

Measuring Camera Spectral Sensitivity Functions Using camSPECS 2.8 (Build 20)

This document is a short but handy manual on using the “camSPECS” hardware and software to measure the camera spectral sensitivity functions. You can find more details in the camSPECS manual provided by the developers. The manual is available at [//icfiler2.epfl.ch/1cavcomm/IVRG/camSPECS](http://icfiler2.epfl.ch/1cavcomm/IVRG/camSPECS) and also on their server <http://www.image-engineering.de/ie-sw/camSPECS/>. The username and password to access the camSPECS server are: IE-Analyzer and ie47sw11, respectively. This document consists of three sections: 1) the hardware, 2) the software, and 3) the known issues in using the camSPECS.

1 The Hardware

To capture the necessary images follow these instructions:

- Put the device in a dark room or cover it properly such that no external light goes through the device or the camera. The camera needs to only capture the light coming from the lamp in the device.
- Turn on the machine. Wait couple of minutes so the projector warms up. The spectral behavior of lamp might change during the warm up.
- Choose one of the filters with wavelength 530-560 nm. Change the camera settings (exposure, f-stop, and ISO) until you get the brightest but not saturated image from one of those filters. If the images are saturated, the information would be lost at some parts of the spectrum. Since for usual cameras one of the 530-560 nm filters makes the brightest image, if these images are not saturated the images of other wavelengths would not be. The format of camera output images has to be raw.
- Fix the camera in an appropriate position with respect to the machine. The camera should not move when you take *all* 55 images during which the first filters slide needs to be replaced with the second one (Fig. 1).
- Capture all 55 images. You can move the slide and put the new filter into the machine using the green button on the side of the device. Be careful to not take the image before the filter is completely placed in the device.

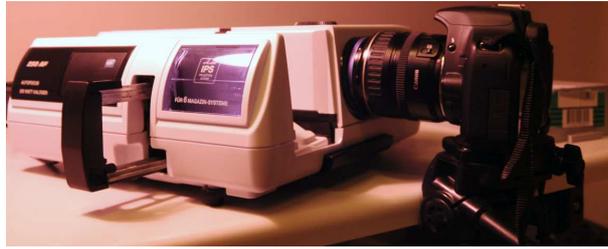


Figure 1: The camSPECS machine.

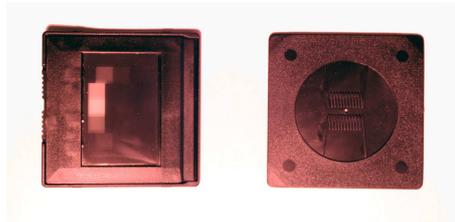


Figure 2: The last pieces in the filters slide.

Note: There are two pieces in the second slide with different shape (see Fig. 2). You do not need to take images from these two filters.

2 The Software

2.1 Installation

- Windows:
 1. Install MATLAB Compiler Runtime (MCR) version 7.14. You can download the installation file from http://www.image-engineering.de/ie-sw/MCR_Installer/PC-Version/.
 2. Download camSPECS 2.8 (build 20) from http://www.image-engineering.de/ie-sw/camSPECS/development_release/ and install it.
- MAC:
 1. Check “/applications/MATLAB/” folder to find out the version of your MCR if any is installed already. If you have MCR 7.14 installed, the camSPECS software can be installed. If not, delete the whole MATLAB folder, download the MCR installer for mac from http://www.image-engineering.de/ie-sw/MCR_Installer/MAC-Version/ and install it.

Note: If you have another version of MCR installed on your machine, it is not possible to install MCR 7.14. Thus, it is important to delete the other version before trying to install version 7.14.

2. Download the camSPECS package from http://www.image-engineering.de/ie-sw/camSPECS/development_release/ and unzip it in the application folder.

Note: Open the automator application. Drag the “camSPEC_V2” application file from the camSPEC folder into the automator. On the 8th line, you find the following command:

“MCRFOLDER=/Applications/MATLAB/v714/#the MCR location”.

Make sure that the location defined in front of the MCRFOLDER is the location of your MCR. If it is not simply change this command to the location you installed the MCR.

2.2 Process Images

- Convert raw files to tiff images:
 - Windows: there is no need to convert the raw files. The software accepts the raw files and then converts them to tiff using the ddraw.exe.
 - MAC: Since the ddraw file provided in the software package can be used only in the windows machine, you have to convert the raw files before using the software and then use the tiff files for image processing. To do this:
 - * Download and install the ddraw for mac.
 - * Use the following command line in terminal to convert the raw files to tiff:
#location of the ddraw application# -4 -D -T #the name of the raw file#
For instance, if you install the ddraw in your user folder, the following command should convert a file named example.CR2 to tiff:
ddraw/ddraw -4 -D -T example.CR2
In the above command, the following ddraw options are used:
-4: linear 16-bit files (convert to 8-bit files results in information loss), -D: document mode, in this mode no interpolation is applied on the images, -T: the output file is tiff.
- Open the software. Click the “advanced” button on the bottom of the window. The last tab of the advanced settings is “DCRaw”. You need to locate the ddraw.exe here. The ddraw.exe is provided in the software package and by default can be found in the folder “app” located in the camSPECS folder.

- You also need to specify the location of the calibration file in the upper left side of the software window. The calibration file is called “calibration_set24” and in the MAC version is located in /Applications/camSPECS_V2_build020_Mac/calibration_files/filter (the location in the windows version is the same).
- Add all the images in the “Select images” tab and click the start button.
- Software recognizes the center of the filters in the first image and asks for your confirmation. After this all the images are processed and the curves are produced. All the numerical results are saved in a text file located in the folder of the images.

2.3 Results

In the text file, the following values are saved:

- lambda: the wavelengths in which the spectral responses are measured.
- R_SR, G_SR, B_SR: normalized spectral sensitivities of three color filters in the camera.
- R_REF, G_REF, B_REF: the reference values computed using the intensity of the neutral filter (the left filter in each image) at each wavelength.
- R_RAW, G_RAW, B_RAW: the raw values read from the right filter (interference filter) in each image.
- Filter calibration: radiance power of interference filters.

The spectral sensitivities (R_SR, G_SR, and B_SR) are computed using the raw, ref, and calibration values as the following:

$$C_{SR}(\lambda) = \frac{C_{RAW}(\lambda)}{C_{REF}(\lambda) \times \text{Calibration}(\lambda)}, \quad (1)$$

where C can be R, G or B and λ is the wavelength. The camSPECS software produces two curves, one is called “RAW data” and shows the C_RAW values and the other one is “standardized output data”, which illustrates the C_SR values.

3 Known Issues

- Clearly there are measurement errors in every experiment. Thus to be more confident about the measured sensitivities, repeat the whole experiment for each camera several times and use the average of different experiments outputs.

- If you get only one curve instead of three at the output, you have to manually define the Bayer pattern used in the camera. To this end, disable the “auto detect” option in the “demosaicing” tab (in the advanced settings). Now you can change the color of each filter and run the software again. You can define the Bayer pattern by trial and error until three curves are produced at the output. Another option is to zoom in the image of the 550 nm filter and find the brightest pixels which are the green pixels (the green pixels are either the diagonal or off-diagonal pixels).
- Note that the filter centers are only recognized in the first image and these locations are used in all the other images. Thus, if there is a significant movement between the first image and other images, the wrong raw values are used in producing the curves. To be sure that the correct filter centers are used in all images, check the tile image produced during the image processing and saved in the images’ location. If during the image processing, you receive any error indicating that the size of the bounding box is zero, it probably means that there is a significant movement in one of the images with respect to others. In this case, you have to repeat the whole experiment.

So far the spectral sensitivities of two cameras (both sensitive to NIR as well) are measured: “Nikon d90” and “Canon EOS REBEL T1i”. The sensitivities of these cameras without any filter (in front of the lens) and also visible blocking and NIR blocking filters are measured. For Nikon “093” and “486” filters and for Canon “092”, “093”, “486”, and “Xnite75” filters are tried. Each experiment was repeated two times (except for Canon without filter where the sensitivities were measured 14 times). All plots and text files containing the numerical results are available at [//icfiler2.epfl.ch/lcavcomm/IVRG/camSPECS](http://icfiler2.epfl.ch/lcavcomm/IVRG/camSPECS).

For further details consult the camSPECS manual accessible from [//icfiler2.epfl.ch/lcavcomm/IVRG/camSPECS](http://icfiler2.epfl.ch/lcavcomm/IVRG/camSPECS) or contact Zahra Sadeghipoor (zahra.sadeghipoor@epfl.ch).