OOIColor

Color Analysis Worksheet

User's Guide

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Overview

OOIColor is a Microsoft® Excel worksheet template, which contains all of the necessary code to access data directly from our line of miniature fiber optic spectrometers. Coupled with the appropriate fiber optic probes, the worksheet and spectrometer combination can measure reflective or emissive color.

The worksheet template operates under Microsoft Excel, version 5.0 or higher. Consult your Excel documentation or help files for instructions on how to open and use worksheet templates.

Install the software by inserting the floppy disk into your disk drive, and running the SETUP.EXE program.

OOIColor is intended as both a stand-alone application that is ready to use, as well as a template for developing your own software. Be sure that you save a copy of the original version of the worksheet template before you make any modifications.
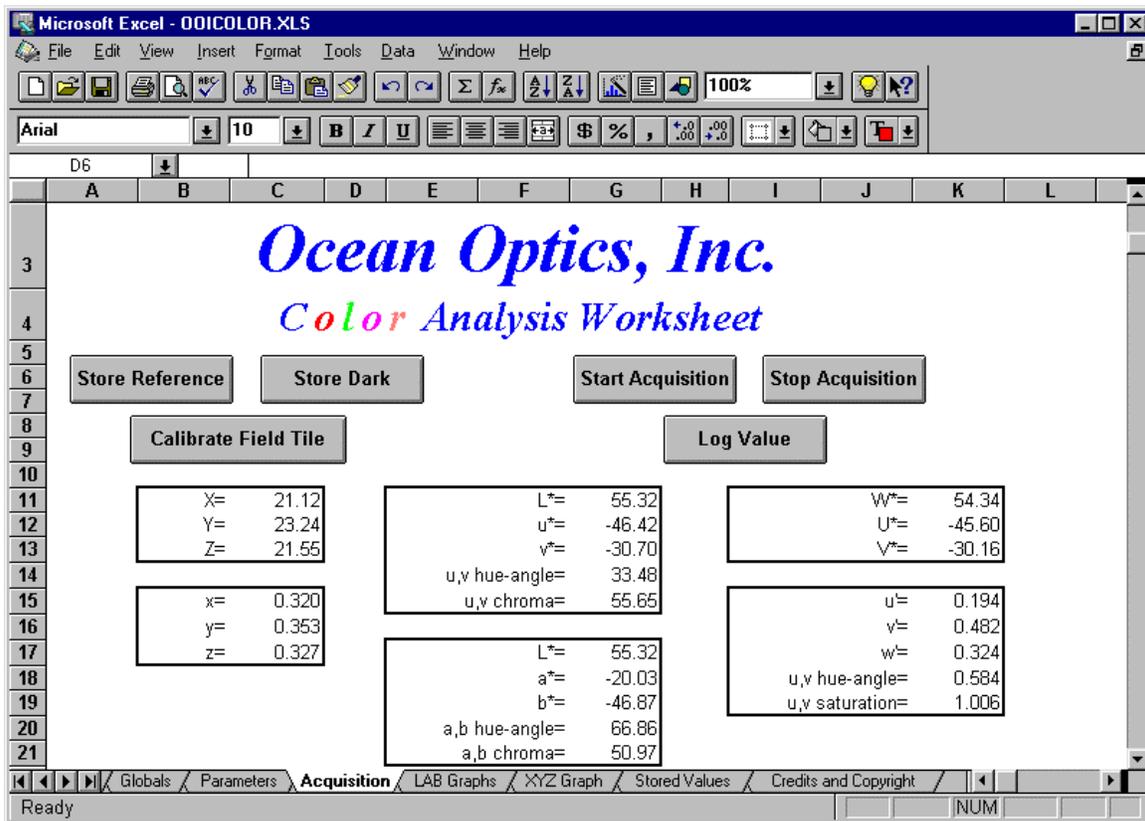
All data acquisition and analysis is performed within this worksheet. Several color space values are reported in numeric form: XYZ, xyz, L*u*v*, L*a*b*, W*U*V* and u'v'w'. Graphs are provided for XYZ and L*a*b* color spaces.

Worksheet Pages

Color Space and Illuminants

This worksheet page contains the tristimulus values for CIE1931 and CIE1964 observers as well as the intensity of the 12 standard CIE illuminants. You should not change these values. When you calibrate a field tile, or working standard, the reflectivity values are also stored on this page.

Functions

This worksheet page contains the source code for all of the data acquisition from the spectrometers and processing macros. You are free to change this code as your experiments dictate, as long as you follow the restrictions contained in the Credits and Copyright worksheet page.

Globals

The macro in this worksheet page defines all of the global variables used in this program.

Parameters

This worksheet page contains all of the parameters necessary for data acquisition and processing:
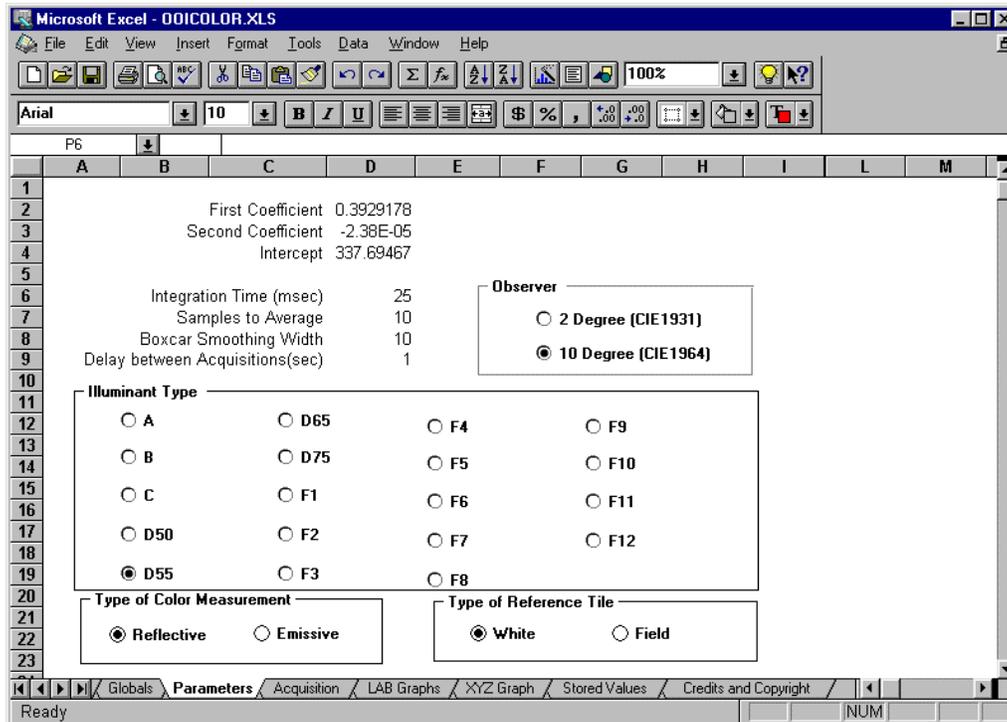
Coefficients and Intercept

These values are the wavelength calibration coefficients of your spectrometer. They are obtained from the calibration sheet that accompanied you spectrometer when you received it from our factory. If you are missing this calibration sheet, please contact us for a free replacement copy.

Integration Time

The integration time of the spectrometer is analogous to the shutter speed of a camera. The higher the value specified for the integration time, the longer the detector "looks" at the incoming photons. If your intensity is too low, increase this value; if too high, decrease the value. The following table lists the valid integration times for each spectrometer and A/D card:

Spectrometer	ADC500	DAQ-700
S1000	8 msec – 16 seconds	40 msec – 16 seconds
S2000	4 msec – 60 seconds	20 msec – 60 seconds

Samples to Average

The value entered here sets the number of discrete spectral acquisitions that are accumulated before OOIBase32 receives a spectrum. The larger the value, the better the signal-to-noise (S:N) ratio. The S:N improves by the square root of the number of spectra averaged.

Boxcar Smoothing Width

The value entered here sets the boxcar smoothing width, a technique that averages across spectral data. This method averages a group of adjacent detector elements. A value of 5, for example, averages each data point with 5 points (or bins) to its left and 5 points to its right. The greater this value, the smoother the data and the higher the S:N . However, if the value entered is too high, a loss in spectral resolution results. The S:N improves by the square root of the number of pixels averaged.

Delay Between Acquisitions

This number controls the amount of time between spectral acquisitions. If you enter a 0 for this value, the worksheet will acquire data as fast as possible. The Stop Acquisition button will not operate, and you will have to press **Esc** to stop the acquisition. If you enter a number greater than or equal to 1, you will be able to switch screens, stop the acquisition or even retake a reference during the acquisition.

Observer

Check the observer that you wish to use. These values are described in the Background section.

Illuminant Type

Check the type of illuminant that you wish to use for the calculations. These values are described in the Background section.

Type of Color Measurement

Check the type of color measurement that you are performing. These values are described in the Background section.

Type of Reference Tile

Check the type of reference tile that you are using. These values are described in the Experimental Techniques section.

Acquisition

This worksheet page has buttons for the control of data acquisition, and displays the color space values for the sample being analyzed.
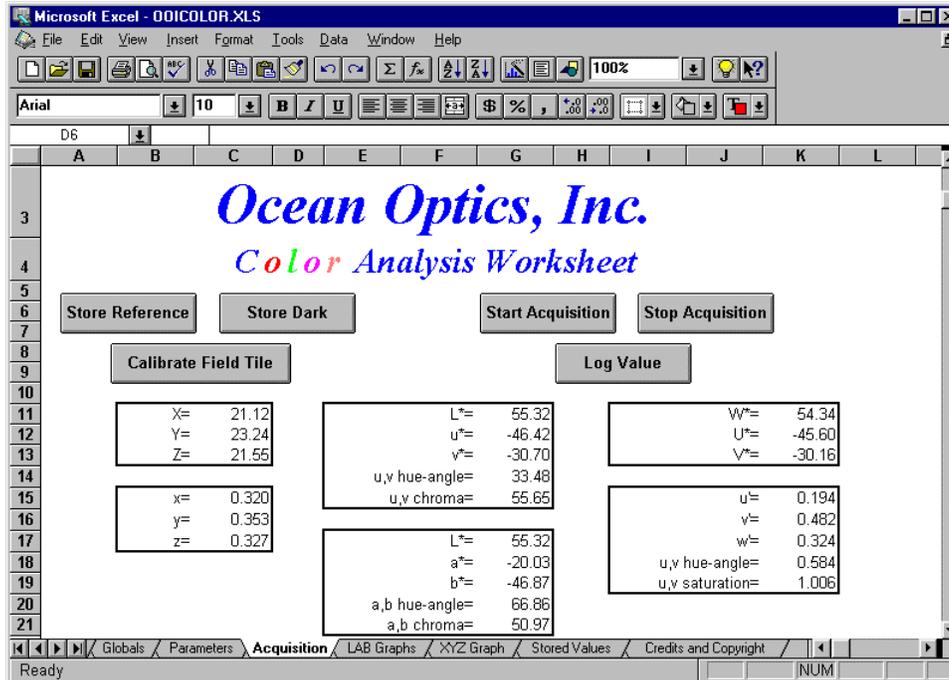
Store Reference

In reflective color measurements, this button stores the reflection spectrum of either the white standard (such as Ocean Optics' WS-1) or your working standard or field tile (see the Parameters page). For emissive color measurements, this button stores the spectrum of a blackbody of known color temperature (e.g., Ocean Optics' LS-1 has a color temperature of 3100K).

Store Dark

This button is for storing the spectrum obtained when there is no light entering the spectrometer.

Calibrate Field Tile

This button is used to calibrate a working standard or field tile so that you can use something other than a white standard to reference your spectrometer system.

Start Acquisition

After storing a dark and a reference, this button start the real-time data acquisition, which constantly updates the color space values and graphs.

Stop Acquisition

This button stops the real-time data acquisition.

Log Value

This button takes the current XYZ and L*a*b* values and stores them in the Stored Values worksheet page along with a time stamp and a brief, user-entered, description of the sample being analyzed.

LAB and XYZ Graphs

These pages display real-time graphs of the L*a*b* or XYZ color spaces, as illustrated below.
The buttons on these pages operate the same as the buttons on the Acquisition page:
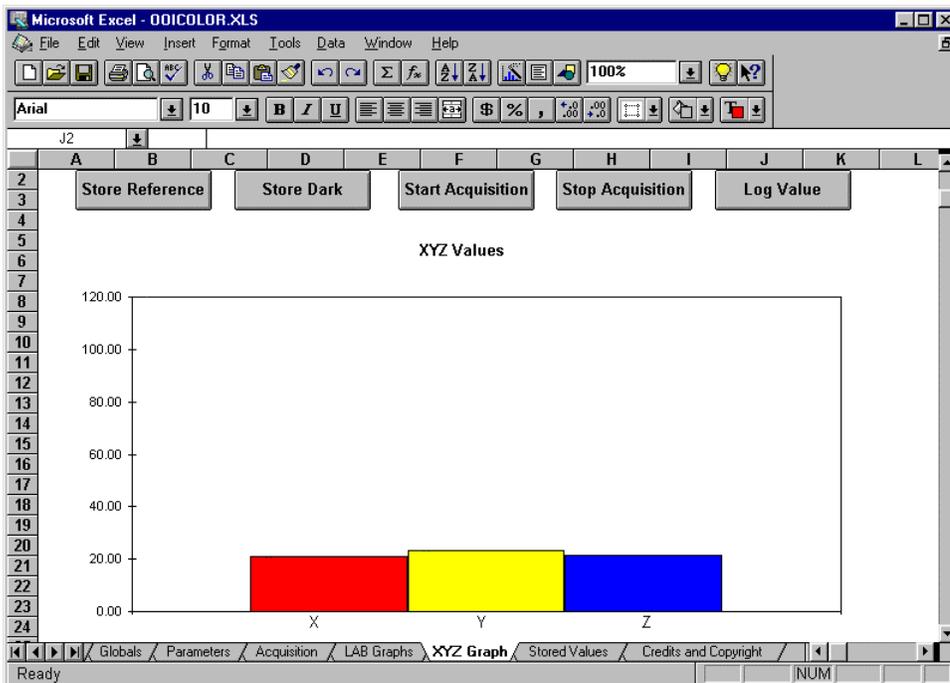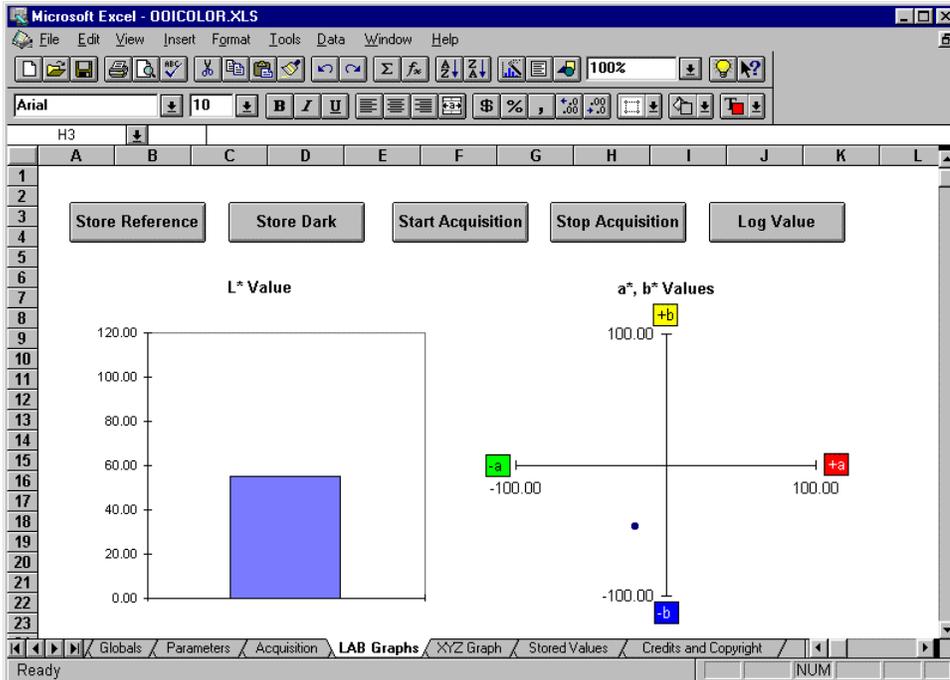
Experiment Tutorial

Reflective Color – An Overview

Ocean Optics offers several experimental arrangements to measure reflective color: our R200 fiber optic reflection probe, our ISP-REF integrating sphere or a custom geometry using optical fibers and collimating lenses (74-VIS or 74-UV). All measurements produce valid results. The choice of method is based on your experimental requirements and any procedural restraints such as industry standards.

The R200 reflection probe consists of a bifurcated optical fiber bundle consisting of seven 200 µm optical fibers arranged in a six-around-one configuration. The outer six optical fibers provide even surface illumination to your sample, while the central fiber reads the reflection from your sample. The optical fiber probe is Y-shaped, with two arms of the Y being terminated in SMA connectors, and the third leg terminated in a ¼" stainless steel tube. The end with the stainless steel tube is the probe end of the fiber, and is positioned near your surface (our reflection probe holder RPH-1 is ideal for this purpose). The other two ends of the optical fiber probe go into the light source and the spectrometer; their orientation is extremely important. Look carefully at the ends of the SMA connectors, and you will see that one has a hole that is about three times larger than the other. The fiber leg with the larger hole MUST be placed in the light source. The leg with the smaller hole is placed in the spectrometer.

Ocean Optics also offers an integrating sphere specifically designed for color measurements. The inside of the sphere is illuminated with a tungsten-halogen light source, which will provide the surface to be analyzed with even, non-directional surface illumination. An optical fiber is then placed in the SMA port marked S, and the other end of the fiber is installed in your spectrometer. The reference or sample is placed over the 1-cm orifice. There is a switch on the integrating sphere marked E and I. This switch opens and closes a small port on the inside of the integrating sphere, which **I**ncludes or **E**xcludes the contribution of specular reflection from the sample.

Reflective Color Measurements with a White Standard

The first step in making a reflective color measurement is to take a spectrum of a physical standard. This standard can be a 100% reflective white standard, such as Ocean Optics part WS-1. The spectrometer response will be set to 100% reflective at all wavelengths.

Before making this measurement in OOIColor, it is a good idea to make the measurement in OOIBase. The OOIBase program will allow you to see the scope-mode spectrum acquired in real-time, and to ensure that the spectrometer is receiving the proper amount of light. If you notice that the spectrometer is saturated, you must either reduce the integration time of the spectrometer (see Parameters worksheet page above), or reduce the amount of light entering the optical fiber. If you are using an R200 fiber optic probe, you can easily reduce the amount of light entering the spectrometer by simply moving the fiber probe farther away from your surface. If you are using the integrating sphere, the only way to reduce the amount of light entering the optical fiber is to use a fiber of smaller core diameter.

If you observe that the light intensity is not very high (less than 2000 counts in scope mode), you must either increase the integration time or move the R200 fiber optic probe closer to your sample. If you are using an integrating sphere, using a larger diameter optical fiber will also increase the signal intensity.

Once you find an experimental configuration that places the spectrum on scale, you are then ready to switch back to OOIColor. Before you do, however, make a note of the integration time that you used. Enter the integration time that you were using in OOIBase in the OOIColor Parameters worksheet page, and make sure that the calibration coefficients of your spectrometer are correctly entered on this page.

Go to the Acquisition worksheet page, place the white standard in the sample position, and click on Store Reference. If you get an error box indicating that the spectrometer is not receiving the proper amount of light, follow the instructions in the pop-up box to correct this problem. After storing the reference, you now must store the dark spectrum. The dark spectrum is the spectrum acquired when there is no light entering the spectrometer. If you are using an LS-1 light source, there is a filter slot in the lamp in which you can insert a light block (a 3½" floppy disk without a label works great). If you are using the integrating sphere, you must turn the internal light off to take a reference. If you do, make sure that you allow the lamp to warm again up for approximately 15 minutes before you continue acquiring data (you may even want to Store Reference again).

After you have stored both the dark and the reference, unblock or turn on the light source and place the substance to be analyzed in the sample location. Click on the Start Acquisition button, and the color coordinates will be reported. To stop acquisition, simply click on the Stop Acquisition button. To store the color space values, click on Log Values and enter a description for the sample. They will be saved in the Stored Values worksheet page.

Field Tiles

White standards are typically expensive and easily damaged. A field tile is a rugged, inexpensive tile which can be calibrated against the white standard. OOIColor allows you to calibrate this field tile, and use it to reference the spectrometer. In order to calibrate the field tile, you will still need a white standard, but you can leave this in a safe environment, and use the field tile as your working standard.

To calibrate the field tile, go to the Acquisition page, and click on Calibrate Field Tile. This will guide you through a series of spectral acquisitions (white tile reflection, dark spectrum and field tile spectrum), which will compute the reflection spectrum of the field tile. This reflection data will be stored in the Color Space and Illuminants worksheet page. After this field tile is calibrated, you must go to the Parameters worksheet page and check the box to indicate that you are using a Field Tile as the reference. You will then acquire data as described above, but instead of using the white standard as the reference, you will be using the field tile that you calibrated. This calibration only needs to be done once, as the reflection data is stored in the worksheet when you exit and save it.

Emissive Color Measurements

OOIColor also supports the measurement of emissive color, such as the light emitted from an LED or a lamp. The experimental techniques are quite different from the measurement of reflective color, and are outlined below.

The experimental configuration of the emissive color measurements consists of a single optical fiber. One end of the fiber is placed in the spectrometer, and the other end is pointed at the light source to be analyzed. To make emissive color measurements, you still must record a reference and dark spectrum. The reference spectrum required for emissive color measurements is the output of a blackbody illuminant at a known color temperature. For example, Ocean Optics offers a miniature tungsten-halogen source, which behaves as a blackbody at 3100K. To take a reference spectrum of the blackbody source, simply point the optical fiber at the source and click Store Reference. You may be instructed to increase or decrease the integration time of the spectrometer, as outlined above. After the reference is stored, you then must click Store Dark to record the dark spectrum of the spectrometer. Make sure that when you do this, the optical fiber is not pointing at any light source. Now, click Start Acquisition to begin acquiring color data, and point the optical fiber at the light source to be analyzed.

Color Measurements: A Computation Tutorial

The fundamental computation involved in the measurement of color is to determine the reflection spectrum of an object and apply it to a standard illuminant (a fictitious light source). The amount of light from this standard illuminant that the object reflects (in terms of energy, not percent reflection) is manipulated and reduced to the tristimulus values X,Y and Z. These values correspond to the physiological response of the three types of color receptors that the typical human has in his/her eye. These X,Y and Z values are then combined into uniform color spaces (L*,a* and b*, for example).

The process begins by the acquisition of a reflection spectrum (R_λ) at 5nm intervals over the wavelength range of 380-780nm (Note: All sums shown here are over this same interval).

$$R_\lambda = \frac{S_\lambda - D_\lambda}{R_\lambda - D_\lambda}$$

…where R_λ is the reflectivity at wavelength λ, S_λ is the sample spectrum intensity at wavelength λ, R_λ is the reference spectrum intensity at wavelength λ and D_λ is the dark spectrum intensity at wavelength λ.

The first step in the calculation is to compute the color matching values for the sample and the reference:

$$x_{ref} = \sum_\lambda I_\lambda x_\lambda$$

$$y_{ref} = \sum_\lambda I_\lambda y_\lambda$$

$$z_{ref} = \sum_\lambda I_\lambda z_\lambda$$

$$x_{sam} = \sum_\lambda R_\lambda I_\lambda x_\lambda$$

$$y_{sam} = \sum_\lambda R_\lambda I_\lambda y_\lambda$$

$$z_{sam} = \sum_\lambda R_\lambda I_\lambda z_\lambda$$

…where x_λ, y_λ and z_λ are the color matching coordinates at a specific wavelength, and I_λ is the intensity of the illuminant at a specific wavelength.

The tristimulus values (X, Y and Z) are computed by the following equations. It is important to note that by convention, these calculations are scaled so that the Y value for all illuminants is 100.00:

$$X = 100 \frac{x_{sam}}{x_{ref}} \begin{pmatrix} x_{ref} \\ y_{ref} \end{pmatrix}$$

$$Y = 100 \frac{y_{sam}}{y_{ref}} \begin{pmatrix} y_{ref} \\ y_{ref} \end{pmatrix}$$

$$Z = 100 \frac{z_{sam}}{z_{ref}} \begin{pmatrix} z_{ref} \\ y_{ref} \end{pmatrix}$$

All other color space values are derived from these fundamental tristimulus values:

$$x = \frac{X}{X + Y + Z}$$

$$y = \frac{Y}{X + Y + Z}$$

$$z = \frac{Z}{X + Y + Z}$$

$$u' = \frac{4X}{X + 15Y + 3Z}$$

$$v' = \frac{9Y}{X + 15Y + 3Z}$$

$$w' = \frac{-3X + 6Y + 3Z}{X + 15Y + 3Z}$$

$$u,v \ \text{hue angle} = \text{atan} \frac{v' - v'_{\text{Illuminant}}}{u' - u'_{\text{Illuminant}}}$$

$$u,v \ \text{Saturation} = 13 \sqrt{\left(u' - u'_{\text{Illuminant}} \right)^2 + \left(v' - v'_{\text{Illuminant}} \right)^2}$$

The derivation of other color space values can be found in references on measuring color. The reference used for all of the coordinates and equations was R.W.G Hunt, *Measuring Colour*, 2nd Edition, Ellis Horwood, 1991.

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