Reference Data Set of Human Skin Reflectance

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1.   Summary

This data set contains 100 reference reflectance spectra of human skin, spanning the wavelength region from 250 nm to 2500 nm. The spectra were acquired with a commercially available spectrophotometer and are directly traceable to the national scale for directional-hemispherical reflectance factor.

2.   Data Specifications

NIST Operating Unit(s)	Physical Measurement Laboratory, Sensor Science Division, Optical Radiation Group
Format	The dataset is provided as a comma-separated file.
Instrument	UV/Vis/NIR Spectrophotometer
Spatial or Temporal Elements	N/A
Data Dictionary	N/A
Accessibility	All datasets submitted to *Journal of Research of NIST* are publicly available.
License	https://www.nist.gov/director/licensing

3.   Methods

3.1   Experimental Methods

3.1.1   Human Subjects

One hundred and ten subjects volunteered to participate in this study.[1] Subjects were recruited by flyer and email and included both federal and non-federal employees. There was no attempt to select subjects

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[1] This human subject study, "Reflectance Measurements of Human Skin" Protocol #382, was approved by the NIST Institutional Review Board on May 29, 2012. Re-approval for continued collection of skin reflectance measurements and data analysis was granted on September19, 2013, December 17, 2015, and December 21, 2015.

based on age, gender, or ethnicity as might be related to skin tone. No subjects were excluded for the use of sunscreen, body lotion, or medication, or for the presence of freckles, moles, tattoos, or skin conditions or disorders.

Each subject participated in only one measurement session. Prior to the start of the measurement session, each subject signed an informed consent form, which described the experiment and the benefits and risks of participation. The measurement session consisted of collecting a photographic image of the test area on the subject's forearm and acquiring reflectance measurements of the test area.

The test area was a 25 mm diameter circle located on the inside of the subject's right forearm. This test area was chosen for practical reasons, namely ease of measurement with the spectrophotometer and decreased prevalence of body hair and sun damage.

3.1.2 Reflectance Measurement

The reflectance measurements of the subject's forearm were acquired using a commercially available ultraviolet/visible/near-infrared spectrophotometer. An integrating sphere accessory was used with the spectrophotometer to acquire directional-hemispherical reflectance measurements. The integrating sphere has a diameter of 150 mm, an oval entrance port measuring approximately 15 mm by 25 mm, and a sample port with a nominal diameter of 25 mm. The sphere is coated with sintered polytetrafluoroethylene (PTFE). The sample beam of the spectrophotometer forms an image of the exit slit of the monochromator at the location of the sample port with an angle of incidence of 8° and dimensions of approximately 14 mm high by 6 mm wide. Because of the geometry of this measurement, the measurand is referred to as 8°/h (8° angle of incidence with hemispherical detection) spectral reflectance factor.

The illuminating source was a deuterium lamp for wavelengths shorter than or equal to 319 nm and quartz-tungsten-halogen (QTH) incandescent lamp for longer wavelengths. The detector was a photomultiplier tube (PMT) for wavelengths shorter than 860 nm and a lead sulfide (PbS) or an indium-gallium-arsenide (InGaAs) detector for longer wavelengths. For all measurements, the incident beam was depolarized using a 30 mm depolarizing element. The spectral bandwidth was fixed to 3 nm over the 250 nm to 860 nm spectral region; it was allowed to vary, with a maximum of 20 nm, over the 860 nm to 2500 nm spectral region. The wavelength scale of the spectrophotometer was validated using the spectrophotometer's internal atomic emission lamps.

The subject positioned his/her bare right forearm next to the sample port of the integrating sphere of the spectrophotometer (see Fig. 1). A post served as a hand grip and was positioned 25 cm from the center of the sample port to ensure proper placement of the test area and consistency between placements. The subject was asked to maintain flush contact with the sample port, but without excessive pressure (as would be indicated by circular impressions of the sample port visible on the skin following the measurement). The researcher placed a black light-proof piece of fabric over the subject's forearm following placement and dimmed the room lights to prevent ambient room light from contaminating the measurement. The subjects we given a choice to sit or stand during the scan. Nearly all subjects stood for the duration of the measurements.

The spectrophotometer was used to acquire the 8°/h spectral reflectance factor of the subject's skin within the test area over the spectral range of 250 nm to 2500 nm at a wavelength interval of 3 nm. For each subject, 3 scans were collected, each lasting approximately 3 minutes. The subject was allowed to rest his/her arm, removing it from the testing position, in between each scan.

A note about safety. The risk to subjects in this study is minimal. The radiation exposure of subjects is below the recommended exposure limits of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [1, 2] by 3 or more orders of magnitude.
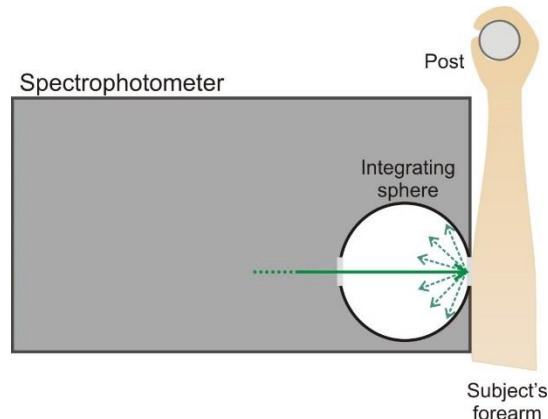
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Fig. 1. Illustration of the measurement setup. The subject positions his/her bare right forearm next to the sample port of the integrating sphere of the spectrophotometer. The sample beam (generated elsewhere within the spectrophotometer) illuminates the subject's skin, and the reflected light is detected within the integrating sphere.

3.2   Data Processing and Uncertainties

3.2.1 Calculation of Reflectance Factors

The reflectance values obtained using the spectrophotometer were determined by a relative measurement. The reference standard used for these measurements was sintered polytetrafluoroethylene (PTFE). The reflectance scale for the reference standard was determined prior to the measurement sessions through comparison measurements of sintered PTFE and pressed PTFE. The spectral reflectance factors for sintered PTFE are traceable to the scale for spectral reflectance factor of pressed PTFE, which were established using the absolute method of Van den Akker [3] in the NIST Spectral Tri-function Automated Reference Reflectometer (STARR) facility [4].

The 8°/h spectral reflectance factor R of a given sample at each wavelength λ can be calculated from the general equation

$$R(\lambda) = \frac{S(\lambda) - S_d(\lambda)}{S_s(\lambda) - S_d(\lambda)} \cdot R_s(\lambda) \tag{1}$$

where S is the signal from a scan of the sample; S_s is the signal from a scan of the standard; S_d is the dark signal (empty sample port); and R_s is the 8°/h spectral reflectance factor of the sintered PTFE standard.

The signals measured by this commercially available spectrophotometer are not accessible to the operator. Rather, the spectrophotometer internally calculates values reported as percent reflectance R'. These values can be substituted into Eq. (1) for the corresponding signal values. Thus, for each subject, a set of three scans $\{R'_1, R'_2, R'_3\}$ were collected. Scans of the reference standard R'_s and the empty sample port R'_d were collected only once daily, prior to the measurement session with a subject. The 8°/h spectral reflectance factors of each subject's scan were calculated using Eq. (1), and the final 8°/h spectral reflectance factors were obtained by averaging the values from the three scans.

3.2.2 Curating the Set

The resulting data for each of the 110 subjects were reviewed, and data from 100 subjects were selected for the final set published here. There were several reasons for removing subject data from the final set. First, two subjects withdrew from the study after the consent form was signed. Data collection was not initiated due to unanticipated instrument difficulty that did not involve risk to the subject or potential for future risk to the subject. The subjects did not reschedule. Second, there was a problem saving the data for one of the subjects, such that only a single scan was eventually saved instead of a set of three. Finally, data for 7 subjects were removed because at least one scan of the set of three acquired for each

subject was deemed an outlier, excessively noisy, or significantly different in magnitude compared to the other two scans. The authors believe these faulty scans were due to human error, such as the subject unintentionally moving their forearm during the scan or improper placement of the subject's forearm against the sample port (e.g., a gap between the arm and port).

3.2.3 Estimation of Uncertainties

The estimated measurement uncertainties for the reflectance measurements are calculated according to the procedures outlines in [5]. Sources of uncertainty are the directional-hemispherical spectral reflectance factor of the sintered PTFE standard, the sphere geometry, the wavelength, and random effects. The standard uncertainty due to the reference standard was evaluated during the scale transfer from pressed PTFE and determined to be 0.0023. The uncertainty due to the difference in sphere geometries of the commercial spectrophotometer used in the skin reflectance study and NIST STARR, which was used to establish the reflectance scale for the sintered PTFE standard, was evaluated by comparing reflectance factors of a NIST-owned sintered PTFE working standard measured using both instruments. The uncertainty caused by wavelength is evaluated form the derivative of the representative spectral reflectance factors of the mean. The repeatability was determined from the standard deviation of repeat measurements of the sintered PTFE standard. The expanded uncertainty ($k = 2$) is the combined (root-sum-square) standard uncertainty from all contributions due to systematic and random effects multiplied by a coverage factor of two [5]. The evaluated contributions of the sources of uncertainty and the expanded uncertainty ($k = 2$) of the instrument are given in Table 1. These uncertainties are representative of the manner in which the instrument was used for this study.

Table 1. Instrument uncertainty and its components

Source of Uncertainty	Standard Uncertainty	Uncertainty Contribution
Reflectance Standard	0.002	0.002
Geometry	0.001	0.001
Wavelength	0.3 nm	0.0008
Repeatability	0.0003	0.0003
		Expanded Uncertainty ($k = 2$)
		0.0048

4.   Impact

While published literature of the optical properties of human skin is prevalent for the visible region, data are sparse in the ultraviolet and shortwave infrared. This data set provides reliable, NIST traceable spectra of human skin reflectance with stated measurement uncertainties. Further, this data set reveals a range and distribution of "typical" human skin reflectance values. It is not known what sample size or source of participants would best describe the population at large. However, it can be expected that the variability is no smaller than the distribution represented in this set.

This data set will be useful for a variety of applications. For instance, the data could be used for the development of physical and digital tissue phantoms or other models for human skin. Likewise, knowledge of the spectral reflectance signatures of human skin over a wide spectral range will aid in the development of imaging/sensing systems used for emerging applications, such as medical treatment and security technology.

Acknowledgments

5. References

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