C15 疲し工学のカラーシミュレーションからのアプローチ
Approach for Iyashi Engineering from Color Simulation

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Key Words:
color reproduction, color difference, CSRBF function

論文要旨

1. Introduction
Colors play an important role for customers in making decisions on what they like or dislike [1]. The perception of the color depends on the devices. For the reproduction of colors is required the color-matching methods to obtain the mapping function. Tominao [2] describes a method for solving the mapping problem for Lab color space to the higher dimensional CMYK color space. The mapping from the space is constructed using a Neural Network (NN). This approach used NN parameters (as network typing, count of hidden layers, learning procedure) for the experiments, but it is not clear if these parameters produce optimal results for all application domains. Compactly-Supported Radial Basis Functions (CSRBFs) were introduced by Wendland [3] to build up function approximations:

\[ f(x) = \sum_{i=1}^{n} \alpha_i \phi(x - \alpha_i) \]

(1)

where \( f(x) \) is represented as a sum of \( n \) radial basis functions, each one associated with a different center \( x_\alpha \) and weighted by an appropriate coefficient \( \alpha_i \). In [3], a popular family of compactly supported radial functions is constructed by starting with the truncated power function strictly \( i \phi(P_i, P) \) This function has different formulas according to the continuity. For 3D space is recommended the continuity \( C_2 \) (see Eq.2). In the formula \( r \) denotes the distance between two arbitrary points \( P_i, P_j \) and \( r_0 \) is the global support radius.

\[ \phi(P_i, P_j) = \begin{cases} (1 - \frac{r}{r_0})^3 \cdot \left( 4 \frac{r}{r_0} + 1 \right) & \text{if } 0 \leq \frac{r}{r_0} \leq 1 \\ 0 & \text{if } \frac{r}{r_0} > 1 \end{cases} \]

(2)

We propose an iterative approach for color reproduction using CSRBF mapping function to make the color-matching. Based on a sample color measured by a photometer, a value of the system color to reproduce the sample in printed format is searched in all system color space. CSRBF interpolation function is used to map system colors and printer colors avoiding the printing process of the partial results.

2. Printer color mapping by CSRBF function

The International Commission on Illumination (CIE) proposed the CIEDE2000 color difference formula [4]. This formula provides an improved procedure for the computation of industrial color difference and it is based on CIELAB color space. The CIELAB color space is more approximated to the human vision and it is devise independent. The color distance allows people to quantify a notion that would otherwise be described with adjectives, to the detriment of anyone whose work is color critical. Common definitions make use of the Euclidean distance in a device independent color space. For this metric, two colors with distance above to 2.3 correspond to just noticeable difference [4]. Some approaches define CIE2000 = 1.0 as the smallest colors difference the human eye can see depending of the application domain [4].

Proposed approach finds the CSRBF mapping function between the input (system) and output (printer) CIELab spaces. Fig.1 shows a flowchart of the construction of CSRBF function \( \Delta(L_{a,b}) \) for both color spaces.

![Figure 1 Flowchart of the mapping process.](image)

The function \( \Delta(L_{a,b}) \) models a mapping between two set of colors, in which the input is \( L_a, b_i, i = 1..n \) values of the system space and the output is the \( L'_{a}, L'_{b_i} \) values of the printer space. For each color dimension \( (L, a, b) \), the system of linear equations is solved to calculate \( \Delta \) vectors using equations (1) and (2). The solution vectors \( \Delta L, \Delta a, \Delta b \) are the distances in \( l \), \( a \), and \( b \) dimensions respectively: \( \Delta L = l_i - l_i', \Delta a = a_i - a_i', \Delta b = b_i - b_i' \). The function \( \Delta(L_{a,b}) \) is used as the interpolation function for the color reproduction process in printer, device to calculate the Lab color printer corresponding to the Lab color system.

3. Iterative algorithm for samples reproduction in printer devices

An iterative approach is proposed to obtain the system color values used to reproduce the samples in the printer using above CSRBF mapping and avoiding users fatigue due to multiple manual adjustments and printing steps. Fig.3 shows the flowchart of the proposed system. The sample colors are measured using a photometer obtaining the Lab values of the samples, \( L_{a_i}, S_{a_i}, b_{a_i}, i=1..n \) (is the count of samples). The proposed method uses the Lab sample values \( L_{b_i} \) as first input. For each input value \( L_{a_i} \) the system creates a set of 27 Lab values (3 for each dimension) in their neighborhood \( (Lab_{a_i}, Lab_{b_i}) \). The original Lab value is also included. We need to test the difference between the Lab \( L_{a_i} \) (after printed) and the sample value \( L_{b_i} \). Using the CSRBF interpolation function referred previously the Lab printer values \( L_{b_i}' \) corresponding to Lab \( L_{a_i} \) values are obtained. Each Lab \( L_{b_i}' \) is compared with the value of the sample Lab \( L_{b_i} \) using the CIE2000 formula[4] and the printer value closest to the sample Lab \( L_{b_i} \) is selected (s represents the selected element). The iteration continues if the selected printer value \( L_{b_i}' \) do not have significant visually difference with the sample. For next iteration,
the input value will be the system value \( L_a \) corresponding to the selected printer value \( L_b \). For some iteration, the distance between sample and selected printer value is not reduced because not all values in the neighborhood are tested. For this case, the neighborhood size is reduced and the procedure continues.

![Flowchart of the color reproduction system](image)

**Figure 3 Flowchart of the color reproduction system**

4. Experimental Results

\( \text{Lab} \) color values of 272 samples provided by Nippon-Paint Company were measured using the Spyder photometer to illustrate the performance of proposed approach. First, 3 users manually adjusted the \( \text{Lab} \) values to reproduce the samples using a Cannon printer. The process was very time consuming (approximately 1 week) and they made many printer impressions. 4 users evaluated the reproduction by visually comparing the samples and the reproduced colors. The users evaluate in Good, Regular or Bad each reproduced colors. Table1 shows the count and percent of the colors evaluated by the users. According to Table1, evaluations were different. For all users, a few colors are visually equals to the samples.

<table>
<thead>
<tr>
<th>Number and percent (%) of colors by category</th>
<th>User</th>
<th>Good</th>
<th>Regular</th>
<th>Bad</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>66(24.29%)</td>
<td>127 (46.69%)</td>
<td>79 (29.04%)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>65 (23.90%)</td>
<td>127 (44.85%)</td>
<td>85 (31.25%)</td>
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</tr>
<tr>
<td>3</td>
<td>45 (16.54%)</td>
<td>118 (43.38%)</td>
<td>109 (40.07%)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>22 (8.09%)</td>
<td>107 (39.34%)</td>
<td>143 (52.57%)</td>
<td></td>
</tr>
</tbody>
</table>

**Table 1** Users evaluations of manually color reproduction.

![Agreement between users and CIE2000 formula](image)

**Figure 4 Agreement between users and CIE2000 formula [4]**

Fleiss' kappa is a statistical measure for assessing the reliability of agreement between a fixed numbers of raters [5]. The coefficient is denoted by \( k \) and range of values is 0 to 1. Fig.4 shows the agreement function of the users evaluations. For all 272 colors the agreement of the evaluations was slight. For the evaluations of 115 colors the agreement classification was fair. Only for 28 colors, the users have perfect agreement. Proposed approach uses the CIE2000 formula [4] to calculate the colors difference by iteration and simulate the user evaluations. A new agreement function was calculated including the CIE2000 formula as another user (see Fig.4). The agreement between users and CIE2000 was substantial for the 28 colors. So, the reproduction of these colors can satisfy the 4 tested users. For the other 244 colors, the reproduction has to be personal.

After the system automatically reproduced the 28 colors using above procedure, we made one impression and User1 visually reevaluated the 28 printed colors. The iterative color reproduction took less than 1 minute needing only 1 impression. Table2 compares the User1 evaluations of the manual and the automatic reproduction of the 28 colors. In the manual process, User1 didn't give Good evaluation to any colors, 19 colors were evaluated with Regular (67.89%) and 9 colors with Bad (32.14%). In the automatic approach, User1 selected 6 colors equal to the sample (21.43%), gave Regular to 11 colors (39.29%) and the other 11 colors were evaluated as Bad (39.29%). For User1, the automatic approach improved the reproduction of 12 colors representing 42.9%. For 6 colors, the user evaluations of manual and automatic results were the same (21.4%) and 6 colors was worse evaluated using automatic results (see last row in Table2). So, the automatic approach improved and the manual procedure in 64.3%, taking less than 1 minute and needing only 1 impression.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Number and percent (%) of colors by category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual</td>
<td>Good</td>
</tr>
<tr>
<td>Manual</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Automatic</td>
<td>6 (21.43%)</td>
</tr>
<tr>
<td>Total</td>
<td>Improved</td>
</tr>
<tr>
<td>12 (42.9%)</td>
<td>6 (21.4%)</td>
</tr>
</tbody>
</table>

**Table 2** Comparison of User1's evaluations for manual and automatic reproduction of 28 colors.

Third experiment compares our proposed approach with ANN [2] for the same 28 colors above. A multilayer perceptron was implemented with 3 hidden layers and the number of input and output neurons equals to the number of \( \text{Lab} \) space dimension. For system evaluations Good represents CIE2000 < 1, Regular represents CIE2000 = 1-5 and Bad is CIE2000 ≥ 5. Using the prediction of ANN, 20 colors (71.43%) are reproduced equals to the samples, 7 colors (25%) are evaluated of Regular and 1 color has Bad system evaluation (3.57%) while proposed approach reproduced the 28 (100%) colors.

5. Conclusion and Future Works

This paper presented an iterative approach to reproduce samples colors in printer devices avoiding human fatigue in the process of color reproduction. Using 28 colors which showed a high agreement between the evaluations of four users, the automatic approach reproduced and improved the manual procedure in 64.3%, taking less than 1 minute and needing only 1 impression. Compared with ANN approach, the proposed CSERBF mapping reproduced the 100% of colors with good accuracy while ANN only reproduced the 71%. A number of significant improvements remain to be considered for the automatic reproduction of colors without agreement in users evaluations.

6. References