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Monochomatic spectral imaging: principles and application for skin chromophore mapping

Janis Spigulis and Ilze Oshina

Biophotonics Laboratory
Institute of Atomic Physics and Spectroscopy
University of Latvia, Riga

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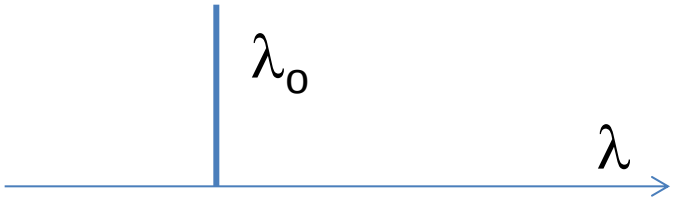
Spectral imaging

- **Spectral image**: an image representing reflection from the object within one specific spectral interval
- **Two ways** to obtain spectral images:
  - By **spectral filtering** of detected light at broadband illumination (e.g. by interference band-pass filters, liquid crystal filters, ...)
  - By narrowband **spectral illumination** (e.g. by color LED or broadband source via band-pass filter) → how narrow?
- **Monochromatic** spectral imaging ($\Delta\lambda << 1$ nm) – nearly impossible to realize by filtering, but relatively easy by **illumination that comprises only one spectral line** (e.g. by a laser beam)



The Riga group

Aim – to develop **affordable for end-users** methods, devices and technologies for clinical diagnostics and monitoring, exploiting optical features of *in-vivo* skin:

- **Skin diffuse reflectance spectroscopy** (DRS**)**:
  - fibre-optic contact probe DRS,
  - multi-spectral imaging → skin chromophore mapping → potential for distant skin assessment
- **Skin autofluorescence spectroscopy** (AF):
  - photo-bleaching (AFPB) effects, skin "photo-memory"
  - parametric AFPB rate imaging → diagnostic potential studies
  - AF kinetic measurements under ps laser excitation
- **Real-time monitoring of skin microcirculation** (photoplethysmography, PPG)
  - bilateral, multi-site and multi-spectral PPG
  - distant (wireless and non-contact) PPG → clinical applications

SkImager: a proof-of-concept device

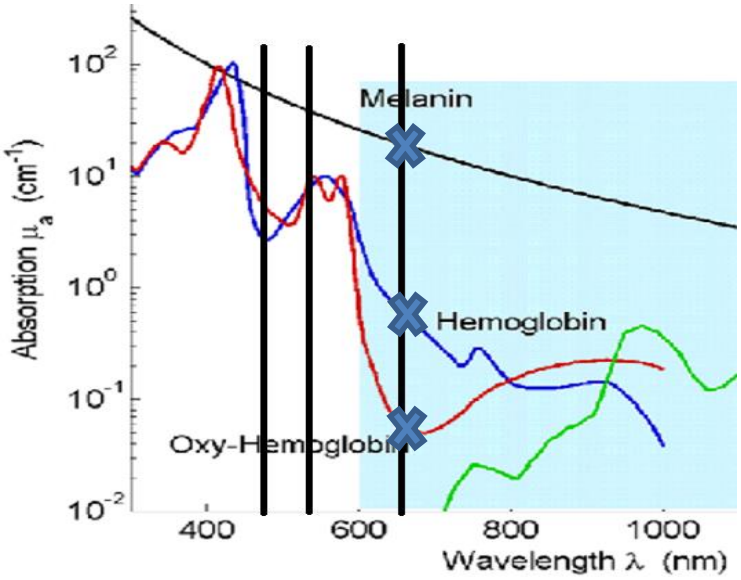
- Wireless, touch-screen, microcomputer
- Performs complex multimodal skin imaging by recording:
  - RGB reflectance image at white polarized illumination → revealing (sub)cutaneous structures
  - **4 spectral images (sequential 450, 540, 660, 940nm LED illumination) → distribution maps of melanin, haemoglobin, bilirubin, erythema index, melanoma/nevus index**
  - Photoplethysmography video-image at green illumination → PPG amplitude distribution → skin blood perfusion map
  - Autofluorescence video-image at UV-excitation → map of photo-bleaching rates → skin fluorophore map

J.Spigulis, U.Rubins, E.Kviesis-Kipge, O.Rubenis. SkImager: a concept device for *in-vivo* skin assessment by multimodal imaging. ***Proc.Est.Acad.Sci.***, 63(3), 213-220 (2014)

Advantages of monochromatic spectral imaging for skin chromophore mapping

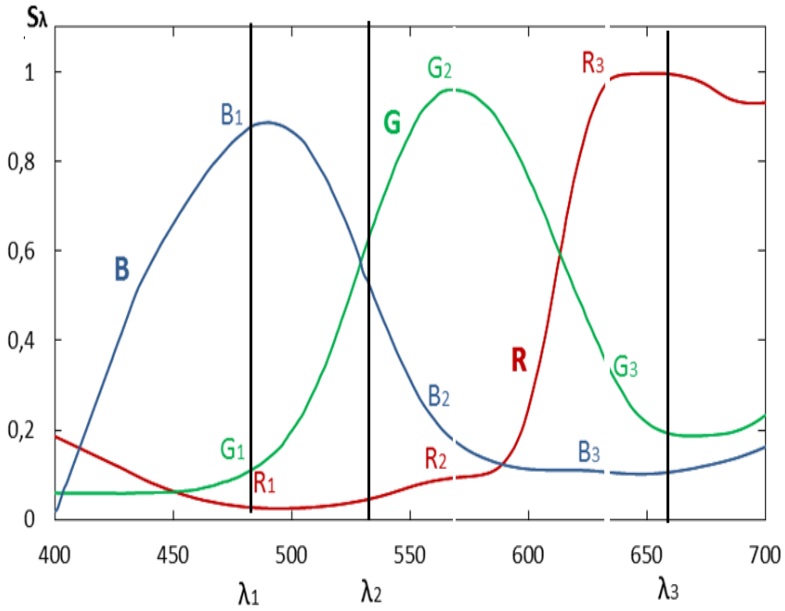
(spectral line illumination *vs* LED band illumination)

- Fixed values of chromophore extinction coefficients at the given λ
- No need for integration over the spectral bands → simpler image processing (set of linear equations derived from the Beer-Lambert law)
- Digital RGB camera allows single-snapshot mapping of 3 main skin chromophores at simultaneous 3-line illumination (convenient)
- Avoids motion artefacts (quality)
- **BUT** – under specific conditions to be observed! →



Extraction of 3 monochromatic spectral images from a single RGB image

- Illuminate simultaneously by 3 wavelengths λ_1, λ_2, λ_3
- Ensure uniform illumination of the object and linear photoresponse of the image sensor
- Exploit the RGB sensitivity curves of the sensor for λ_1, λ_2, λ_3 (manufacturer's or measurement data)
- Switch-off all automatic settings of the camera
- Correct the crosstalk between the R-, G- and B-outputs



J.Spigulis, L.Elste. Method and device for imaging of spectral reflectance at several wavelength bands. **WO2013135311 (A1**), 2012

Next step: conversion of the spectral images into skin chromophore maps (pixel-by-pixel)

Beer-Lambert law:

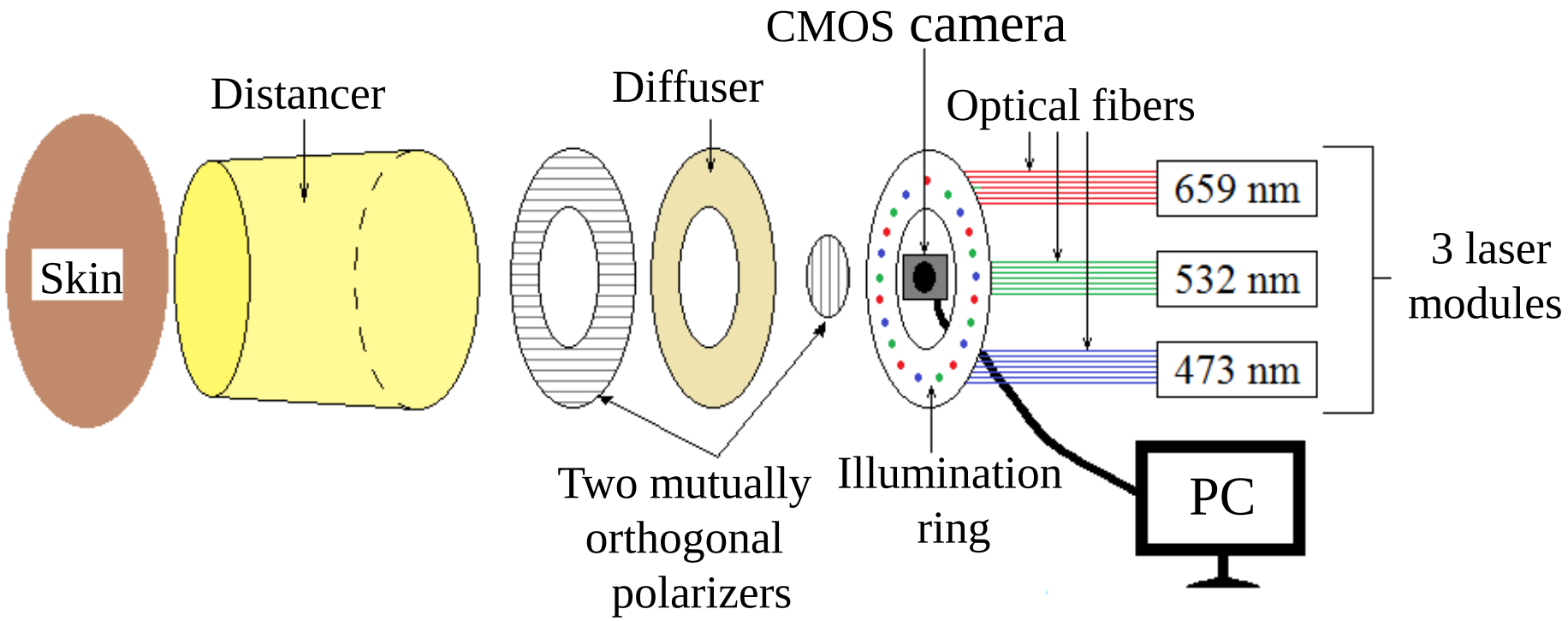
$$\frac{I}{I_0} = e^{-\mu_a d}$$

$$\begin{cases} c_a \cdot \varepsilon_a(\lambda_1) + c_b \cdot \varepsilon_b(\lambda_1) + c_c \cdot \varepsilon_c(\lambda_1) = -\dfrac{\ln k_1}{l_1} \\ c_a \cdot \varepsilon_a(\lambda_2) + c_b \cdot \varepsilon_b(\lambda_2) + c_c \cdot \varepsilon_c(\lambda_2) = -\dfrac{\ln k_2}{l_2} \\ c_a \cdot \varepsilon_a(\lambda_3) + c_b \cdot \varepsilon_b(\lambda_3) + c_c \cdot \varepsilon_c(\lambda_3) = -\dfrac{\ln k_3}{l_3} \end{cases}$$

where k_i – relative (to healthy skin) spectral reflectance at λ_i (λ_1 = 473nm, λ_2 = 532nm, λ_3 = 659nm), l_i – mean optical path length at the particular wavelength, $\varepsilon(\lambda_i)$ - extinction coefficient of the specified chromophore (a – oxy-hemoglobin, b – deoxy-hemoglobin, c - melanin) at the i-wavelength, and c_j **– relative concentration of the chromophore to be mapped** . Tabulated $\varepsilon(\lambda_i)$ values for hemoglobin [3] and melanin [4] were used; estimated $l = 4\delta$ ($l = 2\delta$ for Hb at 473nm), δ – mean penetration depth [5].

$$c_a = 0.145 \cdot \ln k_3 - 0.033 \cdot \ln k_2 - 0.024 \cdot \ln k_1$$
$$c_b = -0.128 \cdot \ln k_3 - 0.024 \cdot \ln k_2 + 0.057 \cdot \ln k_1$$
$$c_c = -0.738 \cdot \ln k_3 + 0.408 \cdot \ln k_2 - 0.806 \cdot \ln k_1$$

Experimental set-up



Results

JBO Letters

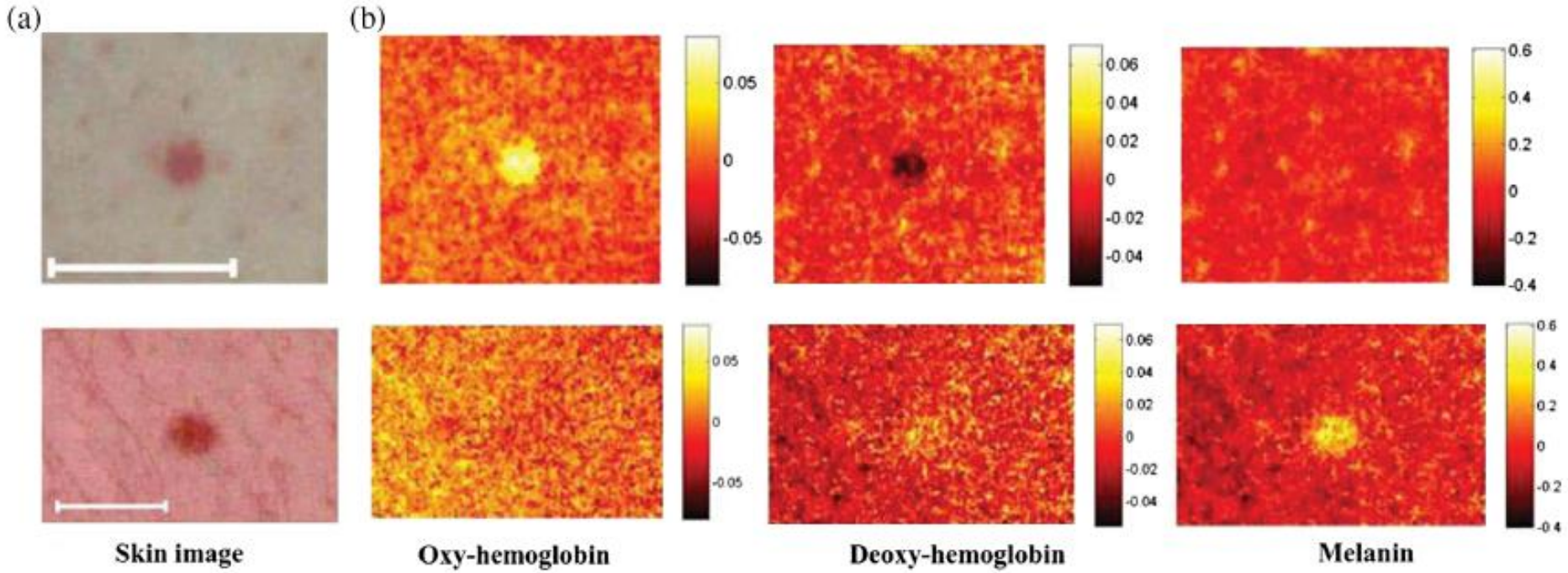
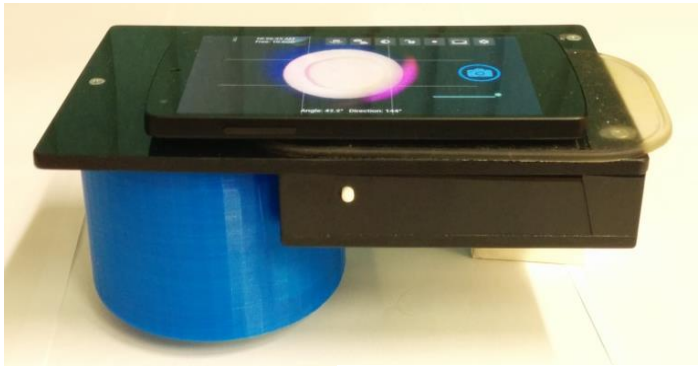


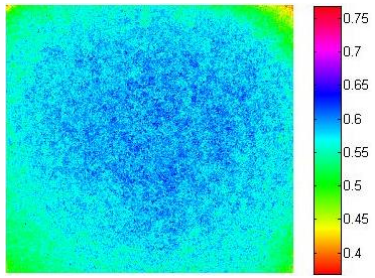
Fig. 1 (a) Skin image at trichromatic laser illumination and (b) distribution maps of three skin chromophores for vascular (upper row) and pigmented (lower row) skin malformations. Scale bar on (a) 1 cm.

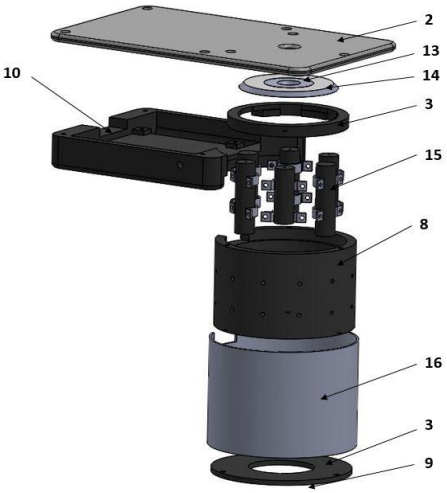
J.Spigulis, I.Oshina. Snapshot RGB mapping of skin melanin and hemoglobin. ***J.Biomed.Opt***., 20(5), 050503 (2015).

Can it be done by smartphone?

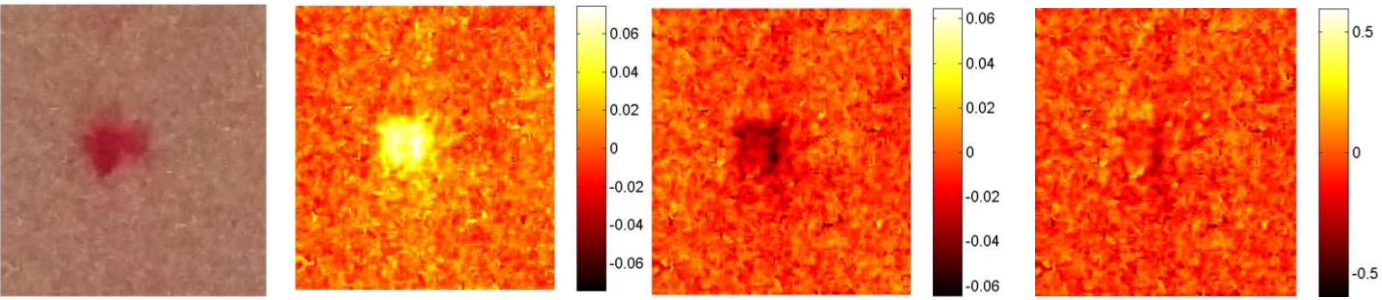
- First prototype created
- 3 pairs of laser modules - 448 nm, 532 nm, 659 nm
- Acceptable uniformity
- First clinical data collected
- Hemangioma:







RGB OH DOH MEL



I.Kuzmina, M.Lacis, J.Spigulis, A.Berzina, L.Valaine. Study of smartphone suitability for mapping of skin chromophores. ***J.Biomed.Opt.***, 20(9), 090503, 2015 (*related to LED-illuminator*)

Bottlenecks and future tasks

- Exact absorption length in skin at specific wavelength? → Applicability of Beer-Lambert for remission?
- Impact of scattering to be considered
- Limited model: also other chromophores (e.g. bilirubin, water) may contribute to absorption
- N = 3 → N > 3, more wavelengths needed
- Laser speckles → incoherent line-spectrum illumination? Uniformity at all wavelengths!!
- RGB sensitivity curves: not always available, measurement method/setup to be developed

Summary

- Monochromatic spectral imaging by means of single-line or multi-line illumination shows potential for skin chromophore mapping
- Image processing technique and related software for snapshot RGB mapping of 3 chromophores was developed
- Skin measurements by laboratory prototype resulted in qualitatively (physiologically) acceptable data
- Smartphone-friendly prototype developed and tested
- Further studies in progress
- **Industrial partners welcomed!**

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Thank You!

- janispi@latnet.lv
- www.lanet.lv/~spigulis