S_X_MPL
Signal Acquisition Modeling and Processing Lab

Electrical Engineering Department
Electronics
Computers
Communications

TECHNION
Israel Institute of Technology

S_X_MPL 2015
"Xampling The Future"

A Wireless Ultrasound Imaging System Utilizing Xampling and Frequency Domain Beamforming

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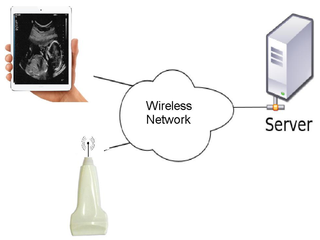
Overview

- 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.



Time Domain Beamforming in State of the Art Systems

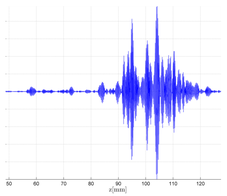
- Focusing along a certain axis – reflections originating from off-axis are attenuated (destructive interference pattern) and SNR is improved.
- Oversampling is required to achieve a high resolution digital beamforming.

Non-linear scaling of the received signals

$$\Phi(t;\theta)=\frac{1}{M}\sum_{m=1}^{M}\varphi_m\left(t-\frac{1}{2}\left(t-\sqrt{t^2-4(\delta_m/c)t\sin\theta+4(\delta_m/c)^2}\right)\right)$$

δ_m - distance from m'th element to origin

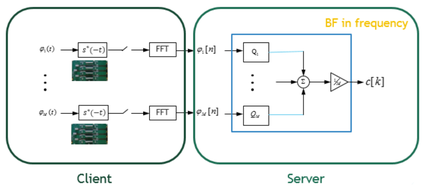
Beamforming in the time domain



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.

Sampling Rate Reduction

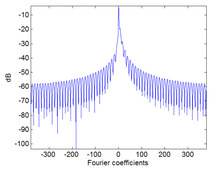
- Scan line DFT coefficients are obtained by linear combination of the DFT coefficients of echo signals received by the ultrasonic transducer elements.
- Due to rapid decay of the distortion (weighting) function, only a subset of the DFT coefficients is required, resulting in efficient implementation:

$$c_k=\frac{1}{M}\sum_{m=1}^{M}\sum_{n}\varphi_m[n]Q_{k,m;\theta}[k-n]$$

DFT coefficients of BF signal

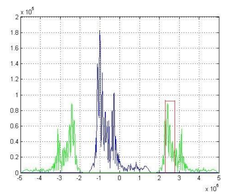
DFT coefficient of signal detected at element m, obtained by Xampling

Fourier coefficients of a distortion function $q_{k,m}(t;\theta)$, are defined by the geometry of the transducer and computed off-line.



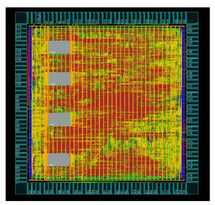
$\{Q_{k,m;\theta}[n]\}_n$ is characterized by a rapid decay

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



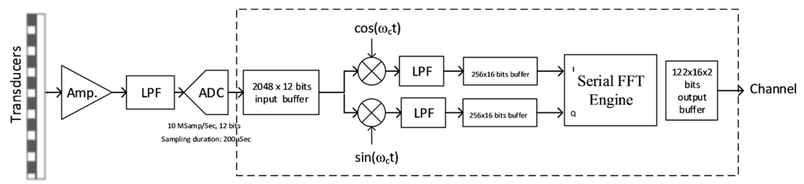
Spectrum of the a received echo signal (green) and IQ demodulated signal (blue)

Xampler



Xampler ASIC layout

- Echo signals received by the ultrasonic transducer elements are sampled and transformed to the frequency domain by a custom designed **Xampler** component.
- **Xampler Input:** 2048 time domain samples.
- **IQ demodulation and decimation** provide for sampling rate reduction.
- The **Serial FFT Engine** transforms the samples to the frequency domain.
- **Xampler Output:** 122 complex DFT coefficients. The acquisition of this subset of signal's DFT coefficients is equivalent to sub-Nyquist sampling.
- **Xampling Gain:** 244/2048 ≈ 1/8 saving in raw data rate.



Xampler Block Diagram

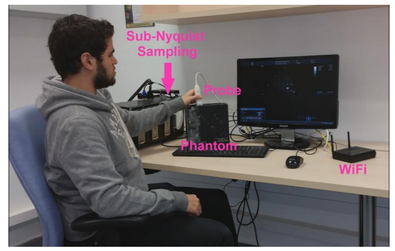
Scan Lines Reconstruction by Compressed Sensing

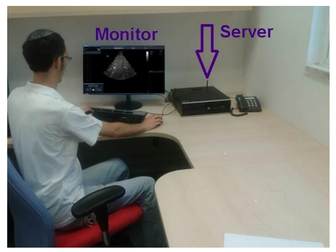
- A typical beamformed signal is comprised of a small number of strong reflections and weaker scattered echoes, thus obeys the stream of pulses model.
- The relationship between the DFT coefficients of the beamformed signal and the unknown parameters of the stream of pulses model can be formalized as a CS problem.
- The parameters vector **b** is obtained by solving an ℓ_1 optimization problem:

$$\min_{\mathbf{b}}\|\mathbf{b}\|_1 \text{ subject to } \|\mathbf{HDb}-\mathbf{c}\|_2\le\varepsilon$$

Where the vector **c** is a subset of the DFT coefficients of the beamformed signal.

Demo

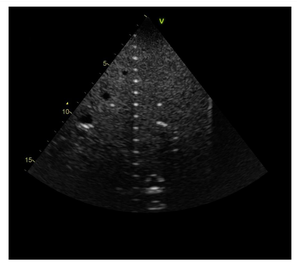




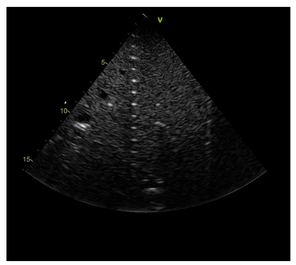
Wireless Ultrasound System lab setup

- Acquisition is performed by a commercial state of the art ultrasound imaging system, on which the Xampler 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