ACOUSTIC VORTICES AND PHASE GRADIENT TECHNIQUES FOR ULTRASOUND ELASTOGRAPHY

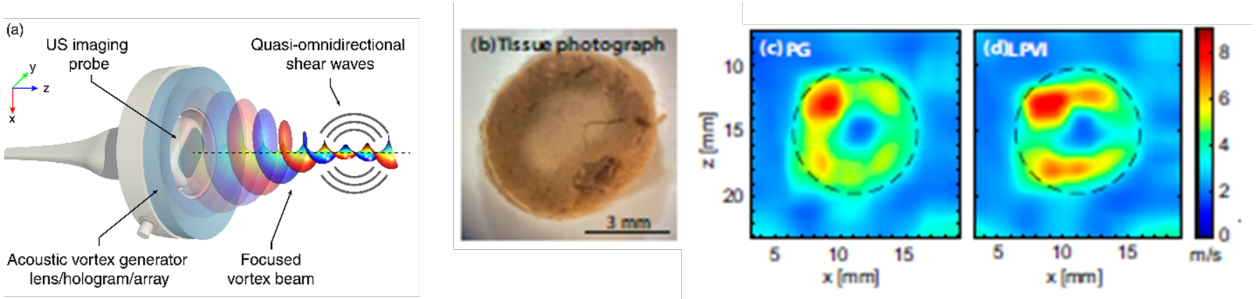
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Background: During the last decades ultrasound elastography has been developed as a reliable technique for medical diagnosis. Commonly, tissues are deformed under the action of the acoustic radiation force by using a pushing acoustic beam. However, using focused beams the acoustic radiation force can only push the tissue in the direction of the propagation of the beam and the degree of freedom to displace the tissue in other directions is limited. In addition, using spectral methods the computational costs associated with calculating the wavenumber of the propagating waves using spatiotemporal Fourier transforms can be remarkably high.
Aims: We present an efficient method for ultrasound elastography based on acoustic vortices to transfer to tissues, in addition to linear, angular momentum. By twisting the tissue in alternating angles, efficient shear wave generation is achieved. Then, to generate the image, we propose a real-time method for shear wave velocity mapping combining spatial filtering and phase gradient techniques.
Methods: A focused vortex beam is generated by a 1.1-MHz piezoelectric source and a helicoidal phase-plate lens that allows the selection of the topological charge of the vortex. The vortex beam was focused into a CIRS-049 phantom and ex-vivo liver-tissue phantoms, and displacements were measured by a 5-MHz probe using a 2-kHz-PRF US and a Vantage system (Verasonics, USA). Then, the angular spectrum of tissue shear-wave displacements is filtered in a directional and bandpass manner. Next, the gradient of the harmonic displacement phase map is calculated to locally estimate the wavenumber. Finally, the phase velocity map at the selected frequency is obtained. Results were compared with a spectral wavenumber estimator for local phase velocity imaging using a pushing beam [1]. Computational times were calculated for different map sizes. **Results:** When the vortex is focused on the tissue phantom, displacement data shows that the angular momentum is transferred to the medium at the focal spot. Under time modulation, this results in a point source of torsional shear waves that quasi-omnidirectionally propagates away from the focus. Then, retrieved elasticity maps show a strong similarity with those obtained by state-of-the-art spectral techniques, but maps are generated in real-time. Experimental results show that the values of 2.50±0.03 m/s and 4.23±0.07 m/s for the background and inclusion, respectively, prove a good agreement with the manufacturer's values of 2.45 m/s and 4.50 m/s, with relative errors ranging from 2-5%. Using this approach images are generated two orders of magnitude faster than other spectral techniques [1], therefore, it may be suitable for real-time elastography applications.
Conclusions: First, the use of acoustic vortices to twist the tissue results in a robust excitation of shear waves with quasi-omnidirectional radiation pattern and arbitrary waveform, which have a great impact in imaging quality for elastography. In addition, the combination of the spatial filtering and phase gradient results in a very efficient strategy to compute the viscoelastic maps, suitable for spectral real-time applications.
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References:

[1] P. Kijanka, M. W. Urban, IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control 67 (3) (2020) 526–537



(a) Scheme of the device, (b) photograph of the ex-vivo liver inclusion, (c) shear wave speed using phase gradient and (d) using LPVI method [1].