

Development of a Wide-Gamut Digital Image Set

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ABSTRACT

A great many imaging devices are consistent with the sRGB colour space. However, wide-gamut display devices exist that conform to colour spaces that have wider gamuts such as Adobe (1998) RGB. There is a shortage of standard image sets that contain colours that are outside of the sRGB gamut. Such images could be useful, for example, for testing various performance metrics in wide-gamut display systems. The purpose of this work is to develop a wide-gamut image set and make it widely available on the internet for the imaging community. Three digital SLR cameras were used to capture a large number of images that contained saturated colours. The colour space of the cameras was set to Adobe RGB and the file format was set to record raw. The images were converted to 48-bit TIFF images in the Adobe colour space and on average had about 18% of their pixels outside of the sRGB gamut. MATLAB was used to process the images and to ascertain the proportion of pixels that were outside of the sRGB gamut in each case. Images have been made available on a website – in both raw and tiff formats – and are categorised according to their colour and also according to the description of the objects for which the pixels are out of gamut. Example, object classifications include textiles, jewellery, arts, plants, foodstuffs and electronics. A total of 100 wide-gamut images were selected and have been made available to the community.

1. INTRODUCTION

Trichromacy is a crucial concept in colour imaging. The majority of digital cameras capture colour using three sensors, usually referred to as RGB, that capture different wavelength properties of the scene. Digital cameras often output images in a standard colour space known as sRGB (Süsstrunk *et al.*, 1999). The sRGB colour space has a gamut that is illustrated in Figure 1 by the black solid lines. The vast majority of image display devices also conform, at least approximately to the sRGB colour space so that they have a limited colour gamut. The vast majority of consumer images are defined in the sRGB colour space.

However, some capture and display devices are based on other colour spaces and one of the most common of these is the Adobe 1998 RGB space (Süsstrunk *et al.*, 1999). This colour space encompasses about 50% of the colours in CIELAB and improves on the gamut of sRGB in the green-cyan colours in particular. The Adobe RGB colour gamut is illustrated by the white lines in Figure 1. As can be seen the major difference between the two colour spaces is the chromaticities of the green primary which, for the Adobe space, is much more saturated. Images that contain colours that are outside of the sRGB colour space are referred to as wide-gamut images. There is some need to have standard wide-gamut images that can be widely available to the scientific community because these can be used to evaluate, for example, properties of so-called wide-gamut devices. With the widespread use of commercialised wide-gamut displays, the demand for wide-gamut content is increasing (Murakami *et al.*, 2013). The majority of LCD displays are based on the sRGB colour gamut whereas AMOLED displays support the Adobe RGB colour space;

based on an analysis of gamut volumes, AMOLED displays have been shown to be able to display 60-80% more discernible colours than the LCD displays (Li *et al.*, 2014). Wide-gamut images can also be useful for evaluating gamut-mapping algorithms (Langendijk *et al.*, 2009).

There have been several approaches to collect wide-gamut images. One approach is to use a spectral camera because this can capture a very wide colour gamut (Murakami *et al.*, 2013) or, alternatively, a multispectral camera (Murakami *et al.*, 2012). However, spectral cameras can be expensive, bulky and sometimes require extensive calibration and these constraints make them not so suitable for capturing images outdoors. A second approach has been to artificially expand the gamut of existing sRGB-specified images. However, in this paper we use consumer-grade digital SLR cameras that have the capacity to record images in Adobe RGB colour space. The aim of the work is to capture a large number of naturally occurring images that contain pixels that are outside of the sRGB colour gamut and to make these images widely available to the community for use.

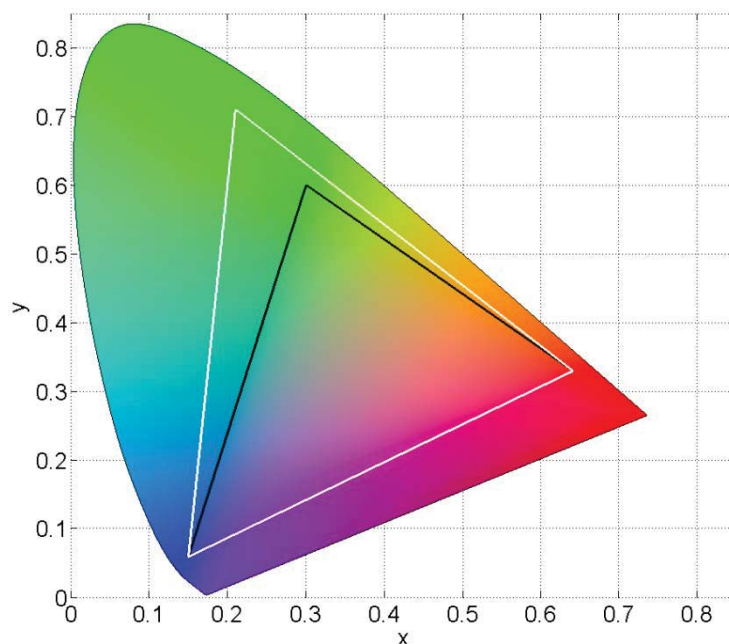


Figure 1: CIE 1931 chromaticity diagram showing the gamut of sRGB (black line) and Adobe 1998 RGB (white line).

2. METHOD

Three different digital SLR cameras were used to capture the images. Table 1 lists the cameras and their settings.

Images were captured as raw files and converted to 16-bit TIFF files with the Adobe sRGB colour space. Note that some images were captured in portrait mode and others were captured in landscape mode.

Table 1: Details of the camera files used in the work.

Device Name	Colour Space	File Type	Conversion File Type	Image Size
Nikon D90	Adobe RGB	RAW	16-bit TIFF	4288 × 2848
Nikon D7000	Adobe RGB	RAW	16-bit TIFF	4298 × 3264
Canon EOS 100D	Adobe RGB	RAW	16-bit TIFF	5184 × 3456

2.1 Image Processing and Selection Criteria

A large number of images were captured and these were processed and then selected to produce a set of 100 images with content outside of the sRGB gamut. A MATLAB program was therefore written to analyse each image. The first step was to convert the raw image to 16-bit Adobe RGB TIFF files. This was done using Corel PaintShop Pro (in the case of the Nikon images) and Canon Image Browser EX (for the Canon images). The second step was to convert from Adobe RGB to CIE XYZ, using the linear transform

$$\mathbf{T} = \mathbf{MC}$$

where \mathbf{T} is a matrix of $3 \times N$ XYZ values (where N is the number of pixels in the image), \mathbf{C} is a matrix of $3 \times N$ linear RGB values, and \mathbf{M} is the 3×3 matrix thus:

$$\mathbf{M} = \begin{bmatrix} 0.57667 & 0.18556 & 0.18823 \\ 0.29734 & 0.62736 & 0.75290 \\ 0.27230 & 0.07069 & 0.99134 \end{bmatrix}$$

The linear RGB values were obtained from the camera RGB values according to the equation

$$C(i, j) = ((D(i, j) + 0.055)/1.055)^{2.199}.$$

for channel $i = 1$ to 3 and pixel $j = 1$ to N and where $D(i, j)$ is the 16-bit RGB value normalized to the range 0-1 for channel i and pixel j . The third step was to convert from XYZ values to sRGB values. The normalized XYZ values \mathbf{T} were converted to linear sRGB values using the matrix equation

$$\mathbf{S} = \mathbf{AT}$$

where \mathbf{T} is a matrix of $3 \times N$ normalised XYZ values, \mathbf{S} is a matrix of $3 \times N$ linear sRGB values, and \mathbf{A} is the 3×3 matrix thus:

$$\mathbf{A} = \begin{bmatrix} 3.2406 & -1.5372 & -0.4986 \\ -0.9689 & 1.8758 & 0.0415 \\ 0.0557 & -0.2040 & 1.0570 \end{bmatrix}$$

The proportion of pixels that were outside of the sRGB gamut was calculated as being the proportion of pixels for which either $A(1, j)$, $A(2, j)$ or $A(3, j)$ was less than zero or greater than 1 at this stage. However, for display and subsequent storage as sRGB values the linear values A were processed thus

$$RGB(i, j) = 1.055S(i, j)^{1/2.4} - 0.055$$

if $S(i, j) > 0.0031308$ and otherwise

$$RGB(i, j) = 12.92S(i, j).$$

Figure 2 shows the flowchart of the colour-imaging workflow.

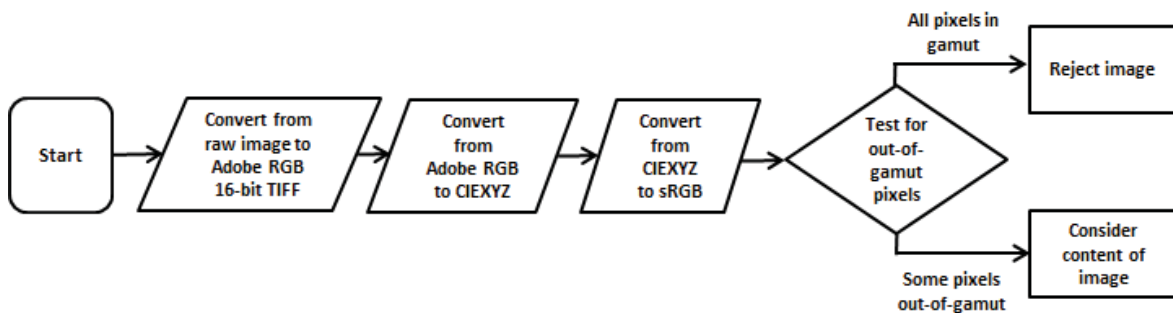


Figure 2: Flowchart illustrating workflow.

The approach of using an Adobe RGB camera system to obtain the images means that only colours that are blue, green, yellow and orange can be captured that are outside of the sRGB gamut. This is because the gamut boundaries of the two RGB systems in the red-magenta-blue region are the same (see Figure 1). A wide variety of content was aimed for including natural (precious stones, animals, plants, food) and manmade (light, textiles, plastics/paints, modern).

3. RESULTS AND DISCUSSION

Figure 3 illustrates some example output from the image processing described earlier. The left-hand upper pane shows the original image (as an sRGB representation) and the left-hand lower pane highlights the pixels that are out of the sRGB gamut (in this image pixels that are inside the gamut are darkened and the out-of-gamut pixels retain their original colour). The yellow colours of the flowers, for example, are out of gamut. The right-hand pane shows a CIE chromaticity diagram and the chromaticities of every pixel in the image. The sRGB and Adobe RGB gamuts are shown as white triangles. It is clear that some of the pixels in the yellow region are out of gamut. However, recall that gamuts are three

dimensional and the out-of-gamut pixels have been identified as those that are outside of the three-dimensional sRGB gamut (as described in the Methods) and are highlighted in pink in the right-hand image. Note that in this example some pixels that are inside the sRGB triangle are actually out of gamut. In Figure 3, it can be seen that 43.8% of the pixels for this particular image were out of gamut. On average the images had about 18% of their pixels outside of the sRGB gamut with the minimum and maximum being 1% and 82% respectively.

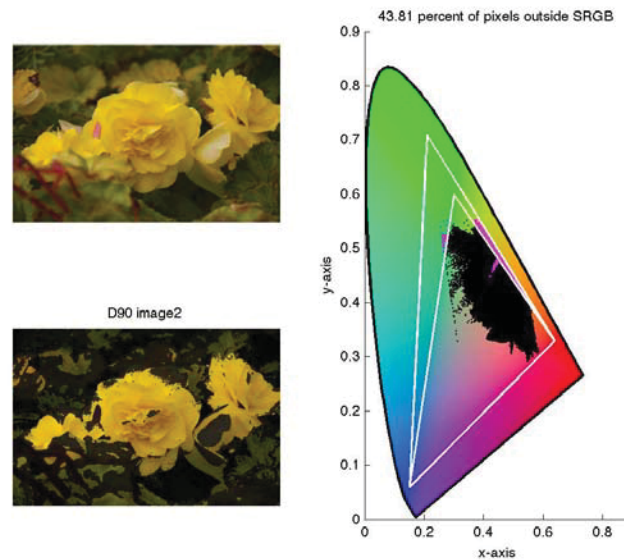


Figure 3: Flowchart illustrating the sample process.

As can be seen in Table 2, the number of images with out-of-gamut blue, green, yellow and orange components was 47, 43, 29 and 12 respectively; these numbers sum to more than 100 because some images contained two or more different colours that were outside of the gamut. Blue and green colours were most prevalent. In terms of categories, animal and jewelry were the most difficult to obtain.

Table 2. Summary of images included in the final database.

		blue	green	yellow	orange
	jewellery	2	0	0	0
natural	animal	0	0	1	0
	plants	0	5	4	2
	food	4	5	7	3
	light	3	6	5	3
manmade	textiles	6	1	3	1
	dyeing	17	11	4	3
	modern	15	15	5	0

The images are publically available at the following website which has been developed to support the images and their use within the scientific community - <http://widegamutimages.wordpress.com/>.

4. CONCLUSIONS

A total of 100 images have been captured with pixels that are outside of the sRGB gamut. On average the images had about 18% of their pixels outside of the sRGB gamut with the minimum and maximum being 1% and 82% respectively. The image contents represent a wide variety of subject matter including natural (precious stones, animals, plants, food) and manmade (light, textiles, plastics/paints, modern) objects. The images

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