Noise correlation based elastography using digital holography in anisotropic media

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Over the last decades, large number of methods have been developed to combine quantitative elastography with biomedical imaging modalities [1-3]. Tissues stiffness has been used since the very beginning of medicine to diagnostic pathologies through palpation because cells and tissues are characterized by their intrinsic mechanical properties. Indeed, mechanical properties of cells are related to their structures and function and change of those properties can reflect certain pathology and also cellular healthy state. Adding this contrast to biomedical imaging is a powerful help to diagnostic.

Elastography in OCT has been introduced by Schmitt in 1998. Since this pioneering work, a large number of methods were developed. In 2016, Nguyen et al introduced in OCT a new passive shear wave elastography approach that overcame a major limitation of classical methods: the need of a well-controlled and well-synchronized shear wave source [5]. Recently, our group proposed an adaptation of this method to Digital Holography [6]. In this study, we propose to take advantage of the 2D acquisition of Digital Holography in order to quantify mechanical (stiffness) anisotropy within soft media.

The principle is to refocus numerically the diffuse shear wave field at each pixel using noise-correlation algorithms. The 2D refocusing gives not only access to the local shear wave wavelength directly related to the local shear wave speed [6] but also intrinsically to the mechanical anisotropy through the 2D shape of the refocusing as illustrated figure 1.

The experimental setup used for this study is an off-axis digital holography setup using a single mode LASER at 671 nm with 20x20 μm resolution over 10x10mm² field-of-view. It allows to record shear wave propagation with a typical sensitivity of 10 nm at 500 frames/s.

We present here our latest result with the validation of the method on finite difference simulation and polymer test sample with homogeneous optical properties and controlled mechanical heterogeneous/anisotropic properties that mimic biological tissues (PVA [7]) and our first results on ex vivo biological sample.

The method to measure stiffness anisotropy from diffuse shear wave field is validated numerically on finite difference simulation and experimentally.

Figure 1: 2D refocused field calculated from a diffuse shear wave field simulated using finite difference method (perfect elastic medium). a) correspond to an isotropic medium with shear wave speed along the x axis V_x and y axis V_y of 3m/s. b) correspond to an anisotropic medium with $V_x = 3\text{m/s}$ and $V_y = 1.5\text{m/s}$.

References

- [1] MARIAPPAN, Yogesh K., GLASER, Kevin J., et EHMANN, Richard L. Magnetic resonance elastography: a review. *Clinical anatomy*, 2010, vol. 23, no 5, p. 497-511.
- [2] TANTER, Mickael, BERCOFF, Jeremy, ATHANASIOU, Alexandra, et al. Quantitative assessment of breast lesion viscoelasticity: initial clinical results using supersonic shear imaging. *Ultrasound in medicine & biology*, 2008, vol. 34, no 9, p. 1373-1386.
- [3] KENNEDY, Brendan F., WIJESINGHE, Philip, et SAMPSON, David D. The emergence of optical elastography in biomedicine. *Nature Photonics*, 2017, vol. 11, no 4, p. 215.
- [4] SCHMITT, Joseph M. OCT elastography: imaging microscopic deformation and strain of tissue. *Optics express*, 1998, vol. 3, no 6, p. 199-211.
- [5] MARMIN, Agathe, CATHELIN, Stefan, and NAHAS, Amir. Full-field passive elastography using digital holography. *Optics Letters*, 2020, vol. 45, no 11, p. 2965-2968.
- [6] NGUYEN, Thu-Mai, ZORGANI, Ali, LESCANNE, Maxime, et al. Diffuse shear wave imaging: toward passive elastography using low-frame rate spectral-domain optical coherence tomography. *Journal of biomedical optics*, 2016, vol. 21, no 12, p. 126013.
- [7] CHATELIN, Simon, BERNAL, Miguel, DEFFIEUX, Thomas, et al. Anisotropic polyvinyl alcohol hydrogel phantom for shear wave elastography in fibrous biological soft tissue: a multimodality characterization. *Physics in Medicine & Biology*, 2014, vol. 59, no 22, p. 6923.