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Application of Synthetic Aperture Imaging to Non-Invasive Vascular Elastography

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The health of the carotid artery is an important indicator of cardiovascular disease (CVD). The advent of CVD results in reduced elasticity and flexibility of the arterial wall. Non-invasive vascular elastography (NIVE) serves as an effective imaging modality to track these changes in the arterial mechanical properties associated with CVD.

Elastography imaging is performed by subjecting the tissue under investigation to a form of mechanical excitation. The resultant tissue displacement vector is measured and can be used compute the spatial variation of strain within the tissue. These strain maps, known as elastograms, serve as surrogates for tissue elasticity. While elastography can be performed with any imaging modality, ultrasound is portable and inexpensive, and provides images at high frame rates, making it ideal for real-time applications. However, ultrasound based elastography has limitations that have hampered its widespread clinical utility. Specifically, ultrasound can accurately measure the component of displacement only in the axial direction.

The objective of this thesis was to investigate the feasibility of using synthetic aperture (SA) ultrasound imaging to improve displacement estimation, thereby improving the performance of NIVE. We demonstrated, through simulation and experimental studies, that SA imaging can measure axial and lateral displacements at high precision. Compared to conventional ultrasound elastography, SA elastography improved the error in lateral displacements and the resultant strain elastograms by an order of magnitude.

However, the low frame rates and large data volumes required by SA imaging render this approach clinically inviable. To overcome this limitation, we developed a prototype sparse array based elastography system. We demonstrated that a sparse array with as few as eight transmit elements can generate radial and circumferential strain elastograms with a 16x improvement in frame rate and data volume, without degrading image quality. It was also demonstrated that sparse array imaging displayed higher lateral sensitivity than compounded plane wave imaging, producing strain elastograms with a 30\% improvement in image quality.

The success of this novel approach to elastography warrants further pre-clinical investigations. Integration of sparse array elastography in a commercial ultrasound scanner can potentially enhance the clinical utility of vascular elastography.