(128 elements, 0.195 mm pitch, 7.8 MHz central frequency, 31.2 MHz sampling frequency).

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FNSNF

A compressed beamforming framework for 2D ultrasound imaging

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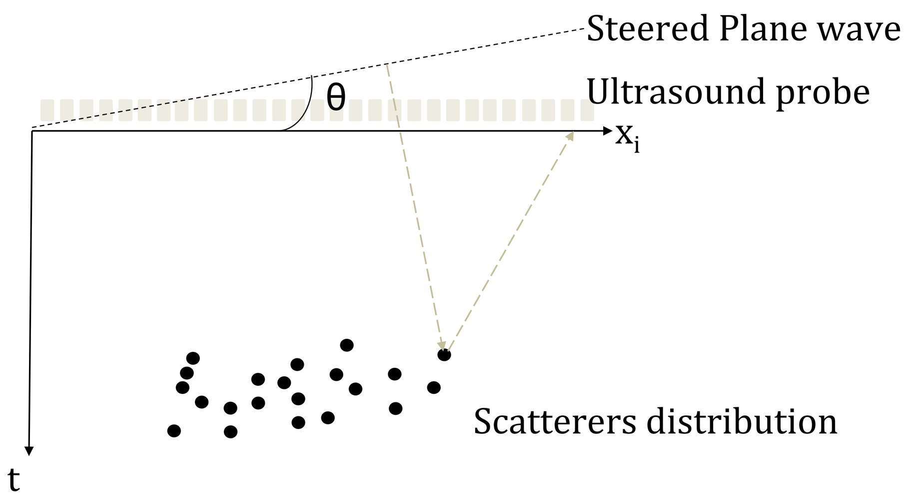
Introduction and motivation

- Reducing the **memory footprint** as well as the **data rate** are two key points for the portability of ultrasound devices
- Classical image reconstruction implies:
  - Storage of echo signals coming from N_t sensors
  - Storage of N_t delays per image pixel
- Memory footprint and data rate can be optimized
- The proposed approach is based on acquiring the echoes with a **reduced number of transducer elements** and on reconstructing a high-quality image with a **compressed-sensing-based algorithm**

Ultrasound propagation as an inverse problem

- Express ultrasound propagation as an inverse problem:



- $r(x_i, t)$ are the echo signals
- $s(x, z)$ is the desired image

Continuous domain

$$r(x_i, t) = \iint_{(x,z)\in\Omega} s(x,z)\,dx\,dz$$

$$\Omega = \{(x,z) \mid (ct - z\cos\theta - x\sin\theta)^2 - (x - x_i)^2 - z^2 = 0\}$$

Discrete domain

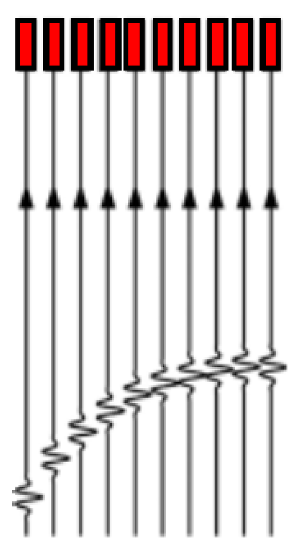
$$R_{ij} = \sum_{(k,l)\in\Omega_d} W_{kl} S_{kl}$$

W is an interpolation kernel

$$\boxed{\boldsymbol{r} = H\boldsymbol{s} + \boldsymbol{n}}$$

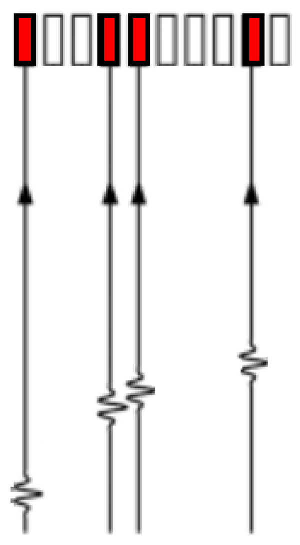
The new sensing strategy

- The new sensing strategy is based on acquiring the echoes with a reduced number of sensors
- Two options:
  - **Uniform spacing:** we keep the same spacing between the sensors (low sidelobes but high grating lobes)
  - **Random spacing:** the spacing between the sensors is random (high sidelobes but low grating lobes)



Classical acquisition[1]

$$\boldsymbol{r} = H\boldsymbol{s} + \boldsymbol{n}$$



Compressed acquisition

$$r_u = H_u\boldsymbol{s} + \boldsymbol{n}_u$$

Compressed beamforming is an ill-posed problem since H_u has far more rows than columns.

Solving the ill-posed inverse problem

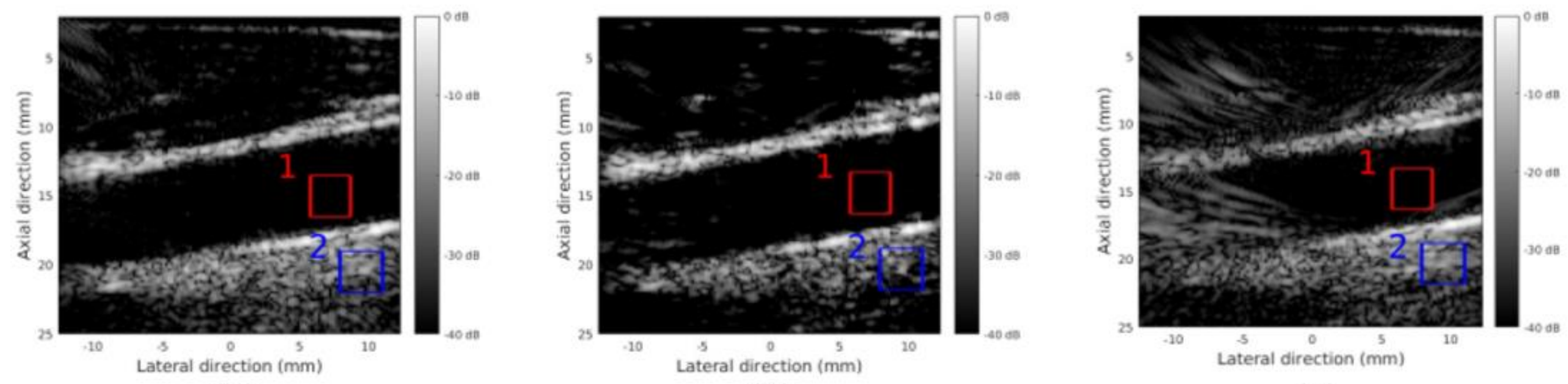
- We exploit the property that the images are sparse in a given model Ψ. Using the ℓ_1-norm as the sparsity measure, we can reconstruct our signal using:

$$\min_s \|\Psi^t s\|_1 \ s.t\ \|r_u - H_u s\| < \varepsilon$$

- The model used in the study is a concatenation of wavelet bases

Results on an *in vivo* carotid

- *In vivo* carotid imaged using a Verasonics system equipped with a linear probe (128 elements, 0.195mm-pitch, 7.8 MHz center frequency)

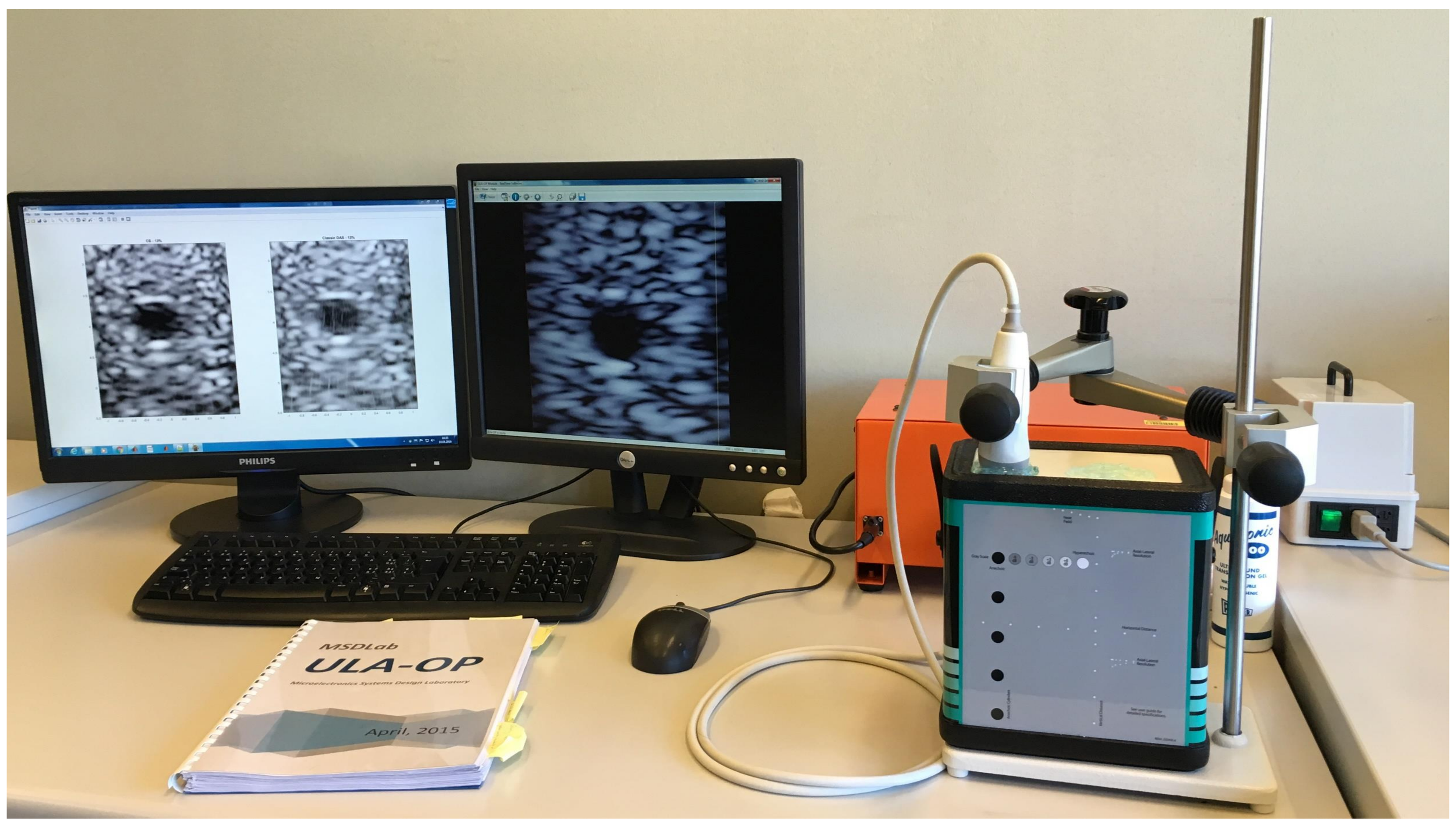


(a) (b) (c)

Figure 1 : B-mode images of an *in-vivo* carotid obtained with 5 SPWs on transmit and with (a) DAS reconstruction with 128 elements on receive (CTR = -31 dB), (b) CB reconstruction with 32 elements on receive (CTR = -31 dB) and (c) DAS reconstruction with 32 elements on receive (CTR = -26 dB).

- Great improvement of image quality with compressed beamforming

Compressed beamforming demonstrator



- Using MATLAB®, we can configure various settings for the transmission of steered plane waves and the reception of echo signals:
  - Desired range
  - Transmitted pulse
- User can compare image reconstruction methods: compressed sensing or classical reconstruction
- Our experimental setup includes a CIRS Model 054GS General Purpose Ultrasound Phantom, a 128-element probe, and an ULA-OP system developed by the MSD Lab in Firenze

Conclusions

- Compressed beamforming allows for the reconstruction of **high quality images** from a **reduced number of echo signals**
- It uses compressed-sensing-based algorithms coupled with novel acquisitions schemes for high quality image reconstruction
- The proposed sensing strategy is compatible with any ultrasound probe

On-going work

- GPU implementation of the image reconstruction
- Extension of the proposed framework to 3D beamforming and to diverging transmit waves
- Porting the framework to Python

[1] Source: David, G., Robert, J., Zhang, B. and Laine, A. (2015). Time domain compressive beam forming of ultrasound signals. *The Journal of the Acoustical Society of America*, 137(5), pp.2773-2784.