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Technical Note

Delineation of malignant skin tumors by hyperspectral imaging using diffusion maps dimensionality reduction

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ABSTRACT

A new non-invasive method for delineation of lentigo maligna and lentigo maligna melanoma is demonstrated. The method is based on the analysis of the hyperspectral images taken in vivo before surgical excision of the lesions. For this, the characteristic features of the spectral signatures of *diseased* pixels and *healthy* pixels are extracted, which combine the intensities in a few selected wavebands with the coefficients of the wavelet frame transforms of the spectral curves. To reduce dimensionality and to reveal the internal structure of the datasets, the diffusion maps technique is applied. The averaged Nearest Neighbor and the Classification and Regression Tree (CART) classifiers are utilized as the decision units. To reduce false alarms by the CART classifier, the Aisles procedure is used.

1. Introduction

In this paper, we introduce a non-invasive method for delineation of lentigo maligna (LM) and lentigo maligna-melanoma (LMM). Lentigo maligna is an early form of melanoma in which the malignant cells are confined to the upper part of the skin, the epidermis; hence it is often reported as in situ melanoma. Lentigo maligna melanoma is diagnosed when malignant melanoma cells have invaded the dermis and deeper layers of skin [1]. Both LM and LMM occur as a brown-to-black patch on a sun-damaged skin, typically in the facial area. Clinically LM cannot be differentiated from invasive LMM. Diagnosis is verified by histopathological evaluation of the skin biopsy samples. The lesion borders can be hard to define by eye, due to subclinical extension. Histopathological analyses of the removed lesion reveal the size of the lesion. Often a re-excision is required [2]. There is a need for a noninvasive method for tumor margin delineation before and during the surgery.

Eight lesions, 3 LMM and 5 LM, in 8 patients were included in the study. The study protocol followed the Declaration of Helsinki and was approved by the Ethics Committee of the Tampere University Hospital District, Finland. The study was conducted in Päijät-Häme Central Hospital, Department of Dermatology and Allergology during 2012–2013.

A hand-held hyperspectral imaging system was developed for the study. The hyperspectral sensor was produced by VTT Technical Research Centre of Finland [3]. This hyperspectral imager uses a wavelength area between 500 and 885 nm, which covers visible light and near infrared area.

The presented method is based on processing hyperspectral images. The research follows a manifold learning approach and supervised machine learning process. The process includes data preprocessing, definitions of training set, algorithm selection, training and evaluation with test set [4].

This article consists of five sections and two appendices. Section 2 provides a brief review of the related literature. In Section 3, we explain in details our hyperspectral imaging system and the data processing chain. Section 4 presents the results from our clinical trial. Finally, in Section 5, we present our conclusions and planned further development. Appendix A outlines the diffusion maps technique and embedding the new data into diffusion spaces by the Geometric Harmonics method. Outline of the CART algorithm is given in Appendix B.

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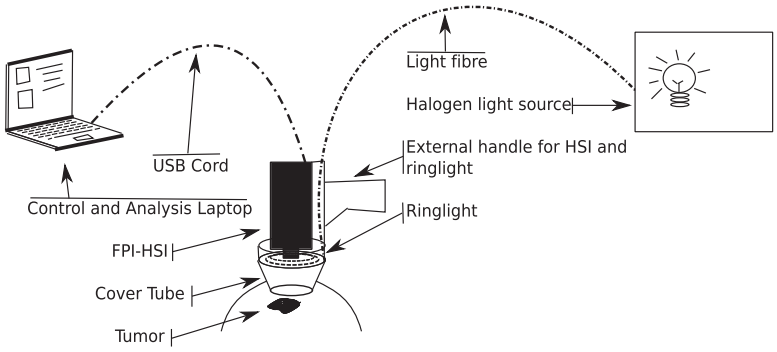

Fig. 1. Hyperspectral imaging system setup.

2. Literature review

In the last years, medical applications of multispectral (MSI) and hyperspectral imaging (HSI) became a field of extensive research.

Different medical applications of HSI are reviewed in the recently published paper [5] by Lu and Fei. They outlined multiple medical applications, where HSI was utilized either for the diagnosis or for the surgical guidance. Two publications [6,7] concentrated on in vivo melanoma studies. Dicker et al. [6] studied the differences between bening skin and malignant melanoma tissue during raf inhibitor treatment. Hennesy et al. [7] studied melanoma's segmentation from diffuse reflectance images. They utilized the principal component analysis (PCA) to reduce data's dimension and *K*-means algorithm for clustering. In their study, they used phantoms rather than the patients examination.

A melanoma screening system based on HSI was designed and tested by Nagaoka et al. [8]. Their hardware consists of the traditional pushbroom scanner and fiberscope. In order to detect the difference between the healthy and melanoma affected skin, they derived an index related to the spectral angle mapper from the spectral library database.

Quinzán et al. [9] studied band selection in non-invasive melanoma diagnosis. They utilized liquid crystal tunable filter for the spectral separation. For the band selection they used sequential forward floating selection procedure, which selects bands. The procedure is based on pattern recognition principles. They treat band selection problem as a feature selection problem in pattern recognition. Once the band selection is accomplished, the support vector machine is used for the classification. They indicated that band selection improve the classification sensitivity.

Diebele et al. [10] report the results of clinically evaluation their MSI system aimed to separate differences between melanoma and benign nevi. They utilized Nuance EX multispectral imager to take spectral images. They use a simple parameter in order to distinguish melanoma from nevus.

A number of studies were focused on modeling the skin's layered structure and utilizing the models for calculation of the spectral images inversion. For example, Tseng et al. [11], Jolivot et al. [12], and Galeano et al. [13] studied different kinds of optical models for the skins reflectance. Basically, those models return thorough inversion maps for different parameters, such as the melanin concentration, the hemoglobin concentration, the water concentration and the dermis thickness.

A number of in vitro studies done with hyperspectral camera in dermatology are reported in Lue et al. [14], Akbari et al. [15], and Dicker et al. [16], to name a few.

Specific features of the presented research: Our investigations differ of those reported in the above publications in a number of aspects.

1. We use the spectral imager based on Fabry–Perot interferometer, which takes the whole spatial plane image at once. This provides a significant advantage over traditional pushbroom scanning, during which either a patient or the camera (or both) can change their position.
2. Our analysis of data consists of blocks, which are conventional in the pattern analysis. These are band selection, features' extraction, dimensionality reduction and finally manifold learning approach. But methods we use are either novel or more sophisticated than those, which are reported in the above publications.
3. We implemented clinical trials in vivo. Our results were evaluated both clinically and histologically, unlike some papers above.

3. Method

A hyperspectral imaging system was developed, which consists of the hand-held hyperspectral imaging device and the data processing unit. Fig. 1 illustrates the system.

3.1. Imaging device

Unlike a regular camera, which captures pictures in three broad wavebands of red, green and blue, hyperspectral cameras capture pictures in dozens or even hundreds narrow wavebands. Our imaging device consists of a hyperspectral imager (FPI–HSI) based on the Fabry–Perot interferometer, a halogen light source, a ringlight and a 3D printed holder for the imager and the ringlight. The hand-held hyperspectral imager is presented in Fig. 2. In front of the holder there is a cover tube, the purpose of which is to block background illumination.

Fig. 2. Hand-held hyperspectral imager in holder. Ringlight is in front of the imager.