# Robust Spectral Detection of Contrast Agents in Photoacoustic Imaging

F Castro[1]

[1]*Escuela de Ingeniería Eléctrica, Universidad de Costa Rica, 11501, San José, Costa Rica.*
*Contact Phone: +50660212722*
Contact Email: franco.castro@ucr.ac.cr

Photoacoustic imaging is a hybrid biomedical imaging modality that combines optical absorption contrast with ultrasonic detection, enabling the visualization of chromophores embedded within biological tissue. One of the principal challenges in spectroscopic photoacoustic imaging is the reliable detection of exogenous contrast agents in the presence of endogenous absorbers such as deoxyhemoglobin (Hb) and oxyhemoglobin ($HbO_2$), particularly under noisy acquisition conditions and spectral overlap.

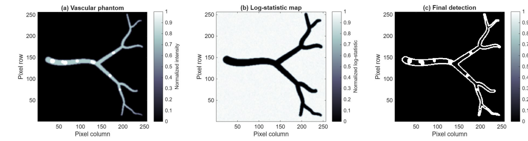


Figure 1: (a) Simulated vascular phantom containing spatially distributed contrast-agent inclusions represented by bright regions. Contrast-agent visibility was intentionally enhanced for visualization purposes and does not represent a quantitative physical scale. (b) Accumulated log-statistic map obtained from noisy photoacoustic realizations, where high-contrast regions contain the most relevant spectral information for detection. (c) Final detection result produced by the proposed spectral detection framework

In this work, we propose a robust spectral detection framework for identifying contrast agents without explicitly estimating chromophore concentrations. Instead of solving a spectral unmixing problem, the proposed approach is restricted to determining whether the target contrast agent is present or absent at a given spatial location.

A wavelength-pair selection criterion based on a max-min separation index was introduced. For a target chromophore $m$ and interferent $n$, the spectral separation index was defined as

$$S_{m,n}(\lambda_+, \lambda_-) = \frac{\varepsilon_m(\lambda_+)}{\varepsilon_n(\lambda_+)} \cdot \frac{\varepsilon_n(\lambda_-)}{\varepsilon_m(\lambda_-)},$$

where $\varepsilon(\lambda)$ denotes the absorption spectrum of the corresponding chromophore. The proposed criterion seeks wavelength pairs that maximize spectral contrast reversal between the target absorber and endogenous interferents. The optimal spectral pair was selected through the robust criterion

$$J_m(\lambda_+, \lambda_-) = \min_n S_{m,n}(\lambda_+, \lambda_-),$$

followed by maximization over all feasible wavelength pairs satisfying spectral inequality constraints that favor the target chromophore over the interferents at $\lambda_+$ while reversing this relation at $\lambda_-$.

The methodology was evaluated through photoacoustic simulations using Hb and $HbO_2$ as endogenous interferents and glycol chitosan coated gold nanoparticles as the target absorber. Curved vascular phantoms with spatially distributed inclusions were generated, and additive Gaussian noise was incorporated into the simulated photoacoustic signals. A cumulative log-regularized statistic derived from repeated noisy realizations of a multiplicative spectral ratio was constructed in order to accumulate spectral evidence while improving robustness against noise and spectral fluctuations. Representative simulation and detection results are shown in figure 1.

Preliminary results demonstrate consistent detection of gold nanoparticle inclusions under noisy conditions, significant reduction of false positives through signal-derived support constraints, and improved detection stability through cumulative spectral evidence integration. The proposed framework constitutes an initial proof of concept for robust contrast-agent detection in spectroscopic photoacoustic imaging.

Future work will incorporate more realistic optical fluence models and quantitative comparisons against conventional spectral unmixing methods reported in the literature.