Design of a compact, low-cost spectroscopic imaging system for quantitative tissue absorption and scattering

Justin Y. Lo [1], Sulochana Dhar [2], Bing Yu [1], Martin Brooke [2], Nan M. Jokerst [2], Nimmi Ramanujam [1]

[1] Department of Biomedical Engineering, Duke University, [2] Department of Electrical and Computer Engineering, Duke University

EDMUND T. PRATT, JR. SCHOOL OF ENGINEERING

Fitzpatrick Institute for Photonics

Fast, Wide-Field Imaging

Diffuse reflectance spectroscopy is sensitive to the absorption and scattering properties of biological molecules in tissue. It is non-destructive and can be used as a tool for quantitative tissue physiology. We have previously developed a benchtop spectroscopic imaging system for margin assessment in breast tumors. The system consists of a broadband source, a monochromator, a fiber optic probe, a cooled CCD, and spectrograph. It is able to provide real-time visual maps of tissue composition using a fast, scalable inverse Monte Carlo model of reflectance. However, the instrument has drawbacks in cost and footprint, and has limited coverage and resolution. For applications in global health, we present the design of a compact and low-cost spectroscopic imaging system.

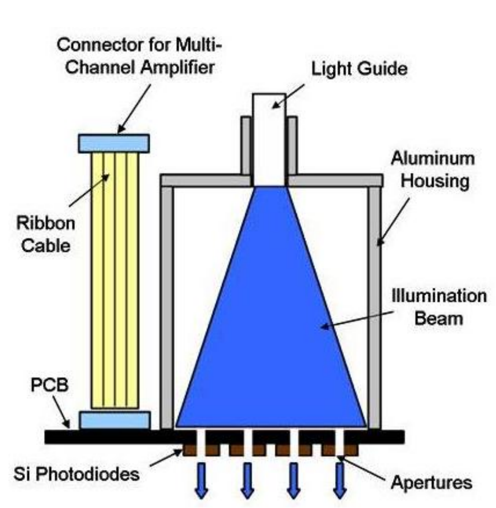
3 Major Design Considerations

I. Light Delivery

An intermediate iteration of system development:

Xenon lamp with filter wheel: 400,420,440,470,500,530,570,600 nm bandpass filters with FWHM = 10 nm

Fiberless back-illumination strategy with detectors at sample surface



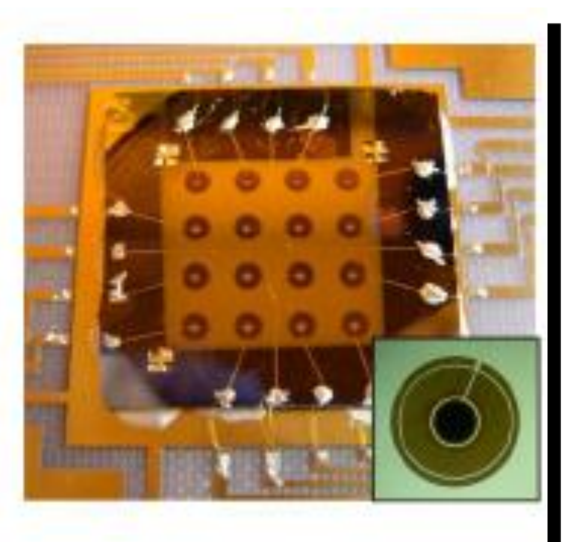
9	23	22	8
24	30	28	20
24	31	30	22
9	24	24	8

Optical Power @ 400 nm (μW)

II. Custom Detector Array

610μm thin silicon photodiode arrays were fabricated in-house. Detector geometry and pixel spacing were customized based on:

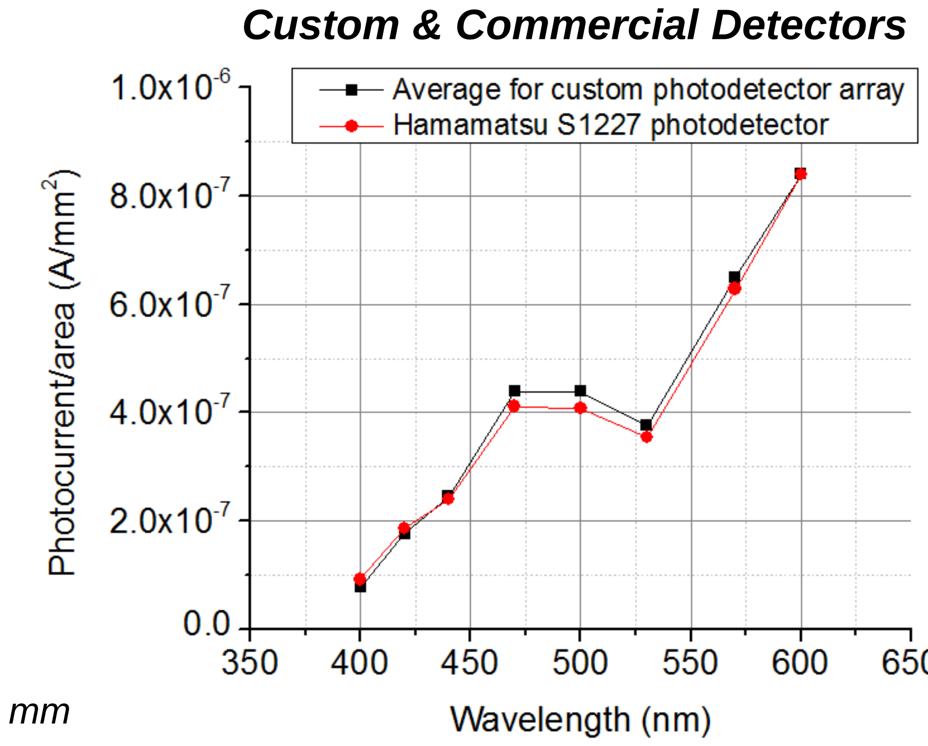
- Optical properties & tissue (contrast) dependent sensing depth
- Maximizing throughput and SNR with central illumination aperture with surrounding ring of active photodiode area
- Minimizing optical cross-talk while maximizing spatial resolution



Sample custom 4x4 Si photodiode array

- *2.5 mm diameter detector*
- *0.75 mm diameter aperture*
- *4.5 mm spacing between detectors*
- *Simulated sensing depth in breast tissue: 0.5 – 2.2 mm*

Performance Comparison of Custom & Commercial Detectors

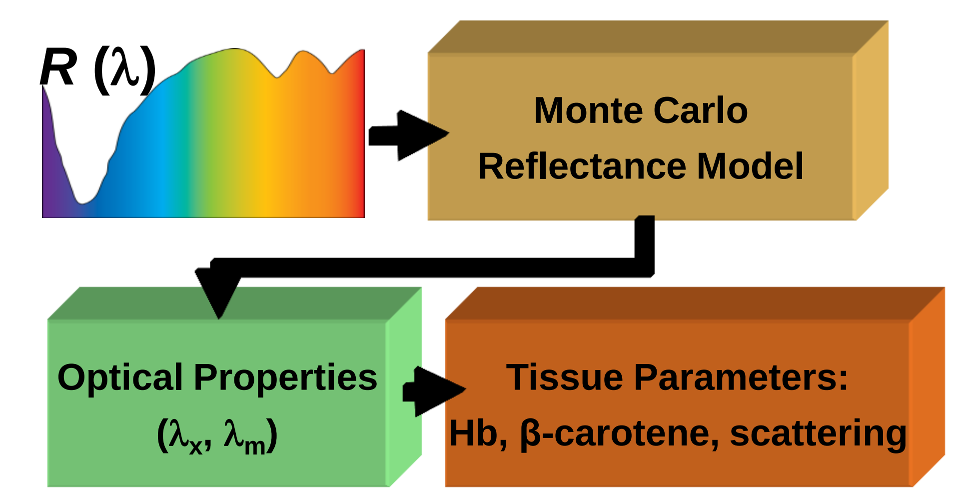


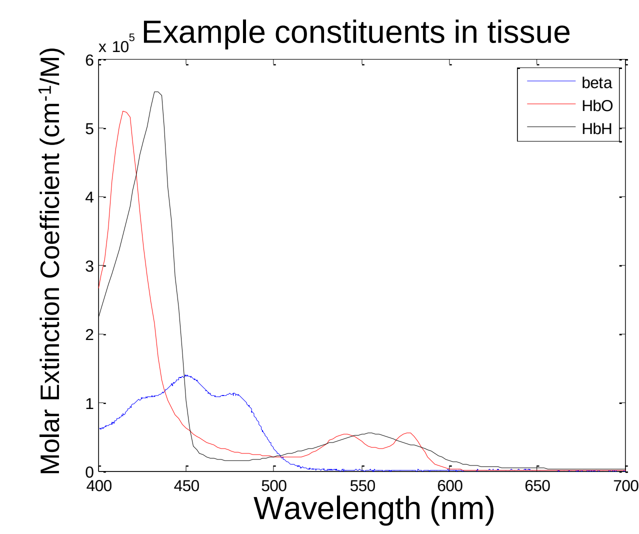
*** Depending on the specific clinical applications, detector geometry and array are customizable for sensing depth and pixel density*

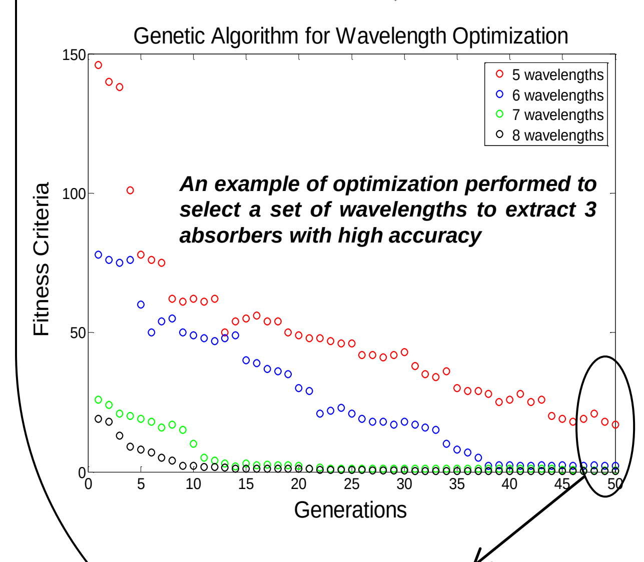
III. Wavelength Selection

A systematic method to select discrete center wavelengths and their bandpasses based on:

- Biological molecules to be measured at the region of interest, i.e. hemoglobin, beta carotene, and melanin
- Wavelengths and sources that are commercially available
- Optical contrast that will provide diagnostic information, i.e. total hemoglobin concentration, tissue oxygenation, etc.

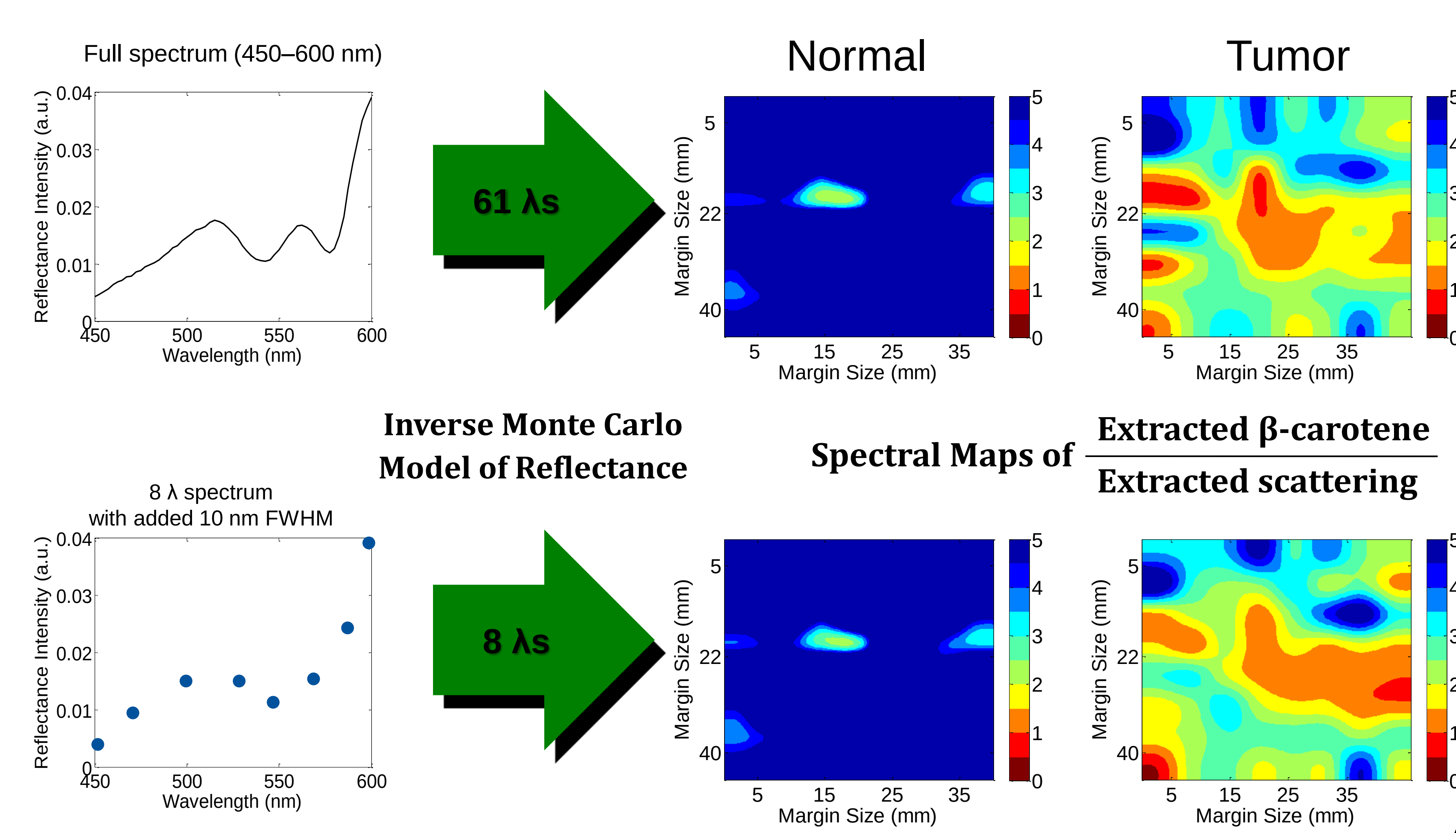






Set of wavelengths with minimized MC inversion errors

Feasibility of extracting tissue parameters with reduced wavelength & increased FWHM



Correlation Coefficients: 0.95 0.89

Summary of System Parameters

We have developed a more compact and cost effective spectroscopic imaging system by modifying the illumination and detection components of our previous benchtop system. In this iteration, the compact system has finer spatial resolution as well as better overall system SNR. The wavelength reduced spectra and extracted tissue parameters show the feasibility of replacing the broadband source completely with LEDs or laser diodes, making our future iteration of this system even more compact, cost effective, and more translatable for applications in global health.

Systems	Source	Detection Components	Light Delivery	Pixels	# of λs	Sampling Area	Resolution	Footprint (LxWxH)	Avg SNR
Benchtop	450W Broadband Xenon lamp	Cooled CCD & spectrograph	Fiberoptic probe	8	61	10 x 30 mm	10 mm	2 x 1.5 x 1 m	42 dB
Compact	300W lamp w/ BP filters	Si PD array with current amplifier	Light guide, free space	16	8	14 x 14 mm	4.5 mm	.35 x .3 x .2 m	Corner pixels: 55.6 dB Center pixels: 55 dB

For more information on our work, please visit Tissue Optical Spectroscopy Laboratory at http://nimmi.bme.duke.edu or email at justin.lo@duke.edu

This work is funded by the Bioengineering Research Partnership grant from the National Institute of Biomedical Imaging and Bioengineering