Light Measurement

Here we introduce various devices available in the lab for measuring light, including spectroradiometers and photometers. There is information about the different devices available, key points about how they should be used, and example code for automating the measurements.

1. Prerequisites

MATLAB (tested on 2022b) (software)

PsychToolbox-3 (tested on version 3.0.19) (software)

Additional functions provided by CRS (available at https://www.crsltd.com/tools-for-vision-science/light-measurement-display-calibation/colorcal-mkii-colorimeter/nest/product-support) (software)

PR-670 (hardware)

SpectroCAL (hardware)

ColourCAL (hardware)

UDT device (hardware)

2. Theory

Light measurement can be a tricky topic. One difficulty students often have is getting to grips with different key terms used, and what type of device takes what type of measurement, and when you'd want each type of measurement. We start by defining some key terms to help with this.

Irradiance is the amount of light hitting a given surface every second (measured in W/m^2). As irradiance is defined at a given position in space, it varies with distance from the source of light being measured (specifically in an inverse square relationship). Irradiance can be measured with a radiometer that measures light intensity in W (and using the known area of the measurement sensor the light falls on one can calculate irradiance in W/m^2).

Radiance (or spectral radiance) is the amount of light being emitted, reflected, or transmitted from a given source (measured in $W/sr/m^2$). Unlike irradiance, radiance has the interesting property that it does not vary with the distance between the measurement device (or eye) and the surface or display. Radiance can be measured with a spectroradiometer.

Luminance (measured in cd/m^2) is a measure of the amount of light that is weighted by human visual sensitivity. Luminance can be calculated from spectral radiance by integrating the light energy across the full spectrum weighted by the **luminous efficiency** of the human eye. Thus, like spectral radiance, luminance does not depend on distance between the measurement device and the surface or display. Luminance can be measured with a photometer, or spectroradiometer.

(NB: **Brightness** is not a measurable quantity; it is a perceptual correlate of how much light is being emitted by a source.)

For your projects you are going to need to take spectral radiance and luminance measurements. Details on how to do so are provided below. If you are interested in learning how to take irradiance measurements please discuss this with the faculty and we will show you how this works using the UDT flexOptometer.

3. Taking Spectral Radiance Measurements

Spectral radiance measurements are taken using **spectroradiometers**. There are two available in the lab - the **SpectraScan PR670** and the **CRS MKII SpectroCAL**. Typically, for spectral measurements the measurement device is placed where the observer's eye will be placed in the experiment. This is in order to capture the full spectrum of light reaching the observer's eye, which may contain light from sources beyond our stimulus.

3.1. PR670

The PR670 can be used as a standalone device or plugged into a computer via the included USB cable and controlled using MATLAB. Measurements can be taken by pressing the 'measurement' button on top of the device. There is an aperture through which you can view what the device is pointing at. The device records a spatial average across the black circle visible through the aperture. There is a dial on the left side of the device, which closes a shutter over the aperture. Be sure to close this when the device is in use to avoid lens reflections affecting the measurement.

When using the PR670 with a computer, connect the devices via USB before turning on the PR670. Control of the device is enabled with PsychToolbox functions. First, a connection must be established between the computer and the device. Use the following function to do this, where 'port' is the USB port the PR670 is plugged into.

```
>> PR670init(port);
```

In order to make a spectral measurement using the PR670, use the following function:

```
>> spd = PR670measspd([380 5 81]);
```

Here, the input argument, [380 5 81], signified the bin size and wavelength range the device records over. In this case, 81 bins in 5-nm increments starting at 380nm. You should hear the sound of the shutter moving inside the device, before a beep. The function returns a one-dimensional array, where each array element corresponds to the power recorded from each bin across the visible light spectrum i.e. the spectral radiance measured in W/sr/m^2.

Note: Because the Psychtoolbox routine provides the data in terms of W/sr/m^2, you would need to divide by the binsize in nm to obtain the power in W/sr/m^2/nm. The convention of providing the spectrum in terms of power per bin allows matrix-based computations to proceed without explicit inclusion of a factor corresponding to the binsize, but can be a little confusing.

3.2. SpectroCAL

The SpectroCAL works slightly differently to the PR670. It does not work as a standalone device, so can only be controlled by a computer. When plugged in, a red light should appear at the back of the device. Press down on this light to turn on the laser pointer. The device records a spatial average across the ring drawn by the laser, centred at the dot in the middle. To record a spectrum measurement, use the following function (there is no need to specifically initialise the device):

```
>> [CIEXYZ, CIEUV, Luminance, Lambda, Radiance]
= SpectroCALMakeSPDMeasurement(port,380,780,5)
```

Here, the four input arguments define the port name (this will depend on your device), the start and end wavelengths, and the bin size between these. This function outputs the CIE XYZ, CIE u'v', luminance (in cd/m^2), the wavelength range captured over (in nm), and the spectral radiance (in W/st/m^2). We are mainly interested in the latter of these.

The MATLAB file 'measureRadiance.m' can be used to make radiance measurements using either device.

4. Taking Luminance Measurements

Photometers are used to carry out luminance measurements. In the lab, we have one photometer – the **CRS ColorCal MKII**.

4.1. ColorCAL

Here we demonstrate how to use the ColorCAL with the functions freely available on the CRS website. These come in the form of a single function structure with many in-built options. To see these options, use:

```
>> help ColorCal2
```

The ColorCAL will measure CIE XYZ values, where the Y value gives luminance in cd/m^2. In order for, the recording to be accurate, you must correct the recording using a calibration matrix stored on the device. For best results, set the ColorCal up on its tripod and gently press the device up to a display, so that any other light is kept out (note this will thus record the luminance of the display itself only, and not any stray light that may reach the observer). Firstly you need to check if the ColorCAL requires zero calibration and if so run zero calibration, as below:

```
>> needsZeroCalib = ColorCal2('NeedZeroCalibration');
>> if needsZeroCalib==1
>>    ColorCal2('ZeroCalibration');
>> end
```

Then you measure the XYZ values with the following command:

```
>> raw_xyz = ColorCal2('MeasureXYZ');
```

These XYZ values are raw/uncalibrated values and must be corrected by multiplying them against the devices internal calibration matrix as below:

```
>> cMatrix = ColorCal2('ReadColorMatrix');
>> corrected_xyz = cMatrix(1:3,:) * [raw_xyz.x raw_xyz.y raw_xyz.z]';
```

4.2. Via a spectroradiometer

As noted above in Section 3.2, the SpectroCAL also outputs luminance measurement in cd/m^2. You can also record luminance in cd/m^2 from the PR670 using the following code:

```
>> xyz = PR670measxyz;
```

Any spectroradiometer is able to also make luminance measurements by integrating the spectral power density function across its recorded range. For physiologically-relevant measurements, this integral is weighted by the **luminous efficiency function** (known as V(λ)), which corresponds to a weighted sum of the L and M cone spectra. Using spectroradiometers to measure luminance can be useful when carrying out a full display calibration, though it is generally not recommended. Photometers have higher dynamic ranges and signal-to-noise ratios, so can provide more accurate measurements of luminance. On the other hand, the filter in a photometer may not be a perfect match to the target luminous efficiency function, which in turn can reduce accuracy. *Can you discuss in your groups when you might want to use a spectroradiometer instead of a photometer to measure luminance?*

The MATLAB file 'measureLuminance.m' can be used to make luminance measurements using either device.

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