5.2.2 Color difference equations

An important property of the human visual system is the nonlinear perception of the color similarity. After a series of experiments assessing the perception of color by human in 1931, CIE developed the standard color space CIEXYZ. It includes all the colors perceived by human, but is nonlinear in terms of a color change in it. To eliminate the nonlinearity in XYZ, in 1976 the CIELAB color space was developed, which is now an international standard. However, there is still some nonlinearity in color change in this color space. Therefore, in this section, we will look at color metrics specifically for the CIELAB space.

The most widely used color difference formula in the CIELAB space is the Euclidean distance (also called CIE76 or ΔE^*_{ab}). It is easy to calculate, but its value does not correspond well to the perceived color difference in the regions of blue colors, neutral colors, and for small color differences.

Currently, the officially recommended CIE/ISO standard among color metrics for the CIELAB space is the CIEDE2000 metric, as it provides the results closest to visual estimates of the color proximity of the human visual system, among the results obtained using previous color difference equations. The high-level structure of the CIEDE2000 is as follows:

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L^*}{k_L S_L}\right)^2 + \left(\frac{\Delta C^*}{k_C S_C}\right)^2 + \left(\frac{\Delta H^*}{k_H S_H}\right)^2 + \Delta R}, \tag{15}$$

where ΔL^* is the arithmetic difference of lightness components; ΔC^* and ΔH^* — the chroma and hue difference, respectively, calculated in the LCH color coordinates (to improve accuracy in the region of low saturated colors, a formula for counting ΔC^* and ΔH^* was developed, scaling the a^* axis (from the CIELAB space) with greater effect for colors close to the neutral region, and smaller for colors with higher saturation); ΔR — correction in the area of blue colors, beyond which it is quite small; S_L, S_C, and S_H — weight functions for lightness, chroma, and hue respectively; k_L, k_C, and k_H — parametric coefficients that are chosen according to different observation conditions, such as texture, background, and so on, for lightness, chroma, and hue components, respectively.

A full description of the calculation of the CIEDE2000 for the CIELAB space is very cumbersome and is given in [41].

In addition, the paper [65] considers the mathematical properties of the CIEDE2000 formula and concludes that some of them (e.g. discontinuities) complicate its use in methods based on gradient optimization.

So, the CIEDE2000 has overcome some of the shortcomings of the previous color difference equations in this way:

1. Introduced hue angle rotation to improve performance in the blue area using ΔR;
2. Improved accuracy in the region of low saturated colors by changing the method of counting ΔC^* and ΔH^*;
3. Introduced compensation for lightness, chroma, and hue using the weight functions S_L, S_C, and S_H.

The work [39] describes the methodology for obtaining the optimal value of k_L for color dif-