In the eye of the beholder – Toward a uniform color space

The sleeves of a blue shirt may be sewn in one section of a factory, the collar in a second and the body in a third. When they finally come together, the blue colors of the various pieces must match or the consumer may reject the final product.

The shirt manufacturer must know how large a color difference the consumer will accept. He must then specify the color tolerance he is willing to allow from the textile manufacturer. The textile manufacturer, who dyes his material by the thousands of yards, must ensure that the color of his product at the beginning of a roll is the same as that dyed at the end. However, industry does not yet have a reliable method of expressing color tolerances which is universally understood.

Color studies relating to this problem are being carried out by the National Research Council of Canada's Division of Physics. Dr. Gunter Wyszecki, Head of the Radiation Optics Section, says: "I don't think anyone in the business these days can economically produce anything without being given tolerances. It's a well-established thing in other industries but not so in color. Current methods of specifying color differences and, in turn, tolerances are not always satisfactory and not yet fully developed."

The measurement of color itself is well established, but there are currently several systems to measure color differences in industry. Color-difference meters are most frequently used but techniques often vary as does the system of units for measurement. Human color matchers or inspectors can also be used but this process is often slow, tiring or too subjective to be effective. Because the human eye has a threshold of sensitivity to color differences, two colors need not be identical to appear as a visual match. Within a certain range, an observer will perceive two physically differing colors as the same.

If a uniform yardstick to measure color difference were established, industry would then have a criterion for acceptable reproduction of any color — a way of saying how close one color must be to another so that the eye cannot see the difference.

A broad base of color theory exists which researchers are trying to expand in order to solve the problem. Any color may be represented in a three-dimensional color space, with axes X, Y, Z corresponding to some function respectively of three primary colors, such as red, green and blue. The color can be composed by mixing three colored lights (of the primary colors) in an additive process. (By contrast, when using pigments or paints, the primaries are commonly red, blue and yellow. Composition of a color by the mixture of three such paints is a complex subtractive process which also involves the chemical nature of the pigments and is quite different in principle from the mixture of lights). A particular color C, for example, orange or yellow, can then be specified in color space by three coordinates or tristimulus values (Figure 1). A second color, C′, just perceptibly different from the first, can also be plotted. The envelope (like the skin of a balloon) of all points showing such perceptible color differences in all directions from C describes the boundary conditions within which colors are seen by the eye as identical to C, and beyond which, as different.

The shape and size of the enclosed volumes of these colors vary with the color C and thus its location in this "color-matching" space. They may be large or small and are frequently ellipsoid or egg-shaped. From the point of view of perceiving color differences, this space is clearly non-uniform.

However, uniform color space may be derived by mathematical transformation of the X, Y, Z color-matching space into a U, V, W space where the enclosed volumes are spherical and also of the same size for any color (Figure 2). The difference, ΔE (delta E), between any two colors represented by points C_1 and C_2 can then be found readily from a mathematical equation. Here, color 1 differs from color 2 similarly in any direction. Scientists have defined the size of this difference, ΔE, to correspond with the color discrimination of the human eye. When ΔE is less than one, color differences are defined as not perceptible. For ΔE=1, the color difference is just perceptible, while for ΔE=2, the difference is twice as large, and so on.

Although the ideal uniform color space has not yet been found, an approximation to it called the CIE (U^*, V^*, W^*) space was developed at NRC and was adopted in 1964 as an international standard by the Commission Internationale de l'Éclairage.

Since 1963, Dr. Wyszecki has been Chairman of the Commission's Colorimetry Committee.

"Some people doubt that a uniform color space can be found," he says, "but I think you can get a very good approximation which will serve almost all purposes. The present CIE (U^*, V^*, W^*) formula still has some shortcomings."

One deficiency of the CIE (U^*, V^*, W^*) space (Cover) is a lack of uniformity in some areas. In the cross-section depicted, differences between neighboring colors are small and of equal size within vertical rows, but larger and more

Figure 1. The 3-dimensional X, Y, Z color-matching space. Axes are some function of three additive primary colors. Any color can be specified by three coordinates but color differences are not uniform.
• Espace tridimensionnel X, Y, Z d'appariage des couleurs. Les axes sont des fonctions de trois couleurs fondamentales additives. Toute couleur peut être définie par un point ayant trois coordonnées mais les différences entre les couleurs ne sont pas uniformes.