Towards quantitative photoacoustic spectroscopy using acousto-optic modulation

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Introduction

Photoacoustic spectroscopy (PAS) has enabled deep tissue functional imaging. However, photoacoustics alone inherently lacks the ability to do quantitative imaging, since the local light fluence $\sigma(\lambda)$ is unknown.

$$\sigma(\lambda) = \Gamma \mu_a(\lambda) \phi(\lambda)$$

$\sigma(\lambda)$: Initial stress distribution, quantity measured in PA imaging
$\Gamma$: Grüneisen parameter
$\mu_a(\lambda)$: Absorption coefficient, enables estimation of chromophore concentration
$\phi(\lambda)$: Local light fluence, unknown parameter in PA imaging

Goals

1) correction of fluence variations experimentally in PAS using acousto-optics (AO) modulation
2) quantitative estimation of simulated blood oxygenation using combination of PA and AO at two wavelengths

Method

- **PA Spectroscopy**: estimation of locally absorbed energy using PA at excitation wavelengths
  - Fluence compensated PA measurements after fluence correction

- **AO Spectroscopy**: measurement of locally modulated light power $P_{123}$ using AO at excitation wavelengths, where $P_{123} \propto \Delta \lambda C$
  - Combination of PA and AO measurements using photon path reversibility principle $P_{12} = P_{21}$ for wavelength dependent fluence variations
  - Quantification of simulated blood oxygen saturation $So_2$ using
  $$So_2 = \frac{C_i}{C_f} = \frac{M^{+}^{2} \mu^{+}^{2} - M^{+}^{-} \mu^{+}^{-}}{M^{+} \Delta \phi^{+} - M^{-} \Delta \phi^{-}}$$

Phantom

- Background: $\mu_a = 11.5 \text{ cm}^{-1}$ @532 nm, 8.0 $\text{ cm}^{-1}$ @ 760 nm, 8.5 $\text{ cm}^{-1}$ @ 720 nm
- Absorbers: two nylon tubes 4 mm and 8 mm deep from side 1, containing different types of ink

Results

- **Before fluence compensation**
  - Absorption Spectra for absorbers at 532 nm and 760 nm
  - PA image intensity at 533 nm and 760 nm, PA image before fluence correction, Absorption Spectrum for absorbers at 532 nm and 760 nm

- **After fluence compensation**
  - Absorption Spectrum for absorbers at 532 nm and 760 nm
  - PA image intensity at 533 nm and 760 nm, PA image after fluence correction, Absorption Spectrum for absorbers at 532 nm and 760 nm

Quantification of simulated blood oxygen saturation ($So_2$)

- Inclusions: two nylon tubes at depths 4 mm and 8 mm containing mixture of black ink (33.3 vol%) and green ink (66.7 vol%)

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