Spatial and temporal skin blood volume and saturation estimation using a multispectral snapshot imaging camera

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Background

- The oxygenation of living tissue is a fundamental parameter to for the homeostasis of cells, tissue and organs.
- Microcirculation of tissue is spatial and temporal heterogeneous.
- Clinically, visual observations of temporal and spatial skin colour variations, as a reaction to provocation, can be used to indirectly assess the microcirculatory blood perfusion and oxygenation.

Background

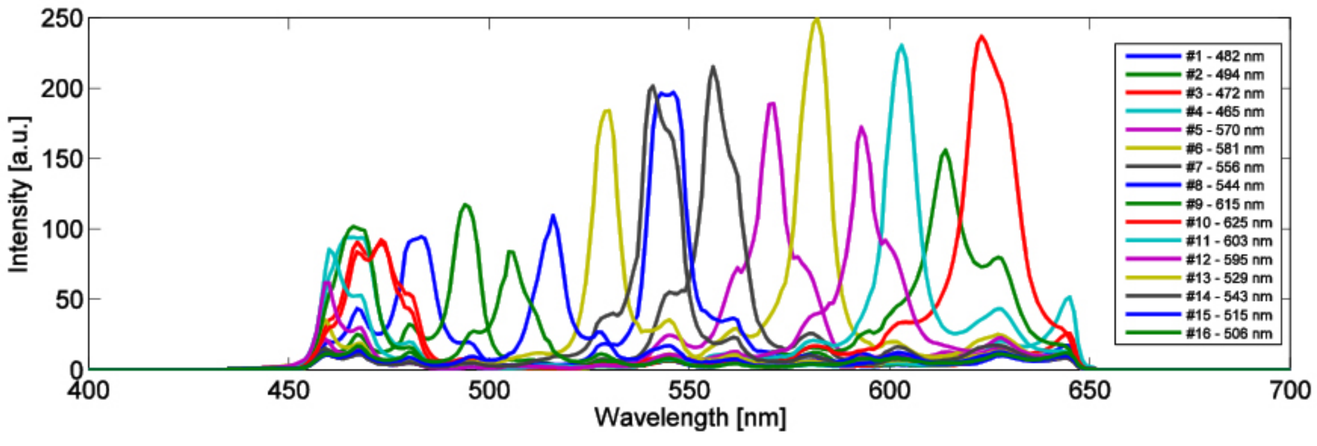
- Standard diffuse reflectance spectroscopy utilize optical fiber probes with a well-defined distance between sending and receiving fibers.
- Hyperspectral imaging combine spectroscopy and imaging techniques to acquire spectral and spatial information.
  - Manual mapping
  - Monochrome camera with LCTF or optoacoustic filters or
  - Hyper- or Multi-spectral cameras

Aim

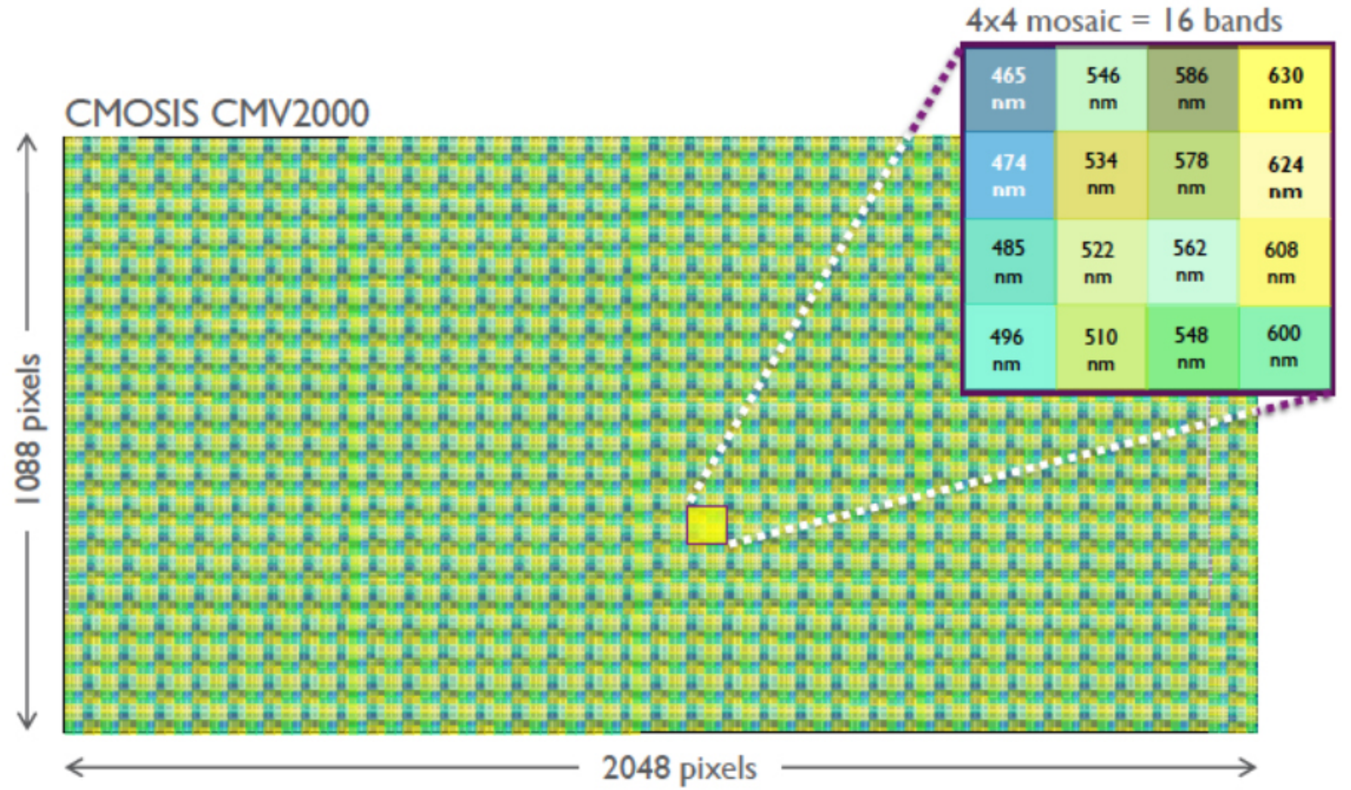
- Evaluate a multispectral snapshot imaging system to estimate skin blood volume and oxygen saturation with high temporal and spatial resolution

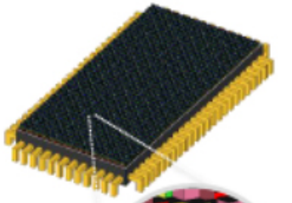
xiSpec camera

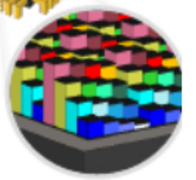
- MQ022HG-IM-SM4X4-VIS, XIMEA®
  - 4x4 mosaic detector (CMOS)
  - 16 wavelength bands (465-630 nm)
  - Image size: 512 x 272 (per band)
  - FPS: 170 data-cubes/s



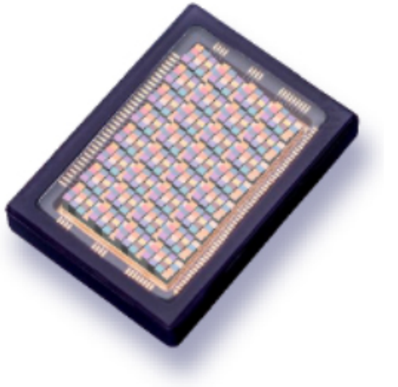
SNAPSHOT MOSAIC **HSI SENSOR** (GEN1)





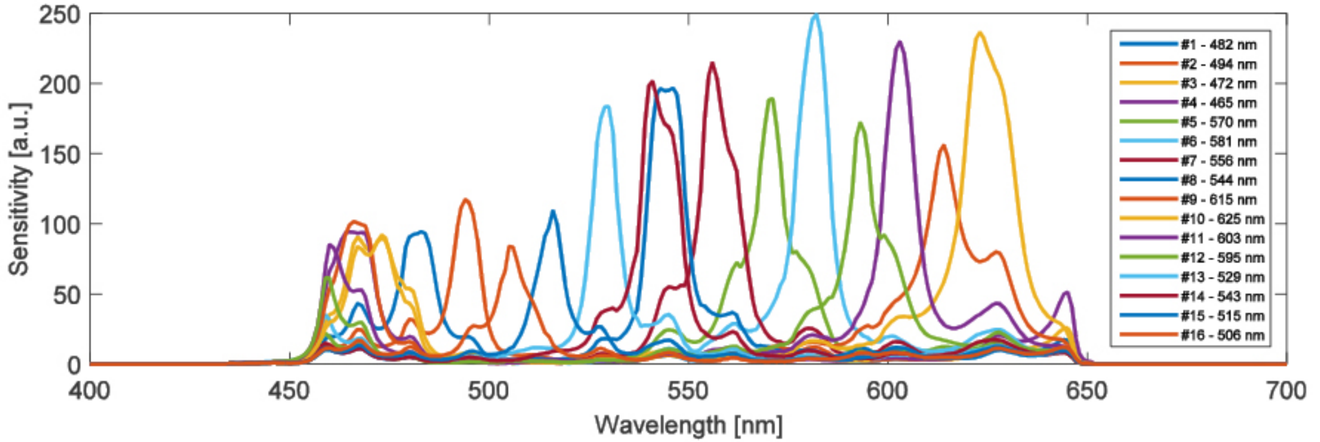


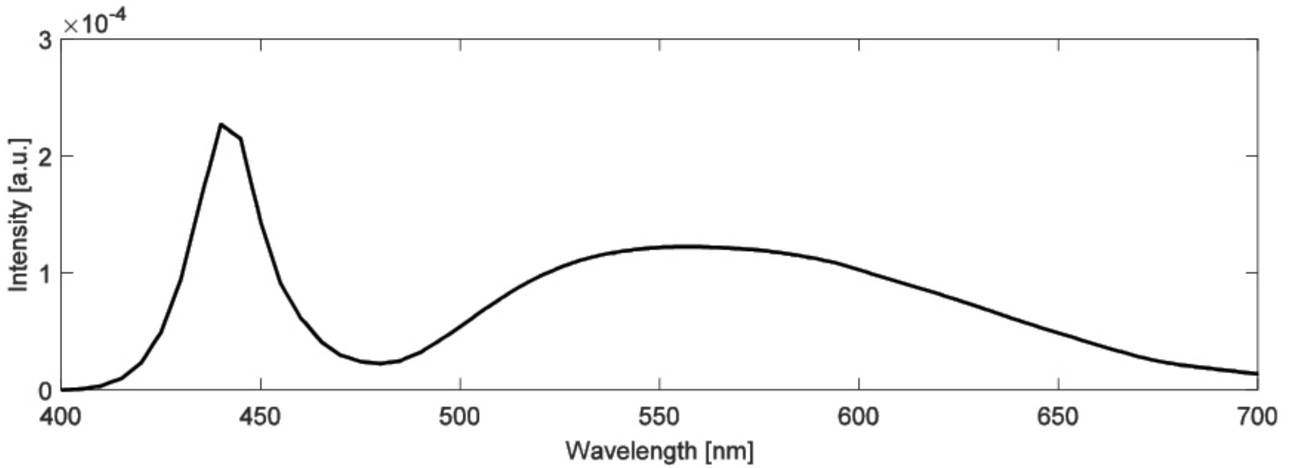
4x4 mosaic



- Key specifications
  - **Spectral resolution**: 4x4 mosaic (1filter / pixel) = 16bands in 470-630nm
  - **FWHM**: ~ 15nm
  - **Spatial resolution**: from 512x272 (RAW per band)
  - **Speed**: up to 340 data-cubes / s (max sensor limit)

Modelling detected light



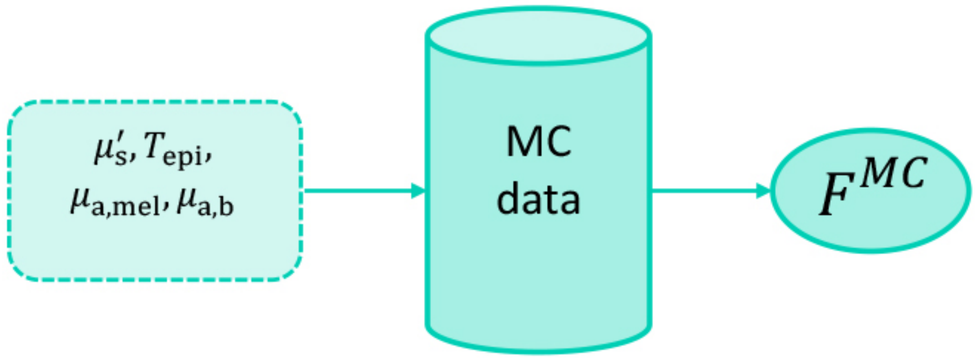


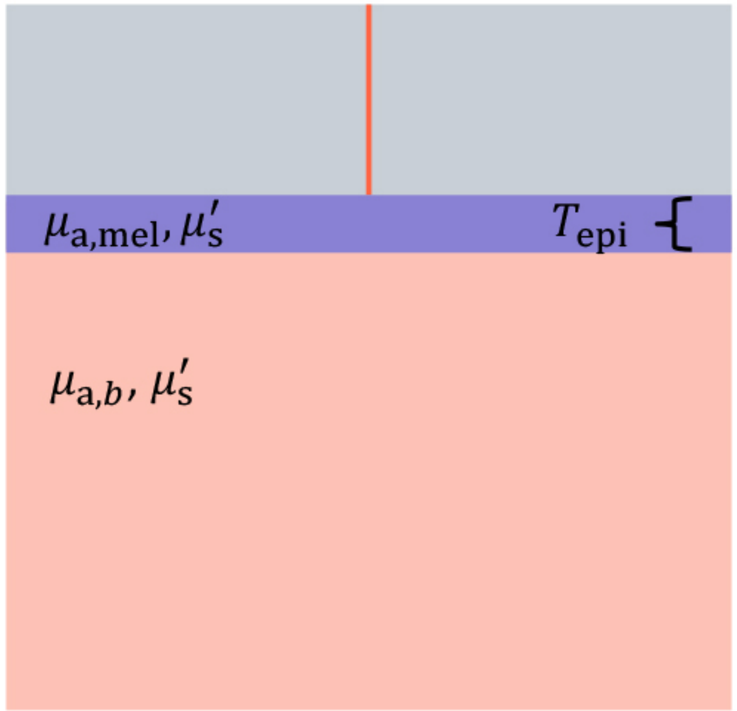
Forward Monte Carlo model

- Monte Carlo simulations to create a look-up table
  - Two-layered tissue model
  - Discrete values of

    μ'_s, T_{epi}, $\mu_{a,mel}$ and $\mu_{a,b}$

    relevant to human skin





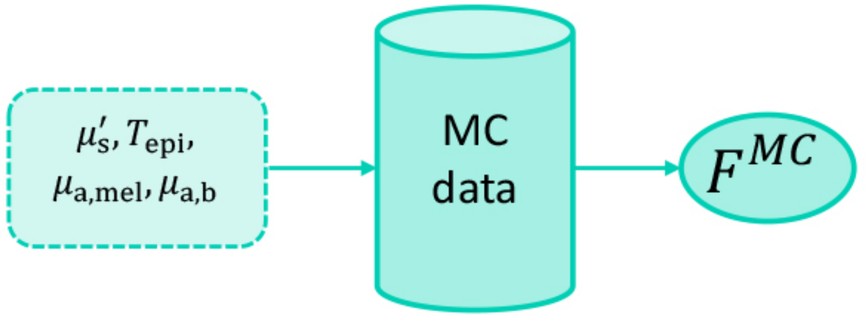
Forward Monte Carlo model

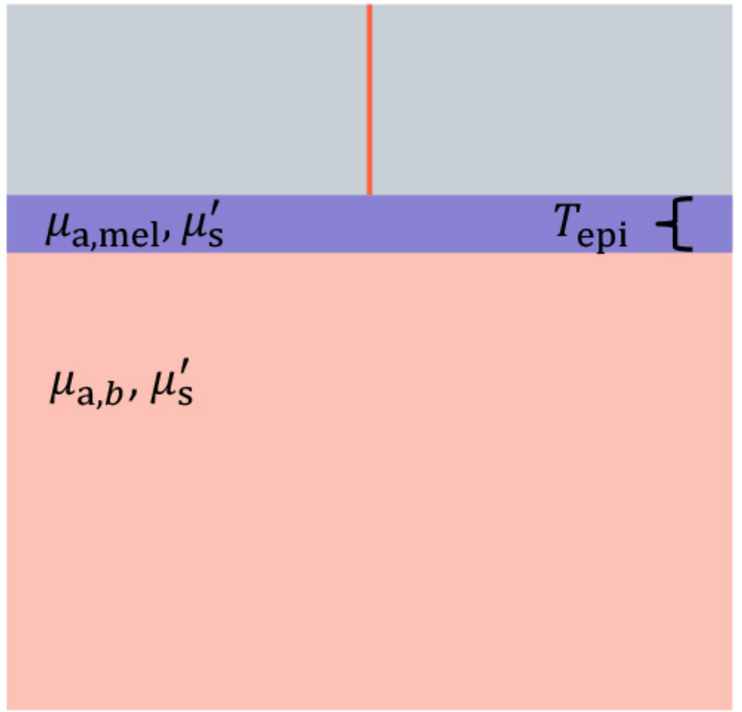
- Monte Carlo simulations to create a look-up table

$$\mu_s'(\lambda) = \alpha \cdot \left(\frac{\lambda}{500}\right)^{-\beta}$$

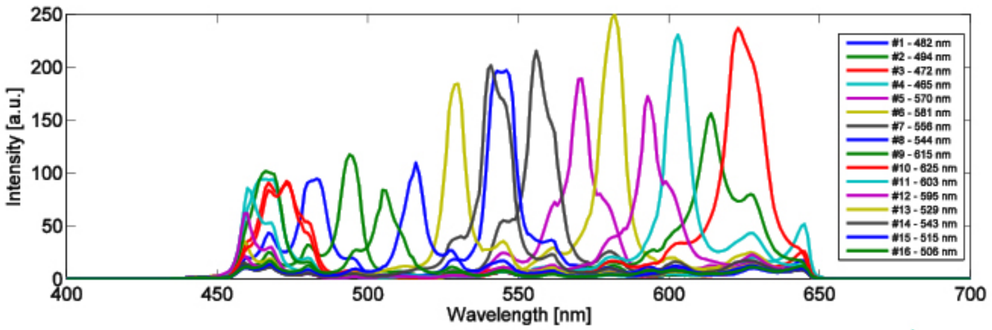
$$\mu_{a,mel}(\lambda) = c_{mel} \cdot 51.9 \cdot \left(\frac{\lambda}{500}\right)^{-3}$$

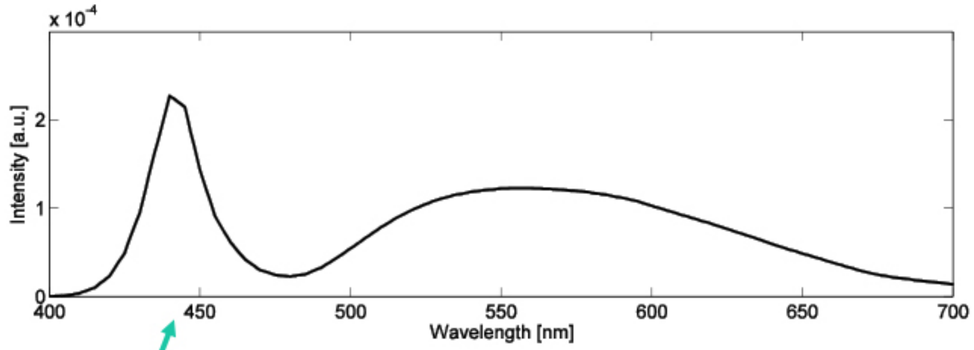
$$\mu_{a,b}(\lambda) = (1 - s_b) \cdot c_b \cdot 0.15 \cdot \mu_{a,Hb}(\lambda) + s_b \cdot c_b \cdot 0.15 \cdot \mu_{a,HbO2}(\lambda)$$



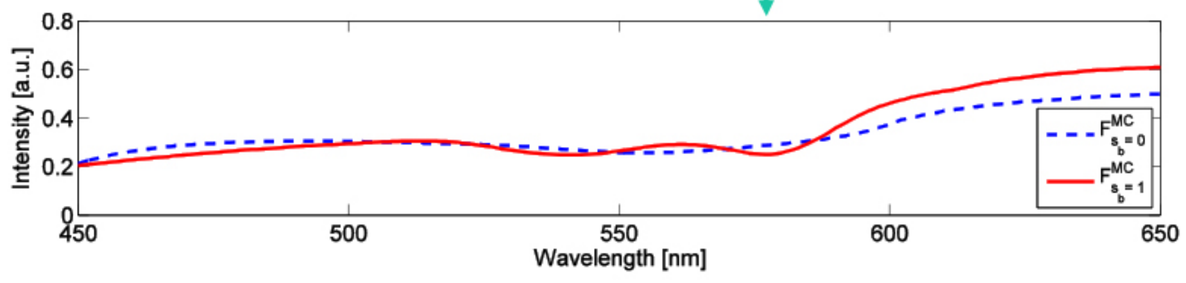


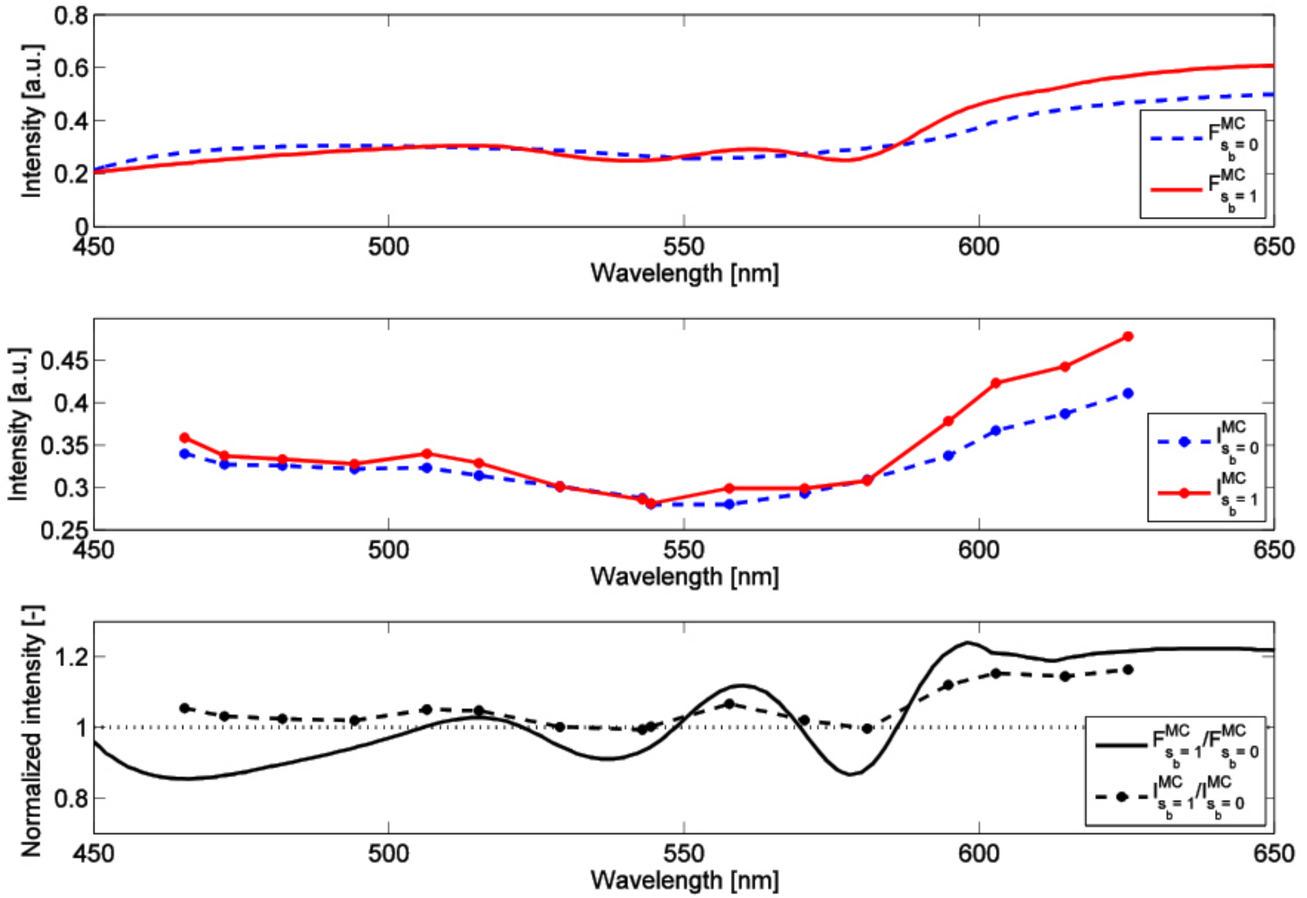
Modelling detected light

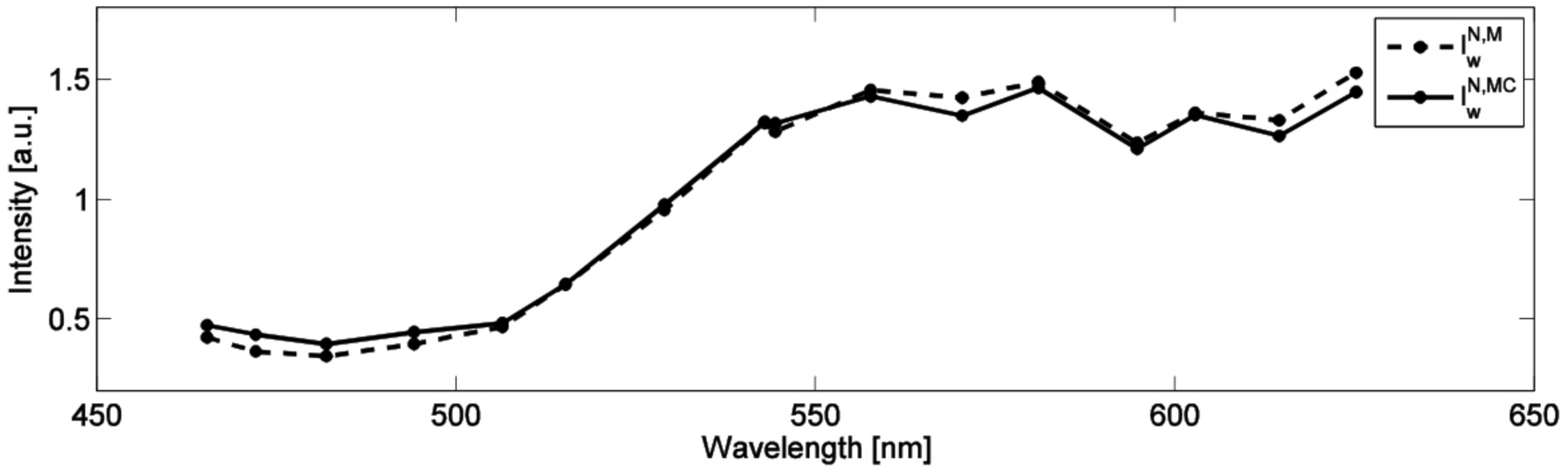




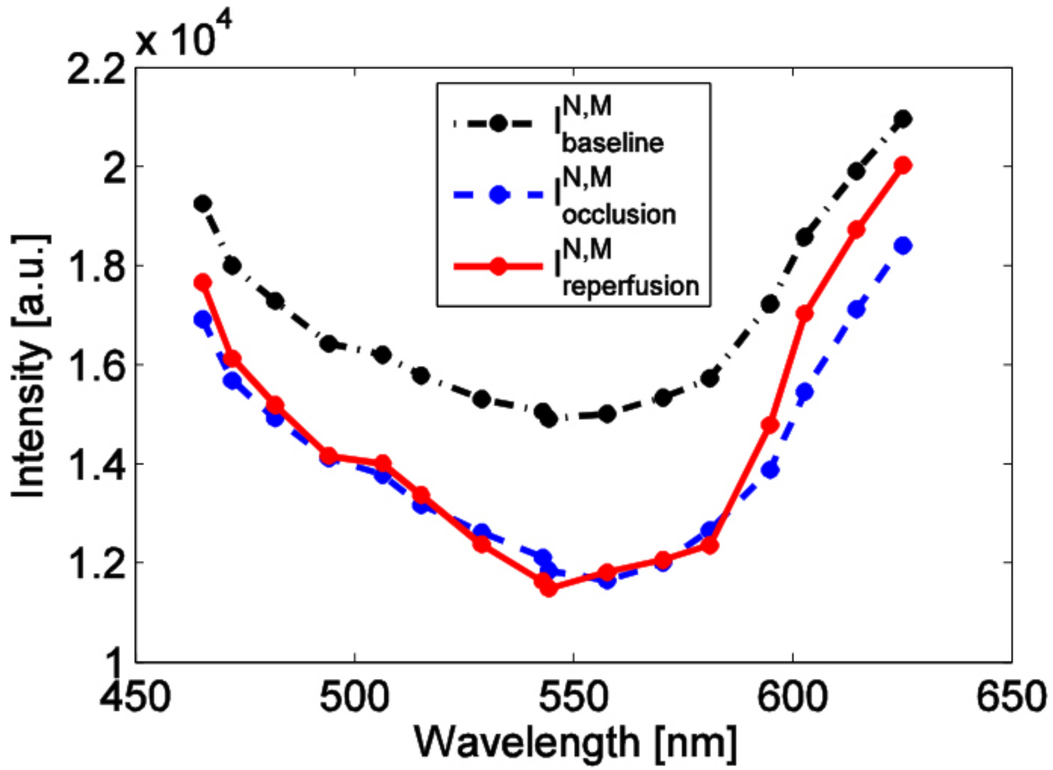
$$I_{\mathrm{x}}^{\mathrm{MC}}(n) = \sum_{\lambda} r_{\mathrm{n}}(\lambda) \cdot L(\lambda) \cdot F_{\mathrm{x}}^{\mathrm{MC}}(\lambda)$$

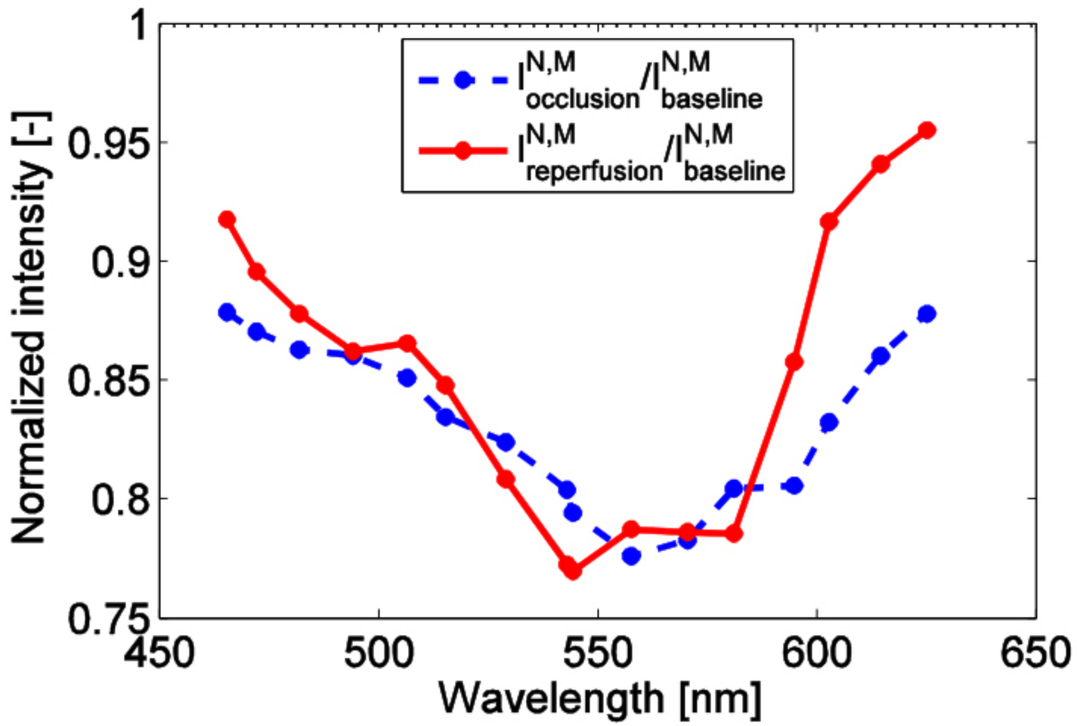



Intensity [a.u.]
Wavelength [nm]
$F^{MC}_{s_b=0}$
$F^{MC}_{s_b=1}$
Intensity [a.u.]
Wavelength [nm]
$I^{MC}_{s_b=0}$
$I^{MC}_{s_b=1}$
Normalized intensity [-]
Wavelength [nm]
$F^{MC}_{s_b=1}/F^{MC}_{s_b=0}$
$I^{MC}_{s_b=1}/I^{MC}_{s_b=0}$

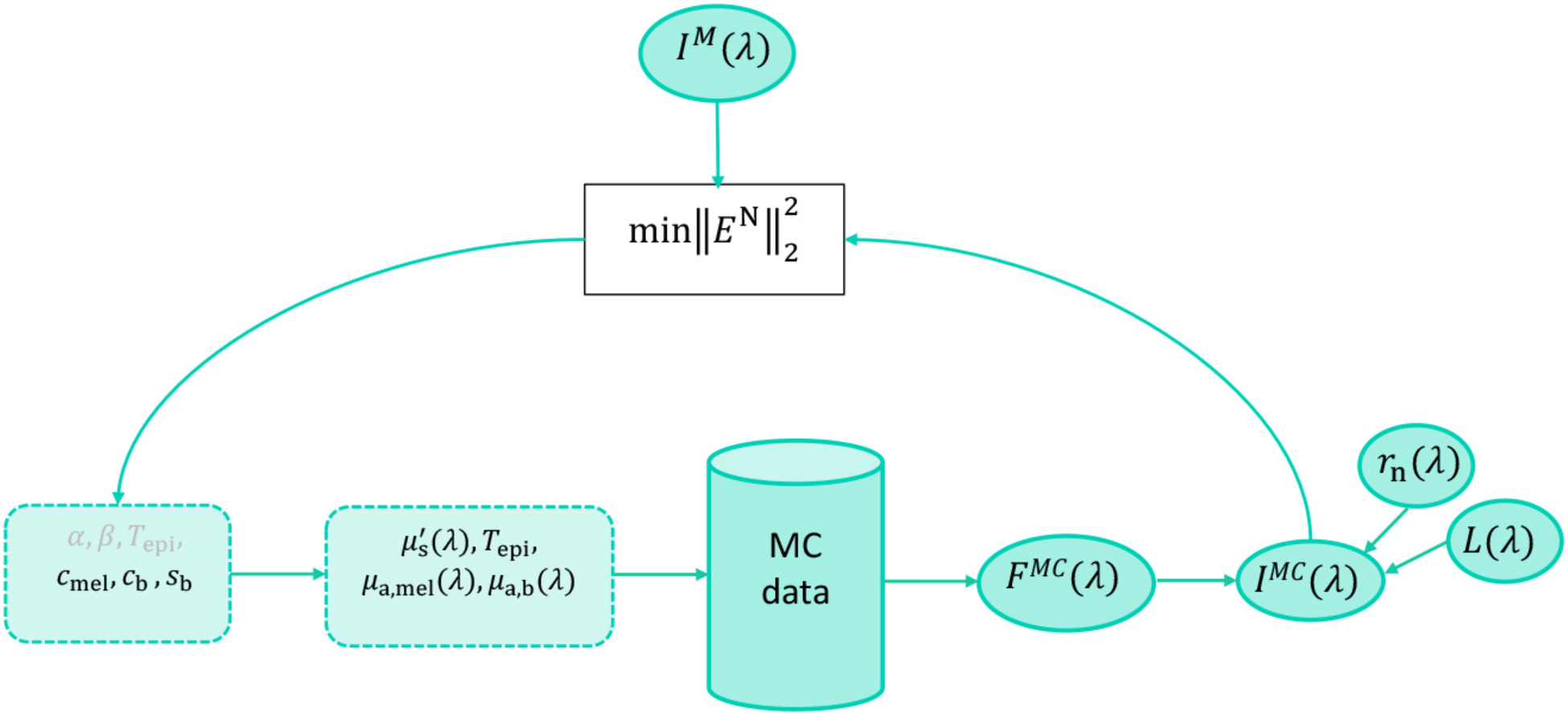

Intensity [a.u.]
1.5
1
0.5
450
500
550
600
650
Wavelength [nm]
$I_w^{N,M}$
$I_w^{N,MC}$

Measurement data





Inverse Monte Carlo algorithm



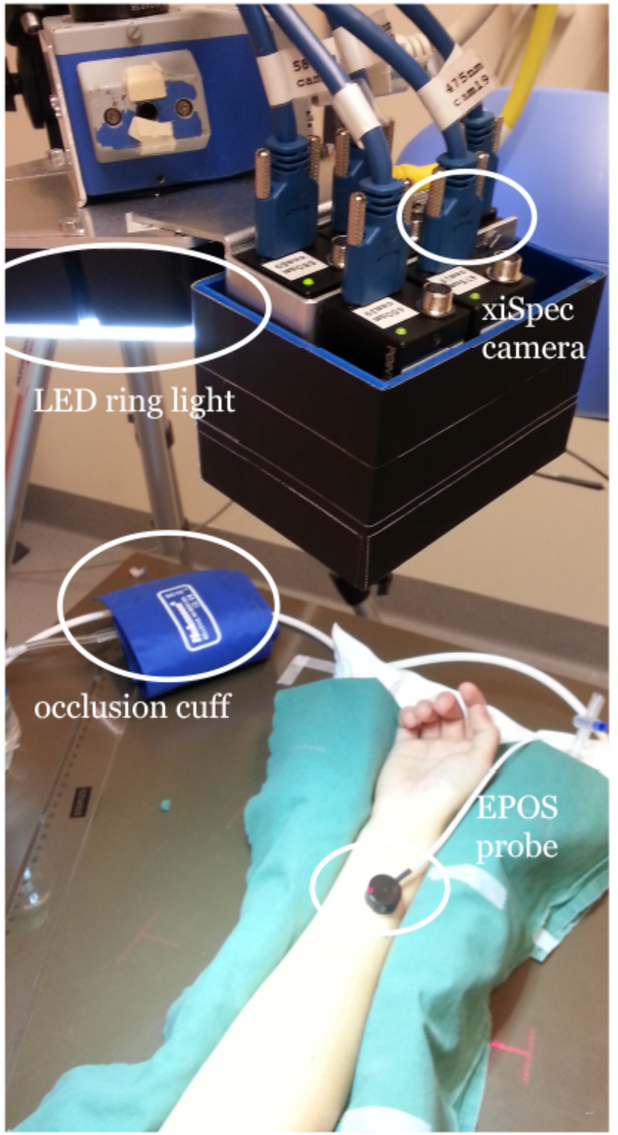
Penalty function

$$E^{\mathrm{N}} = \begin{bmatrix} E_{\mathrm{I}}^{\mathrm{N}}(n) \\ 10 \cdot E_{\mathrm{S}}^{\mathrm{N}} \end{bmatrix}$$

- Spectral fit (chosen channels): $E_{\mathrm{I}}^{\mathrm{N}}(n) = \dfrac{I_{\mathrm{x}}^{\mathrm{N,MC}}(n)}{\langle I_x^{N,MC}(n)\rangle_n} \Big/ \dfrac{I_{\mathrm{x}}^{\mathrm{N,M}}(n)}{\langle I_{\mathrm{x}}^{\mathrm{N,M}}(n)\rangle_n} - 1$
- High saturation sensitivity: $E_s^{\mathrm{N}} = \dfrac{I_{\mathrm{x}}^{\mathrm{N}}(557) + I_{\mathrm{x}}^{\mathrm{N}}(570)}{I_{\mathrm{x}}^{\mathrm{N}}(544) + I_{\mathrm{x}}^{\mathrm{N}}(580)}$
- Minimize penalty function: $\min \|E^{\mathrm{N}}\|_2^2$

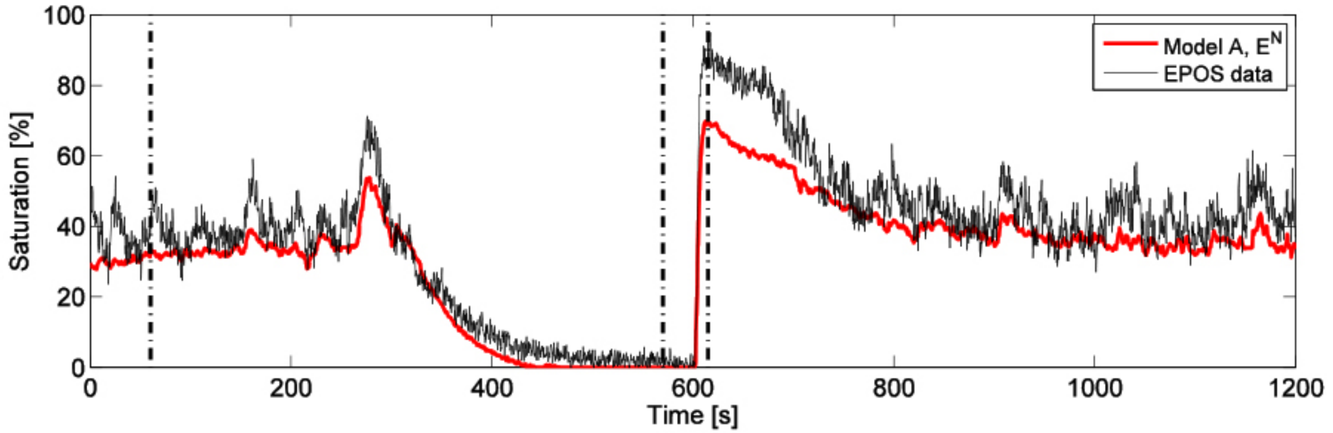
Provocation protocol

- Measurement setup
  - xiSpec camera
  - LED ring light
  - Probe DRS (EPOS) as reference
- Arterial occlusion of forearm
  - 5 min baseline
  - 5 min occlusion (250 mmHg)
  - 10 min after release

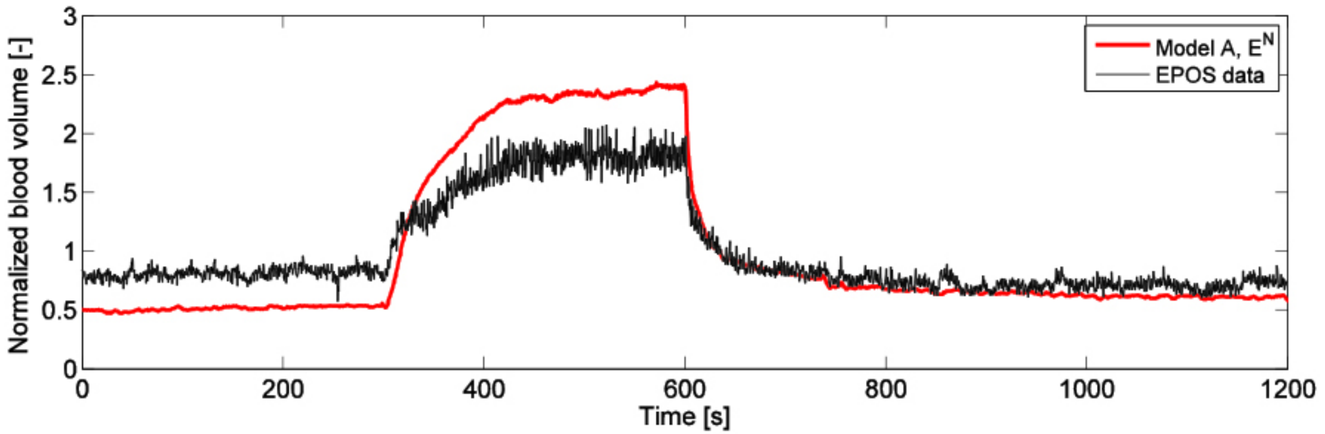


Results - temporal

Arterial occlusion protocol:

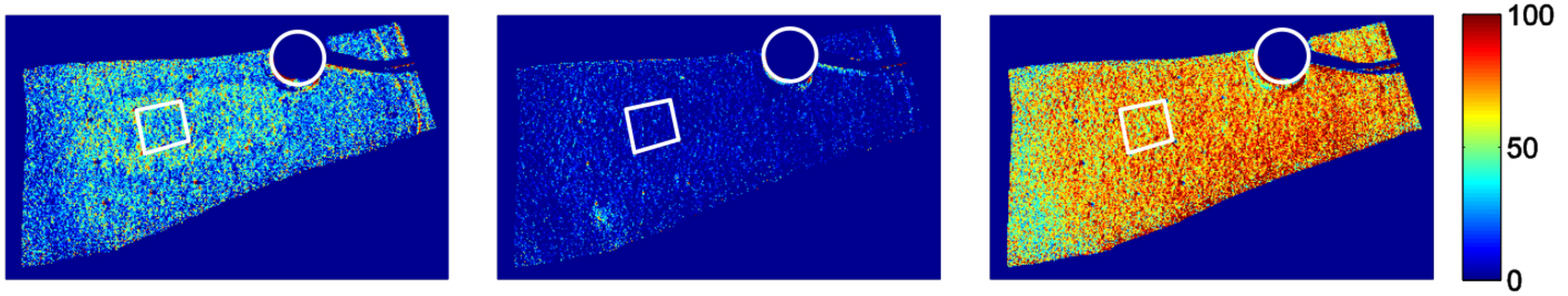


Venous occlusion protocol:



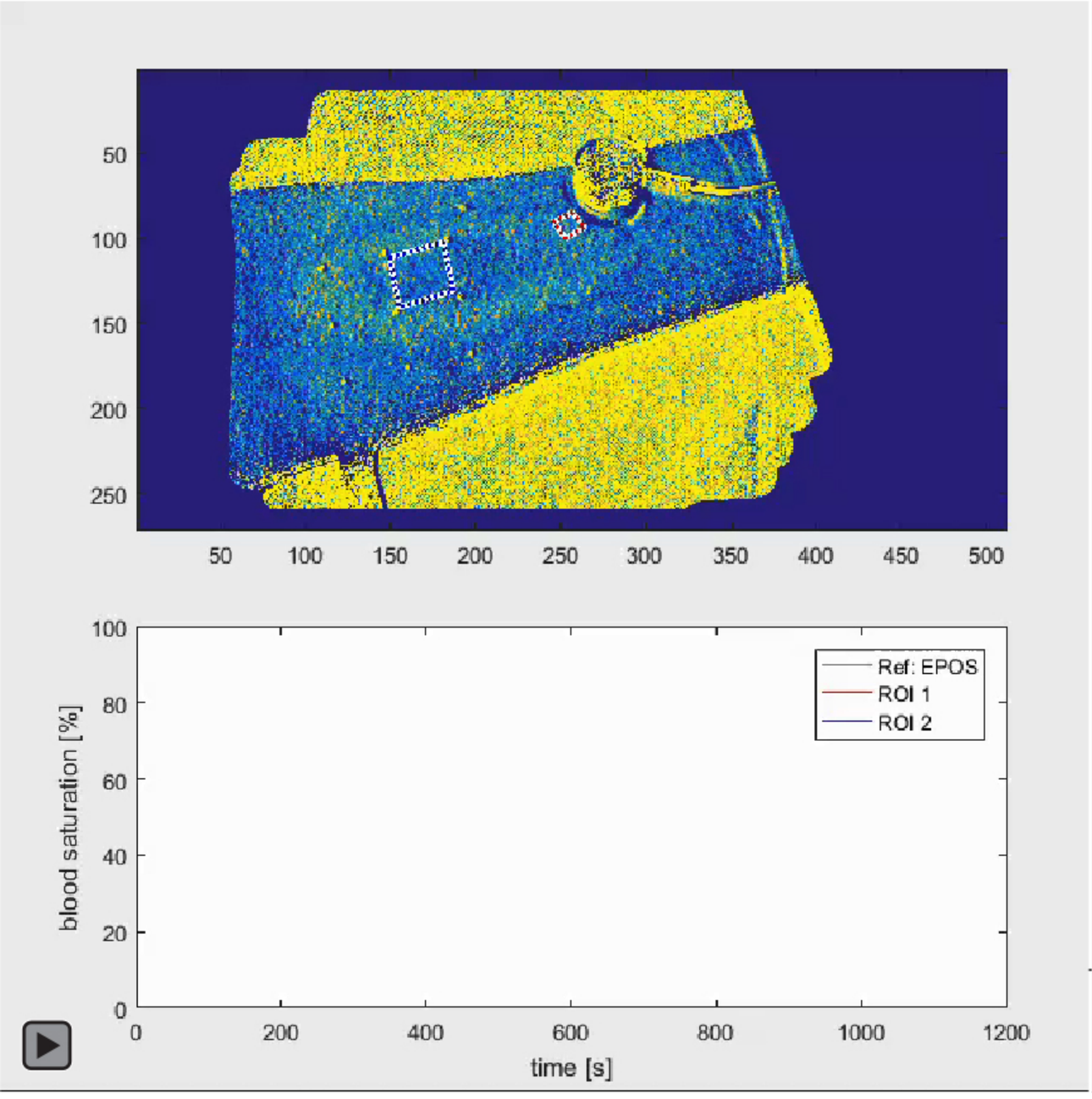
Results - spatial

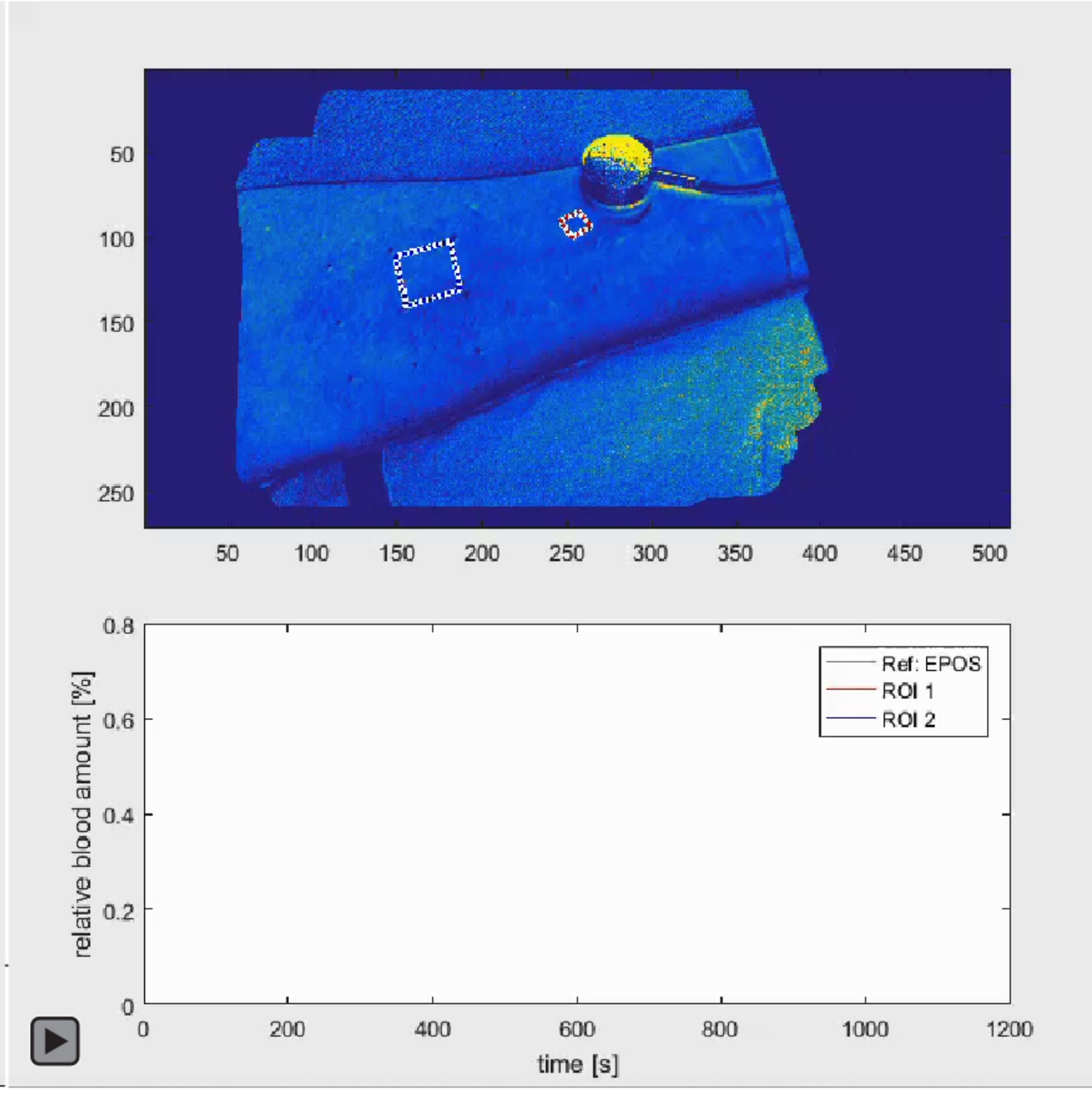
Arterial occlusion protocol, saturation:



Baseline Occlusion Reperfusion

Results – temporal and spatial





Conclusions

- Oxygen saturation sensitive
- Blood concentration sensitive
- Visualize spatial and temporal
  - oxygen saturation and
  - blood concentration maps

Thank you for listening!

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