The sYCC Color Space

Douglas A. Kerr, P.E.

Issue 2
October 29, 2005

ABSTRACT

The sYCC color space is an alternative representation of the "sRGB" color space, with a special wrinkle though which it can represent a larger color gamut than the sRGB space proper. In this article we review the definition, principles, and implications of the sYCC color space.

INTRODUCTION

A widely used color space in which the colors of the pixels in an image are represented in the field of digital photography is the sRGB ("standard RGB") color space. It is the default color space for many modern digital cameras, and is the default color space for images to be presented on Web pages. It is a precisely-specified color space within the broader "RGB" color space family.

The most widely-used file format for digital camera images, the Exif format (JPEG form), prescribes that the standard basic color space in which the images are represented be the sRGB space. But in fact the image is actually transformed to a form of the YCbCr space before encoding under the JPEG compression system.

A particular form of the YCbCr space, called "sYCC", used for this purpose, actually has a larger color gamut than the sRGB space from which it is derived—that is, it can represent colors that cannot be represented in the sRGB space itself (in its normal form). Thus we have the potential of conveying, in an Exif JPEG file, this larger gamut of colors. This could of course be beneficial in cases where the image is to be rendered by a device capable of a larger color gamut than that which can be represented in the sRGB color space itself (true of may photo printers today).

THE COLOR SPACES

The sRGB color space

The sRGB color space, like all RGB-family color spaces, describes a color in terms of a "recipe" for composing the color with designated amounts of light from three "primary" sources, identified by the broad names "red", "green", and "blue (identified as R, G, and B), and having certain specified chromaticities. We will use the symbols **r**, g, and **b** to represent the quantities of these three primaries that make up the color of interest.

However, it is not the quantities **r**, **g**, and **b** that are "sent" to indicate the color of a particular image pixel but rather versions of the same quantities on a non-linear scale. These are identified by the symbols R, G, and B. This nonlinear transformation is often called "gamma precompensation", since its original motive was to allow the values R, G, and B to directly control the three "guns" of a tricolor cathode ray tube (CRT) display device in a television receiver. In such a device, the luminance generated by a gun is not proportional to the voltage signal applied to the control electrode of the gun, but typically to some power of that voltage (perhaps 2.2). That exponent is called "gamma" by parallel with a similar parameter that describes the response of black ad white negative film to exposure.

The use of "gamma precompensation" in the "sent" representations of the amounts of the three primaries avoids the need, in the display chain, to "linearize" the response of the guns. Although this was the initial motivation for the adoption of gamma precompensation, there are other advantages, which are beyond the scope of this article. The principle of gamma precompensation has been carried forward from television practice to application to RGB color spaces used in digital photography.

Different color spaces in the RGB family use different gamma precompensation functions. In the sRGB color space, it works this way. Here, c represents any of the "linear" variables, **r**, **g**, or **b** (on a scale of 0-1), while C represents the corresponding gamma-precompensated variable, R, G or B (also on a scale of 0-1).

$$C = 12.92c \qquad \text{for } 0 < c \leq 0.0031308$$

$$C = 1.055c^{1/2.4} + 0.055 \qquad \text{for } 0.0031308 < c$$

The YCbCr color space

In analog television broadcasting, although the color representation is initially developed in a certain defined RGB color space, the format in which that information is transmitted uses a transformation of that space called the YUV color space. Similarly, when a still image in RGB form is being prepared for encoding under the JPEG image encoding and compression system, it is transformed to another representation very similar to the YUV space, known as the YCbCr space. Let's look at its definition.

We begin with the gamma-precompensated R, G, and B values, having a range of 0-1, and derive from them the value Y, thus:

$$Y = 0.299R + 0.587G + 0.114B$$

Note that despite its symbol, Y does not represent the luminance of the color represented by R, G, and B, although it is something like it. It is sometimes called *luma* (a term drawn from television transmission technology). Y can have any value from 0-1.

We then develop two "color difference" values, Cb and Cr, thus:

$$Cb = 0.564(B - Y)$$

$$Cr = 0.713(R - Y)$$

The coefficients in those expressions ensure that (if R, G, and B are within the range of 0-1) Cb and Cr will lie in the range -0.5 to +0.5.

The values of Y, Cb, and Cr, converted to 8-bit digital form, are then used to describe the color of the individual pixel. (Cb and Cr are not represented as "signed integers" but rather in an "offset" form, in which the digital value 128 represents a value of zero.)

GAMUTS

We refer to the range of colors that can be described by a particular color space as its gamut. In the sRGB space, that gamut comprises all colors for which the value of R, G, and B all lie in the range 0-1. This of course only embraces a portion of all "visible" colors.

In the YCbCr color space, if we consider all the colors for which Y is in the range 0-1 and Cb and Cr are in the range -0.5 to +0.5, we find that this more than embraces all the colors in the sRGB gamut (and in fact includes a large range of "invisible" colors). Conversely, if we transform into the YCbCr representation only colors that can be represented in the sRGB space, not all combinations of "allowed" values of Y, Cb, and Cr will occur.

Figure 1[1] shows the gamuts of the two color spaces, presented as an oblique projection in a Y, Cb, Cr coordinate system.

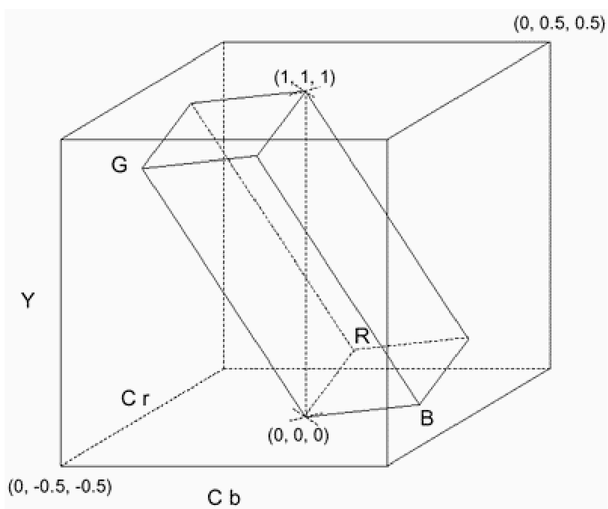

Figure 1. YCbCr and RGB color spaces

You can readily see the much greater gamut of the YCbCr space. Note however (and this is of course not shown on this figure) that much of the volume of the YCbCr space that lies outside the RGB space also lies outside the realm of realizable (visible) chromaticities.

---

[1] Taken from *MPEG+ Compression Of Moving Pictures For Digital Cinema Using The MPEG-2 Toolkit* by Michael W. Bruns and James T. Whittlesey, Grass Valley Group

THE sYCC COLOR SPACE

The international standard for the sRGB color space (IEC 61966-2-1) provides, in Annex G, a definition of a YCbCr color space for use in the sRGB environment. It is designated the “sYCC” color space (the YCbCr transformation of sRGB). It basically follows the familiar definition of a YCbCr color space, as we discussed above.

But in fact the sYCC color space as defined carries a further, and important, property. All combinations of “legitimate” values of Y, Cb, and Cr that imply visible colors (whether or not those colors exist within the sRGB color space) are deemed to represent valid colors under sYCC. Thus, by this simple stroke of the specification-writer’s pen, the sYCC color space is invested with a larger gamut than that of the sRGB space from which it is derived.

Thus, we have in effect defined a special variant of the sRGB space (not having a designation![2]) whose gamut is the same as that of sYCC. To permit this, this special sRGB space must allow a greater range in the values R, G, and B than for the “normal” sRGB space.

For “visible” colors lying in the sYCC gamut, but not in the “normal” sRGB gamut, there still can be a representation in terms of the variables R, G, and B (based on the traditional primaries, R, G, and B), but at least one of the three variables must have a negative value or a value greater than 1 (not allowed by the sRGB specification itself). In this special “parent of sYCC” form of sRGB, such excursions **are** allowed. While this cannot have physical meaning (in terms of an “amount” of a certain primary light), it is perfectly acceptable mathematically, and after all, we are not actually “generating” any light at this point—just describing its color.

This of course also implies excursions of the underlying “linear” variables, **r**, **g**, and **b**, into negative or greater-than-1 territory.

To make this possible, the gamma precompensation function needs to be redefined so as to work with negative input (and output) values. This expanded definition is:

$$C' = -1.055(-C)^{1/2.4} + 0.055 \qquad \text{for } C < -0.0031308$$

$$C' = 12.92C \qquad \text{for } -0.0031308 \leq C \leq 0.0031308$$

$$C' = 1.055C^{1/2.4} - 0.055 \qquad \text{for } 0.00031308 < C$$

This un-named expanded version of sRGB does not have a standard way of representing it in binary form—that is only prescribed for its sYCC transformation. It is a “virtual” color space, an ethereal step on the way to representing an image in sYCC form. In general, representing a color under this color space in binary form

[2] It is not, for example, the “extended sRGB” (e-sRGB) color space, although it has some things in common with it.

requires at least 9 bits per "channel" if we are to retain the customary precision in the values R, G, and B..

Note however that the sYCC representation requires just 8 bits per channel.

IMPLICATIONS ON DIGITAL PHOTOGRAPHY

The "JPG" files delivered by most modern digital cameras follow the JPEG option of what is known as the Exif file definition. Under that definition, the image is carried in a JPEG-encoded form of the YCbCr color space—to be precise, by default, the sYCC space.

The file format specification is quite clear that this is to be interpreted as meaning that the representation of colors lying outside the sRGB gamut but within the sYCC gamut is legitimate in an Exif JPEG file.

But it does not seem that, at present, typical applications that decode a JPEG file and deliver an output to computer memory for editing, or to a display or a printer, are prepared to deal with such "out-of-sRGB-gamut" colors that might be found in the JPEG-encoded sYCC data.

Thus, I doubt that any cameras today actually exploit the expanded gamut of sYCC in their JPEG output files. It seems likely that, when delivering images in JPEG files (and assuming the "sRGB" color space has been selected) the output gamut is in fact restricted to that specified for sRGB (just as the selection of the sRGB color space would imply).

However, it certainly appears that both modern Canon and Nikon cameras, when operating in a "direct-to-printer" mode, may well exploit the greater potential gamut allowed by the sYCC color space (to the extent that the connected printer is capable of handling that).

Definitive information on this is hard to come by.

Perhaps in the future we may have applications that will accept a JPEG image file in which "out-of-sRGB-gamut" colors appear, and cameras that can be set to use the "sYCC" color space when delivering a JPEG output file.

#