A spherical color model is intuitively simple and perceptually harmonious

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The three coordinate components of a properly rotated spherical coordinate system perfectly describe the perceptual attributes of a color.

A perceptual color model uses color attributes that are well recognized by human vision—such as hue, saturation, and brightness—to describe colors. For electronic systems that use the RGB (red, green, blue) color model to display colors (e.g., computers and color televisions), a color is described by three nonnegative decimals indicating the RGB amounts that compose it. This model has the advantage of being straightforward to implement on hardware, but it does not ‘perceive’ colors the way humans do. Consequently, there is demand for a perceptual color model that is convenient and easy to use in applications where color selection or comparison is important. For instance, in clothing factories, jeans are washed from their original deep hues to lighter ones to meet design requirements. The extent of the washing is determined by how closely the jeans match a sample. A computer program based on a perceptual color model could be used to precisely control the washing process.

Existing perceptual color models are basically similar in concept. HSV (hue, saturation, value) is the most common among them. It was first introduced as a hexcone\(^1\) (hexagonal cone) and then evolved to a cylinder to describe the color attributes that measure the departure of a given hue from black. Other commonly used perceptual color models include HSL (hue, saturation, lightness)\(^2\)\(^-\)\(^3\) and HSI (hue, saturation, intensity).\(^4\) A common problem with these models is the appearance of starlike rays on surfaces defined by constant hue or constant brightness, making color change perceptually unsmooth near these rays (colors appear to condense along the starlike rays, so a small shift in distance would result in a big perceptual difference in color). In addition, converting between these models and the RGB model is not intuitively simple and thus is hard for non-specialists to understand.

We discovered that a mathematical coordinate system built on a properly rotated space is a very practicable perceptual color model that meets two essential criteria: color changes perceptually smoothly throughout the system, and converting between the model and the RGB model is mathematically simple.\(^5\)

To build the spherical color model, first we rotated the coordinate system of the RGB model such that the main diagonal of the RGB color cube was on the vertical axis and the red vertex was on the plane with the azimuthal angle being zero: see Figure 1 (left). Then we superimposed the mathematical spherical coordinate system over the RGB system. Our objective was a spherical cone that tightly circumscribes the RGB color cube: see Figure 1 (right). The spherical system has three coordinate components—\(\rho, \theta, \text{ and } \varphi\)—where \(\rho\) measures the distance between a point and the origin, \(\theta\) measures the azimuthal angle, and \(\varphi\) measures the polar angle.

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The component \( \theta \) is essentially the same as the hue component in a conventional perceptual model. The component \( \varphi \) measures the opening of a circular cone, determining the extent of a color’s departure from the corresponding gray (i.e., it describes a color’s saturation). Figure 2 (left) shows a circular cone within the color cube with a constant value of \( \varphi \), and Figure 2 (right) shows its projection on the underlying plane. Perceptually, color changes smoothly on the cone surface, and the starlike ray phenomenon does not occur. The component \( \rho \) is the distance between a color point and the black color point, and hence describes the brightness attribute of a color. Figure 3 (left) shows a spherical surface within the color cube, and Figure 3 (right) shows its projection on the underlying plane. Color changes perceptually smoothly on the spherical surface, and starlike rays do not occur.

In summary, the spherical color model is conceptually simple and perceptually harmonious. It is conceptually similar to existing perceptual color models, including the commonly used HSV model, but it is more intuitive and easier to interpret. Mathematically, converting between the spherical color model and the RGB color model involves standard coordinate system transformations that have been well studied. Most important, in the spherical color model, color changes more perceptually smoothly than in existing perceptual color models. The spherical model makes color specification more convenient, and color comparison is perceptually more accurate. As a next step, we plan to use the spherical color model to compare colored cloth and to apply the results to color comparison of jeans to achieve perceptually satisfactory results.

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References