# A Software Prototype of Compressed Ultrasound imaging over WIFI

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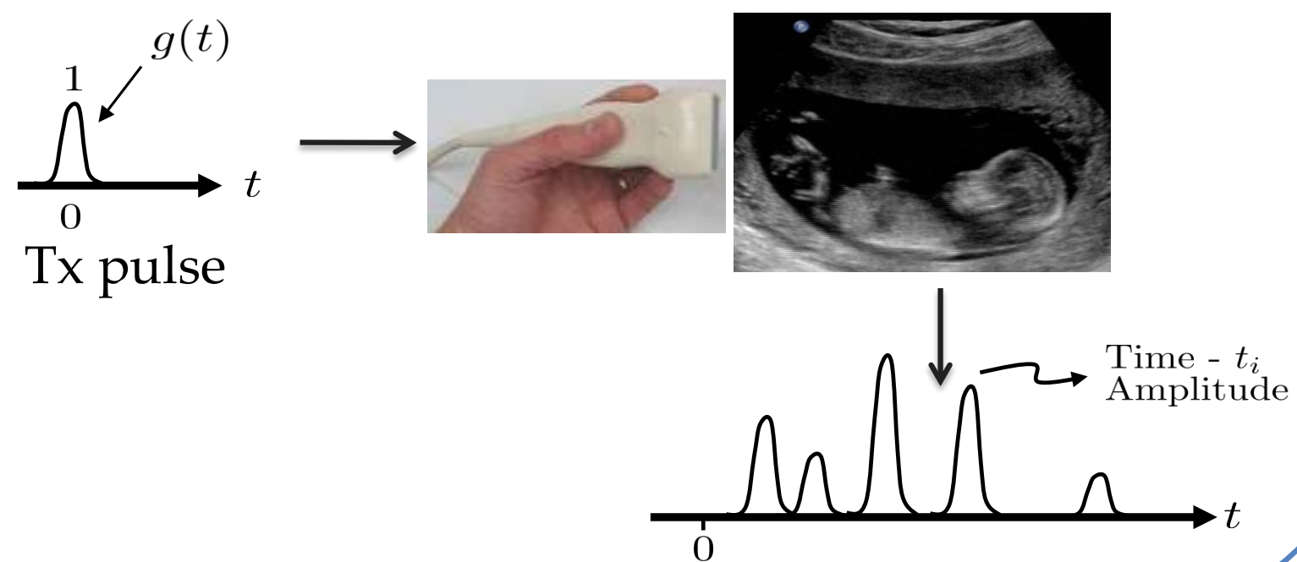
## Motivation and Contributions

- ❑ Ultrasound imaging is one of the most common medical imaging technique
- ❑ The commercially used US machines are relatively large, with limited image resolution and contrast
- ❑ Uncomfortable cable management
- ❑ Reducing sampling rate and data size while ensuring high image quality can make US imaging the chosen imaging method in many medical scenarios
- ❑ We present a low rate US imaging technique with sub sampled channel data transferred over WIFI

## Ultrasound – delay and sum beamforming

- ❑ Echoes result from scattering in the tissue
- ❑ The image is formed by identifying the scatterers
- ❑ To increase SNR and resolution an antenna array is used
- ❑ SNR and resolution are improved through beamforming by introducing appropriate time shifts to the received signals $\boxed{\Phi(t;\theta)=\frac{1}{M}\sum_{m=1}^{M}\varphi_m\left(t-\frac{1}{2}\left(t-\sqrt{t^2-4(\delta_m/c)t\sin\theta+4(\delta_m/c)^2}\right)\right)}$
- ❑ Steers the beam in a desired direction and focuses it in the ROI
- ❑ **Requires high sampling rates and large data processing rates**



## Compressed beamforming

- ❑ Each individual trace is buried in noise and has no structure
- ❑ Structure exists only after beamforming which improves resolution/SNR
- ❑ How can we perform beamforming on low rate data?

- **Enables beamforming from low rate samples**
- **Key idea: Perform beamforming in frequency**

Logic:

1. BMF signal is a stream of pulses => can be recovered from a small number of $c_k$
2. Small number of $c_k$ requires only a small number of $\varphi_m[n]$

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

Fourier coefficient of BMF signal

Fourier coefficient of signal at element $m$

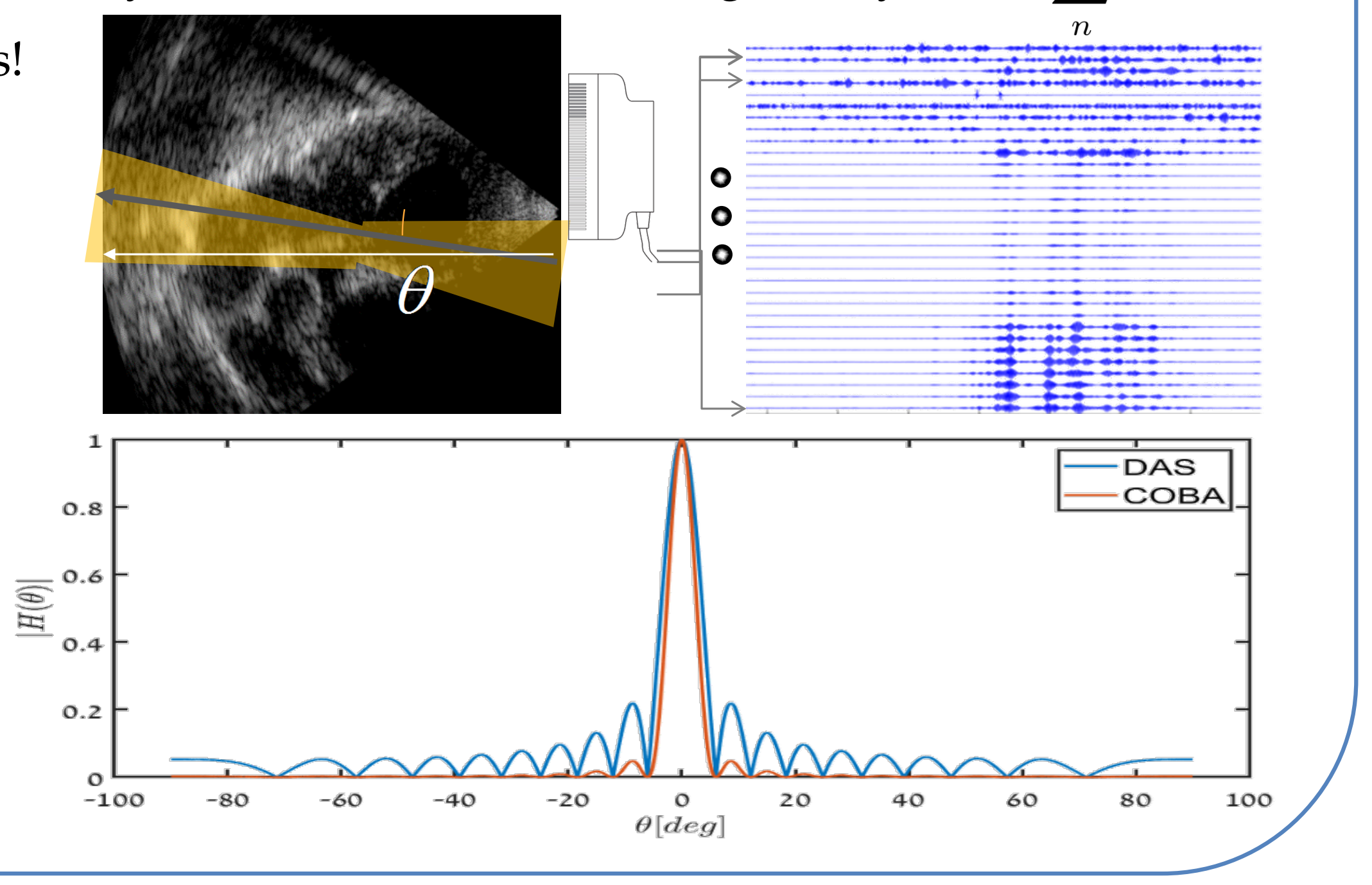
$Q_{k,m;\theta}[n]$ are the Fourier coefficients of $q_{k,m}(t;\theta)$

$$q_{k,m}(t;\theta)=I_{[\delta_m/c,\tau_m(T;\theta)]}(t)\left(1+\frac{(\delta_m/c)^2\cos^2\theta}{(t-(\delta_m/c)\sin\theta)^2}\right)\times \exp\left\{i\frac{2\pi}{T}k\frac{\delta_m/c-t\sin\theta}{(t-\delta_m/c)\sin\theta}\delta_m/c\right\}$$

## Convolutional Beamforming – Array Selction

- ❑ Image quality is determined by the beampattern $H(\theta)$ which represents the directivity of the beamformer and is given by $H(\theta)=\sum_n e^{-2\pi j\frac{\sin(\theta)}{\lambda}nd}$
- ❑ Convolutional beamforming - same and better beampattern with less elements!
- ❑ Output of a standard delay and sum beamformer:

  $\Phi(t;\theta)=\sum_{n=-N}^{N}\hat{\phi}_n(t;\theta)$, where $M=2N+1$, $\hat{\phi}_n$ are the delayed signals
- ❑ Convolutional beamformer (COBA):
- ❑ Compute $y_n=\sqrt{(\hat{\phi}_n)}sign(\hat{\phi}_n)$
- ❑ Convolve $\mathbf{s}=\mathbf{y}*\mathbf{y}$
- ❑ Sum $b=\sum_{n=-2N}^{2N}s_n$
- ❑ The resulting beampattern is: $H(\theta)=\sum_{n=-2N}^{2N}(2N-|n|)e^{-2\pi j\frac{\sin(\theta)}{\lambda}nd}$



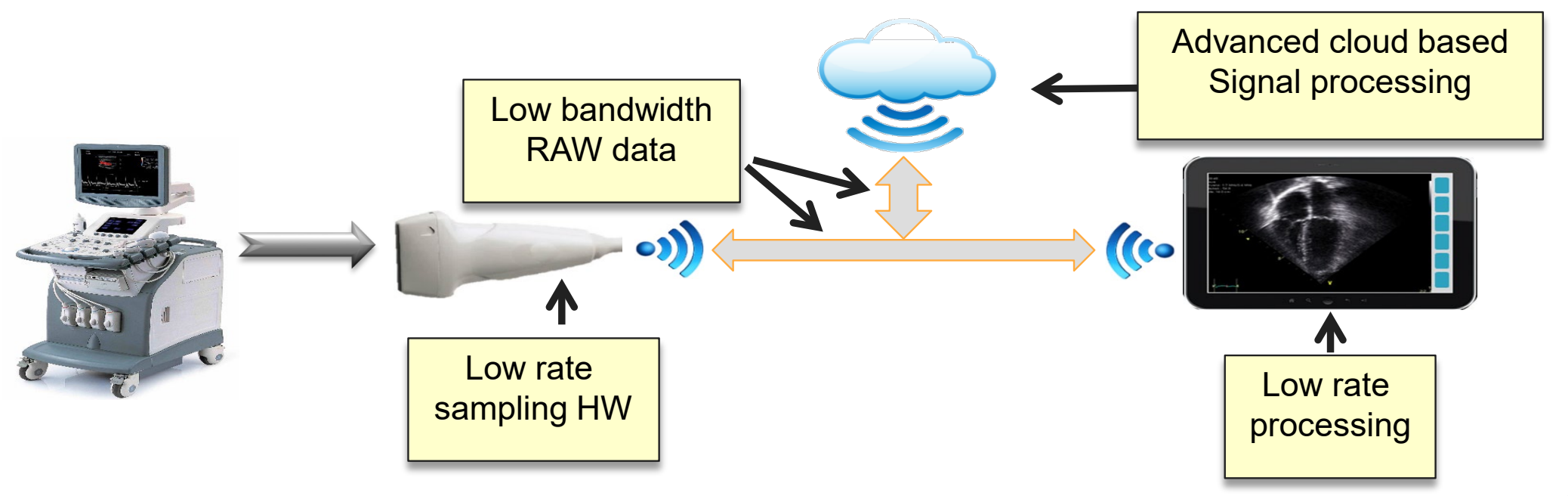
## Compressed Frequency COBA

- ❑ Reconstruct the sparse convolutionaly beamformed signal from only a portion of the bandwidth of the signal received by sparse set of array elements
- ❑ Acquire non delayed data, $\varphi_m(t;\theta)$, by sparse set of elements
- ❑ Compute: $y_m=\sqrt{(\hat{\varphi}_m)}\text{sign}(\hat{\varphi}_m)$
- ❑ Compute Fourier transform, $\mathcal{F}\{y_m(t;\theta)\}$, and apply delay in frequency domain: $\hat{c}_m[k]=\frac{1}{M}\sum_n c_m[k-n]Q_{k,m,\theta}[n]$
- ❑ Calculate the Fourier coefficients of the convolutionally beamformed signal using the convolution theorem and 2-D IFFT: $\hat{c}[k]_{COBA}=N\sum_{l\in S_{\tilde{U}}}(\hat{c}\underset{s}{*}*\hat{c})[k]$
- ❑ Reconstruct the signal based on the square of the square of the transmitted pulse

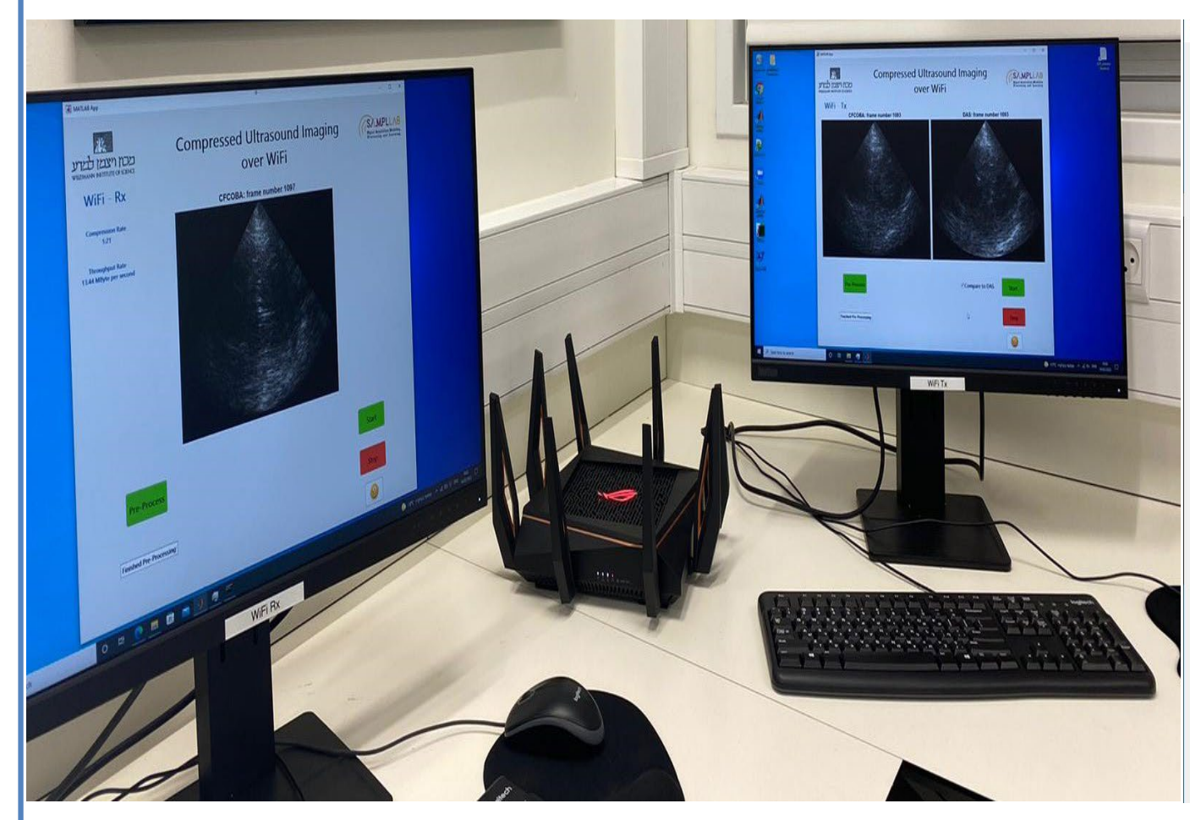
$$\min_b ||b||_1 \quad s.t \quad ||GDb-\hat{c}||_2\le\epsilon \quad \xrightarrow{\text{NESTA}} \quad \hat{\Phi}_{COBA}(t)=\sum_{s=1}^{S}\left(\sum_{l\in\tilde{U}}\sum_{m\in\tilde{U}}a_{s,l}a_{s,m}\right)h^2(t-t_s)=\sum_{s=1}^{S}b_s g(t-t_s)$$

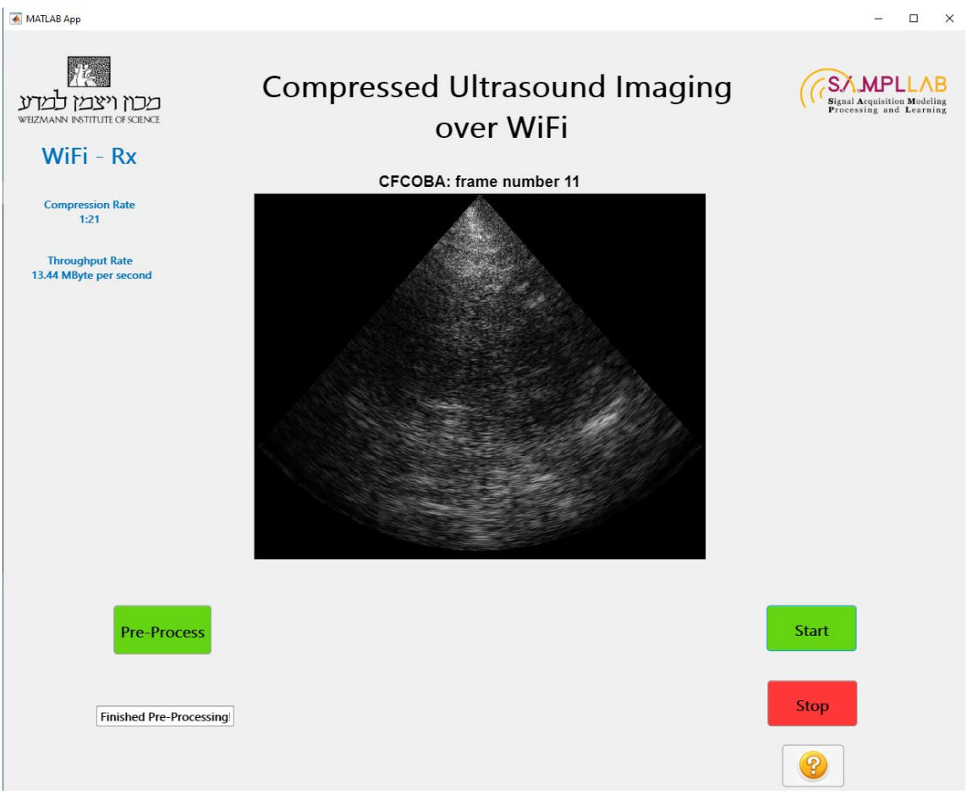
## From Vision to Implementation

- ❑ Sample within the probe
- ❑ Transmit channel data
- ❑ Recover in any imaging platform – tablet, cellular …
- ❑ Send to cloud for advanced signal processing and AI methods



## Software + WIFI





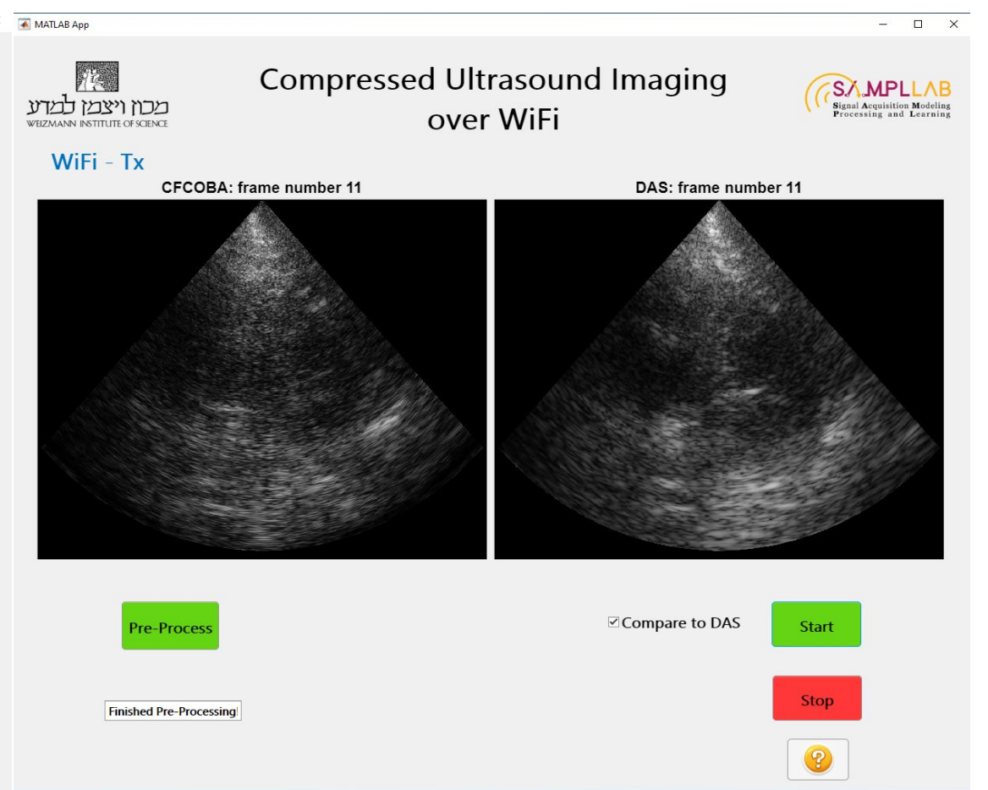
Compressed Ultrasound Imaging over WiFi

CFCOBA: frame number 11

Compression Rate 1:21

Throughput Rate 13.44 MByte per second

Finished Pre-Processing



Compressed Ultrasound Imaging over WiFi

CFCOBA: frame number 11

DAS: frame number 11

Finished Pre-Processing

In this model we transfer 0.9~ Mbyte per frame over WIFI. We present 2 Ultrasound image frames per second.