Overestimation of the spatial resolution of advanced algorithms using the PSF method on PAT systems

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Introduction

Background

Although the **spatial resolution estimation** using a single source (Point Spread Function, **PSF**) is much simpler than working with two parallel sources (Rayleigh Criterion, **RC**), and despite it can be useful in some contexts, does not provide an adequate result when working with **coherent signals**, such as photoacoustic signals.

Our proposal

In this work we have determined numerically and experimentally the lateral and axial resolution overestimation of a linear probe photoacoustic tomography system (PAT) using the PSF compared against RC.

Methods

Theoretical resolution

The theoretical lateral (R_L) and axial (R_A) resolution of an acoustically resolved PAT system is defined by:

$$R_L = 0.71 \frac{c_0}{\mathrm{NA}\, f_0}$$

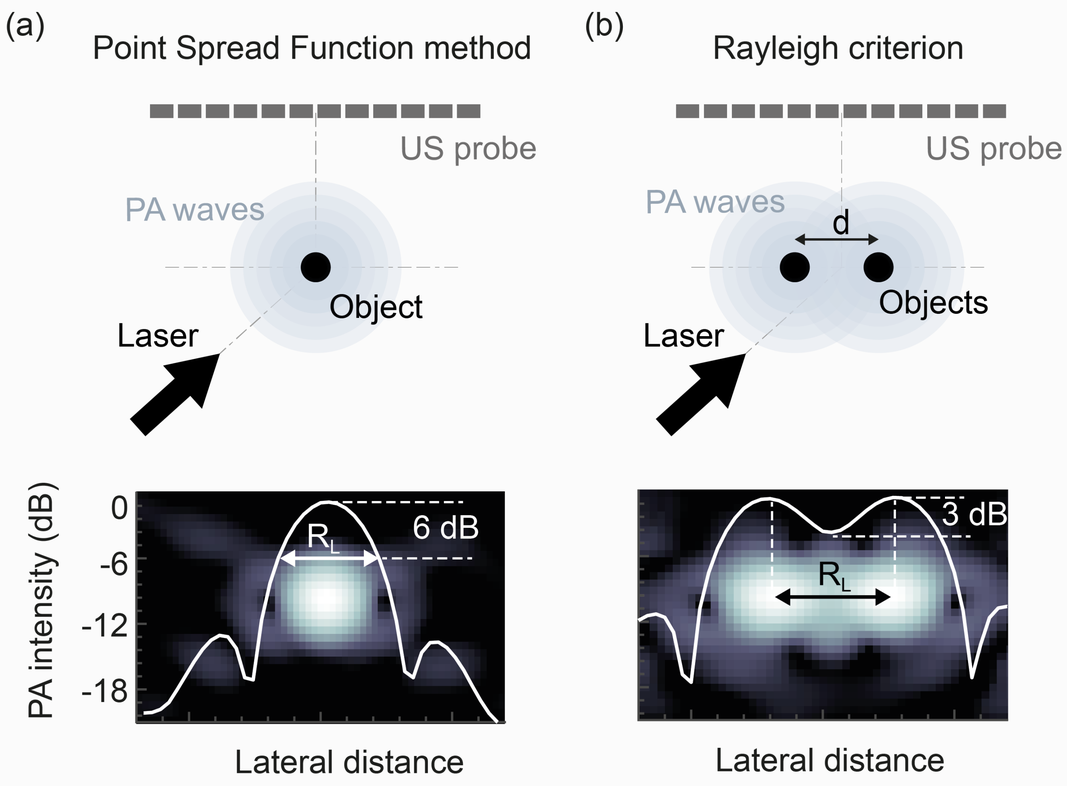
$$R_A = 0.88 \frac{c_0}{\Delta f}$$

where c_0 is the sound speed in the medium, NA is the numerical aperture of the probe, f_0 is the signal center frequency and Δf is the frequency width of the signal [1].

In our particular case, the theoretical spatial resolutions are R_L = 231 µm and R_A = 226 µm.

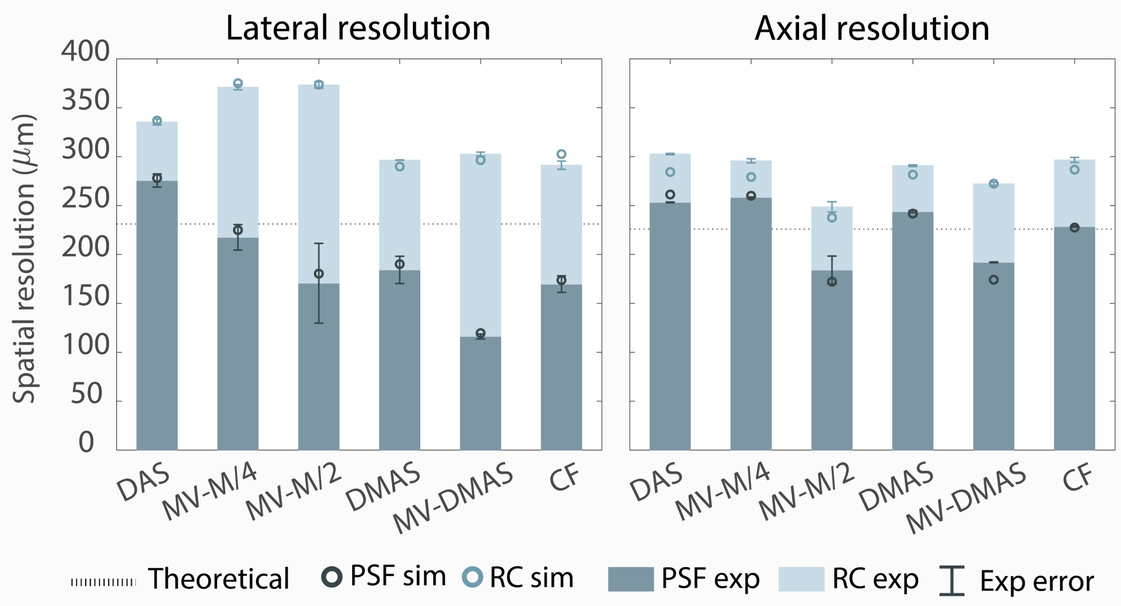
Numerical and experimental resolution

Spatial resolution has been estimated through **PSF** and **RC** (see (a) and (b) respectively in the figure below) for Delay And Sum **(DAS)**, Delay-Multiply-And-Sum **(DMAS)**, Minimum-Variance **(MV)**, MV-DMAS and Coherence Factor **(CF)** beamformers.



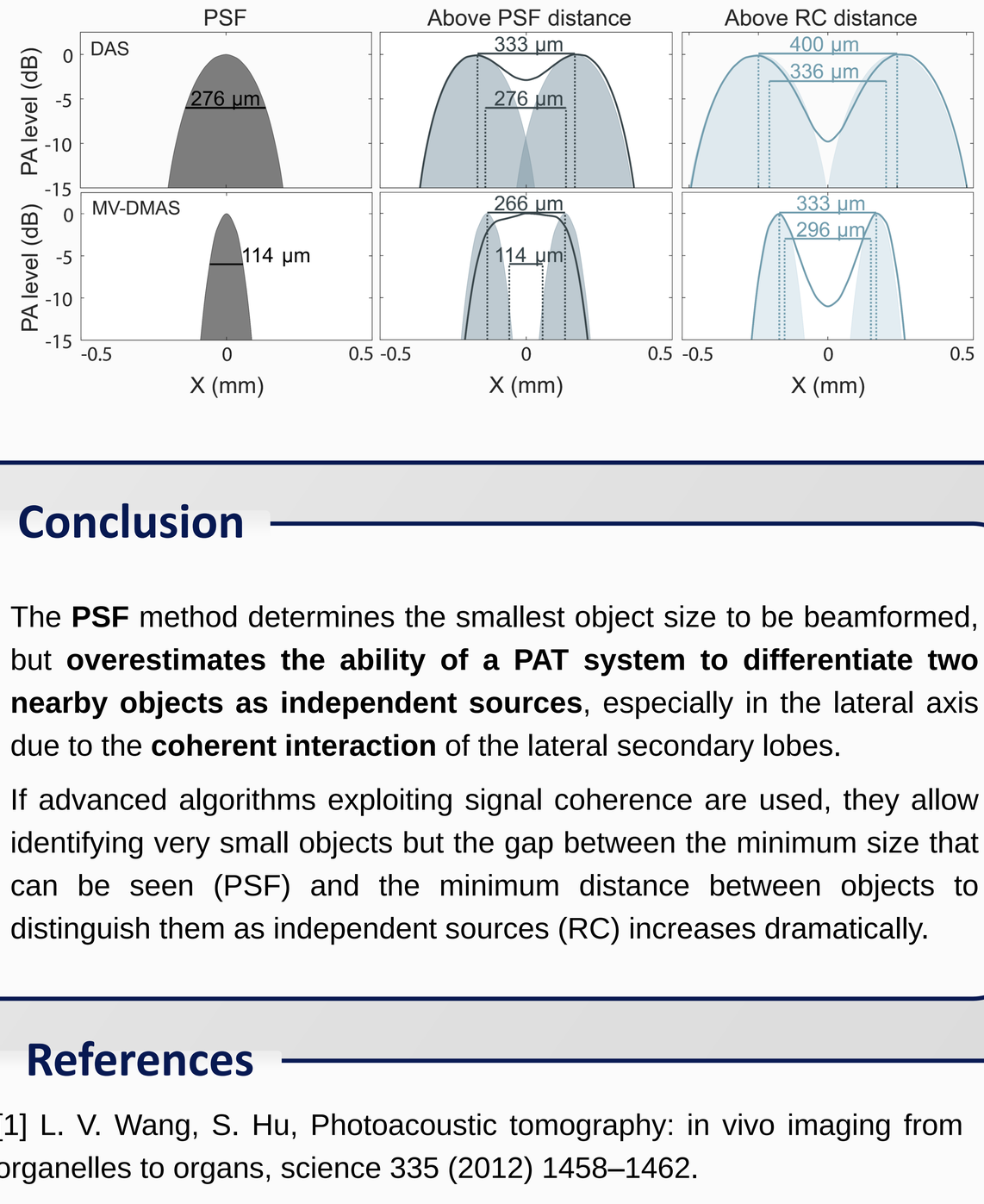
Results

The following figure shows the Full Width at Half Maximum values obtained with PSF, in dark blue, and the difference between this value and the resolution based on RC, in light blue.



In DAS, a difference of about 25 % in lateral and 10 % in axial resolution is observed. With the non-linear and adaptive algorithms, the overestimation of the PSF for lateral resolution increases dramatically.

The figure below shows how two sources separated above the PSF distance are not resolved in DAS; in MV-DMAS is much worse, since at 152 µm above the PSF-based resolution, the system would not be able to distinguish the two sources as independent entities.



Conclusion

The **PSF** method determines the smallest object size to be beamformed, but **overestimates the ability of a PAT system to differentiate two nearby objects as independent sources**, especially in the lateral axis due to the **coherent interaction** of the lateral secondary lobes.

If advanced algorithms exploiting signal coherence are used, they allow identifying very small objects but the gap between the minimum size that can be seen (PSF) and the minimum distance between objects to distinguish them as independent sources (RC) increases dramatically.

References

[1] L. V. Wang, S. Hu, Photoacoustic tomography: in vivo imaging from organelles to organs, science 335 (2012) 1458–1462.

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