TECHNICAL NOTE 2023_4 – TEMPERATURE MEASUREMENT USING HSI CAMERA

Introduction

In many applications, temperature needs to be monitored. Contactless methods are very valuable as they do not pollute the samples or can be used in harsh environments where distance from the samples is needed. In this TN, we explain the theoretical background on temperature measurements with the use of hyperspectral cameras, also illustrated by a concrete case.

BB = BLACKBODY

SWIR = SHORT WAVE INFRARED (1000 – 2500 NM)

Article

Spectral cameras can measure the spectral radiance of objects. Raw data needs to be first converted into radiance with the mean of a radiometric calibration file (see TN05_How to use the radiometric calibration file). Unless an object is as cold as 0 degrees K (i.e. absolute 0), it would emit some radiations. The intensity and the spectral distribution of the emitted signal depends on its temperature. This is a well-known phenomenon following the Planck' law (Fig.1). Besides, the wavelength with the maximum of radiance emission goes longer when the temperature of the sample decreases (Wien's displacement law).

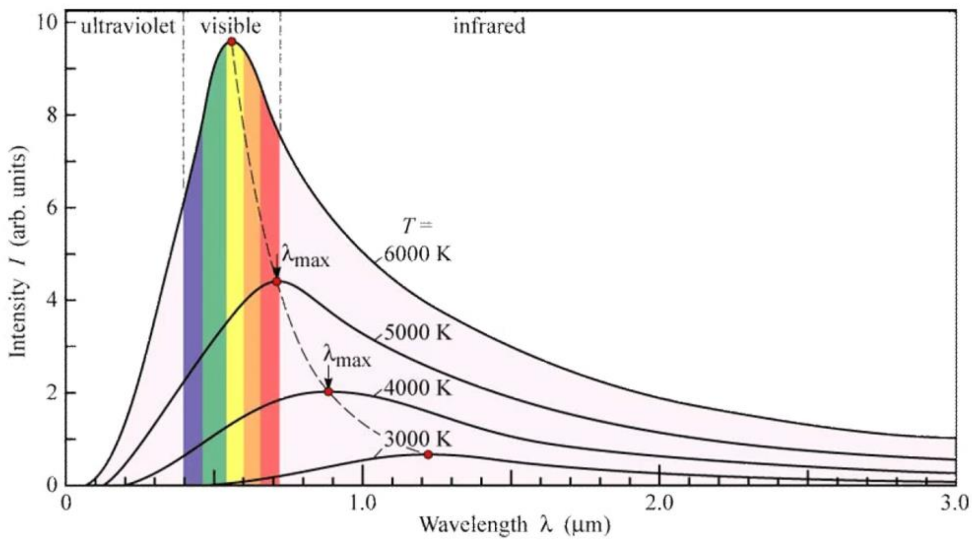


Figure 1: Spectral emission of a blackbody at different temperatures following the Plank's law.

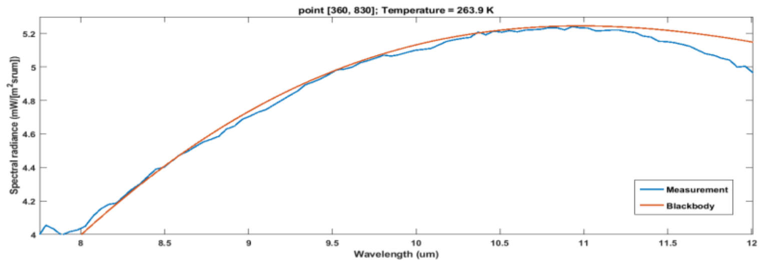
The emission curves following the Plank's law are correct for "perfect" samples, also called "blackbodies". Those blackbodies, i.e. theoretical objects, do not have any spectral signature. They emit as the Plank's theoretical emissions, for all wavelengths (meaning they also totally absorb light over the full spectral range, hence their naming).

In the real world, objects do not behave exactly like blackbodies. There are some wavelengths at which the emission is not maximal: there is then a spectral signature. This is actually the essence of spectroscopy, to identify materials or quantify variables based on their spectral signatures. Even though real objects do not behave exactly like blackbodies, we can assume that at some wavelengths they do. This assumption is actually crucial for determining the temperature of the object: a spectral emission curve following the Plank's law is fitted on the measured spectral emissivity. From this fitted curve, at the highest parts of the measured emission, a temperature is deduced. Notice that if the sample does not behave as a blackbody for any wavelength, then the temperature is underestimated.

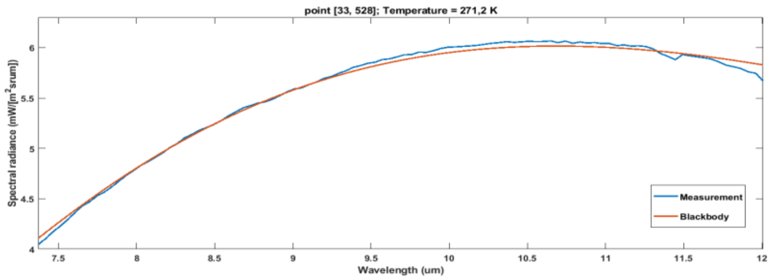
It is important to notice that temperatures can only be deduced from emission data. Not from reflectance neither transmittance.

To illustrate the above, we will consider the below example. A SPECIM thermal camera covering the spectral range 7.5 to 12 um was flown over Oulu, Finland, in winter. Since at the lower end of the spectral range the radiometric calibration is the least accurate (mostly due to strong atmospheric contribution), data were reduced to 8 – 12 um. From the raw data, spectral radiance was obtained. As explained above, Plank's theoretical curves were fitted.

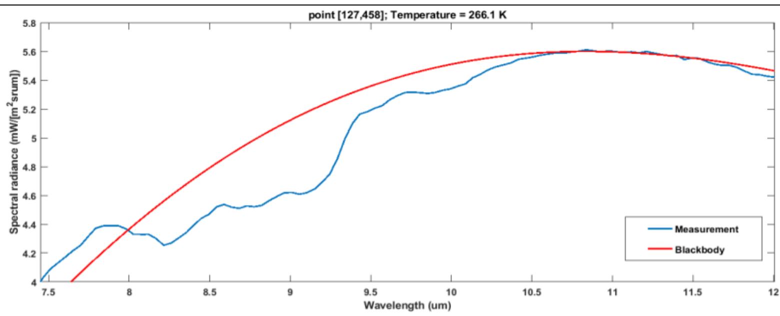
False RGB of the radiance data



Point 1 (roof top of a building)



Point 2 (frozen sea = ice)



Point 3 (sand on the beach)

Spectral radiance on 3 different points with the related matching BB curves

Figure 2: spectral radiance of the imaged area with related theoretical Plank's spectral emission curves at 3 different points. Measured spectral are here averaged over 5x5 pixels.

In this example, the temperature at points 1, 2 and 3 can be estimated to 263.9K (i.e. -3.9 °C), 271.2K (i.e. -2.0 °C) and 266.1 K (i.e. -7.1 °C). This can be applied to all pixels in the image to obtain a heat map (Fig.3).

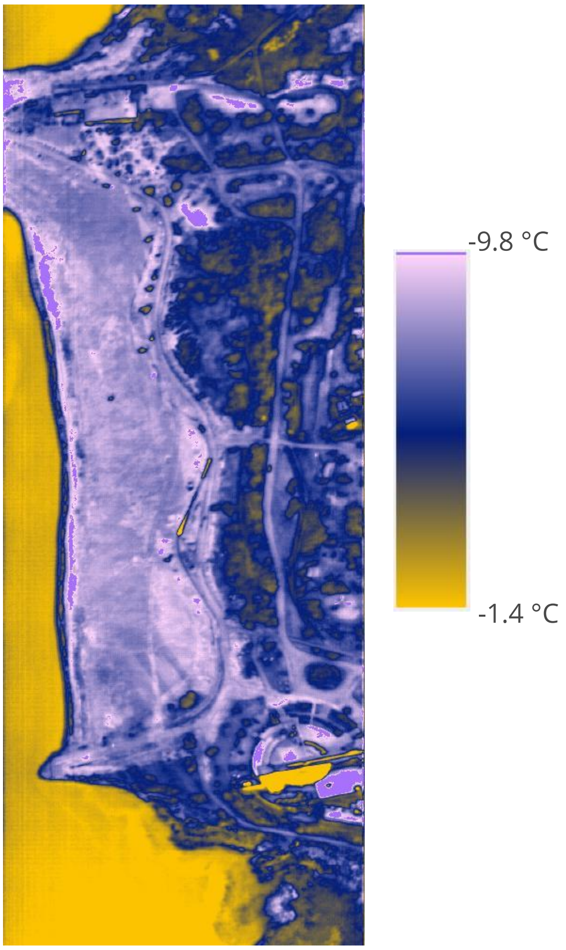


Figure 3: Heat map obtained from the radiance data over the full imaged area.

In the above example, a spectral camera covering the spectral range 8 to 12 um was used, being part of the commonly called thermal infrared region. However, the method described in this TN could also be used with other cameras encompassing different spectral range. Those would be most suitable for different temperature ranges (see Table 1 below).

Spectral range / camera	Optimized temperature range (K)
400 – 1000 nm / FX10, IQ	3000 - 7000
900 – 1700 nm / FX17	1700 - 3000
1000 – 2500 nm / SWIR	1000 – 3000
2700 – 5300 nm / FX50	500 – 1000
8000 – 12000 nm / FX120	240 – 400

Table 1: Optimized temperature ranges to be estimated for each spectral camera.

Disclaimer

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Version history

Version	Date	Author	Comments
1.0	Jan 14th 2024	MMA, HHO	