Color measurement on a flexo press with an RGB camera

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Summary

A number of companies are offering CIELAB or CIELAB-like measurements with their RGB camera web inspection systems. Unfortunately, the capabilities and limitations of these systems are not always clearly identified and understood. This paper is an attempt to set reasonable expectations for CIELAB measurements derived from an RGB camera.

Regardless of claims or implications otherwise, CIELAB measurements derived from an RGB camera will not agree well with a spectrophotometer. Because of this, an RGB camera should not be used to decide at makeready whether the color is in tolerance. However, the conclusion of this paper is that after color ok, colorimetric measurements derived from an RGB camera *can* be used to maintain color to a target, and to reliably report color differences.

How accurate does an online colorimeter need to be?

The ISO 12647 family of documents gives requirements for the print process. Part 2 covers commercial web offset, part 3 covers coldset presses, part 4 covers gravure, part 5 covers screen printing, and finally, part 6 covers flexo.

There are three requirements for color in 12647-6:2006. These are illustrated in Figure 1.

The first requirement is that the measurements of the proof must match a set of numbers specified in the standard. There are required CIELAB values for solid and overprint patches on uncoated paper, coated paper, corrugated board, and for film and foil. The second requirement is that the color OK sheet must match the proof – and not the specified numbers – to within 8 ΔE. This spec refers only to the solid patches. If no proof is supplied, then the numbers in ISO 12647-6 are the target.

Finally, the third requirement is that 68% of the sheets from the production run must match the OK sheet to within 2.5 ΔE. Note that there are stacked up tolerances here. While the tolerances between production sheets are fairly tight, a production sheet may be up to 10.5 ΔE away from the numbers in ISO 12647-6 and still be considered acceptable.

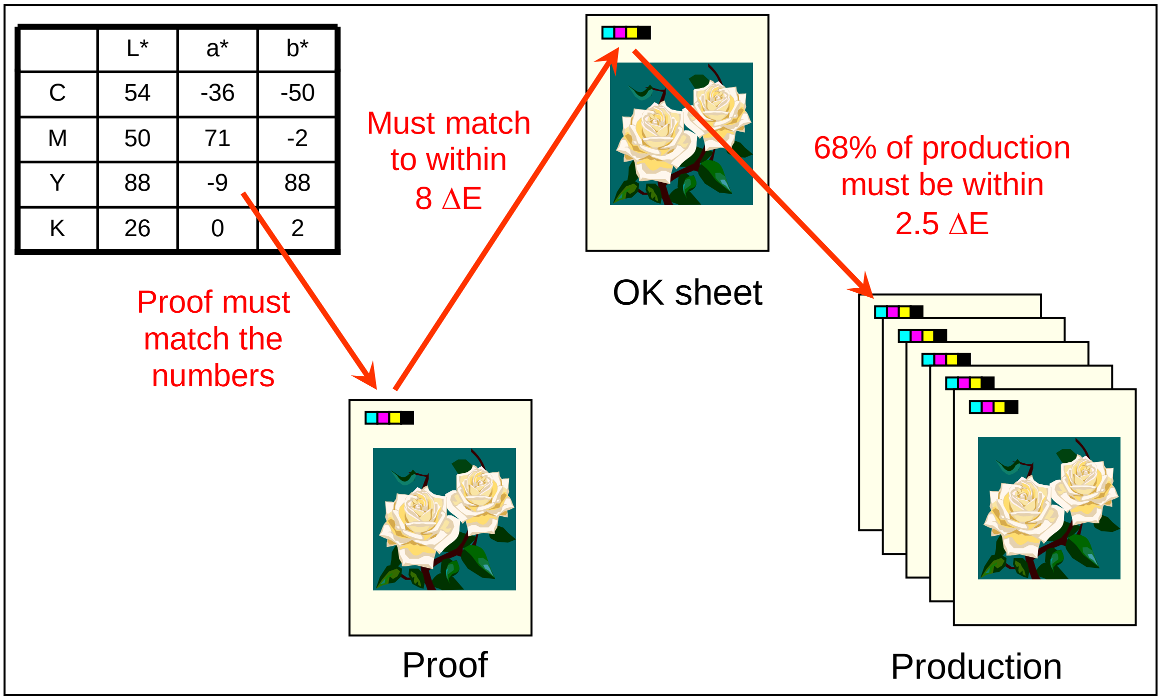

Figure 1 – ISO 12647-6 color requirements

One shortcoming of the standard is that it does not say how close the proof has to come to the published numbers, so this first requirement does not help us decide how accurately we need to measure. The other two tolerance windows, however, can be used to establish how accurate a color measurement device must be.

If I am supposed to make widgets that are between 23.7 and 23.8 inches long, and my yardstick could be off by up to an inch, then this is not a particularly helpful device for process control. How accurate does my yardstick need to be? The statistical process control gurus say that ideally, the measurement error of a device should not be more than 10% of the tolerance window for it to be an acceptable measurement device. If the error of a measurement device uses up more than 30% of the tolerance window, then it is considered unacceptable.

Based on the tolerance windows in ISO 12647-6, Table 1 shows the requirements for a device that measures CIELAB values.

Color requirement	Ideal	Maximum allowable
Color OK	0.8 ΔE	2.4 ΔE
Production run	0.25 ΔE	0.75 ΔE

Table 1 – Accuracy requirements for a colorimeter

How accurate are online RGB cameras?

There are a number of vendors selling web inspection systems that use an RGB color camera to report CIELAB values. One vendor claims an accuracy of 1.0 ΔE, while another claims an accuracy of 0.2 ΔE. It would appear that either system would be accurate enough to meet the ISO needs.

However…

There are a number of factors that limit the accuracy of colorimetric measurements that are derived from an RGB camera. For example, the design of the illumination presents a considerable engineering challenge. In order to agree with a standard color measurement device, all of the light must come in at 40º to 50º. Furthermore, the light must come in from at least three directions, that is, in a cone-shaped pattern. The detection of light must be made perpendicular to the surface[1].

As shown in Figure 2, if the angle of illumination is too steep, the camera will see more gloss than the standard and the measurement will be too bright. If the angle of illumination is too shallow, the measurement will be too dark.

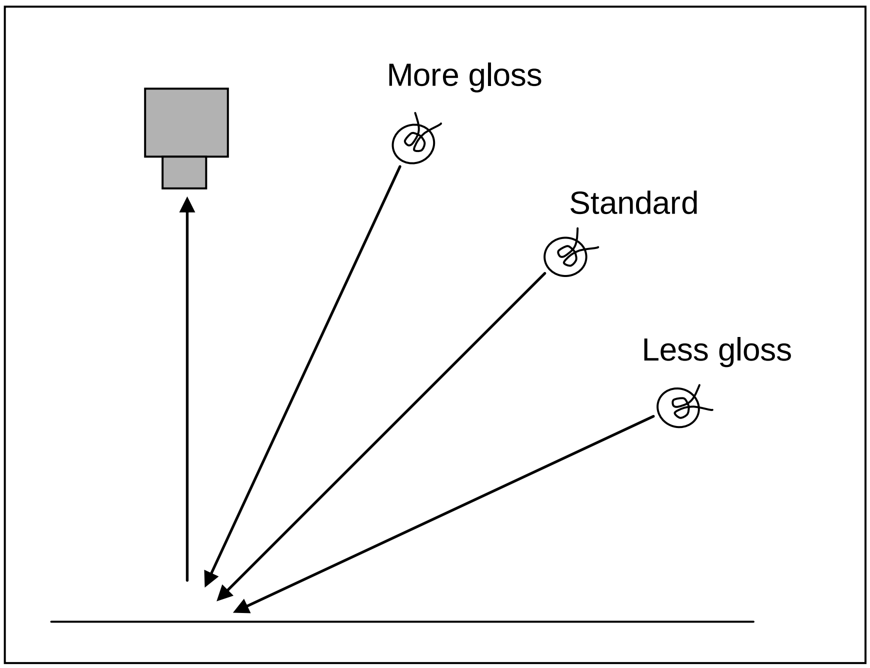

Figure 2 – the effect of changing angle of illumination

This so-called goniophotometric error is unfortunately not easy to correct, since the error depends a lot on the gloss of the stock. If the stock is very smooth (that is, like a mirror), then the angle must change appreciably before the camera starts to see gloss. If the stock is very matte (i.e. rough) then there is also little change with angle. On the other hand, pretty much everything we print on lies between these extremes where the dependence on angle is largest.

For makers of handheld spectrophotometers, getting the right angles of illumination is a challenge. For illumination of a moving web the challenge is greater. Fast web speeds and small targets mean short shutter times, so a lot of light is needed. On the other hand,

[1] The angles of lighting and camera could be reversed without changing the measurement.

fundamental principles of optics mean that the keeping the light between 40º and 50º requires that an appreciable amount of light must be thrown away. Thus, the engineer who designs a web inspection system must balance the need for accurate measurement geometry against the cost of generating the appropriate lighting solution.

The spectral component of the illumination is another source of error, especially if the substrate or the ink fluoresces. If two color measurement devices have a different amount of UV in their illumination, then the activation of the fluorescence will be different, and the devices will read differently.

This is a particular problem for measurements made on a web. Online systems typically use either xenon strobes or LEDs for illumination. The strobes have an appreciable amount of UV, the LEDs have virtually none. Handheld spectrophotometers, however, generally use incandescent lighting, which has some UV but not as much as a strobe.

Scattered light poses yet another problem. Light scatters within the camera and is measured at the wrong position in the image. Figure 3 shows light rays (in green) that are imaged on the detector in the correct place, and light rays (in red) that are imaged in the wrong place. On the left, light scatters when it reflects from the lens holder. On the right, light that should be collected at one spot on the detector, but instead reflects from the surface of the detector and then reflects again from the protective glass cover plate. Thus, light from a very light portion of the web may contaminate a very dark patch to be measured.

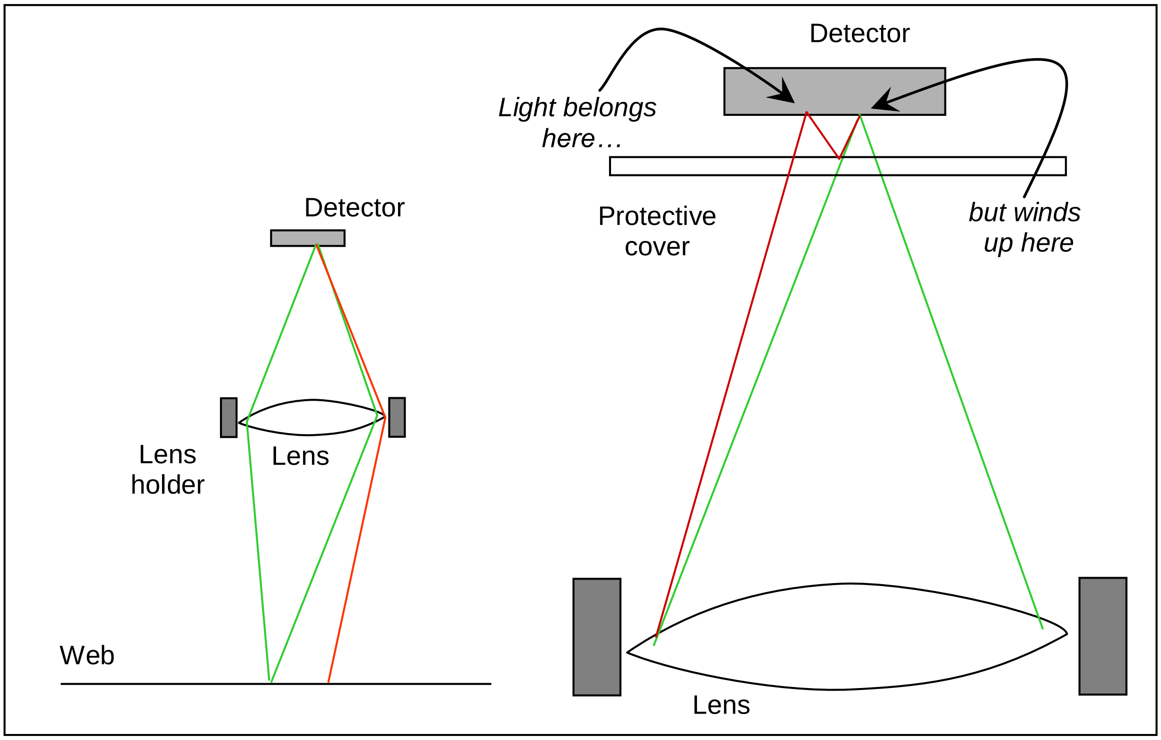

Figure 3 – some examples of how light can scatter in a camera

Scattered light can increase the apparent reflectance of an area by a few percentage points. While this may not sound like much, it can have considerable effect, especially in the darker portions of an image. The effect of adding 1% reflected light to a black area with reflectance of 1% will change the L* value from 9 to 15.5.

Correction for this scattered light is possible, but difficult because it depends to a varying degree on every pixel in the image. Correction requires a painstaking characterization of the camera.

A dirty lens is one particularly nasty cause of scattered light. A dirty lens will add an overall haze to the image, much like viewing the web through a fog. Pressurized air can reduce the accumulation of the dust and mist, but accurate measurements still require periodic careful cleaning of the first glass surface.

Even if these engineering issues are properly dealt with, there is still a fundamental limit to the accuracy of colorimetric measurements derived from an RGB camera: the spectral response. RGB cameras unfortunately do not respond to different wavelengths of light in the same way that a colorimeter (or the human eye) does. Two objects that have the same CIELAB values may look considerably different to an RGB camera.

There have been numerous papers written about various methods to convert RGB values from a camera or scanner into CIELAB values. I found eight papers that provided enough explanation of the methods and experimental data to allow comparison.

Generally speaking the average color error that is reported is from 4 to 10 ΔE. Only three papers report an accuracy that is at or below the absolute minimum requirement of 2.4 ΔE. Two of those papers were reporting errors strictly due to spectral response, so the actual error will be larger than this. The third paper reports accuracy as good as 1.2 ΔE, but the measurements are limited to a small number of patches on a single newspaper stock.

Based on this, it is doubtful that claims of accuracy at or below 1.0 ΔE are real.

Test of color *difference* accuracy

To meet the ISO "color OK" requirement, one needs to match color against a number that another instrument read from the proof, so one needs accuracy of CIELAB values. But for the "production run" requirement, only relative accuracy is required. It can be assumed that during the production run, the pigments are the same, the gloss is relatively constant, the effect of scattered light remains the same (so long as you compare the same spot in the printed image on different impressions), and the UV brightener content is constant. This makes the job considerably easier since many of these sample differences that confound accuracy go away.

The previous papers all focused on the absolute accuracy of RGB camera derived CIELAB measurements. I have only found a few papers that look at how accurately a camera can measure color difference. One paper reported an accuracy of color difference of 2 ΔE; the other reported 0.5 ΔE.

I decided to try this experiment myself. How well could a theoretical RGB camera agree with a spectrophotometer?

I started with the assumption that the fixable sources of error would be taken care of through engineering, and that the major source of error would be the spectral response of the camera. In that way, I could start with measured spectra and compute everything I needed.

I collected nine press sheets from a web offset run. The sheets were run at nominal densities, with cyan low, with cyan high, with magenta low, and so on. Each sheet had 1,296 patches. The spectrum of each of these patches was measured. From the spectra, I computed CIELAB values and color differences between corresponding patches.

In addition to using the spectra to compute CIELAB values, I also estimated what three commercially available RGB cameras would measure, and also estimated what a Status E densitometer would measure. This graph illustrates the spectral response of one of the three RGB cameras.

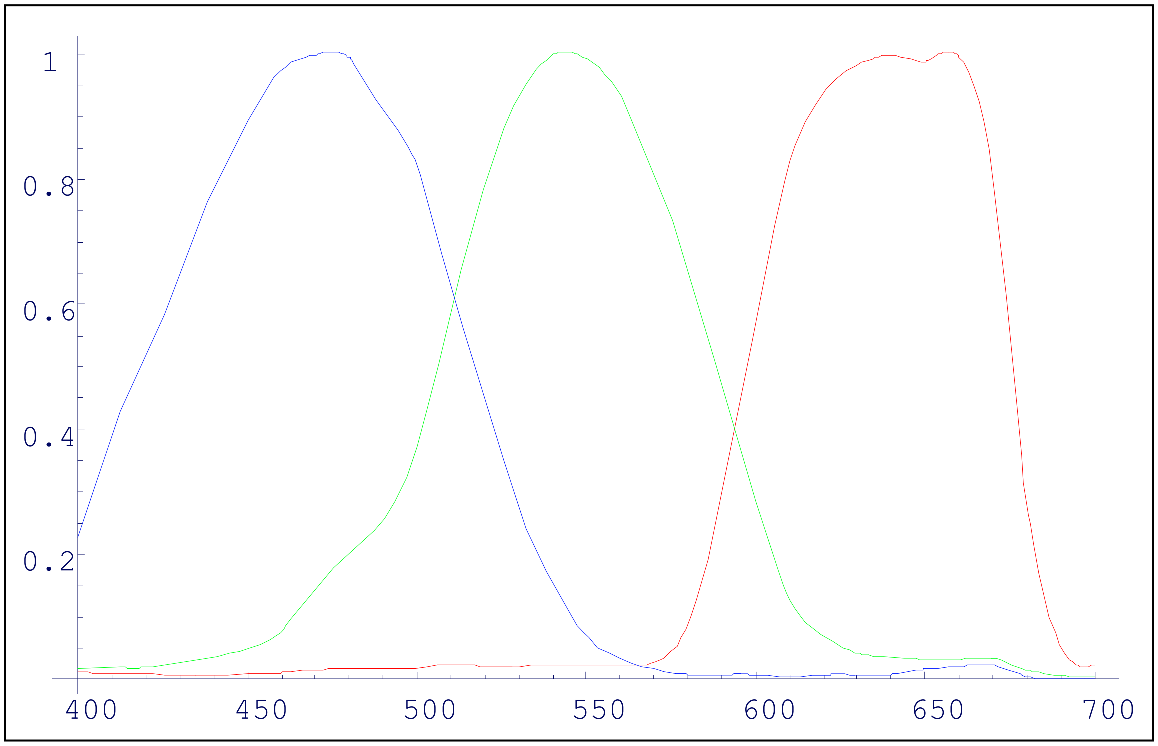

Figure 4 – spectral response of one commercially available RGB camera

I used a “standard” technique to estimate CIELAB values from the RGB camera responses. I used regression to determine the optimal 3X9 matrix that would transform RGB reflectance into XYZ values. Camera derived CIELAB values were then computed for all the patches.

The average color error (between CIELAB values computed directly from the spectra and color values as computed through the camera response) was between 1.5 ΔE and 2.3 ΔE. This is not out of line with the previous results, but one must bear in mind that 1) these are hypothetical results, assuming only spectral errors, and 2) this transform has been optimized for this particular stock. If this transform were to be applied to measurements with a different stock, I would expect them to be appreciably worse.

But more to the point of this section, I looked at the measurement of color differences. Figure 5 may be helpful to understand the complicated test. The figure shows an arbitrary patch measured on two arbitrary sheets from the seven sheets of this press run. For each patch I computed the true CIELAB values, and also the CIELAB values that an RGB camera and appropriate transform software might report.

It would be a natural test of the camera to compute the ΔE between the actual and the camera CIELAB values. In this case, however, I computed the ΔE between sheets as measured by the camera, and also computed the actual ΔE between the two sheets. These two ΔE values were then compared.

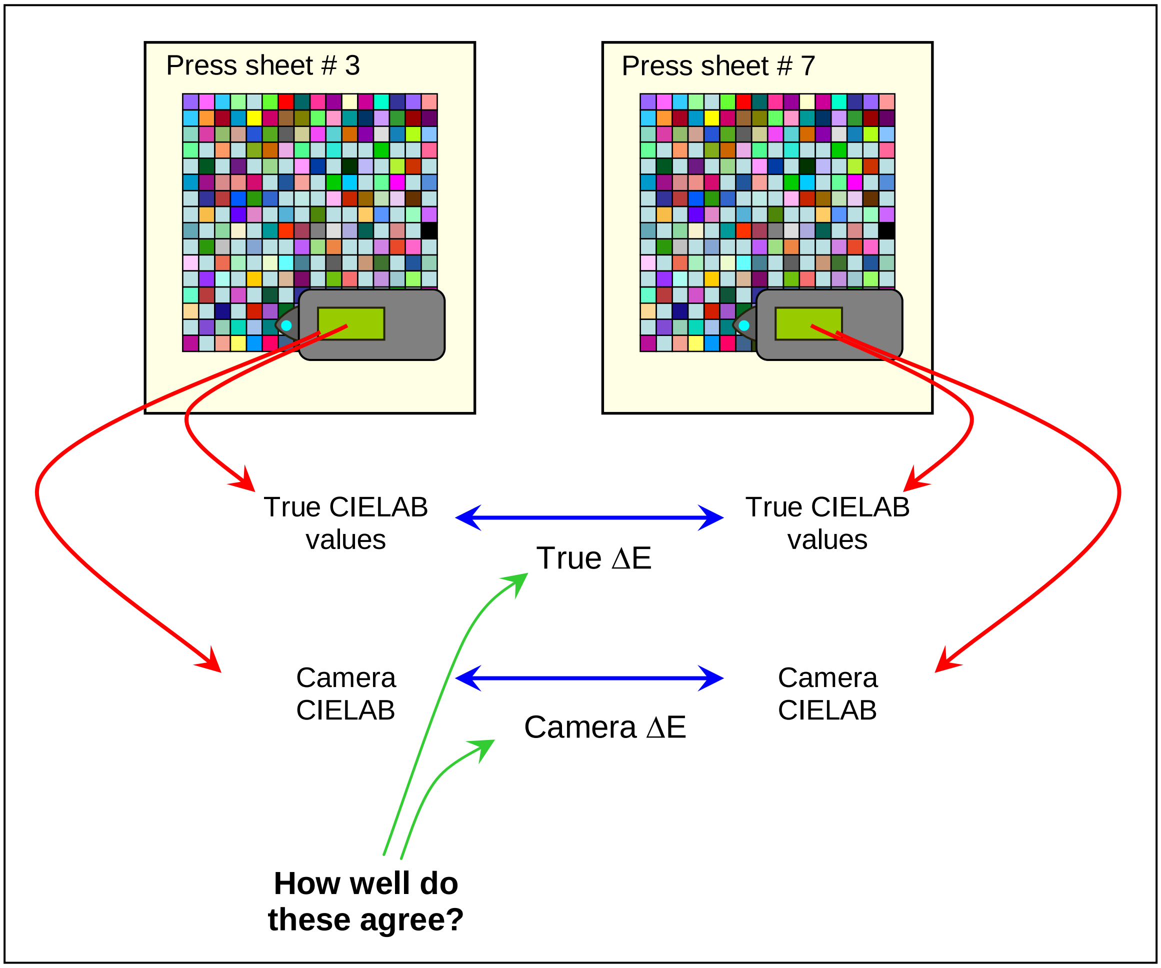

Figure 5 – Test of how well the camera can measure ΔE

Thus, I had 1,296 different pairs of ΔE values to compare for each combination of two sheets. A little cogitation will show that there are 36 distinct pairings between the nine sheets. This results in 46,656 comparisons. I generated these for each of the four cameras. Table 2 summarizes how well each of the RGB devices would be able to estimate ΔE.

RGB device	RMS error	False conclusion rate
Camera 1	0.28 ΔE	3.5%
Camera 2	0.34 ΔE	3.4%
Camera 3	0.23 ΔE	3.0%

Status E	0.24 ΔE	2.7%

Table 2 – Accuracy of color difference measurement with an RGB camera

Recalling from before that an ideal color measurement device should be able to measure with accuracy of 0.25 ΔE, and that 0.75 ΔE is still acceptable, any of these devices are acceptable for the *production run* requirements of ISO 12647-6.

The table also lists what I call the "false conclusion rate". A measurement of the color of a production sheet results in a sheet either being in tolerance or not. The false conclusion rate is the percentage of time that a spectrophotometer and an RGB camera would disagree on whether a sheet is in tolerance. Clearly we would want the two to never disagree, but is 3% an acceptable error rate?

These pass/fail numbers are used to assess the run. The ultimate useful measurement is whether 68% of the sheets are passing. The tolerance range (for assessing the whole run) is thus 0% to 68%. By the previous discussion, a device to measure the number of sheets that are within tolerance should be accurate to within 6.8 percentage points, and must be accurate to within 20 percentage points.

An RGB camera is clearly acceptable for measuring a color change during the run.

This experiment will be described in more detail in the TAGA 2009 proceedings.