Human Wound Photogrammetry with Low-Cost Hardware Based on Automatic Calibration of Geometry and Color

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ABSTRACT

Photographic documentation and image-based wound assessment is frequently performed in medical diagnostics, patient care, and clinical research. To support quantitative assessment, photographic imaging is based on expensive and high-quality hardware and still needs appropriate registration and calibration. Using inexpensive consumer hardware such as smartphone-integrated cameras, calibration of geometry, color, and contrast is challenging. Some methods involve color calibration using a reference pattern such as a standard color card, which is located manually in the photographs. In this paper, we adopt the lattice detection algorithm by Park et al. from real world to medicine. At first, the algorithm extracts and clusters feature points according to their local intensity patterns. Groups of similar points are fed into a selection process, which tests for suitability as a lattice grid. The group which describes the largest probability of the meshes of a lattice is selected and from it a template for an initial lattice cell is extracted. Then, a Markov random field is modeled. Using the mean-shift belief propagation, the detection of the 2D lattice is solved iteratively as a spatial tracking problem. Least-squares geometric calibration of projective distortions and non-linear color calibration in RGB space is supported by 35 corner points of 24 color patches, respectively. The method is tested on 37 photographs taken from the German Calciphylaxis registry, where non-standardized photographic documentation is collected nationwide from all contributing trial sites. In all images, the reference card location is correctly identified. At least, 28 out of 35 lattice points were detected, outperforming the SIFT-based approach previously applied. Based on these coordinates, robust geometry and color registration is performed making the photographs comparable for quantitative analysis.

Keywords: wound imaging, photographic documentation, automatic calibration, geometric correction, lattice detection, color calibration, calciphylaxis, reference card

1. INTRODUCTION

Due to the lack of standardization, photographic documentation is crucial in medical imaging. Perspective distortions of the geometry are superimposed with optical pin-cushion distortions from lenses, and measured colors are shifted from scene illumination and ambient light. Quantitative photographic imaging usually requires high-quality hardware and calibration steps, which are expensive and time-consuming, respectively. Quantitative monitoring of the development of a disease, e.g., a wound or a skin lesion, requires additional calibration and hence, it is not performed per clinical protocol yet [1].

On the other hand, photographic documentation of lesions and wounds is considered essentially, in particular for home care nurses, since skilled home care under the supervision of a certified wound, ostomy, and continence nurse is often expensive and unavailable [2]. Mobile imaging is suggested to substitute the expert's visit. In 2005, Buckley, Adelson & Hess further proposed the development of wound photography competency with a standard operation procedure for acquisition and annotation of digital photography [2].

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Recent advances in wound photography and assessment methods have been reviewed by Ahn & Salcico [3]. Beside one- (1D) and two-dimensional (2D) manual assessment, novel recording hardware is supporting three-dimensional (3D) measurements of wounds. Stereo-photographic systems have been built from two cameras or with the aid of color-coded structured light to project parallel stripes of alternating colors onto the wound area to reconstruct the 3D geometry using computer software detecting the intersection of the stripes with the wound surface [3]. However, such devices are expensive and not applicable for mobile wound documentation.

For objective wound evaluation, standardization of wound photography is required. The camera must be oriented in parallel to the major axis or surface of the wound, for 1D or 2D measures, respectively [4]. In addition, a calibrating device such as a ruler must be placed near the wound and oriented accordingly. Then, the pixel area can be calibrated to metric measures and lengths or areas of wounds are assessed quantitatively. This assessment, however, is disregarding any curvature of the skin.

More recently, color calibration methods have been proposed to assess the color of wounds, too. While in principle, the color of an object can be estimated even in uncontrolled illumination setting [7], the use of color calibration pattern is certainly more accurate. Van Poucke et al. have developed automatic colorimetric calibration of human wounds [5,6] that is based on a reference card composed of 4 x 6 color plates (MacBeth Colour Checker Chart Mini, Switzerland). With a growing demand for randomized clinical trials in chronic wound care and increasing economic pressure on health budgets a key point for optimal data sharing is standardization with agreement on the definitions of structures, processes, and formats used [5]. Fauzi et al. have suggested a probability map computation for quantitative wound assessment in red white black yellow (RWBY) color space using special (self-made) color reference pattern that was printed on white paper and placed next to the wound. For color calibration, the pattern is manually localized and automatically delineated in the images [8]. This pattern, however, does not support any geometric reference due to corrugation and bending.

In our previous work [9], we have applied a ruler and a color reference card (CameraTrax, USA) for geometric and color calibration, respectively. Detection of color card was done by finding corresponding points between a reference image of the color card and the clinical photograph using the scale invariant feature transform (SIFT) method [10]. The accuracy depends on the number and location of SIFT matching points and needed careful adjustment of the parameters.

In this paper, we aim at (i) improving reliability of both, geometric and color registration, (ii) integrating the calibration steps into one fully automatic process, and thereby (iii) supporting low-cost consumer hardware without any additional standardization.

2. MATERIAL AND METHODS

We focus on mobile imaging equipment as it is required in multi-centered clinical trials and registries or for home care nursing. The general idea is to reduce hardware costs by using consumer hardware of somehow lower accuracy and by paying for it with improved and automatic image processing. Accordingly, we describe the imaging equipment, the automatic calibration procedure, and the evaluation methodology.

2.1 Imaging Equipment

Smartphone-integrated cameras (e.g., Samsung Galaxy Tab3, Samsung Electronics GmbH, Germany) and a consumer color reference card (2x3-inches, 24 color plates, CameraTrax, USA) are placed next to the wound that shall be recorded as described by Rennert et al. for the Wound Electronic Medical Record [4]. In particular, the card is placed into the main plane and orientation of the region of interest (ROI), which is a necrotic skin lesion in our application domain of the calciphylaxis rare disease. The reference card is composed of 24 squared color plates covering the entire red green blue (RGB) color space and delivers 35 corner points for geometric adjustment.

2.2 Automatic Calibration

Using the reference pattern, geometric and color calibration is performed. The image processing chain therefore includes (1) location of the card within the image, (2) location of the color tiles within the card, and (3) measuring the color within the tiles. Adopting the approach of Park et al. for deformed lattice detection in real-world images [11], steps (1) and (2) are merged. The method applied for (3) has been described previously [9], and is not repeated here. The combined card and tile detection uses the lattice structure, which the regular tiles are forming. Due to perspective projection, the lattice is expected to be deformed. Hence, the first and most critical step of the algorithm is lattice detection. Once the lattice points are detected and stabilized, the next major step is lattice point labelling. The final step of image processing which is the geometric correction of images.

2.2.1 Lattice Detection

Recently, Park et al. have introduced a mean-shift belief propagation algorithm for automatic detection of deformed lattices in real world images [11]. Such near-regular patterns are created from buildings, fences, and other man-made textures, as well as our color reference cards. Reliable robustness is the advantageous characteristics of Park's approach, which is achieved by an iterative growth of the deformed lattice interleaved with thin-plate spline (TPS) warping.

Figure 1 illustrates the iterative card detection process. Figure 1a shows candidate corner points, which have been extracted using the KLT corner extractor from an edge map that is computed from a smoothed photograph. They are clustered using a mean shift approach [11]. Iteratively (Fig. 1b to 1e), the grid structure of the color card becomes prominent since the lattice detection algorithm easily hypothesis the core part of the card, and extends the number of extracted corner points following the non-parametric belief approach. In Figure 1f, the final detection result is superimposed to the original image. Due to the lattice hypothesis and TPS warping, the corner points are already stable with respect to their exact position, which might be affected by noise if each point is detected individually, as for instance by following our previous SIFT-based approach.

2.2.2 Lattice Point Labelling

Once the lattice detection is complete, we obtain the lattice points of the color card in the image. However, the detected points may be incomplete, and some additional points may be included to the lattice, which actually are located outside the reference card. Hence, we cannot assume correctly which lattice point corresponds to which corner point in the reference card.

To face the challenge of robustly finding the correspondence between the points, a color feature vector is composed for each detected lattice point. The feature vector consists of 4 sub blocks of 3 elements each, making the total length of each feature vector to 12. For computing the feature vector, first a quadratic bounding box is considered around the lattice point. Since each lattice point is surrounded by 4 different color patches, the 4 corners of the bounding rectangle will be in 4 different color regions (Fig. 2a). Hence, the colors at the corners of the bounding box are extracted as sub block [r, g, b] for red, green and blue color value, respectively. This results in a 12 dimensional feature vector. The elements in each sub block [r, g, b] are normalized in order to compensate for the illumination changes in images.

$$[r, g, b] = [R/I, G/I, B/I], \text{ where } I = R + G + B \tag{1}$$

In order to determine the matching pairs, the Euclidian distance between the feature vectors from lattice points and reference card is computed in the 12 dimensional feature space. The one with minimum distance is considered as the corresponding match for a particular point in the reference card. The matching pairs obtained are illustrated in Fig. 2 (b).

2.2.3 Geometric Correction

In this step, the best fitting projective transform of the detected lattice points to the reference card points is determined using homographic coordinates and the least-squares approach to obtain sufficient robustness against outliers [12]. This yields a robust estimate for each of the eight parameters that are describing the perspective transform of imaging the color card. The inverse transform is applied to achieve a corrected image, where the card is now aligned appropriately on both, horizontal and vertical directions as well as it appears scaled with respect to the standard reference size.

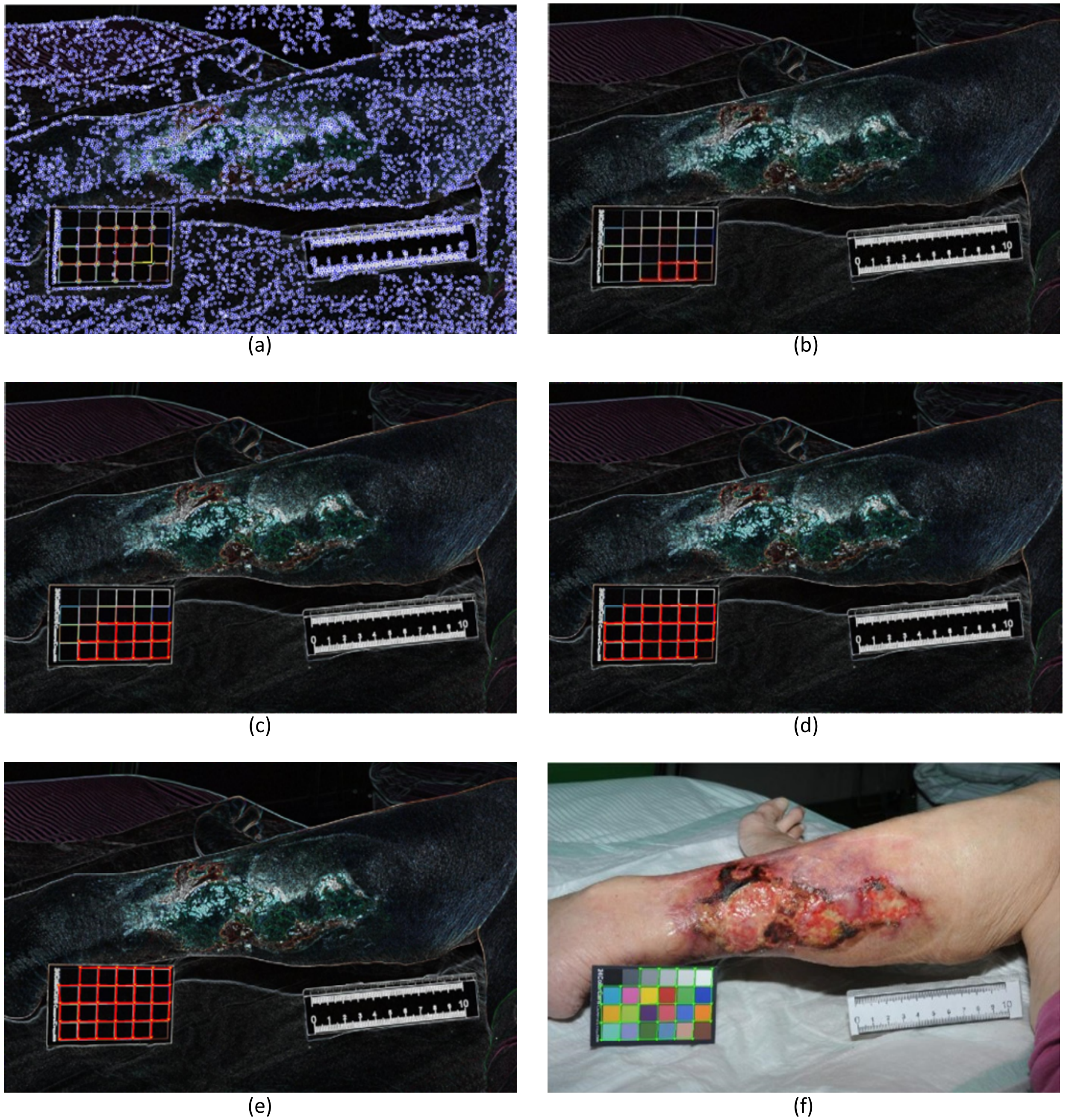

Figure 1: Stages of the lattice detection process. Edge map with feature points and selected candidate points of lattice (a); iterative process of lattice detection (b) – (e); and final lattice grid superimposed on the original photograph (f).

2.3 Evaluation

The approach was tested on 37 photographs collected within the German Calcyphylaxis Registry [13]. We define precision p as the ratio of the number of correct lattice points detected to the total number of lattice points detected in experiment. Recall r is defined as the ratio of number of correct lattice points to the total number of lattice points in an image.

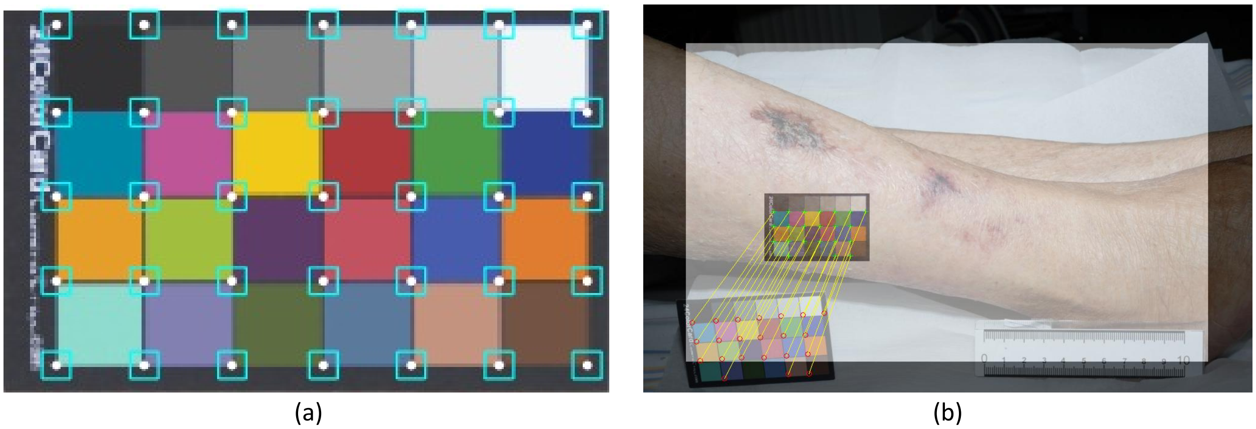

Figure 2: Stages of the lattice point alignment. Bonding boxes to compose the feature vector (a) and point alignment based on Euclidean distance I the 12 dimensional feature space (b).

For quantitative assessment, the F-measure is calculated as

$$F = (2 \times p \times r) / (p + r) \quad (2)$$

The recall assesses the robustness of the geometric calibration, whilst the precision determines its exactness. Hence, the F measure indicates the overall performance.

We also compare the results in terms of r, p, and F values with those obtained using our previous approach [9], based on SIFT point correspondences solely and disregarding the lattice structure of the corner points of the color card.

3. RESULTS

Figure 3 is illustrating the registration results. A female subject suffering from calciphylaxis was photographed over a period of 18 days disposing a rapidly growing skin lesion. All images have been registered such that the color reference card appears in the same size with horizontally and vertically aligned edges. In addition, color calibration was performed as described in [9]. After all the entirely automatic transforms, the images become visually comparable and quantitatively evaluable.

More quantitatively, the mean value and standard deviation of recall using the lattice-based approach are 0.972 and 0.041, respectively. The corresponding values for precision are 0.892 and 0.060, respectively. At least, 24 out of 35 points have been detected. The number of outliers (wrong lattice points) was not more than 2 in all the cases, and in 21 out of the 37 images, no false lattice point was indicated at all.

In comparison, the mean values for the SIFT-based method on the same images yielded 0.679, 0.356, and 0.467 for precision, recall, and F-measure, respectively. Figure 4 draws a comparison between the lattice detection method and the SIFT-based approach. The robustly and almost completely detected lattice is shown in Fig. 4a. Note the outlier on the right hand side of the card. This false lattice point is excluded automatically in the lattice point labeling process, as described in Section 2.2.2. Contrarily, the SIFT points were not uniformly distributed in the card region and also not precisely located in the color card lattice points (Fig. 4b).

Figure 3: Results. Calciphylaxis wound photogrammetry with low-cost hardware after automatic calibration of geometry and color. The images were taken from the German Calciphylaxis Registry [13].

4. DISCUSSION

In medical diagnostics and clinical research, photographic documentation and wound assessment is important. Photographic imaging requires proper registration and calibration in order to support quantitative assessment. In our method using a reference color card with 35 color plates, capturing it with low-cost consumer hardware, and incorporating the lattice detection algorithm, we were able to precisely detect the location of the color card and the color tiles within the card in one processing step without any manual adjustments. This supports robust and reliable geometric

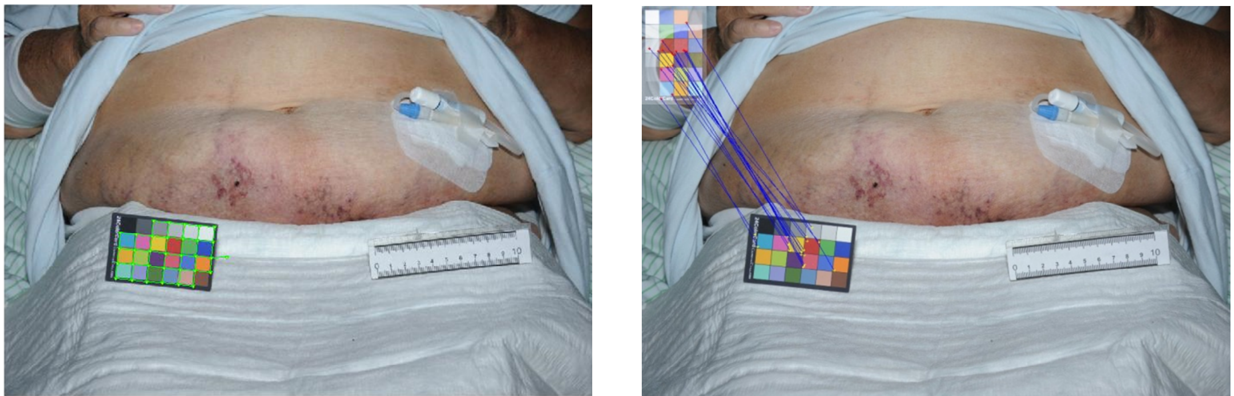
(a) (b)

Figure 4: Results: Detected points using the novel lattice-based approach (a) and the previous SIFT key point-based algorithm (b).

and color adjustment of images acquired at different points of time. It turns out to be superior to the previously SIFT-based method.

The main advantage of the proposed method is the full automation involving detection of lattice points and least squares for robust geometric correction and color calibration. In the contrary, Molnar et al. have developed a method for standardized photographic documentation [14], but color adjustments and geometric correction were performed manually. Images were taken using the same and rather expensive camera system in all study sites. In a recent work by Shetty et al. [15], a new method of photographic wound measurement was developed. They used a printed grid and ImageJ for geometric measurement. However, color calibration was not performed. In our previous work, [4] we used a SIFT-based approach to detect the color card, extract the individual color tiles, and then computed a color calibration. A ruler placed in the image was used for scale normalization. However, in the SIFT-based method, the adjustment of parameters was difficult and done manually for images taken by different devices at different sites. The current method is more robust and fully automated. Also taking advantage of the increased precision in lattice point positioning, the need for the calibration ruler has gone since the color card's dimensions are well known and usable as a geometric reference, too.

Our approach can be improved with better arrangement of the color plates within the card, i.e., mixing the gray wedge tiles over the entire color plate rather than placing them into one line of tiles (cf. Fig. 2a). In particular, the upper leftmost reference point is undetectable, since the black tile is framed with a black border. Furthermore, our approach can be applied on all relevant scales. A smallest card that might be produced with a 600 dpi printer is about 1 inch in size, supporting each color tile with 10 x 10 = 100 dots, and will be easily positioned next to a nevi or melanoma. Larger lesions such as from inflammatory or burning may be supported with more than one reference cards on different sides of the lesion.

However, our results also indicate that the card must be placed carefully within the plane of the lesion, which might not always be possible. Best practice guidelines for medical photography are required to ensure consistency and standardization of color and geometry in medical imaging. This is in line with the consensus report of the Summit on Color in Medical Imaging, which has recently held by the Food and Drug administration (FDA) and the International Color Consortium (ICC) [16]. To achieve color accuracy and color consistency, standard operation procedures have to be established in particular for mobile devices, as we suggest using. Hence, our approach might help in standardization of photographs taken at different sites with different devices under different lighting conditions.

5. CONCLUSION

In conclusion, incorporating the lattice detection algorithm of Park et al [11], which has been initially developed for real-word images, to extract the corner points of color card in medical photogrammetry is more effective as compared to the conventional SIFT feature point-based detection process [9]. While the SIFT-based method depends on the number point matches obtained from carefully adapted parameters, the lattice-based algorithm detects almost all the corner points precisely. Using heuristic knowledge on how the references are composed of individually colored tiles, matching coordinate pairs are extracted robustly and geometric correction as well as color calibration is performed automatically without any user interaction.

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