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

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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 spectograph. 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:

- Fiberless back-illumination strategy with detectors at sample surface
- Xenon lamp with filter wheel: 400, 420, 440, 470, 500, 530, 570, 600 nm bandpass filters with FWHM = 10 nm
- Optical Power @ 400 nm (µW)

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

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

Performance Comparison of Custom & Commercial Detectors

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

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.

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

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

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