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GENERIC DYEING AND COLOR CORRECTION

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ABSTRACT

A novel approach for computer color matching is proposed. In contrast to the existing computer color matching processes, this approach does not need the database of colorants with their absorption and scattering coefficients in order to predict the dyeing recipe and correct it. Despite various factors of the color device, dyes, dyeing medium, and dyeing conditions, the color can be corrected using this algorithm based on available color information of the sample and its real time output.

The basic aim has been to predict recipe for reproducing desired color by using only three primary subtractive colors: Cyan, Magenta, and Yellow, then be able to correct it dynamically for a reproduction close to the target. This generic process has other applications too, like displaying the same color across different monitors, or reproducing color from a sample to print.

Keywords: Color, Color Correction, Dyeing, Neural Network

1. INTRODUCTION

Color matching is one of the most important tasks in the carpet industry for the industry needs to reproduce the wool samples in the exact color. As it is not feasible in terms of time and economy to use a new colorant every time a new color needs to be developed, they keep about 30 colorants in stock using which all other colors are developed on trial and error basis. Unless the recipe of the desired color or a color very close to it has been already developed, it requires a highly experienced professional to reproduce the sample color exactly on wool by dyeing it using the colorants that the factory stocks. Modern carpet businesses also need to be able to digitally represent their designs and colors for efficient communication between manufacturer, importer, and the end customer. Owing to the unpredictability of color across different computer monitors and printers, they still rely on woolen color tufts or swatches for reconfirming colors before proceeding with their custom carpet production [1].

After nearly a decade's devotion to this field of research, Laxmi Malla [2] has published monograph on the use of vegetable dyes for dyeing woolen yarn used mainly for weaving carpets in Nepal. In her research, 32 plants were selected to develop 161 colors shades. The technology that can revive and adapt the traditional methods of dyeing to modern needs was then thought to be an urgent agenda that could easily be replicated from laboratory conditions to the workshop floors of industries.

Theoretically, all colors can be reproduced using either the additive primary colors: Red (R), Green (G) and Blue (B) or the subtractive primary colors: Cyan (C), Magenta (M) and Yellow (Y) [3]. While a particular value of RGB will always give same values of CMY on theoretical conversion, the color represented by this RGB value will appear different on different monitors [4, 5]. Similarly, the output color will appear different when the dyeing medium varies, or colorants from different manufacturers are used. Due to this practically imperfect theory and unpredictable nature of digital devices, colorants, and media, it is not possible to get the correct recipe of a given color using a computer in order to reproduce it.

There are several software offering computer color matching system, particularly based on the Kubelka-Munk series of equations [6]. These need a database of colorants with their absorption and scattering coefficients specific to the dyeing materials used for predicting the formula for a desired color. These coefficients are obtained through a series of calibration dyeing, and subsequent measurement of the dyed sample color with a Spectrophotometer [6]. While preparation of this database is costly and time consuming, the accuracy of the results from the color matching process depends upon the accuracy of production and evaluation of these primaries. The first formula usually gives a more or less unsuitable match [7], so it must be corrected, dyed again, measured and corrected once or more.

If these issues of color conversion and reproduction could be addressed by using the ever increasing computing power and decreasing cost of color measuring instrument through clever programming of correction method, there is a possibility that colors could be converted from one color space to another, and reproduced in generic environment without going through calibration and characterization. Because of the varying nature of the colorants as well as dyeing material from lot to lot, this method could give significant advantage over characterization based matching for industries that do not keep large volumes of inventory. More importantly, because all colors can be theoretically reproduced using Cyan, Magenta and Yellow, use of this method in dyeing will dramatically reduce the number of base colors the industry has to stock for the purpose.

This paper, therefore, investigates an engineering solution in the form of a color correction algorithm that works in generic environment to *dynamically correct colors such that a desired matching could be obtained independent of underlying variables that affect the color output.*

2. MANUAL COLOR MATCHING

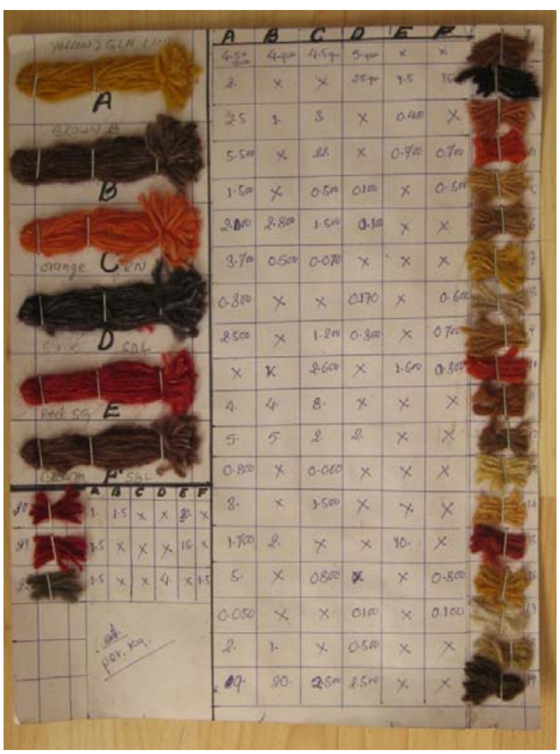

Figure 1. Base dyes and samples in manual dyeing

In industrial applications, a particular single color, termed as the 'spot color', needs to be reproduced. In textile dyeing, carpet designs and wool dyeing, many of the industries are still following their traditional process of reproducing color for which they stock more than 30 colorants to be used as their base to develop any desired color by mixing these in appropriate proportion. Figure 1 shows an actual set of base dyes (color A, B, C, D, E and F), and the resulting colors by mixing these in various proportions. Though exact number and colors of these base colorants vary from factory to factory, it is evident from Figure 1 that the dye masters do have limited knowledge of color mixing, and all resulting colors are of the similar color family as the base dyes. These are obtained through a series of trial and error episodes of adding one or two constituent, reducing another, or adding a new constituent color, until the result is accurate. When only one of these 30 or so base colorants that they used to stock goes out of production, the entire recipe have to be revised.

3. THE PROPOSED METHOD

The 'true' color specification is obtained through a color measuring instrument (i1 Photo Spectrophotometer) in XYZ color space. Using one of the various transform matrices, this XYZ data is translated to RGB as computer color value, though it is device dependent, and so not reliable in appearance. The RGB value is further translated to the theoretical CMY value, which is then mapped to it corresponding dye weight. By the time we get dyed yarn as color output, it has translation errors as well as dyeing specific errors, including the color of the medium being dyed. The idea is to treat all these "variables" as a "black box" and do corrective measure based on target color and its real time output (also read through spectrophotometer), without having to address to these variables individually.

Instead of using device specific translation table as in case of profiling, and maintaining database of reflectance through calibration dyeing as in case of computer color matching, the focus is on investigating the input side itself to get the desired result. When we input Color X in the system, the resulting output will be some other color, Color Y (Figure 2), because of the many variables involved in the process.

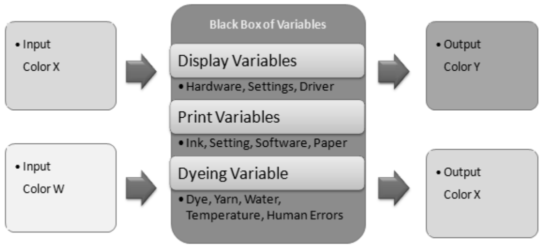

Figure 2. The color output system, and process variables

It, therefore, follows that, we need to input a third color, Color W in order to get the desired output, Color X. If we know the specification of the color that we want as the output of the system, then with the information of the current input and output color specification, we should be able to derive this unknown color, W, that will produce the desired output, X, from the given system without having to deal with all variables involved in the color reproduction.

Several standard matrices do exist for converting XYZ data into RGB, but obviously, with poor results because of the "generalization". The matrix 709 has been chosen for use in this research, giving

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} 3.240479 & -1.53715 & -0.498535 \\ -0.969256 & 1.875992 & 0.041556 \\ 0.055648 & -0.204043 & 1.057311 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

The choice of matrix didn't need any discretion because it only provides "initialization" values, and if this transform matrix could be modified in real time for each color, the matching goal could be achieved. The modification requires feedback based upon the error between desired target and obtained output. This leads to a situation very similar to training of a neural network.

Neural networks are best suited for error minimization. They learn through update of weights when target output is presented to the network. If the output and the target are different, the learning procedure is to update iteratively each weight by a fractional number, which is either a fraction of the weight, or a fraction of the error, depending on the learning rule. While complex learning techniques are prevalent, simple update logic like incrementing and decrementing weights in digital memory devices have also been proven to work [8] in attaining the desired output through iterative update of weights. Neural method has also been found to achieve results that are superior to other methods for correcting images from different cameras to produce results that appear similar to each other in color [9].

In order to use neural network learning method for color correction, the color reproduction process is mathematically modeled as shown in Figure 3 for error minimization through iterative weight update. Being generic, this approach is fundamentally different from other iterative approaches found for image restoration and refinement of look up table for print matching [10].

The enormous task of trial and error experimentation in the search for an efficient weight update model was made possible only through the interfacing of the spectrophotometer and automation of the feedback and correction process. Many interpretations of color difference, and weight update mechanisms were tried to identify a satisfactorily functional method first. One of such weight update methods, which is found to work satisfactorily for the purpose, in effect resembles successive approximation approach to iterative restoration procedure [11]. The convergence of this iteration, which forms a basis of a large number of iterative recovery algorithms, is analyzed in detail in [12].

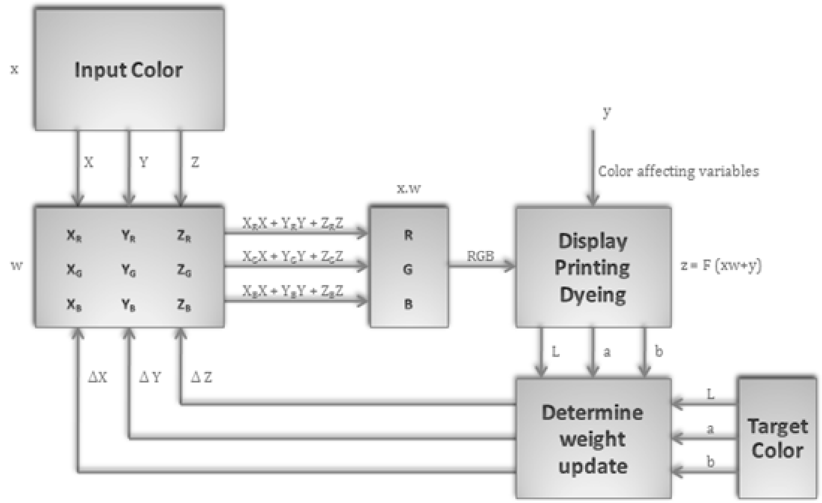

Figure 3 Mathematical model of neural learning for color correction

For simulation purpose, if the physical color as displayed by using particular set of RGB value is treated as the desired target, this color can be read by spectrophotometer to acquire XYZ value, which in turn can be converted to theoretical set of RGB employing the chosen transform matrix. The RGB thus calculated may appear different than the desired target based upon all variables involved in the display system used, as illustrated with exaggeration for understanding purpose in Figure 4.

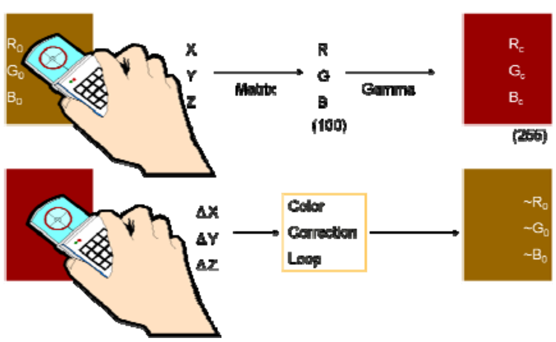

Figure 4. Illustration of color reading, conversion and correction

This transform matrix, serving as "weights" to relate the input to the output, can then be "updated" in real time, such that the transformed RGB value produces the target color after several iterations. Because it is the same screen on which we are trying to find a matched color, besides a visual match and XYZ proximity, the 'matched result' must also have RGB values similar to original RGB from where we started. Verification of the working of the correction algorithm could be simply and more convincingly reinforced due to this situation.

4. RESULT

A simulated test was carried out on a set of 125 color samples uniformly distributed in RGB color space. For a tolerance of $\Delta E = \sqrt{(\Delta L^2 + \Delta a^2 + \Delta b^2)} = 0.5$, all 125 Colors converged to its final match, with an average of 3 iterations per match. The actual number of matches on each iteration of color correction is shown in Chart 1.

In display (also in printing), the interpretation of RGB values for providing color output is handled by the device drivers and circuitry. In dyeing, these RGB values need to be related to the weight of base color dyes. For this purpose, three dyes were chosen, one each from Cyan, Magenta, and Yellow family, and grey gradients were produced by mixing these in appropriate proportions in varying strengths.

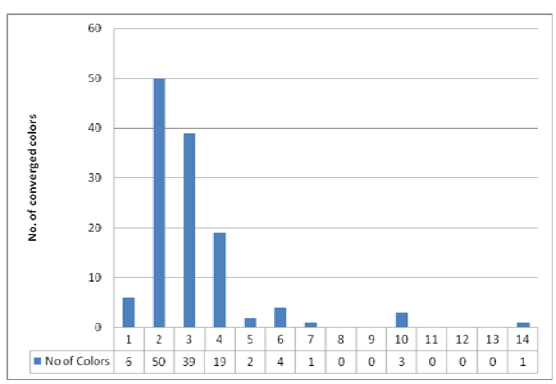

Chart 1. Number of matching colors in each iteration for 125 colors

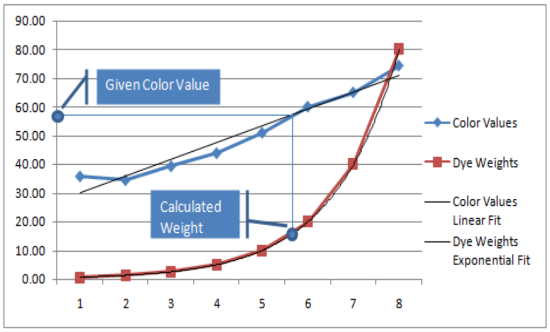

Chart 2 Model for mapping color values to dye weights

Based on the experimental data it is approximated that to effect a linear change in the resulting CMY, an exponential change is needed in the amount of dye required, as shown in Chart 2, leading to the following relationship:

$$x = 0.00017 * x_{max} * 1.1025^{y}$$

Where

x = weight of the dye (CMY)

x_{max} = weight of the dye that produces 100% strength

y = numeric value of the dye for which the weight is to be determined.

Owing to the time consuming nature of this experiment, the dyeing had to be limited to several varied nature of sample colors which could indicate the possibilities as well as limitations. Therefore the working of the algorithm was verified through a computer simulation as well as printing experiments first. The actual dyeing experiment was then conducted for the colors as shown in Figure 5, which were selected by dye masters to represent a good practical spectrum.

Figure 5. CMY dyes and developed samples

The average color difference at each iteration is shown in Chart 3. Correction results were promising for eight colors out of ten. There were two mismatches:

Faint pink mismatch (row 3, column 3 in Figure 5): In very light colors the dye weight required is so low that it is comparable to the tolerance of the color reading device. Hence on light colors, too close 'visual' match is practically limited. However, the readings show that the colors are pretty close to each other ($\Delta E = \sqrt{(\Delta L^2 + \Delta a^2 + \Delta b^2)}$ = low).

Strong red mismatch (row 1, column 2 in Figure 5): CMY set has a known limitation of its gamut that it cannot produce strong reds, greens, and blues. In dyes, it could be theoretically possible by using dyes quantities more than 100 percent, but in such cases dye weights become significantly high and wool being dyed cannot absorb all of that quantity. Hence, in this case, there is a visual as well as numerical mismatch. Experiment on this particular color was dropped after the first trial, so it doesn't appear in the list of analyzed data.

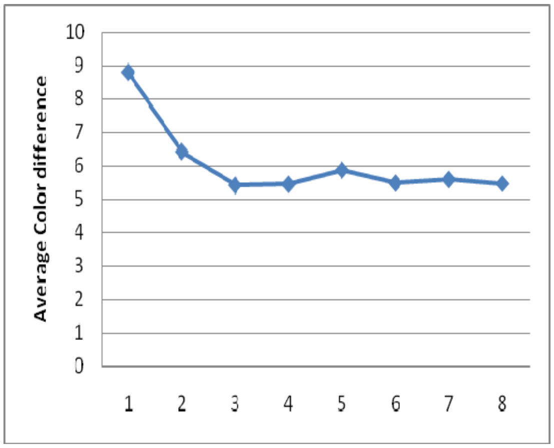

Chart 3. Average color difference at each iteration of dyeing

While the use of a spectrophotometer more suitable to measure yarn colors could have solved the faint color mismatch error, CMY gamut could be enhanced by adding RGB dyes as well, making the total number of base dyes to six to resolve the gamut limitation and allow strong red, green, and blue matches as well. Addition of Black as the seventh base dye could further reduce the cost of dyeing, as the per unit weight of Black dye is relatively cheaper. Even in such a practically viable case, the total number of base dyes required will be dramatically reduced when this color correction algorithm is used in dyeing, giving benefits of lesser inventory, cleaner working space, etc. besides the fact that the system can given instantaneous result without having to go through calibration dyeing and database preparation.

5. CONCLUSION

The proposed color correction algorithm works along with a color measuring device to dynamically correct colors such that an acceptable degree of color matching could be obtained independent of underlying variables that affect the color output. The correction is done based on the reading of the target color and the real time output of the system. This is an iterative process taking only 3 to 4 iterations in an average, and besides dyeing in generic environment, it works for displaying and printing the right color too.

Though there are far more variables in dyeing environment (namely the quality and color variation of the base dyes, color of the yarn, quality of water, inconsistent dyeing temperature, mapping approximations of computer values to dye weights, and most importantly, inaccuracies and errors of a human operator), the algorithm performs satisfactorily both in objective as well as subjective term. Though too light colors and too strong colors have limited success in this method due to practical reasons, this didn't imply any limitation in the correction algorithm itself.

The carpet factory in which the arrangements were made for the final experiments is already convinced to adopt the new dyeing method based on this research in place of their traditional one. On one hand, it will dramatically reduce their dye stock, on the other, the owner is also expecting cost benefit when the 3 dyes are purchased in bulk instead of purchasing so many base dyes in small quantities. The dye masters were expecting that it will also minimize the problem of variation of dye properties from one lot to another, when same dyes are purchase in small quantities over different times.

As every research output from the lab, this one also has certain limitations due to which, in its current form it cannot yet become a commercial solution as a new method for dyeing. The range of reproducible color is limited to the color gamut of CMY primaries, which is slightly smaller than physical world of all possible colors. So, red, green, and blue primaries will be needed to produce strong red, green, and blue samples respectively. Similarly, since the i-1 Photo spectrophotometer used in the experiment was designed particularly for profiling computer screen and printer, a better spectrophotometer suitable for yarn color reading will dramatically improve correction performance, especially while dyeing light colors.

For the carpet and dyeing industry, as their 25 to 60 colorants could be replaced by merely few when such a technology is used, this could prove to be a transforming solution. This could also be an alternative solution to the existing computer color matching systems, especially for smaller industries, whose frequency and volume for dyeing are lower. At the same time, the finding of this research has also shown newer possibilities of simpler yet powerful applications suitable for addressing specific color related business needs.

REFERENCES

[1] Berns, R.S., Imai, F.H., Burns, P.D., Tzeng, D.Y., 1998, *Multi-spectral-based color reproduction research at the Munsell Color Science Laboratory,* Symposium on Electronic Image Capture and Publishing. Zurich, Switzerland, part of Europt. SPIE Proceedings, Volume 3409

[2] Malla, Laxmi, 1993, The Natural Dyes of Nepal, Research Centre for Applied Science & Technology, Tribhuvan University, Kirtipur, Nepal

[3] Sharma, Gaurav and Trussell, H. Joel, 1997, Digital Color Imaging, IEEE Transactions on Image Processing, Vol. 6, No. 7, July 1997, pp. 901 – 932, [Online], Available: http://www.ph.tn.tudelft.nl/~lucas/docs/1997_IEEETIP_Sharma.pdf.

[4] ICC Color Management, 2003, [Online], Available: http://www.color.org/slidepres.html

[5] Apple Colorsync, 2003, [Online], Available: http://www.apple.com/colorsync/benefits/training/intro.html#intro.

[6] Butts, Ken, Database Preparation for Successful Computer Color Matching, [Online], Available: http://www.techexchange.com/thelibrary/colormatching.html

[7] Berger-Schunn, Anni, 1994, *Practical Color Measurement: A Primer for the Beginner, A Reminder for the Expert*, John Wiley and Sons, Inc.

[8] Tandukar, J., 1994, *VLSI Neural Networks: Digital Implementation,* Master's Dissertation, University of Wales, UK

[9] Yin, J., Cooperstock, J.R., February 2004, *Color Correction Methods with Applications to Digital Projection Environments,* Journal of WSCG, Vol. 12, No. 1-3., ISSN 1213-6972, WSCG 2004, Plzen, Czech Republic

[10] Balasubramanian, T., July 1997, Iterative technique for refining color correction look-up tables, US Patent No. 472080

[11] Katsaggelos, A.K. and Tsai, C.J., 2005, *Iterative Image Restoration,* Handbook of Image and Video Processing, Elsevier Academic Press, pp. 235-252

[12] Ortega, J.M. and Rheinboldt, W.C., 1970, *Iterative Solution of Nonlinear Equations in Several Variables,* Academic Press

APPENDIX: SUPPLEMENTARY MATERIAL

PICTORIAL EXPLANATION OF DYEING LAB TRANSFORMATION

Figure F1. Notebooks of dyeing recipe and samples

This pile of notebooks belongs to a carpet factory which has a dyeing lab for their in-house use only. The colorful elements seen on both sides are the actual dyed samples of the yarn that they use, and against each sample, they do have manual records of quantities of based dyes used. This is expected to be replaced with a computer with the color correction algorithm, and a spectrophotometer that is seen in the picture along with the pile.

Figure F2. Boxes of different base dyes, the weighing scale, and solution preparation.

The dye-master is seen working in his storage space to prepare a solution of dyes in Figure F2. All of these cluttering boxes of bases colors will disappear once they resort to CMY dyeing method.

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Figure F3. The dye solutions

Various dye solutions used in the process of developing colors on yarn is seen in the picture of Figure F3. The three bottles in front are a set of CMY dye solutions that were used in the experiment to develop all colors of Figure 5. Unlike Figure 1, where the base dyes are used to develop only similar colors due to the lack of concept of color mixing and result prediction when dyeing is done manually, technology can help in developing a wide spectrum of colors by using only those three dyes. While it is obvious that the predicted CMY recipe cannot give satisfactory result due to the color affecting variables (like the quality and color variation of the base dyes, color of the yarn, quality of water, inconsistent dyeing temperature, mapping approximations of computer values to dye weights, and most importantly, inaccuracies and errors of a human operator), the color correction algorithm developed in this research can correct the output very close to the target.