Spectral reflectance variability of skin and attributing factors

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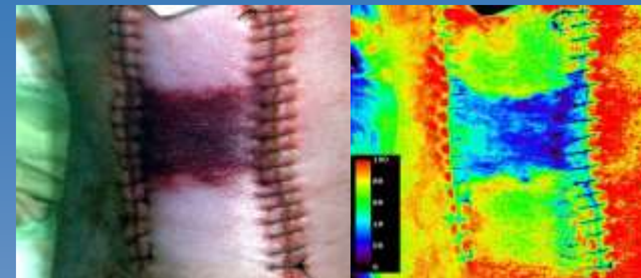
Motivation

Spectral imaging

Earth remote sensing

Image credit: NASA/GSFC/METI/Japan Space Systems and U.S./Japan ASTER Science Team

Medical imaging



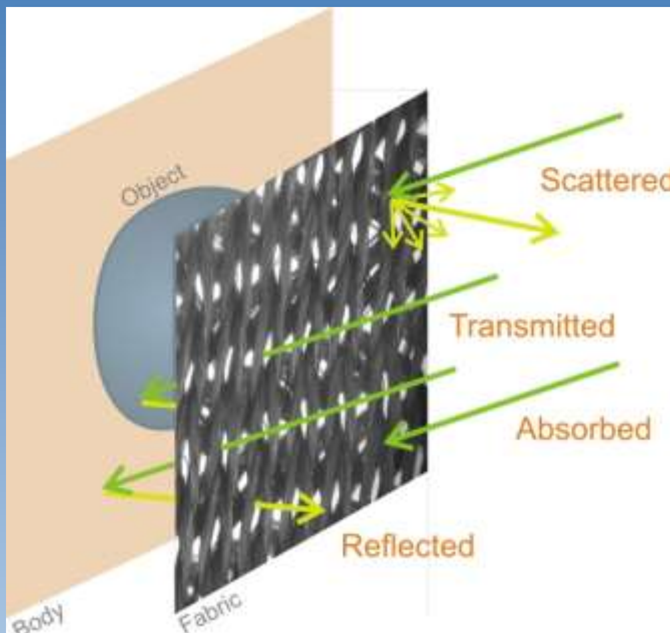
Color composite | Relative oximetric map

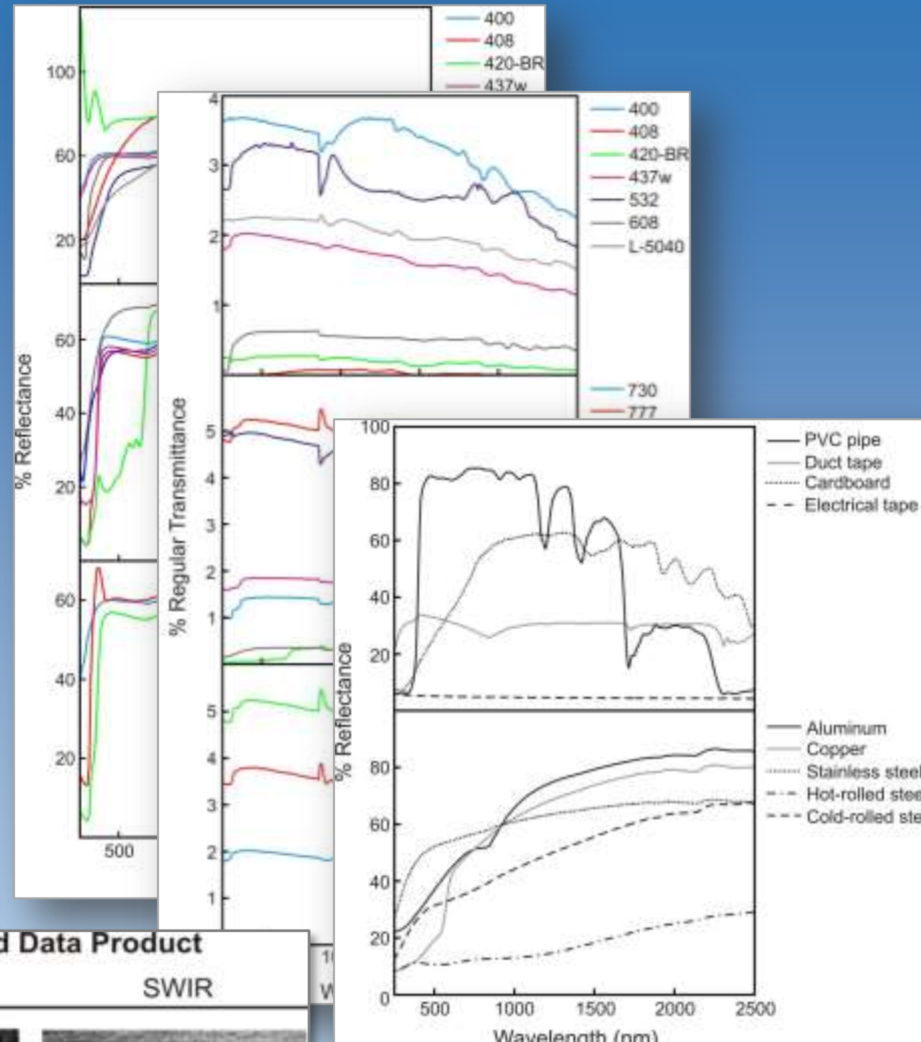
Security and defense

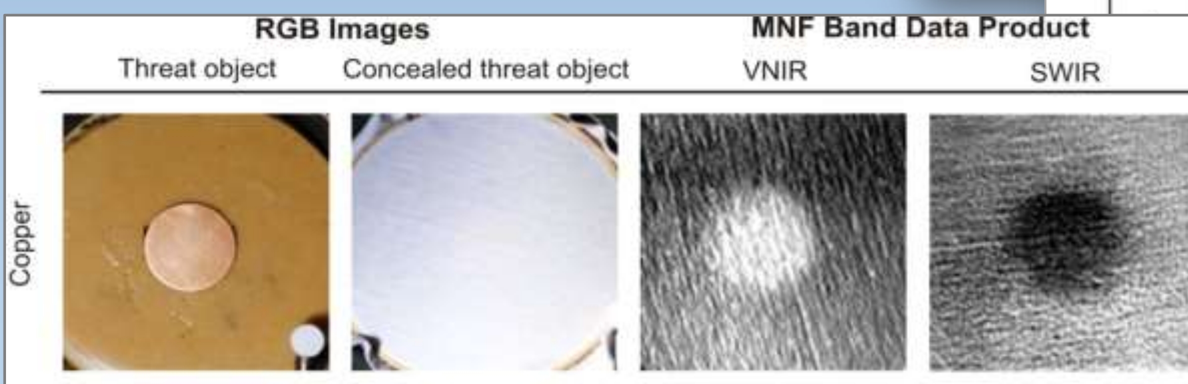
Image credit: http://sarasotanewsleader.com/siesta-theft-suspects-caught-on-tape/macys-male-suspect/

Applications

Stand-off detection



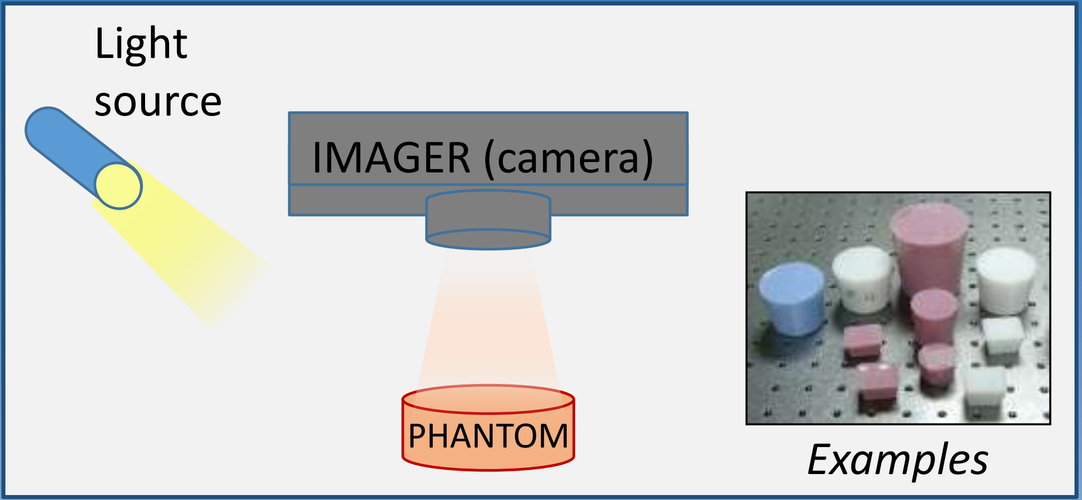




Applications

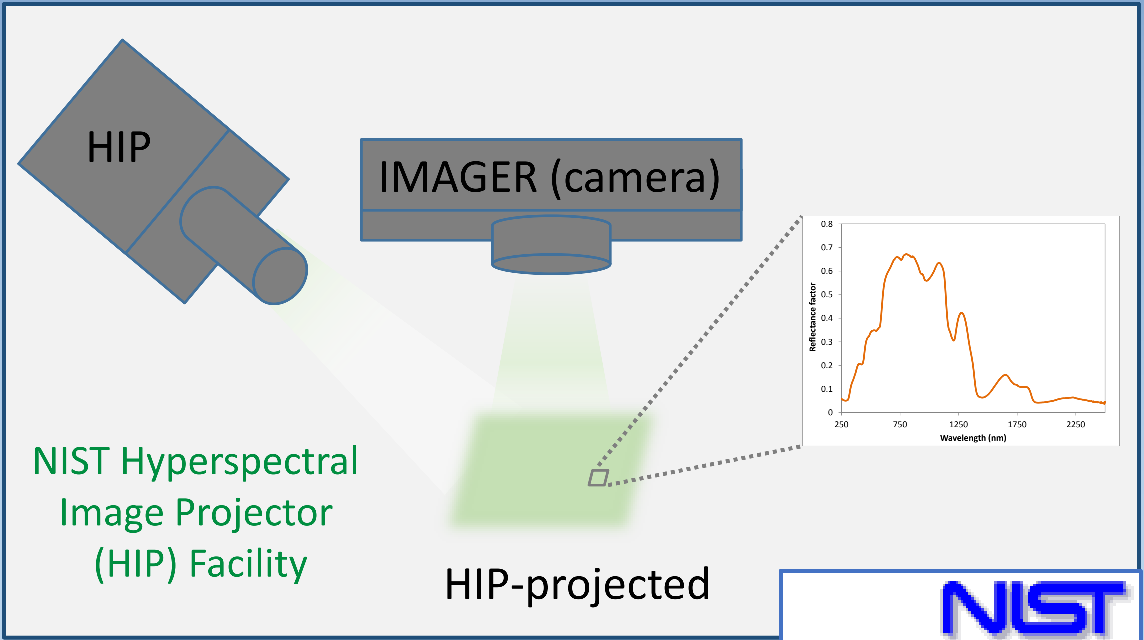
Traditional tissue phantoms

- Simulate tissue
- Calibrate imagers
- Problems: variability, shelf-life, not realistic



Digital tissue phantoms

- Projection system that provides full spectral and spatial scenes of relevance to an optical medical imager (microscope, endoscope, or wide field imager)
- Enables product development, performance testing, calibration, and validation



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Biological variability

Optical properties of human skin

- Dependent on many components and surface features
- Expect variations across body, due to level of activity and time, between individuals

⇒ What's a "typical" spectral signature for human skin?

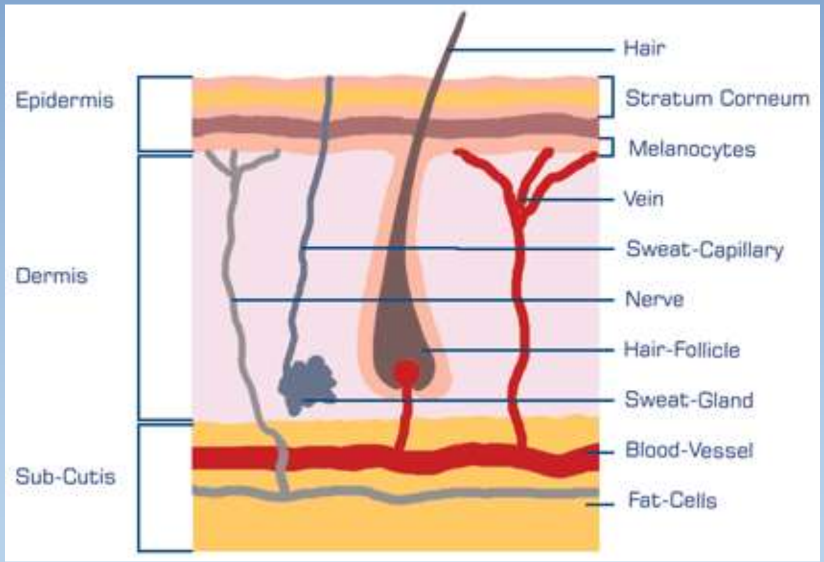

Image credit: www.swiss-creations.com

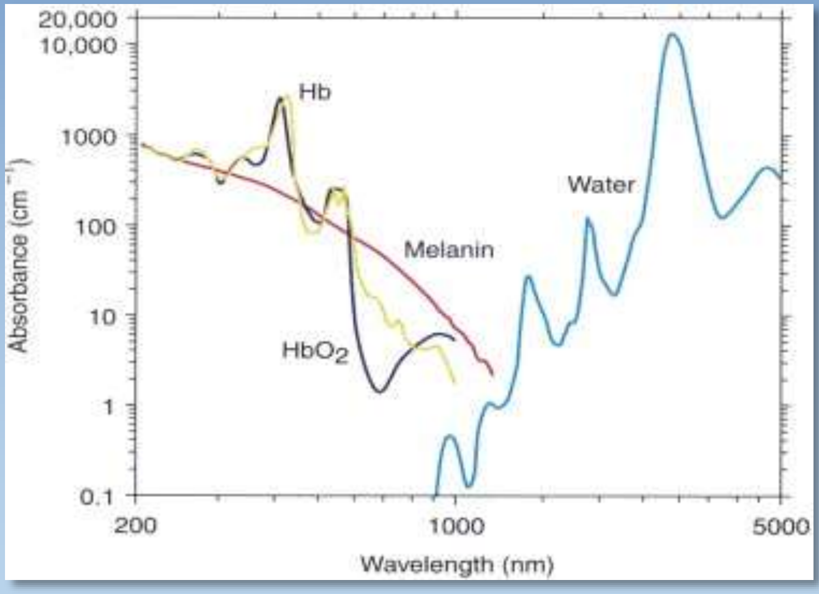

Image credit: Fig. 1 from Kauver et al Phlebology 24 184

Project overview

Goals:

- Acquisition of high quality, NIST-traceable reflectance spectra of human skin
- Apply analysis methods to describe variability of skin reflectance spectra

What we are going to do:

Use commercially available spectrophotometer to acquire reflectance of human skin

- Over a broad spectral range (beyond visible region)
- Stated uncertainties
- Directly traceable to the national scale of reflectance

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Technical approach

Human subjects*:

- 51 subjects volunteered
- Solicited via advertisement
- No selection process based on age, gender, or ethnicity (random)
- No one was excluded for
  - Use of sunscreen, body lotion, or medication
  - Presence of freckles, moles, tattoos, of skin conditions or diseases
- Each subject participated in one 30 minute measurement session:
  - Review and sign informed consent form
  - Collection of photographic image of the test area
  - Measurement of reflectance

*NIST Institutional Review Board approved this human subject study, “Reflectance Measurements of Human Skin” Protocol #382, on 5/29/12, re-approved on 9/19/13 and 12/17/14.

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Technical approach

Test area:

- Inside of subject’s right forearm
- Less hair
- Less sun exposure/tanning/skin aging
- Easy to access (no undressing)

Image collection:

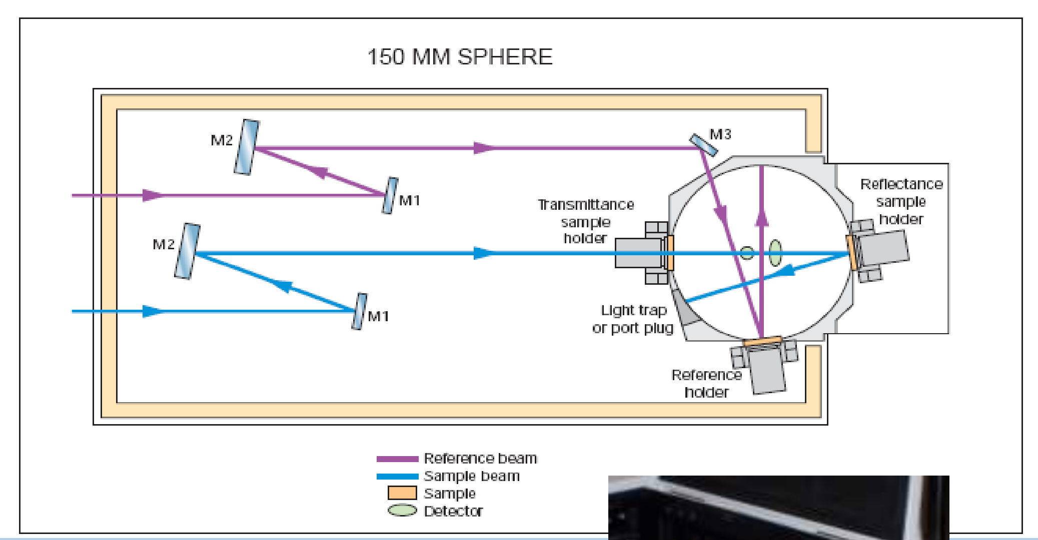
- Digital image of test area
- Spatial information related to non-uniformities, hair, freckles, tattoos, etc.
- Test area masked
- Near uniform illumination
- In-scene PTFE reference targets

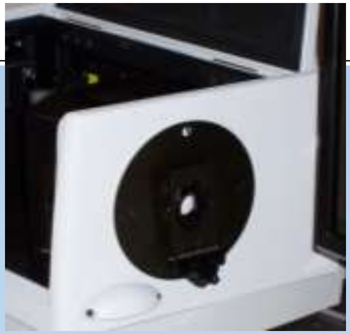
Technical approach

Spectrophotometer with near-normal reference integrating sphere:

Capabilities

- Reflectance, transmittance, absorbance
- Ambient temperature
- Absolute and relative measurements
- Uncertainties (k = 2): 0.5 - 3 %





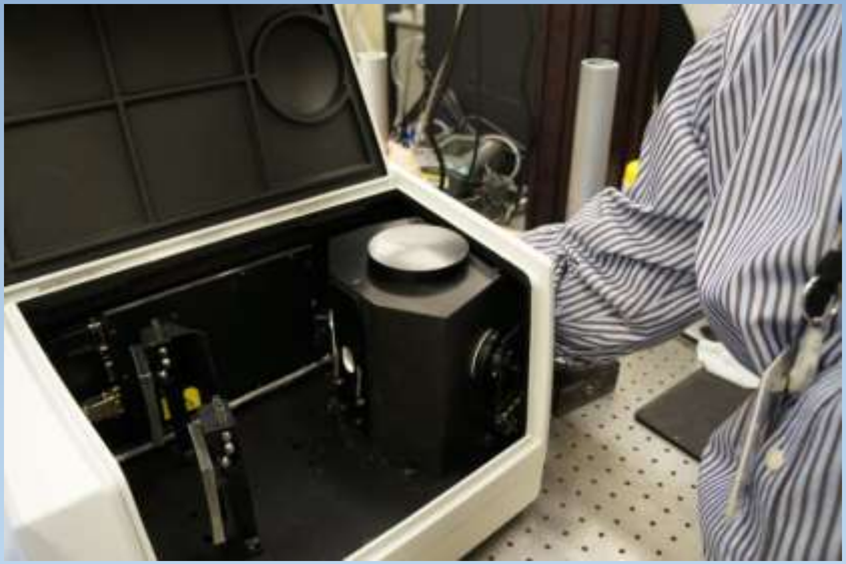
Specifications

- 150 mm diameter sphere
- Sintered PTFE
- 8°incidence angle
- 25 mm diameter sample port
- λ range: 250 nm to 2500 nm
- D_2 and QTH sources
- PMT and InGaAs detectors

Technical approach

Reflectance measurements:

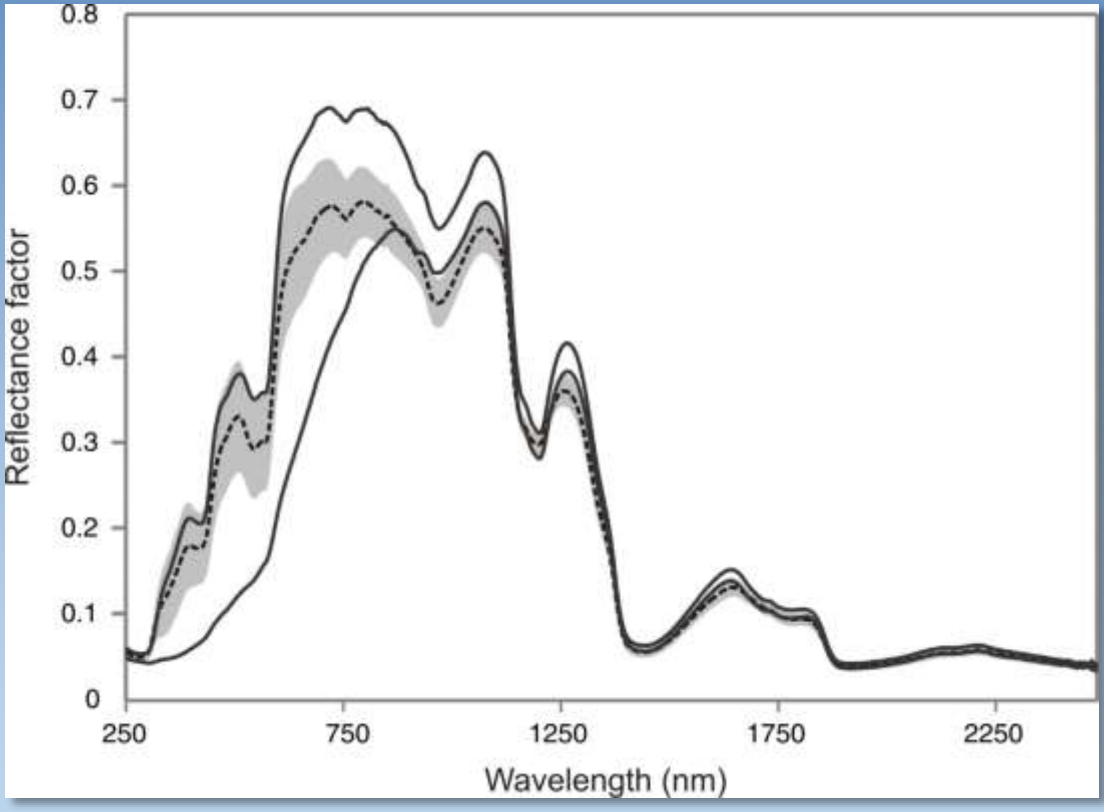
- Flush contact with the sample port without excessive pressure
- Scan wavelengths from 250 nm to 2500 nm at every 3 nm
- Each scan is approx. 3 min.
- Total of 3 scans with resting period of approx. 3 min. between each scan
- Relative measurement: sintered PTFE as standard
- Wavelength scale validated with internal atomic emission lamps



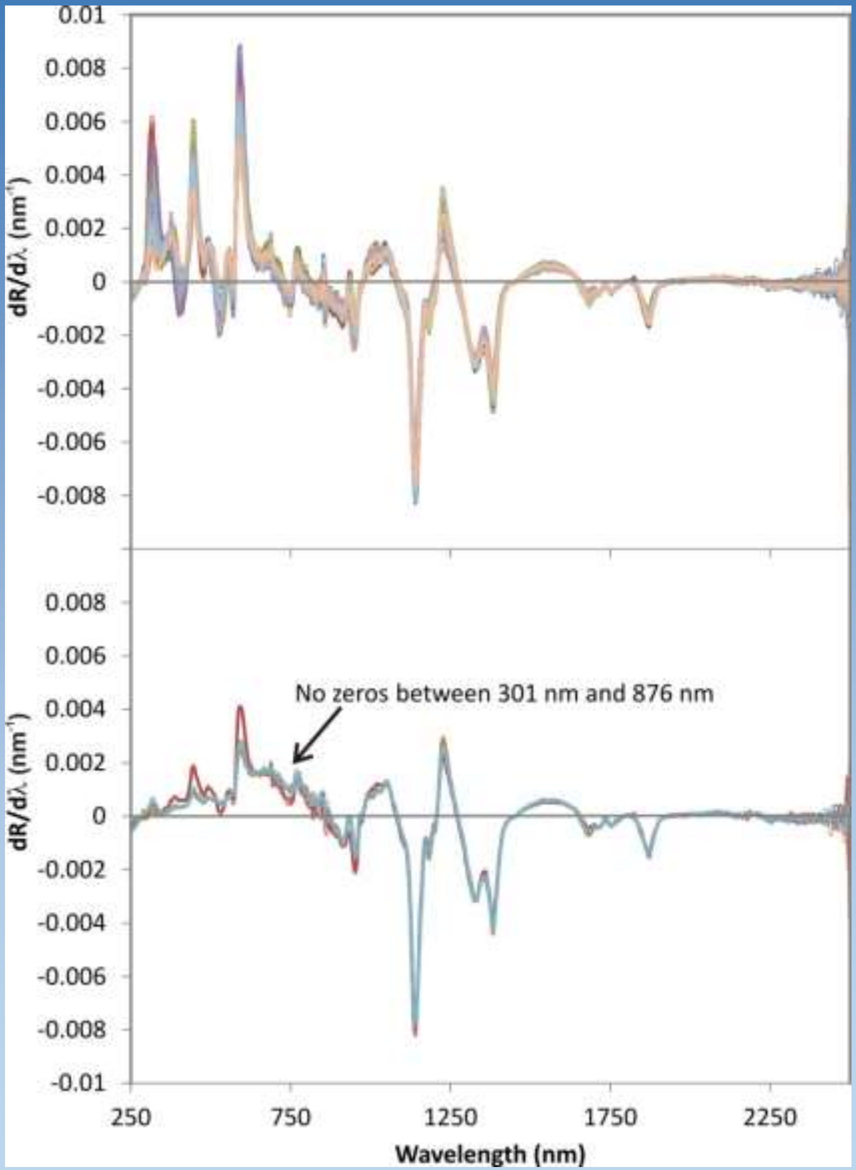
Reflectance of human skin

8°/h spectral reflectance factor *R* at each wavelength λ :

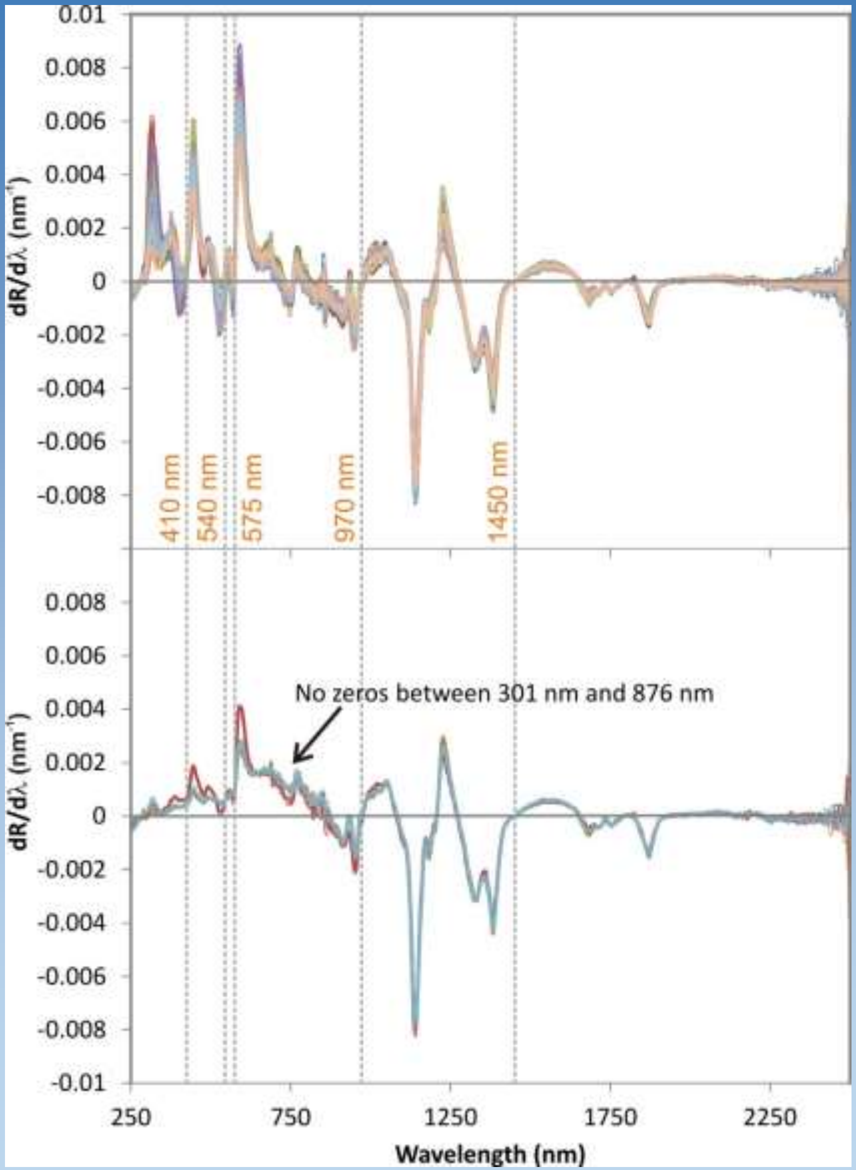
$$R(\lambda) = \frac{S(\lambda) - S_d(\lambda)}{S_s(\lambda) - S_d(\lambda)} \cdot R_s(\lambda)$$



Reflectance of human skin



Reflectance of human skin



Reflectance of human skin

Instrument uncertainty:

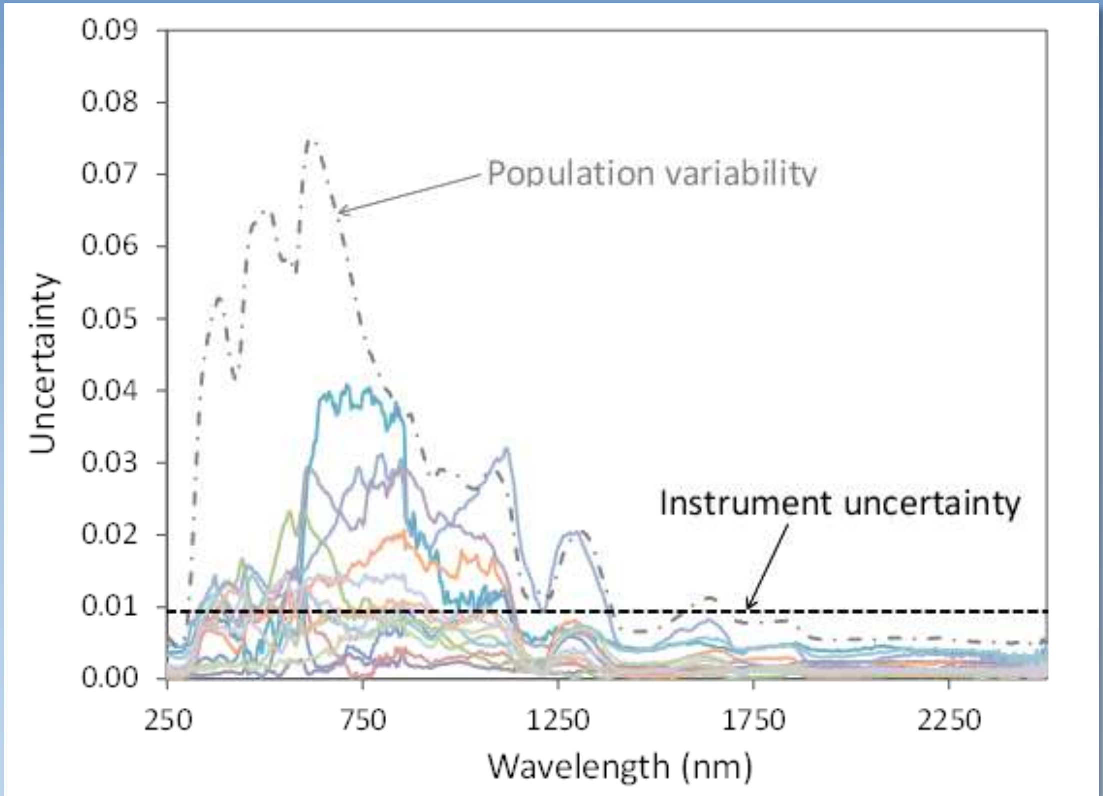
- Sintered PTFE standard
- Sphere geometry
- Wavelength
- Random effects

Subject variability:

Standard deviation of subject's 3 scans

Population variability:

Standard deviation of full set of scans



Analysis

Spectral angle:

- Divergence in angle between spectra when treated as vectors
- Sensitive to spectral shape, not overall lightness or darkness

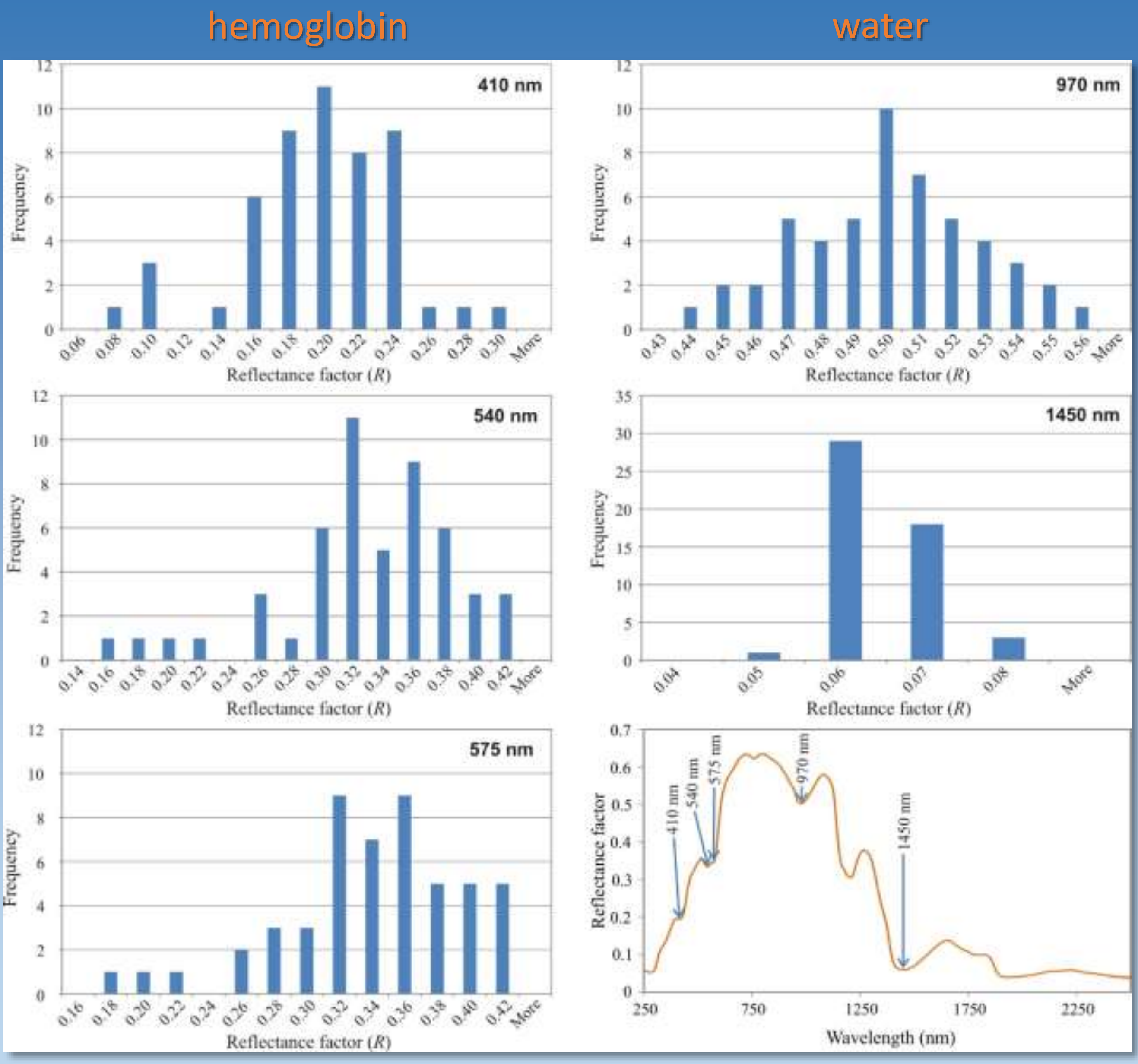
$$\theta = \cos^{-1}\left(\frac{{R_{mean}}^{T} R_i}{\|R_{mean}\| \|R_i\|}\right)$$

	Spectral Angle (radians)			
Wavelength Range (nm)	**Minimum**	**Maximum**	**Mean**	**Standard Deviation**
UV: 250 to 403	0.018	0.369	0.092	0.074
VNIR: 403 to 1003	0.006	0.267	0.046	0.050
SWIR: 1003 to 2500	0.007	0.112	0.030	0.015
Full: 250 to 2500	0.014	0.251	0.055	0.046

Analysis

Histograms:

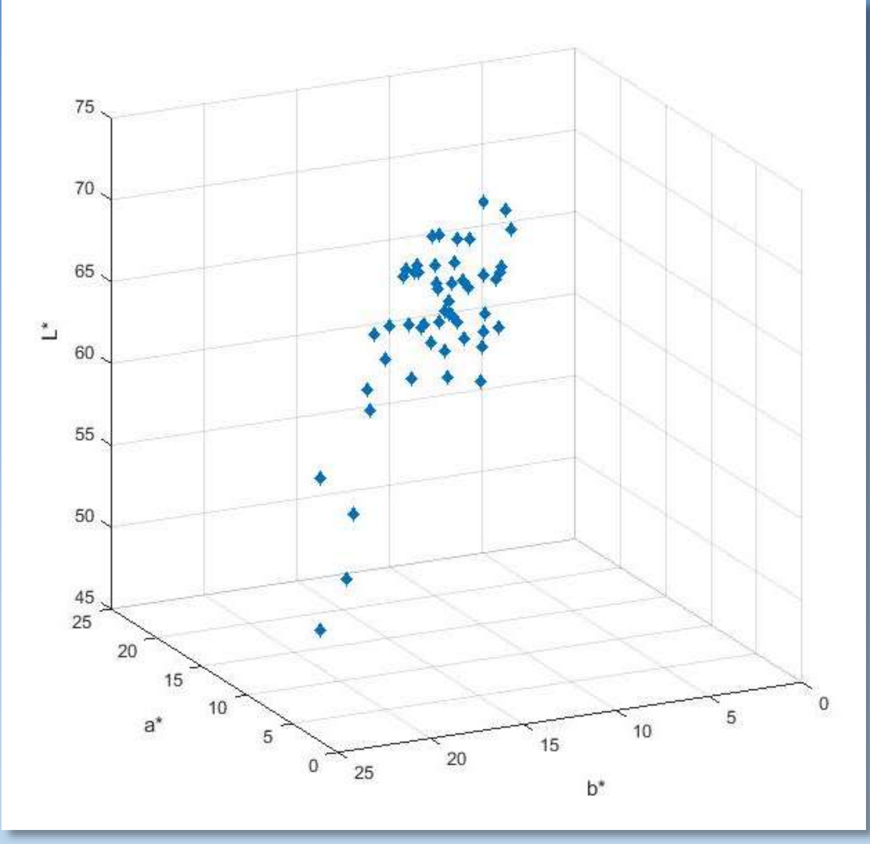
- Spread larger in VIS than NIR and SWIR
- Distribution skewed in VIS in contrast to distribution in NIR and SWIR



Analysis

CIELAB:

- Color space where L* represents lightness, a* and b* represents colors along the magenta-green and yellow-blue continuums, respectively



Conclusions

- ✓ Presented a sample set of skin reflectance spectra
  - Over a broad spectral range
  - Stated uncertainties
  - Directly traceable to the national scale of reflectance
- ✓ Subject and population variability is considerable in UV and VNIR; instrument uncertainty dominates in SWIR
- ✓ Spectra presented here may be used as a
  - Reference point for researchers who might need an example of a generalized skin reflectance spectrum
  - Foundation for a model for both physical and digital tissue phantoms
- o Future work
  - Expand data set to include 100 individuals
  - Perform a meta-analysis expand data set to further explore variability in population