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THE MEASUREMENT OF COLOR IN A QUALITY CONTROL SYSTEM: TEXTILE COLOR MATCHING

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Abstract - In this paper we propose a criterion for uncertainty evaluation in a color quality control. In a joint project between two laboratories of the Faculty of Engineering in Florence we study a PC-CCD system, called Textile Color Match (TCM) for the digital acquisition of the colorimetric coordinates of a wool sample. One of the main result is the achievement of a threshold of tolerance for the reproduction of this colored sample.

Keywords: Color quality control, Colorimetric coordinates, Chromatic tolerance

1. INTRODUCTION

It's important to take into consideration all the objective parameters linked to the quality control of a product, expecially those that interfere with human sensations like color perception, smell, taste. In particular the task to find reliable chromatic tolerance in industrial production of tinted wool implies different problems of quality control and, in general, this task is not related to the physical size of the product like its dimension, weight or strenght that are measured during the production cycle. This study interacts with the visual human sensation and with the eye capacity of chromatic discrimination. Usually, the color quality control of a product is made by direct observation: we compare the test color of this product with the sample item, or with a color set (i.e. Pantone [1] in textile industry). In advanced production a spectrophotometer is also used to estimate the surface reflectance; in this way it is possible to calculate the "colorimetric distance" between a sample and the reference.

In this paper we propose a criterion for the uncertainty evaluation in a color quality control process

It is important to underline that the color perception is linked to the neuro-physiology of our brain. This means that our feelings and our behaviour are anyway related to this color perception.

In fact, not only physicians and painters approached this fascinating topic but also poets, philosophers and psychologists. Neuro-science demonstrated recently a direct connection between psychological and physiological stimula: our feelings and emotions are a fascinating theatre in which the color has a primary role.

George Simmel [2], a german philosopher and sociologist, put in evidence our habit to consider the prices of the products like an intrinsic property of them and not related to the effect of dynamics between supply and demand. This happens also in the color evaluation, that in opposition to the common perception it is not an intrinsic characteristic of the objects, not a phisical quantity, but a quality, an attribute of the visual feeling and so subjective and inexpressible.

This seems to deny every measure of color; but if we consider that different people may agree on color evaluation, we understand that this is not completely true.

Moreover the procedures of standardization are not so well defined and, on the other side, the instruments and the techniques for the color meausurement often are not economically suitable to this aim.

2. TEXTILE COLOR MATCHING (TCM) SYSTEM

In order to define the criterion to evaluate the color control quality, we have designed a system consisting of a personal computer (Intel Pentium III 700 MHz processor) and a linear scanning system with a professional scanner with optical resolution, dynamic range, scan speed, showed with other important characteristics, in Table I.

TABLE I. Characteristics of TCM system

Optical resolution	1000 * 2000 dpi
Dynamic range	3.7 D
Scan speed	10 ms B/N 12 ms color
Scan area	16 cm²
A/D Converter	14 bit
Illumination system	cold cathode lamp

The brain of this system includes a software purposely implemented in Visual C++, that supplies the colorimetric distance based on the CIELab coordinates [3] between a sample and the reference standard and all the eventual corrections given to the operator. The selection of the acquisition area is automatically carried on: the operator must only place the reference standard and the test sample on two windows (4 x 4 cm) realized on an appropriate mask of black color equipped with the colorimetric standard scale IT8 7/2 for the system calibration, as we can see in Figure no.1

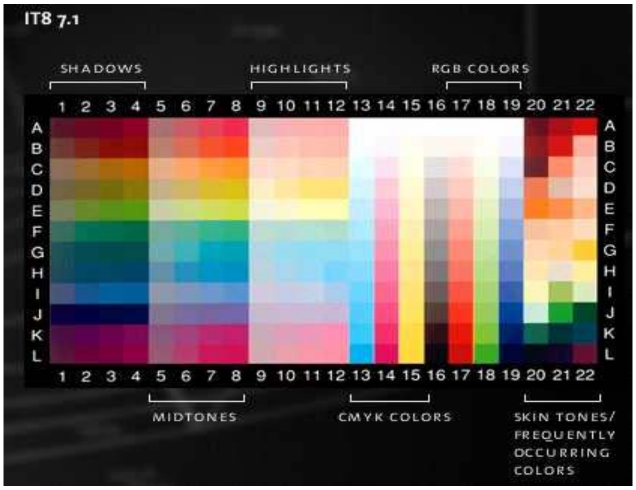

Figure 1. Chromatic mask for TCM system calibration

Three selections allow the user to acquire RGB coordinates with resolution equal to 16 bpp (bit per pixel) of the white standard point, of the reference standard and of the test sample. White standard acquisition is very important because the CIELab coordinates (X_n, Y_n, Z_n) of the illuminant are related to a perfect reflecting surface.

For the assessment of these coordinates we consider the reproduced white standard of IT8 thin cardboard like a perfect reflecting surface, and we calculate the CIELab coordinates measuring this area.

In the next step we introduce the reference code of the product and then we save these three images in order to realize a quality control archive. Moreover we also saves the coordinates RGB, XYZ and CIELab of each image, with the values of the colorimetric distances calculated with CIELab, CMC(l:c), CIE94 formulae. [4], [5].

In order to better understand the following result it is useful to put in evidence the techniques adopted to acquire the images with TCM system. In fact, the three fundamental colors, Red, Green and Blue correspond to the three types of CCD sensors, in particular white color corresponds to the following coordinates: red = R = 65535, green = G = 65535 and blue = B = 65535.

TCM Software management system offers many possibilities to elaborate the acquired images; one of the most important is the automatic color balance that computes the nearest white point to the theoretical white, calculating the differences between RGB coordinates and those of the theoretical white. In some situations this balance operation changes the colors, rendering the obtained images less reliable and usable for the purposes of this study. However we do not perform any kind of elaboration, assuming all the chromatic information. On the other hand this fact does not exlude however that in the progress of this resarch we can elaborate the acquired images to facilitate the colorimetric comparison in some kind of samples, like those “melange” or those particularly colored. Finally it is important to emphasize that the reproduction time of this TCM system is maintained less or equal to the two minutes, and this is an important characteristic with respect to the economy of the production.

3. TEMPORAL UNCERTAINTY OF TCM SYSTEM

In order to characterize the stability of this system, we carried out a temporal analysis by acquiring the white standard point every 2 minutes for the first 48 minutes from the start up of the device. We have chosen to center this analysis on the white standard point because its acquisition is done every time the system is used. The measurement of the white standard point accounts for the radiaton emitted by the system lamp: since this radiation is completely reflected, this point is detected by the CCD sensor. On the other side, studying the answer of the acquisitions of a whichever colored sample, would have been differently stimulated the three channels of CCD sensors and every comparison between them would be inadequate.

Therefore we have considered the first 25 acquisitions of the white standard point, in the same operating conditions, on the three channels R, G and B, every two minutes from the start up of the device and we calculate the average values on three repetitions. Working with 16 bpp the values of the colorimetric coordinates belong to the range (0:65535), hence the theoretical white standard point that reflects all the radiance emitted from the lamp, excites the three channels of CCD sensor in the same way (if the spectral power density of the radiant is constant) and we would have values R = G = B = 65535. In the practical case with the spectral power density variable in frequency, the reflected radiance will not be theoretically white, and so the quantic efficiency of the channels will not be the same because the number of absorbed and incident photons would be different.

These last considerations put in evidence that the temporal characterization of the channels excitation levels reflect this stochastic behaviour; therefore the value 65535 will be only a useful theoretical reference for the comparison between them.

3.1. Temporal characterization of R coordinate

In Figure no.2, we can see the time series of the average on three repetitions of the first 25 acquisitions of the R channel, every two minutes from the start up interpolated with a continuous line. The R coordinate varies from 64773.54 to 64956.20 with an average value equal to 64871.58 and with a range equal to 182.66, representing the 0,28% of the average value. From the variance, equal to 2628.42 we compute type A standard uncertainty equal to 51.26.

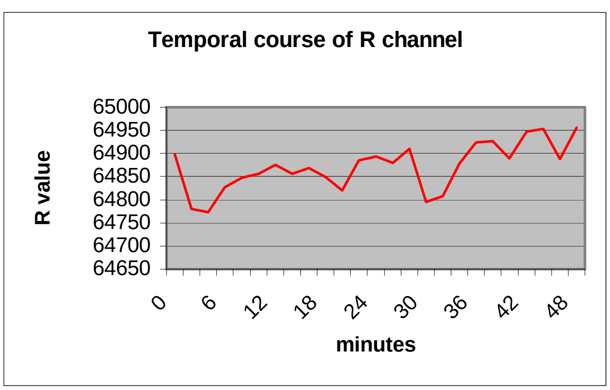

Figure 2. Drift of the R channel, in the first 48 minutes of operation

3.2. Temporal drift of G coordinate

In Figure no.3, we can see the time series of the average on three repetitions of the first 25 acquisitions of the G channel, every two minutes from the start up interpolated with a continuous line. The G coordinate varies from 65134.88 to 65233.49 with an average value equal to 65194.86 and with a range equal to 98.61, representing the 0,15% of the average value. From the variance, equal to 618.70 we compute type A standard uncertainty equal to 24.87.

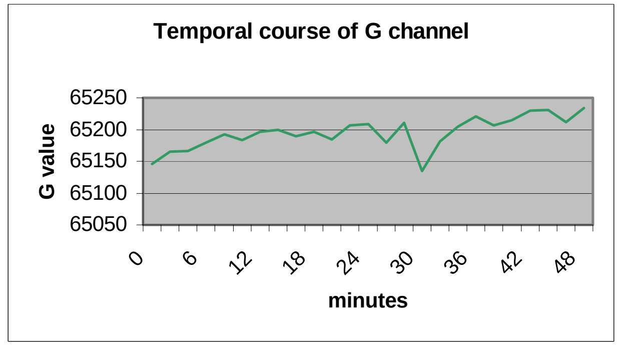

Figure 3. Drift of the G channel, in the first 48 minutes of operation

3.3. Temporal drift of B coordinate

In Figure no.4, we can see the time series of the average on three repetitions of the first 25 acquisitions of the B channel, every two minutes from the start up interpolated with a continuous line. The B coordinate varies from 64989.71 to 65194.15 with an average value equal to 65140.01 and with a range equal to 98.61, representing the 0,31% of the average value. From the variance, equal to 2149.37 we compute type A standard uncertainty equal to 46.36.

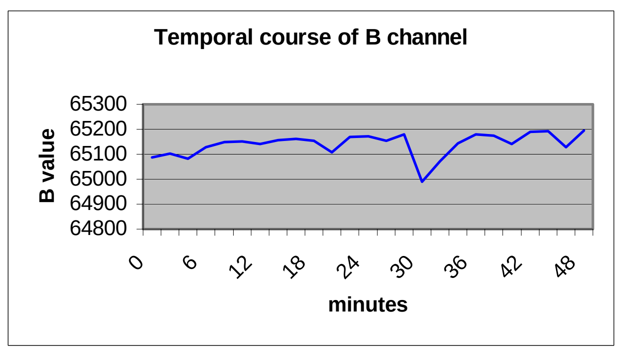

Figure 4. Drift of the B channel, in the first 48 minutes of operation

3.4. Comparison between the temporal drifts of the three channels

In Figure no.5 we can see the time series of the average of the data showed in the previously three figures (the R, G, B channels) and represented with dotted, continuous and dashed line respectively. Also in this case the acquisition is done every two minutes from the start up for a total of 48 minutes. We also compute the correlation coefficient between the R-G channels equal to 0.76, while the same computation between R-B and G-B channels gives us the result of 0.85 in both cases.

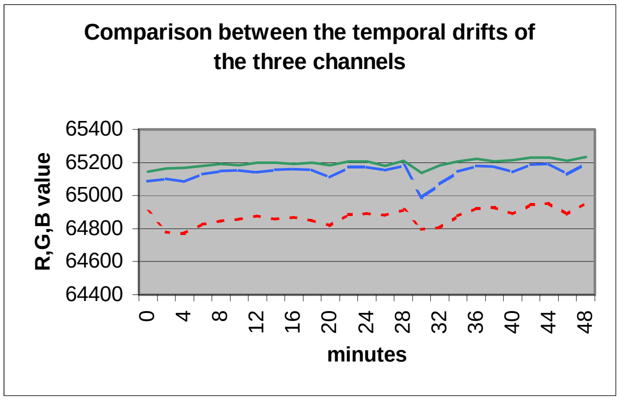

Figure 5. Comparison between the temporal drifts of the three channels R, G and B, in the first 48 minutes

In Table II we can see the variability of the TCM system on the three channel where we approach the theoretical case in which the standard white point would be equal to 65535. In this case, the time series of the average of the values belonging to R remains under the level of 65000. The maximum difference with respect to the average value remains under 0.5% so that in the first 48 minutes the system remains in a steady state. This is particularly obvious for the G channel, whose variance is approximatively the half than in the other two channels.

TABLE II. Variability of the temporal answer of TCM system on the three channels

Coord.	R	G	B
Average	64871.58	65194.86	6514 0.01
Variance %	0.28%	0.15%	0.31%
Uncertainty %	0.07%	0.04%	0.07%

4. ANALYSIS OF THE UNCERTAINTY OF TCM SYSTEM

To certify the repeatability and stability characteristics of the system, we have studied the statistic variability during the acquisition of the white standard point, considering 250 reading operations executed during three consecutive days. The time interval between two acquisitions is so variable and connected to the production and quality control. We also think that this spreading of data is related to the normal running of this system.

4.1. R channel uncertainty

In Figure no.6 we show the values belonging to the red channel in 250 asynchronous acquisitions of the white standard point interpolated with continuous line.

The R coordinate varies from 63540.62 to 65279.28 with an average value equal to 64798.04 and with a range equal to 1738.66, representing the 2.6% of the average value. From the variance, equal to 220302.89, we compute type A standard uncertainty equal to 469.36.

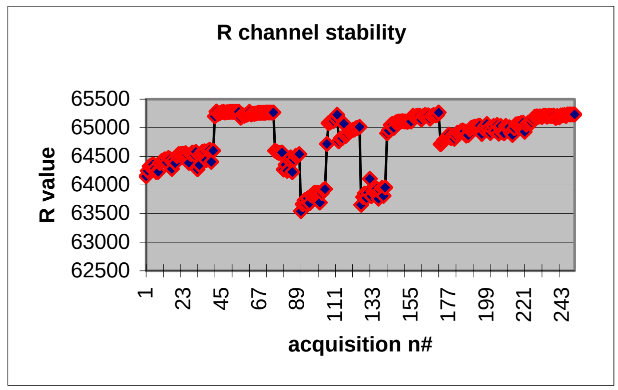

Figure 6. R coordinate values in 250 acquisitions of the white standard point

If we observe the behaviour of the system in the first 48 minutes, we can see that the range of the R coordinate together with the uncertainty value, increases of approximatively 9 times while the average remains approximatively constant (-0,1%).

4.2. G channel uncertainty

The G coordinate varies from 64194.90 to 65276.09 with an average value equal to 65049.92 and with a range equal to 1081.19, representing the 1.6% of the average value. From the variance, equal to 82420.79 we compute type A standard uncertainty equal to 287.09 (Figure no.7).

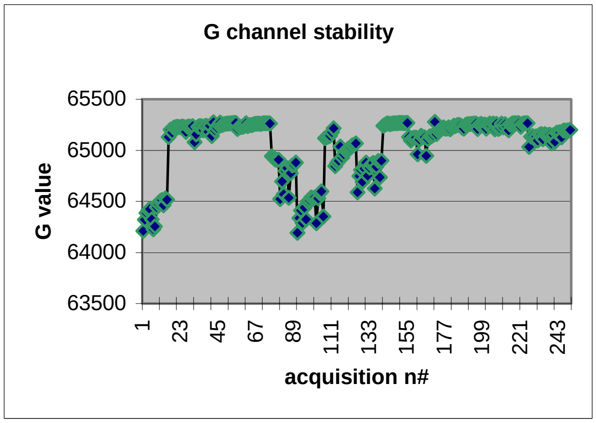

Figure 7. G coordinate values in 250 acquisitions of the white standard point.

If we observe the behaviour of the system in the first 48 minutes, we can see that the range of the R coordinate together with the uncertainty value increases of approximatively 11 times while the average remains approximatively constant (-0,2%).

4.3. B channel uncertainty

The B coordinate varies from 63780.77 to 65273.93 with an average value equal to 65073.33 and with a range equal to 1493.21, representing the 2.2% of the average value. From the variance, equal to 57444.99 we compute type A standard uncertainty equal to 239.67 (Figure no.8).

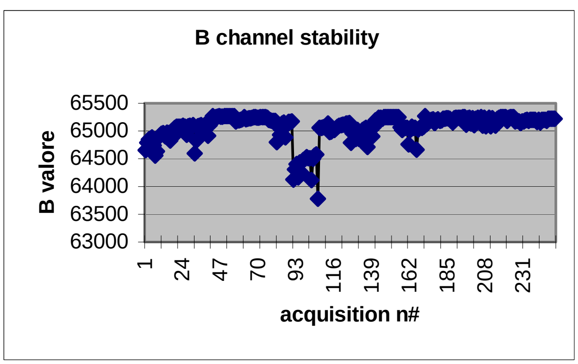

Figure 8. B coordinate values in 250 acquisitions of the white standard point

If we observe the behaviour of the system in the first 48 minutes, we can see that the range of the R coordinate together with the uncertainty value increases of approximatively 7 times while the average remains approximatively constant (-0, 1%).

4.4. Comparison between the three channels

In Figure no.9 we can see the time series of the 250 acquisitions of white standard point showed in the previously three figures (the R, G, B channels) and represented with dotted, continuous and dashed line respectively. We also compute the correlation coefficents between the R-G, R-B, G-B channels and we found them equal to 0.76, 0.73 and 0.82 respectively. In conclusion we can say that the correlation cofficients between the same three channels are approximatively of the same order and that there is not any appreciable difference between the starting behaviour of the system and its statistical average.

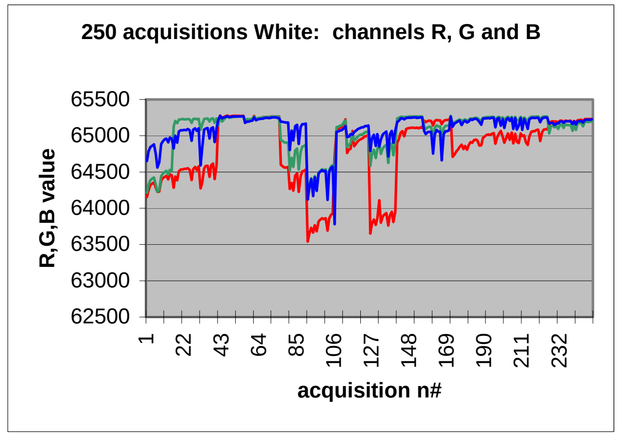

Figure 9. Comparison between uncertainty of the three channels: R, G and B.

In Table III we can see the comparison between the variability of the system in the first 48 minutes and in 250 asynchronous acquisitions of the white standard point. These data approached the theoretical case in which the white standard point would have coordinates equal to 65535. In spite of this fact the R coordinate is maintained under the level of 65000 but however, in all the three cases, the average is near to this value.

TABLE III. Comparison between the variability of system TCM in the first 48 minutes and in 250 asynchronous acquisitions of the white standard point.

Coordinate	250 acquisitions		
	R	G	B
Average	64798.04	65049.92	65073.33
Variance %	2.6%	1.6%	2.2%
Uncertainty %	0.72%	0.44%	0.36%
Coordinate	First 48 min.		
	R	G	B
Average	64871.58	65194.86	65140.01
Variance %	0.28%	0.15%	0.31%
Uncertainty %	0.07%	0.04%	0.07%

We can therefore assert that this system demonstrates good stability on the three channels. There is not any appreciable difference between the starting behaviour of the system and its statistical average that maintains its value less than 1%: this is a typical value in chromatic acquisition systems using cameras or spectrophotometer.

5. CONCLUSION

The observation and the study of the methods which the operators traditionally adopt to keep the system under control, put in evidence the need to investigate from the theoretical point of view what it is commonly called "color". This word, always present in every moment of our life, is today still wrapped in the fog of common sense.

All the theoretical recognition brought back this study to the search of an "optimal" chromatic tolerance. We move our resarch from the subjective level of the chromatic feelings to the level of the colorimetric science. We have been studied all those reproductions that exceed the factory traditional control, acquiring the colorimetric coordintaes through a PC-CCD system called TCM. This system was purposely implemented and tested in a joint research project between the Electronic and Telecommunication Department and the Energetic Department of the Faculty of Engineering in Florence, Italy.

The main results obtained in this study concerns the analytical evaluation of the operators in quality control also in relation to the definition of chromatic tolerance classes. We also study the stability of TCM system for the digital acquisition of the colorimetric coordinates of the sample to achieve the definition of a threshold of chromatic tolerance, for reproducing a wool sample of a given color.

We also supply the company with an analytical criterion on which setting up the chromaticity verification of the realized sample. It has been possible to reduce the customer claims from 14% to 6%.

The future development of this research implies the verification of the goodness of the proposed method through a wide sample diversification, expecially for chromatic characteristics. Moreover some techniques that allow to take into account the various chromatic yields of several natural fibers or crafts ("*melangé*", "*puntinato*") are necessary to better evaluate the colorimetric distance in function of these kinds of samples.

With TCM system is also possible, in spite of the spectrophotometer instrument usually used in the company, to analyze the variation of the colorimetric coordinates between the reference and sample test, in function of the image single pixel.

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