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Study of Skin Cancer Lesions through Multispectral and 3D Techniques

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ABSTRACT

The effective and non-invasive diagnosis of skin cancer is a hot topic in biophotonics since the current gold standard, biopsy followed by histological examination, is a slow and costly procedure for the healthcare system. Therefore, authors have put their efforts in characterizing skin cancer quantitatively through optical and photonic techniques such as 3D topography and multispectral imaging. Skin relief is an important biophysical feature that can be difficult to appreciate by touch, but can be precisely characterized with 3D imaging techniques, such as fringe projection. Color and spectral features given by skin chromophores, which are routinely analyzed by the naked eye and through dermoscopy, can also be quantified by means of multispectral imaging systems. In this study, the outcomes of these two imaging modalities were combined in a machine learning process to enhance classification of melanomas and nevi obtained from the two systems when operating isolately. The results suggest that the combination of 3D and multispectral data is relevant for the medical diagnosis of skin cancer.

Keywords: Skin cancer, surface morphology, fringe projection, multispectral imaging, machine learning.

1. INTRODUCTION

The main factors that predispose to the development of skin cancer seem to be mainly connected with the exposure to ultraviolet (UV) light apart from other risk factors such as age, fair skin or family history. The incidence of skin cancer increases every year so that its diagnosis and treatment is crucial. The World Health Organization estimates that 60.000 people die every year from skin cancer: 48.000 from melanoma, which is the most aggressive form, and 12.000 from other non-melanocytic skin cancers. Visual inspection aided by dermoscopy is the classical approach to diagnose this disease. The so-called $ABCDE$ rule helps to outline warning signs of the most common type of melanoma: A is for asymmetry, B is for border irregularity, C is for color, D is for the diameter and E for its evolution[1]. However, they fail in the correct discrimination of lesions in a relevant percentage of cases producing false positives. Nowadays, the only gold standard is histological examination, which requires the surgical excision of the tumor through a biopsy. This contributes to the high direct annual costs for the diagnosis and treatment of skin cancer making it also a long-term process[2] apart from being highly uncomfortable for patients. For these reasons, several efforts have been put in detecting skin cancer quantitatively and non-invasively through optical and photonic devices such as multispectral (MS) and three-dimensional (3D) imaging technology.

MS imaging systems are capable of acquiring images through several spectral bands with high spatial resolution[3]. Thus, it is possible to obtain pixel-wise spectral features of the skin lesion, which can then be used as a spectral signature. Commercial devices based on this principle, such as SIAscope® and MelaFind®[4,5] often present high values of sensitivity to distinguish melanoma from other benign lesions, but they retrieve low values of specificity. In order to raise specificity values, others MS imaging devices have been built using extended spectral range in the visible and infrared ranges and combining spatial and spectral features to assess the spectral features of non-melanocytic skin cancers in addition to melanoma lesions[6,7]. On the other hand, 3D technology is now available to retrieve information of the micrometric topography of cutaneous lesions by acquiring height maps of their surface; an example of this is the fringe projection technique. It is based on the triangulation measuring principle, combined with the light intensity modulation using sinusoidal functions[8,9]. From this, the volume, area, texture and roughness of the samples under analysis can be

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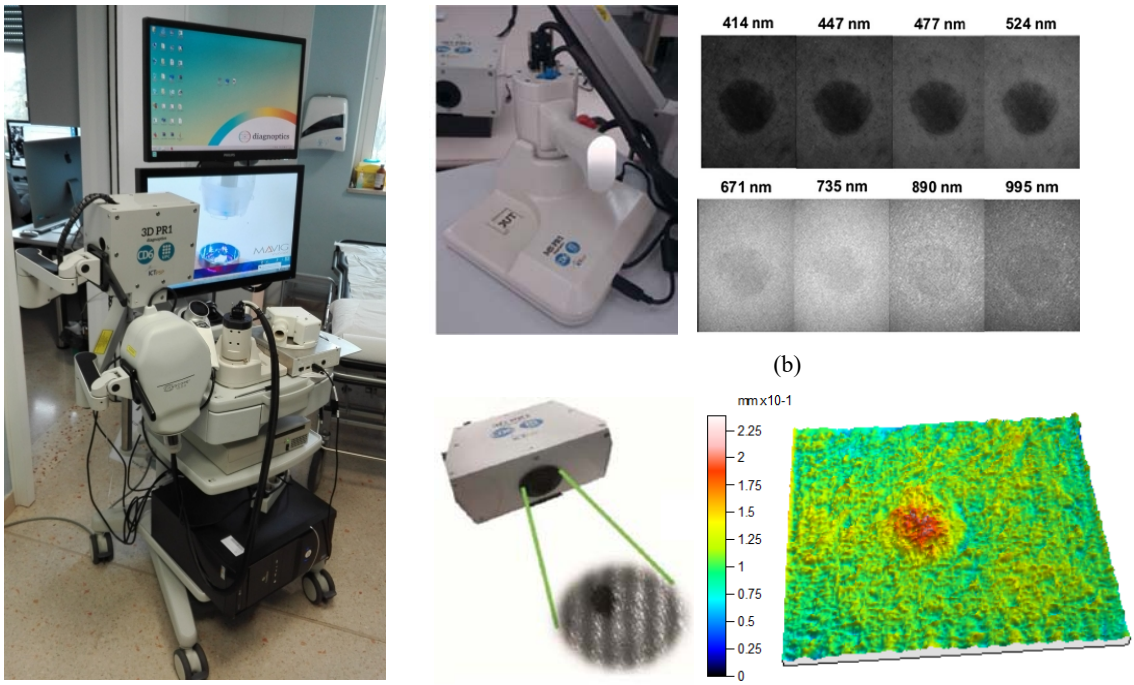
obtained according to the parameters of the International Organization for Standardization (ISO)[10]. However, the combination of MS and 3D data to analyze skin lesions in vivo in order to distinguish benign from malignant ones has not been considered yet. The goal of this study was to combine the outputs of a MS imaging system and a 3D scanner based on fringe projection in order to improve the diagnosis of skin cancer. Machine learning tools were also used to enhance classification of mainly melanomas and nevi.

2. EXPERIMENTAL SETUP AND CLINICAL MEASUREMENTS

A multiphotonic platform including a MS imaging system and a 3D scanner developed in the framework of the EU project DIAGNOPTICS "Diagnosis of skin cancer using optics" was used in order to evaluate skin lesions (Figure 1a). These devices provided spectral and color data based on the principal chromophores of the skin lesion and morphological information of its surface.



(a) (b) (c)

Figure 1. Multiphotonic platform installed at the hospitals including MS and 3D technologies (a). MS (b) and 3D (c) systems with the corresponding outputs: spectral images taken at several wavelengths and microtopography, respectively.

The developed MS imaging system (Figure 1b) included 8 spectral bands from 414 nm to 995 nm by integrating an LED-based multiplexed illumination and a monochrome CCD camera with 12-bit depth and resolution of 1280 x 960 pixels. The CCD is coupled to a lens in a hand-held instrument allows focusing the skin lesions at a distance of 40 mm providing a field of view (FOV) of 15 mm x 20 mm [6]. The 3D imaging system (Figure 1c) was built based on a combination of stereovision and fringe projection; it incorporates two monochrome CCD cameras placed in a standard stereo geometry with a working distance of 110 mm, a fixed focal lens of 25 mm and a FOV of 19 mm x 14 mm. In between the cameras, a picoprojector creates an image of a vertical fringe pattern that is projected onto the skin and moved horizontally a small distance while the cameras capture images, from which the topography can be derived by triangulation[9]. With both systems, 608 lesions of different etiologies were analyzed in the Hospital Clínic i Provincial de Barcelona (Spain) and the Università di Modena e Reggio Emilia (Italy). Each lesion was considered suspicious unless it presented obvious clinical-dermoscopic features of benignity. Patients were asked to remain still during measurements to avoid motion artifacts; the measurement area over the skin was cleaned and hair was carefully cut instead of shaved to avoid irritation. A metallic ring was glued to the patient's skin for the tip of the devices to be placed in the same position and parallel to the surface of the skin. All patients in the study provided written informed consent before any

examination and ethical committee approval was obtained. The study complied with the tenets of the 1975 Declaration of Helsinki (Tokyo revision, 2004). The lesions were diagnosed by dermatologists (SP, JM, GP, and SB) using a commercial dermoscope and the confocal laser scanning microscope VivaScope® 1500. When malignancy was suspected, the lesion was excised and a histological analysis was carried out.

3. CLASSIFICATION ALGORITHM

3.1 Spectral & 3D parameters and preliminary statistical analysis

The images obtained with both systems were processed by means of a purpose-built Matlab® R2015a (1984-2015 The MathWorks Inc., U.S.) image processing interface and a commercial software for the processing of 3D images, Mountains Map Universal® (1996-2011 Digital Surf, France); representative examples of processed lesions are shown in Figure 2. From them, a total of 319 parameters were computed, accounting for spectral-based characteristics: mean reflectance at each wavelength, differences in color (ΔE in the CIELAB color space) between the lesion and healthy skin, spatial distribution of reflectance values on the segmented lesion (entropy, skewness, etc. of the histogram), etc.; and also 3D features: perimeter, tridimensional area and volume, distribution of height values, etc.

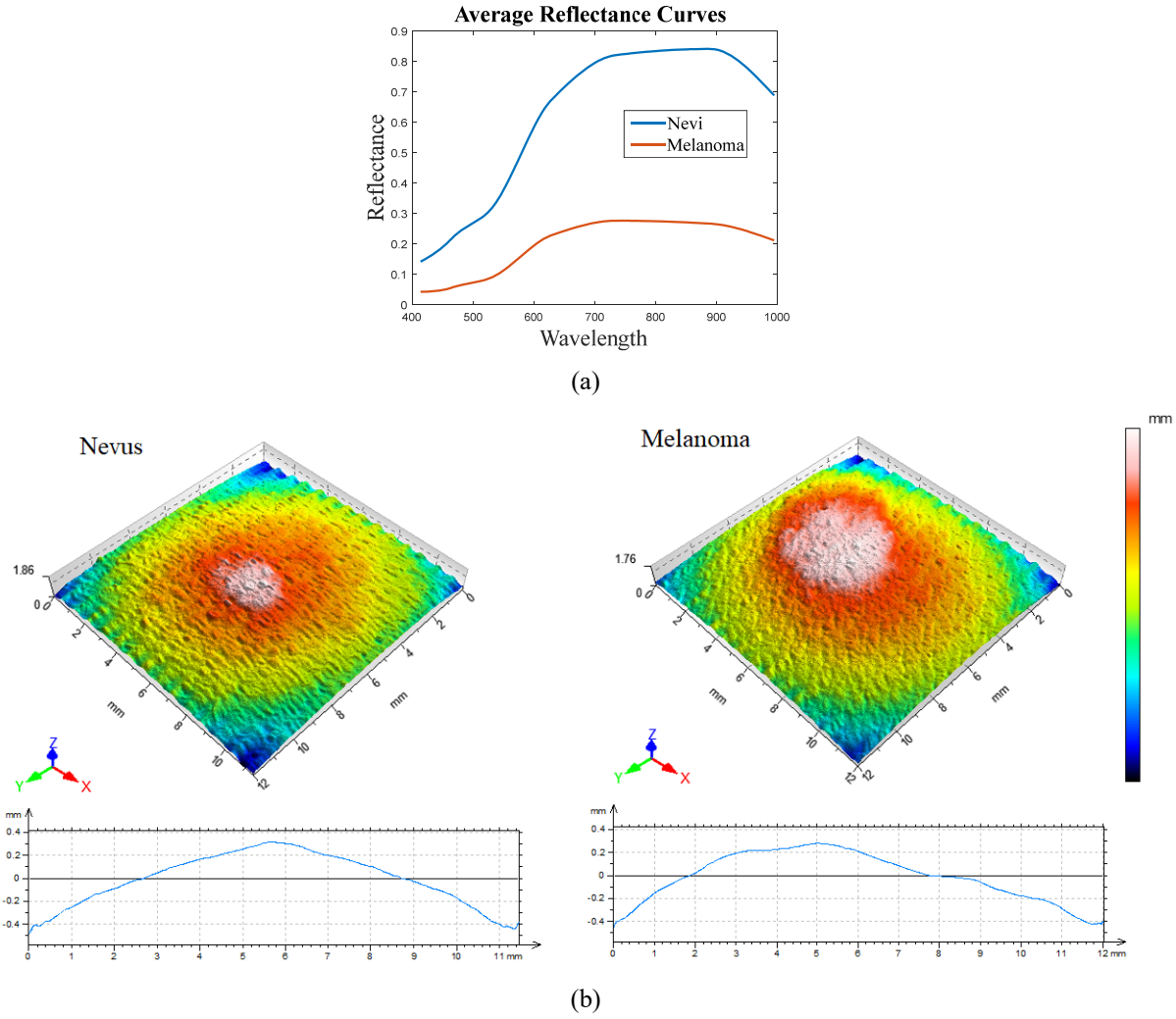


Figure 2. Averaged spectral reflectance values of the whole lesion for a nevus and a melanoma computed from the spectral images obtained with the MS system (a). 3D surfaces and measured profiles of a nevus and a melanoma after post-processing the reconstructed height maps obtained with the fringe projection system (b).

From the 608 lesions measured, a set of 155 (26%) lesions could be properly analyzed with both systems, while the remaining 453 (74%) were rejected mainly due to the presence of artifacts in the 3D images or because lesions went out of the FOV of the systems. From the outcomes properly acquired and processed 81 (52%) consisted of benign nevi (melanocytic, dysplastic, blue, junctional or Spitz nevi); 56 (36%) were melanomas; and 18 (12%) were basal cell carcinomas. In order to perform a robust statistical analysis, only nevi (81) and melanomas (56) were finally considered. In fact, it is to be highlighted that these are the main types of lesions which experts have difficulties to discern.

The data were analyzed using the SPSS software for Windows (V.23.0. IBM Corp., Armonk, NY). Comparisons were considered to be statistically significant for p values of less than 0.05. The Kolmogorov-Smirnoff test was used to evaluate the normal distribution of all variables. Normal variables (MS and 3D parameters) were analyzed with a T-student test to seek for statistical significant differences between classes. For variables that did not meet the criteria for normal distribution, the Mann-Whitney U test was used to compare the main outcome measures between each class. From the total set of 319 parameters, a number of 151 showed differences among the groups that were significant.

3.2 Training and validation of classification models

The 151 parameters with statistical significance were used to train and validate several classification models included in the Matlab® extension Classification Learner[11]. An automated training was performed to search for the best classification model type, including decision trees, discriminant analysis and support vector machines, among others. The data was arranged into validation and training groups according to a cross validation set with k = 2, which alternates the groups of training and validation. The same models were applied to the MS and 3D parameters independently to analyze the influence of merging both kinds of data in the classification. Table 1 contains the validation scheme and the classification models for MS, 3D and combined MS and 3D parameters that provided the lowest error rate. The predictive accuracy of each classification model is shown in terms of sensitivity (SN) and specificity (SP), i.e. the percentage of melanomas and nevi correctly identified as such, respectively.

Table 1. Sensitivity (SN) and specificity (SP) values of the best supervised machine learning classification models with a cross validation scheme.

Parameters	Validation Scheme	Classification Model	SN (%)	SP (%)
MS	Cross Validation (k=2)	Boosted Trees	73.2	75.0
3D	Cross Validation (k=2)	Cubic SVM	71.4	69.9
MS & 3D	Cross Validation (k=2)	Boosted Trees	75.0	76.8

4. CONCLUSIONS

The use of both techniques led to a slight increase of the sensitivity and the specificity (see Table 1) that could be improved in the future with a larger data set. On the other hand, in this work the specificity was particularly increased with respect to the study of Delpueyo et al.[6], thus decreasing the amount of false positives, one of the drawbacks reported by other authors. In this previous study, a larger set of melanomas (95) and nevi (290) was evaluated only with the MS system obtaining SN of 87.2% and a SP of 54.5%. In this, the total set of lesions was also divided into training and validation sets, but the classification was experimentally based. Regardless the fact that the dataset was larger than ours, the classification methodology used in the current work achieves a remarkable enhancement of the SP.

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