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Local Orientation Imaging for Tissue Structure Using Ultrasound Imaging

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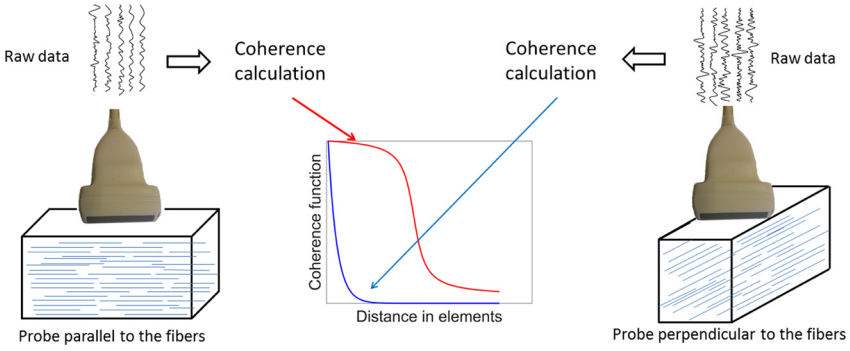
Highlights

- A method determining local anisotropic was studied.
- We are the second team to study this method.
- Results obtained with this method are very hopeful.

Graphical abstract



Abstract

Cardiovascular diseases and myocardium infarction are main causes of death worldwide. After acute myocardium infarction, remodeling occurs within weeks resulting from a loss of cardiomyocytes in the damaged myocardium, and subsequent changes with regional tissue organization. Imaging methods able to render the local tissue directivity would be useful to detect the lesion and evaluate its extent. In this field, diffusion MRI is the reference. However, because of its long acquisition time, it is not simple to make an image of the moving heart *in vivo*. For this reason, faster methods using ultrasound were developed. The purpose of this work is to study the spatial coherence method with an ultrasound plane wave ultrafast imaging approach. Simulations have been performed with CREANUIS software on a medium constituted by many angled fibers in order to mimic the orientation changes that appear in the myocardium. Experimental data were also acquired on a wires phantom. The wires of the phantom were set in parallel planes with changing orientation between [−45° and 45°] at a depth between [20 and 40 mm]. Results obtained with the method have permitted to evaluate properly the orientation with RMSE of 11.2° and 16.5° for simulation and experiments, respectively.

Keywords: Ultrasound; Heart; Fibers; Spatial coherence

1. Introduction

Cardiovascular disease remains the leading cause of death in adults and in industrialized countries (WHO, update 2014). Among them, ischemic heart disease is the main cause of death and hospitalization with infarct size being the major factor of prognosis after acute myocardial infarction (AMI). It is a main cause of heart failure. Interventions to reduce final infarct size thus have a major clinical interest in improving the prognosis of patients referred for myocardial infarction. The current management of myocardial infarction is to reperfuse the my-

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ocardium as soon as possible by primary percutaneous coronary intervention (PCI). The muscular cells in the heart tissue, the cardiomyocytes, are elongated. They are assembled in fibers which are elongated too. In the unfortunately unsaved myocardium, cell loss is irremediable leading to a progressive local disorganization and change in the tissue structure then functioning of the heart [1]. Cells are too small to be detected by ultrasounds but their organization in the myocardial tissue and so their orientation is very important and can be detected. An imaging method able to measure the local tissue organization, structure and directivity would be extremely useful to qualify and characterize the lesion. The purpose of this work is, thus to develop an ultrasound based imaging method that enables to determine the local tissue orientation in the heart and provide new solutions to enable advanced tissue characterization by ultrasound imaging.

Imaging of the fibers orientation can already be performed using diffusion MRI [2] which is the reference in this field. However, long acquisition time is still required (approximately 25 min in clinical cases), with motion of the organs being a main source of bias to circumvent prior quantitative estimates of the tissue structure could be obtained with the high reliability needed for clinical application. This is why, faster methods allowing to obtain images *in vivo* at high frame rate have to be developed: in this context ultrasound is an excellent candidate. Indeed, ultrasound allows imaging the heart at several tens of frames per second in conventional imaging and can even reach several thousand frames per second with high frame rate strategies. Only three methods have been developed previously to image tissue anisotropy based on ultrasound: shear wave speed propagation [3], the backscatter coefficient [4] and the spatial coherence [5–7].

The aim of this paper is to present our preliminary results of the spatial coherence method proposed in [5]. One main objective was to evaluate the possibility to reproduce the results in [5].The method is presented in the next section and then results obtained with this method from simulations and experimental acquisitions are presented and discussed.

2. Method

There are two ways to apprehend spatial coherence: coherence function and coherence imaging. They are based on the same transmission scheme with plane wave insonification. Only coherence function and its applications are detailed in this part.

2.1. Coherence function

The evaluation of the spatial coherence based on coherence factors calculated between the pre-beamformed signals obtained from focused ultrasound transmissions was initially proposed in [8]. However, the frame rate that can be achieved with focused transmission is too low to study *in vivo* the heart in three dimensions. In this case, ultrafast imaging based for example on plane wave imaging is more suitable. Plane wave imaging can reach several thousand volumes per second depending on the number of plane waves in transmission and the required depth used for the reconstruction. This is the reason why spatial coherence imaging was extended to plane wave imaging [5]. However, in order to calculate the coherence function it is necessary to have focused pre-beamformed RF signals. Therefore, a coherent plane wave compounding of the pre-beamformed signals is necessary as explained in [9] and detailed hereafter.

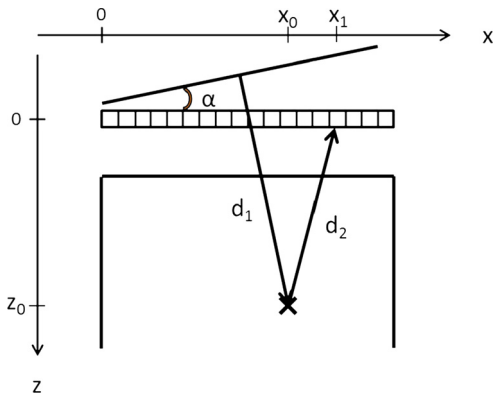

Fig. 1. Delay calculation for each point of the medium to each element on the probe. d_1 corresponds to the distance for the wave to reach the point-of-interest and d_2 corresponds to the distance for the wave to travel from the point-of-interest to the probe element in x_1.

In ultrasound plane wave imaging, a plane wave is transmitted in the medium and is scattered by the inhomogeneities of the medium. The echoes received by the probe elements are recorded and beamformed to produce an image [10]. These delays used to perform receive focusing are calculated for each point in the medium. For each plane wave a so-called low resolution image is beamformed and these images are coherently summed up to obtain the final image.

Spatial coherence calculation needs focused or rephased single element signals both in transmit and receive. In order to obtain these signals with plane wave transmissions, it is necessary to calculate the right delays for each point of the medium and each probe element. By choosing the right delays and after summation of the rephased signals from all plane waves, single element signals, written S, are obtained. This signals are equivalent to those obtained after receive focusing of the single element signals from focused transmissions. By applying delays on the pre-beamformed signals and summing them up, a synthetic transmit and receive focus is created. The travel time for the wave, with an α angle, to reach the scatterer (d_1 on Fig. 1) and travel back to the element in x_1 (d_2 on Fig. 1) were calculated for each spatial point [9].

$$d_1 = x_0 * \sin(\alpha) + z_0 * \cos(\alpha) \tag{1}$$

and

$$d_2 = \sqrt{z_0^2 + (x_0 - x_1)^2} \tag{2}$$

The focused or *rephased* signals written S_i where i corresponds to the probe element number, are used in the spatial coherence calculation for each spatial point. It consists of calculating a correlation factor between signals received by the different probe elements. Thus, for a point of the medium and after