Colour Measurement With
MCS3 and MCSi Colour Sensors

APPLICATION REPORT

Colour measurement with JENCOLOUR colour sensors
by calibration and correction matrix

The filter functions of JENCOLOUR sensors MCS3 and MCSi (see Figure 1) are provided by three band passes. One for the red, one for the green and one for the blue spectral range. These sensors are uniquely suited to identify colours by way of teaching and, hence, to detect coarse differences in the colour of individual samples (also see MAZeT Data Sheets for these colour sensors).

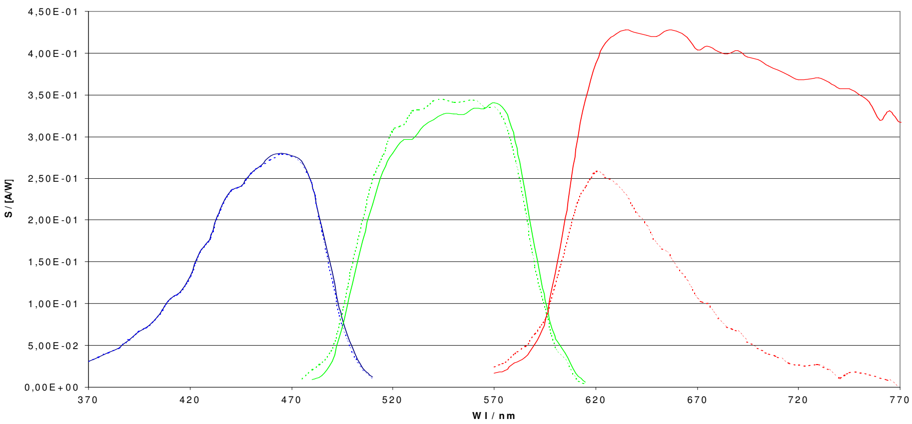


Figure 1: Spectral sensitivity of MCS3 and MCSi colour sensors

In addition, JENCOLOUR sensors may also be applied to simple colour measurement. If this is done equating the standardised measured RGB values with the standard spectral values XYZ for colour position calculation as shown in CIE-Yxy (see Figure 2), major deviations from the actual standard colour positions are initially obtained.

These deviations are firstly due to the fact that the colour sensors' spectral sensitivity is not exactly matched to that of the standard distribution function and secondly, sensor manufacturing inherently includes certain tolerances in terms of filter offset and location.

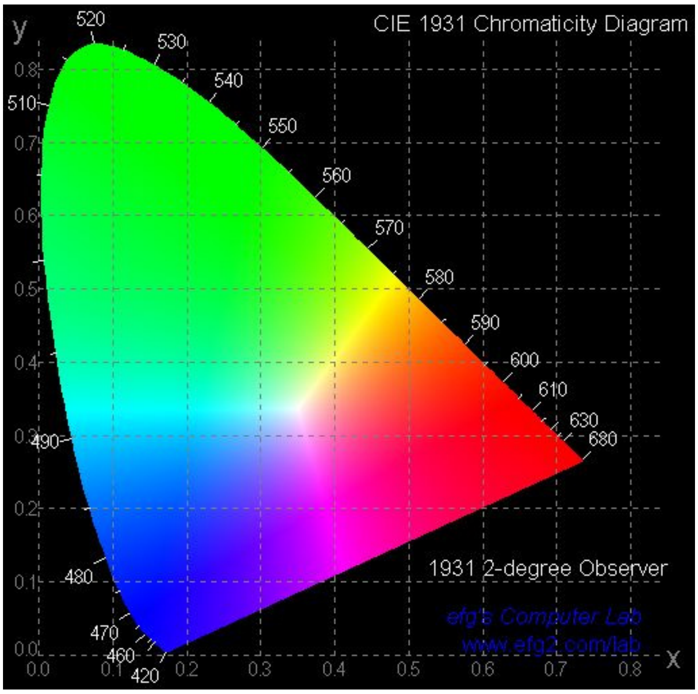


Figure 2: CIE-Yxy colour space

MAZeT GmbH 2005 APP-99-112e V1.0

MAZeT GmbH Sales • Göschwitzer Staße. 32 • 07745 Jena • Herr Frank Krumbein • Tel.: +49 3641 2809-17 • Fax: +49 3641 2809-12 • E-Mail: sales@mazet.de

These tolerances can be mutually matched and a good approximation to a colour-space-true reproduction quality be achieved by a simple target-addressed calibration transforming the measured values in a linear relationship. The appropriate correction matrix is determined by comparing the measured (RGB) values to the colorimetric nominal standard spectral values (XYZ) of selected targets (see Fig. 3).

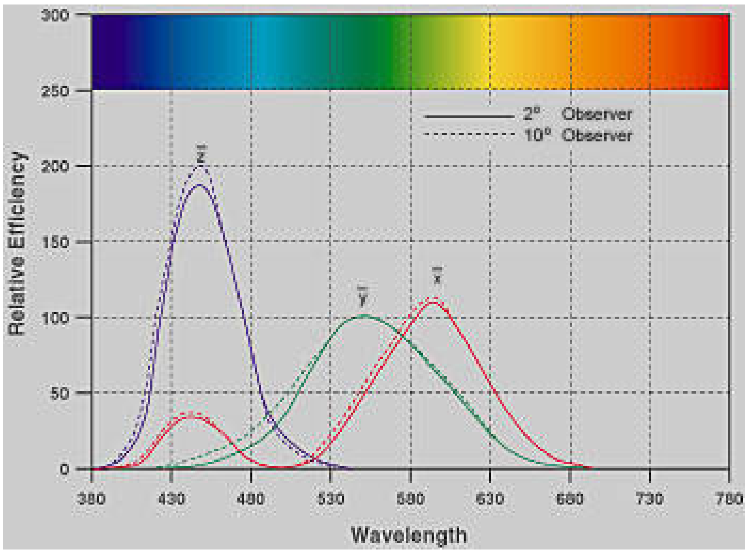


Figure 3 - Standard spectral value function

Colour sets under DIN or so-called colour checkers can be used as nominal master target colours. These target sets contain suitably defined support points in their colour space and are available with XYZ and Yxy nominal colour values (see Figure 4 – example of ColorChecker® from GretacMacbeth© for D65 illumination under DIN5033) for standardised light sources.

		CIE (1931)		
No.	*Name*	*x*	*y*	*Y*
1	dark skin	.400	.350	10,1
2	light skin	.377	.345	35,8
3	blue sky	.247	.251	19,3
4	foliage	.337	.422	13,3
5	blue flower	.265	.240	24,3
6	bluish green	.261	.343	43,1
7	orange	.506	.407	30,1
8	purplish blue	.211	.175	12,0
9	moderate red	.453	.306	19,8
10	purple	.285	.202	6,6
11	yellow green	.380	.489	44,3
12	orange yellow	.473	.438	43,1
13	blue	.187	.129	6,1
14	green	.305	.478	23,4
15	red	.539	.313	12,0
16	yellow green	.448	.470	59,1
17	magenta	.364	.233	19,8
18	cyan	.196	.252	19,8
19	white	.310	.316	90,0
20	neutral 8	.310	.316	59,1
21	neutral 6.5	.310	.316	36,2
22	neutral 5	.310	.316	19,8
23	neutral 3.5	.310	.316	9,0
24	black	.310	.316	3,1

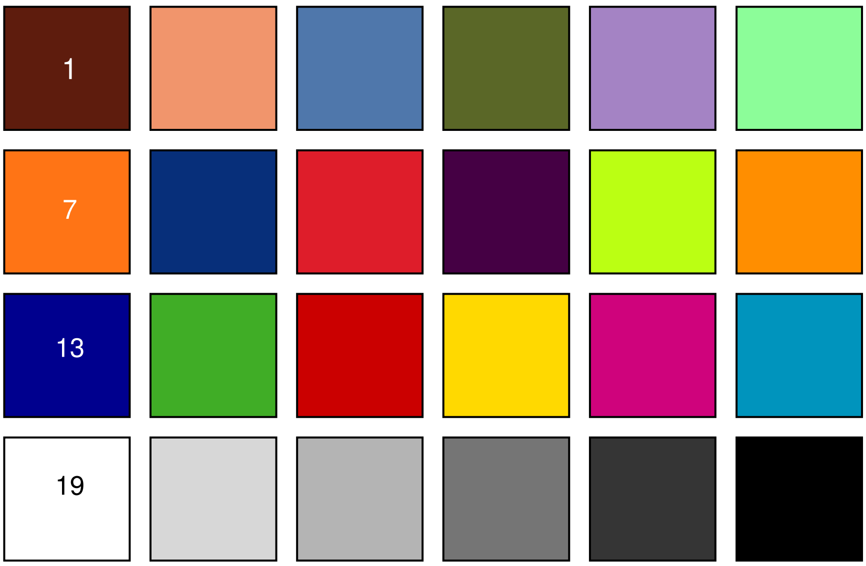


Figure 4: Colours of the GretagMacbeth© ColorChecker®

(s.a. http://www.edmundoptics.com/IOD/DisplayProduct.cfm?productid=1815)

MAZeT GmbH Sales • Göschwitzer Staße. 32 • 07745 Jena • Herr Frank Krumbein • Tel.: +49 3641 2809-17 • Fax: +49 3641 2809-12 • E-Mail: sales@mazet.de

A matrix of coefficients[1] A is determined by recording the values that have been measured for the colours to be balanced (RGB matrix$_{Ist}$) and performing a subsequent matrix operation, based on the standard colour values (XZ matrix$_{Soll}$).

Equation 1, matrixation

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \cdot \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

Equation 2; determination of matrix of coefficients

$$A = (Matrix_{Soll} \cdot Matrix_{Ist}^{T}) \cdot (Matrix_{Ist} \cdot Matrix_{Ist}^{T})^{-1}$$

Once a matrix of coefficients has been established[2], any measured RGB value can be transformed into an XYZ standard value (see Equation 1, matrixation). Using the transformation equations specified under DIN5033, they can then be transferred to any desired colour space. When recording the actual colour values, one should make sure that measurement is performed with the same illumination (e.g. D 65) that was selected to fabricate the standard colour values of colour masters. It should also be considered that MCS3 and MCSi colour sensors are suitable for measurement of non highly saturated colours. Consequently, they provide excellent results for many types of naturally (r)emitting surfaces. For a colour space thus restricted in its saturation, an accuracy of $\Delta E < 3..5$ (delta E[3]) can be achieved.

JENCOLOUR sensors (plus calibration) provide a compact low-cost alternative especially where colours have to be measured with an accuracy that is on a level with human vision. In some cases, they allow completely new technical approaches that have not been possible with such diversity or only possible in spectral terms (e.g. for the assessment of light colours and lighting surfaces). As a vital prerequisite therefore, the sensors must have been calibrated to the specific application or system. The target-referred method described herein represents a simple application for automated production processes with performance specs that can easily be integrated into a host system. With μC-based sensors, nothing more than simple software adjustments and integration of a calibration step in sensor manufacturing or prior to sensor operation are typically required. JENCOLOUR sensors include high-grade colour filters that are thermally stable and develop no aging effects. A recalibration is thus only required in the event of changes to the system environment.

---

[1] This approach assumes a global sensor calibration using a coefficient matrix and linear transformation from $\underline{F}_{korr} = \underline{\underline{A}} * \underline{F}_{ist}$.
2 Also refer to Exhibit
[3] For comparison, the human eye perceives colour differences starting from a level of $\Delta E = 3$

"Calibrate" Function on MCS-EB1 Evaluation Board

To demonstrate a targeted calibration of JENCOLOUR sensors, the application software of the MCS-EB1 evaluation board (Version 1.10) has been extended by the two functions *Calibrate* and *Yxy* (see Tools) and ColorChecker® and GretacMacbeth© have been used as demonstration samples.

All restrictions and advisory notes which are contained in this paper must be taken into account for interpretation of the results of these two functions.

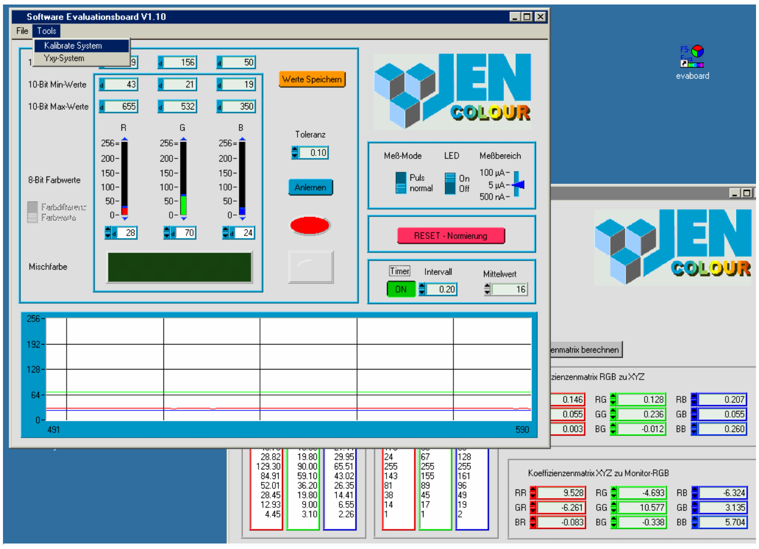


Figure 4 – Selection of "Calibrate"

For example, the Yxy values of the ColorChecker® under CIE 1931 and DIN 5033 refer to a D65 illuminator, while the evaluation system relies on white light LEDs of type NSPW 500 BS from Nichia.

As a consequence, the resulting absolute values show some variation although they have been calibrated to this standard. This means that the Yxy values are only approximately reached when measured after calibration. Furthermore, certain adverse influences by ambient light, thermal effects, sensor-position-induced variances and rotation of the optical axis have to be considered.

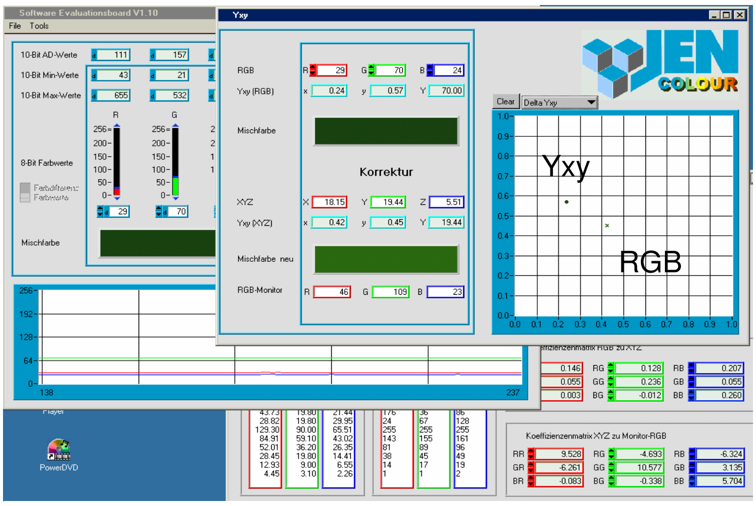
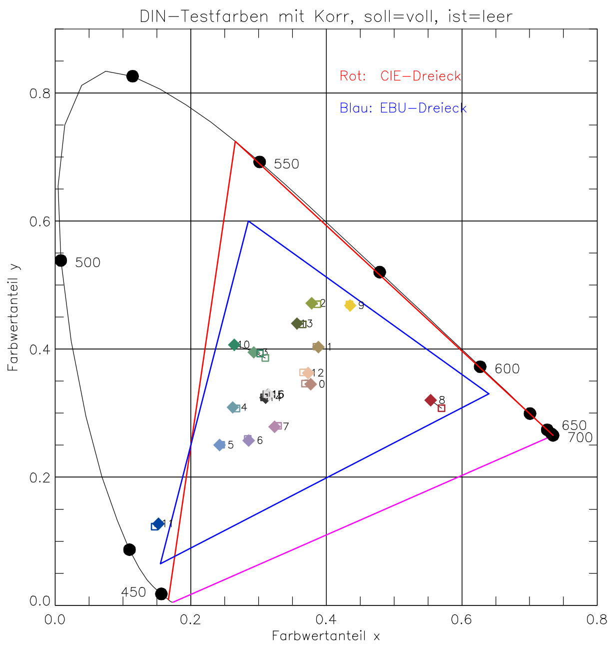


Figure 5: Result of GREEN target sample as an RGB / Yxy signal

After "Calibrate" has been selected in the Tools menu, previously measured values can be used for the ColorChecker® or be redetermined in manual mode. Once the respective correction matrixes have been calculated, the Yxy display function can be selected to represent the resulting RGB signal (non-calibrated) or the Yxy signal (calibrated) and/or the differential amount between the two in the colour space on the screen. One should however make sure that the timer is on and the sensor in a position above the sample to be measured. A direct comparison between a nominal (ColorChecker®) and an actual colour on the screen reveals differences in colour. In addition to the reasons described above or to possible changes in the environment, this may also be due to a certain variance in the colour representation of display sreens and panels.

E X H I B I T 1

DIN test colours with linear correction without offset and D 65 standard illuminant.



Index	Soll			Ist			Farb-abstand	Farbe Soll / Ist
	X	Y	Z	X	Y	Z		
0	32,75	30,01	24,15	31,28	29,38	24,22	3,20	
1	28,17	29,25	15,14	27,78	29,11	15,18	1,08	
2	24,75	30,86	9,80	25,77	31,30	9,54	3,11	
3	21,44	28,91	22,86	23,83	29,70	23,39	7,97	
4	25,78	30,41	42,21	26,78	30,74	42,51	2,91	
5	28,15	29,08	58,90	28,61	29,24	58,90	1,20	
6	32,24	29,08	51,67	31,75	29,01	50,96	1,63	
7	35,78	30,79	43,93	36,68	31,22	43,58	1,82	
8	17,83	10,30	4,04	21,32	11,50	4,58	9,05	
9	55,92	60,17	12,40	55,53	60,06	12,35	0,71	
10	12,55	19,32	15,65	15,68	20,40	15,81	14,46	
11	7,28	6,08	34,40	7,06	5,91	35,14	1,76	
12	59,30	57,63	41,98	57,04	56,75	42,25	3,61	
13	9,64	11,88	5,49	10,05	12,07	5,39	2,20	
14	3,45	3,60	4,06	3,40	3,58	4,05	0,51	
15	18,93	19,83	21,55	18,61	19,73	21,46	1,13	
16	72,82	76,13	82,24	72,09	75,87	82,10	1,04	

Board : DIN- test colors with linear correction without offset and
white LED lighting. Middle colour desistance in the CIE-L*a*b*-Raum: $\Delta E = 3$

E X H I B I T 2

Matrixation (coefficients) used to perform calibrated measurement with MCS3 and MCSi JENCOLOUR sensors

"Nominal" designates the matrix of XYZ values for a known set of target colours (in the given example "ColorChecker from GretagMacbeth" – see application paper "Colour Measurement With MCS3 and MCSi Sensors From MAZeT") with known standard colour values.

The colour values provide a defined basis for determining a matrix of coefficients with subsequent linear correction of the measured values.

"Actual" is the matrix of sensor values that were measured for RGB, referenced to the same colour and gray value targets.

$$\text{Nominal} := \begin{bmatrix} 33 & 27.81 & 23.9 & 20.43 & 24.99 & 28 & 33.32 & 37.61 & 20.57 & 54.89 & 12.13 & 6.23 & 58.88 & 9.33 & 3.42 & 18.73 & 72.02 \\ 29.79 & 29.03 & 30.4 & 29.48 & 30.84 & 29.76 & 29.37 & 31.32 & 11.23 & 58.99 & 20.37 & 6.43 & 57.1 & 11.7 & 3.6 & 19.81 & 76.11 \\ 24.52 & 14.91 & 9.9 & 21.26 & 40.38 & 56.85 & 53.2 & 45.4 & 4.34 & 11.97 & 15.33 & 27.58 & 41.31 & 5.39 & 4.06 & 21.5 & 80.93 \end{bmatrix}$$

$$\text{Actual} := \begin{bmatrix} 23.15 & 19.86 & 18.42 & 17.83 & 20.98 & 23.71 & 25.89 & 29.3 & 17.18 & 38.55 & 12.51 & 6.95 & 41.6 & 7.44 & 2.59 & 14.04 & 54.27 \\ 26.06 & 26.08 & 28.61 & 28.58 & 29.56 & 28.49 & 27.05 & 28.5 & 9.67 & 52.9 & 20.69 & 6.61 & 50.65 & 11.14 & 3.31 & 18.19 & 69.9 \\ 15.39 & 9.93 & 7.29 & 13.88 & 24.34 & 33.16 & 30.71 & 26.51 & 3.8 & 10.12 & 10.04 & 16.54 & 26.14 & 3.77 & 2.45 & 12.89 & 48.27 \end{bmatrix}$$

The formula to calculate and determine a 3 x 3 coefficients matrix is obtained as follows:

$$\text{Coefficients matrix} := \left(\text{Nominal} * \text{Actual}^T\right) \cdot \left(\text{Actual} * \text{Actual}^T\right)^{-1}$$

Where "Matrix T" means a transposed and "Matrix --1" an inverted version of a matrix:

$$\text{Coefficients matrix} = \begin{bmatrix} 1.508 & -0.036 & -0.18 \\ 0.212 & 0.973 & -0.081 \\ -0.042 & -0.091 & 1.832 \end{bmatrix}$$

This matrix is now used to transform all measured RGB values as follows:

For an RGB value of 10; 30; 25, the following XYZ is obtained: $R := 10$ $G := 30$ $B := 25$

$$X := R \cdot \text{Coefficients matrix}_{0,0} + G \cdot \text{Coefficients matrix}_{0,1} + B \cdot \text{Coefficients matrix}_{0,2} \qquad X = 9.501$$

$$Y := R \cdot \text{Coefficients matrix}_{1,0} + G \cdot \text{Coefficients matrix}_{1,1} + B \cdot \text{Coefficients matrix}_{1,2} \qquad Y = 29.272$$

$$Z := R \cdot \text{Coefficients matrix}_{2,0} + G \cdot \text{Coefficients matrix}_{2,1} + B \cdot \text{Coefficients matrix}_{2,2} \qquad Z = 42.645$$

or as a matrix operation respectively $\text{RGB} := \begin{bmatrix} R \\ G \\ B \end{bmatrix}$ $\text{RGB} = \begin{bmatrix} 10 \\ 30 \\ 25 \end{bmatrix}$ $\text{XYZ} := \text{Coefficients matrix} \cdot \text{RGB}$ $\text{XYZ} = \begin{bmatrix} 9.501 \\ 29.272 \\ 42.645 \end{bmatrix}$

MAZeT GmbH Sales • Göschwitzer Staße. 32 • 07745 Jena • Herr Frank Krumbein • Tel.: +49 3641 2809-17 • Fax: +49 3641 2809-12 • E-Mail: sales@mazet.de