An Ultra-bright White LED Based Non-contact Skin Cancer Imaging System with Polarization Control

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ABSTRACT

Early detection and excision of melanoma skin cancer is crucial for a successful therapy. Dermoscopy in direct contact with the skin is routinely used for inspection, but screening is time consuming for high-risk patients with a large number of nevi. Features like symmetry, border, color and most importantly changes like growth or depigmentation of a nevus may indicate malignancy. We present a non-contact remote imaging system for human melanocytic nevi with homogenous illumination by an ultra-bright white LED. The advantage compared to established dermoscopy systems requiring direct skin contact is that deformation of raised nevi is avoided and full-body scans of the patients may time-efficiently be obtained while they are in a lying, comfortable position. This will ultimately allow for automated screening in the future. In addition, calibration of true color rendering, which is essential for distinguishing between benign and malignant lesions and to ensure reproducibility and comparison between individual check-ups in order to follow nevi evolution is implemented as well as suppression of specular highlights on the skin surface by integration of polarizing filters. Important features of the system which will be crucial for future integration into automated systems are the possibility to record images without artifacts in combination with short exposure times which both reduce image blurring caused by patient motion.

Keywords: non-contact dermoscopy, remote detection, automated skin cancer screening system, melanoma identification

1. INTRODUCTION

Early diagnosis of melanoma skin cancer is crucial as surgery at early stages significantly increases the five-year survival rates. Optical inspection, i.e. dermoscopy, is the standard method for skin cancer screening and melanoma detection today. Commercially available dermoscopes range from simple optical instruments providing 10-fold magnification to more advanced imaging systems providing up to 70-fold magnification as well as overview imaging and software for mapping of pigmented lesions for follow-up examination. A widely used tool for early detection of melanoma is the ABCD-rule [1]. It makes use of various features of the nevus such as color, symmetry, border structure or size in order to identify suspicious lesions. The 7-point-checklist [2] describing relevant optical structures of melanoma is a similar common approach at scoring and evaluating pigmented nevi. This checklist evaluates the nevi with three main criteria like an atypical pigmented network, a grayish-blue haze and an atypical vascular structure. For each of these criteria the scoring system gives 2 points. The four side criteria asymmetrical line structure, irregular pigmentation, points and globuli and the regression structures give one point for each parameter. The scoring threshold to classify the inspected nevi as suspicious for this checklist is three points. Another important parameter which has to be examined is the evolution E of the nevi over time. For each parameter checked, a score is assigned. If the sum over all parameters exceeds a certain threshold a nevus is considered suspicious of malignancy and has to be excised for histologic diagnosis. Long-term surveillance of (atypical) nevi allows to observe significant changes in these features and increases the sensitivity for skin cancer detection.

So far, nevi have to be scanned manually by imaging each lesion in direct contact with the skin. As the contact plate is pressed onto the skin, it flattens the skin lesion, thus, image reproducibility is difficult, in particular, for compound nevi with an out-of-plane structure. Furthermore, the imaging procedure may even be painful for large nevi. Also, lesions at strongly curved parts of the body such as the foot are difficult to image using the standard contact techniques. These drawbacks can be avoided by non-contact remote dermoscopy which would furthermore allow implementing automated screening protocols and consequently could significantly improve reproducibility and time-efficiency of nevi screening. Implementation of an automated system for remote skin cancer screening requires (i) reduction of specular highlights at the skin surface, (ii) accounting for patient motion, i.e. breathing, (iii) implementation of a bright and homogeneous

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illumination at the required distance of 60 cm, (iv) an appropriate magnification and resolution as well as (v) true color rendering of the imaging camera, required to ensure comparable conditions during follow-up checks and for the application of the ABCD-rule , and (vi) realization of a compact setup to be integrated into a prototype system.

2. OPTICAL SETUP AND CHARACTERIZATION

2.1 Laboratory prototype

The illumination in our laboratory prototype was realized by an ultra-bright white LED source (Luminus, CBT 90 White). Homogeneous and bright illumination was achieved by collimation of the LED's 130 ° output cone via reflector and lens system on the target area, i.e. the field of view of the imaging camera, at a distance of 60 cm. The prototype system described here is displayed in Fig.1. Major challenges here were reduction of losses in luminous flux especially at the LED – optical system interface and homogenizing the LED column output pattern to achieve illumination uniformity. Thermal management is easily accomplished by using a small fan, thus, facilitating a compact setup. Furthermore, the small size of the device allows for straight-forward integration into an automated system.

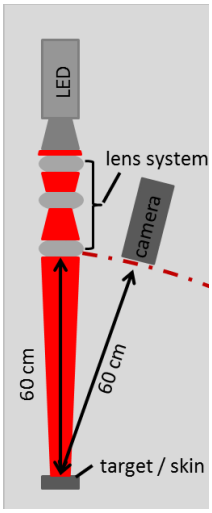

Fig.1: Schematic of the laboratory setup for remote, non-contact skin cancer screening

In addition, two polarizing filters were implemented for glare reduction. One polarizer is used to linearly polarize the illumination light. The other polarizer is positioned at cross polarization in front of the imaging system. Polarization is preserved for specular reflection at the skin surface while scattering within the skin tissue generally leads to depolarization. Consequently, specular highlights can efficiently be filtered from images by implementing polarizers in cross orientation. A CCD-camera (Point Grey, FI3-GE-2854C-C) which is also located at a distance of 60 cm from the target close to the illumination system was used for image recording. The used camera system consists of a GigE CCD-camera with an image resolution of (1928 x 1448) pixels and a pixel size of 3.69 µm x 3.69 µm and a customized lens system.

2.2 Illumination homogeneity

A crucial requirement of the system developed here is the homogeneous illumination in the field of view of the CCD camera. This was optimized by illuminating a white plane surface target and analysis of the resulting light distribution for different beam shapes. The images obtained for the white target were evaluated by analyzing the intensity of each pixel using a Matlab® code. Fig. 2 shows the intensity along a horizontal and vertical line across the image plane for the optimized setup.

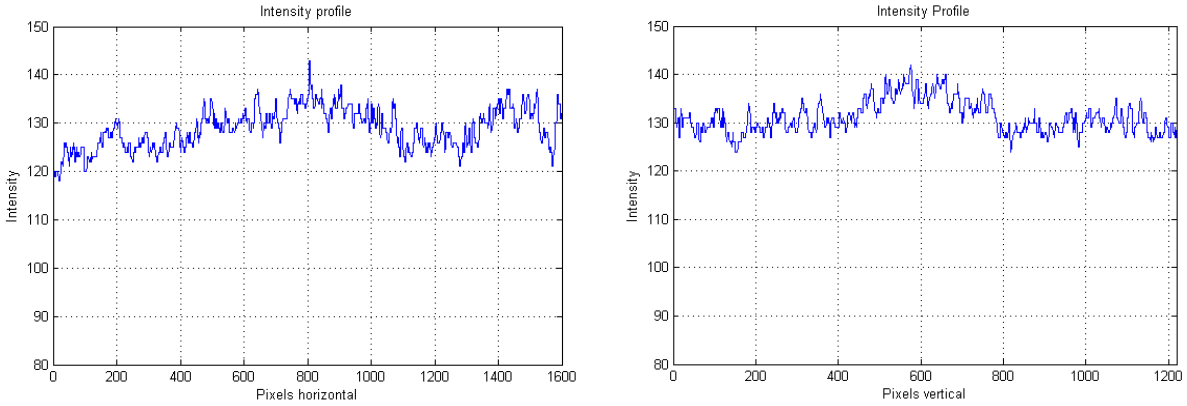

Fig.2: Intensity profile across a horizontal (left) and vertical (right) line of the CCD camera.

The evaluation of the whole field of view delivers an average intensity of 124.8 with a standard deviation of 2.7 which corresponds to a relative variance of 2.2 %. This is a commonly accepted value for homogeneous illumination conditions.

2.3 Spatial resolution

For a dermoscopic system, a minimum resolution of 30 µm is required in order to resolve small significant structures of a nevus, such as blood vessels or pigmentation. The spatial resolution of the presented system was tested by using a USAF 1951 target. The results of the resolution measurement are shown in Fig.3.

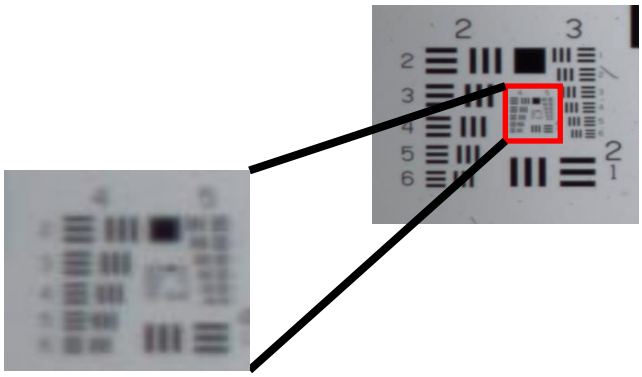

Fig.3: Determination of the system resolution with the USAF-1951 target

The smallest element of the USAF-1951 target which can reasonably be resolved is element 5 in group 4. This element contains 25.39 line pairs/mm corresponding to a resolution of 19.7 µm. Element 1 in group 4 (16 line pairs/mm), which corresponds to a resolution of 31.25 µm, gives a good idea of the system performance with respect to the minimum requirements for the optical system.

2.4 Depth of field

Another important parameter for imaging is the depth of field (DoF). For dermoscopy, a sharp image of features from different depths within the skin has to be obtained. Nevi may be several millimeters thick, so the imaging system should permit comparable imaging depths, even though deep tissue features may be difficult to image due to the limited penetration depth of visible light. Furthermore, the system has to tolerate small movements of the patient during acquisition time. For example, regular breathing should not lead to defocused images or image artifacts. To achieve this, a DoF of 10 mm is considered sufficient. Larger movements will be compensated for by mechanical tracking in the integrated, automated system.

The DoF of the optical system was measured by using an appropriate target (Edmund Optics, DOF 5-15 Depth of Field Target).

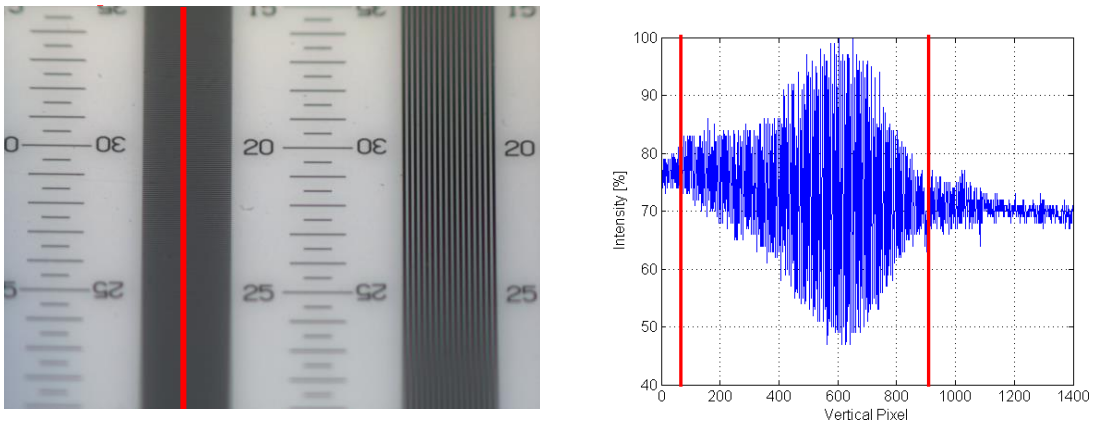

Fig.4: Depth of Field measurement. Left: standard used for the measurement; Right: vertical intensity profile along the red line

This depth of field target displays different scale structures to be viewed at an angle of 45°. It consists of horizontal lines at a frequency of 15 line pairs per mm and vertical lines at a frequency of 5 line pairs per mm. In order to obtain the value for the DoF, it is necessary to analyze the intensity profile along one vertical line crossing the scale structure shown in Fig. 4 (left). The intensity profile across the red line is also shown in Fig 4 (right). The DoF value is obtained by measuring the distance between pixels where the intensity compared to the maximum value decreased to a certain, pre-defined level, in our case 10 %. For our system, the DoF value is 8.7 mm.

2.5 Color rendering

Color or colored features are important in both the ABCDE and the 7-point scoring system. In order to ensure reproducibility to be able to reliably follow the evolution of a given nevus, true color rendering is required as well.
For this purpose, various RAL-color cards (RAL gGmbH) were used as standard color reference with predefined RGB-values for calibration. The RGB-values of the images of these cards were compared with the reference RAL-values. The system settings of the camera were optimized until the color properties of the images showed reasonable agreement with the reference. In our case, we chose the colors fire red, reseda green and rape yellow with their predefined [R, G, B]-

values [171, 31, 28], [252, 189, 31], and [94, 125, 79]. With optimized system settings, [179, 49, 23], [245, 187, 51] and [99, 118, 87], respectively were measured for the same color cards, showing good agreement with the reference values.

2.6 Suppression of specular highlights

Glare effects which have their origin in surface reflection of light have to be suppressed in order to avoid artifacts which might otherwise obscure important features of the imaged skin. For glare elimination, two polarizing filters (Moxtek, WGP00027, 50 mm diameter) are used. The first filter is located behind the illumination lens system in order to linearly polarize the light emitted by the LED. If this light is reflected from the skin surface, polarization is preserved. Thus, by using a second polarizing filter in crossed orientation, the reflected light can easily be eliminated. The influence of the polarizing filters is shown in Fig. 5.

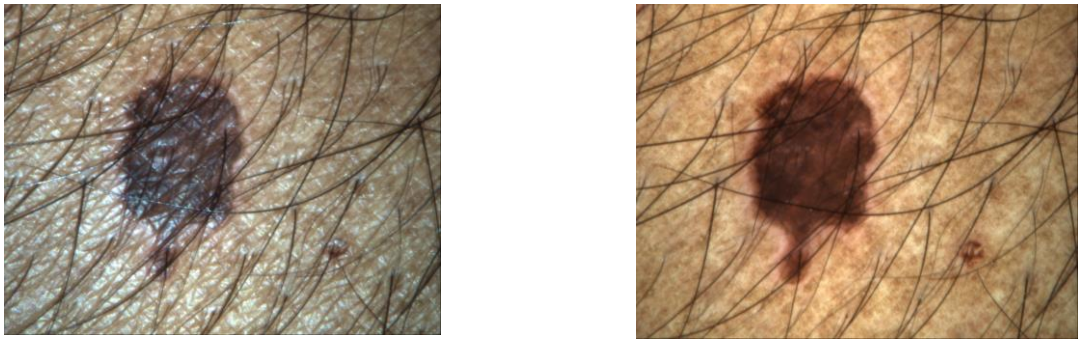

Fig.5: Comparison of pictures recorded without (left) and with the polarizing filters in place (right)

Usually, the use of polarizing filters is associated with significant intensity losses. In our setup, this is compensated by the use of an ultra-bright LED.

3. PRELIMINARY RESULTS – IMAGING OF PIGMENTED SKIN LESIONS

A pilot patient study with the laboratory prototype was performed at the Hanover Medical School (MHH) and at the University Medical Center Göttingen (UMG). As an example, Fig. 6 displays the image of a small pigmented nevus. Digital zooming on the nevus clearly reveals the pigmented network of the nevus, thus demonstrating the resolving power of the setup.

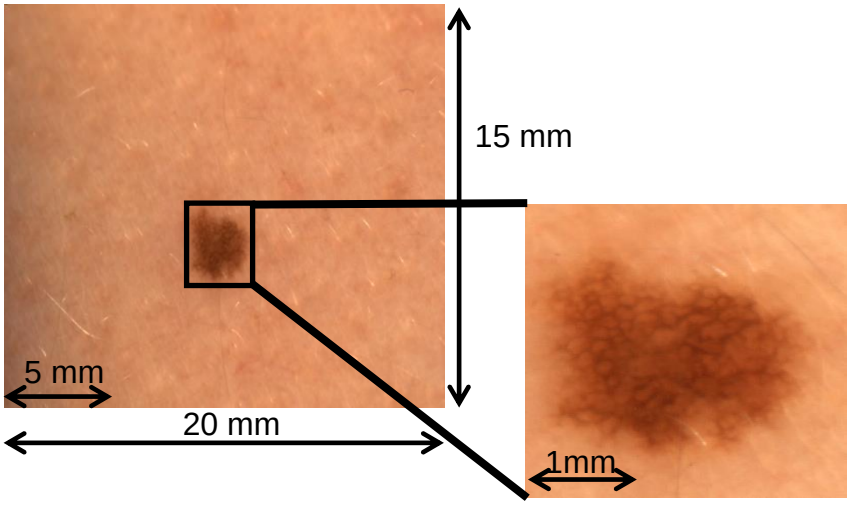

Fig. 6: Full field-of-view image of a small pigmented nevus (left) and digital zoom of the area of interest (right) in order to resolve the fine pigmented network

The images taken during the pilot study were compared with images obtained with an established commercial dermoscopic system (Dermoscope with Medicam 800HD, FotoFinder Systems GmbH). First results are shown in Fig. 7.

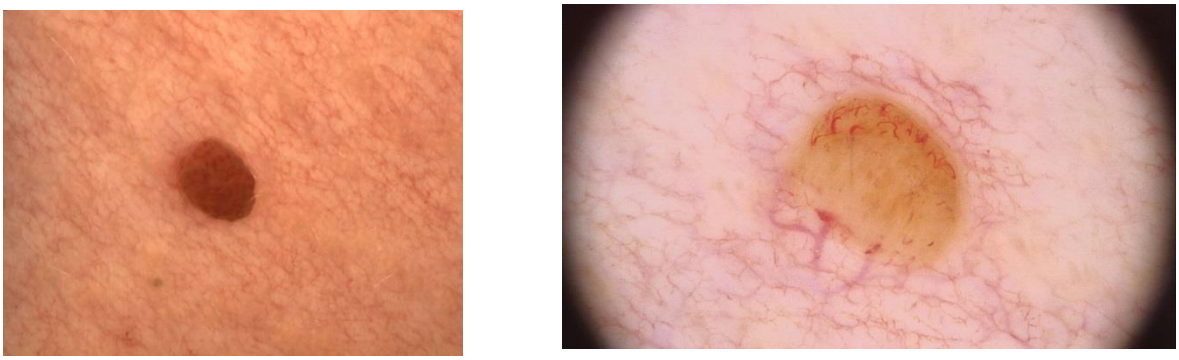

Fig. 7: Comparison of images of the same small nevus taken with our setup (left) and with the dermoscope of FotoFinder Systems GmbH (right)

The images show a compound nevus with out-of-plane topography. As the established dermoscopic systems require direct contact to the patient's skin, the nevus is flattened. The image taken with the laboratory prototype system described in this work displays natural colors and does not exhibit deformation of shape of the nevus.

4. SUMMARY

This work describes a non-contact remote imaging system for dermoscopy of human melanocytic nevi. Homogeneous and bright illumination of the target skin is achieved by using an ultra-bright white LED. The setup offers several advantages over established dermoscopic systems which require direct skin contact, e.g. the possibility to obtain full-body scans of patients within a short time, by integration of the optical system into an automatized device. Other important features include true color rendering, appropriate resolving power and magnification, glare-reduction, and avoidance of movement artifacts.

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