# Evaluation of lateral and axial resolution in photoacoustic tomography with linear US probe and pixel-based beamformers

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## INTRODUCTION

### Background

Photoacoustic (PA) imaging techniques use the ability of some materials (chromophores) to **emit sound after being excited by pulsed light** [1]. These materials, after absorbing laser energy, become acoustic sources whose signals can be recorded with a typical ultrasonic (US) acquisition system and conform molecular images [1]. This technique allows to differentiate the chromophores of the tissue, for example oxyhemoglobin and deoxyhemoglobin, since each chromophore has a characteristic absorption spectrum, which makes it a promising **medical imaging technique**, with molecular contrast, better **resolution** than pure ultrasound imaging, and greater tissue **penetration** than optical techniques [1].

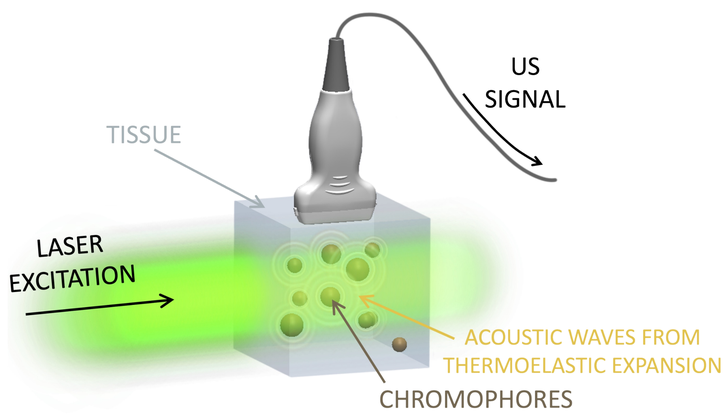



Figure 1. Operating principle of PA tomography.

### Objective

Compare the resolution of a PA tomography system using a linear ultrasound probe and pixel-based beamformers and evaluate the **effect of the field of view (FOV)** of the US probe and its **frequency response**.

## METHODS

Two point-like absorbers started being overlapped are separated until we are able to identify them as two independent sources in the reconstructed image.

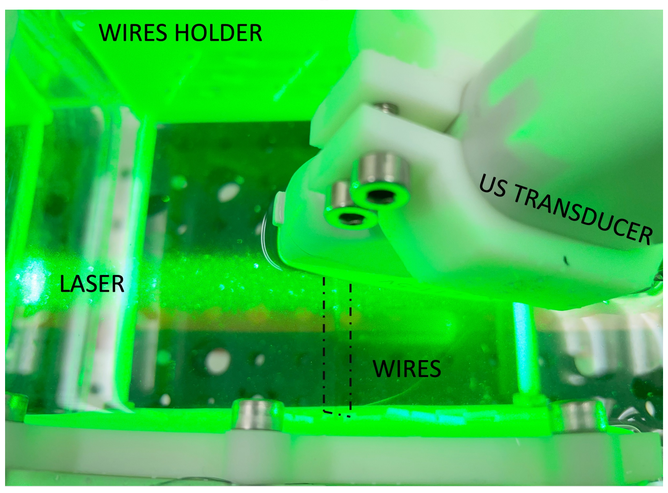



Figure 2. Experimental set-up.

### Experiments

**Black nylon wires** of 0.1 mm diameter fixed at the desired distances using a 3D-printed wire holder were excited with an **Optical Parametric Oscillator laser** tuned at 532 nm with beam cross-section diameter of 15 mm, 10 Hz pulse repetition rate and pulse energy of 30 and 60 mJ. The PA signals were registrated by a Verasonics Vantage $256^{TM}$ system with the L11-5v ultrasound **phased-array.**

### Simulations

A set of numerical simulations has been carried out with the k-Wave MATLAB toolbox. Simulated conditions:

- **Cond. 1:** full FOV, freq. response up to 15.2 MHz
- **Cond 2:** Cond. 1 + probe directivity limited to 0.5 rad.
- **Cond 3:** Cond. 1 + frequency response limited to $f_c$ = 7.6 MHz and 77% bandwidth.
- **Cond 4:** Cond. 2 + Cond. 3 (realistic conditions).

### Data processing

The Delay And Sum (**DAS**) [2], Delay Multiply And Sum (**DMAS**) [3], Minimum-Variance (**MV**) [4] and **MV-DMAS** [5] beamforming algorithms have been implemented. All of them are pixel-based, however those based on minimum variance are **adaptive**, so they calculate the optimal weight to each channel of the array based on the received signals.

## RESULTS

### Reconstructions

When the distance is close to the resolution limit of the system, the beamformer used determines whether or not the two independent sources are resolved based on the criterion explained below.

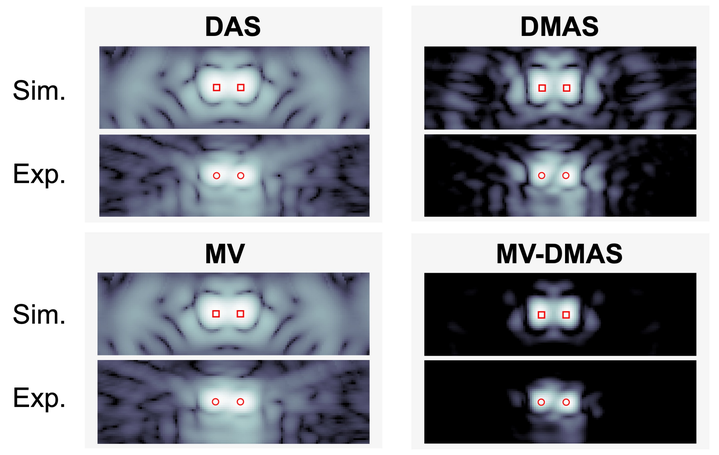



Figure 3. Beamformed simulated (Cond 4.) and experimental data from lateral resolution study, all reconstructions are shown with a dynamic range of 60 dB. The original sources have been marked in red.

### Lateral and axial profiles

When the amplitude between the peaks (sources) and the valley between them is greater than 3 dB, we assume that the imaging system distinguishes them; and when it is greater than 6 dB, that it resolves them.

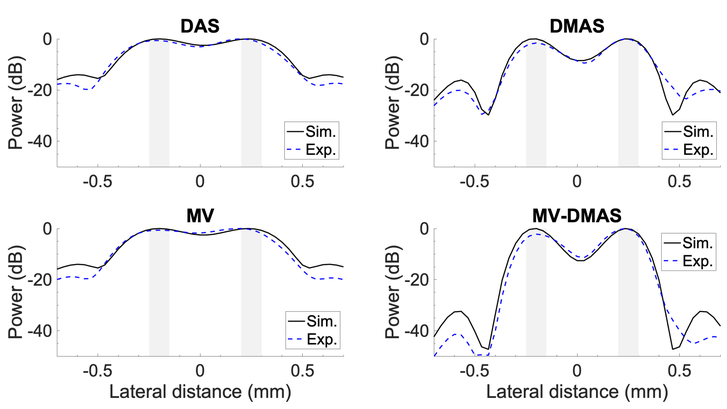



Figure 4. Lateral profiles of beamformed simulated (Cond 4.) and experimental data. The gray areas represent the actual size and position of the sources.

### Peak-valley distance

Finally, if we calculate the distance between the peaks and the valley for each of the distances studied, we can determine the resolution for each of the simulated conditions and for the experiments carried out.

#### Lateral resolution

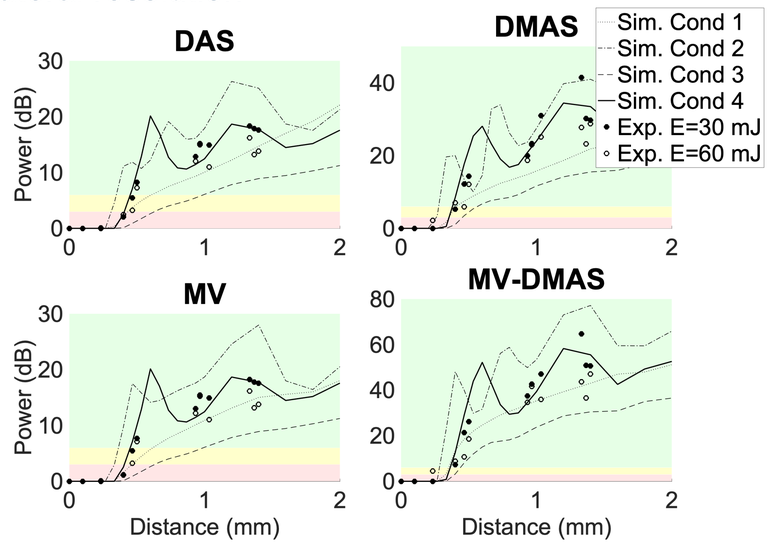



Figure 5. Peak-valley amplitude difference in lateral profiles of beamformed simulated and experimental data. Red area: undistinguished; yellow area: distinguished; green area: resolved.

#### Axial resolution

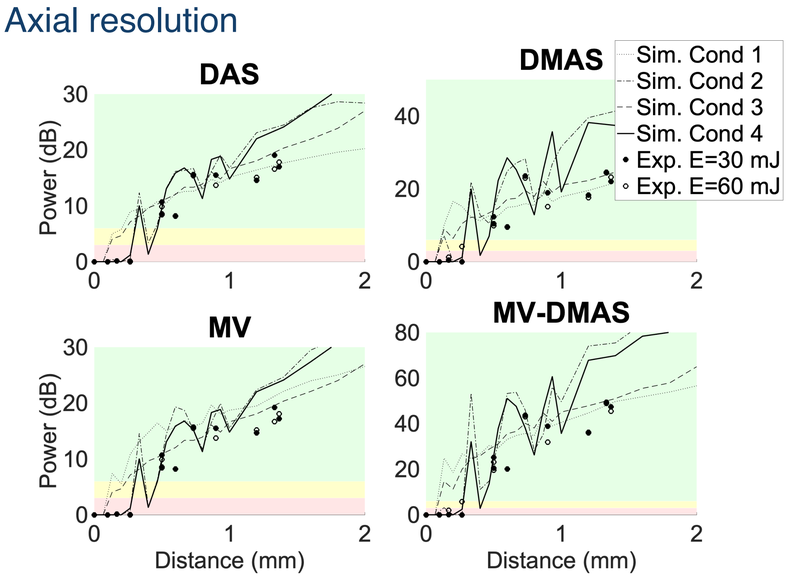



Figure 6. Peak-valley amplitude difference in axial profiles of beamformed simulated and experimental data.

## CONCLUSIONS

It has been studied how **limiting the frequency response** of the probe (**Cond 2**) affects the resolution of the PAT system through simulations, it is concluded that it mainly affects the **axial resolution,** making it take longer distances to resolve the sources separated on the vertical axis and causes oscillation in the peak-valley distance. It has also been studied how **limiting the FOV** (**Cond 3**) affects mainly **lateral resolution,** making it take longer distances to resolve horizontally separated sources.

A series of **experiments** with two closely spaced thin wires has been conducted showing a **good agreement** with the more **realistic scenario** simulated (Cond. 4).

## REFERENCES

[1] P. Beard, “Biomedical photoacoustic imaging,” Interface Focus, vol. 1, no. 4, pp. 602-631, 2011, doi: 10.1098/rsfs.2011.0028.

[2] V. Perrot, M. Polichetti, F. Varray, and D. Garcia, “So you think you can DAS? A viewpoint on delay- and-sum beamforming,” Ultrasonics, vol. 11, no. May 2020, p. 106309, 2021, doi: 10.1016/j.ultras.2020.106309.

[3] G. Matrone, A. S. Savoia, G. Caliano, and G. Magenes, “The delay multiply and sum beamforming algorithm in ultrasound B-mode medical imaging,” IEEE Trans. Med. Imaging, vol. 34, no. 4, pp. 940– 949, 2015, doi:10.1109/TMI.2014.2371235.

[4] N. Q. Nguyen and R. W. Prager, “Minimum Variance Approaches to Ultrasound Pixel-Based Beamforming,” IEEE Trans. Med. Imaging, vol. 36, no. 2, pp. 374–384, 2017, doi: 10.1109/TMI.2016.2609889.

[5] M. Mozaffarzadeh, A. Mahloojifar, M. Orooji, K. Kratkiewicz, S. Adabi, and M. Nasiriavanaki, “Linear-array photoacoustic imaging using mínimum variance- based delay multiply and sum adaptative beamforming algorithm,” J. Biomed. Opt., vol. 23, 2018, doi: 10.1117/1.JBO.23.2.026002.