A Wireless Ultrasound Imaging System Utilizing Xampling and Frequency Domain Beamforming
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Overview
- A wireless probe performs sub-Nyquist sampling (Xampling) and transmits the low rate data to the server for processing.
- Frequency Domain Beamforming is utilized in the server for image reconstruction.
- The image is displayed on a monitor.
- The quality of the obtained image is similar to that of a state of the art medical ultrasound imaging systems.

Sampling Rate Reduction
- Scan line DFT coefficients are obtained by linear combination of the DFT coefficients of echo signals received by the ultrasonic transducer elements.
- Due to rapid decay of the distortion (weighting) function, only a subset of the DFT coefficients is required, resulting in efficient implementation:

\[ a_n = \frac{1}{M} \sum_{m=0}^{M-1} p_m[n]q_{mn}[k-n] \]

- Fourier coefficients of a distortion function \( q_{mn}(C,T) \) are defined by the geometry of the transducer and computed off-line.

- Sampling rate reduction is obtained by demodulation and narrow band sampling of the ultrasound signal about DC.

Xampling and Frequency Domain Beamforming
- Xampling (Compression and Sampling) is the process of sampling a signal at a low rate in a way that preserves the information required for recovery.
- Frequency Domain Beamforming reconstructs the DFT coefficient of an image scan line from the DFT coefficient of the echo signals detected by the transducer elements.
- Compressed Sensing techniques are utilized to reconstruct successfully scan lines, using a partial set of its DFT coefficients.

Frequency Domain Beamforming: Client-Server Configuration
- Client: Echo signals received by the ultrasonic transducer elements are sampled and transformed to low rate samples in the frequency domain.
- Server: The image is reconstructed through Frequency Domain Beamforming.

Scan Lines Reconstruction by Compressed Sensing
- A typical beamformed signal is comprised of a small number of strong reflections and weaker scattered echoes, thus obeys the stream of pulses model.
- The relationship between the DFT coefficients of the beamformed signal and the unknown parameters of the stream of pulses model can be formalized as a CS problem.
- The parameters vector \( \mathbf{b} \) is obtained by solving an \( \ell_1 \) optimization problem:

\[ \min_{\mathbf{b}} \text{subject to } |H\mathbf{b} - \mathbf{c}|_1 \leq \epsilon \]

Where the vector \( \mathbf{c} \) is a subset of the DFT coefficients of the beamformed signal.

Demo
- Wireless Ultrasound System lab setup
- Acquisition is performed by a commercial state of the art ultrasound imaging system, on which the Xampling operation is simulated.
- Low rate sub-Nyquist frequency domain samples are transmitted over a wireless link to the server.
- Frequency domain beamforming is performed by the server.
- The image is displayed on a monitor.

Results
- Phantom image obtained by a commercial, state of the art system
- Phantom image obtained by the wireless ultrasound demo system