A cost-effective diffuse reflectance spectroscopy device for quantifying tissue absorption and scattering *in vivo*

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ABSTRACT

We developed a single-point optical device, which uses a multimode fiber coupled to a xenon lamp and monochromator for illumination and an inexpensive silicon photodiode for collection. Together with a fast inverse Monte Carlo (MC) model of reflectance, this device can quantify tissue absorption and scattering *in vivo*. The performance of the technology was tested in synthetic tissue phantoms over a wide range of optical properties. Wavelength reduction of the phantom data was also simulated to show feasibility for making the illumination source more cost effective. The overall errors for the extracted μ_a and μ_s' are comparable to those of our previously developed optical fiber-based spectroscopy system.

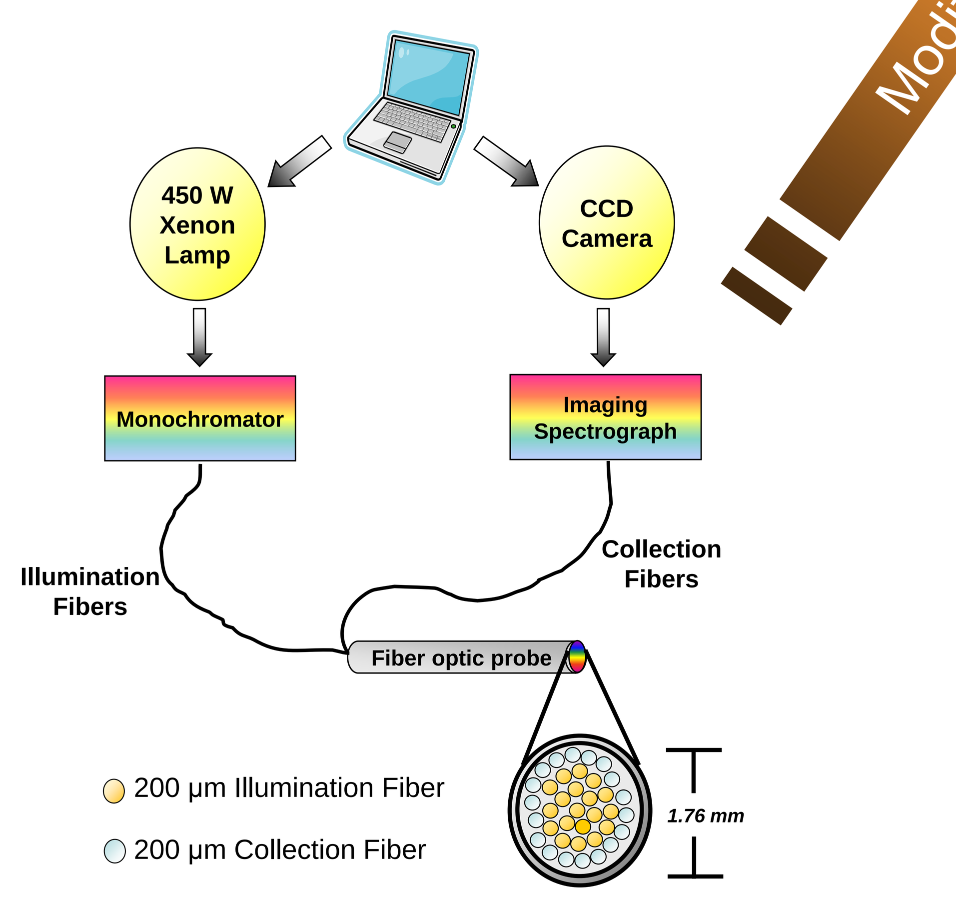
BACKGROUND

Diffuse reflectance spectroscopy is sensitive to the absorption and scattering properties of tissue and thus can be used as a tool for quantitative tissue biology *in vivo*. Potential clinical applications include:

- monitoring of tissue oxygenation & blood loss
- pre-cancer and cancer detection
- intra-operative tumor margin assessment
- assessment of tumor response to therapy

Our group has previously developed a fiber-optic based diffused reflectance spectroscopy system and a fast inverse Monte Carlo model of reflectance to quantify tissue absorption and scattering *in vivo*. The system is illustrated below:

Current bench-top system



Although our toolbox is able to discern malignant from benign tissues with high sensitivities and specificities, there are some drawbacks to this system. It requires high quantum efficiency, low-noise detectors, which are inherently expensive. In addition, it is unwieldy when expanded for use in imaging applications.

For more information…

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More information on our group and other related projects can be found at the Tissue Optical Spectroscopy Laboratory website at: *www.nimmi.bme.duke.edu*

OBJECTIVE

To create a cost-effective diffuse reflectance spectroscopy device by:

(1) Designing new probes that eliminate the need for costly detection equipment

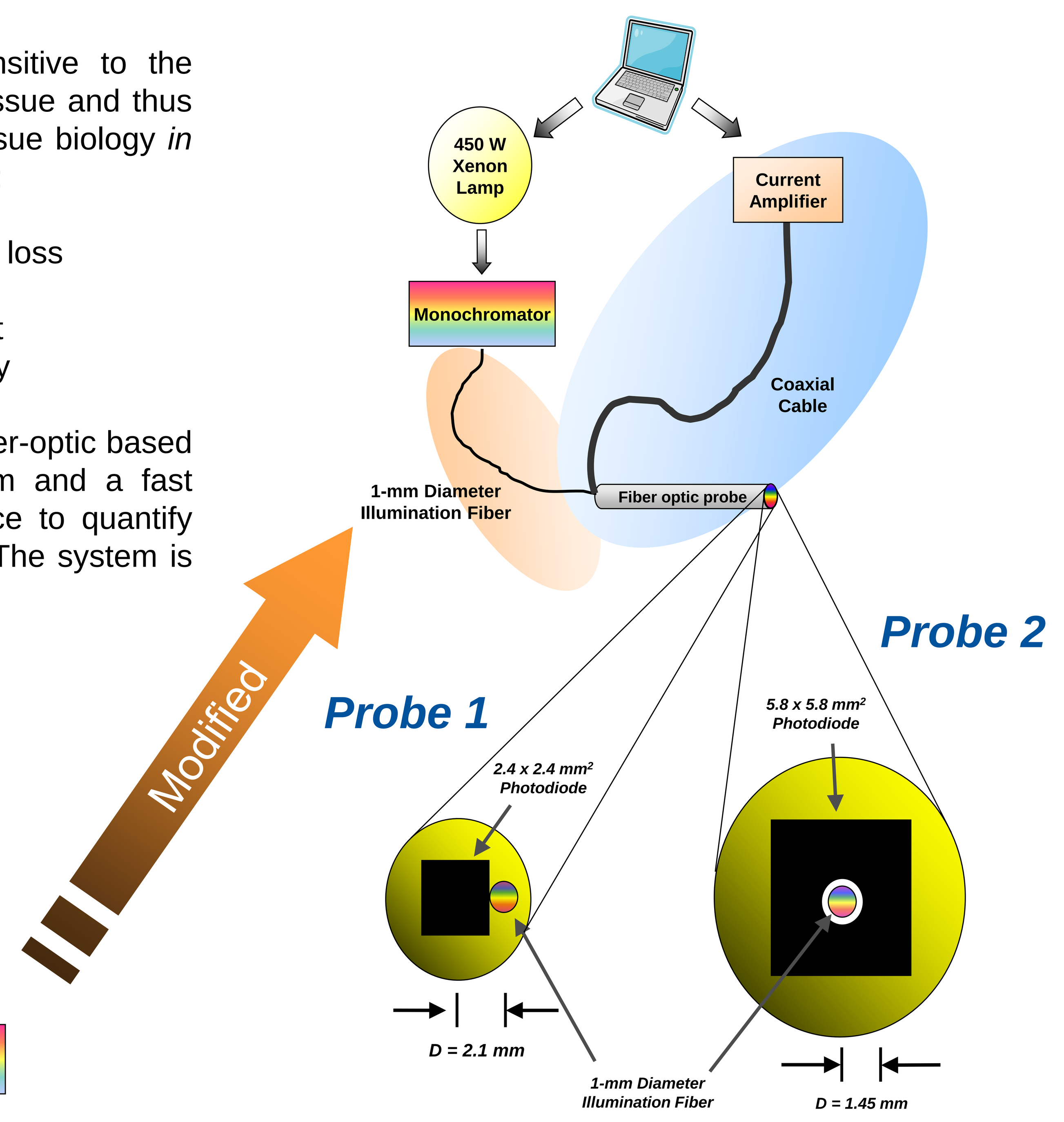
(2) Testing probes in phantoms and extracting optical properties by MC inversions

(3) Simulating λ reduction to assess the feasibility of replacing the costly tunable light source with inexpensive LEDs in the next iteration of system modification

METHODS

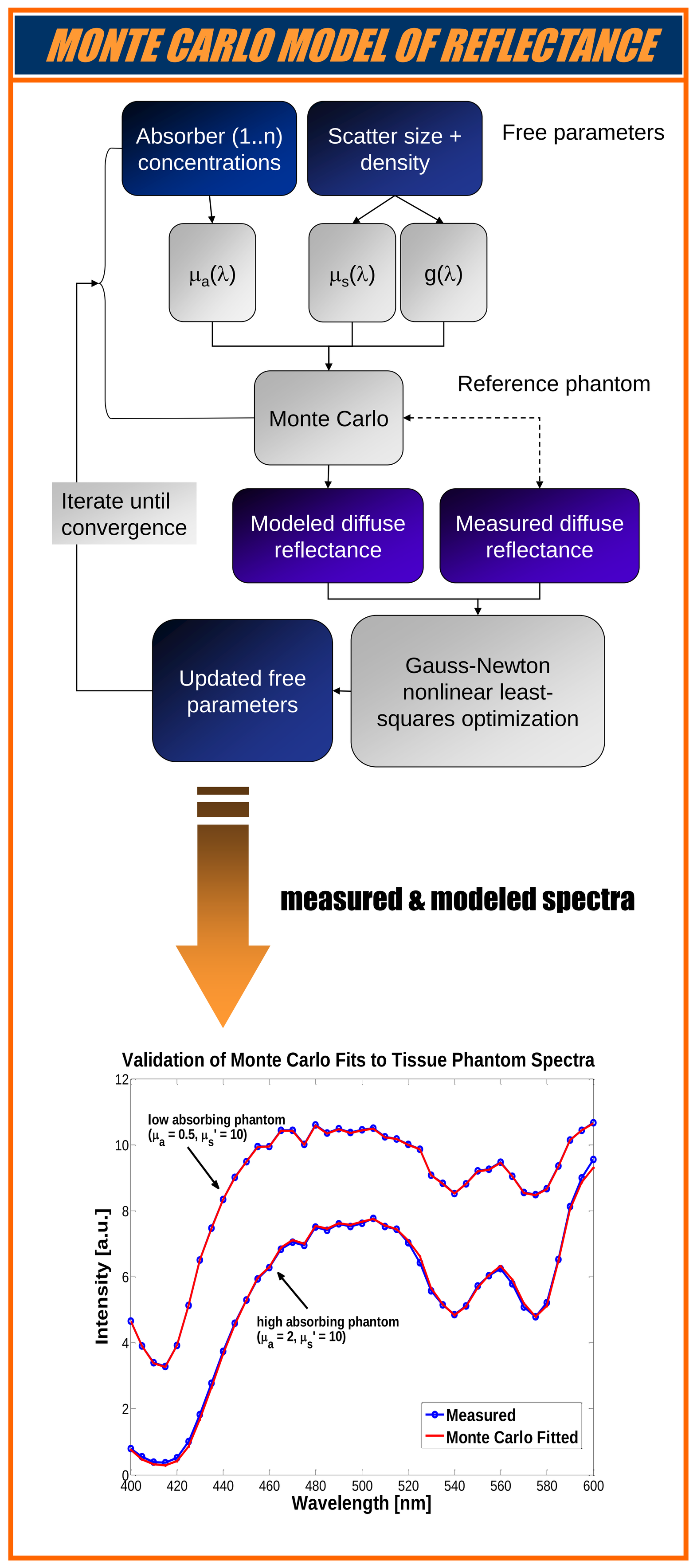
1. System modification & probe geometries

The CCD and spectrograph were replaced by a single silicon photodiode placed directly at the tissue surface for improved collection efficiency and reduced cost of the detection portion of the system. Two different probe geometries were evaluated for SNR and MC inversion performance.



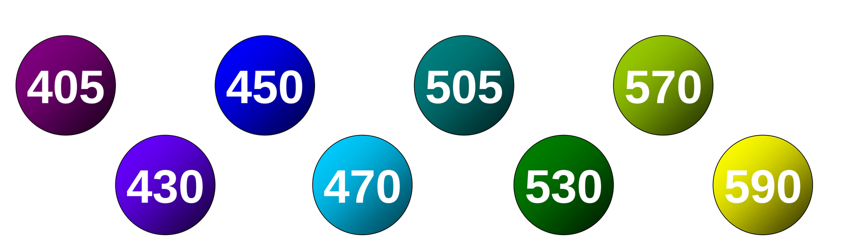
2. Synthetic tissue phantom study

Hemoglobin and 1-μm polystyrene spheres were used to create phantoms over a wide range of optical properties similar to those of human breast tissue. Diffuse reflectance measurements were taken from 400-600 nm in increments of 5 nm. A previously developed Monte Carlo model of reflectance (shown below) was used to perform inversions to extract optical properties from the measured data.



3. Simulated wavelength reduction

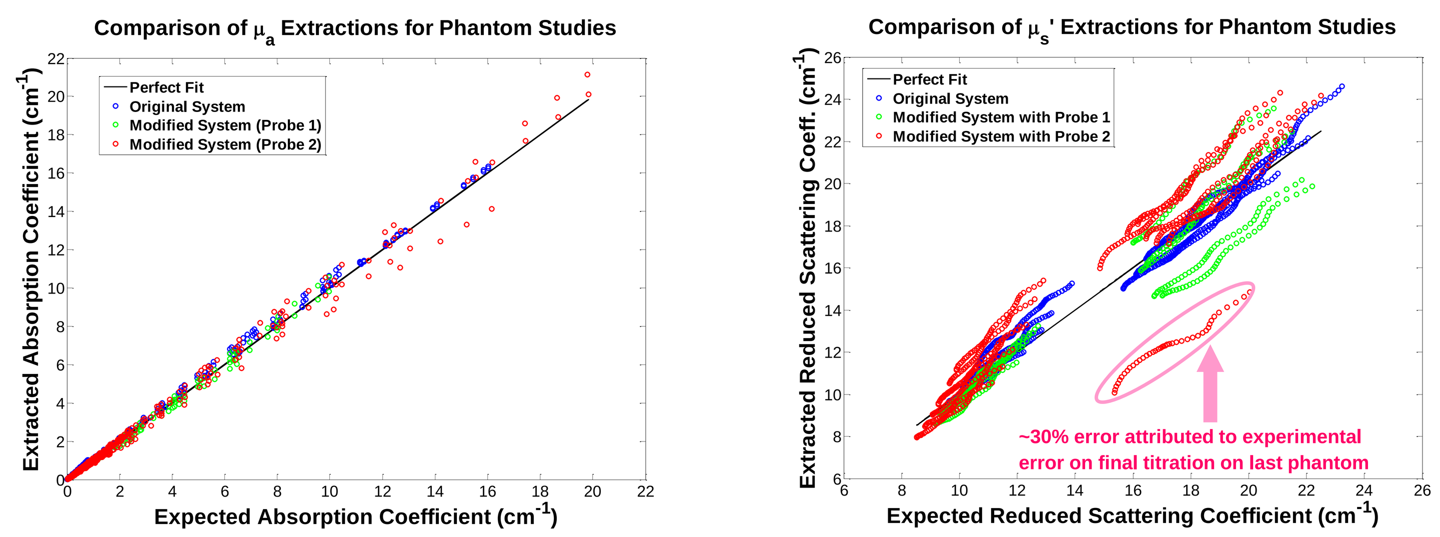
To further decrease the cost of the original bench-top system, we investigated the potential use inexpensive LEDs in the 400-600 nm range to replace the lamp and monochromator. 8 commonly available wavelengths, each with bandwidth of ~20 nm, were chosen:



The collected spectra from the two phantom studies were processed such that data points from all wavelengths were taken out, except for those of the LED wavelengths. MC inversions were performed with the newly created LED spectra, and errors of extracted optical properties were evaluated.

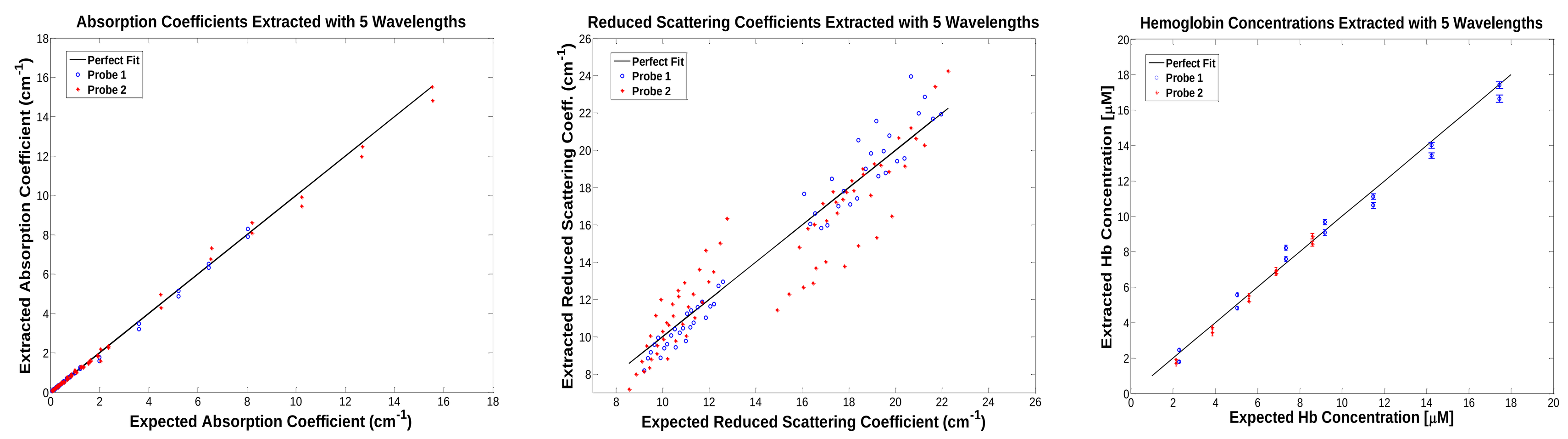
RESULTS

Monte Carlo Inversion Results: Comparison with Original System



Wavelength Reduction:

To be conservative initially, 8 wavelengths were chosen. However, our later MC simulations showed that there is no significant decrease in inversion errors for as few as 5 wavelengths used. The following figures are the extractions for 5 wavelengths: 405, 450, 505, 530, and 590 nm.



Summary of Optical Properties & Inversion Errors

	Mean μ_s' range [cm^{-1}]	Mean μ_a range [cm^{-1}]	Hb range [μM]	μ_s' error	μ_a error
Original system	12.7 ~ 24.0	0.2 ~ 3.3	0.7 ~ 14.3	4.4 ± 3.4%	9.2 ± 12.4%
Probe 1	11.7 ~ 21.7	0.5 ~ 2.0	2.2 ~ 8.6	8.9 ± 6.5%	8.0 ± 6.2%
Probe 2	10.9 ~ 22.0	0.5 ~ 3.8	2.3 ~ 17.5	12.1 ± 3.6%	8.5 ± 7.5%
Probe 1: λ-reduced	11.7 ~ 21.7	0.5 ~ 2.0	2.2 ~ 8.6	8.94 ± 6.26	8.27 ± 9.30
Probe 2: λ-reduced	10.9 ~ 22.0	0.5 ~ 3.8	2.3 ~ 17.5	12.40 ± 11.64	7.99 ± 7.26

CONCLUSION

We have modified the detection part of our bench-top system by replacing the spectrograph and CCD with an inexpensive silicon photodiode. By placing the detector directly at the tissue surface, we have improved the collection efficiency of the system, thus reducing the cost associated with expensive and sophisticated CCD cameras. Through phantom studies, we have shown that the modified system has comparable performance for extracting optical properties as that of the original system. Wavelength reduction simulations were also performed to show the feasibility of replacing the lamp and monochromator with inexpensive LEDs for illumination while still maintaining the ability to quantify tissue absorption and scattering. This study shows the great potential of this smaller, cheaper device being expanded for multi-point, spectral imaging in the near future.

Future Work

- Test of single-channel device in murine model of breast cancer
- Design, characterize, and test 2nd generation device with LEDs in place of lamp and monochromator

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