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Enhanced Resolution Pulse-echo Imaging

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Ultrasound imaging is a non-invasive, non-ionizing, inexpensive, and portable imaging modality that enables real-time diagnosis. However, ultrasound images suffer from relatively poor resolution. Non-blind and blind deconvolution approaches have been developed for resolution enhancement.

In this thesis, in the context of Z-transform and bounded-output and bounded-input stability, stable inverse filtering for deconvolution is considered first. The constraints for stable inverse filters are derived for Gaussian beam patterns in both narrowband and broadband ultrasound imaging systems. Coherent stable inverse filtering (CSIF) is developed and evaluated for lateral resolution enhancement, where results of parameterized stable inverse filters generated from down-sampled and centered/shifted point spread functions are selected through coherent pooling (CP). Coherent deconvolution (CD), a more general framework, is abstracted from CSIF.

This framework is then extended to the axial direction. The CSIF approach was employed, with axial and lateral parameterized stable inverse filters sequentially applied onto the in-phase and quadrature image data. Different CP strategies are also compared, featuring the harmonic mean calculation. Resolution is enhanced in images simulated using Field II [1, 2] and scanned using a Verasonics V1 (Verasonics, Inc., Kirkland, WA, USA) and an L7-4 transducer (Philips Healthcare, Andover, MA, USA) at 5 MHz. The images include tissue-mimicking phantoms and an *in vivo* human carotid artery.

The enhanced coherent deconvolution (ECD) framework with accurate PSF sampling and inter-dimensional filtering is established to address speckle erosion, the major drawback of the proposed framework. As another realization of the CD/ECD framework, coherent Wiener filtering (CWF) replaces the inverse filters in CSIF by Wiener filters, and demonstrated better noise robustness over CSIF.

The framework is further extended to the elevational dimension in 3D, and CWF was performed for resolution enhancement on volumetric data simulated by Field II using a square two-dimensional transducer array. A variable harmonic mean index which takes different portions of the CP candidates can emphasize imaging objects with different characteristics.

Applying our framework to medical ultrasound images, the resolution is enhanced by up to 8.75 times laterally, 10.75 times elevationally, and 20.5 times axially, considering the −6 dB width of the autocorrelation of the envelope images.