Contribution to the Colour Segmentation by Means of an Algorithm Which Reduces the CCDs Saturation Problems

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Abstract. Sometimes, the results provided by colour image processing systems are not accurate enough due to the physical process of image formation. One of that problems is colour clipping, which appear when at least one of the sensor components is saturated. We propose a method to recover the chromatic information of those pixels on which colour has been clipped. The chromatic correction method is based on the fact that some chromatic characteristics are invariant to the uniform scaling of the three RGB components. In this paper we present this method and one study of the chromatic components to which it can be applied.

Key Words : Colour Clipping, Colour recovering, Colour segmentation.

1 Introduction

Colour has been proved to be useful information in computer vision systems, although most of the usual problems in computer vision can be solved on grey-level images. However, in some situations, taking out chromatic information can highly improve the accuracy of the algorithms (see, for instance, Luong [6] and Gershon [3] papers).

There are some steps in the image formation processes which could make changes in the original colour. Actually, if we focus on the first one of this steps, it is obvious that CCD cameras make some important changes in supplied images (see, for instance, Novak [8]).

There are several different ways to model the response of the camera. Shafer notation, shown in [11] is probably one of the most accepted. For a single pixel x, the response of the camera is given by the following equation:

$$C_x = \begin{bmatrix} r_x \\ g_x \\ b_x \end{bmatrix} = \begin{bmatrix} \int X(\lambda)\tau_r(\lambda)s(\lambda)d\lambda \\ \int X(\lambda)\tau_g(\lambda)s(\lambda)d\lambda \\ \int X(\lambda)\tau_b(\lambda)s(\lambda)d\lambda \end{bmatrix} \quad (1)$$

where $X(\lambda)$ represents the amount of incident light, $s(\lambda)$ corresponds to the camera responsivity and $\tau_r(\lambda)$, $\tau_g(\lambda)$, $\tau_b(\lambda)$ correspond to the filters' transmittance of the three components red, green and blue.

Cameras are finite devices, so there is a maximum value that cameras can provide called the dynamic range. It is usually assumed that camera output ranges from (0,0,0) to (1,1,1). Every value of r_x, g_x or b_x in equation 1 greater than 1 is clipped by the camera to 1 and it is said that this component is saturated.

Some work has been done in order to recover the chromatic information of those pixels of which at least one of RGB components is saturated. This work was based on making assumptions about the actual colour of the pixel from the colour of the neighbouring pixels; see for example the works of Perez and Koch [9] and Klinker et al. [5].

We have proposed a method to recover the chromatic information of a pixel without looking at the neighbouring pixels, and we have studied its applicability to several chromatic characteristics that have been defined on the 0. Section 2 gives an outline of the method, in section 3 we present the chromatic components that have been studied, in section 4 some experimental results are shown and, finally, in section 5 the conclusions to this work are presented.

2 Outline of the proposed method

From equation 1 it can be deduced that for a given colour, the camera response follows a straight line inside the RGB space when light intensity changes. This is illustrated in figure 1. However, due to the limitations of cameras, this response is only linear for one interval of intensities: interval $[a, b)$ in figure 1. For values higher than b, the camera reaches its maximum in at least one of its components. In the interval $[b, c)$ the red component is saturated, and in the interval $[c, d)$ red and green components are saturated. For values higher than d the three components are saturated and white is obtained as the camera response .

This nonlinearity in the camera response produces undesired effects on the algorithms that work with chromatic components such as hue, that are stable under variations in the illuminant intensity. The sketch of the method we propose (which is detailed on our previous work [10]) is:

1. Find the straight line $\rho(t) = (\rho_r(t), \rho_g(t), \rho_b(t))$ that describes the camera response in front of light intensity changes. This line will provide the expected camera response, assuming that the camera has not any physical limitation.
2. From this line $\rho(t)$ it is possible to estimate the actual camera response, which will be the minimum between $\rho(t)$ and the maximum value the camera can return; that is, the actual camera response will be $(\min(\rho_r(t), 1)$, $\min(\rho_g(t), 1)$, $\min(\rho_b(t), 1))$.
3. A mapping is defined from the actual camera response (step 2) to the colour cube in the following way: the expected camera response $(\rho_r(t), \rho_g(t), \rho_b(t))$ is multiplied by a constant k, $0 < k < 1$ and the value obtained is assigned to the actual camera response $(\min(\rho_r(t), 1), \min(\rho_g(t), 1), \min(\rho_b(t), 1))$.
4. The mapping obtained in the previous step is stored in three LUTs, which will be addressed by the camera output. The output of this three LUTs will

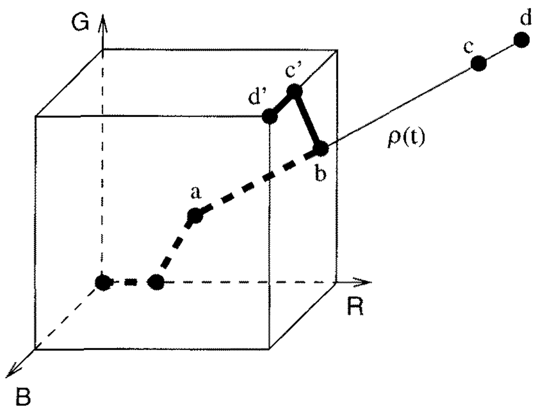

Fig. 1. *Camera response for a giver colour when light intensity changes. From a to b the camera response is linear and, from intensity values higher than b, colour is clipped (thick line).*

be the corrected RGB values. Alternatively, the LUTs can be loaded with a transformation to any colour space, such as HSI and, so, it is possible to get the corrected HSI values in real time.

Note that this method works in a two-steps basis: first, colours are characterized offline (the straight lines that describe the colours are estimated) and then, colour correction is performed in real time using LUTs, because the colour correction is defined as a point operation.

3 Chromatic components studied

Our method can be applied to any given chromatic transformation $T(R, G, B)$ which holds the scale invariance property; that is, if $\forall\alpha > 0 \quad T(R, G, B) = T(\alpha R, \alpha G, \alpha B)$. Several chromatic components used on the literature have been studied and the results obtained are summarized in table 1. These transformations from the RGB space to the chromatic components are now presented (for each transformation, a reference to a work in which it has been used is given):

HSI space (Perez and Koch) [9]

$$H(r, g, b) = \arctan \frac{\sqrt{3}(g - b)}{(r - g) + (r - b)} \quad (2)$$

$$S(r, g, b) = 1 - \frac{\min\{r, g, b\}}{(r + g + b)/3} \quad (3)$$

$$I(r, g, b) = \frac{r + g + b}{3} \quad (4)$$

HSI space (Carron and Labert) [2]

$$H(r,g,b) = \begin{cases} \arccos(C_2/S) \text{ if } C_2 \geq 0 \\ 2\pi - \arccos(C_2/S) \text{ if } C_2 < 0 \end{cases} \tag{5}$$

$$S(r,g,b) = \sqrt{C_1^2 + C_2^2} \tag{6}$$

IC1C2 space (Barni et al.*) [1]*

$$C_1(r,g,b) = \frac{b}{r+g+b} \tag{7}$$

$$C_2(r,g,b) = \frac{2r+b}{r+g+b} \tag{8}$$

HSV space (Smith) [12] Hue is given in the interval $[0, 2\pi]$, although the following hue expression returns a value between $[-pi, pi]$.

$$H(r,g,b) = \begin{cases} \pi/3(g-b)/\Delta(r,g,b) & \text{if } r = \max\{r,g,b\} \\ \pi/3(2+(b-r)/\Delta(r,g,b)) & \text{if } g = \max\{r,g,b\} \\ \pi/3(4+(r-g)/\Delta(r,g,b)) & \text{if } b = \max\{r,g,b\} \end{cases} \tag{9}$$

$$\Delta(r,g,b) = \max\{r,g,b\} - \min\{r,g,b\}$$

$$S(r,g,b) = \frac{\max\{r,g,b\} - \min\{r,g,b\}}{\max\{r,g,b\}} \tag{10}$$

$$V(r,g,b) = \max\{r,g,b\} \tag{11}$$

HLS space (Joblove and Greenberg) [4]

$$L(r,g,b) = (\max\{r,g,b\} + \min\{r,g,b\})/2 \tag{12}$$

$$S(r,g,b) = \begin{cases} \dfrac{\max\{r,g,b\} - \min\{r,g,b\}}{\max\{r,g,b\} + \min\{r,g,b\}} \text{ if } L \leq 0.5 \\ \dfrac{\max\{r,g,b\} - \min\{r,g,b\}}{2 - (\max\{r,g,b\} + \min\{r,g,b\})} \text{ if } L > 0.5 \end{cases} \tag{13}$$

HSV space (Tenembaum) [13]

$$S(r,g,b) = 1 - 3\min\left\{\frac{r}{r+g+b}, \frac{g}{r+g+b}, \frac{b}{r+g+b}\right\} \tag{14}$$

HSV space (Yagi et al.*) [15]*

$$S(r,g,b) = \max\{r,g,b\} - \min\{r,g,b\} \tag{15}$$

RGB normalized space (Nevatia) [7]

$$Y(r,g,b) = c_1 r + c_2 g + c_3 b \text{ where } c_1 + c_2 + c_3 = 1 \tag{16}$$

$$T_1(r,g,b) = \frac{r}{r+g+b} \tag{17}$$

$$T_2(r,g,b) = \frac{g}{r+g+b}$$

*CIEL*u*v* space (Wyscecki and Stiles) [14]* CIE components are defined in terms of XYZ components instead of RGB components. There exists a linear transformation from RGB space to XYZ space.

$$h_{uv}(x,y,z) = \arctan\frac{v^*}{u^*} \tag{18}$$

$$L^*(X,Y,Z) = \begin{cases} 116\sqrt[3]{Y/Y_n} - 16 \text{ if } Y/Y_n > 0.008856 \\ 903.3(Y/Y_n) \text{ if } Y/Y_n \leq 0.008856 \end{cases} \tag{19}$$

$$C^*_{uv}(x,y,z) = \sqrt{v^{*2} + u^{*2}} \tag{20}$$

$$s_{uv}(x,y,z) = \frac{C^*_{uv}}{L^*} \tag{21}$$

*CIEL*a*b* space (Wyscecki and Stiles) [14]*

$$h_{ab}(x,y,z) = \arctan\frac{b^*}{a^*} \tag{22}$$

$$C^*_{ab}(X,Y,Z) = \sqrt{a^{*2} + b^{*2}} \tag{23}$$

4 Results

Figure 2 shows an example of the results obtained with the proposed method applied as a preprocessing step in a hue-based segmentation algorithm. Figure 2.a corresponds to a series of 12 images acquired under illumination changes and figure 2.b shows the same images once they have been corrected. In this case three colours have been corrected: the locomotive colour (orange) and the two wagon colours (green, on the middle, and cyan). Figure 2.c shows the results of the segmentation of the original images and, finally, figure 2.d shows the results of the same segmentation applied to the corrected images. As can be seen in the first eight images of the series, the segmentation has been qualitative improved with the colour correction method.

Quantitative measurements of the segmentation improvement are shown on figure 3. The x-axis corresponds to the percentage of pixels with at least one saturated component and the y-axis shows the percentatge of pixels of the object correctly segmented. Figure 3.a corresponds to the locomotive, figure 3.b corresponds to the green wagon and figure 3.c corresponds to the blue one. As it can be seen, when there are a lot of pixels with some saturated component, the segmentation performs better after colour correction in the locomotive and in the gren wagon. The results obtained with the cyan wagon are similar before and after colour correction: this is due to the fact that cyan composition – in terms of red, green and blue primaries– has similar amounts of green and blue and it nearly has not red.

Component	Chromatic Space	Equation	Invariant
T_1, T_2	normalized RGB	17	Yes
C_1	IC_1C_2	7	Yes
C_2	IC_1C_2	8	Yes
H	HSI	2	Yes
H	HSI	5	Yes
H	HSV	9	Yes
H	$CIEL^*u^*v^*$	18	Yes
H	$CIEL^*a^*b^*$	22	Yes
S	HSI	3	Yes
S	HSI	6	No
S	HSV	10	Yes
S	HSV	14	Yes
S	HSV	15	No
S	HLS	13	Yes if $L \leq 0.5$ No if $L > 0.5$
S	$CIEL^*u^*v^*$	21	Yes
C	$CIEL^*u^*v^*$	20	No
C	$CIEL^*a^*b^*$	23	No
I	HSI	4	No
V	HSV	11	No
L	HLS	12	No
Y	normalized RGB	16	No
L^*	$CIEL^*u^*v^*$	19	No

Table 1. *Chromatic components and their scale invariance property.*

5 Conclusions

We have described a simple preprocessing system, but it is its newness that contributes robustness to segmentation systems based on the hue and saturation components, expanding the range of the virtuality of the camera. Several chromatic components have been analyzed in order to study if the proposed method can be applied to them.

Our system can be applied in areas like the tracking of a known moving object, allowing the effects that changes in the incident light intensity produce on the hue component while the object is moving to be reduced.

We have tested its functioning in different scenes. As was expected, with the method presented the final segmentation is greatly improved when the number of pixels which suffer from colour clipping is high.

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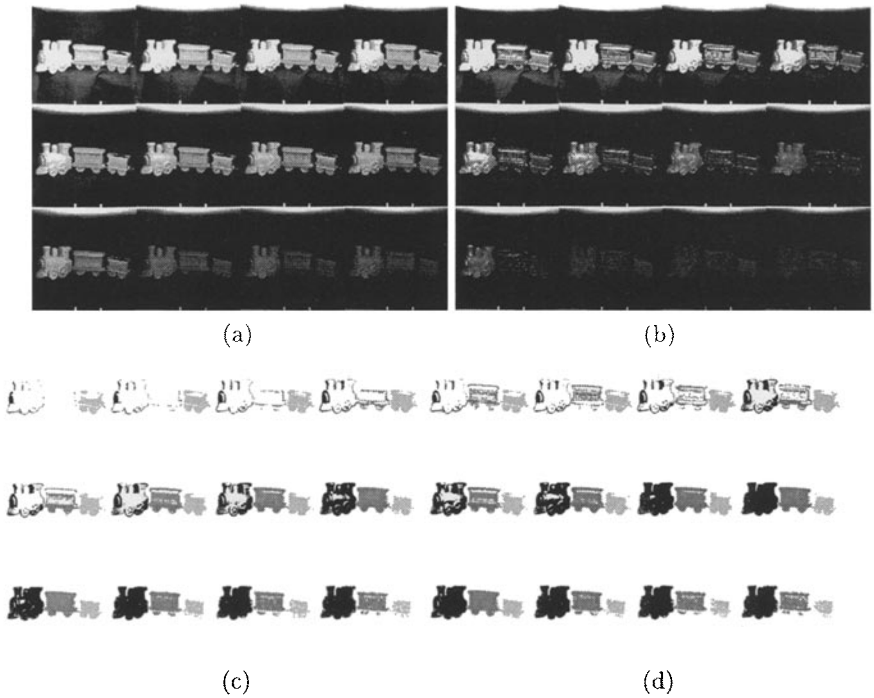

Fig. 2. *Some results obtained: Original images (a), corrected images (b), segmentation results in original images (c) and segmentation results in corrected images (d).*

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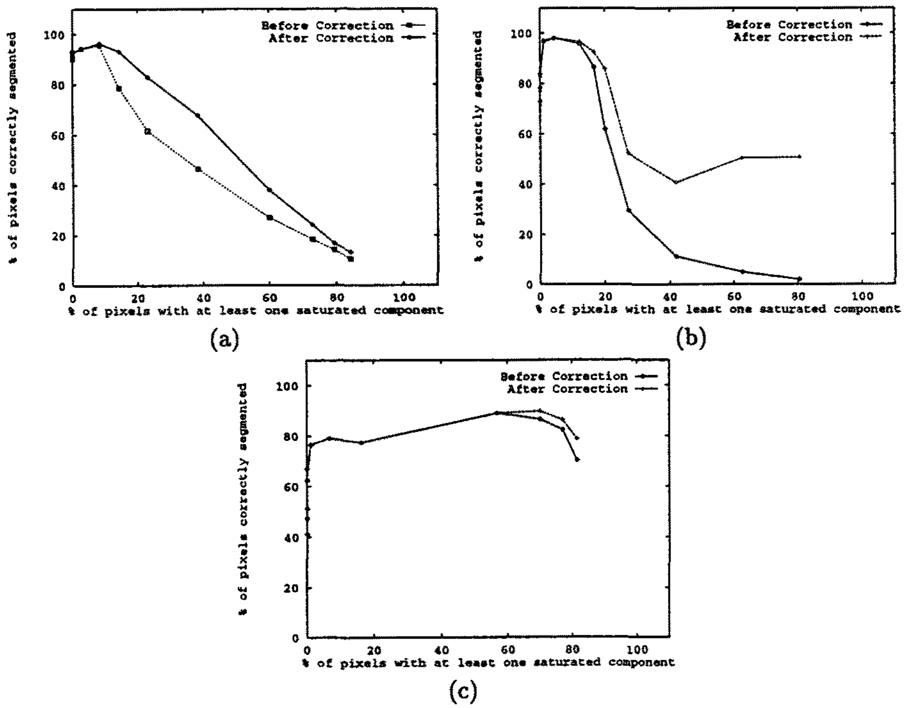

Fig. 3. *Quantitative measurement of the segmentation accuracy improvement after colour correction. Locomotive (a), green wagon (b) and blue wagon (c). Dashed line plots the behaviour of the colour segmentation accuracy before colour correction and the solid line plots the behaviour after colour correction.*

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