Colorimetric calibration of images of human skin captured under hospital conditions

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ABSTRACT

In this paper we study the problem of acquiring colorimetrically-calibrated images of human skin under hospital conditions with uncontrolled multiple illuminants. The application domain is diagnosis of skin burns based on the measured colour. To give some control over illumination we have experimented with xenon flash in an attempt to dominate the ambient illumination. We have used a Macbeth DC Color Checker as a test target to make measurements of observed colour using a digital camera under various illumination conditions. We present an iterative colorimetric calibration algorithm which determines both a spatial image correction profile and a transformation matrix to convert measured pixel values into calibrated CIE *XYZ* values. We have obtained a colorimetrically calibrated burn photograph database by applying this method.

1. INTRODUCTION

Computer Aided Diagnosis (CAD) systems are getting more popular in medicine. However, nowadays, research in the field of colour skin image analysis is being developed slowly due to the difficulty of translating human colour perception into objective rules, analyzable by a computer[1]. The main characteristic for giving an assessment about the depth of a burn that physicians take into account is colour. So, an image acquisition system must preserve this property as well as possible. We decided to use a digital photographic camera, which meets the following clinical needs: it is cheap (the cost involved in a real implementation of the system must be low), it is easy to use (no specialist in acquiring images is going to be at local medical centres) and it preserves the burn characteristics[2].

But the problem we encountered when trying to analyse burn wound digital photographs is that, in a practical situation, illuminant conditions in a hospital are uncontrolled. Then, measured pixel values depend on the illuminants and with multiple illuminants the measured values cannot be accurately converted to a known colour space without some additional information. This issue has been previously addressed in telemedicine applications such as teledermatology[3,4]. The main problem we encountered in these studies is that they used very specialized cameras and other hardware elements like filters, creating a complicate system not easy to reproduce in every local medical centre. We need a system easy to use and to implement in order that physicians can utilize it easily.

In this paper we demonstrate that the xenon flash illumination is sufficiently strong to dominate artificial illumination (e.g. from fluorescent lamps), which is an important fact when using digital cameras as acquisition systems for automatic burn diagnosis, because that means that the users will have to calibrate images only each time they change the camera, and not each time the patient is treated in a different room.

The second part of the paper consists in the calibration of the images. Three things have to be taken into account: 1) correction is needed for the non-uniformity of the illumination, 2) correction is needed for the spatial non-uniformity of the camera sensitivity, and 3) the *RGB* primaries of the camera for xenon flash illumination are unknown. Therefore we need to determine in some way a transformation matrix to convert from measured *RGB* into a device-independent colour representation system.

2. METHOD

To study the problem of image capture under uncontrolled hospital conditions we have captured images of the Macbeth DC Color Checker (Gretag-Macbeth GmbH, Martinsried, Germany) under carefully controlled conditions in order to separate out the various factors. The image acquisition was carried out by means of a digital photographic camera, the Canon EOS 300D (Canon Inc., Tokyo, Japan). Any non-specialized person should be able to acquire data from the patient, because it is not possible to have an expert in each centre. A digital photographic camera is easy to utilize and people are used to them.

The problems we found that had to be solved when using a digital photographic camera for this application are explained in the following subsections.

A. Illumination influence

The most important source of information for our system in order to classify burn depths is colour, which is extremely influenced by the illumination. In hospitals the lightning conditions can change depending on the room where the patient is. Then, measured pixel values depend on the illuminants and with multiple illuminants the measured values cannot be accurately converted to a known colour space without some additional information. Therefore, a study about the influence of the different sources of illumination is needed. To perform this study, we photographed the Macbeth ColorChecker DC chart under three different illuminations: in a darkroom with the built-in flash (guide number=13 meters at ISO 100), in a darkroom with fluorescent light and in a room under diffused sunlight. Under these three different situations, we fixed the ISO speed to 100, the f-stop (Av) to 20 and we varied the exposure time (Tv). We define that the exposure time is optimum under a particular illuminant when it is the maximum time without saturating any channel. The ratio between the exposure times will give us the influences of the different sources of light.

B. Calibration

An additional problem we encountered is that manufacturers normally do not publish either the *RGB* primaries of the camera or the colour temperature of the flash. Therefore we need to determine in some way a transformation matrix to convert from measured *RGB* coordinates to a device-independent colour representation system.

For this purpose, we find the matrix transformation between *RGB* and CIE *XYZ* (device-independent colour space). In the literature there are many transformation matrices from *RGB* to *XYZ* colour space, but they are defined for specific illuminants (D65, D50, etc) and specific *RGB* primaries (CCIR Rec.709, FCC-NTSC, etc). We have developed a calibration method based on the Macbeth ColorChecker DC chart, which is specifically designed for calibration of digital cameras. The Macbeth ColorChecker DC chart has 240 colour chips and it is supplied with data giving the CIE *XYZ* chromaticity coordinates of each chip under D50 illuminant. The 240 chips occupy an area of 12cm × 20cm. Our method finds the transformation matrix from *RGB* under unknown illuminant to *XYZ* under D50, and corrects the non-uniformity of the illumination as well as the spatial non-uniformity of the camera sensitivity. This algorithm performs iteratively the following steps:

1) Without correcting the illumination profile and using only three colour patches, we calculate the initial matrix M_1 that converts from *RGB* under an unknown illuminant to *XYZ* under D50.
2) In the i-th step, using the 240 color patches in the chart and the matrix M_{i-1}, we calculate the profiles, $P_{R,i}(x,y)$, $P_{G,i}(x,y)$ and $P_{B,i}(x,y)$, so that, for each patch, the R, G, B corrected with the profiles and multiplied by M_{i-1} are the X, Y, Z values specified by the manufacturer of the colour chart. That is, for each patch k in the position (x_k,y_k) the following equation is performed:

$$\begin{bmatrix} P_{R,i} \\ P_{G,i} \\ P_{B,i} \end{bmatrix} = \begin{bmatrix} 1/R(x_k,y_k) \\ 1/G(x_k,y_k) \\ 1/B(x_k,y_k) \end{bmatrix} (M_{i-1})^{-1} \begin{bmatrix} X_k \\ Y_k \\ Z_k \end{bmatrix} \quad (1)$$

3) We calculate the three fourth order surfaces, $P'_{R,i}(x,y)$, $P'_{G,i}(x,y)$ and $P'_{B,i}(x,y)$, that matches best the profiles $P_{R,i}(x,y)$, $P_{G,i}(x,y)$ and $P_{B,i}(x,y)$ calculated in step 2). Previously, we have experimentally determined that a fourth order surface approximates adequately the sensitivity of the camera and the non-uniformity of the flash illumination altogether.
4) Using this profile, we calculate the matrix M_i that best maps the *R*, *G*, *B* values into the *X*, *Y*, *Z* values specified for all the patches in the colour chart. To determine this optimum M_i the following mean square error is minimized:

$$\varepsilon^2 = \frac{1}{240}\sum_{k=1}^{240}(X_{tk} - X_k)^2 + (Y_{tk} - Y_k)^2 + (Z_{tk} - Z_k)^2 \tag{2}$$

where X_{tk}, Y_{tk} and Z_{tk} are the *X*, *Y* and *Z* values of the *k*-th colour patch, in the position (x_k,y_k), specified by the manufacturer.

5) Repeat from step 2 until the mean square error ε begins to grow.

It must be emphasized that the matrix *M* is the product of two matrices: the transformation from *RGB* to *XYZ* under an unknown illuminant and the linear transformation to perform the chromatic adaptation from an unknown illuminant to D50[5]. This matrix *M* is specific for each camera, so calibration should be performed for every camera used.

3. RESULTS

The first thing done was to calculate the optimum exposure times under the different illuminants. The experiment was performed with a Canon EOS 300D camera and photographs were taken of the Macbeth colour chart. The optimum exposure times were 1/200s, 0.6s and 1.6s for the flash, sunlight and fluorescent light respectively. That means that the flash is 320 times stronger than the fluorescent and 120 times stronger than the sunlight. In other words, if we choose Tv=1/200 and 8 bits per colour component, the fluorescent light will not influence even the least significant bit and the sunlight will influence the 2 least significant bits. In fact, we took a photograph under both fluorescent and sunlight illuminations with this parameter (Tv=1/200) and only these two least significant bits had values different to 0.

Another analysis that has been performed was to compare the maximum pixel values obtained under flash illumination, under daylight plus fluorescent illumination and with no illumination at all (with the lens of the camera covered with the cap) for the same camera parameters (Av=20, ISO=100, Tv=1/200). Results, summarized in Table 1, confirm that other illuminations different from the flash only influence the two least significant bits.

Table 1: Maximum pixel values of a photograph of the Macbeth Color chart for different illuminations for the same camera parameters.

Illumination	***R***	***G***	***B***
Flash	227	196	188
Fluorescent+daylight	5	7	4
No illumination	4	5	4

We can conclude that the xenon flash illumination is sufficiently strong to dominate illumination. That is an important result because in this way we only have to calibrate the images once for each camera, and not for each room where patients are treated.

Once we know that the main contribution to the illumination is due to the flash, we have to determine the profile due to the non-uniformity of the flash illumination as well as the spatial sensitivity of the camera. We have determined the profile due to both non-uniformities altogether, in conjunction with the matrix to transform into *XYZ* colour coordinates. For the matrix and the profile found, the average distance from the real colour to the estimated colour is 1.97. This is a good estimation if we take into account that the dynamic range is

$$d = \sqrt{\varepsilon^2} = \sqrt{\frac{1}{240}\sum_{k=1}^{240}(X_{tk} - X_k)^2 + (Y_{tk} - Y_k)^2 + (Z_{tk} - Z_k)^2}$$
$$= \sqrt{\frac{1}{240}\sum_{k=1}^{240}(255-0)^2 + (255-0)^2 + (255-0)^2} = 255 \cdot \sqrt{3} = 443.41 \tag{3}$$

where X_{tk}, Y_{tk} and Z_{tk} are the theoretical *X*, *Y* and *Z* values of the *k*-th colour patch, in the position (x_k, y_k), specified by the manufacturer, and X_k, Y_k and Z_k are the values estimated by the proposed algorithm.

In Figure 1, an example applied to a photograph of a burn wound from the database is shown.

(a) (b)

Figure 1: (a) Original digital photographic image of a burn wound. (b) Calibrated image.

4. CONCLUSIONS

In this paper the problem of calibrating a digital camera under unknown illuminant conditions is addressed. It has the main advantage that it does not need any specialized equipment, not available under hospital conditions.

By finding the exposure time required to obtain pixel values which are just below the saturation level, we have shown that the main illumination under mixed fluorescent lighting, diffused sunlight and xenon flash is the flash.

Likewise, we have designed a new algorithm to calibrate colour images using unknown *RGB* primaries and under an unknown xenon flash illuminant. With this algorithm we determine the conversion matrix from the unknown *RGB* primaries under the unknown illuminant to the device-independent *XYZ* under D50. At the same time, we determine the correction profile to be applied to the three colour channels.

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