JOURNAL OF MEDICAL INFORMATICS & TECHNOLOGIES Vol. 14/2010, ISSN 1642-6037

human skin colour, classifier, decision rules

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THE NEW RULE BASED COLOUR CLASSIFIER IN THE PROBLEM OF HUMAN SKIN COLOUR DETECTION

This article presents new rules, which can be used to construct a classifier for image areas segmentation. Segmentation is made on upon the colours, which are commonly associated with human skin colour. The new rules of this classifier have been developed on the basis of the analysis and modifications of two other classifiers, which has been described in the literature. Nowadays, such classifiers are commonly used in practice: in photographic equipment, photo-editing software, biological images analysis or in-room person detecting systems.

1. INTRODUCTION

It is hard to overestimate the importance of colours in everyday life. In the year 1802 Young, and later in 1852 Helmholtz noticed, that human eye retina has a set of three receptors, which are responsible for observing only one hue each: red, green or blue. So the hue perception relays on these three stimuli and of the intensity of each of them. In real, the phenomenon of colour perception is much more complex, because besides depending on sight physiognomy it also depends on the phenomenon of metamerism. This phenomenon manifests itself when the two colours viewed in the same type of light (e.g. daylight) are perceived as similar each other, but when viewed in different light (e.g. light bulb) as different.

The colour is a psychophysical feature of visual perception. The perception is only possible when the following three processes take place: light emission, retina receptors stimulus and processing impulses transmitted by the optic nerve in the cortex. Each colour is defined by three attributes: hue (tint), saturation and brightness. By observing the Newtonian white light splitting by the prism it is possible to distinguish light spectrum stripes of different wavelengths. We call this characteristic of visual sensation a colour. Of course there exists a pallet of many other colours which are possible to observe. Each of them can be made by mixing it up with a ray of white light. We call this characteristic of visual sensation, which allows us to evaluate the share of colour attribute, saturation (chrominance). It is also possible to change the colour by changing the intensity of light (increasing or decreasing). It affects neither the hue nor the saturation. We call this characteristic brightness (intensity, luminance).

Concluding foregoing simplified considerations we may state that the hue is an attribute of colour and is independent of lightness and saturation. Saturation is an attribute of colour and is independent of hue and lightness. Lightness is an attribute of colour and is independent of colour and saturation.

In many practical applications it is a quite frequent need to identify or analyze different colour areas i.e. on computed tomography pictures, x-ray pictures, thermographic images, biological materials' photographs, road traffic objects etc.

In particular cases the process of recognition may consider areas of human skin presence. Techniques of segmenting such areas are nowadays used in photo cameras for locking on photographed person's face, in the procedures of segmenting palms for sign language transliteration, in algorism detecting human presence in the room, etc.

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Due to the fact that different scene lighting is possible exact skin colour areas matching is not a trivial task. This article presents modifications of skin colour detection algorithms, which has already been described in literature. Classifier presented in this article has a better accuracy than compared methods.

For the purpose of comparing human skin colour matching algorithms two measures, based on a FAR and FRR coefficients commonly used in biometry, has been introduced – *NSE* (Non-Skin Error) and *SE* (Skin Error).

Let:

T	-	background pixel count erroneously classified as human skin colour pixel
Q	-	human skin colour pixel count erroneously classified as background pixel
P	-	total human skin colour pixel count

Then:

$$NSE = \frac{Q}{P} \qquad SE = \frac{T}{P} \tag{1}$$

The value of NSE coefficient is determined as the ratio of human skin colour pixels misinterpreted as a background to the total count of human skin colour pixels. The value of SE coefficient is determined as the ratio of background pixels misinterpreted as human skin colour pixels to the total count of human skin colour pixels.

2. COLOR SPACE MODELS

Most commonly used and most natural colour space for digital images is the RGB space. It is based on an additive model and it's graphical representation is a hexahedron (cube). Each point of the image (pixel) defined in this colour space is described by three values – *R*(ed), *G*(reen) and *B*(lue), which are defining the intensity of adequate base colours. Unfortunately in the aspect of human skin colour detection id has a major disadvantage – it does not allow to directly determine the hue of a pixel.

There is also a slightly modified version of RGB colour space – the rgb colour space. It has normalized components and thus it's components no longer depend on intensity of light on the scene. From the mathematical point of view this conversion is very simple, but also it is irreversible – the luminance factor is lost during conversion.

The HSx colour model family present a different approach to colour representation. These models are based on P. Runge's observations, who were XIX century German painter. These models also describe each pixel by three values, but these values describe different aspects of a colour:

- Hue (*H*) – it is a hue or a tint of a colour, it starts and ends on red; 0-360°.
- Colour saturation (*S*) – it is a normalized chrominance of a colour; from gray to pure colour; 0-100% or 0-1.
- Lightness (*I*/*V*/*L*) – it is a simplified luminance of a colour; 0-100% or 0-1.

There are three major colour models in this family – HSI, HSV and HSL. Although they all belong to the same family, the only common parts are general hue definition, and the fact that all of them are based on a RGB gamut. These models were all attempts to create an perceptual colour model for computer image processing. Unfortunately they are not perfect, they not only share all limitations of the RGB gamut, but also not fully fulfil their principle – full perceptual independence of hue, saturation and intensity. As all of these HSx models are based on RGB model the lossless bidirectional conversion is possible, and what's more – HSL and HSV models are optimized for such conversion was not only possible but also very efficient.

As it was mentioned earlier in this chapter the most natural model for encoding digital images is RGB model and the first analyzed skin colour detection algorithm is based on this model – the Kovac, Peer and Solina classifier [1]. Because of the model nature and limitations, this algorithm is very sensitive to the scene light conditions (intensity, and colour temperature). For better efficiency there are two variants of this algorithm – one for daylight and second for artificial light (preferably camera flashlight). The second analyzed algorithm was created by Wang and Youan [2]. This model has classification (filtering) rules defined in two colour models – normalized rgb and HSV. Because of these models' properties it is much more independent of light conditions, but it requires colour space conversions.

3. COLOR SPACE CONVERSION METHODS

As mentioned before the bidirectional conversion is possible between RGB, HSI, HSL and HSV models. This conversion is relatively simple and except for HSI – quick. For normalized rgb there is only one way conversion.

3.1 NORMALIZED RGB MODEL

This colour space is also called a chromatic space. It is the simplest transformation which allows to get chromatic coordinates by the means of mixing of base-colours from RGB model. The conversion procedure is as follows:

$$r = \frac{R}{R+B+G}$$

$$g = \frac{G}{R+B+G} \tag{2}$$

$$b = 1 - r - g$$

3.2 HSI COLOUR MODEL

HSI colour model is basic perceptual colour model based on RGB colour space. Conversion is relatively time consuming, because it requires trigonometric transformations:

$$H = \begin{cases} \sin^{-1} \dfrac{\frac{1}{2}[(R-G)+(R-B)]}{\sqrt{(R-G)^2+(R-B)(G-B)}} & \text{for } B \le G \\ 360° - \sin^{-1} \dfrac{\frac{1}{2}[(R-G)+(R-B)]}{\sqrt{(R-G)^2+(R-B)(G-B)}} & \text{for } B > G \end{cases}$$

$$S = \frac{1 - 3\dfrac{\min(R,G,B)}{R+B+G}}{255} \tag{3}$$

$$I = \frac{\frac{1}{3}(R+G+B)}{255}$$

3.3 HSV COLOUR MODEL

HSV model is a simplified variant of HSI model, optimized for computer processing. It was introduced in 1978 by A. R. Smith:

$$H = 60° \times \begin{cases} \text{undefined} & \text{for } R = G = B \\ \dfrac{G-B}{\max(R,G,B)-\min(R,G,B)} \bmod 6 & \text{for } R = \max(R,G,B) \\ \dfrac{B-R}{\max(R,G,B)-\min(R,G,B)} + 2 & \text{for } G = \max(R,G,B) \\ \dfrac{R-G}{\max(R,G,B)-\min(R,G,B)} + 4 & \text{for } B = \max(R,G,B) \end{cases}$$

$$S = \begin{cases} 0 & \text{for } R = G = B \\ \dfrac{\max(R,G,B)-\min(R,G,B)}{255 \times \max(R,G,B)} & \text{for other cases} \end{cases} \tag{4}$$

$$V = \frac{\max(R,G,B)}{255}$$

3.4 HSL COLOUR MODEL

HSL colour model, like HSV, is a modification of original idea of HSI colour model optimized for computer processing and image analysis. It was introduced in 1978 by Joblove and Greenberg [4]. It uses same definition of hue as HSV, but differs in definitions of saturation and lightness (which is an equivalent of value):

$$H = 60^\circ \times \begin{cases} undefined & for\ R = G = B \\ \dfrac{G-B}{\max(R,G,B)-\min(R,G,B)} \bmod 6 & for\ R = \max(R,G,B) \\ \dfrac{B-R}{\max(R,G,B)-\min(R,G,B)} + 2 & for\ G = \max(R,G,B) \\ \dfrac{R-G}{\max(R,G,B)-\min(R,G,B)} + 4 & for\ B = \max(R,G,B) \end{cases}$$

$$S = \begin{cases} 0 & for\ R = G = B \\ \dfrac{\max(R,G,B)-\min(R,G,B)}{2\times\frac{1}{2}\left[\max(R,G,B)-\min(R,G,B)\right]} / 255 & for\ L \le \frac{1}{2} \\ \dfrac{\max(R,G,B)-\min(R,G,B)}{2-2\times\frac{1}{2}\left[\max(R,G,B)-\min(R,G,B)\right]} / 255 & for\ L > \frac{1}{2} \end{cases}$$

$$L = \frac{\frac{1}{2}\left[\max(R,G,B)-\min(R,G,B)\right]}{255} \tag{5}$$

4. FACE DETECTION METHODS USING SKIN COLOR

4.1 “KOVAC, PEER, SOLINA” CLASSIFIER

This method is based on rule classifiers defined exclusively on the RGB colour space. These are two sets of rules for different light conditions:

1) For natural light:

$$\begin{aligned} & R > 95 \wedge G > 40 \wedge B > 20 \wedge \\ & \max\{R,G,B\} - \min\{R,G,B\} > 15 \wedge \\ & |R-G| > 15 \wedge R > G \wedge R > B \end{aligned} \tag{6}$$

2) For artificial light:

$$\begin{aligned} & R > 220 \wedge G > 210 \wedge B > 170 \wedge \\ & |R-G| \ge 15 \wedge R > G \wedge R > B \end{aligned} \tag{7}$$

4.2 "WANG, YOUAN" CLASSIFIER

This classifier is based on a normalize rgb colour space and HSV colour space.

$$\begin{aligned} &0{,}36 \le r \le 0{,}465 \wedge \\ &0{,}28 \le g \le 0{,}363 \wedge \\ &0 \le H \le 50 \wedge \\ &0{,}20 \le S \le 0{,}68 \wedge \\ &0{,}35 \le V \le 1{,}0 \end{aligned} \tag{8}$$

5. AUTHOR'S METHOD

Parameters of the new classifier have been estimated on a base of statistical analysis of the photographs downloaded from the Internet. The base of 145 photographs of human faces had been created and 90 of them, having different skin carnation and having total area not less than 40% of the area, were chosen for further analysis. Using these photographs a test image (see Fig. 1) containing human faces with manually filtered skin areas (remaining area has been left black) have been created.

Fig. 1 „Faces" test image

Statistical analysis of this test image had been carried out – average values and standard deviations were calculated for the *R*, *G*, *B*, *r*, *g*, *b*, *S* and *V* parameters. The *H* parameter required special analysis, due to its nature. Acceptance range for this parameter values had been analyzed using Image Processing Lab [5] program and it was found that, on areas containing human skin colour, it takes values from range (9).

$$H \in [0°;34°] \cup [347°;359°] \tag{9}$$

During further analysis of remaining parameters it was observed that histogram of parameter *g* is closest to the normal distribution. As a result it has been assumed that data from this channel are most significant.

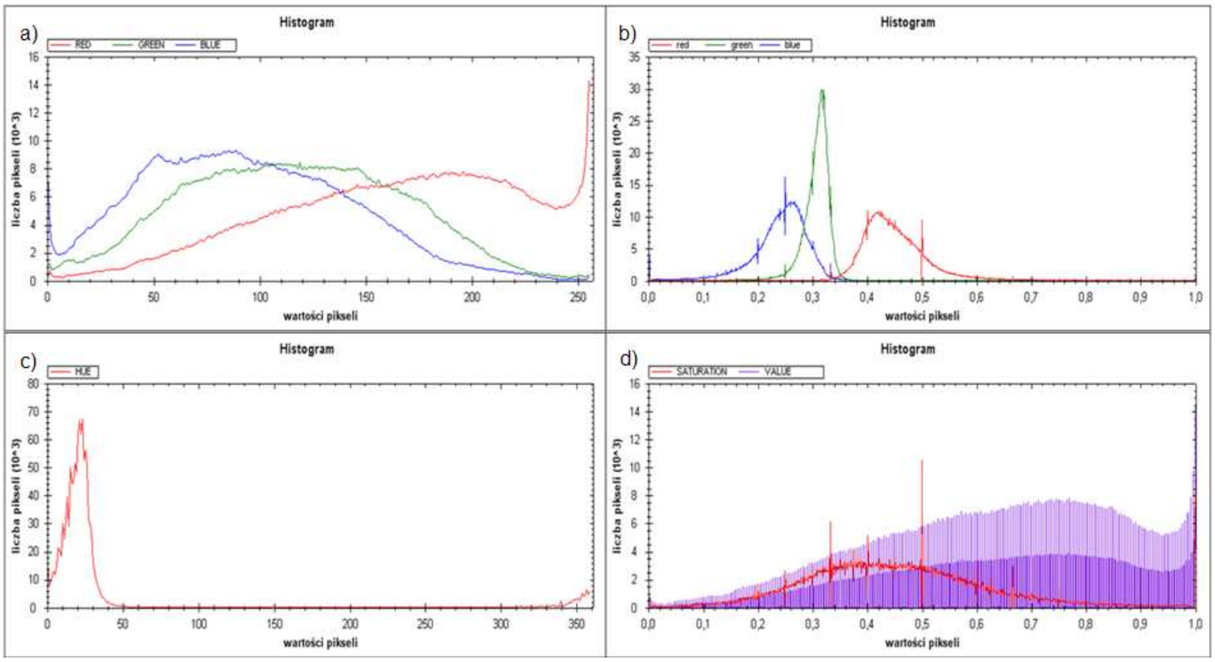

Fig. 2 Parameters distribution for different colour spaces:
a) RGB, b) rgb, c) H of HSV, d) S and V of HSV

Despite the fact that all of the colour models presented above are based on a RGB colour model, separate analysis for each of the models have been performed. Treating RGB model as a base model, there is a way to convert single picture point coordinates to any of presented models. However rules defined for one model cannot be easily transformed to another model and checking a converted condition would require at least same time as converting a pixel to adequate colour space.

For each of the analyzed parameters the accepted value ranges had been created and on this basis the decision rules were created. In the next step each of the rules had been tested against all of the 145 test images and the best rules were picked up, basing on the SE coefficient. On this stage the RGB model based rules have been eliminated.

In order to choose acceptance range for parameter *H*, it have been generated 48 test images, containing gradients for earlier chosen *H* value and full range of *S* and *V* values. *S* and *V* value ranges were initially limited using Wang and Youan rules (8). In the result of further analysis limits were changed to $0{,}20 \le S \le 0{,}747$ and $0{,}35 \le V \le 1{,}00$. These rules allowed to eliminate 64,8% of colours different than human skin colours. Finally HSV domain part of the filter was defined as:

$$\begin{aligned} &H \in [0°;34°] \cup [347°;359°] \\ &S \in [0{,}2;0{,}747] \\ &V \in [0{,}35;1{,}0] \end{aligned} \tag{10}$$

This rule set (10) had been compared with the HSV part of Wang and Youan classification rules and the following results were achieved:

Table 1. Wang, Youan vs. Author's Classifier comparison - HSV

Classifier	*SE Average Value* (*skin error*)	*NSE Average Value* (*non-skin error*)	Average Skin Colur Classification Error Value *E = SE + NSE*
Wang and Youan filter subset for HSV:	0,2524	0,1417	0,3941
Author's filter for HSV:	0,2142	0,1132	0,3274

Because for the given range of Hue parameter the most dominant colour is red, so using conversion formula (4), it is possible to replace *V* parameter range with equivalent *R* parameter range:

$$V \in [0{,}35;1{,}0] \Rightarrow R \in [90;255] \quad (11)$$

In the next step the classification rules in normalized rgb space have been defined. These rules have been established on the basis of the histogram generated from test images and have following form:

$$\begin{aligned} r &\in [0{,}385;0{,}522] \\ g &\in [0{,}277;0{,}335] \end{aligned} \quad (12)$$

There is no need for defining range for *b* component, because in this model *b=1-(r+g)*. As in the case of HSV, the efficiency of classifiers have been compared with Wang and Youan classifier part for rgb space and results are presented in the table:

Table 2. Wang, Youan vs. Author's Classifier comparison – rgb

Classifier	*SE Average Value* (*skin error*)	*NSE Average Value* (*non-skin error*)	Average Skin Colur Classification Error Value *E = SE + NSE*
Wang and Yuan filter subset for rgb:	0,36	0,2548	0,6147
Author's filter for rgb:	0,2635	0,1473	0,4108

From the measured classification errors it is clear that it is impossible to segment human skin colour areas correctly using only those rgb classifiers. This is due to the fact that rgb classifier rules are based only on chrominance factors, while shaded areas on digital photos may have unexpected hue and chrominance values. To eliminate this problem it is crucial to include a parameter which describes lightness (luminance) of the area – as this would allow eliminating dark areas in deep shadow.

From Table 1 and Table 2 it can be seen that Average Skin Colour Classification Error is lower for rules based on HSV model (10). Using these rules as a base it a test image (Fig. 3) containing all the colours and shades found on the previous test images.

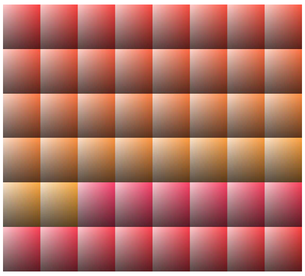

Fig. 3 "Colour Palette" test image

Elimination of background pixels may lead to eliminating some of the "Colour Palette" test image pixels. Therefore, efforts should be made to minimize *NSE* ratio for "Colour Palette" test image and *SE* ratio for "Faces" test image. For evaluating *r* and *g* parameter ranges with minimal *E* factor, a series of tests have been performed. Tests had been made using different limitations for *r* and *g* parameters and best results were achieved for rule:

$$g \in [0{,}277;1] \quad (13)$$

Table 3. Classification errors for different sub-ranges of rule (12)

Parameter limitations	*SE* (*skin error*) For "Faces" test image	*NSE* (*non-skin error*) For "Colour Palette" test image	*Average Classification Error* *E = SE + NSE*
0,385≤r≤0,522 ^ 0,277≤g≤0,355	0,2642	0,4826	0,7468
r≤0,522 ^ 0,277≤g≤0,335	0,2028	0,5342	0,737
r≥0,385 ^ 0,277≤g≤0,335	0,2062	0,5223	0,7285
r≥0,385 ^ g≥0,277	0,1649	0,5728	0,7377
r≥0,385 ^ g≤0,335	0,1202	0,8916	1,0118
r≤0,522 ^ g≤0,335	0,1136	0,7078	0,8214
r≤0,522 ^ g≥0,277	0,1745	0,5901	0,7646
0,385≤r≤0,522 ^ g≥0,277	0,139	0,7604	0,8994
0,385≤r≤0,522 ^ g≤0,335	0,1763	0,7505	0,9268
0,277≤g≤0,335	0,1448	0,5739	0,7187
0,385≤r≤0,522	0,1781	0,7058	0,8839
r≥0,385	0,0792	0,9421	1,0213
r≤0,522	0,0994	0,7637	0,8631
g≥0,277	**0,0873**	**0,6307**	**0,718**
g≤0,335	0,0577	0,9432	1,0009

Using this data, following classifier rules have been achieved:

$$\begin{aligned} & g \in [0{,}277;1] \\ & H \in [0°;34°] \cup [347°;359°] \\ & S \in [0{,}2;0{,}747] \\ & R \in [90;255] \end{aligned} \qquad (14)$$

In the final inve3stigation, phase test images had been filtered using the new classifier rule (14) and the results were visually examined. This examination has led to the observation that many of the background pixels are accepted as human skin colour pixels, so the rule has been modified to achieve a better (lower) *NSE* ratio and in the same time not to degrade Average Skin Colour Classification Error ratio. The final choice was to use limiting rule $g \in [0{,}277;0{,}335]$ and the final classifier has been defined as follows:

$$\begin{aligned} & g \in [0{,}277;0{,}335] \\ & H \in [0°;34°] \cup [347°;359°] \\ & S \in [0{,}2;0{,}747] \\ & R \in [90;255] \end{aligned} \qquad (15)$$

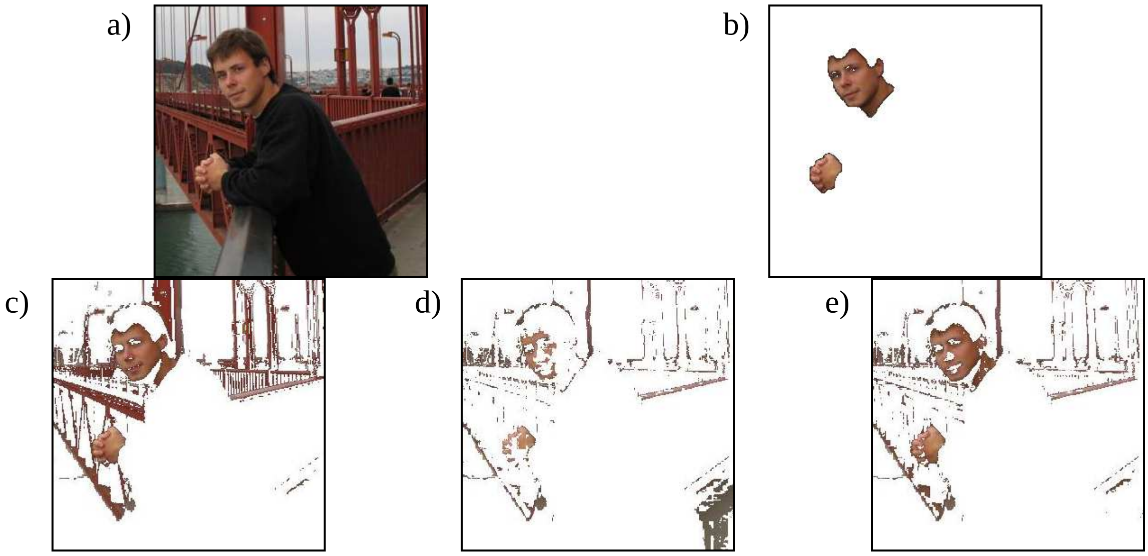

Fig. 4 Visual comparison of presented methods:
a) original image; b) manually segmented picture; c) Kovac, Peer, Solina method; d) Wang, Youan method; e) Author's method

6. SUMMARY

Presented method of estimating classification rules allows to achieve a better human skin areas segmentation in comparison with other methods described in this paper and can be used for initial image analysis for more complex face detection algorithms.

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