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Lung ultrasound aberration correction with singular value decomposition beamforming and pulse-coded excitation

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Background: The poor propagation of acoustic waves in air-filled tissues is a challenge for ultrasound imaging. The lung is composed of alveoli, which are tiny air-filled sacs at the ends of the bronchioles, responsible for the exchange of oxygen and carbon dioxide between the lung and the blood. The complex propagation phenomena in these tissues are translated into different image artefacts, and its mere appearance can be profited to diagnose different diseases. However, as information goes beyond anatomy and morphology, trained personnel is needed to interpret images. In this work, we propose advanced beamforming and codding methods for ultrasound imaging reconstruction, with the aim of providing quantitative and automatic methods to evaluate lung tissue.

We use singular value decomposition (SVD) to perform fast aberration correction during real-time ultrasound imaging. The method mitigates aberrations from second-order random scattering allowing for ultra-fast imaging in lung tissue. Importantly, as B-lines do not arise as a multiple random scattering process, the algorithm will keep the B-lines in the image, as this valuable artefact is commonly used to identify diseases. In addition, we incorporate pulse-coded excitations to improve the signal-to-noise ratio and mitigate attenuation in lung tissue. The combination of aberration-free ultrafast imaging with pulse-encoded excitation has the potential to penetrate deeper in lung tissue, allowing its quantitative characterization by ultrasound. In this work, the performance of the above techniques is evaluated in a lung phantom, and safety tests were performed according to international recommendations.

Methods: A lung phantom was constructed using agar-gelatine to simulate skin and muscle tissue, pig ribs to simulate human ribs, a layer of nitrile to simulate pleura and a triphasic porous structure (wet sponge) to simulate lung tissue. Steel wires were placed at different distances into the sponge to quantify the penetration of ultrasound. For the ultrasonic measurements, a research imaging system (Vantage 256) was used, with a 64-channel phased array imaging probe with a centre frequency of 2.7 MHz and a bandwidth between 1.7 and 3.7 MHz, and a 128-channel probe using a central frequency of 7.5 MHz. Two types of transmissions were used, a conventional short pulse and a synchronised sine sweep excitation. On these two emissions, 3 types of beamforming approaches have been applied: planewave compounding, multiple planewave compounding, and multiple planewave compounding using SVD, where a total of 100 transmissions are emitted in an angular scan (-60º to 60º), the IQ image is formed for each of the receptions and an SVD is applied, to obtain an image capable of correcting the aberrations.

Results and conclusions: We have performed a total of 12 tests with the same conditions as the phantom. By comparing the different beamforming and compounding strategies, we observe that by using synchronized sine sweep excitation penetration and the signal-to-noise ratio are increased, and by using SVD beamformer aberrations can be mitigated. The results of this work open the possibility of retrieving valuable information from the microporous structure of lung tissue, allowing the use of quantitative ultrasound and automatic methods to evaluate lung tissue.

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