\Delta t) = K + 2Hlog|\Delta t| \quad (2)$$

H may vary between 0 and 1, with higher values indicating less roughness, and therefore a smoother texture [13].

III. RESULTS

The Fractional Dimension D and the Hurst exponent H derived from it were calculated from the milk images captured by the lensless camera. The effect of changing the milk temperature was studied at the first place by raising the temperature from 30° to 55° (by steps of 5°). Ten images were captured at every temperature, resulting in 60 images in total. For each image, H and D were computed then the average values of all the ten images corresponding to the same temperature were calculated. At a second time, the milk layer was progressively increased, and 14 thickness variations were considered. Five images were captured for every thickness, thereby resulting in 70 images in total. In the same way, the average H and D were computed for the images of the same thickness.

The results of the Hurst exponent H with respect to the eventual changes in the milk layer temperature are presented in Figure 3. The variation of H relative to the successive milk layer thickness changes is also displayed in Figure 4. Table 1 shows the average value of H for each group of the ten speckle images captured at every temperature of the milk diffusing medium. Table 2 displays the average values of H for each group of the five speckle images captured at every thickness of the milk diffusing medium (the listed thicknesses are in increasing order).

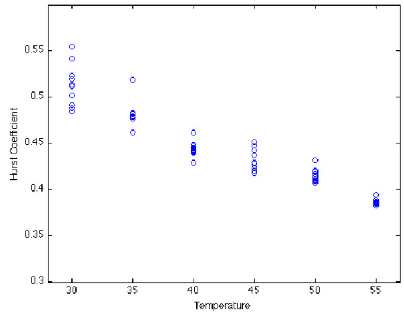

Figure 3: The variation of H with temperature for the milk speckle images.

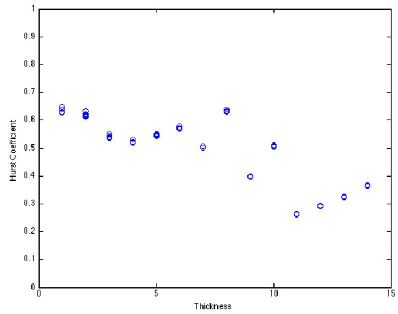

Figure 4: The variation of H with milk layer thickness for the milk speckle images.

IV. DISCUSSION-CONCLUSION

As expected, increases in temperature and in thickness both cause an elevated roughness in the texture of the resulting speckle image. In fact, the photons directed from the laser source to the diffusing medium follow random optical paths. The arbitrary dephasing of the corresponding waves by the diffusing medium generates random interferences which can be either constructive (causing white regions) or destructive (causing dark regions) [14]. As a result, a higher temperature of the diffusing medium causes the molecules to move faster thereby generating speckle more intensely (causing more granulation or shattering in the images). The increased thickness of the diffusing medium results in the same phenomenon as it induces a higher number of interactions between the emitted photons and the milk particles.

This is consistent with our experiments, where the resulting values of the Hurst Exponent H show that the increase in the temperature of the milk diffusing medium causes H to decrease (Figure 3 and Table 1), knowing that a lower H indicates a more granular texture. On the other hand, we observe that increasing the milk layer thickness leads to changes in H that are less clearly correlated (Figure 4 and Table 2). We can assume that the layer thickness induces physical modifications that are probably more complex than the ones caused by the increase in temperature which mainly affects the kinetic energy of the molecules.

Temperature	**Hurst Exponent**
30°C	0.5131±0.0114
35°C	0.4825±0.0071
40°C	0.4441±0.0041
45°C	0.4321±0.0059
50°C	0.4157±0.0036
55°C	0.3880±0.0019

Table 1: The average values of the Hurst Exponent for every temperature value of the milk diffusing medium.

Thickness	**Hurst Exponent**
Thickness 1	0.6344±0.0044
Thickness 2	0.6202±0.0040
Thickness 3	0.5419±0.0031
Thickness 4	0.5243±0.0028
Thickness 5	0.5475±0.0017
Thickness 6	0.5738±0.0020
Thickness 7	0.5020±0.0015
Thickness 8	0.6350±0.0021
Thickness 9	$0.3972 \pm 5.2249 \times 10^{-4}$
Thickness 10	0.5064±0.0011
Thickness 11	$0.2634 \pm 2.9496 \times 10^{-4}$
Thickness 12	$0.2922 \pm 2.5348 \times 10^{-4}$
Thickness 13	$0.3235 \pm 4.1322 \times 10^{-4}$
Thickness 14	$0.5654 \pm 2.7295 \times 10^{-4}$

Table 2: The average values of the Hurst Exponent for increasing milk layer thicknesses.

In conclusion, in this paper, we verify that H and D are suited to characterize changes of speckle properties and could therefore be used to attempt to discriminate Cardiac Hypertrophy pathologies through echocardiographic imaging. Consequently, the obtained results will be adapted to perform this discrimination study of hypertrophic heart diseases on a database of cardiac ultrasound images under development.

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