LOW-COST DEVELOPMENT AND TESTING OF AN ON-LINE MEASUREMENT SYSTEM COLOR OF INDUSTRIAL APPLICATION

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Abstract- This paper presents a new kind of colour sensor based on the measurement of the three channels of the CIE XYZ colour space, using optical fibres to conduct light from the illuminant to the probe and from the probe to a XYZ photo-sensor. Instead of performing conventional colour space transformation from CIE XYZ to CMY, we used a statistical procedure, avoiding the transformation dependence on illuminant.

This paper shows a brief description of the colour measurement process, a prototype implementation and several experimental results.

Keywords: colour space, colour sensor, optical fibre, illuminant, CIE XYZ, CMY, RGB.

I. INTRODUCTION

Colour is a fundamental property in some industrial sectors (Food processing, Textil Industry, Print, etc) [1] because the colour can be an important quality indicator for their products.

A lot of people consider that foods that have a nice colour are better than others, which increase the consumption of these products. Colours are even associated with certain qualities. Such as green, which is associated with ecological and healthy products, while red is associated with blood and war...

So, when performing any type of design it is very important to be able to translate the initial design to the final product, ensuring that the chosen colours in the design are the same.

Because of the importance of colour in quality control in industry, and the high cost of commercial colorimeters, it was decided to design a low-cost generic colorimeter. This equipment is based on the measurement of the three channels of the XYZ colour model and can perform the conversion to other colour models.

Light sources (illuminants) typically used in colorimetry (D50, D65) [2] are very expensive device. However a low-cost light source has been used, and determines a significant part of the final cost of colorimeters.

So, a low-cost light source has been used for our colorimeter in order to reduce the final cost of equipment. Low-cost illuminant must be selected taking into account their emission spectrum to guarantee enough light power in all areas of visible wavelengths.

However, the transformation equations between different colour spaces [3][4] have a hard dependence on illuminant, that is, the spectral response of illuminant affects those transformations. So, if we use a non-standard illuminant all transformation equations should be derived. This derivation becomes not easy (or not feasible) due to the low flatness of light spectrum of the low-cost illuminants, based on LED sources, usually constituted by three or more independent emission areas.

To overcome the above problem a statistical method is proposed in this paper. This method consists of the establishment of multivariate correlation between XYZ readouts of sensor from a pattern and the real values of these patterns in the desired colour space. The final results should be a set of equations which allow us an efficient transformation from XYZ colour space to any other.

II. COLOUR MEASUREMENT PRINCIPLES

The proposed measurement system is based on two well-known principles, reflection and absorbance. The emitting light from the illuminant lights the pattern, thus a part of that light is reflected (with the same lit angle) and the other part is absorbed by the measurement area. The reflected light contains the colour information of the pattern.

III. SYSTEM DESCRIPTION

A colorimeter is equipment that is based on the characterization of the colour by directing illuminant light through the pattern and measuring the light reflected in the pattern with a XYZ photo-sensor.

The first step is to ensure that the only light that arrives at the photo-sensor is the light reflected at the pattern, in order to avoid noise and interferences.

Optical fibre is used to transmit light through the system. The excitation light transmitted to the measurement area is reflected and reaches the photo sensor. Optical fibre passes through a hollow screw mounted on a probe as is shown in Fig 1.

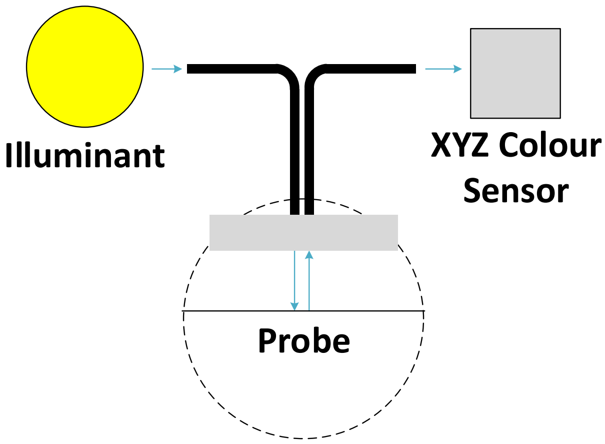

Fig 1. Colour measurement system

A high intensity commercial LED from OSRAM OSTAR [5] Headlamp has been used as the illuminant. This LED emits light in the visible spectrum, which ensures that the measurement areas of the spectrum are illuminated, as is shown in Fig 2.

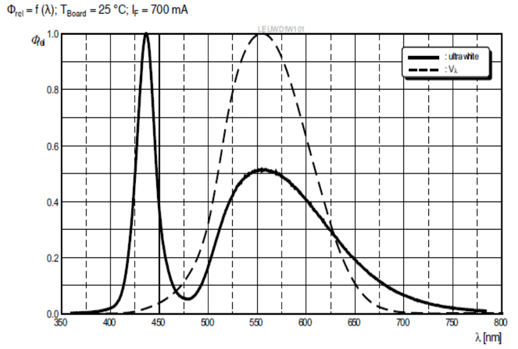

Fig 2. Spectral emission of the illuminant (dash line corresponds to the standard eye response curve).

The sensor, which receives the reflected light, is an MTCSiCT –T039 [6], a monolithic of 19 x 3 photo diodes integrated on chip. Each of these photodiodes is sensitized with a new dielectric spectral filter for the primary colour standard CIE colour space.

This sensor is committed to implementing the standard distribution functions as defined under DIN 5033 Part 2-Color Measurement [7]; CIE 1931 Standard Colorimetric Systems [8].

Finally, a conditioning circuit to transform the colorimetric information to voltage signals becomes necessary. For which an MTI04CS multi-channel programmable gain trans-impedance amplifier [9] is used. The final system includes a MCU for calculation purposes, able to carry out the transformation process, display data, and control the on-time of the illuminant.

Temperature can affect the operation of both the illuminant and photo-sensor array. During system calibration it was observed that the measured data varied depending on the room temperature.

This was confirmed by an experiment in which the system was placed within an isothermal oven to observe it is behaviour. After analysing the impact of temperature, we proceeded to compensate this behaviour by means of a thermal probe based on an LM35 integrated sensor. In Figure 3 we can see the thermal behaviour of X value.

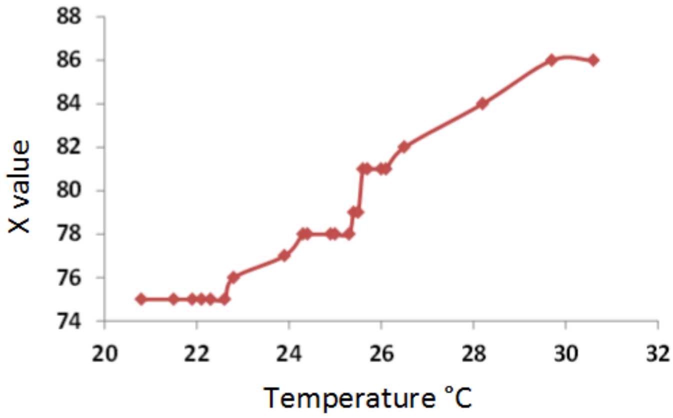

Fig 3. Thermal behavior of X value is quite similar to Z and Y.

In Fig 4, a scheme of system operation is shown.

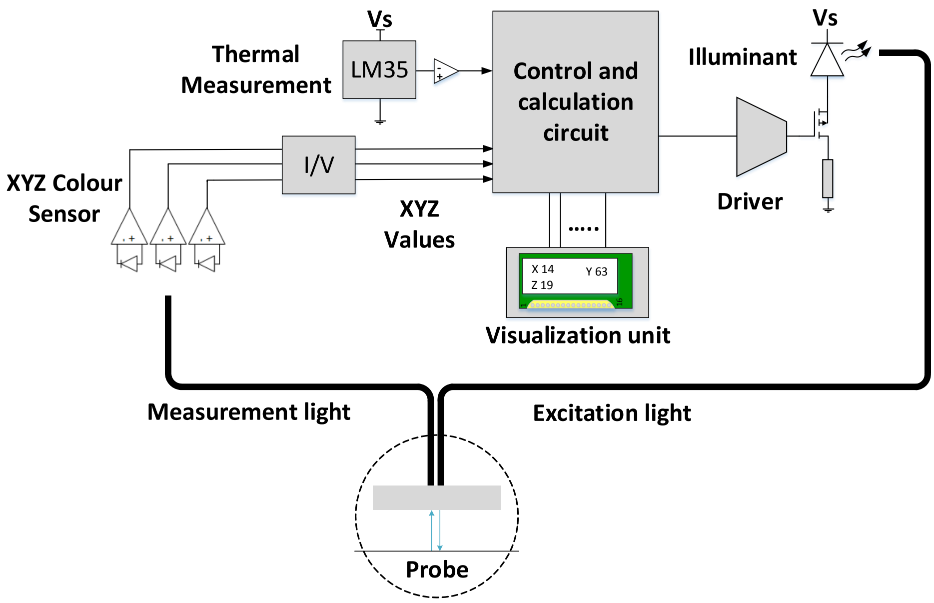

Fig. 4 System makes a thermal measurement, to do the thermal compensation, after receiving the measurement order. Then the control circuit turns on the illuminant, the excitation light goes through the optical fiber and lights the pattern. The reflected light is captured by the XYZ sensor that generates electric currents which then are converted to voltage. These voltages are read by the A/D converter. The results are shown in a LCD display.

IV. DETERMINATION OF TRANSFORMATION EQUATIONS

The objective of this stage was to make conversion from the values of XYZ colour space to CMY, RGB, HSV, HSL and CIE L*a*b colour spaces by means an empiric relationship, that avoids the inclusion of the illuminant characteristics. For this purpose, several test charts (patterns) for colour were used on coated paper with a Fiery DocuColor 5000 v2.0 printer. These patterns are constituted by several colour items from 0 to 100% of each component.

For example the CMY colour space pattern is a set of tables with C values on the vertical axis and M values on the horizontal axis. The Y value is constant to each table, but varies from on to another. All of them are increased by 10 units, taking values from 0 to 100, consisting each table consists of 121 colours. This is achieved by having a total of 1331 colours patterns characterized for 3-cordinates in the CMY colour space.

The calibration process used the measurement at 23 points over 11 tables; the total measured values were 253 colours. Measurements were performed on different days achieving high reproductivity (2 error units).

Such the used parameters were numerous, all the possible realizations were analysed for the purpose of find the better dependence relationship.

C coordinate

The estimation of coefficient R^2 was 0.9797 with a standard error of 4.594 in a regression, with 5 degrees of freedom, was obtained:

$$C = 284.4 - 0.5057 \cdot Y - 2.373 \cdot Z - 202.2 \cdot \frac{X}{Z} + 0.00104 \cdot Z \cdot Y + 177.6 \cdot \frac{Z}{Y} \qquad (1)$$

We should point out that the “t statistic” is used to analyse the parameters which have more importance estimating the value of “C”.

As it can be seen in the results of the "t-statistic", all regression parameters included in previous equation are significant in predicting C. The five parameters used to predict readings Z and Y are part of the five parameters; this indicates that C parameter has a strong dependence on Z and Y.

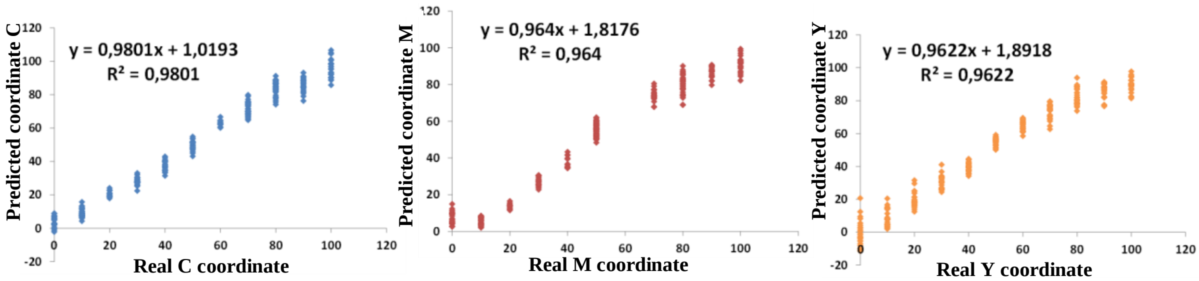

Fig 5. Relationship between real coordinate of CMY colour space and the predicted coordinate.

M coordinate

The estimation of coefficient R^2 was 0.9630 with a standard error of 6.1270 in a regression with 6 degrees of freedom was obtained.

$$M = 550.3 - 122.2 \cdot \frac{X}{Y} - 289.4 \cdot \frac{Y}{X} + Y^2 \cdot 0.00462 - 1.581 \cdot Y + 0.0045 \cdot X \cdot Z - 0.978 \cdot Z \qquad (2)$$

We should point out that the “t statistic” is used to analyse the parameters which have more importance in estimating the value of “M”.

As can be seen in the results of the "t-statistic", all regression parameters are significant predicting M and the prediction includes X and Y in five of them. This means that there is a strong dependence on both X and Y.

Y coordinate

In this case, the coefficient of determination $R^2 = 0.9612$ was estimated, with a standard error of 6.2379 in a regression with 6 degrees of freedom:

$$Y = 243.3 - 3.857 \cdot Z + Z^2 \cdot 0.00032 + 199.3 \cdot \frac{Z}{X} - 304.9 \cdot \frac{Z}{Y} - 76.85 \cdot \frac{Y}{X} + \frac{Z^2}{X^2} \cdot 6.322 \qquad (3)$$

We should point out that the “t statistic” is used to analyse the parameters which have more importance estimating the value of “Y”.

As can be seen in the results of the "t-statistic", all regression parameters are significant predicting Y.

C	Coefficients	Statistical t	M	Coefficients	Statistical t	Y	Coefficients	Statistical t
Interception	284,5	87,703198	Interception	550,3	14,711734	Interception	243,3	23,046107
Y (0-255)	-0,5057	-21,453997	(X/Y)	-122,2	-7,379333	Z (0-255)	-3,857	-24,86677
Z (0-255)	-2,373	-22,809693	(Y/X)	-289,4	-13,71006	Z^2	0,00032	16,086511
(X/Y)	-202,2	-86,3303	Y^2	0,00462	14,046043	(Z/X)	199,3	6,6064702
(Z*Y)	0,00104	16,012323	(X*Z)	0,00453	6,0706182	(Z/Y)	-304,9	-13,20819
(Z/Y)	177,6	35,804913	Y (0-255)	-1,581	-25,92704	(Y/X)	-76,85	-6,972277
			Z (0-255)	-0,978	-10,86718	Z^2/X^2	6,322	3,6661544

Table 1. Statistical results of analysis of CMY transformation from XYZ colour space.

The values of “t statistic” in Table 1 clearly verify the dependence relationships indicated previously.

The good behaviour of the transformation process was verify by the residuals (error) obtained from previous equations. In Fig 6, the plots of residuals are shown, and a low error in estimation of CMY from XYZ values can be verified.

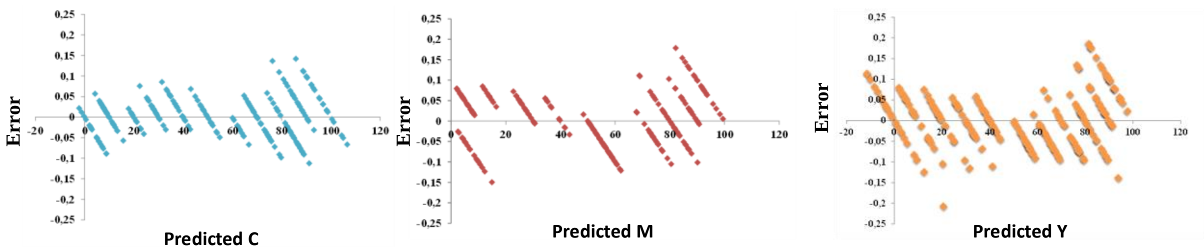

Fig 6. Final error of calculated coordinate for transformation between XYZ and CMY colour spaces.

This study can be extended to other colour spaces, such as RGB colour space HSV, HSL or CIE L*a*b. Thus, we can use any appropriate illuminant without the restrictions (and cost) of standard illuminants.

V. CONCLUSIONS

The experimental results have demonstrated that the use of a low-cost non-conventional light source can be an alternative to conventional light sources (D50, D65) assuming measurement error, which is small. Because of the good results of the calibration, the colorimeter can show colours in the CMY besides the XYZ model whit a small error and an excellent repeatability.

The next step would be to show more colour models obtained through transformations from XYZ and CMY model and check the results through new colour charts.

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