Qualitative characterization of skin tissue with Dynamic Laser Speckle

Abstract—**This work presents a preliminary study for the effective characterization of the skin tissue surface by means of Dynamic Laser Speckle (DLS). Although dermoscopy is widely used to perform this analysis, DLS was applied as a complementary technique for skin assessment, aimed to help medical diagnosis by giving additional information regarding texture patterns and microcirculation profiles. Due to the nature of the underlying phenomena, the study of the temporal evolution of Speckle diagrams provides an interesting non-destructive and non-invasive tool to characterize microtexture changes in the skin, reflecting physiological variations contained in sample activity over time. This analysis will assist the characterization of normal skin tissue, enabling the establishment of qualitative comparisons with ongoing skin diseases and to treatments monitoring.**

The skin microcirculation profile after a pressure protocol was assessed in healthy skin, to achieve a qualitative measure of the reperfusion based on dynamic speckle activity. The applied methodology is based on a multi-descriptor approach after a Self-Organizing Map segmentation process.

Index Terms—**Dynamic Laser Speckle, Skin tissue, Self-organized networks.**

I. Introduction

Characterization of skin tissues conventionally is performed through semi-quantitative markers, (i.e. texture analysis, lesion shape and symmetry, flow and temperature changes among others) translating state patterns of cell physiology whose assessment is made using dermoscopy [1]. This diagnostic technique is non-invasive and allows in-depth visualization of skin lesions through a hand lens or dermoscope. This practice improves the diagnostic accuracy of pigmented lesions, as well as an early diagnosis of potentially malignant melanocytic lesions, in particular in the case of melanomas. Usually, the dermoscope amplifies from 2 to 10 times the image and uses a lighting system with polarized light, which eliminates the reflection of light when it hits the horny layer. This procedure allows physicians to visualize in vivo structures and colors of the epidermis, dermoepidermal junction and superficial dermis, which are not visible by the simple naked eye inspection.

Although it is a frequently used technique in dermatology, its correct use requires a long process of learning, and the characterization of cutaneous lesions by this way is essentially static (or at least depends on the time between examinations).

The main goal of this work is to propose a way to characterize normal skin through dynamic markers, to further join the morphological information of dermoscopy. Hence, we introduced Dynamic Laser Speckle (DLS) as a complementary technique for medical diagnosis in dermatology.

When a surface, illuminated by a coherent light source, presents some type of local activity, the intensity and shape of the observed interference pattern of scattered rays (i.e. speckles) evolve with time, being the speckle patterns time dependent. This phenomenon is also characteristic of biological samples and is known as Biospeckle. The Biospeckle activity is the consequence of microscopic movements or local changes in the refractive index of the sample properties. Biospeckle patterns can be classified also as “boiling” patterns [2-4], once the speckles move, deform, disappear and reappear without any significant displacement of their mean position. This behavior can also be observed in some non-biological processes, such as drying of paints, corrosion, etc. Both the time evolution of pixel intensity and its spatial distribution over an image show seemingly random variations similar to those found in the height distributions of a rough surface. The characterization of rough surfaces requires the measurement of a considerable set of parameters. A similar behavior can be expected for speckle patterns, added to the fact that the inner dynamics of the process that produces them are most of times poorly known. Due to the nature of the phenomena, the study of the temporal evolution of Speckle diagrams provide an interesting non-destructive and non-invasive tool to characterize skin tissues and to provide an insight of its main changes related with skin diseases process. This characteristic is highlighted by the additional advantage provided by this technique, allowing for an evaluation of the subcutaneous activity [5-7].

The identification of dynamic markers that allow the characterization of the cutaneous surface through DLS is thus a tool with high potential for the extraction of functional features, by which, joining other features obtained by dermoscopy, will allow a whole morphological and functional characterization of the skin.

This work presents preliminary results regarding the characterization of functional markers on healthy skin in response to external changes (i.e. controlled pressure), to further be used as a comparison response patterns to assess skin diseases. The remaining of the work is organized as follows: In section II materials and methods are presented and in section III the results are shown. Finally, in section IV and V some discussion and conclusion remarks will be presented highlighting perspectives of future work.

II. Materials and Methods

A. DLS Video acquisition protocol

Dynamic laser speckle (DLS) techniques are widely used in

many applications in biology, biomedicine, industry, etc. Signals generated by the intensity changes in each pixel through the speckle sequence are processed for identifying the underlying activity in each point. Figure 1 shows the generic experimental setup for acquisition and storage of the so called subjective images of a sample showing dynamic speckle. The samples were illuminated with an expanded and attenuated 10 mW He–Ne laser. The subjective speckle images were then registered by a charge-coupled device (CCD) camera (Imaging Source DMK23G618) and stored in the memory of a personal computer. For the speckle to be well resolved, we chose the speckle size to be about four to five pixels by adjusting the diaphragm aperture (f/#=16).

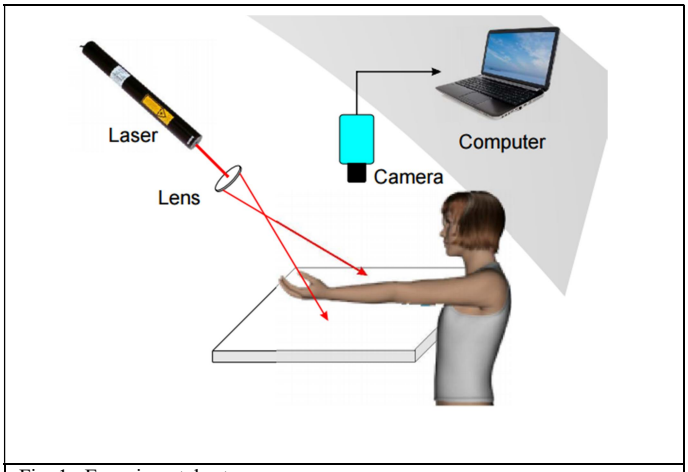


Fig. 1. Experimental setup

Due to the nature of the tested sample (human skin in the forearm) and to the need of establishing a motionless position, in a first approach several experimental setups were tested and adjusted. Next, different rehearsals were proposed, under different temperature and compression conditions, where the subcutaneous circulation patterns were evaluated.

The tested region, to be illuminated by the expanded laser beam, comprises a region at the forearm of a leucodermic person, in which is possible to identify normal skin around a common melanocytic benign lesion (e.g. a mole). As is possible to observe in Figure 2 this mole is roundish/oval presenting 3, 3×4,4 mm of axis lengths, whose color is mostly composed of two shades of brown, on a smooth surface with well-defined edges, thus being compatible with a typical nevus.

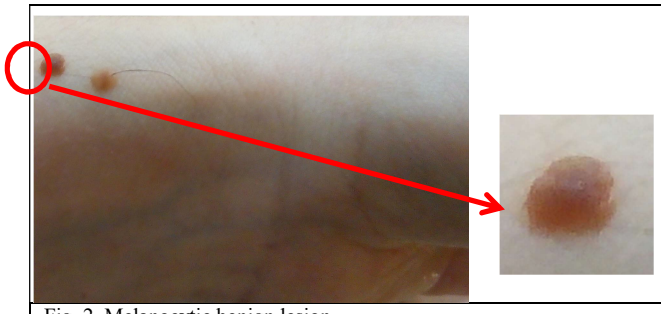


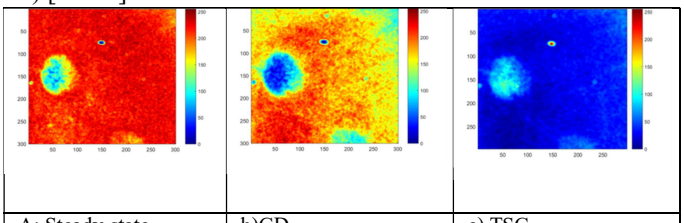
Fig. 2. Melanocytic benign lesion

Due to the central importance micro-vascularization in skin diseases in general (and in the melanoma assessment and prognosis, in particular), a practical protocol was conducted to test the ability to identify changes in the circulation pattern using DLS, as a response to an external stimulus. Accordingly, after de definition of the Region of Interest (ROI) one first experiment was made to test the microcirculation steady-state. Afterward, it was applied a controlled pressure of 200 mmHg (at the same arm) during a period of 20 seconds by using a sphygmomanometer, whose cuff was opened after this period to rapidly cease the imposed pressure. In both cases, the video duration was 90 seconds at 30 frames per second.

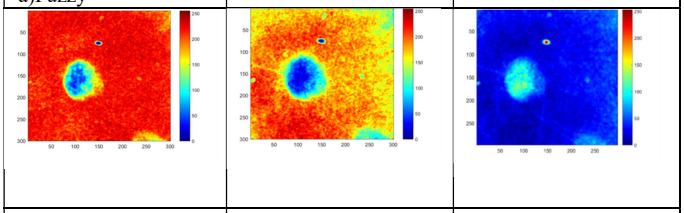
B. DLS Video processing methodology

The identification of speckle patterns related to the evolution of the microcirculation state is one way of assessing the perfusion state of the tissues. In the experimental protocol that was performed within the scope of this study, the application of controlled pressure in a region proximal to ROI is intended to reduce blood flow through large vessels, and therefore to limit the perfusion at the periphery in the evaluated skin area.

The flow velocity is a variable that presents variations (depending on body composition, body zone, vessel type and resistance to flow between others) and whose value depends on the reperfusion time after pressure application. Due to this fact, two experimental conditions, Steady state and Post pressure period, rehearsals were proposed. Afterwards, the video is acquired and the intensity series belonging to each pixel are processed. A set of dynamic speckle descriptors is computed and their performance is compared with regard with their ability to segment the activity regions. Each one of the different conditions stages was used to calculate time and spatial descriptors. We selected three descriptors, (Fuzzy, Generalized Differences (GD) and Temporal Space Contrast (TSC)). The first one is base in fuzzy logic, the second one calculated image intensity differences and the last one explores time and spatial variations simultaneously (see Figure 3) [10-12].



A: Steady-state
a)Fuzzy | b)GD | c) TSC



B: Post-pressure period
a)Fuzzy | b)GD | c) TSC

Fig. 3.Calculated descriptors

Next, a multi-descriptors approach is proposed to improve the results obtained with an individual descriptor using unsupervised machine learning techniques to identify similar speckle patterns in a given speckle image.

The SOM proposed by Kohonen is a popular unsupervised neural network model [8]. The SOM quantizes the data space of training data and simultaneously performs a topology-preserving projection of the data space onto a regular neuron (or cell) grid. The SOM structure is usually a regular two-dimensional grid of neurons, though they can be arranged in one-dimensional (line) or three-dimensional (space). Considering D-dimensional input data, each neuron is connected to the inputs by D weights. From another point of view, these weights can be seen as cells built up with vectors of D dimensions. This set of reference vectors is called the SOM codebook. The map cells are related each other by a neighborhood function. There are no weights that explicitly interconnect the neurons. During training, in every step one sample vector from the input dataset is taken and a similarity measure is computed between the input vector and all the codebook vectors. The cell whose weight vector has the greatest similarity with the input sample is selected as the best-matching unit (BMU). The similarity is defined by means of a distance measure, typically Euclidean distance. After finding the BMU, the codebook is updated. The reference vectors of the BMU and its topological neighbors (according to the neighborhood function) are changed in order to be 'closer' to the input vector in the input space. This adaptation procedure stretches the BMU and its topological neighbors towards the sample vector. A Self-Organizing Map (SOM) was trained using the set of features. Next a SOM visualization technique is developed (to visualize the trained SOM choosing a proper coloring code for the codebook). Lastly a Pseudo colored image is created (assigning the color of each pixel, taking the color of the SOM cell, which is the BMU for the vector of the pixel)

A multi-descriptor approach driven by the dynamics of the phenomenon itself does not require the assistance of an expert in the learning stage, and it shows better performance than those provided by single descriptor analysis. Post processing techniques were applied in order to improve the activity segmentation and characterization. A previously presented new contribution technique is coloring images obtained from dynamic speckle laser videos, in order to help an automated system to identify a particular region of interest [9]. Using this information, a qualitative analysis of the skin activity will be made, by integrating the activity information and the underlying physiology of the skin.

III. Results

SOM trained colormap obtained using the mentioned descriptors are shown at Figure 4. It presents 4 images in chronological order for the steady-state (Fig. 4 a) A1, A2, A3 and A4) and 4 images are shown for the post-pressure state (Fig. 4 b) B1, B2, B3 and B4, (A: Steady-state and B: Post-pressure period), 4 stages of 22.5 seconds each.). SOM application showed a well performance not only to improve information obtained using different descriptors but also to precisely characterized skin activity, presenting a quantization error of 0.4±0.023 and a cero topographic error of in all the cases.

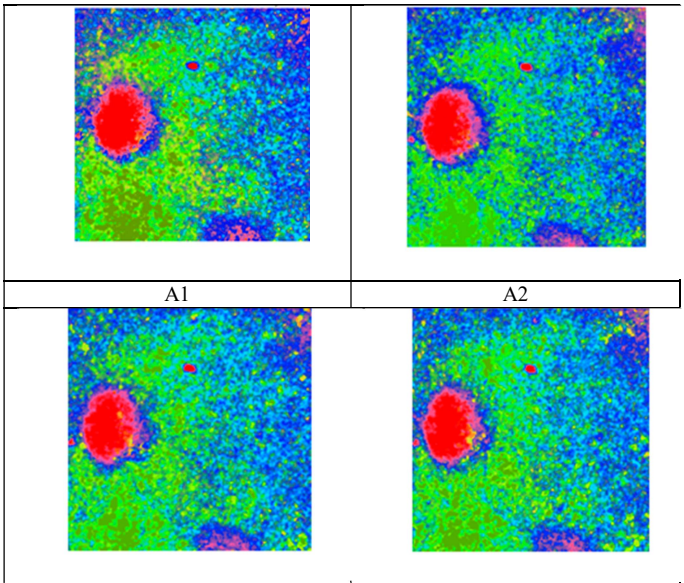


Fig. 4a. Coloured trained SOM result : Steady-state

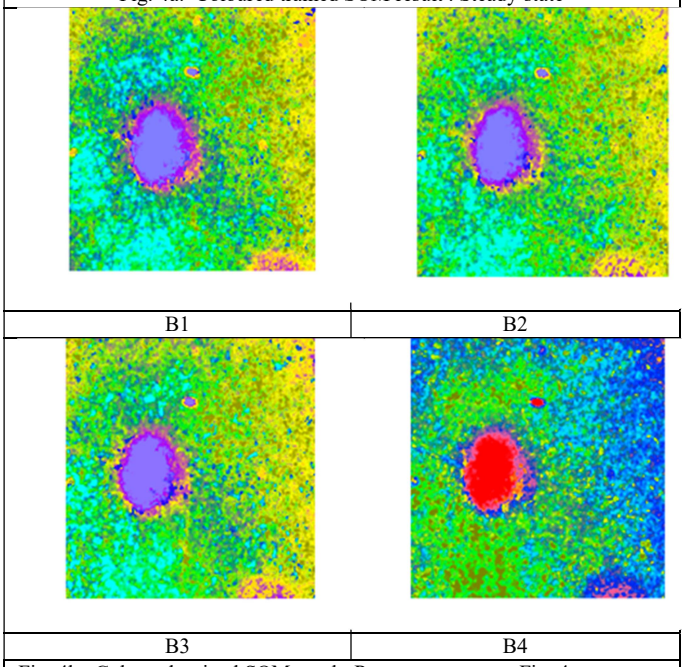


Fig. 4b. Coloured trained SOM result: Post-pressure state Fig. 4.

IV. Discussion

A qualitative analysis of Figure 4 allows, in a first view, to clearly identify two distinct zones: one related to the melanocytic lesion and the other to the surrounding area of the lesion, both presenting distinct activity patterns. Another conclusion that can be obtained is that, as expected, there are no significant changes in the activity in the 4 images of state A. In this way, and in terms of reference for comparison with

the images of state B, we can use any one of the four images.

When we perform an analysis of the images related to state B, it is possible to verify that with respect to images B1, B2 and B3 it is possible to identify an area with changing activity around the mole, but, regarding the alteration of the activity in the lesion itself, only in state B4 it is possible to detect color changes. The previously reported changes assume an increasing pattern of magnitude, which is consistent with the increase in flow to ROI, after releasing the pressure that has been imposed upstream. It should also be noted that after the 90 seconds of recording, the B4 image shows an activity pattern similar to the initial state, which makes sense, since the effect of the pressure in the flow supply will have already passed.

Finally, it should be noted that the time that the tissues were with decreased perfusion can alter the tissue architecture, and therefore, in terms of global changes of texture, a result that is not completely concordant with the images of the state A (this recovery depends on the waiting time).Preliminary results presented in response to a perfusion assessment protocol shows that the proposed methodology has potential in terms of flow characterization through DLS in normal skin. This result can be explored in order to evaluate the speed of reperfusion in ischemic diseases, for which it is essential to know the pattern of perfusion of healthy skin and its main constituents (as is the case of the mole presented here). In this work, a technique of quantitative evaluation of the cutaneous surface was presented through the use of the dynamic speckle. The proposed methodology is based on an optical acquisition setup together with a multi-descriptor approach to characterize dynamic speckle images of normal skin in the presence of a common melanocytic lesion (typical nevus).

V. CONCLUSIONS

The cutaneous characterization through evolution markers has potential interest in the identification of temporal patterns to which skin morphological information obtained by dermoscopy can be associated.

The joint use of these two techniques will have potential in terms of obtaining markers (evolution and morphological) to be used in the context of automatic diagnostic systems (DAC) to aid in medical diagnosis.

As a future work, it is intended to apply this technique to a wider number and variety of cutaneous lesions, in order to obtain a global characterization of healthy skin through DLS.

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