Color-Difference Ellipsoids Follow from Metamer Mismatching

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Many psychophysical experiments have shown that color discrimination thresholds vary as a function of the color center under consideration, MacAdam ellipses being a prime example. Color discrimination thresholds are usually modelled either as ellipses in chromaticity space or ellipsoids in 3D color space. Various color difference models, such as those of Luo et al. [1] [2], have been developed based on fits to the data obtained from psychophysical experiments (e.g., Li et al. [3] [4]). However, such models do not explain why the color difference thresholds vary across color space as they do. Funt et al. [5] show that the uncertainty created by metamer mismatching provides a very interesting explanation. Extending that theory as described below enables it to predict, not only the ellipsoid volumes, but the shapes and orientations of the ellipsoids as well, thereby providing further evidence of its validity.

Metamer mismatching results from the fact that the relationship between cone triples and surface reflectances is one-to-many. Under some fixed illuminant, there are many different surface reflectances leading to the same cone response triple. Such reflectances are generally referred to as metamers. Under a second illuminant these different reflectances will usually lead to quite distinct cone response triples. The set of all such cone triples is known as the metamer mismatch body [6]. This phenomenon is referred to as metamer mismatching. Because of the one-to-many relationship between a cone response triple and surface reflectances, the eye cannot uniquely identify a surface’s reflectance and so might, for example, misidentify a poisonous plant as an edible one. The likelihood of this misidentification depends on the extent of metamer mismatching, which varies across color space. The more serious the metamer mismatching, the more precisely colors need to be discriminated from one another to avoid mistakes; and hence, the need for an inverse relationship between the extent of metamer mismatching and color discrimination thresholds.

Color difference thresholds are usually represented by ellipses in a 2D chromaticity space or ellipsoids in 3D color space. Funt et al. [5] show that the volume, $M$, of the Metamer Mismatch Body (MMB) normalized by the cube of the distance, $C$, between a color center and the origin of the coordinate system is inversely proportional to the volume of the color discrimination ellipsoid ($E_{vol}$). In other words, $C^3/M \propto E_{vol}$. This relationship—the one indicating two identical ellipsoids from Metamer Mismatching. In order to evaluate the accuracy of the method’s predictions, an ellipsoid similarity measure is needed. One such measure is that defined by Merritt [8]. The Merritt similarity measure varies from 0 to 1, with 1 indicating two identical ellipsoids.

The MMBs for the 19 color centers in the Melgosa dataset [9] (derived from the original data in RIT-DuPont dataset [10]), the 17 color centers in Huang dataset [11], the 5 color centers in Cheung dataset [12] and the 4 in Witt dataset [13] are calculated for illuminant change D65 to A using the algorithm of Logvinenko et al. [14]. The equivalent ellipsoids corresponding to these MMBs are then calculated and compared to the experimental data using the Merritt similarity measure (Table 1).

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Merritt</th>
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</thead>
<tbody>
<tr>
<td>Melgosa</td>
<td>0.79</td>
</tr>
<tr>
<td>Huang</td>
<td>0.78</td>
</tr>
<tr>
<td>Cheung</td>
<td>0.80</td>
</tr>
<tr>
<td>Witt</td>
<td>0.84</td>
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</tbody>
</table>

Table 1 Merritt similarity measure comparing the predicted color discrimination ellipsoids to the measured ellipsoids from four datasets.

Color discrimination thresholds are known to vary throughout color space. The degree of metamer mismatching (which reflects the underlying degree of uncertainty as to the actual reflectance producing the color) also varies throughout color space. Hence, color discrimination thresholds and the degree of metamer mismatching are inversely related. This principle can be used to predict the orientation and dimensions of color discrimination ellipsoids quite well.

References


