Spectral Sensitivity Estimation Without a Camera

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Full paper

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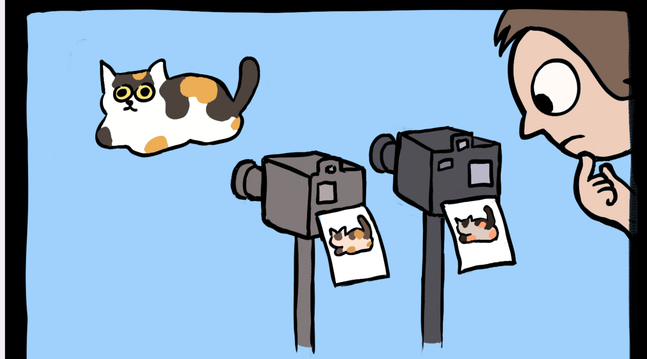
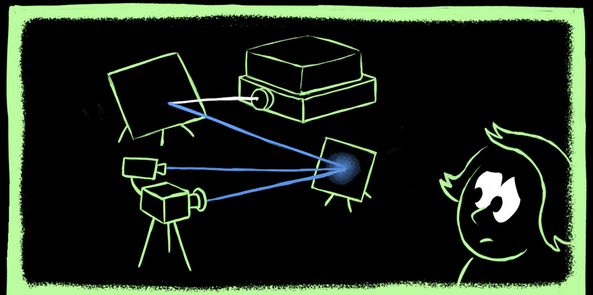
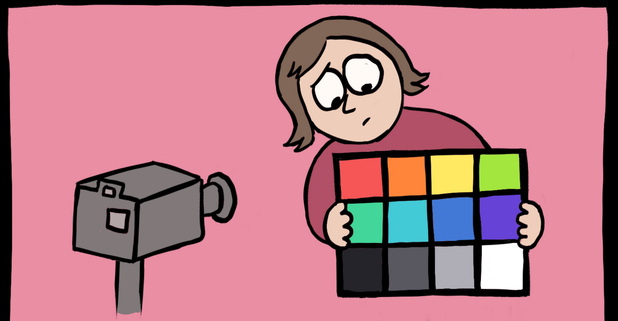


Every camera captures colors differently, in the unique color space of its sensor, determined by its spectral sensitivities. Many tasks in computer vision and related fields would become easier if camera sensitivities were known, but manufacturers do not make this information public. Consequently, researchers working on color-sensitive tasks have to estimate the spectral sensitivities of their cameras themselves.



The gold standard of spectral sensitivity estimation involves a monochromator - a device that produces narrowband light. After being reflected off a surface, this light can be captured by the camera, while a radiometer measures its spectrum. This is a direct method for measuring the camera's sensitivity to a single wavelength, and it can be repeated for all wavelengths in the camera's sensitivity range, revealing the sought spectral sensitivities in the process. This specialized optical setup costs more than $40,000, making it inaccessible for many research labs.



A seemingly low-cost alternative to the expensive monochromator setup is an indirect approach that uses a photograph of a color chart. Using the image formation model for clear air, a linear system of equations describing the spectral sensitivities can be constructed from the RGB values, the patch reflectances and the light spectrum. Yet, most color charts contain too few patches with linearly independent reflectances to guarantee a unique solution. On top of that, the light spectrum is usually also not known (necessitating an expensive radiometer to measure), contributing with even more unknowns and making the system non-linear!

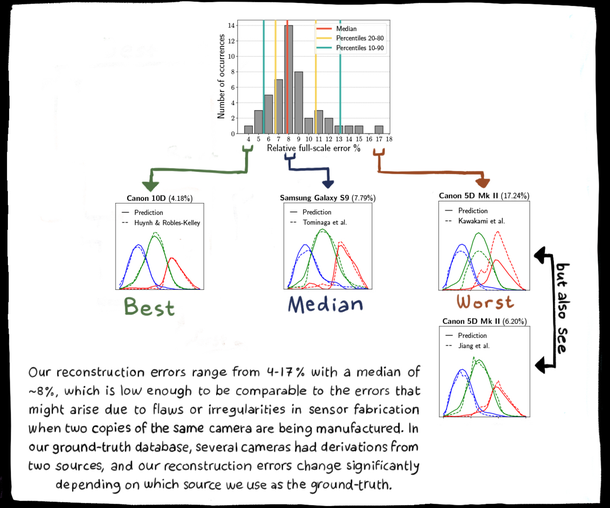
Loss = Specific Term + Universal Term

Experimental Data General Assumptions

Commonly, the sought out spectral sensitivities are obtained by solving an optimization problem whose objective function is comprised of two terms: one that originates from the system of equations and is specific to the camera under consideration ("specific term"), and one that corresponds to additional assumptions made about all possible spectral sensitivities ("universal term"). Using a monochromator would yield nearly perfect information for the specific term, rendering the universal term unnecessary.

We designed a framework for spectral sensitivity estimation that not only does not require any specialized hardware (including a color chart), but also does not require physical access to the camera itself. Similar to other work, we formulate an optimization problem that minimizes an objective function composed of a "specific term" and a "universal term". Different than other work, we utilize publicly available high-quality calibration data to construct both terms.

To formulate the "specific term", we used the two colorimetric mapping matrices provided by Adobe DNG (for illuminants A and D65). To formulate the "universal term", we used an autoencoder trained on a database of ground-truth curves that we collected from the literature.



Our reconstruction errors range from 4-17% with a median of ~8%, which is low enough to be comparable to the errors that might arise due to flaws or irregularities in sensor fabrication when two copies of the same camera are being manufactured. In our ground-truth database, several cameras had derivations from two sources, and our reconstruction errors change significantly depending on which source we use as the ground-truth.

We predicted the spectral responses for 1000+ cameras in the market. Knowing camera response not only reduces the number of unknowns but also helps relate RGB values to spectral quantities. We give an example from the marine domain where we recover the *diffuse downwelling attenuation coefficient* K_d.

Light (E) attenuates exponentially with depth D:

$$E_D = E_0(\lambda)e^{-K_d(\lambda)D}$$

Wavelength λ Wavelength λ

The image formation model for short-distance imaging underwater is given as:

$$I = \int_{\lambda_1}^{\lambda_2} \rho(\lambda)E_D(\lambda)S(\lambda)d\lambda$$

Where ρ is the reflectance of a patch in the color chart and S is the spectral sensitivities of the camera. K_d can be estimated through optimization: