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A snapshot multi-wavelengths imaging device for *in-vivo* skin diagnostics

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ABSTRACT

A portable proof-of-concept prototype device for single snapshot capturing of four spectral line images has been designed, assembled and laboratory-tested. It comprises optical unit that ensures even illumination of the skin target area simultaneously at four laser wavelengths - 450 nm, 523 nm, 638 nm and 850 nm, double-camera image recording system, micro-computer managed operation system and a touch-screen display for image control and displaying the concentration distribution maps of four skin chromophores - melanin, oxy-hemoglobin, deoxy-hemoglobin and bilirubin. Besides, the device captures skin auto fluorescence image at 405 nm laser excitation to separate seborrheic keratosis from other pigmented skin lesions. Skin chromophore maps are calculated offline by an external computer.

Keywords: optical skin diagnostics, multi-spectral-line imaging, fluorescence imaging, skin chromophore mapping.

1. INTRODUCTION

Spectral image by definition is an image of target taken at a single working wavelength λ, associated with a narrow spectral line. The widely used multi- or hyper-spectral imaging technologies are mostly based on sequential capturing of images within much broader spectral bands of typical half-width ~ 10…40 nm. Acquisition process of the spectral image set may last from several seconds to a minute or longer[1], so movements of the target area (e.g. *in-vivo* tissue) during the procedure can cause image artefacts. Besides, the selected spectral band shapes have to be taken into account during the image processing which may cause additional problems, e.g. if the distribution maps of absorbing pigments (chromophores) are calculated from the set of spectral images. Obviously, both acquisition time of the spectral image set and the spectral bandwidth of each image have to be minimized.

Ultimate performance can be achieved if the set of monochromatic (single-wavelength) spectral images is obtained by a single snapshot; this technique is provisionally called "snapshot multi-spectral-line imaging" or SMSLI.[2,3] In this case, a set of spectral line images can be obtained if the target is uniformly illuminated simultaneously by several spectral lines, e.g. emitted by lasers, and the image sensor system has the corresponding number of spectral sensitivity bands. For instance, standard RGB color cameras can record three spectral line images by a single snapshot at specific illumination that comprises only three spectral lines, each of them positioned within one of the detection bands (R, G or B).[4-6] Triple spectral line imaging has been successfully applied for counterfeit detection[2,7] and for remote distribution mapping of three main skin chromophores - melanin, oxy- and deoxy-hemoglobin.[8,9]

However, also mapping of other skin chromophores (e.g. bilirubin, lipids and water) is of diagnostic interest. Fast mapping of a certain number of chromophores by this technique is possible only if the corresponding number of spectral line images is available, so more complicated SMSLI technologies have to be developed. This paper reflects our attempt to develop a proof-of-concept device for snapshot acquisition of four spectral line images to map four skin chromophores, also being able to capture skin autofluorescence (AF) image under the violet 405 nm laser excitation.

2. DESIGN AND OPERATION

Functional scheme of the device is presented on Fig.1. Two laser modules – RGB fiber coupled module (*Elite Optoelectronics*, CN) emitting ~20 mW at each of the three spectral lines (450 nm, 523 nm, 638 nm) and 850 nm / 40 mW module (RLDH850-40-3, *Roithner*, AT) – are used for 4-wavelengths illumination of skin via the light diffusing

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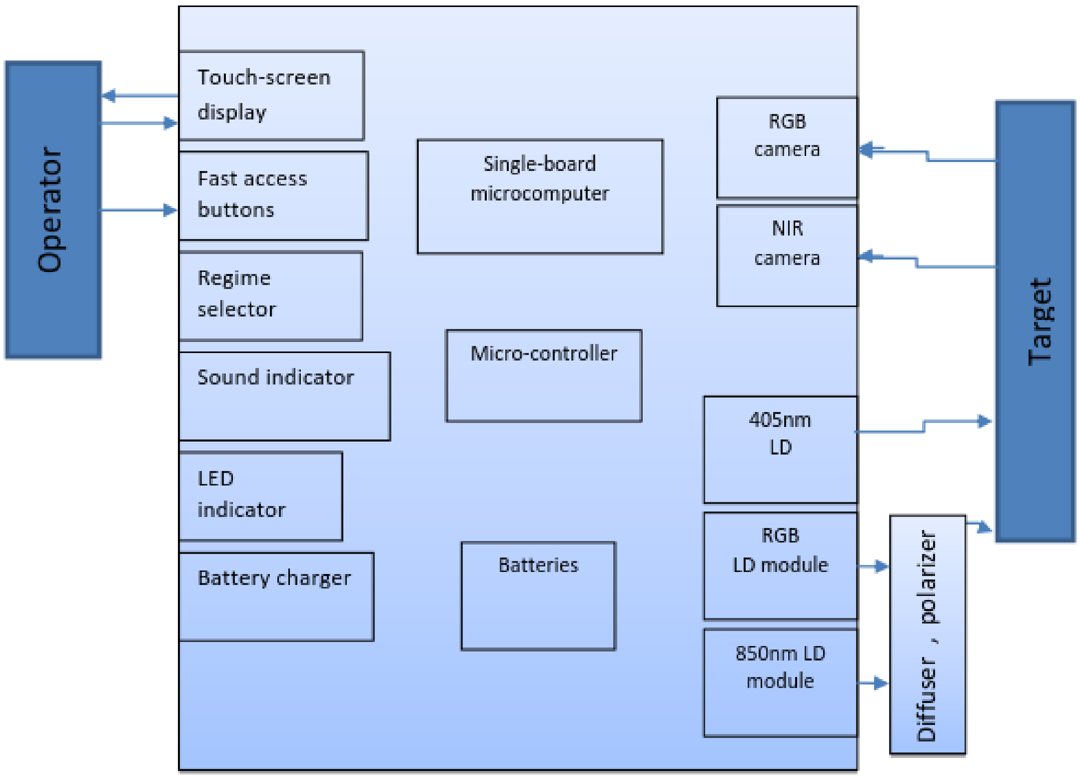
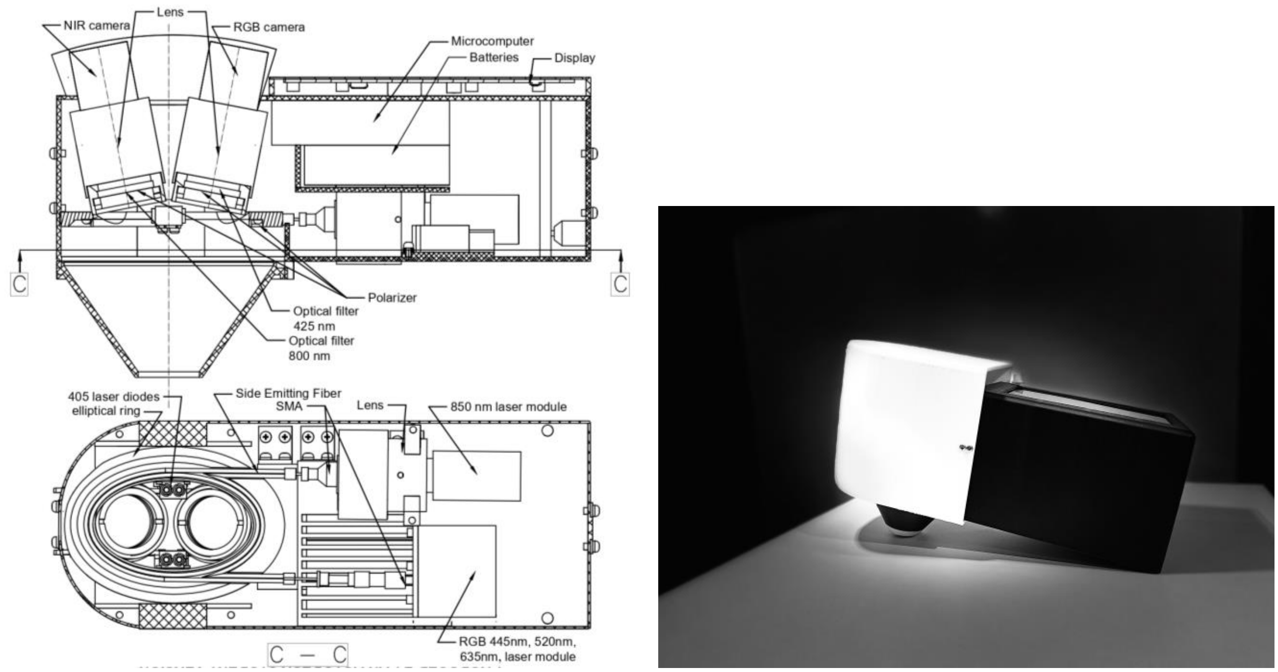


Fig.1. Functional scheme of the device.

system and visible-NIR polarizer. Two cameras (RGB and NIR, MQ022CG-CM and MQ022RG-CM respectively, *Ximea, DE*) equipped with 425 nm and 800 nm long-pass filters (mod. #84-742 and #66-235, *Edmund Optics*, GB, respectively), and orthogonally oriented polarizers (not shown in the scheme) are capturing simultaneously images of the same skin area with subsequent extraction of four spectral line images for further calculation of four chromophore distribution maps using the previously developed methodology.[9] Within a second the laser modules are switched off and skin autofluorescence (AF) image at the G-channel of RGB camera is captured under illumination by four 405 nm, 40 mW laser diodes (DL-5146-101S, *Roithner*, AT), in order to discriminate skin melanoma from seborrheic keratosis.[10]

The device is initiated by operator pushing the START button and selecting the appropriate operation regime (SMSLI only, AF image only, combined mode) and exposure times for the RGB and IR cameras. Then both cameras and RGB lasers are switched on and the device is properly placed on the skin target area (monitored on the display). After pressing the SHOT button, micro-controller (STM32G071, *STMicroelectronics*, CH) synchronizes proper illumination of the target to capture the image (or set of images) that is/are read by the single-board-computer (SBC, Rock960, *Vamrs*, CN). The recorded images can be seen on the display (5.5inch HDMI AMOLED, *Waveshare*, CN) or transmitted via SBC's *wi-fi* to the remote computer for calculation of chromophore maps or performing other tasks. The device is fully self-sustained by using rechargeable Li-ion batteries (INR18650-25R, *Samsung*, KR) as the power supply.

Design scheme of the device is presented on Fig.2. Both cameras with lenses are tilted to capture images of the same round skin area of diameter 30 mm. Several semi-elliptical loops of side-emitting 400 micron silica core optical fiber (*Light Guide Optics Ltd*., LV) are exploited as the light source for even multi-laser illumination of the target area.[11] The fiber is SMA-terminated at both ends; one of them is used for the RGB laser input and the other one – for the 850 nm laser input. In result, the examined skin area is uniformly illuminated by the four above-mentioned laser spectral lines. Four 405 nm laser diodes for autofluorescence excitation are square-placed in the middle zone of illuminator.



a b

Fig.2. Design scheme (a) and outlook (b) of the prototype device.

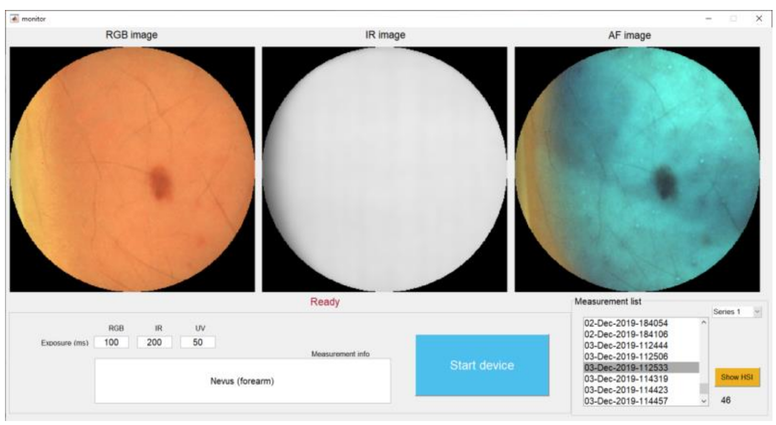


Fig. 3. The user's interface.

The developed user's interface (Fig.3) allows adjusting on the touch-screen the proper exposure times for both cameras and entering specific information about the patient and examined skin malformation, as well as restoring the previously stored images listed on the right bottom corner. After completing the working cycle, the color (RGB) image, 850 nm line (IR) spectral image and autofluorescence (AF) image of the malformation are visualized at the upper part of screen. The operator can monitor each measurement also in offline mode. The three spectral line images are extracted from the RGB image data by a corresponding algorithm[9] on the remote computer, along with the 850 nm image captured by the NIR camera and the autofluorescence image captured at the G-band of RGB camera at 405 nm laser excitation. Example of two captured/calculated image sets – for a combined nevus and for a seborrheic keratosis – is presented on Fig.4. One can see the main differences in the 850 nm spectral line images and in autofluorescence images where nevus exhibits as darker spot than the surrounding skin while the autofluorescence intensity of keratosis is higher than that of healthy skin.

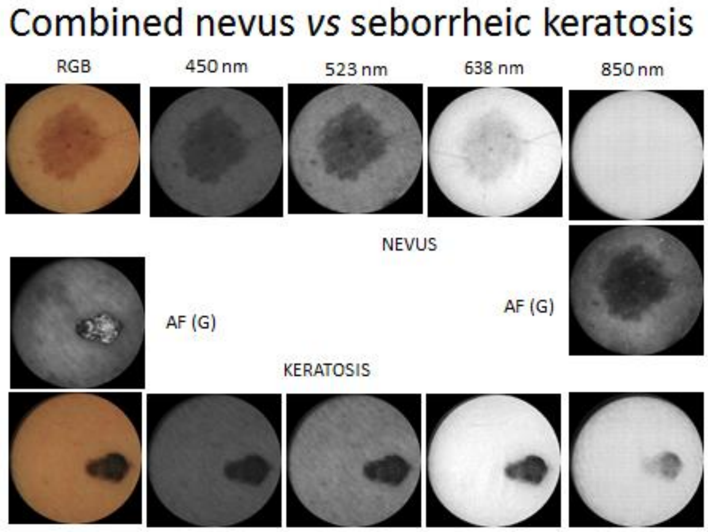


Fig.4. A color image (RGB) and four spectral line images of a combined nevus (upper raw) in comparison with the same set for a seborrheic keratosis (bottom raw) and both autofluorescence (AF) images extracted from the G-channel of RGB image sensor at 405 nm laser excitation.

3. SUMMARY

Design and operation of a portable proof-of-concept diagnostic prototype device comprising five laser emitters and two cameras has been described in details. The device ensures single snapshot capturing of four spectral line images and an autofluorescence image of a skin malformation for obtaining clinically valuable information on the concentration distributions of four skin chromophores and on the autofluorescence intensity distribution that helps to discriminate skin melanoma from seborrheic keratosis. The device is just assembled and will pass its clinical validation in the coming months.

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