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Spatio-Temporal Encoding For High-Resolution Photoacoustic Tomography With Reduced Hardware Requirements

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Abstract Text:

Photoacoustic tomography (PAT) is an emerging biomedical imaging modality that combines high optical contrast with deep acoustic penetration, offering strong potential for clinical diagnosis. However, its widespread adoption remains limited by instrumental complexity and the large number of detectors required in conventional system configurations. This contribution addresses these challenges from a physics-driven perspective oriented toward clinical translation.

The present study focuses on the development of spatio-temporal encoding strategies that significantly reduce hardware requirements without compromising image quality. In particular, two approaches are explored: the use of acoustically dispersive coupling media, which introduce controlled scattering to encode spatial information into time-domain signals and enable super-resolution through dynamic absorbers; and reverberant cavities equipped with quadratic residue diffusers, capable of encoding complex angular information and enabling three-dimensional reconstructions with a drastically reduced number of detectors.

These strategies are complemented by tools that enhance their applicability and robustness. First, an image reconstruction method based on a self-calibrated model is introduced, enabling the recovery of spatio-temporal information without prior knowledge of the scattering field. Second, a resolution assessment methodology based on the Rayleigh criterion is employed, providing a more physically meaningful metric than conventional point spread function-based approaches. In addition, biocompatible nanoparticles are integrated as contrast agents, providing strong and stable photoacoustic signals. Together, these elements enable a more rigorous validation of system performance and improved image quality under realistic conditions.

Experimental results obtained in controlled environments and in vivo demonstrate that resolutions comparable to conventional systems can be achieved while maintaining a robust signal-to-noise ratio, even under highly undersampled acquisition schemes. Overall, this work proposes physical solutions that simplify PAT systems, reduce cost, and facilitate their implementation in real clinical settings.

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