Oximetry in the eye using hyperspectral imaging

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Outline

• Spectral imaging in the retina
• Instrumentation
• Algorithms for oximetry
• Validation
  • Monte-Carlo modelling
  • Phantom eye
Hyperspectral imaging

Quantify chemical abundances by analysis of *spectra*
Oximetry of retinal blood vessels

- Anterior chamber (full of aqueous humour)
- Posterior chamber
- Vitreous humour
- Retina
- Optic disc
- Optic nerve
- Choroid
- Macula
- Sclera
- Lens
- Iris
- Cornea
- Light

Ocular structures are labeled to illustrate the anatomical locations relevant to retinal oximetry.
The Role of Spectral Retinal Imaging

• By 2020 there will be 200 million visually-impaired people worldwide
  • Glaucoma, diabetic retinopathy, ARMD
  • 80% of those cases are preventable or treatable
    • Screening and early detection are crucial
• Can spectral imaging offer enhancements to current screening techniques?
• Spectral imaging is non-invasive and safe
  • cf. fluorescein angiogram
• Spectral imaging can enable imaging of
  • Retinal biochemistry
    • Blood oximetry
      • Diabetic retinopathy, glaucoma
    • Lipofuscin etc
      • Age-related macula degeneration
Time-sequential multi-spectral Retinal Camera

Sequential retinal images are taken using wavelengths of light from 500-700nm.
Oximetry

Absorption Coefficient for HbO2 (cm$^{-1}$)
Absorption Coefficient for Hb (cm$^{-1}$)

Isobestic point

Transmission light
A versus $\mu_a$ for a scattering and absorbing sample

\[ A = f(\mu_a) \text{ non-linear} \]

Offset $A_{\text{scatt}}$

Linear over small $\lambda$ range

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Light paths in retina

- Recorded light intensity is due to the sum of many light paths.
  Dominant paths:
  - Double pass
  - Specular
  - Backscatter
  - Single pass

- Physical model required to derive accurate oximetry algorithms
Retinal ‘transfer function’
Validation with eye phantom

- Sclera layer
- Lens
- Vessel and removable vessel holder
- Choroid and RPE layers
- Back plate

- ~200 µm
- FEP capillary (vessel)
- Mylar or FEP (RPE)
- Blood-filled cavity (choroid)
- Spectralon (sclera)

- ~200µm
- ~25µm
- 500µm
- 3000µm
Oximetry with a bright, spectrally-neutral background

- Sodium dithionite used to deoxygenate blood

![Graph showing oxygen saturation vs. sodium dithionite concentration](image)

- Modified Beer-Lambert with contrast adjustment gives accurate results for absolute oximetry results in this simple case
Retinal vessel oximetry with multi-spectral fundus camera measurements

\[ OD(\lambda) = S(\lambda) + \eta c_{Hb_{TOTAL}} d \left[ (\varepsilon_{HbO_2}(\lambda) - \varepsilon_{Hb}(\lambda)) OS + \varepsilon_{Hb}(\lambda) \right] \]

\[ OD_{\lambda_A} / OD_{\lambda_B} \propto OS \]
Normal and diseased retinas

Normal retina

Diabetic retina

• **Objective and motivation**
  • Accurate/sensitive and reliable oximetry
  • No equivocal artefacts
Arteritic ischaemic optic neuropathy (biopsy proven)

At presentation:
VA: PL: ?reduced RGC O2 consumption

After 3 days, and 3g IV Methylprednisolone:
VA 6/12: ?increased RGC O2 consumption
‘Snapshot’ retinal oximetry with ‘IRIS’

- novel spectral imager (‘IRIS’) integrated into a retinal camera
- retina is imaged at eight wavelengths simultaneously
- allows accurate calculation of intravascular haemoglobin O2 sat. No registration difficulties
- validated using *model eye*
Monte-Carlo Modelling

- **Accurate method of modelling radiative transfer in turbid media**
- **Scattering and absorption parameters for oxygenated and deoxygenated blood are well known**
- **Fundus not as well characterised**
Full field illumination, centre detection

- pathlength only in vessel, includes backscatter
- 3 peaks – backscatter, single pass, double pass
Illumination from both sides detection above vessel

- Structured illumination offers the potential to restrict the path lengths in the vessel
- Getting close to simple algorithms such as the modified Lambert Beer Law being valid
Conclusions

- **Quantitative retinal oximetry**
  - Accuracy requires physical model
  - Snapshot
  - ‘Structured illumination’ reduces light-path uncertainty
- **Spectral imaging in the retina is a window on whole-body health**
- **Oximetric techniques transferable to body tissue**