

Figure 1.35 (a) Original color image. Different representations of the hue component: (b) Hue component with red at 0° . (c) Sine of hue angle divided by two, which gives a measure of distance from red at 0° . Observe that the regions in green and blue in the original color image have similar values in the present result, indicating that they are almost equally separated from red. (d) Sine of hue angle minus 120° divided by two, which gives a measure of distance from green at 120° . Observe that the regions in red and blue in the original color image have similar values in the present result, indicating that they are almost equally separated from green. See also Figures 1.18 and 1.34.

originally inconsequential hue values undesirably enhanced in the displayed image due to the maximal saturation and intensity applied). To overcome this unwanted effect, achromatic (or nonchromatic) pixels with saturation less than a threshold or intensity above or below suitable thresholds could be assigned the corresponding intensity values with no color (zero saturation, hue not relevant) in the output.

Figures 1.37 and 1.38 also show (in part c of each figure) isointensity renditions with the original hue and saturation but intensity equal to unity for the entire image. Images of this nature may be used to analyze the color composition, chrominance, or chromaticity (in terms of hue as well as saturation) of an image without consideration of the intensity. Information regarding the

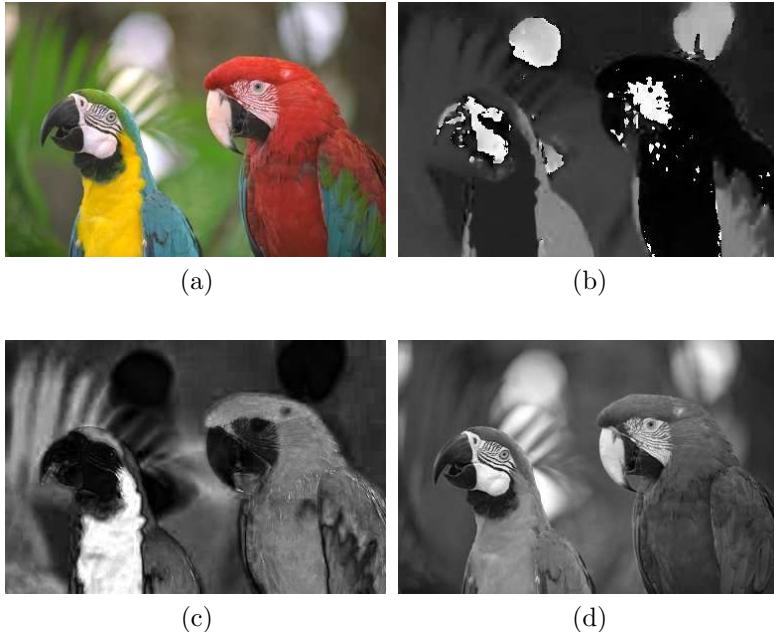


Figure 1.36 (a) Original color image. Representation using the *HSI* components: (b) Hue component. (c) Saturation component. (d) Intensity component. See also Figure 1.26.

intensity (luminance or achromatic composition) is provided by the intensity or value components as shown in part (d) of the same figures for the two images.

An application of thresholding based upon saturation and intensity is demonstrated in Figure 1.39. Part (a) of the figure shows the original image in full color; part (b) shows the selection of pixels with saturation less than 0.2 and intensity less than 0.2 times the maximum intensity in the original image. The resulting image shows the pixels in the original image that are nearly black, with little or no color, that is, achromatic and dark. An arbitrary color has been assigned to the background or the rest of the image, which represents the chromatic pixels in the original image. Part (c) of the same figure shows the selection of pixels with saturation less than 0.2 and intensity greater than 0.8 times the maximum intensity in the image. The resulting image shows the pixels in the original image that are nearly white, with little or no color, that is, achromatic and bright. Part (d) shows the result of applying a condition on saturation alone (less than 0.2) with no condition on intensity: the result shows all achromatic pixels that are dark or bright. Note that the hue component is not used in this example.

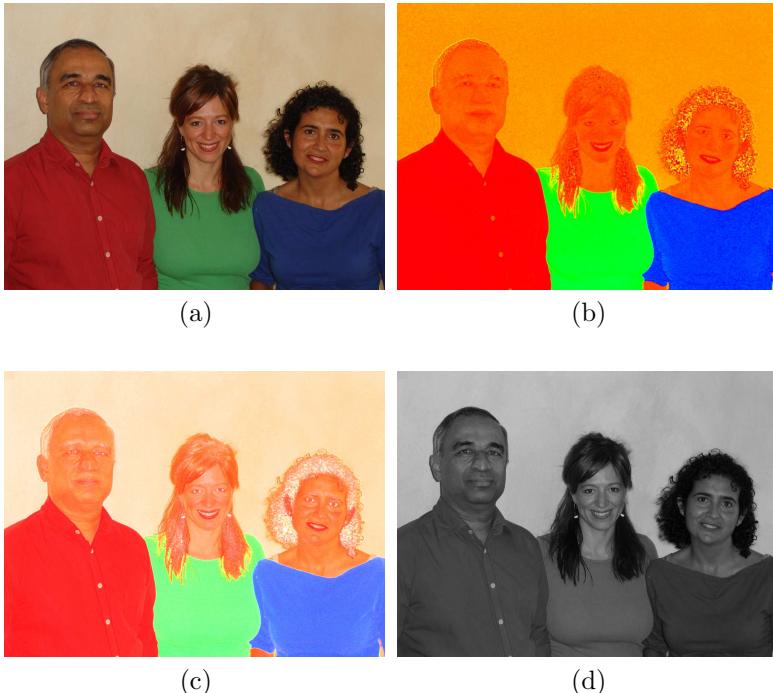


Figure 1.37 (a) Original color image. (b) Hue component with maximum saturation and intensity. (c) Isointensity rendition with the original hue and saturation but intensity equal to unity for the entire image. This image gives the chrominance information. (d) Intensity component; this gives the luminance information. See also Figures 1.18 and 1.34.

1.3.4 Histograms of HSI components

The distribution of pixels in a given image against various hues of color may be plotted as an angular histogram or a rose diagram [6, 122], with hue represented over the range $[0^\circ, 360^\circ]$ as illustrated in Figure 1.18. Figure 1.40 illustrates a rose diagram representing the distribution of hue in a test image with six diamond-shaped regions in the six primary colors (*RGB* and *CMY*). As expected, the rose diagram indicates the presence of equal numbers of pixels with red, yellow, green, cyan, blue, and magenta. Given the ambiguity of hue (color) at low levels of saturation and intensity, it may be desirable to place limits such that the only pixels counted in the given image have saturation and intensity values higher than certain prespecified thresholds (in the *HSI* system).

Figure 1.41 illustrates a rose diagram representing the distribution of hue in a color image. Note that the background color of the wall has a distribution of hue between yellow and red, and that some regions of skin and hair have

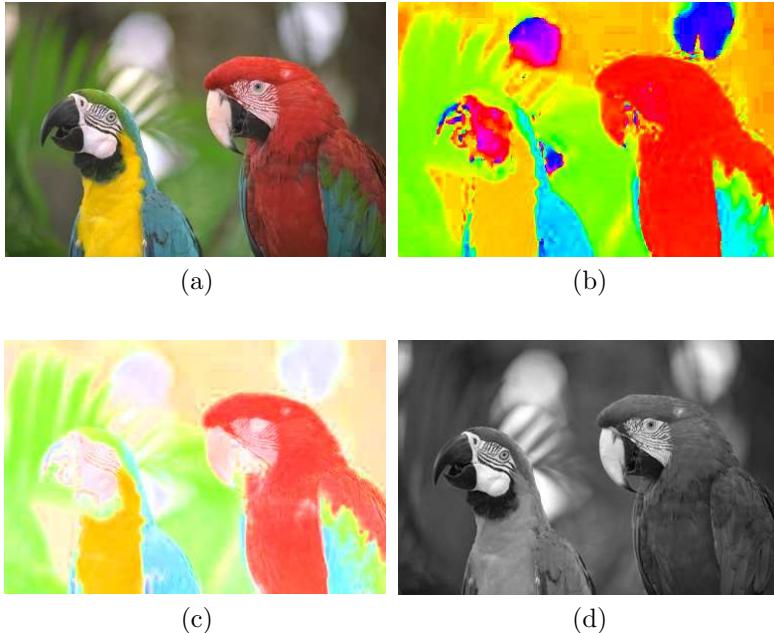


Figure 1.38 (a) Original color image. (b) Hue component with maximum saturation and intensity. (c) Isointensity rendition with the original hue and saturation but intensity equal to unity for the entire image. This image gives the chrominance information. (d) Intensity component; this gives the luminance information. See also Figures 1.18 and 1.36.

contributed to incidences of pixels with various values of hue in the range of red.

A more detailed representation of the *HSI* components can be provided by using multiple and combined histograms of the components. Although each component could be represented by its individual histogram on its own, it is advantageous to consider the hue and saturation components together, given that they jointly convey information regarding the chromaticity of the image [2]. The intensity component could be represented by a histogram of its own, similar to the case of a grayscale image.

Figure 1.42 shows a color image, a 2D histogram of the hue and saturation components, and a 1D histogram of the value component (as in the *HSV* system); see also Figures 1.25, 1.27, and 1.34. The hue–saturation histogram includes a ring showing the fully saturated colors as a function of angle (hue); see also Figure 1.18. The value or displayed intensity of each point within the ring corresponds to the number of pixels in the original image with a given hue (angle) and saturation (distance from the origin of the ring). A logarithmic transformation (\log_{10} of the count of pixels augmented by one)

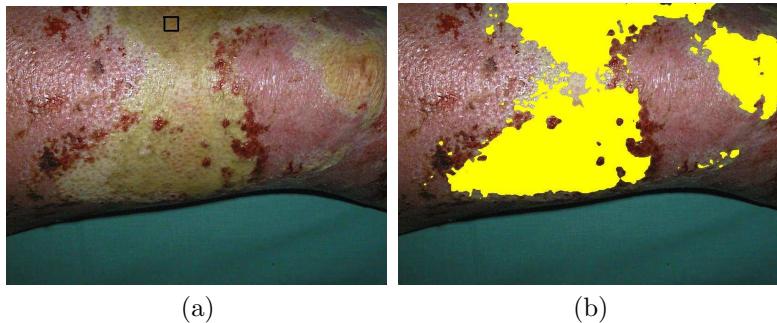


Figure 5.35 Segmentation result for a full-thickness burn. (a) Original image, which has both superficial dermal burn (the red part) and full-thickness burn (the cream-colored part). (b) Segmented image. In this case, the user has made the selection in the cream-colored part such that the algorithm segments the full-thickness-burn parts of the image. See also Figure 5.31. Reproduced with permission from Acha et al. [410].

shape, and spatial distribution of the regions with different colors and the associated types of tissue. Computer-aided analysis of color images of skin lesions could assist in improved long-term care of patients with chronic skin ulcers and associated problems [153–156, 414].

5.8 Biomedical Application: Segmentation of Blood Vessels in the Retina

The structure of the blood vessels in the retina is affected by diabetes, hypertension, arteriosclerosis, and retinopathy of prematurity through modifications in shape, width, and tortuosity [137–142]. Quantitative analysis of the architecture of the vasculature of the retina and changes as above could assist in monitoring disease processes, as well as in evaluating their effects on the visual system. Images of the retina can also reveal pathological features related to retinopathy, such as microaneurysms, hemorrhages, exudates, macular edema, venous beading, and neovascularization [137]; see Section 1.5. Automated detection and quantitative analysis of features as above could assist in analyzing the related pathological processes.

In many applications of image processing in ophthalmology, the most important step is to detect the blood vessels in the retina [137, 141, 144, 146, 415–420]. The following paragraphs provide a brief review of some of the methods proposed for the detection of blood vessels in the retina.

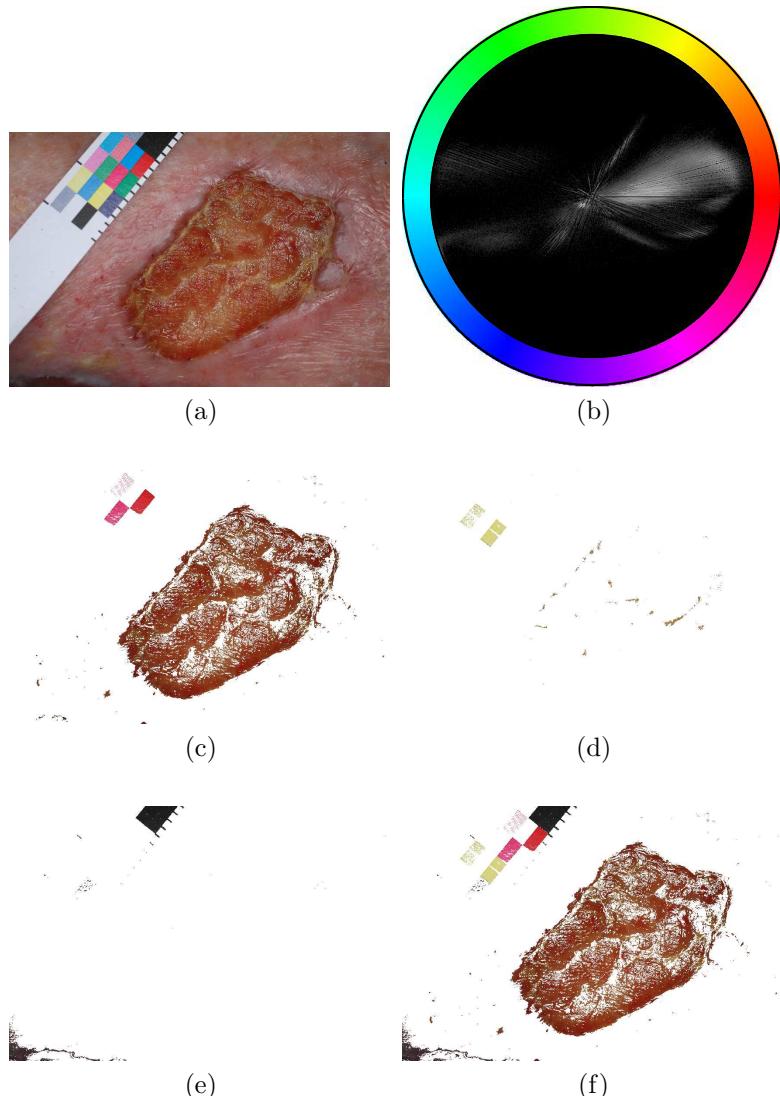


Figure 5.36 Segmentation of a color image of a skin ulcer based upon hue angle and saturation: (a) original color image; (b) HS histogram of the image; (c) segmented red component; (d) segmented yellow component; (e) segmented black component; (f) union of the segmented RYK components. Original image courtesy of Dr. Paulo M. de Azevedo Marques and Dr. Marco A.C. Frade, University of São Paulo, Ribeirão Preto, São Paulo, Brazil.

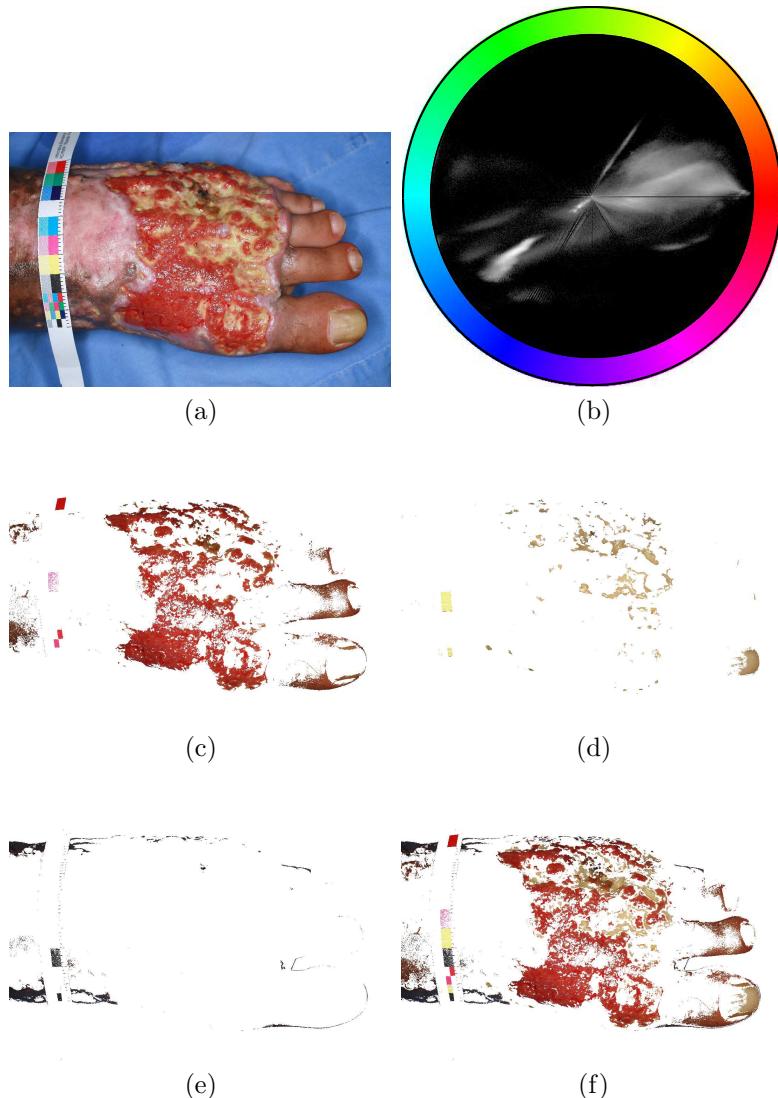


Figure 5.37 Segmentation of a color image of a skin ulcer based upon hue angle and saturation: (a) original color image; (b) HS histogram of the image; (c) segmented red component; (d) segmented yellow component; (e) segmented black component; (f) union of the segmented RYK components. Original image courtesy of Dr. Paulo M. de Azevedo Marques and Dr. Marco A.C. Frade, University of São Paulo, Ribeirão Preto, São Paulo, Brazil.