Experimental phantom verification studies for simulations of light interactions with skin: Solid Phantoms

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Where are we from?
Outline

Motivation for the work
Phantom preparation and measurements
Computer model

Simulation
Imaging
Comparison
Conclusions
Motivation for work

• Laser or light treatment modalities are increasing
• Human skin absorbs and scatter light – skin tone important
• Melanin content in epidermis differ
• Can the computer model be used to predict light levels at a specific depth into skin?
• Need to verify the model
• Measurements on patients are impractical
• Use phantoms to verify model
Verification comparison

• Layered structure of skin can be modelled
  • Solid or liquid phantoms can be used for verification
  • Solid phantoms prepared from resin, absorbing and scattering particles – advantage: multi layers possible and phantoms stable and durable for repeatability studies
  • Liquid samples made from Intralipid® and black ink – optical properties of Intralipid® is well documented in literature

• Manufacture phantoms – use phantom parameters in computer model
  • Measure transmitted light through phantom and model
Phantom preparation and measurements
Sample preparation

- Solid phantoms prepared by mixing
  - TiO particles (particle size < 25 nm, density 3.9 g/mL) – scattering particles
  - Carbon Black – absorbing particles – different skin tones
  - Optically clear resin (Akasel)
    

- Sample holder diameter = 30 mm
- Samples cured for 24 hours
- Cut in slices
- Optical properties, total transmission and reflection measured with Integrating Sphere (IS)
Integrating Sphere measurements

Measurements of the total transmittance and reflectance of a thin slab-shaped multiple scattering sample can yield the absorption- and the reduced scattering coefficient of the sample.

\[
R = R_{\text{BS}} \left( \frac{I_R}{I_{\text{ref}}} \right) \\
T = \frac{I_T}{I_{\text{ref}}} \\
\text{Beer-Lambert Law} \\
l = I_0 \exp(\mu_t d)
\]

\[
\mu_a \quad \text{and} \quad \mu_s'
\]

Setup
Computer Model
Computer model (I)

- **Modelling done in ASAP software**
  - Non-sequential ray tracing
  - Monte Carlo simulations
  - Rays can automatically split into reflected, refracted, diffracted, polarized, and scattered components as they propagate through the system
Computer model (II)

• **Input parameters**
  - Geometry of model – disc with 1 or 2 layers, disc diam = 30 mm
  - Light source specification – 633 nm, beam diameter 1 mm
  - Specify the optical properties (specify $u_a$, $u_s$, $g$ and $n$) of each layer
  - Assume the optical properties are uniform with in each layer
  - Trace ~ 3.1 mil rays through sample

• Set up a transmission detector (absorbing disc) and a reflecting detector behind light source (absorbing semi sphere)

• Evaluation slices in model ~ 0.1 mm thick

• Voxels ~ 0.1X0.1X0.1 mm$^3$
Optical parameters

• Optical properties of phantoms measured at 632.8 nm (HeNe) with integrating sphere.

• 3 different samples (diameter for all 30 mm)
  • Sample A and B – different TiO and carbon black concentrations
  • 2 Layered phantom - Sample C combination of A (d=1.7 mm) and B (d=2.2mm)

• Parameters used in model

<table>
<thead>
<tr>
<th>Sample</th>
<th>$u_a$ (mm$^{-1}$)</th>
<th>$u_s$ (mm$^{-1}$)</th>
<th>d (mm)</th>
<th>n</th>
<th>g</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.268</td>
<td>10.38</td>
<td>1.66</td>
<td>1.4</td>
<td>0.79</td>
</tr>
<tr>
<td>B</td>
<td>0.138</td>
<td>4.85</td>
<td>2.4</td>
<td>1.4</td>
<td>0.79</td>
</tr>
<tr>
<td>C</td>
<td>Use A and B values</td>
<td>Use A and B values</td>
<td>3.9</td>
<td>1.4</td>
<td>0.79</td>
</tr>
</tbody>
</table>
Simulation results
Propagation of beam through sample B
Comparing transmission, absorption and reflectance measurements (on the IS system) to simulation results

<table>
<thead>
<tr>
<th>Sample</th>
<th>% Abs (Sim)</th>
<th>% Trans (IS)</th>
<th>% Trans (Sim)</th>
<th>% Refl (IS)</th>
<th>% Refl (Sim)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>65</td>
<td>10</td>
<td>8.8</td>
<td>27</td>
<td>25</td>
</tr>
<tr>
<td>B</td>
<td>59</td>
<td>19</td>
<td>17</td>
<td>27</td>
<td>24</td>
</tr>
<tr>
<td>C</td>
<td>70</td>
<td>4</td>
<td>2.7</td>
<td>20</td>
<td>26</td>
</tr>
</tbody>
</table>
CCD images of phantoms

Experimental setup. P (Polarizer), S (Sample), L (Lens f= 100mm, D=50.8mm), CCD (Camera), PC (Computer), u (Object distance = 500 mm), v (Image distance = 125 mm) M= 0.25  HeNe Laser 9 mW
CCD images - Camera size: 7.1mm x 5.4 mm

A (Beam diam 10.1 mm)  B (Beam diam 9.6 mm)  C (Beam diam 12.6 mm)

Simulation images at back of sample mages – size 5mm x 5 mm

A Fluence  B Fluence  C Fluence
Conclusions
Conclusions

• Relatively good agreement between measured and modelled values when comparing transmitted and reflected values
• Image comparisons show good trend, but absolute values differ – maybe due to interpretation of CDD images and light settings used
  • This needs to be investigated further
• Computer model shows potential and with further refinement can be used to predict light intensities at specific distances into skin
Thank you