COLORIMETRIC CHARACTERISATION OF TRICHROMATIC RGB DIGITAL IMAGES. I. COMPARATIVE HSL COLOUR FEATURES

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Abstract

The linear and uniform RGB colour space can include up to 255 x 255 x 255 = 16,581,375 colours, far exceeding the capabilities of the human eye in the 400 - 700 nm wavelength interval. In colour rendering technique, each pixel contains information about the trichromatic components red, green and blue, specific to additive mixes, in [r g b] form with each component value ranging between 0 and 255 or in standard form, in which case the colour cube faces are even. From the standpoint of the colour designer, any random colour can be characterised by hue, lightness and, saturation. The interpretation of the values of these basic features by digital image analysis is important in industrial practice for correcting printed designs and also for the technological analysis of print quality. The paper presents three methods of comparative analysis of trichromatic digital image and possibilities of retouching.

Keywords: colour, hue, saturation, lightness, model..RGB

The linear and uniform RGB colour space can include up to 255 x 255 x 255 = 16,581,375 colours, far exceeding the capabilities of the human eye in the 400 - 700 nm wavelength interval. In colour rendering technique, each pixel contains information about the trichromatic components red, green and blue, specific to additive mixes, in [r g b] form with each component value ranging between 0 and 255 or in standard form, in which case the colour cube faces are even.

The RGB Colour Cube

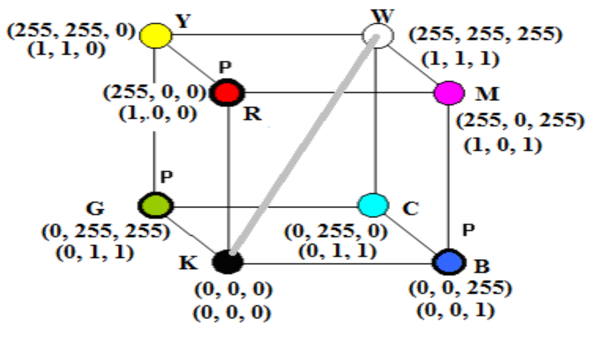

Figure 1. **The RGB colour cube**

A colour **C_{RGB} (102, 140, 166)** within the cube may be expressed through its parts:
R=102/255=0,40=1-C;
G=140/255=0,55=1-M;
B=166/255= 0,65 =1-Y,
considering:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} C \\ M \\ Y \end{bmatrix}; . \begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}.$$

Through the addition of black (K) in a subtractive mix in order to expand the colour palette, the following transformation relations are performed:

$$\begin{bmatrix} K \\ C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} \min(C,M,Y) \\ (C-K)/(1-K) \\ (M-K)/(1-K) \\ (Y-K)/(1-K) \end{bmatrix}; \begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} \min(1, C\times(1-K)+K) \\ \min(1, M\times(1-K)+K) \\ \min(1, Y\times(1-K)+K) \end{bmatrix}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} \min(1, C\times(1-K)+K) \\ \min(1, M\times(1-K)+K) \\ \min(1, Y\times(1-K)+K) \end{bmatrix}$$

MATERIAL AND METHOD

RGB trichromatic digital images

Trichromatic digital images are built on a m x n pixel network, with each pixel being assigned the triplet (r g b). The tridimensional (:,:,(r, g, b)) structure emerges. A random pixel (i,j), i=1:n – number of rows and j=1:m – number of columns, incorporates the r, g, b values in the 0:255 range or in standard form in the 0:1 interval, with double accuracy, i.e. double(R, G and/or B)./255. The practical methods employed on trichromatic spectrum images R (red), G (green), B (blue), using the Matlab work environment, are described below.

The Eric Boyer - Aldo Morales Method

For the purposes of the analysis, a colour palette with the h, l, s differentiating features was

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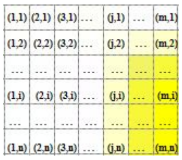
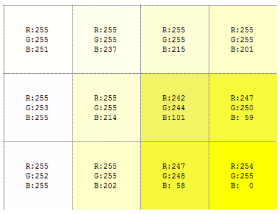
employed, with a 108 x 339 pixels size. The WA image is uncorrected, while the WD image is corrected by MOPM (Microsoft Office Picture Manager) using the command Picture – Auto Correct.





R:255 G:255 B:251	R:255 G:255 B:237	R:255 G:255 B:215	R:255 G:255 B:201
R:255 G:253 B:255	R:255 G:255 B:214	R:242 G:244 B:101	R:247 G:250 B: 59
R:255 G:252 B:255	R:255 G:255 B:202	R:247 G:248 B: 58	R:254 G:255 B: 0

Figure 2. **Geometry of trichromatic digital images**

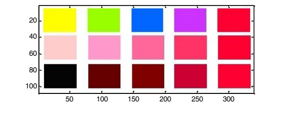


Figure 3. **Uncorrected WA image and properties**

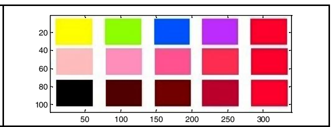


Figure 4. **WD image corrected using MOPM and properties**

Dimensions	339 x 108
Width	339 pixels
Height	108 pixels
Horizontal resolution	96 dpi
Vertical resolution	96 dpi
Bit depth	24

R:255 G: 4 B: 54	R:228 G: 5 B: 50	R:192 G: 31 B: 64	R:255 G:224 B:241	R:255 G:239 B:240	R:255 G:255 B:251
R:234 G: 7 B: 52	R:218 G: 19 B: 60	R:177 G: 34 B: 62	R:255 G:228 B:243	R:255 G:246 B:248	R:254 G:255 B:250
R:192 G: 27 B: 61	R:179 G: 34 B: 63	R:152 G: 49 B: 70	R:255 G:236 B:248	R:255 G:250 B:251	R:249 G:254 B:250
R:255 G:222 B:243	R:255 G:226 B:246	R:255 G:235 B:250	R:255 G:239 B:249	R:255 G:252 B:255	R:252 G:255 B:255
R:255 G:239 B:246	R:255 G:244 B:252	R:255 G:248 B:255	R:255 G:251 B:255	R:252 G:253 B:255	R:251 G:255 B:255
R:255 G:255 B:255	R:255 G:254 B:255	R:255 G:254 B:255	R:253 G:254 B:255	R:252 G:255 B:255	R:250 G:253 B:255

Figure 5. **WA image sequence, position 15, pixel (333,101) with values [152, 49, 70]**

R:181 G: 12 B: 43	R:156 G: 13 B: 41	R:133 G: 27 B: 49	R:244 G:173 B:189	R:244 G:207 B:215	R:255 G:246 B:249
R:158 G: 16 B: 42	R:147 G: 28 B: 50	R:121 G: 30 B: 48	R:249 G:187 B:200	R:255 G:222 B:229	R:255 G:247 B:250
R:133 G: 27 B: 49	R:120 G: 31 B: 49	R:106 G: 38 B: 53	R:249 G:203 B:214	R:253 G:228 B:234	R:252 G:241 B:245
R:246 G:175 B:191	R:244 G:183 B:198	R:251 G:205 B:216	R:242 G:211 B:219	R:255 G:243 B:249	R:255 G:250 B:252
R:244 G:206 B:217	R:246 G:213 B:222	R:254 G:228 B:237	R:255 G:236 B:245	R:255 G:244 B:250	R:253 G:247 B:251
R:255 G:246 B:252	R:255 G:243 B:248	R:255 G:247 B:251	R:255 G:247 B:250	R:255 G:251 B:255	R:247 G:242 B:246

Figure 6. **WD image sequence, position 15, pixel (333,101) with values [106, 38, 53]**

For the comparison the Eric Boyer – Aldo Morales method was used, by performing a pixel-by-pixel analysis based on the formula [1]; mydata(DXX,DYY)=sum(sum(abs(double(WD)-double(WA)))), for each of the three colour components:

RESULTS AND DISCUSSION

Red

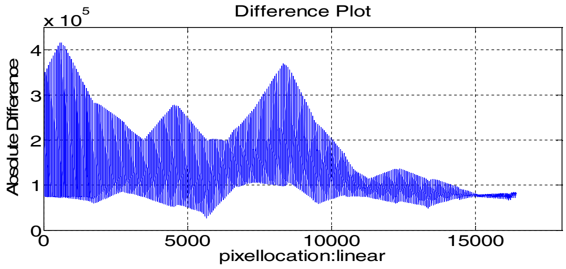


Figure 7. **Absolute difference for Red**

Green

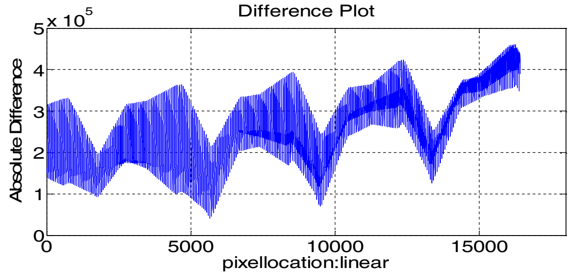


Figure 8: **Absolute difference for Green**

Blue

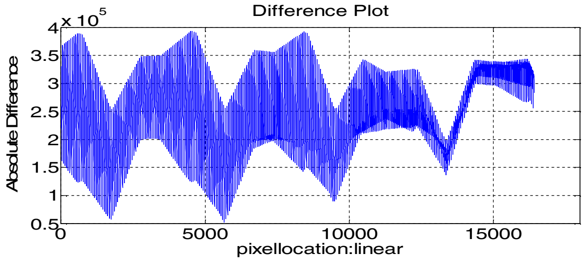


Figure 8. **Absolute difference for Blue**

Analysis based on colour characteristics

To perform the colour analysis, the specific Matlab functions **citestexy01hsl.m** and **locusimagine.m** were used.

Whiteness of printing material

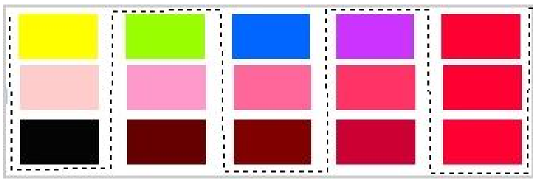


Figure 9. **Determining the uniformity of the printed background**

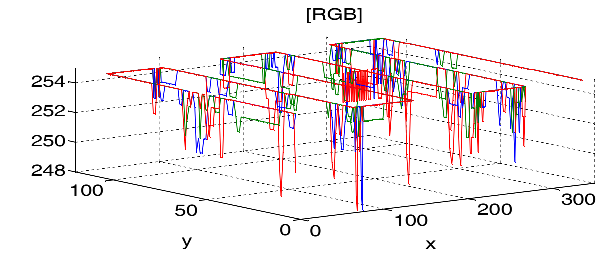


Figure 10. **RGB values of the printed background**

Whiteness is within the 248 ...255 range for R, G, B values, with the ideal whiteness value being 255 for the three colour components.

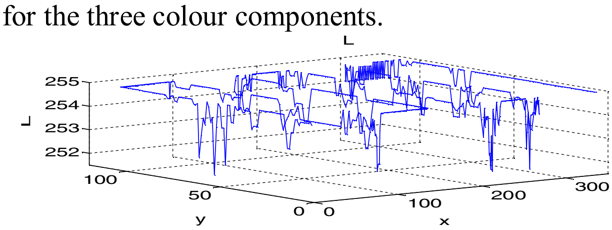


Figure 11. **LAB space luminance of pixels used in assessing printed background**

In the LAB space, L values fall within a limited range.

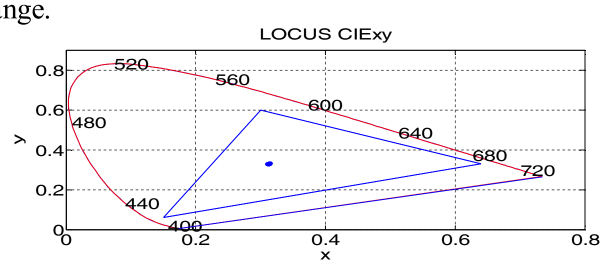


Figure 12. Whiteness of printed background in the CIE xy space

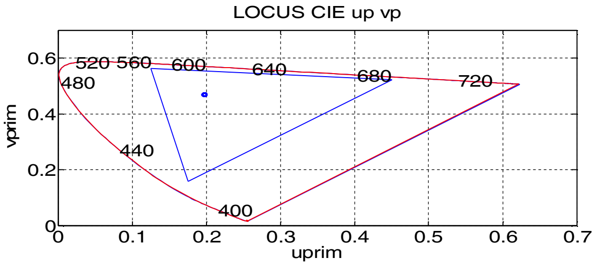


Figure 13. **Colour position of the printed background in the CIE upvp space**

CIE xy and CIE upvp whiteness occupy clearly defined positions, with acceptable spread levels.

Primary identification of colour positions in WA image

Figure 14. **Pixels selected from WA image to conduct colour analysis**

TABLE I. SELECTIVE COLORIMETRIC CHARACTERISTICS OF WA IMAGE

Nr.	RGB	CIE xy
1	255 255 0	0.4193 0.5052
2	153 254 0	0.3835 0.5337
3	1 102 255	0.1933 0.2135
4	204 51 255	0.2974 0.1969
5	254 0 50	0.5083 0.2575
6	254 204 203	0.3292 0.3296
7	255 153 203	0.3326 0.3018
8	255 103 154	0.3595 0.2943
9	255 51 102	0.4077 0.2819
10	254 0 50	0.5083 0.2575
11	4 4 4	0.3127 0.3290
12	102 0 0	0.6400 0.3300
13	128 0 0	0.6400 0.3300
14	204 0 51	0.4841 0.2441
15	254 0 50	0.5083 0.2575

Nr.	CIE upvp	CIE Lab
1	0.2039 0.5529	236.5969 -40.2385 201.2725
2	0.1776 0.5561	214.1893 -60.2587 180.9562
3	0.1494 0.3712	91.5621 -8.6686 -162.9228
4	0.2495 0.3717	98.2611 50.1237 -154.0697
5	0.4008 0.4568	57.6269 56.1573 5.2047
6	0.2092 0.4711	214.5614 -0.2261 -7.5609
7	0.2234 0.4560	178.3009 18.2102 -37.7619
8	0.2474 0.4557	139.0066 30.7848 -24.5354
9	0.2929 0.4557	98.0655 43.7497 -9.8667
10	0.4008 0.4568	57.6269 56.1573 5.2047
11	0.1978 0.4683	4.0000 -0.1982 -0.3550
12	0.4507 0.5229	21.6924 20.3778 19.7204
13	0.4507 0.5229	27.2219 25.5721 24.7471
14	0.3903 0.4428	47.0655 46.2765 -5.3402
15	0.4008 0.4568	57.6269 56.1573 5.2047

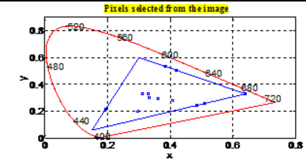


Figure 15. **Locus CIE xy**

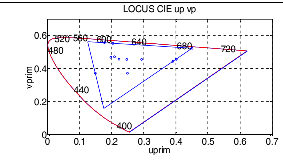


Figure 16. **Locus CIE upvp**

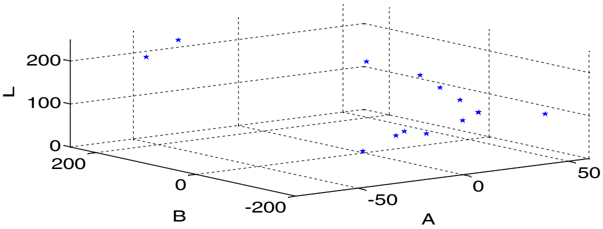


Figure 17. **The LAB space**

Hue

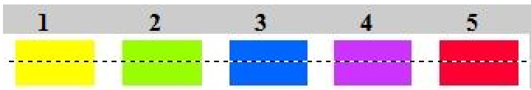


Figure 18. **The hue range**

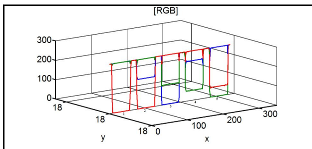


Figure 19. **RGB colour values of the hue range**

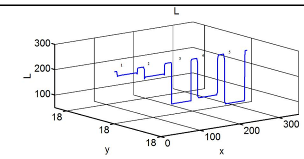


Figure 20. **L component in the LAB space of the hue range**

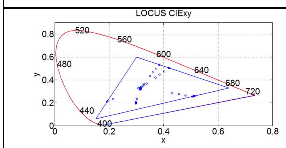


Figure 21. **Locus CIE xy**

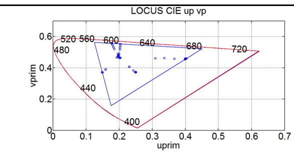


Figure 22. **Locus CIE upvp**

Saturation

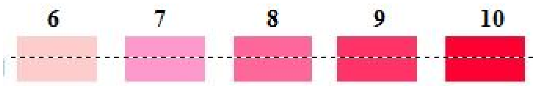


Figure 23. **Saturation range**

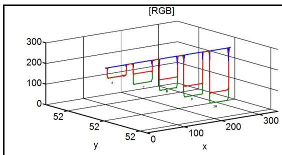


Figure 24. **RGB colour values of the saturation range**

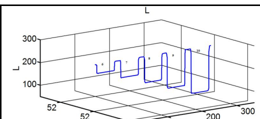


Figure 25. **Component in the LAB space of the saturation range**

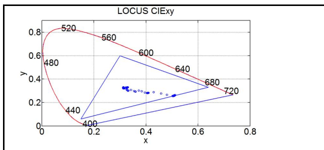


Figure 26. **Locus CIE xy**

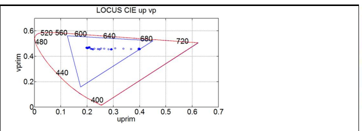


Figure 27. **Locus CIE upvp**

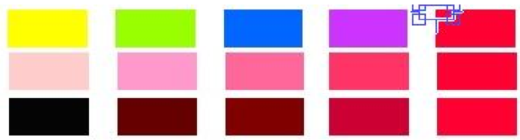
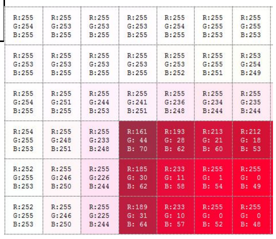


Figure 36. **WA image. Border analysis.**



R:255 G:254 B:255	R:255 G:253 B:255	R:255 G:253 B:255	R:255 G:253 B:255	R:255 G:254 B:255	R:255 G:255 B:253	R:255 G:255 B:253
R:255 G:253 B:255	R:255 G:253 B:255	R:255 G:253 B:255	R:255 G:253 B:255	R:255 G:253 B:252	R:255 G:255 B:251	R:253 G:254 B:249
R:255 G:254 B:255	R:255 G:251 B:255	R:255 G:244 B:253	R:255 G:241 B:251	R:255 G:236 B:248	R:255 G:234 B:244	R:255 G:235 B:244
R:254 G:255 B:253	R:255 G:248 B:251	R:255 G:233 B:248	R:161 G: 44 B: 70	R:193 G: 28 B: 62	R:213 G: 21 B: 60	R:212 G: 18 B: 53
R:252 G:255 B:253	R:255 G:246 B:250	R:255 G:226 B:244	R:185 G: 30 B: 62	R:233 G: 11 B: 58	R:255 G: 1 B: 54	R:255 G: 0 B: 49
R:252 G:255 B:253	R:255 G:246 B:250	R:255 G:225 B:244	R:189 G: 31 B: 64	R:233 G: 10 B: 57	R:255 G: 0 B: 52	R:255 G: 0 B: 48

pixel info(282,5) [161 44 70]

WA image sequence, position 5, pixel info (282,5) [161 44 70]

Mapping the WA image

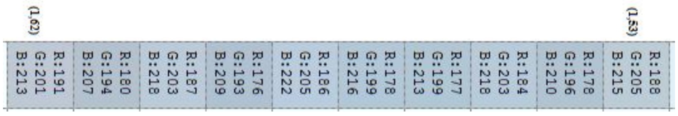


Figure 37. Mapping pixels (1,53:1,62)

Accidental pixels

Re-pixelating the WA image

Background colorimetric characteristics

Table II. Values used in re-pixelating the image WA

Colour characteristic	Nr.	R	G	B	
hue	1	255	255	0	
	2	150	255	0	
	3	0	100	255	
	4	200	50	255	
	5	255	0	50	
saturation	6	255	200	200	
	7	255	150	200	
	8	255	100	150	
	9	255	50	100	
	10	255	0	50	
luminance	11	1	1	1	
	12	100	0	0	
	13	125	0	0	
	14	200	0	50	
	15	255	0	50	

Recreating image WA

```
R(1:108,1:339)=255;
G(1:108,1:339)=255;
B(1:108,1:339)=255;
r=size(R)
g=size(G)
```

Luminance

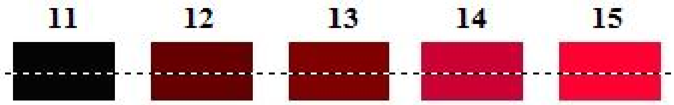


Figure 28. **Luminance range**

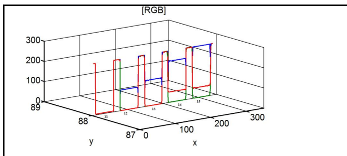


Figure 29. **RGB colour values of the luminance range**

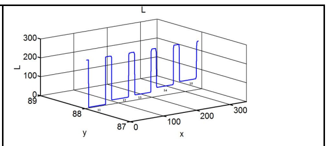


Figure 30. **Component of the LAB space of the saturation range**

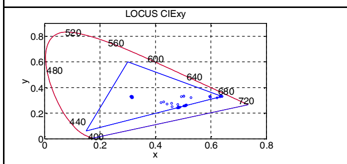


Figure 31. **Locus CIE xy**

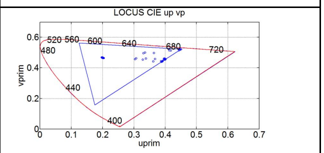


Figure 32. **Locus CIE upvp**

CIE xy chromaticity diagram

CIE upvp chromaticity diagram

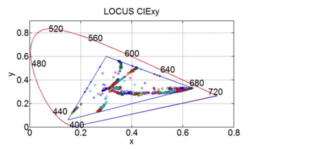


Figure 33. **The colour gamut of the WA image**

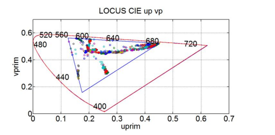


Figure 34. **Colour gamut of image WA**

CIE XYZ, LAB, Luv, Lch colour spaces

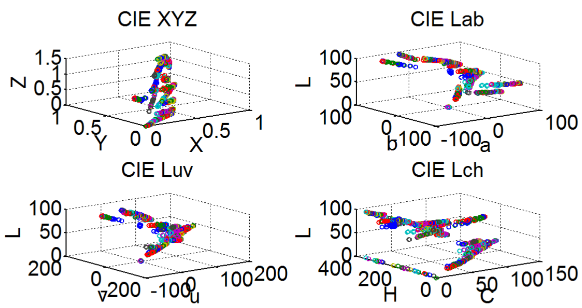


Figure 35. **Colour distribution in CIE spaces**

Constructive features

```
>> A=imread('WA.jpg.'); imtool(WA)
```

Border pixels

```
b=size(B)
%colour position
%1 yellow
R(5:33,9:59)=255;G(5:33,9:59)=255;B(5:33,9:59)=0;
%2 green
R(5:33,78:128)=150;G(5:33,78:128)=255;B(5:33,78:128)=0;
%3 blue
R(5:33,147:196)=0;G(5:33,147:196)=100;B(5:33,147:196)=255;
%4 violet
R(5:33,214:263)=200;G(5:33,214:263)=50;B(5:33,214:263)=255;
%5 red
R(5:33,282:332)=255;G(5:33,282:332)=0;B(5:33,282:332)=50;
%6
…………………………………………………………………………..
%15
R(73:101,283:333)=255;G(73:101,283:333)=0;B(73:101,283:333)=50;
R;G;B;
A=cat(3,R,G,B);
WK=double(A)./255
>> image(WK)
```

Edit – Copy Figure

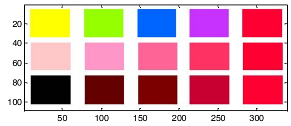


Figure 38. Matlab figure of **image WK** re-pixelated from image WA

Sequences I, II and III

I.

\>>**imtool**(WK)

Tools – Pixel Region (in standard form, 0;1)

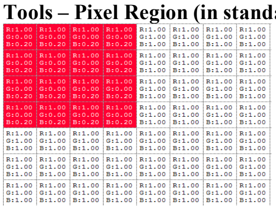


Figure 39. Sequence of **figure WK**, standard, pixel info (333,101) [1.00 0.00 0.20]

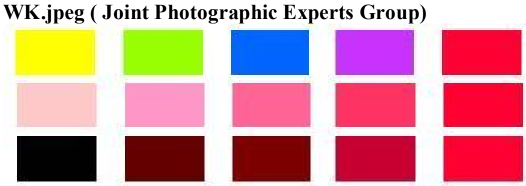
The standard structure of **image (WK)** in the interval 0:1 is pure, without any border pixels.

II.

\>>**imtool**(WK)

File – Save As

WK.jpeg (Joint Photographic Experts Group)



Dimensions	339 x 108
Width	339 pixels
Height	108 pixels
Horizontal resolution	96 dpi
Vertical resolution	96 dpi
Bit depth	24

Figure 40. **Image saved as WK, jpeg and its characteristics**

III.

>> WK=imread('WK.jpg');wk=size(WK)
wk =
108 339 3
>> imtool(WK)
Tools –Pixel Region

Structure **WK.jpg** contains border pixels.

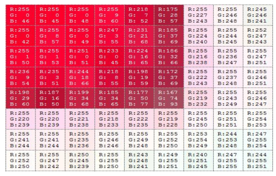
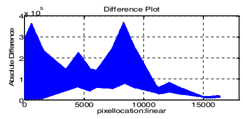
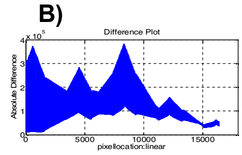
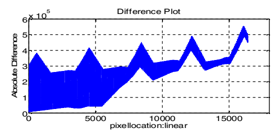
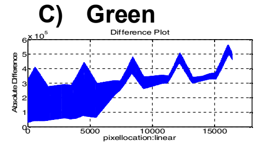
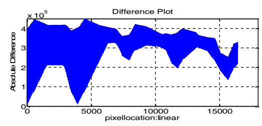
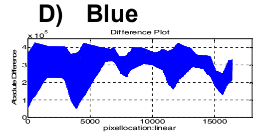


Figure 41. **Sequence from image WK, position 15, pixel (333,101) with values [167, 74, 93]**

Comparative analysis of WA and WK	Comparative analysis of WD and WK
A) Red  Figure 42. **Absolute difference for Red**	**A) Red** **B)**  Figure 43. **Absolute difference for Red**
B) Green  Figure 44. **Absolute difference for Green**	**C) Green**  Figure 45. **Absolute difference for Green**
C) Blue  Figure 46. **Absolute difference for Blue**	**D) Blue**  Figure 47. **Absolute difference for Blue**

The colour gamut of image WK.m

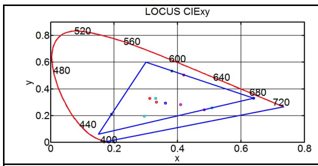
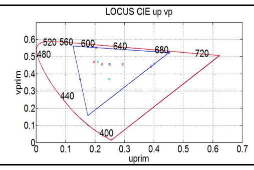
	

Figure 48. **Locus CIE xy**	Figure 49. **Locus CIE upvp (fig.36)**

CONCLUSIONS

1. Trichromatic digital images with the spatial geometric structure: A=cat(3, R, G, B) are characterised by the components R (red), G (green), B (blue) as follows:
R=A(:,:,1);
G=A(:,:,2);
B=A(:,:,3),

with values ranging in the 0:255 interval or in standardised form in the 0:1 interval.
Table A in standardised form serves to represent images saved with various extensions, such as jpeg.
2. The pixel-by-pixel comparative analysis using the ERIC BOYER – ALDO MORALES method requires two tables of the same size.
3. By correcting image WA, figure 3, using Microsoft Office Picture Manager a new image is obtained, i.e. WD, figure 4, with the change in the R/G/B ratio in the structure of border pixels (outline), figure 5 and figure 6, position 15, pixel (333,101).
4. The absolute differences, determined using the ERIC BOYER – ALDO MORALES method, are up to a maximum of 5 x 10^{-5}, with significant changes for the Green component, figure 8.
5. In the space between colour positions (1:15), the whiteness of the background approaches the ideal levels (a value of 255 for each of the R, G, B components), figure 11, as highlighted by the chromaticity diagrams CIE xy and CIE upvp, figure 13 and figure 14, through a limited representation domain.
6. The pixels selected from image WA, figure 15, are characterised by the chromatic values in table I and represented in the diagrams and spaces specific to locus CIE xy and CIE upvp, LAB, by means of specific spatial transformations, representations 16,17,18.
7. The transverse analysis of the hue, saturation, luminance colour characteristics (h, s, l) in the original, WA image - figures 20, 24, 29 - within each colour range, a change occurs in the R/G/B ratio for positions: 1:5, 6:10, 11:15, figures 20, 25, 30. For each colour range (h, s, or l) the value L in the LAB space serves to highlight the above mentioned colour positions, figures 21, 26, 31. In the chromaticity diagrams 22, 23, 27, 28, 32 and 33, each colour position (1:15) is characterised by several colours, which indicates the change in value of the initial R, G, B components. Component L, on the margin of the position, has rounded, gradient values.
8. The complete colour gamut of image WA is rendered in figures 34 and 35. The spread of colours is dependent upon the representation space, figure 36, the LAB space being the most uniform.
9. The multitude of colours in image WA, figure 37, is accounted for by border (outline) pixels – figure 38, adjacent transition pixels, mapping pixels – figure 39 and by accidental (isolated) pixels.
10. In recreating image WK similar to image WA, one starts from the R, G and B values in table II. Each colour position (1:15) is replaced with the new values to obtain figure WK in Matlab, figure 40, with values ranging between 0 and 1, standard form, for each of the three chromatic components, figure 41. Figure WK is pure in colour terms, with a clear-cut distinction between the colour position (1:15) and the white background, figure 41. Sequence II leads to image WK with the **.jpeg** extensions (one of the available options), corresponding to figure WK, with the properties listed in figure 42. Image WK. jpg includes the pixels marked in the 0:255 interval, figure 43. In image WK the border and adjacent pixels are identified.
10. The comparative analysis of images WA, WD and WK is outlined in figures 44 – 49, with WK serving as benchmark for the comparison. Differences from image WK are insignificant, i.e. the R, G, B values in the two images (WA and WD) are close.
11. Correction using MOPM results in changes to the R, G, B values.
12. The colours that form figure WK, 15 in total, are present in figures 50, 51 and in locus CIE xy and CIE upvp of figures 16 and 17. In conclusion, in order to perform a comparative analysis of scientific data the use of background pixels is recommended.

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