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A NEW CHROMATIC ENCODING FOR MACHINE VISION INVARIANT TO THE CHANGE OF ILLUMINANT

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MOTS CLÉS:
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Une nouvelle codification chromatique pour vision artificielle insensible au change spectral de l'illumination

SUMMARY: The human visual system is adapted to assign constant chromatic attributes to objects in spite of the alterations in spectral distribution of the illuminant or the spatio-chromatic arrangement of the visual field. This visual capacity is called colour constancy. However, artificial vision systems do not usually have this ability. So, when these vision systems operate outdoors for example, chromatic codification errors are usually very significant. Basing ourselves on the theories about colour constancy in the human visual system, fundamentally in the principles of the Retinex theory, in this work we have implemented an algorithm for colour constancy. For this, we propose some new colour-descriptors for a stimulus, practically invariant to the spectral change of the illuminant. Finally, we check experimentally the statistical stability of these colour-descriptors, corresponding to standard colour samples (Munsell chips), against a range of standard illuminants, as well as their validity rank.

RÉSUMÉ: Les observateurs humains sont capables d'assigner aux stimulus des attributs chromatiques constants dans des environnements qui changent, comme par exemple, à la suite d'une variation spectrale de l'éclairage. Cette capacité visuelle porte le nom de constance de couleur. Toutefois, les systèmes de vision artificielle (SVA) n'ont pas cette extraordinarie aptitude. Ainsi, quand ceux-ci agissent à l'extérieur par exemple, les erreurs de codage chromatique sont habituellement assez significatives. Prenant en considération les théories de la constance de couleur du système visuel humain (SVH), comme la théorie Retinex, nous avons implementé sur un SVA un algorithme de constance de couleur fondé sur des nouveaux descripteurs de couleur du stimulus à peu près invariants au changement spectral de l'éclairage. La stabilité statistique des descripteurs-couleur face à une gamme d'illuminants sur des échantillons standard de couleur (papilles de Munsell) est remarquable.

INTRODUCTION

The property of colour constancy in the Human Visual System (HVS) lies in the perceptual ability to assign the same chromatic attributes (lightness, hue and chroma) to stimuli which vary colorimetrically due to the spectral change of the illumination. That is to say, information about the colour stays invariant. Classic psychophysic displays of this ability can be seen in the experiments of E. H. Land [1, 2] and R. W. G. Hunt [3, 4].

At present, it is established that the human visual system is capable of compensating for colorimetric shift which is produced in the colour stimulus due to the effect of change in the illuminant, creating an adaptative shift which permits the visual system to maintain the same judgement about colour appearance around the stimulus [5]. However, Machine Vision Systems (MVS) only capture the colorimetric shift because optical sensors, like those of the CCD type, operate as very simple retinas [6, 7].

Colour constancy is a problem to be solved in the industrial ambit of colorimetric reproduction [8, 9] and in applications for the recognition of objects by chromatic discrimination [10]. Thus, in artificial vision systems which operate under illumination which is not controlled for example, outdoors, the property of the invariance of the colour is essential for not making errors in the detection and recognition of an object by its colour.

To be able to implement a compensated chromatic codification of the effect of the illuminant (algorithm of colour constancy) in an MVS it is important to understand how the visual system work [11]. On one hand, planning and experimenting with those aspects of chromatic vision in the HVS, grouped under the ability of colour constancy, will help us to develop new algorithms of chromatic codification in artificial vision systems. On the other hand, there are also other interpretations of a mathematical nature concerning colour constancy, grouped under the denomination of linear models [12, 13].

Specifically, in this work we have used the concepts of the Retinex theory [2, 14-17], to design a chromatic codification based on new colour-descriptors, practically invariant to the change of the illuminant.

Through the use of certain digital image techniques (histogram, colour-quantization, colour-segmentation), the design of this chromatic codification made from initial RGB signals is facilited. The statistical stability of colour-descriptors will be tested against a range of four spectrally different CIE standard illuminants (A, D65, D32 and C) and using a set of standard colour samples (Munsell chips) as a scene. Finally, we will show the general scheme of an algorithm for chromatic recognition of objects enabled with colour constancy.

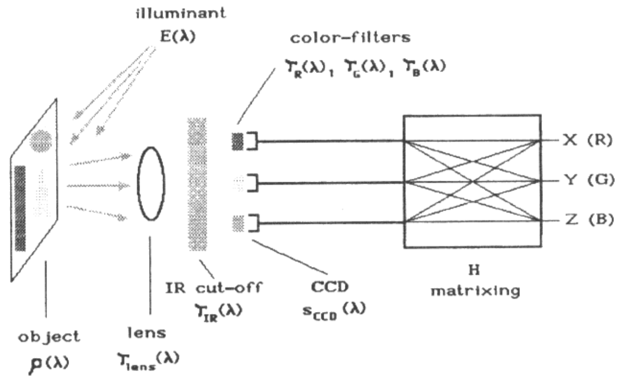


FIG. 1. — *Chromatic codification processing scheme of the CCD RGB camera.*

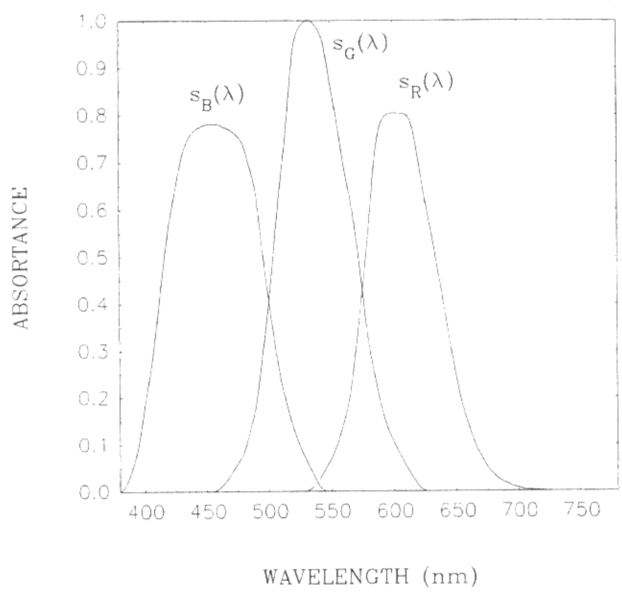


FIG. 2. — *Spectral response of the CCD RGB SONY XC 711-P camera.*

Colorimetric description of the MVS

Our artificial system consists of a CCD RGB camera, model SONY-711P connected to a typical hardware-software unit for the digital processing of images [6, 7]. The chromatic codification processing of a CCD RGB camera is as shown in *figure 1* [18].

The light coming from objects, the colour-signal $C(\lambda) = E(\lambda) \cdot \rho(\lambda)$ is filtered by the optical components of the camera (focus lens, IR cut-off filter, CCD array, colour filters) in accordance with an additive colorimetric reproduction, based on the spectral responses $s_R(\lambda)$, $s_G(\lambda)$ y $s_B(\lambda)$ of the CCD RGB camera *(fig. 2)* :

$$s_k(\lambda) \propto \tau_{\text{lens}}(\lambda) \cdot \tau_{\text{IR}}(\lambda) \cdot s_{\text{CCD}}(\lambda) \cdot \tau_k(\lambda) \qquad (1)$$

$$k = \text{R, G, B} .$$

In the RGB data digital output, of 8 bits, the level of grey R_k^x of the pixel x under the spectral channel k is described as follows :

$$R_k^x \propto \int_{380}^{780} E^x(\lambda) \cdot \rho^x(\lambda) \cdot s_k(\lambda)\, d\lambda . \qquad (2)$$

It is always possible and necessary to apply colour-digitalization to a standard colorimetric space. In *figure 3* the position of the three RGB primary colours of the camera in the CIE 1931 XYZ chromatic diagram is shown, describing the triangle which contains all the colours reproducible by these three primary colours. This is carried out by means of the external processing of matrixing not often implemented in the electronic design of the output register of the CCD RGB camera. So, with regard to CIE-1931 XYZ space, the matrixing H is :

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{CIE-1931}} = \frac{100}{255} \begin{bmatrix} 0.6259 & 0.2071 & 0.1670 \\ 0.4162 & 0.4787 & 0.1051 \\ 0.0007 & 0.0496 & 0.9497 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix}_{\text{CCD}} \tag{3}$$

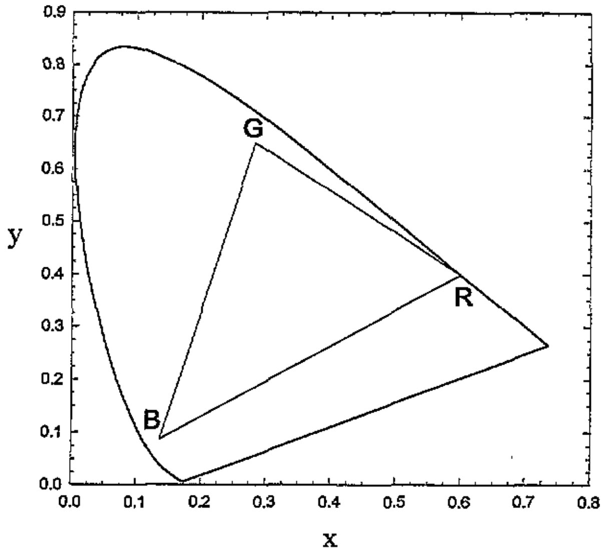


Fig. 3. — *Representation in the CIE-1931 colour space of the triangle of colour reproduction formed by the chromatic coordinates of the primary colours of the CCD RGB camera (spectral response).*

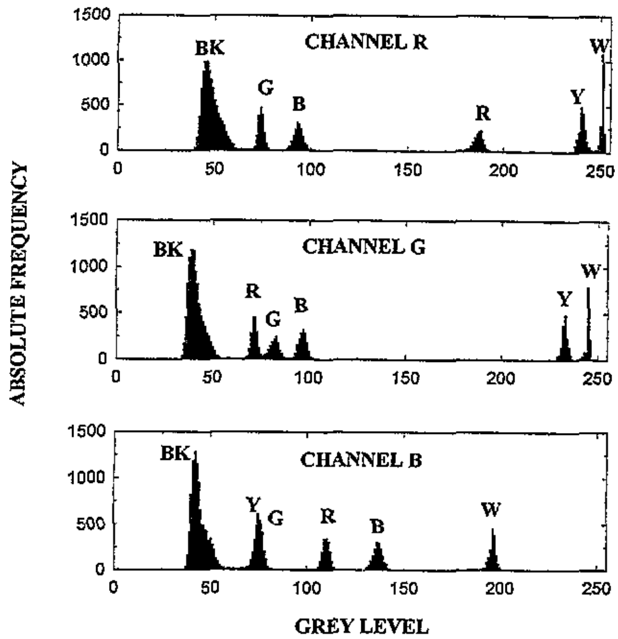


Fig. 4. — *Representation of the histogram of the RGB images of a scene formed by various coloured areas (Mondrian) : BK (black), R (red), Y (light yellow), G (dark green), B (blue), and W (white).*

The lack of unification when it comes to agreeing about an (internal) output register of the optical sensors, like those of CCC RGB type, in a unique standard colourimetric space (CIE XYZ, NTSC, RGB, etc), due to different applications, makes a certain colour digitalization/reproduction difficult. Generally, reproduction problems come upt with regard to the saturation variable, a reduction of a factor 2 in our CCD RGB camera, for which electronic [19] as well as optical-colorimetric [18] compensation methods are required. On the other hand, to measure colorimetric reproduction capacity of optical sensors (actually, that of their colour filters), there are mathematical calculus methods of goodness or reproduction quality [20]. So, the quality factor of the filters of our CCD RGB camera is of 0.9421 (a value of one unit would mean a perfect colour reproduction in the CIE XYZ space).

Image processing

Typical scenes for studying colour constancy in HVS are the Mondrian patterns : a set of matt coloured areas. This is why we will use these same patterns as scenes, in order to study an MVS.

After capturing the image of the scene by means of three images R, G and B "lightness", of pixel size 512×512, we perform a reduction/compression process to 128×128 pixels. In continuation, we do for each of the R, G and B images, a register of appearance frequencies for each level of grey, this is to say, a histogram for each image. In this way, in a scene composed of white (W), blue (B), dark green (G), red (R), light yellow (Y) cards, approximately of equal size, on a black background (BK) subjected to a pre-determined strength of light, it is possible to distinguish clearly the six peaks in a certain level of grey, for each one of the channel-histograms (*fig. 4*).

By applying a texture analysis process over the R, G and B images, called colour-quantization [21], it is possible to reduce the peak colour-area i to a unique value $(\overline{R}_i, \overline{G}_i, \overline{B}_i)$. Subsequently, it would always be possible to apply colour-segmentation techniques to coordinate the colorimetric information $(\overline{R}_i, \overline{G}_i, \overline{B}_i)$ with the spatial information x [22, 23]. Specifically, we have applied in an indirect way this double chain of processes. The determination of each $(\overline{R}_i, \overline{G}_i, \overline{B}_i)$ has been taken according to the more frequent grey level or brightness, while colour-segmentation has been effected by coordinating the colorimetric information with the spatial one to display the results much better. The final objective of this double process would be to automate it completely in an algorithm for the chromatic recognition of objects, combining spatial and chromatic information. But, for the moment, it allows us to perform a set of tasks as for example image understanding modules (object labeling) to be able to apply a certain chromatic codification and understand the results better.

Under this representation, the following experimental fact related to colour constancy is produced : the ordering of grey levels or brightnesses the three R, G, B, channels of "lightness" is kept practically unaltered when the illuminant is changed. For example, in *figure 5,* we can see this fact when we go from illuminant A (representing an incandescent lamp, that is to say, a orange light) to illuminant D65 (representing daylight, that is to say, a bluish light).

Therefore, it would be interesting to express mathematically this global behaviour of colorimetric information of the image against the spectral change of the illuminant. This would permit us to develop a *chromatic codification practically invariant to light* changes, starting from RGB signals. To carry out this idea, we will base ourselves on the principles of the Retinex theory of colour vision.

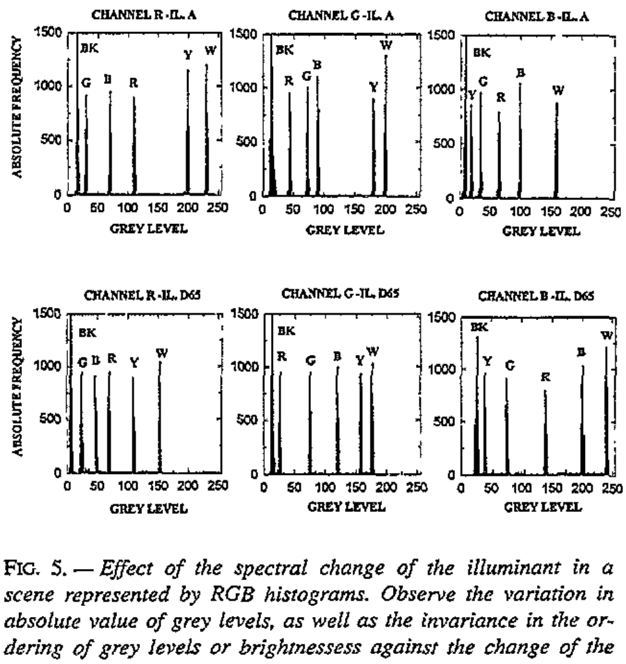


FIG. 5. — *Effect of the spectral change of the illuminant in a scene represented by RGB histograms. Observe the variation in absolute value of grey levels, as well as the invariance in the ordering of grey levels or brightnessess against the change of the illuminant.*

Chromatic codification

The Retinex theory proposed by Land [2, 14] rests on the assumption that the human visual system codifies colour by taking into account the comparison of three width lightnesses independently calculated in each spectral band R (long), G (medium), B (short). The underlying information in the edges (sudden change of intensity) between the colour stimuli is, according to this theory, the one used by the visual system to codify chromatically by means of the lightness variable. The computational version, from the point of view of the digital processing image, of the lightness variable is the integrated reflectance ρ_k^x [15-17] :

$$\rho_k^x = \frac{R_k^x}{R_k^W} \tag{4}$$

where k is the waveband or spectral channel R, G, B, x is the pixel of the image, R_k^x the grey level of the pixel x in the channel k and R_k^W the grey level of the white pixel (W) in the channel k. Basically, the principles of Retinex theory are equivalent to the ancient *von Kries* transformation that it has been used for years by the CIE [9] and by different colour appearance models [3-5].

Generally, (R^W, G^W, B^W) can be expressed as $(R_{max}, G_{max}, B_{max})$, because from a colorimetric point of view, it will always be fulfilled. In the same way, if there is a black stimulus (BK) in the scene, this will be specified as $(R^{BK}, G^{BK}, B^{BK}) = (R_{min}, G_{min}, B_{min})$. In this way, once colour-quantization and colour-segmentation have been applied, it will be possible to detect and recognise the black and the white when they are present in the image, coordinating the chromatic and spatial information. That is to say, a colour area will be specified as white (black) when the values $R_{max}(R_{min})$, $G_{max}(G_{min})$ y $B_{max}(B_{min})$ coincide in the same region :

$$\forall x \equiv (ij)/R^x = R_{max}(R_{min}) \wedge G^x = G_{max}(G_{min}) \tag{5}$$

$$\wedge\, B^x = B_{max}(B_{min}) \Rightarrow x \equiv \text{label: white (black)}.$$

In this way, in an image made of colour-stimuli n, like those in the previous example,

$$R_{max} = \max\{R_1, R_2, R_n\} \Rightarrow$$

$$R^W = \max\{R^Y, R^G, R^B, R^R, R^{BK}, R^W\}.$$

(In the same way for R_{min}, and for $G_{max}(G_{min})$, $B_{max}(B_{min})$.

Nevertheless, it is important to write up the difference between R_{max} and $\max(R^x)$ [16]. $R_{max}(R_{min})$ avoids the "noise tails" which appear in histograms, once the colour-quantization has been applied, while max (R^x) takes the maximum value of all the pixels R^x of the image, thus taking into account the noise effect for which the colorimetric information taken is not completely precise.

Let us consider again *figure 5* and remember that the question was, how to be able to express mathematically this global behaviour of the colorimetric information of the image, against the spectral change in the illumination. It is evident that the chromatic coordinates vary when the illuminant changes. However, we can observe the "accordion" behaviour of all the peaks in each channel-histogram against the variation of the illuminant. For instance, $\{W, B, R, G, Y, BK\}_{channel-B}$ rank-series under illuminant A is maintained even under illuminant D65, but it is necessary to normalize the relative distances between a pair of colour-peaks/stimuli: $B^R(D65) > B^R(A)$, but $B^R(D65) < B^B(D65) \Rightarrow$ stimulus $B^R(A, D65) =$ *rank three*, stimulus $B^B(A, D65) =$ *rank two*. That is to say, the relative distance between a pair of colour-peaks/stimuli *i, j* ($R_i - R_j$) is rescaled with regard to the effective colorimetric dynamic rank ($R_{max} - R_{min}$). So then, we can consider that the colour-descriptor:

$$\alpha_{ij} = \frac{R_i - R_j}{R_{max} - R_{min}} \cdot 100 \qquad (6)$$

can be stable against the spectral change of the illuminant ($\beta_{ij} \rightarrow$ channel G, $\gamma_{ij} \rightarrow$ channel B).

The relationship between the descriptor α_{ij} with the integrated reflectance $\rho^i \equiv \rho^x$ is evident:

$$\text{if } R_{max} \equiv R^W \wedge R_{min} \equiv R^{BK} = 0 \Rightarrow \alpha_{iBK} = \frac{R_i}{R^W} \cdot 100 = \rho^x_R \cdot 100 . \qquad (7)$$

This means that in the design of the colour-descriptors ($\alpha_{ij}, \beta_{ij}, \gamma_{ij}$), the simultaneous contrast present in the scene by means of ($R_i - R_j$) is implicit.

We can now differenciate clearly between the additive and substractive reproduction of colours, in accordance with the expressions of colour-descriptors ($\alpha_{ij}, \beta_{ij}, \gamma_{ij}$):

— additive reproduction:

$$j \equiv BK \rightarrow R_{min} \equiv R^{BK}$$

$$\Rightarrow \alpha_{iBK} = \frac{R_i - R_{min}}{R_{max} - R_{min}} \cdot 100 \qquad (8)$$

particular case:

$$R_{min} = 0, R_{max} \equiv R^W \rightarrow \alpha_{iBK} = 100 \cdot \rho^i_R$$

(integrated reflectance);

— substractive reproduction: $j \equiv W$

$$\Rightarrow \alpha_{iW} = \left(1 + \frac{R_i - R_{max}}{R_{max} - R_{min}}\right) \cdot 100 . \qquad (9)$$

Moreover, if we bear in mind that the HVS response against the intensity can be described logarithmically [4], we can improve these colour-descriptors in the following way:

— additive reproduction:

$$\alpha'_{iBK} = \frac{\log(R_i + 1) - \log(R_{min} + 1)}{\log(R_{max} - R_{min} + 1)} \cdot 100 \qquad (10)$$

— substractive reproduction:

$$\alpha'_{iW} = \left(1 + \frac{\log(R_i + 1) - \log(R_{max} + 1)}{\log(R_{max} - R_{min} + 1)}\right) \cdot 100 \qquad (11)$$

(in a analogous way for $\beta'_{iBK}, \beta'_{iW}$ y $\gamma'_{iBK}, \gamma'_{iW}$).

At a practical level, the substractive colorimetric reproduction, based on the white reference stimulus is the most used (excluding reproduction on TV). For that reason, we are going to test experimentally the statistical stability of the triplet of colour-descriptors ($\alpha'_{iW}, \beta'_{iW}, \gamma'_{iW}$) against a range of spectrally different illuminants. On the other hand, it will also be interesting to apply the same test to the three colour-descriptors ($\alpha'_{iBK}, \beta'_{iBK}, \gamma'_{iBK}$).

RESULTS

To test the statistical stability of the colour-descriptors against the change of the illuminant, we have chosen 10 Munsell samples (standard colour samples belonging to the colour Munsell Book) of lightness value V = 6, croma C = 6, with the fundamental hues H = 5.0 (R, YR, Y, GY, G, BG, B, PB, P, RP), on a black background, arranged as shown on *figure 6*. In all, we have identified in the scene 12 well-defined colours: 10 Munsell samples, the black of the background and the white of the cards holding the samples.

With a configuration d/45 (difused illumination/capture image at 45), we have captured the same scene under two different illuminants, CIE-A (incandescent light, partially orange) and CIE-D65 (daylight corresponding to a colour temperature (T_c) of 6 500 K), provided by an illumination booth (Macbeth). The reading of the values

$$(\max(R^x)_A = 197, \ \min(R^x)_A = 13),$$
$$(\max(G^x)_A = 173, \ \min(G^x)_A = 8),$$
$$(\max(B^x)_A = 145, \ \min(B^x)_A = 12),$$

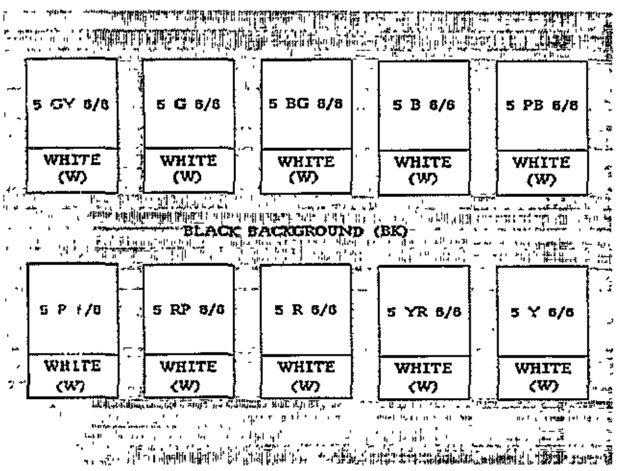


FIG. 6. — *Spatial arrengement of colour samples in the experimental test (Mondrian).*

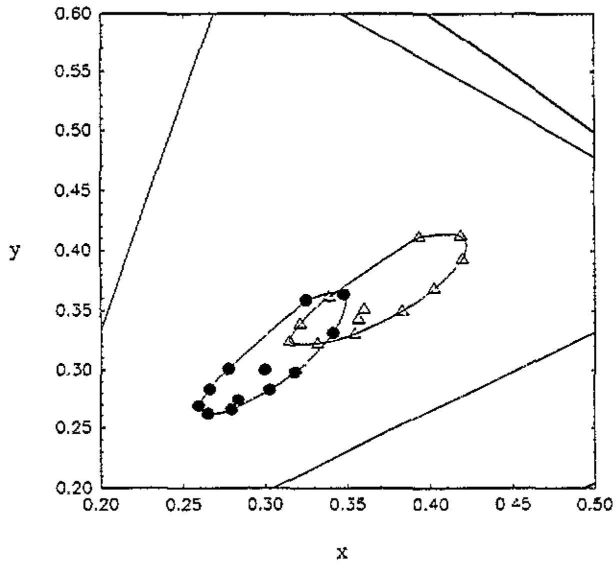


FIG. 7. — *Chromatic coordinates of Mondrian test colour samples in the CIE-1931 (x, y) space : (●) samples under D65 illuminant ; (Δ) samples under A illuminant. Observe the strong colourimetric shift produced by the change of illuminant.*

and,

$$(\max (R^x)_{D65} = 154, \quad \min (R^x)_{D65} = 12),$$
$$(\max (G^x)_{D65} = 176, \quad \min G^x)_{D65} = 8),$$
$$(\max (B^x)_{D65} = 227, \quad \min (B^x)_{D65} = 21)$$

show us the way in which the CCD RGB camera acquires the chromaticity of the illuminants.

Once the three RGB "lightness" images have been captured and digitalized, we have progressively carried out our particular "colour-quantization" (by means of programmes designed in C) to obtain the values $(\overline{R}_i, \overline{G}_i, \overline{B}_i)$, with their respective deviations $(\sigma_R, \sigma_G, \sigma_B)$, to identify the peaks of the three channel-histograms and to be able to carry out the phase of the designed chromatic codification. We can simultaneously use the matrixing H of the system to represent the colour samples in the CIE-1931 space *(fig. 7)*, where the variation of colourimetric coordinates when the illuminant changes can be observed.

The experimental fact of having captured the scene under a configuration d/45, makes our "colour-quantization" and recognition processing difficult, mainly due to the fact that the optical components of the camera prevent the recording of all the Munsell samples of the same size. Therefore, to improve the displaying of the results and establish a reliable statistical variation of the colour-descriptors $(\alpha'_{iW}, \beta'_{iW}, \gamma'_{iW})$ and $(\alpha'_{iBK}, \beta'_{iBK}, \gamma'_{iBK})$ against various illuminants, we have captured again the same scene under two new illuminants (with configuration d/0) defined as D32 (daylight of a $T_c = 3\,200$ K) and CIE-C (day light partially blue). Again, the values

$$(\max (R^x)_{D32} = 240, \quad \min (R^x)_{D32} = 18),$$
$$(\max (G^x)_{D32} = 223, \quad \min (G^x)_{D32} = 9),$$
$$(\max (B^x)_{D32} = 201, \quad \min (B^x)_{D32} = 16),$$

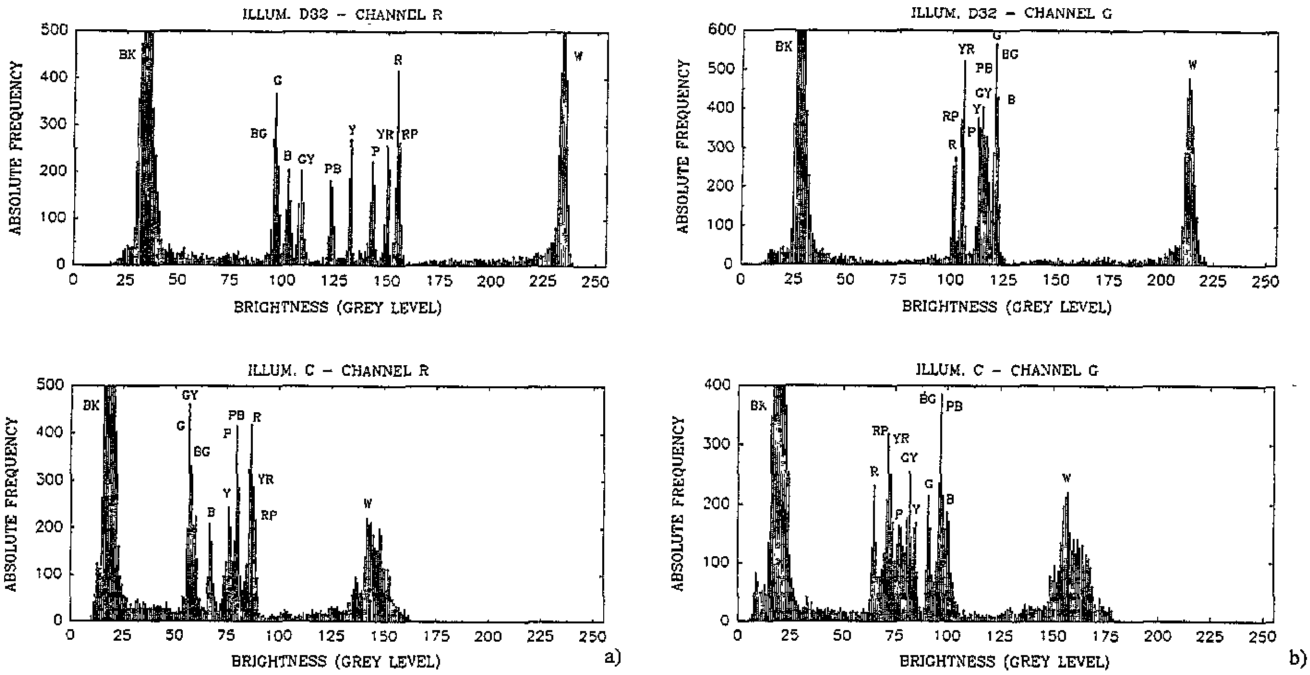
and

$$(\max (R^x)_C = 164, \quad \min (R^x)_C = 9),$$
$$(\max (G^x)_C = 184, \quad \min (G^x)_C = 5),$$
$$(\max (B^x)_C = 248, \quad \min (B^x)_C = 14)$$

show us the way in which the CCD RGB camera acquires the chromaticity of the illuminants. In *figure 8a, b, c,* we represent the channel-histograms of the same image captured under these last illuminants.

Once the average values $(\overline{R}_i, \overline{G}_i, \overline{B}_i)$ have been calculated, by means of this colour-quantization/segmentation method, we proceed to the designed chromatic codification. Of the 66 possible different combinations $(\alpha_{ij}, \beta_{ij}, \gamma_{ij})$, the experimental results show that 88 % of these colour-descriptors stay practically stable against the range of illuminants used, within a rigorous criterion of reliability. This imposed criterion requires that the standard deviations of the three descriptors $(\alpha_{ij}, \beta_{ij}, \gamma_{ij})$ must be simultaneously smaller than six arbitrary units.

To show the statistical stability of the colour-descriptors $(\alpha'_{iW}, \beta'_{iW}, \gamma'_{iW})$ and $(\alpha'_{iBK}, \beta'_{iBK}, \gamma'_{iBK})$ against the range of the four illuminants used, we



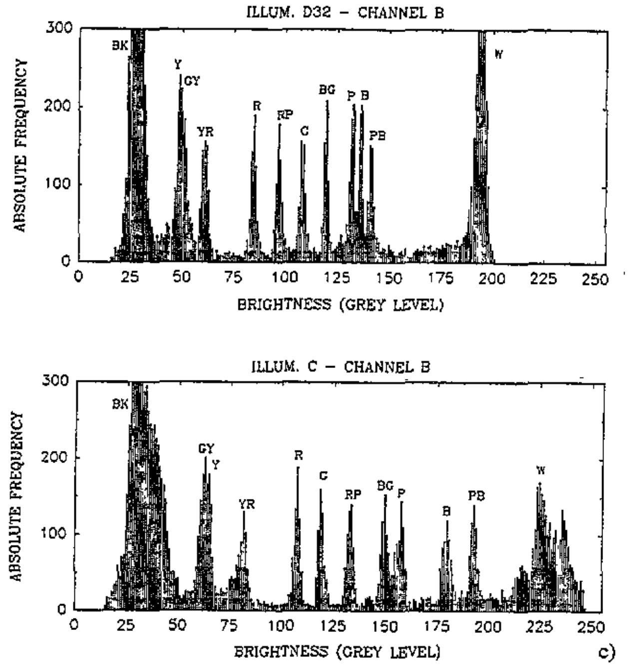


FIG. 8. — *a) Channel-histogram R of the image formed by 10 Munsell samples (GY, G, BG, PB, P, RP, R, YR, Y), the black of the background (BK) and the white (W) under D32 and C illuminants. b) Channel-histogram G of the image formed by 10 Munsell samples (GY, G, BG, PB, P, RP, R, YR, Y), the black of the background (BK) and the white (W) under D32 and C illuminants. c) Channel-histogram B of the image formed by 10 Munsell samples (GY, G, BG, PB, P, RP, R, YR, Y), the black of the background (BK) and the white (W) under D32 and C illuminants.*

will bidimensionally represent in the three planes of the space the coordinates $(x'_{iW}, y'_{iW}, z'_{iW})$, described in the following way:

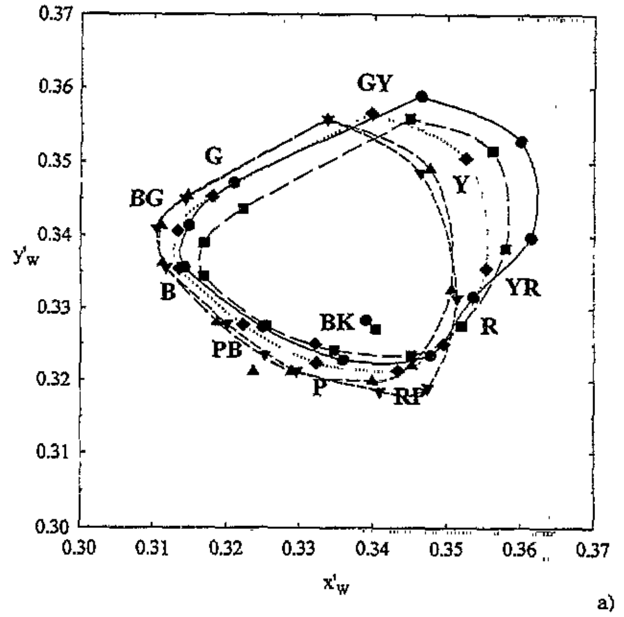
$$x'_{iW} = \frac{\alpha'_{iW}}{\alpha'_{iW} + \beta'_{iW} + \gamma'_{iW}} \quad (12)$$

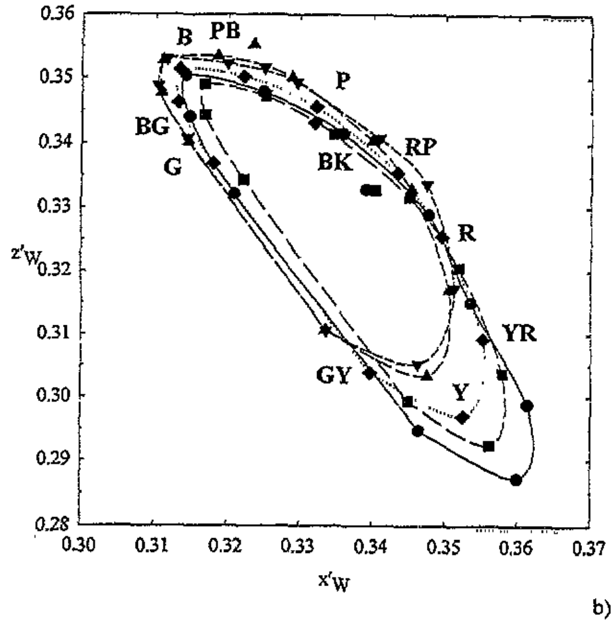
$$y'_{iW} = \frac{\beta'_{iW}}{\alpha'_{iW} + \beta'_{iW} + \gamma'_{iW}}$$

$$z'_{iW} = \frac{\gamma'_{iW}}{\alpha'_{iW} + \beta'_{iW} + \gamma'_{iW}}.$$

(In an analogous way for $((x'_{iBK}, y'_{iBK}, z'_{iBK}))$.

In the bidimensional representations (x'_{iW}, y'_{iW}), (x'_{iW}, z'_{iW}), (y'_{iW}, z'_{iW}) (*fig. 9a, b, c*) and (x'_{iBK}, y'_{iBK}), (x'_{iBK}, z'_{iBK}), (y'_{iBK}, z'_{iBK}) (*fig. 10a, b, c*) we can observe the notable superposition of the pseudo-ellipses that the colour samples form despite the spectral variation of the illuminant. For instance, there are some inversions in the rank of colour-stimuli in *figure 8a* between B-peak and GY-peak and between PB-peak and Y-peak, and also in *figure 8c* between RP-peak and G-peak. Nevertheless, although these inversions correspond to the





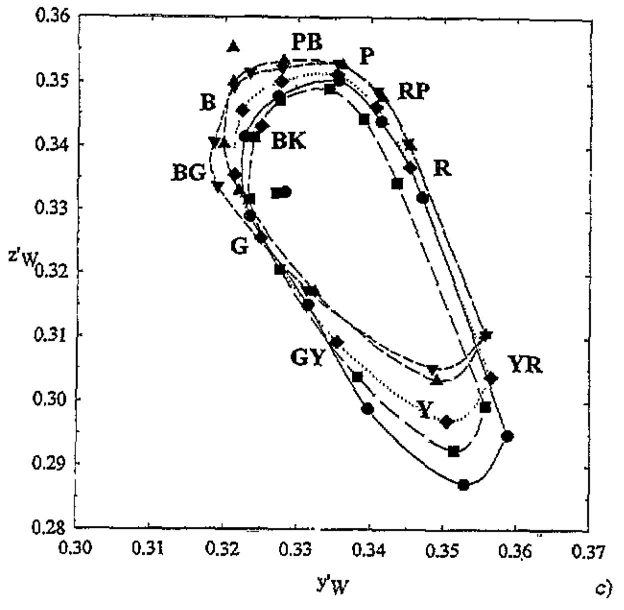


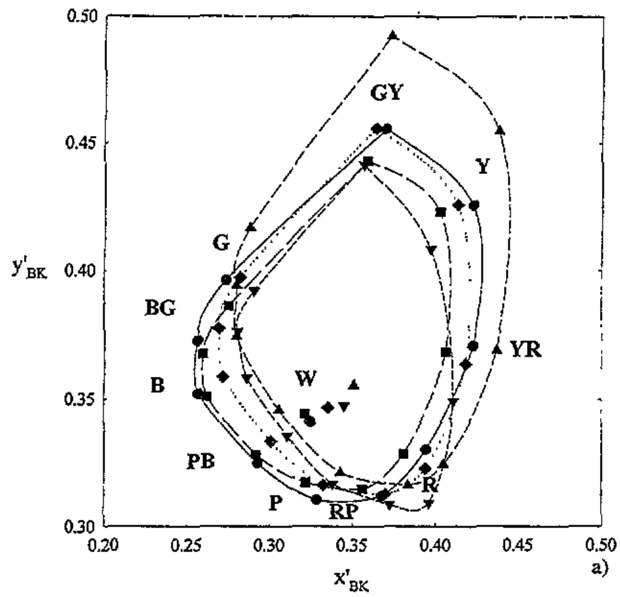
FIG. 9. — *a) Representation of the statistical variance of colour samples against spectral change of the illuminant according to* (x'_{iW}, y'_{iW}) *(See text). Observe, in comparison with figure 7 the small shift produced with this chromatic codification. (Note the difference of the rank in the scale of the axes). b) Representation of the statistical variance of colour samples against spectral change of the illuminant according to* (x'_{iW}, z'_{iW}) *(See text). c) Representation of the statistical variance of colour samples against spectral change of the illuminant according to* (y'_{iW}, z'_{iW}) *(See text). (●) samples under A illuminant ; (■) samples under D32 illuminant ; (▲) samples under D65 illuminant ; (▼) samples under C illuminant and (◆) samples under (A, D32, D65, C) average illuminant.*

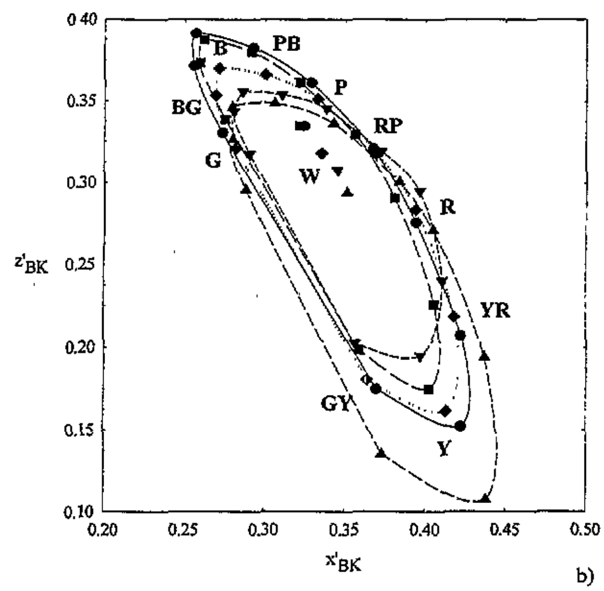
12 % of non stable colour-descriptors, they do not show so dramatically in *figure 9abc* and *figure 10abc*. If we compare it with the previous results, we can observe that the colourimetric shifts of these coordinates *(fig. 9a)*, on changing the illuminant, are much lower than when using the classic CIE-(x, y) chromatic coordinates *(fig. 7)*. Moreover, it is easy to observe that the statistical dispersion of colour-descriptors $(\alpha'_{iW}, \beta'_{iW}, \gamma'_{iW})$ is smaller than that of colour-descriptors $(\alpha'_{iBK}, \beta'_{iBK}, \gamma'_{iBK})$, which makes it more reliable to refer to the colours in the scene with regard to a white rather than a black.

CONCLUSIONS

The results of the experiments show that the chromatic codification carried out by an MVS, with the proposed colour-descriptors, is practically invariant to the change of the illuminant. This means that an MVS which can detect and recognise a certain object by the colour, will not make errors when the illuminant changes.

Starting from the initial RGB chromatic signals we have designed new colour-descriptors for a colour-object stimulus *i* of the scene, $(\alpha'_{iW}, \beta'_{iW}, \gamma'_{iW})$ and $(\alpha'_{iBK}, \beta'_{iBK}, \gamma'_{iBK})$ basing ourselves on the principles of the Retinex theory and bearing in mind the simultaneous contrast present in the scene. The statistical stability of the colour-describers $(\alpha'_{iW}, \beta'_{iW}, \gamma'_{iW})$ against a range of four spectrally different illuminants is completely satisfactory, in comparison with the codification according to the initial RGB or XYZ values. On the other hand, it is also important to consider the difference between the colour-descriptors according to the way





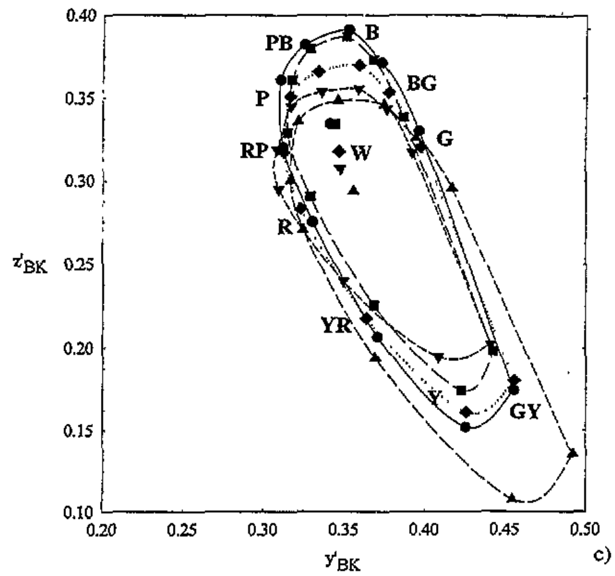


FIG. 10. — *a) Representation of the statistical variance of colour samples against spectral change of the illuminant according to* (x'_{iBK}, y'_{iBK}) *(See text). Observe, however, that in comparison with the codification in relation to white (Fig. 10a), the shifts are noticeably bigger. b) Representation of the statistical variance of colour samples against spectral change of the illuminant according to* (x'_{iBK}, z'_{iBK}), *(See text). Observe, however, that in comparison with the codification in relation to white (Fig. 10b), the shifts are noticeably bigger. c) Representation of the statistical variance of colour samples against spectral change of the illuminant according to* (y'_{iBK}, z'_{iBK}) *(See text). Observe, however, that in comparison with the codification in relation to white (Fig. 10c), the shifts are noticeably bigger. (●) samples under A illuminant; (■) samples under D32 illuminant; (▲) samples under D65 illuminant; (▼) samples under C illuminant and (♦) samples under (A, D32, D65, C) average illuminant.*

they are determined with respect of the white stimulus (W) or the black one (BK). In this way, we obtain a smaller deviation in the colour-descriptors $(\alpha'_{iW}, \beta'_{iW}, \gamma'_{iW})$ than in the colour-descriptors $(\alpha'_{iBK}, \beta'_{iBK}, \gamma'_{iBK})$, from which can be confirmed the principle for always establishing a reference with respect to the white stimulus.

In this way, the artificial vision systems that are used in environments with variable illumination (outdoors for example) will be able to assign, practically without errors colour-codes constant to the objects present in the scene, increasing in this way their effectiveness and reliability.

This proposed method has been achieved within certain conditions. This implies that the conclusions furnished will only be valid, in principle, within the said conditions which, it should be said, are not excessively severe. Despite this, it is important to clarify what the restrictions that limit their use are. These are: 1) The samples must be flat and matt, that is to say, they must not shine. 2) In the scene a black or white surface must appear as in (5). 3) The spectral variation of the illuminant is limited to that for CIE standard illuminants.

It is evident that the conditions 2) and 3) are easy to accomplish. However, this cannot be said for 1). Avoiding shines would imply making the method more complex, implementing one of the computational processes for detecting shines [24] and eliminating them, for otherwise it would provide false information about the colour of a surface.

Finally, it is possible to insert this chromatic codification in an algorithm for the chromatic detection and recognition of objects, whose scheme is shown in *figure 11*.

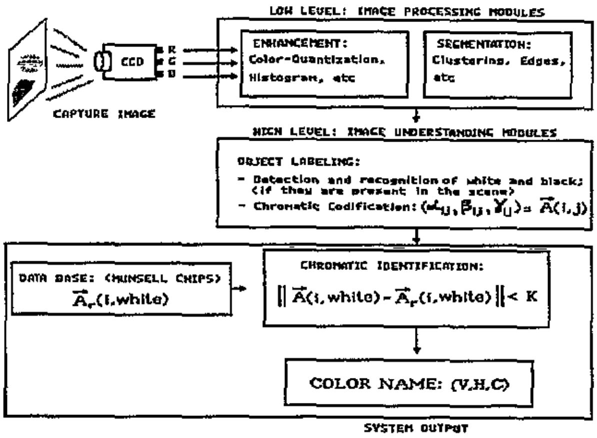


FIG. 11. — *Algorithm flow diagram for the recognition of objects, enabled with colour constancy.*

Within this algorithm we can distinguish three principal phases :

a) Image processing : after capturing the image of the scene, we will apply a series of processing techniques [6, 7] to facilitate the chromatic codification phase, reducing superfluous chromatic and spatial information. Among these techniques we can highlight the colour-quantization [24], the histogram and the colour segmentation [22, 23].

b) Chromatic codification : by detecting and recognising the white (black) labeling-stimuli, we proceed to execute the designed chromatic codification in this work by means of the calculation of colour-descriptors $(\alpha'_{iW}, \beta'_{iW}, \gamma'_{iW})$ for all colour-object stimuli i present in the scene.

c) Chromatic identification : what's more, we can assign to an object i, codifies as $(\alpha'_{iW}, \beta'_{iW}, \gamma'_{iW})$, the same perceptual attributes (lightness, hue and chroma) as those for human observers by means of a chromatic identification process. For this, we proceed as follows : under an illuminant and a standard white reference, we codify all the samples of a colour atlas according to the designed colour-descriptors, like for example the Munsell Book with its notation hue H, lightness V/chroma C. In this way, we will have a theoretical perceptual space which will act as a database. Minimizing the projection distance between the real values $\vec{A}(i, W) = (\alpha'_{iW}, \beta'_{iW}, \gamma'_{iW})$ of a sample-problem i, over the theoretical perceptual space, there will be a point (i_0, W) which will permit us to assign the same attributes (V, H, C) of i_0 to the real colour i object/stimulus :

$$\sqrt{(\alpha'_{iW} - \alpha'_{i_0 W})^2 + (\beta'_{iW} - \beta'_{i_0 W})^2 + (\gamma'_{iW} - \gamma'_{i_0 W})^2} < k \qquad (13)$$

$$\| \vec{A}(i, white) - \vec{A}(i_0, white) \| < k .$$

In this way, the MVS will identify a colour with the same attributes as the HVS, and moreover it will not make colour errors when the illumination changes.

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