A New Clustering-based Thresholding Method for Human Skin Segmentation Using HSV Color Space

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***Abstract*—Skin detection based on color can be applied in eHealth systems for preventive healthcare and computer-aided diagnosis. These algorithms could be incorporated in acquisition and preprocessing steps of the applications that assist with skincare, as prevention and detection of melanoma. In this paper we present the results of a study that investigated the reduction of the color spectrum in the HSV system for sample-based skin detection of individuals of different ages and ethnicities. The proposed HSV filter reduced the color spectrum by 97.4648% so as to select candidates for human skin tones. It achieved low sensitivity (54.6333%) and high specificity (92.6390%) in human skin detection in color digital images when compared to the performance of other algorithms proposed in the literature. Different from other filters described in the literature which propose a single interval for human skin in the HSV system, this model presents and discusses 13 intervals in the possible spectrum which present a well-defined variation in terms of tone.**

***Index Terms*—clustering, thresholding, skin detection, color segmentation, HSV**

I. Introduction

Skin detection techniques are widely applied to locate and track human body parts for posterior recognition [1]. These techniques have drawn the attention of many research groups in recent years due to the numerous possibilities of application, such as facial detection and tracking, nudity detection, hand movement tracking, among others [2].

Studies using skin detection showed that human skin tones are usually grouped in specific bands of color spaces - RGB, HSV, YCbCr, CIELAB among others - and thus they can be used to identify skin pixels in digital color images [3]–[5]. However, there are some factors which may influence results negatively, such as variations in lighting conditions, complex backgrounds whose color tones resemble those of human skin, variations in acquisition devices, ethnic diversity and physical characteristics present in the visible spectrum [6], [7].

eHealth systems may benefit directly from skin detection algorithms based on color processing. Several studies which rely on preprocessing steps and computer vision techniques have been performed as attempts to improve preventive healthcare based on computer-aided diagnosis of melanoma [8]–[10].

In [11], 40 smartphone applications which focused on assisting preventive skin care were cataloged. Among those, 4 were developed to perform risk assessment. From this observation, it seems important to study and deploy strategies which include preprocessing and segmentation techniques to detect the many different tones of skin color. The algorithms created henceforth could be incorporated into electronic health applications for preventive skin care, especially in the acquisition and preprocessing steps, thus providing input for machine learning algorithm to create system alerts when relevant findings are identified, for instance.

This paper aims to present the results of a research work which investigated the reduction of the HSV color spectrum for human skin detection based on samples from individuals with different ages and from different ethnicities. Along with this, we propose a mathematical model to detect skin in the HSV color space, consisting on a set of rules to perform classification in skin and non-skin pixels in digital color images.

II. Related Works

Considering the ethnic diversity of individuals, one of the biggest challenges in establishing rules to perform the classification of pixels in images into skin and non-skin lies in contemplating the variability of skin tones in a comprehensive way. Recent studies have tried to model these sets of rules in a combined manner so as to determine efficient methods.

Using RGB images converted into HSV, [12] considered the H (Hue) channel to determine the color region for face detection, thus providing experimental proof that the tonality of human skin lies in a well-defined region of the color space.

Four different color spaces - namely, RGB, YCbCr, HSV and CIELAB - are used by [13] to detect faces in stages: skin segmentation, image binarization, rejection of non-skin regions based on geometrical properties of the human face and the determination of the area of face in the image.

A new algorithm was suggested by [14] for skin detection based on the combination of YCgCr and HSV color spaces. The input image is color-balanced so as to correct lighting variations and is simultaneously converted into HSV and YCgCr. After segmentation, morphological operations are performed in the region of skin and the face proportion is calculated to discard non-face regions.

A static filter for human skin detection in HSV color space is proposed by [15]. The authors claim that the color of skin can be determined efficiently using the hue and saturation levels for a determined pixel. In [16], a model in HSV color space combined with RGB to detect, segment and track human faces in color images with complex backgrounds was used. Another HSV skin cluster proposed by [17] was used by [18] to detect and track human faces. A hybrid approach for skin detection using a static filter in the HSV color space combined with RGB was proposed by [19].

These works found in the literature do not consider that, for each H channel band, the different tones of human skin also have varying values for the S and V channels. Thus, the thresholding filter that we propose strives to find more specific bands for human skin tones, which could minimize false-positives and maximize true-negatives.

III. Materials and Methods

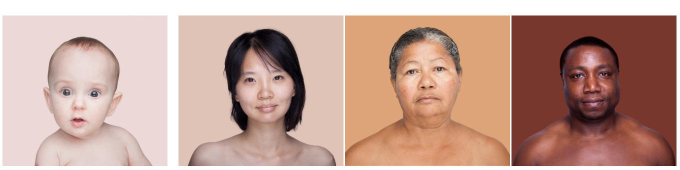
Several important properties of hue channel in the HSV color space may be listed, as observed by [20], regarding lighting conditions. It is considered to be invariant in: white light sources, matte surfaces, ambient light and surface orientation regarding the light source.

In order to understand system response, we chose the mechanistic model, dividing the HSV system into components, observing their particular roles and the interactions among them. Figure 2 illustrates the 9 steps performed to obtain such model.

951 skin samples were cut from the region between the lines of the eyes and nose, into 20x20 pixel squares. This region was chosen for it does not contain any hair. They were taken from pictures of individuals from different ages which were taken in controlled environments by [21] as a part of the Humanae Project, which aimed to store and categorize every skin tone there is (Fig. 1). The non-skin samples are extracted from images that knowingly do not contain human skin, e.g., animals, plants, objects and others (Fig. 2 *step #1*). In skin and non-skin samples, we calcutated the average pixels to reduce noise and the amount of data (*step #2*). Then, we converted the samples from RGB to HSV and separated the H, S and V channels (*step #3*).

Each component of the HSV color space had its scale divided into 10 intervals in the definition phase. The Hue (H) component, which is scaled from 0° to 360°, was divided in 36 primary intervals, namely [0°, 10°],]10°, 20°],]20°, 30°],]30°, 40°], ...,]350°, 360°]. The Saturation (S) and Value (V) components, which are scaled from 0% to 100%, were separated into 10 primary intervals, namely [0%, 10%],]10%, 20%],]20%, 30%], ...,]90%, 100%] (*step #4*).

Still in the definition phase, the 56 defined intervals - 36 from the Hue component and 10 from the Saturation and Value components each - were applied to the 951 skin samples extracted from the pictures of the individuals comprised by the Humanae Project and the non-skin samples, and we observed which intervals contained at least one tone which could be regarded as a human skin tone (*step #5*).



(a) (b) (c) (d)

Fig. 1: Some individuals photographed by [21], representing the diversity of the skin tone characteristic.

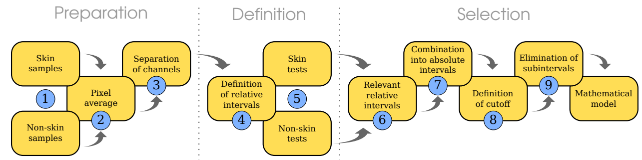


Fig. 2: Diagram of the proposed model for skin detection in the HSV color space.

For the H component, the skin samples were located in the relative intervals [0°, 40°] and [340°, 360°]. Considering that the HSV color space is geometrically represented as a cone and that the Hue component is defined at the bottom of that cone, it can be observed that the 2 intervals for this component form a single continuous interval. For the S component, the skin samples are located in the relative interval [0%, 80%], and for the Value component in the relative interval [20%, 100%].

In the next stage, the 22 relevant relative intervals which were observed in at least one skin sample (*step #6*) - 6 bands from the H component, 8 from the S component and 8 from the V component - were combined into 384 absolute intervals in order to find the HSV color spectrum bands in which tones likely to correspond to human skin tones could be found (*step #7*).

91 bands were selected from the total, establishing a 0.2604% cutoff. This is the individual percentage for each investigated band from a total of 384 bands (*step #8*), which represents a 97.4648% reduction in the HSV spectrum, considering a color space with 3,672,360 possible colors (360x101x101). The observation that many of these intervals were either overlapped or formed continuous intervals led to the decision to group them into 13 sets (*step #9*). Equation 1 presents the skin detection filter proposed for the HSV color space.

$$
if \begin{cases}
0^\circ \leq H \leq 10^\circ, \begin{cases} 0\% \leq S \leq 20\%, 70\% < V \leq 100\%\ or \\ 20\% < S \leq 30\%, 70\% < V \leq 90\%\ or \\ 30\% < S \leq 40\%, 70\% < V \leq 80\% \end{cases} & or \\
10^\circ < H \leq 20^\circ, \begin{cases} 0\% \leq S \leq 30\%, 30\% < V \leq 100\%\ or \\ 30\% < S \leq 50\%, 30\% < V \leq 90\%\ or \\ 50\% < S \leq 60\%, 30\% < V \leq 40\%\ or \\ 50\% < S \leq 60\%, 50\% < V \leq 60\% \end{cases} & or \\
20^\circ < H \leq 30^\circ, \begin{cases} 0\% \leq S \leq 30\%, 40\% < V \leq 100\%\ or \\ 30\% < S \leq 50\%, 40\% < V \leq 90\%\ or \\ 50\% < S \leq 60\%, 40\% < V \leq 80\% \end{cases} & or \\
30^\circ < H \leq 40^\circ, \begin{cases} 0\% \leq S \leq 30\%, 70\% < V \leq 100\%\ or \\ 30\% < S \leq 40\%, 70\% < V \leq 90\% \end{cases} & or \\
350^\circ < H \leq 360^\circ, 0\% \leq S \leq 20\%, 80\% < V \leq 100\%
\end{cases} then\ skin \tag{1}
$$

IV. Results

Figure 3 represents the color range selected by the proposed model (Eq. 1) containing all the 93,100 probable human skin tones, ordered from lightest to darkest.

After applying all 13 rules from the mathematical model in the HSV system spectrum and after visual inspection of the plot for the RGB color space, we observed that the human skin tones can be found in a well-defined band of the color spectrum, which in its turn is determined by a group of characteristics.

Figure 4 displays all the H, S and V intervals selected in the model for human skin detection individually as projections on the RGB color space. In addition, for visual inspection, each HSV dispersion interval also displays the automatically generated color spectrum representation below it.

By analysing the color spectrum labeled as skin by the intervals presented in Figure 4, it can be observed that intervals I3 (Fig. 4c) and I13 (Fig. 4m) tend to select skin tones starting from white and comprising pinkish and less grayish tones, whereas interval I8 (Fig. 4h) also starts from white, but comprises brown and black tones. Interval I11 (Fig. 4k) starts from white and comprises yelowish tones.

The other intervals comprise less skin tones in the HSV color space. While interval I6 (Fig. 4f) represents predominantly dark tones, I12 (Fig. 4l) comprises yellow tones. It can also be observed that dark skin tones are located in the lower portion of the selected color spectrum (Fig. 4f and Fig. 4g), lighter tones in the upper portion (Fig. 4c and Fig. 4m), the yellow ones in the center (Fig. 4k and Fig. 4l) and the brown tones between the central and lower portions (Fig. 4i and Fig. 4j).

Intervals I4 (Fig. 4d), I5 (Fig. 4e) and I8 (Fig. 4h) are the most representative from the ones in the model's final build, comprising 23%, 13% and 20% of the skin tones, respectively. These intervals present the highest dispersion in their spectra, thus comprising a wide range of tones.

The developed method and related methods were applied on the images from the FDDB facial image database [22] in order to demonstrate the method and verify its efficiency.

Generally, all algorithms used in human skin detection presented high true negative rates, yielding at least 80% in all cases, including the proposed model. The developed model mislabeled 7.3610% of the pixels from the test images (false negative), thus being more efficient then the models proposed by [18] (16.3449%), [16] (10.0077%) and [19] (7.5647%).

For evaluation of the models, we calculated some performance metrics during testing - sensitivity, specificity, F-*measure* and G-*measure* - thus providing with their generalization capability. Table I presents these metrics obtained from the models from image test set. In general, all methods yielded high specificity rates in human skin detection for images stored using the HSV color space. The highest specificity among the related works was reported by [15], 97.7094%, and the lowest (83.6551%) by [18]. In regards to sensitivity, the best performance was obtained by [18], with a 79.6028% hit rate. The worst performance, with a 45.1644% hit rate, was yielded by [15].

Fig. 3: Color range for human skin obtained by the HSV proposed mathematical model in order of intensity.

The filters described in the reviewed bibliography present similarities in defining the band with the probable human skin tones in the HSV color space and projected on the RGB color space. Among these, the presented model yielded the highest reduction of the HSV spectrum (97.4648%), followed by [15] (96.8905%). [18] presented the lowest reduction (93.6744%), as seen in Table I.

TABLE I: Performance measurements for the models. For each metric: top two results underlined and the best result identified by the character (*).

Models	**Sensitivity**	**Specificity**	**F-*measure***	**G-*measure***	**Reduction**
Tsekeridou & Pitas	45.1644%	97.7094%*	0.5835	0.6643	96.8905%
Wang & Yuan	76.8465%	89.9923%	0.7019*	0.8316*	95.5968%
Udo Ahlvers & Zolzer	79.6028%*	83.6551%	0.6410	0.8160	93.6744%
Roy & Bandyophadyay	56.7631%	92.4353%	0.6020	0.7244	94.7745%
Model HSV proposed	54.6333%	92.6390%	0.5887	0.7114	97.4648%*

V. Conclusion

This work presented a method to reduce the amount of color tones labeled as skin tones for the detection of white, yellow, brown and black skin tones in digital color images in the HSV color space.

The proposed HSV filter (Eq. 1) selected a well-defined band in the geometric representation of the color space reducing the spectrum to 94,030 tones (2.5352% of the total spectrum), thus rejecting 97.4648% of colors as probable human skin tones.

The experimental validation of the HSV model showed that the proposed filter presents conservative characteristics in regards to skin detection in digital images. In comparison to the 4 models found in the literature, it mislabeled only 7.3610% of the 32,008,742 non-skin pixels comprised by the test image set. The HSV model presented low sensitivity (54.6333%) and high specificity (92.6390%) rates when compared to the other works found in the literature.

Different from other filters described in the literature which propose a single interval for human skin in the HSV system, the proposed model presents and discusses 13 intervals in the possible spectrum which present a well defined variation in terms of tone. These intervals could be further elaborated on and/or could be used in classification problems regarding skincare in eHealth systems.

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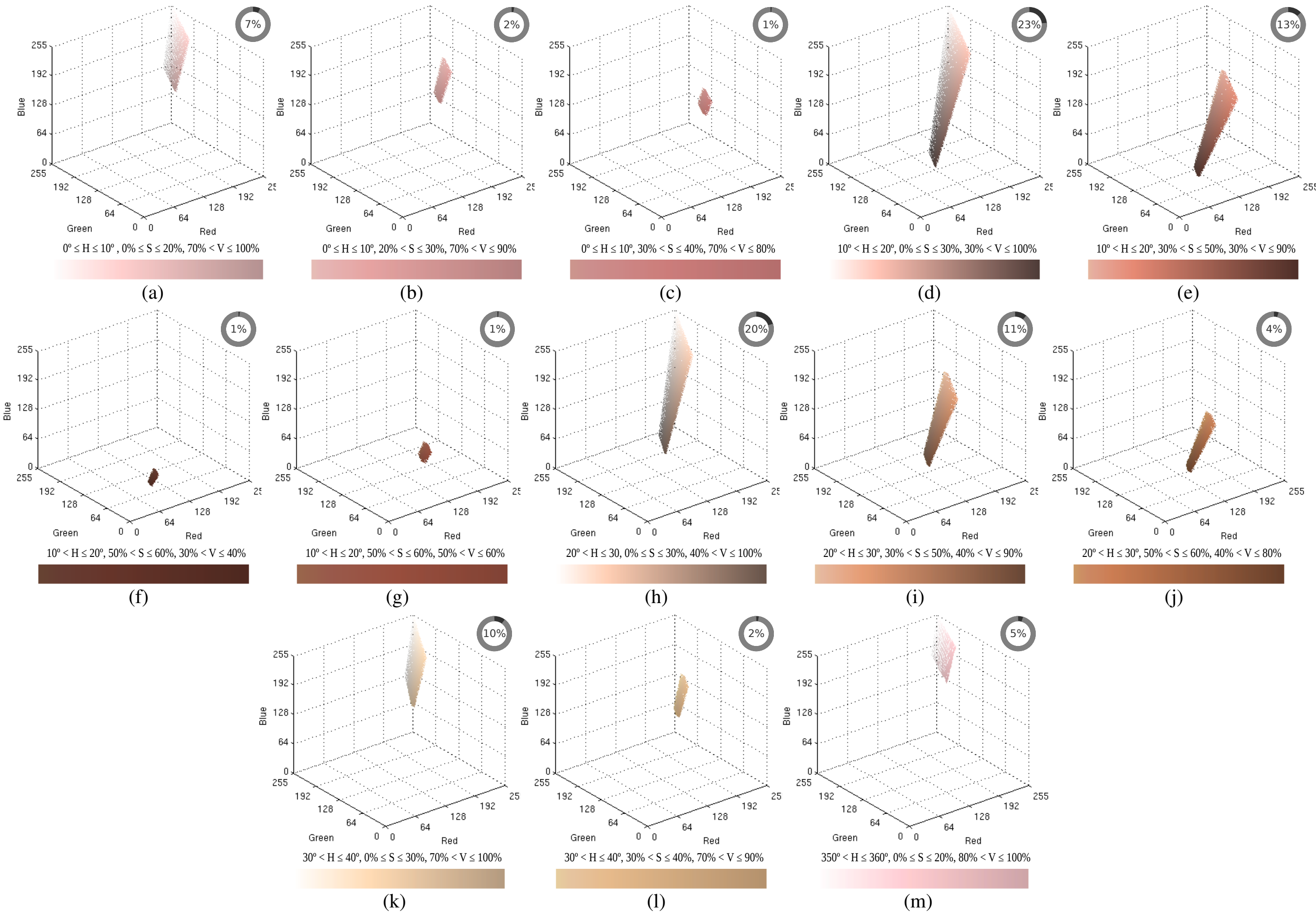

Fig. 4: Dispersion of skin tones in the HSV color space as projected on the RGB color space and selected by intervals I1 (a), I2 (b), I3 (c), I4 (d), I5 (e), I6 (f), I7 (g), I8 (h), I9 (i), I10 (j), I11 (k), I12 (l) and I13 (m) with respective values ranges (H, S and V) and percentage of contributions in model (%)

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