A calibrated color imaging system for use in dermatology

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Abstract— **We propose a novel imaging system useful in dermatology. The system consists of a Pentium PC equipped with a RGB frame grabber, a 3-chip CCD camera controlled by the serial port and equipped with a zoom lens and a halogen annular light source.**

Calibration of the imaging system provides a way to transform the acquired images, which are defined in an unknown RGB color space, to a standard well-defined color space called sRGB. A total of 15 types of polynomial RGB to sRGB transforms will be tried, including some optimized using the perceptual color difference metric in CIE L*a*b* ($\mathbf{\Delta E^*_{ab}}$).

The calibration procedure is based on 24 patches with known color properties, and takes about 5 minutes to perform. It results in a number of settings called a profile which remains valid for tens of hours of operation. Such a profile is checked prior to acquiring images using just one color patch, and is adjusted on the fly to compensate for short-term drift in the response of the imaging system. Precision or reproducibility of subsequent color measurements is very good with $\langle \mathbf{\Delta E^*_{ab}} \rangle = \mathbf{0.3}$ and $\mathbf{\Delta E^*_{ab}} < \mathbf{1.2}$. Accuracy compared to spectrophotometric measurements is fair with $\langle \mathbf{\Delta E^*_{ab}} \rangle = \mathbf{6.2}$ and $\mathbf{\Delta E^*_{ab}} < \mathbf{13.3}$.

Keywords— **Dermatology, Color imaging, Imaging system calibration, Colorimetry, CIE**

I. INTRODUCTION

IN dermatology, color and color difference as well as shape often convey important diagnostic information. It is, however, very difficult to perform a quantitative measurements of such features using traditional photography, mainly due to variations in film and development. It's usually also not very practical to do so. Digital imaging might provide a solution, but suffers some of the same drawbacks as traditional photography: a non-reproducible varying color representation. Luckily, it is possible to calibrate a digital imaging system by controlling its settings and determining the relationship between its unknown device-dependent input color space, and some colorimetric or related device-independent color space. This relationship can then be used to transform acquired images to that device-independent color space for further processing and storage.

II. IMAGING SYSTEM COLOR SPACES

In our imaging system the *sRGB* color space will be used as the device-independent color space for the calibration. It is based on the phosphors used in many modern CRT-based display devices, including computer monitors. This means that images stored in *sRGB* do not have to be converted before display, and should look fairly realistic on a computer monitor. It is the subject of standardization, so meaningful exchange of images is also possible. Crucially, *sRGB* has a known relationship to the CIE XYZ and $L^*a^*b^*$ color spaces, two human vision based colorimetric spaces. CIE $L^*a^*b^*$ is an attempt at a perceptually uniform color space, which means the distance between two colors, notated as ΔE^*_{ab}, is proportional to their perceived color difference.

The *sRGB* and its related CIE color spaces provide a proper framework for subsequent development of segmentation, measuring and classification methods. Especially segmentation should benefit from the availability of a perceptual color difference and produce results which are more in agreement with a human observer. Moreover, any such segmentation, measurement or classification method should have a wider applicability due to its independence from an imaging system.

III. MATERIALS

The imaging system consists of a 3-chip CCD camera with a zoom lens, a halogen light source and a frame grabber. The camera is controlled using the serial port of a PC and has field of view of 1.6 cm by 1.2 cm. With an image containing 760 by 570 pixels the resolution is thus 47.5 pixels/mm. A continuous annular light diffuser is fitted around the lens in order to provide a spatially homogeneous light field in the focal plane. The diffuser is connected to a halogen light source using an optical fiber. See fig. 1 for more details of the camera assembly. The frame grabber is responsible for digitizing the video signals sent to it by the camera. It is fitted in a standard PC, and acquisition is done using the PAL analog RGB format which is digi-

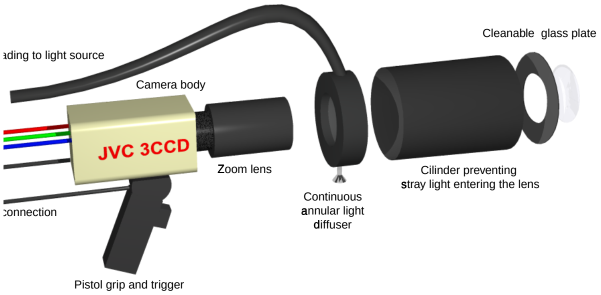

Fig. 1. Schematical drawing of the camera and its accessories. All components are drawn approximately to scale.

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tized with 8-bit precision per color channel. The settings of the frame grabber are controlled by software. The color patches used in the calibration are taken from the MacBeth Color Checker Chart[1] (MBCCC).

IV. Calibration

Based on a simple empirical model of the imaging system, optimal settings are determined in several successive steps in order to make optimal of the dynamic range of the camera. Basically, we make sure a totally black object, i.e. with luminance $Y = 0$, is mapped to *RGB* value $(0, 0, 0)$, and totally white object, $Y = 100$, is mapped to *RGB* $(1, 1, 1)$. The response of the imaging system to intermediate luminances is linearized using a look-up table based on the 6 MBCCC gray scale patches with luminances ranging from 3 to 90.

The relationship between the unknown *RGB* input color space and the *sRGB* color space is modeled using a polynomial transform. Several transforms of varying complexity will be tried, with 3, 6, 8, 9 and 11 terms respectively. The coefficients of these transforms are determined by comparing the *RGB* values of the MBCCC patches as measured by the imaging system and those measured with a spectrophotometer. This leads to a set of overdetermined linear equations which can easily be solved in a least-squares sense using singular value decomposition. However, the sum-of-squares in *sRGB* is hardly representative for the human perception of the mapping error associated with a certain polynomial transform. We therefore also try to compute the coefficients by non-linear optimization in the perceptually uniform CIE $L^*a^*b^*$ color space. Both the average ΔE^*_{ab} error per patch and the maximal ΔE^*_{ab} error over all patches were used, leading to a total of 15 tested polynomial transforms.

The settings determined during calibration are stored in a calibration profile, and this profile will be recalled prior to acquisition.

V. The acquisition procedure

During the acquisition procedure the user makes sure the stored profile is still valid by comparing the current color of the MBCCC 'white' test patch with its color during the calibration procedure. If this color difference falls within certain limits, the profile is accepted and may be adjusted in order to compensate for the drift in response of the imaging system. Such an adjusted profile remains valid for 10-15 minutes, during which images can be acquired freely without any extra profile checks. Fig. 2 shows an example of an acquired image.

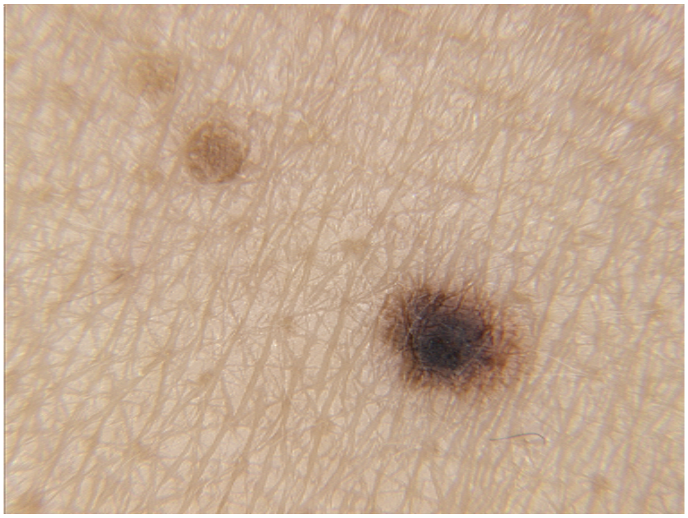

Fig. 2. A junction naevus shot with the imaging system.

VI. Experimental results and discussion

With precision we mean the reproducibility of measurements, or the way repeated measurements are spread around the average of those measurements. The most important type of precision here is the long-term or inter-profile precision when talking about the agreement between measurements made under different calibration profiles. The average and maximal errors over all the MBCCC patches for the long-term precision are $\langle \Delta E^*_{ab} \rangle = 0.30$ with $\Delta E^*_{ab} < 1.2$.

With accuracy we mean the way in which measurements of colors made with the imaging system are close to the measurements made by a reference instrument, a spectrophotometer in this case. To quantify the accuracy we compute the average and maximal ΔE^*_{ab}, obviously over a set of test patches different from the MBCCC patches used in computing the polynomial transforms. This test set consists of 15 plastic and paper patches, as well as 12 skin areas (normal Caucasian and Asian skin, moles, pimples, ...) from human volunteers.

Surprisingly, the simplest polynomial transform, i.e. the 3 by 3 linear transform computed using singular value decomposition, has the lowest average ΔE^*_{ab} at 6.21 and the second lowest maximal ΔE^*_{ab} at 13.31 over the test set. Very probably this is due to the limited number of patches used in computing the transforms, leading to a very sparse sampling of the *RGB* and *sRGB* color spaces. This hardly affects the linear transforms which have very good generalizing properties, but may lead to uncontrolled, oscillating behavior between the sample points for higher-order transforms.

VII. Conclusions and future work

We have proposed a color imaging system which allows reproducible and colorimetrically fairly accurate acquisition of images. These images are transformed to the standard *sRGB* color space, allowing realistic viewing and meaningful exchange of images. The link of *sRGB* with the CIE colorimetric spaces means it is possible to develop human vision and device-independent image processing for the acquired images.

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[1] Macbeth, 405 Little Britain rd, New Windsor, NY 12553-6148, USA