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A device for the color measurement and detection of spots on the skin

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Background/purpose: In this work, we present a new and fast easy-to-use device that allows the measurement of color and the detection of spots on the human skin. The developed device is highly practical for relatively untrained operators and uses inexpensive consumer equipment, such as a CCD color camera, a light source composed of LEDs and a laptop. The knowledge of the color of the skin and the detection of spots can be useful in several areas such as in dermatology applications, the cosmetics industry, the biometrics field, health care, etc.

Methods: In order to perform these measurements the system takes a picture of the skin. After that, the operator selects the region of the skin to be analyzed on the displayed image and the system provides the CIELAB color coordinates, the chroma and the ITA parameter (Individual Tipology Angle), allowing the comparison with other reference images by means of CIELAB color differences. The system also detects spots, such as freckles, age spots, sunspots, pimples, black heads, etc., in a determined region, allowing the objective measurement of their size and area.

Results: The colorimetric information provided by a conventional spectrophotometer for the tested samples and the computed values obtained with the new developed system are quite similar, meaning that the developed system can be used to perform color measurements with relatively high accuracy. On the other hand, the feasibility of the system in order to detect and measure spots on the human skin has also been checked over a great amount of images, obtaining results with high precision.

Conclusion: In this work, we present a new system that may be very useful in order to measure the color and to detect spots of the skin. Its portability and easy applicability will be very useful in dermatologic and cosmetic studies.

Key words: digital camera – color measurement – spots detection – human skin – multispectral imaging

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In this work we present a new system for the color measurement and the spots detection on the human skin. The developed device is composed of standard and relatively inexpensive equipment, such as a CCD color camera, a light source composed of LEDs and a laptop, and it has a simple software interface, which simplifies its use for untrained operators.

By means of the described components, the system is capable of acquiring color images of a certain area of the skin. Once the acquisition has been performed and the color image is available, the operator can easily choose a region of analysis and the system provides the mean CIELAB color coordinates, the chroma and the individual topology angle (ITA) parameter corresponding to it (1). The system also allows the comparison between the analyzed sample and a reference by means of CIELAB color differences. The methodology used to obtain the colorimetric information from the corresponding digital levels is based on multispectral imaging techniques (2, 3). These techniques permit to compute a transformation matrix between the measured RGB signals and the colorimetric values, such as the CIELAB $L^*a^*b^*$ coordinates, and therefore the chromatic information of any area of the imaged skin can be obtained. Specifically, the mathematical method used in this work is based on the Moore–Penrose pseudoinverse technique (4–6).

On the other hand, the system allows the detection of spots present on the analyzed skin region, such as, age spots, sunspots, pimples, black heads, etc. The implemented algorithm is capable of measuring the dimensions corresponding to the spots objectively, using algorithms based on the histogram equalization, OTSU binarization (7) and morphological operators (8), which allow to establish the contour of the spots and consequently, to perform their measurement.

The knowledge of the color of the skin can be useful in many areas such as:

- Dermatology (9, 10): especially, when objective and quantitative data are required. Fields of application include assessment of physiological parameters of skin, the monitoring of skin response to various stimuli and the evaluation of colored skin lesions.
- Cosmetics (11, 12): for automated and objective evaluation of the efficacy and safety of treatments for changing the color of the skin.
- Biometrics: to aid in person recognition within small groups in which determination of skin coloring is useful.

Furthermore, the measurement of spot sizes, their related color and variations along the time could be applied in areas, such as the health care and the cosmetics field.

Method

The developed system (Fig. 1) consists of an RGB CCD camera with an 8-bit depth (AVT Marlin F-033C, AVT GmbH, Stadtroda, Germany), a 16 mm objective lens, an illumination system composed of white LEDS (CCS LDR2-90-SW, CCS Inc., Kyoto, Japan) (Fig. 2) and a PC. For a correct assembly of the components and a proper performance of the system, several mechanical pieces corresponding to the instrument head were developed, which allow to support the system on the subject skin and to perform the measurement comfortably.

Fig. 1. Experimental set-up of the system.

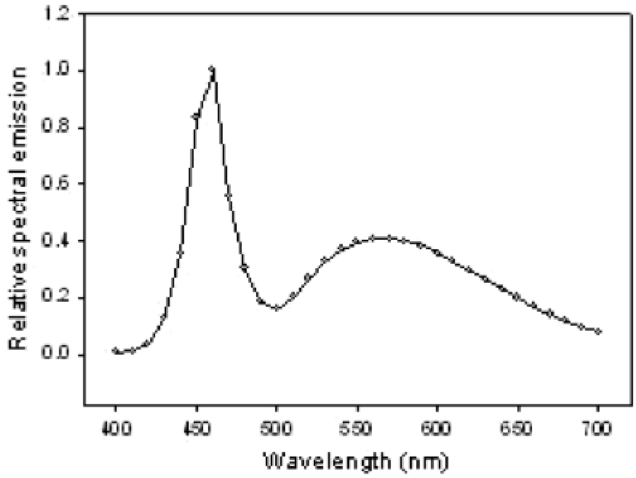

Fig. 2. Relative spectral emission of the LEDs used in the illumination system (CCS LDR2-90-S W).

The software developed to control the system allows the acquisition of an image of the skin and the selection with the mouse of a specific region of analysis. Once the acquisition has been performed, the system applies an algorithm for the spatial non-uniformity correction of the image (flat field correction) (13, 14), which is fundamental in order to use the CCD color camera as a high spatial resolution instrument for measurement purposes, and to make the entire camera detection area available. This algorithm permits the correction of the scene illumination across the imaged field, which is non-uniform because of the position and the emission of the LED source used, and also the correction of the CCD camera response, which can present different pixel sensitivities and responses due to the optical system and the CCD sensor itself. In order to compute this correction, an image corresponding to a uniform gray card placed at the exact location where the skin images will subsequently be captured, and therefore captured under the same illumination and exposure conditions, is acquired. Assuming that the image corresponding to the gray card must be completely uniform, it is used to numerically compensate for the effect of the spatial non-uniformity on each of the images captured, by means of a linear correction with a gain (G) and an offset (O) matrix:

$$DL_c(i,j) = O(i,j) + G(i,j)DL(i,j) \tag{1}$$

where $DL_c(i,j)$ and $DL(i,j)$ are the digital levels of the (i,j) pixel of the corrected and original images, $O(i,j)$ represents the (i,j) element of the correction offset matrix and $G(i,j)$ represents the (i,j) element of the correction gain matrix. The dimension of these matrixes ($i = 1, \ldots, m$ and $j = 1, \ldots, n$) depends on the number of pixels available on the CCD sensor used, in our case 480 × 640.

The implemented software interface clearly presents two distinguished parts: the color analysis and the detection of spots.

The color analysis section allows the computation of the CIELAB color coordinates L^*, a^* and b^*, the chroma (C^*) and the ITA parameter, which is related with the hue angle (Eq. (2)) and it is commonly used to classify different kinds of skin:

$$\mathrm{ITA}(^\circ) = [\arctan(L^* - 50)/b^*] \times \frac{180}{\pi} \qquad (2)$$

Furthermore, the software permits to obtain the CIELAB color difference (ΔE^*) with respect to a reference sample, which can be conveniently selected. The reference illuminant taken into account in the study is the white associated with the emission of the LEDs of the illumination system.

The computation of the color coordinates from the digital levels of the image is performed using multispectral techniques, specifically with the Moore–Penrose pseudoinverse (4–6). With this method and using a training set of representative samples, a transformation matrix between the measured signals (RGB) and the colorimetric values ($L^*a^*b^*$) can be calculated. The correct choice of the training set is of great importance if we want to obtain high color accuracy measurements with the developed system. The training set used in this work consists of 74 patches with similar coloration to the human skin corresponding to two standard color charts: the color checker CCCR and CCDC. In order to test the feasibility of this system, the CIELAB color coordinates of these patches have been measured using a spectrophotometer MINOLTA CM-2002 (Minolta Camera Co., Ramsey, NJ, USA) and have also been computed from the RGB signals provided by the developed system, and the CIELAB color difference between both sets have been calculated. The mean and the standard deviation obtained in CIELAB units are 3.09 ± 1.73. The choice of these standard patches also allows to obtain real skin color measurements with acceptable uncertainty associated, as it will be seen in the following section.

The spots detection section is based on the application of several filters and image processing tools (8). These procedures allow to determine the areas with a different coloration with respect to the background of the image. The average color of the skin is essential to determine the spot, so the system takes up a histogram equalization (stretch) in order to contrast the spot with respect to the skin. Afterwards, the RGB color image is transformed to a black and white image, and the histogram is stretched again in order to magnify the spots, losing the minimum quantity of information. Afterwards, the system applies a binarization threshold determined at runtime by the Otsu operator (7); the reason is that no previous assumptions can be done about the skin color, and this threshold has to be calculated in every case. The resulting image is processed using morphological algorithms in order to obtain an optimal segmentation in the areas with different coloration. First, an erosion using a rhomboid structural element with 5 × 5 size is performed, and, second, a dilatation using a square structural element with 3 × 3 size is applied. Then, the isolated pixels are removed (spikes). Finally, the system counts the number of regions within a range supplied by the user.

We define the membership of two pixels to a region as follows: given two pixels P and Q in the image I, both of color c ($c \in \{0,1\}$), P and Q belong to the same region in $I \iff$ there exists a subset of adjacent c-colored pixels between P and Q in I. This region count is done by a two-step process: (a) determining the regions of the image, doing a pixel-by-pixel check, (b) counting the number of resulting regions. In order to determine the regions of an image, the algorithm considers that black pixels in the binarized image correspond to non-spotted skin and white pixels correspond to spots.

The two last steps of the algorithm's zone determination:

Any black region contained totally in a white region is considered part of the white region, because it is considered skin that belongs to a bigger spot, and the system paints this black region into white. This process does not change the number of white regions.

Any white region next to any edge of the image is automatically discarded, as it can be assumed that there is not enough information on the image to determine if it is really a spot or not. So, it is important that the system operator try to center the spot in the image when taking images with the camera, in order to avoid discarding information with this post-process.

Once the system knows the pixel-region correspondence, a count of the number of non-discarded white regions with an area within a range determined by the user is performed, and the corresponding zones are shown on the screen as well as the information corresponding to them (area, length and height, in pixels and mm^2).

Results

Using the described system, we have performed color measurements over a set of 30 real skin samples corresponding to different subjects. The color coordinates associated to an area of approximately (1×1) cm of these samples have been measured using the conventional spectrophotometer MINOLTA CM-2002 and have also been calculated from the RGB digital levels corresponding to the images acquired by the developed system. In this case, the mean CIELAB color difference and the standard deviation obtained between both sets of values is of 4.94 ± 1.84, which only represents a small increase with respect to the results obtained for the patches corresponding to the training set.

Furthermore, as the system should allow the correct color comparison between different skin samples, the accuracy of the system has also been checked studying the CIELAB color differences obtained when different samples are taken into account. Figure 3 shows two specific examples: plot (a) illustrates the spectral reflectances associated with the measured skin samples with maximum and minimum L^* belonging to two different subjects (1 and 2), and plot (b) shows the spectral reflectances associated with two different samples belonging to a specific analyzed subject (3a and 3b). Table 1 shows the colorimetric information associated with these samples provided by the spectrophotometer, as well as the computed values obtained using the new system developed. As it can be seen, the values obtained using both methodologies are quite similar, meaning that the developed system can be used to perform color measurements with a relatively high accuracy.

On the other hand, the feasibility of the system in order to detect spots on the human skin has also been checked over a great amount of images. Figure 4 shows a specific example. In this case,

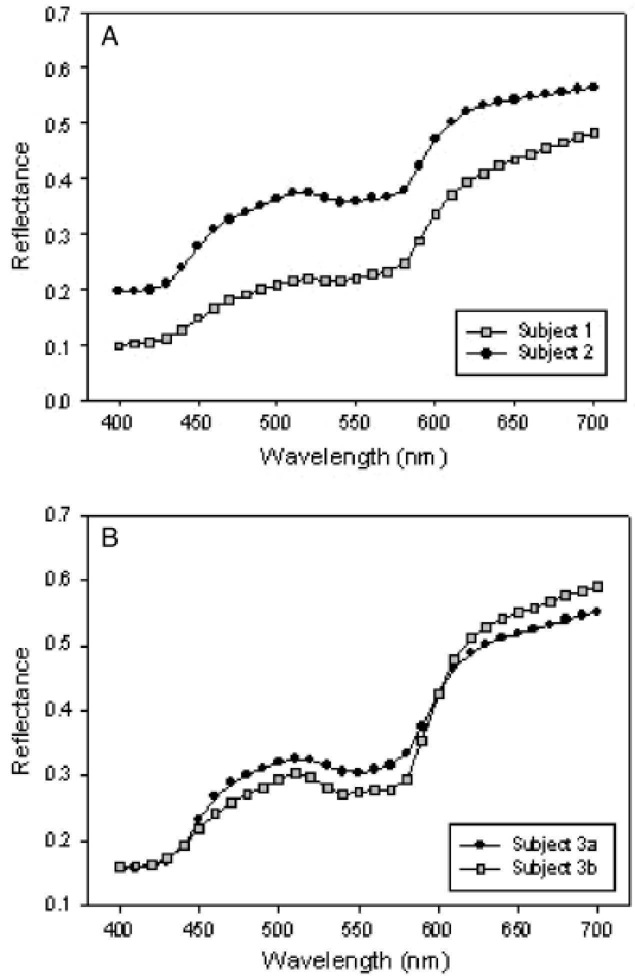

Fig. 3. Spectral reflectances corresponding to the samples with maximum and minimum L (a) and to two similar samples of the same subject (b).*

TABLE 1. Specific examples of CIELAB color coordinates and color differences measured using the spectrophotometer MINOLTA (MIN) and estimated using the developed system (EST)

Sample	L^* MIN	a^* MIN	b^* MIN	ΔE MIN	L^* EST	a^* EST	b^* EST	ΔE EST
Subject 1	57,31	7,19	18,25	12.98	61,79	8,75	19,00	10.63
Subject 2	68,79	3,62	13,41		70,35	5,07	13,87	
Subject 3a	65,31	5,28	13,93	4.41	68,79	6,01	15,20	5.24
Subject 3b	63,46	9,28	13,94		65,20	9,75	15,52	

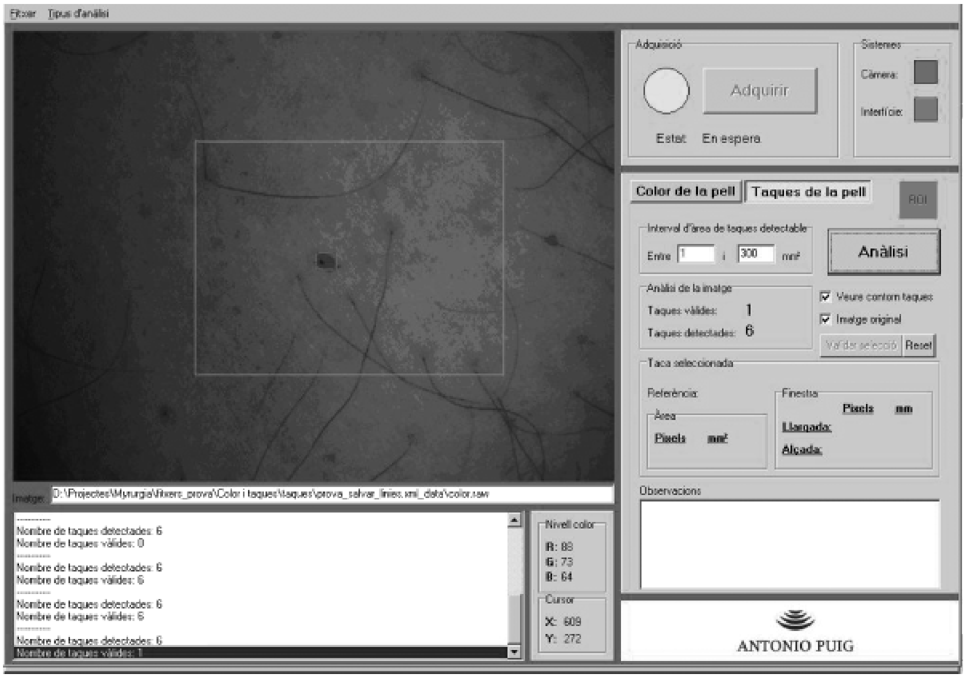

Fig. 4. Example of the detection of a spot on a skin sample.

the system operator has restricted the analysis to the lime square area because of lack of illuminance in the edges. Another restriction is the spot area range; in this case, only spots between 1 and 300 mm^2 are analyzed; the reason is that there is hair and other elements in the image that could interfere with the final results. The detected spots are surrounded by a red square, and the operator can examine each detected spot's properties in a very simple way.

The available properties for every detected spot are

(a) Spot area (in source image pixels and mm^2).
(b) Spot's corresponding red square width and height (both in source image pixels and mm). This is useful to determine the width and the height of the spot.

Conclusion

In this work, we present a new system developed for the measurement of color and the detection of the spots on the human skin. The system, which is composed of a CCD color camera, a LED light source and a laptop, permits to perform color measurements and detection of spots of skin samples by just acquiring an RGB image of the analyzed sample. The system provides the CIELAB color coordinates, the chroma and the ITA parameter of a selected region, allowing the comparison with other reference images by means of the CIELAB color differences. Furthermore, the system also detects spots, such as freckles, age spots, sunspots, pimples, black heads, etc., allowing the objective measurement of their size and area. The work reported in this study shows the high accuracy achieved in the color measurements performed and also the great precision of the system to detect and measure spots on the skin.

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