Building a 1-D Look up Table for Device Calibration in Printers

Background and Overview: Calibration and Characterization

In the inverse color management problem, the goal is to estimate what RGB value should be sent to a device (in this case, a printer) to reproduce a desired CIELab value. This can be difficult due to the varying nonlinear color response of each printer. To color manage a printer, one must first model the transformation from the device-dependent color space (RGB) to the device-independent color space (CIELab). This process can be separated into two main stages. The first stage is calibration which works toward linearizing the printer [2].

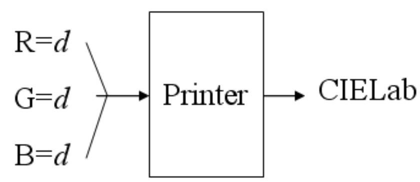

FIGURE 1. Problem with uncalibrated printers: When sending the printer a gray valued RGB (where R=G=B), the printer should print a gray value that is equivalent to CIELab $(100(d/255), 0, 0)$. Instead, the printed value may not necessarily be neutral.

To do this, first build three 1-D look up tables (LUTs) that will convert each channel, R, G, and B to R', G', and B' respectively. This will gray balance the printer so that equal amounts of R, G, and B (passed through the LUT) correspond approximately to neutral gray values. The R'G'B' will be the values needed to produce the gray values in the printer. See Figure 2.

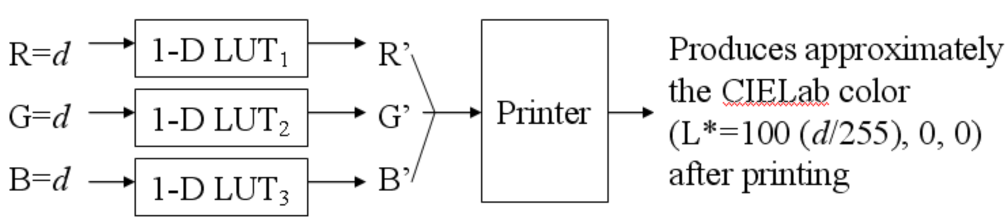

FIGURE 2. Effect of the 1-D LUTs: Pass the LUT RGB with equal amounts and it will return the R'G'B' that will produce the gray when sent to the printer.

The second stage is to characterize the calibrated printer. Using the calibrated RGB values and CIELab pairs, create a 3-D LUT that will translate CIELab to RGB.

Ultimate goal: Inverse Color Management

Once we have calibration and characterization functions for the printer, we can start with the desired CIELab values and pass the values through the characterization function (a 3-D LUT). From this we get the RGB. Then to calibrate the RGB values, we will pass each channel through the 1-D LUT to get R'G'B' values. The outcome is the R'G'B' value that will give us the desired colors when passed through the printer. See Figure 3.

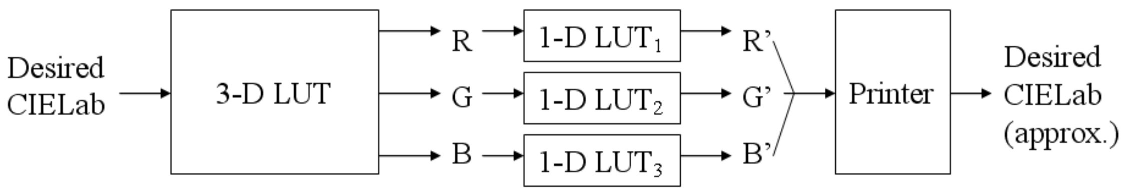

FIGURE 3. Inverse color management: To determine what RGB value to pass to a printer to get the desired value, start with the desired value in the CIELab device-independent color space. Then use the 3-D LUT to get the RGB value. This is then passed through the 1-D LUTs to get the new R'G'B' value.

Process

How and when does one generate the 1-D LUT? Although the calibration of the printer is performed after the characterization function is applied, to derive the calibration LUT, the 1-D table is built before characterization [1].

Steps to create the 1-D calibration LUT:

(1) Print an RGB color chart.
(2) Measure the printed colors in CIELab with a spectrophotometer to get (RGB, L*a*b*) pairs. Note: The patches where the input R, G, and B values are equal (R=G=B=d where d is 0 to 255) are the supposed neutral patches. If you had R=G=B=127 you would expect it to be 50% gray of its producible luminance range (because 127/255=.50). The (RGB, CIELab) pairs will make up the training set (for building the 1-D LUTs).
(3) Find the range of the measured luminance values. This will become the range of L* values for the test set. Divide the range into even increments of (maximum luminance - minimum luminance)/255. The list should consist of (L*, 0, 0) where L* is in even increments between the minimum and maximum producible luminance values measured in the training patch. This represents the incremental shades of gray in CIELab space and will make up the test set.

(4) Use this data, to estimate the R'G'B' values for each L*: For each value in the test set, find its nearest neighbors (using the the same neighbor algorithm that will be used for the 3-D characterization). Then use local linear or ridge regression to get the R'G'B' value that is expected to be equivalent to (L*, 0, 0).

(5) The LUTs can then be built. Because we want R=G=B=255(L*/100), 255(L*/100) is the input to each 1-D LUT, and the output is the derived R' (or G' or B') value.

When you input (d, d, d) in RGB, the 1-D LUTs will convert it to R'G'B' values that correspond to (100(d/255), 0,0) in CIELab space.

Once the 1-D LUTs are built you can then proceed to use these LUTs to create the 3-D LUT. First take the inverse of the 1-D LUTs (using 1-D linear interpolation) and use these inverse tables to look up the RGB values in the training pairs to get new (adjusted RGB, CIELab). Then use these new pairs to characterize the printer and create the 3-D LUT.

Side note: Inverting the 1-D LUT works best when the values are monotonic and range of the 1-D LUT is equal to the domain of the inverse 1-D LUT. If the 1-D LUTs' R'G'B' values do not span 0 to 255, when taking the inverse of the 1-D LUT, for any estimate below the minimum value in the 1-D LUT, set the inverse LUT value to the R (or G or B) that derives the the minimum R' (or G' or B') and for any estimate above the maximum value, set it to the R (or G or B) that derives the the maximum R' (or G' or B').

References

[1] M. R. Gupta and R. Bala, "Personal communication with Raja Bala."
[2] G. Sharma, *Digital Color Imaging*. United States of America: CRC Press LLC, 2003, ch. 5.