Gamut Visualization Tools and Metrics

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Abstract

Gamut volume is a metric that is often used to compare ink sets or printing methods. Gamut volume does not, however, give any information about the distribution of the colors in the gamut. 3-D gamut plots or 2-D projections give more distribution information but can be difficult to use when a comparison of multiple color gamuts is needed. A new color gamut visualization method is presented which allows several gamuts to be plotted together for easy comparisons. Two different examples of this new tool are demonstrated. The first example compares three different printers and the second example compares three different ink sets.

Introduction

Gamut volume is a metric that can be used to compare ink sets and printing methods. In general, this is a useful technique. However, a single number like gamut volume does not provide any color distribution information. 3-D plots or 2-D projections of the gamut in a visually uniform color space are other useful tools. These tools offer a clearer picture of color distribution. However, the 3-D plots and 2-D projections do not always allow simple comparisons of two or more gamuts. This paper will present a new metric for visualizing and comparing gamuts.

The gamut volume distribution metric is based on gamut volume but provides more color distribution information than the alternatives discussed above. It may be applied to any visually uniform or approximately uniform color space that has a lightness component, a chroma component and a hue component. The CIELAB color space will be used for this paper, but it is important to note that the choice of color space is critical. The gamut volume distribution metric, as with most gamut volume based metrics, assumes a visually uniform color space. Any visual non-uniformity in the chosen color space will produce error in the metric.

The following sections will begin with a general overview of current gamut visualization methods. A detailed description of a new method and its particular application will then be presented. Finally, an analysis of specific data sets using the aforementioned tools and metrics will be discussed.
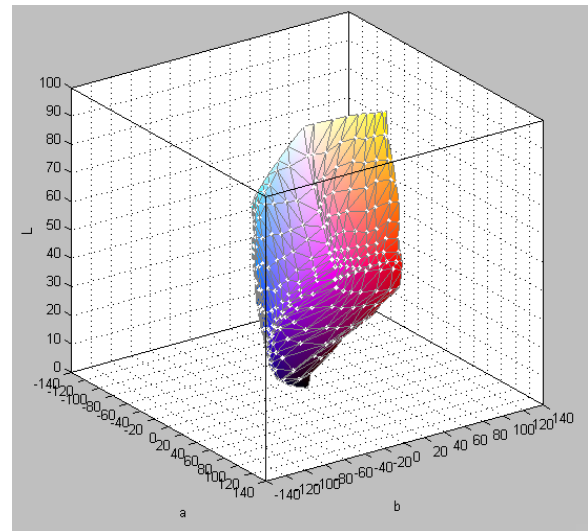

Figure 1. 3-D gamut surface plot for the Lexmark 5700 on Kodak Inkjet Photo Paper.

Gamut Visualization Methods

There are several ways to measure and visualize the color gamut of a device.[1,2,3] It is assumed that the color gamut of a device will be determined by some means and that the gamut will be measured in some 3-coordinate color space such as CIELAB.

The most straightforward method of visualizing a color gamut is a 3-D gamut surface plot. Figure 1 shows an example of this type of plot. It is usually somewhat difficult ascertain useful information from a 3-D plot, especially when it is a static print. For this reason, the 3-D surface plot is often projected onto a 2-D plane.

Figures 2, 3, and 4 show the same 3-D data shown in figure 1 projected onto the a-b, L-a, and L-b planes. These projection plots make it easier to obtain more useful information, but there is still significant information hidden by the projections.

So far all of the visualization methods have used the L*a*b* space. If we convert this data into $L*C_{ab}*h_{ab}$ space, the gamut may be visualized in another manner. Plotting the $L*C_{ab}*h_{ab}$ data in a mountain-range gamut plot[1] is a different way of viewing the same data. Figure 5 shows a mountain-range plot of the same data used in figure 1.

A mountain-range plot is a 3-D plot and as such has some limitations when displayed as a static print. Figure 6 displays the same information that is contained in the mountain-range plot, but uses a contour plot. This eliminates the problem of "seeing around" a static 3-D plot.

All of these methods of visualizing color gamuts are useful for viewing a single color gamut. The preferred visualization method will depend on the particular application. There are many occasions, however, when two or more color gamuts may need to be compared. With all of the previously discussed methods, this is not a simple task. Overlaying two plots can be more confusing than helpful, and viewing two plots side by side can make it difficult to make direct point-to-point comparisons. That is where the gamut volume distribution plot can be an extremely valuable tool.
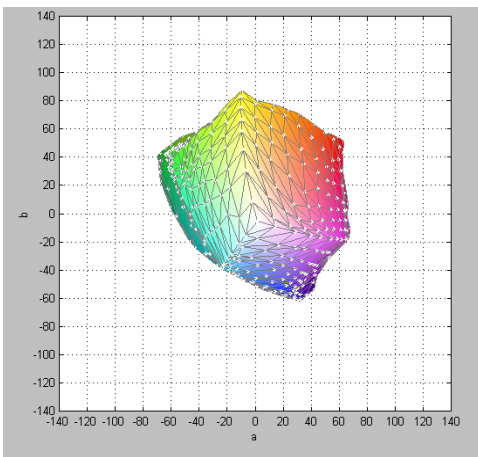

Figure 4. 2-D projection onto the L-b plane of a gamut surface for the Lexmark 5700 on Kodak Inkjet Photo Paper.
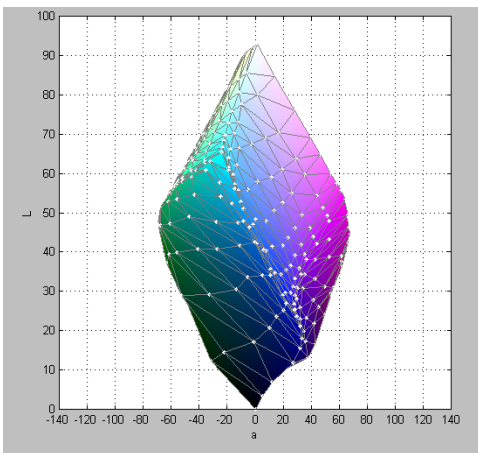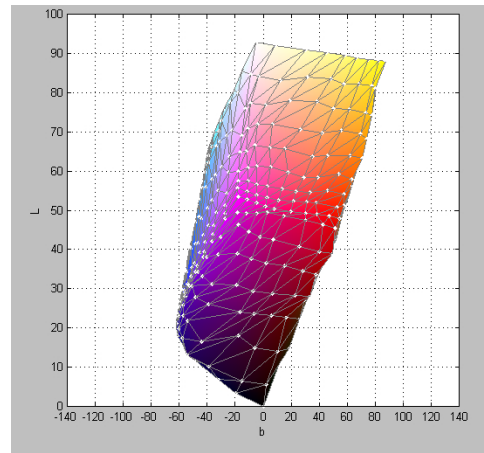

Figure 2. 2-D projection onto the a-b plane of a gamut surface for the Lexmark 5700 on Kodak Inkjet Photo Paper.
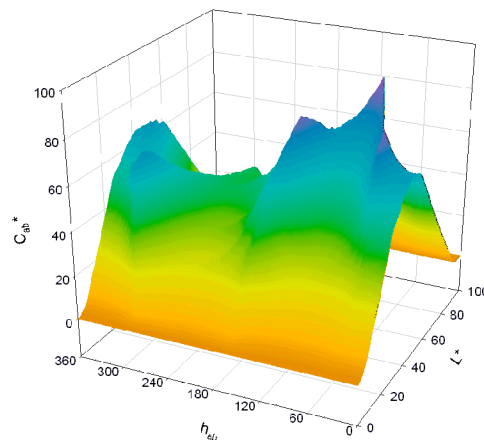

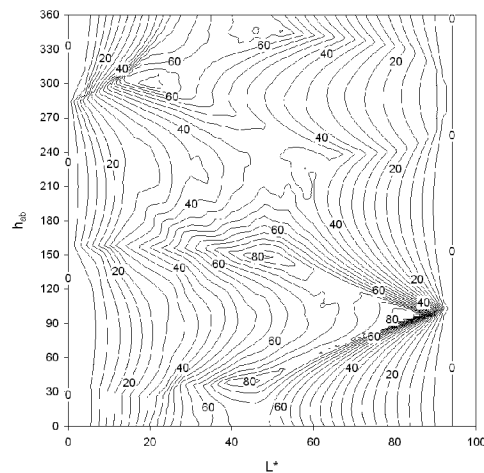*Figure 5. Mountain-range gamut plot for the Lexmark 5700 on Kodak Inkjet Photo Paper.*

Figure 3. 2-D projection onto the L-a plane of a gamut surface for the Lexmark 5700 on Kodak Inkjet Photo Paper.

Figure 6. Contour gamut plot for the Lexmark 5700 on Kodak Inkjet Photo Paper.

Gamut Volume Distribution

The first step in computing the gamut volume distribution is to sample and measure the gamut of the device. Since we are ultimately measuring volume, if the device gamut is smooth and uniform, points on the exterior surface of the gamut are of primary importance. Secondly, the component of the color space against which the gamut volume distribution is to be plotted must be selected. Hue and lightness are obviously the most interesting components against which the gamut distribution can be plotted, although chroma may provide some interesting information for some applications. Once a component is chosen, it must be divided up into bins. For instance, the hue component ranges from 0 to 360 degrees, and bins of 5 degrees might be chosen. Finally, the volume of each of the bins is computed from the measured data and plotted against the chosen component.

For illustrative purposes, so that a more detailed description of the gamut volume distribution plots may be discussed, the CIELAB color space will be used and the gamut volume distribution will be plotted versus CIELAB hue angle (h_{ab}). Choosing a different visually uniform color space or a different color space component to plot against will be a simple extension of this discussion.

The device of interest, for our example, is an inkjet printer. The gamut is sampled by printing (through the printer driver color tables) an image of 729 color patches (9x9x9 evenly spaced samples in RGB space) and measuring their CIELAB values. The interior points are of less interest, but they can be used to ensure the gamut sampling is smooth and uniform. Note that it might be useful to print and measure more points on the surface of the gamut if the surface is not very smooth.

These measured data are then sampled to build a 2-D array of maximum chroma (C_{ab}^*) values. The array stores the maximum C_{ab}^* of the gamut at every two units of L^* and every two degrees of h_{ab}. This array defines the boundary of the gamut or the gamut volume. The CIELAB space is then divided up into cubes of equal volumes. The C_{ab}^* of the center of each cube is then compared to the maximum C_{ab}^* array to determine if the cube is inside the gamut. If the cube is inside the gamut, then the h_{ab} of the center of that cube is compared to the histogram hue boundaries, and the volume of that cube is added to the appropriate bin. Note that, as the volume of the cubes decrease, the accuracy of the volumes increases, and the speed of the computation decreases. However, due to the sampling, there is a limit to the accuracy that can be obtained by decreasing the volume of the cubes. Accounting for the sampling of 9x9x9 and the speed of the algorithm, a cube size of 1x1x1 or 2x2x2 seems reasonable. The result of this algorithm is shown in figure 7. The gamut

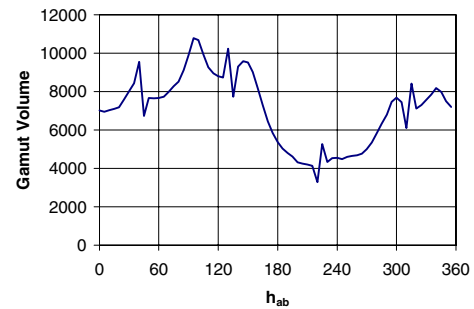volume distribution plotted against L^* and C_{ab}^* is shown in figures 8 and 9.

Figure 7. Gamut volume distribution versus h_{ab} for the Lexmark 5700 on Kodak Inkjet Photo Paper.
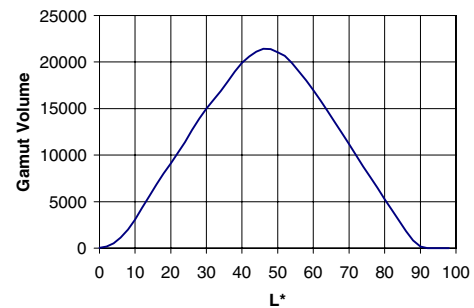

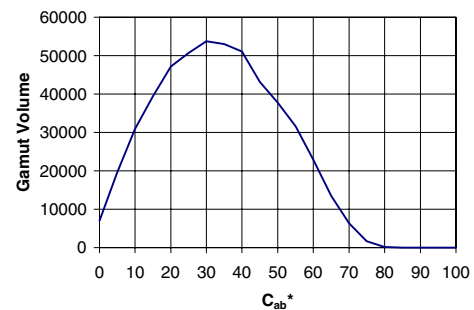*Figure 8. Gamut volume distribution versus L^* for the Lexmark 5700 on Kodak Inkjet Photo Paper.*

Figure 9. Gamut volume distribution versus C_{ab}^* for the Lexmark 5700 on Kodak Inkjet Photo Paper.

Gamut Comparison Examples

In this section, the gamut volume distribution plots will be used to make comparisons between different color device gamuts. The first comparison is between three inkjet printers that use different formulations of cyan, magenta, and yellow inks as well as different spot sizes. The three printers are the Lexmark 5700, the Lexmark 1100, and the Lexmark Z51. Table 1 shows the total gamut volume for

each printer. The gamut volume distribution plots are shown in figures 10, 11, and 12. The plots show that the 1100's gamut volume is clearly the smallest and the Z51's gamut volume is slightly larger than the 5700's.
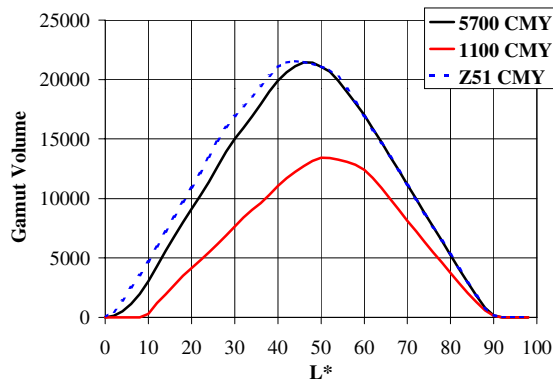

Figure 10. Gamut volume distribution plot versus L* for the Lexmark 5700, Lexmark 1100 and the Lexmark Z51 on Kodak Inkjet Photo Paper.
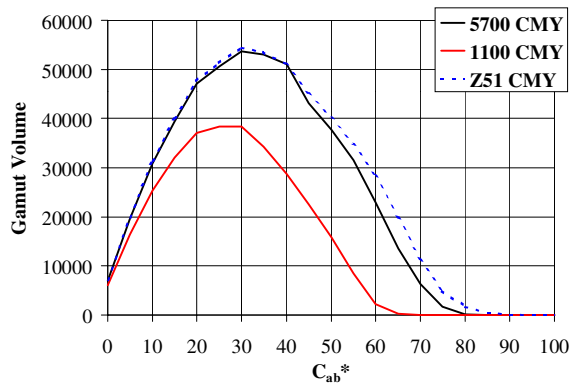

Figure 11. Gamut volume distribution plot versus C_{ab}* for the Lexmark 5700, Lexmark 1100 and the Lexmark Z51 on Kodak Inkjet Photo Paper.

Table 1.

Total Gamut Volume	
Lexmark 5700	509,356
Lexmark 1100	305,820
Lexmark Z51	543,248

Table 2.

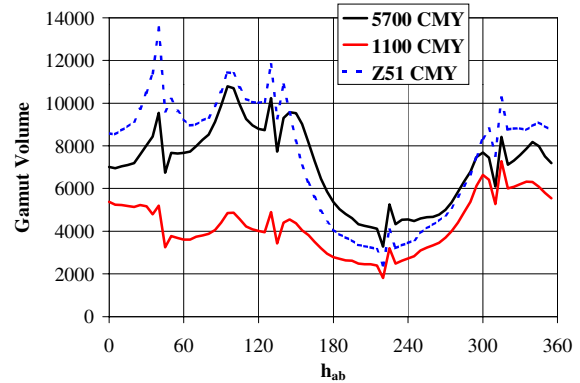| Total Gamut Volume	
CMY	509,356
CMYKcm	564,619
CMYKOG	642,791

Figure 12. Gamut volume distribution plot versus h_{ab} for the Lexmark 5700, Lexmark 1100 and the Lexmark Z51 on Kodak Inkjet Photo Paper.

The second comparison uses different ink sets in the Lexmark 5700 printer. The first ink set is cyan, magenta, and yellow inks (CMY). The second ink set is the same CMY inks with dye black, dilute cyan, and dilute magenta inks as well (CMYKcm), commonly referred to as "photo printing". The third ink set is again the same CMY inks and the same dye black ink with orange and green inks (CMYKOG), a setup frequently used in HiFi color applications. Table 2 shows the total gamut volume for each printer. The gamut volume distribution plots are shown in figures 13, 14, and 15. The plots show that the CMY gamut volume is the smallest and the CMYKOG gamut volume is the largest. Note that especially in the case of this comparison, the single gamut volume number does not tell the whole story. For instance, the CMYKOG volume is larger below an L* of 50, but the CMYKcm volume is larger above an L* of 50.
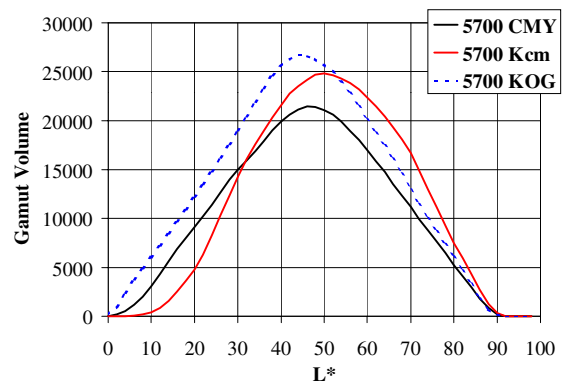

Figure 13. Gamut volume distribution plot versus L* for the Lexmark 5700 using CMY, CMYKcm, and CMYKOG inks on Kodak Inkjet Photo Paper.
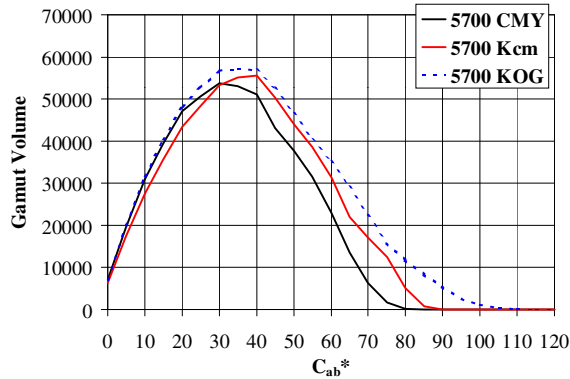
Figure 14. Gamut volume distribution plot versus C_{ab}^* for the Lexmark 5700 using CMY, CMYKcm, and CMYKOG inks on Kodak Inkjet Photo Paper.
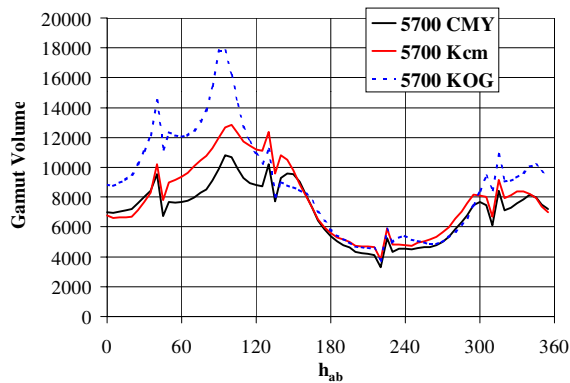

Figure 15. Gamut volume distribution plot versus h_{ab} for the Lexmark 5700 using CMY, CMYKcm, and CMYKOG inks on Kodak Inkjet Photo Paper.

Conclusion

This paper has presented many different ways to visualize color gamuts. While the 3-D plot or 2-D projections are useful, they are not as useful when it is necessary to compare two or more color gamuts. Gamut volume is also a useful tool for a "quick-look" comparison between several color gamuts, but it does not give a complete picture. The gamut volume distribution plot can be a valuable tool when comparing multiple color gamuts.

References

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