SPECKLE MODELIZATION IN OCT IMAGES FOR SKIN LAYERS SEGMENTATION

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Keywords: Medical image analysis, Statistical approach, Segmentation and grouping, Optical coherence tomography.

Abstract: In dermatology, the optical coherence tomography (OCT) is used to visualize the skin over a few millimetre depth. These images are affected by speckle, which can alter the interpretation, but which also carry information that characterizes locally the visualized tissue. In this paper, we present a statistical study of the speckle distribution in OCT images. The capability of three probability density functions (pdf) (Rayleigh, Lognormal, and Nakagami) to differentiate the speckle distribution according to the skin layer is analysed. For each pdf, the vector of parameters, estimated over several images which are annotated by experts, are mapped onto a parameter space. Quantitative results over 30 images are compared to the manual delineations of 5 experts. Results confirm the potential of the method for the segmentation of the layers of the skin.

1 INTRODUCTION

The diagnosis and the treatment of pathologies of the skin are largely based on a visual examination by the dermatologists. This examination requires a great experience because the skin can present ambiguous states that are not easily interpretable. Often, as for the monitoring of cancer, biopsies and histological analysis are used to resolve these ambiguities. The development of optical coherence tomography (OCT) imaging aims at the realization of non invasive optical biopsies.

OCT images allow the visualization of the structures of the skin, like the sweat glands, the stratum corneum, or the change of contrast at the junction between the dermis and the epidermis. However, the detailed examination of the images is strongly disturbed by the presence of speckle. The speckle reduces contrast and makes difficult the interpretation of the images. It creates inter and intra variability among the experts for the identification of the borders between the different layers of the skin. This is particularly true for tissues with high diffractors density like the skin. The speckle is thus often regarded as a noise. It is generally admitted that two types of speckle can be found in OCT images(Schmitt, 1999; Raju and Srinivasan, 2002). The first one comes from the interference of several reflected photons. It appears as pixel-sized dots with random value that can be filtered via averaging techniques. The second type of speckle results from the interferences caused by the retrodiffusions of the propagating waves front within the resolution cell of the imaging device. This speckle can be found everywhere in the image. Several methods can be found in the literature to reduce the speckle in OCT images. Among these methods, the angular and spatial compounding significantly increase the

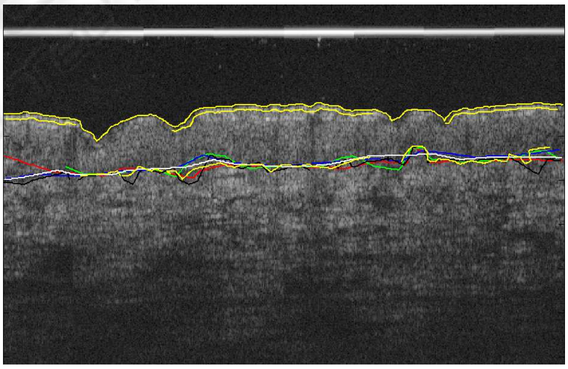

Figure 1: Optical coherence tomography image of the skin with manual delineations of two layers.

Mcheik A., Tauber C., Batatia H., George J. and Lagarde J. (2008).
SPECKLE MODELIZATION IN OCT IMAGES FOR SKIN LAYERS SEGMENTATION.
In *Proceedings of the Third International Conference on Computer Vision Theory and Applications*, pages 347-350
DOI: 10.5220/0001086603470350

signal to noise ratio (SNR) of images and improve the contours detection(Bashkansky and Reintjes, 2000). Adaptive filtering techniques are also used to preserve and reinforce contours between the skin layers, while reducing the effects of speckle(Iftimia et al., 2003). However, for a given location and studied tissue, the speckle has the same characteristics in OCT images. Even though speckle is generally regarded as a noise, it is also a source of information for tissue characterization.

The analysis of the statistics of speckle in each layer of the dermis and epidermis would facilitate the differentiation of the skin tissues and thus provide a model for robust segmentation. This paper is a contribution to this analysis. It presents a statistical study of the distribution of the speckle in OCT images. The sizes and densities of the diffractors in the visualized tissues characterize the speckle. We measure these variations to modelize the speckle, by the estimation of the parameters of three probability density functions, namely the Rayleigh, Lognormal and Nakagami distributions.

The remainder of this paper is organized as follow. Section 2 describes the models of distribution that we uses to caracterize the speckle and the respective estimation of their parameters. The experimentations are detailled in section 3. Finally we draw some conclusions in section 4.

2 SPECKLE MODELIZATION AND PARAMETER ESTIMATION

Estimation of the parameters of all three distributions was done using the method of moments (MM)(Nicolas, 2006).

2.1 Rayleigh Distribution

This model was introduced in a study of speckle in laser imaging. It supposes a fully developped speckle, and results from the central limit theorem. The backscattered signal can be modelized as a phasor sum of the returns from several scatterers within the resolution cell of the system. The Rayleigh pdf and cummulative distribution function (cdf) are given by :

$$p_R(r) = \frac{r}{\sigma^2} e^{-\frac{r^2}{2\sigma^2}} \quad r \geq 0;\ \sigma > 0 \tag{1}$$

$$F_R(r) = 1 - e^{-\frac{r^2}{2\sigma^2}} \tag{2}$$

Where σ is the scale parameter.

The estimation of σ by the methods of moments is given by :

$$\hat{\sigma} = \sqrt{\frac{2}{\pi}} \frac{\sum_{i=1}^{N} x_i}{N} \tag{3}$$

where N is the number of data and x_i the data itself.

2.2 Lognormal Distribution

The lognormal distribution has two parameters μ and σ. Its pdf and cdf are given by :

$$p_L(r) = \frac{1}{\sigma r \sqrt{2\pi}} e^{-\frac{1}{2}\frac{(\log r - \mu)^2}{2\sigma^2}} \tag{4}$$

$$F_L(r) = \pi\left(\frac{\log r - \mu}{\sigma}\right) \tag{5}$$

The parameters can be estimated from the calculus of the first two moments :

$$\begin{cases} \hat{\sigma} = \sqrt{\log \frac{m_2}{m_1}} \\ \hat{\mu} = 2\log(m_1) - \frac{1}{2}\log(m_2) \end{cases} . \tag{6}$$

2.3 Nakagami Distribution

The Nakagami distribution can modelise the dispersion of several backscattered clusters of waves added incoherently. It includes the Rayleigh distribution as a special case and can approximate the Rician distribution. The signal to noise ratio of the Nakagami distribution can take any positive value. Its pdf and cdf are given by :

$$p_N(r) = \frac{2}{\mu} \frac{\sqrt{L}}{\Gamma(L)} \left(\frac{r\sqrt{L}}{\mu}\right)^{2L-1} e^{-\left(\frac{r\sqrt{L}}{\mu}\right)^2} \tag{7}$$

$$F_N(r) = \Gamma_{\mathrm{inc}}(L, \frac{Lr^2}{\mu}) \tag{8}$$

where L is the shape parameter and μ the scale parameter, with $r \geq 0$ and $\sigma > 0$. Γ_{inc} is the incomplete gamma function.

As the Nakagami function has two parameters, moments of order 1 and 2 needs to be calculated. After the classic approximation based on the properties of the Gamma function, the system to calculate the parameters is given by :

$$\begin{cases} \hat{L} = \frac{1}{8} \frac{1}{\frac{\sqrt{m_2}}{m1} - 1} \\ \hat{\mu} = \sqrt{m_2} \end{cases} . \tag{9}$$

3 EXPERIMENTATIONS

3.1 Experimental Corpus

The experimental corpus is made of images of the skin provided by the Laboratory ANONYMOUS. We used an ISIS SkinDex 300 OCT imaging device. This device, specifically dedicated to skin imaging, illuminates the skin with 8 LED, emitting a light close to the infra-red range (1300nm). The 8 diodes are used simultaneously to recover the signal on 8 parallel channels. Shifts in intensity between the various channels are at the origin of a phenomenon of bands which appear on the produced OCT images. This imaging device reaches a depth of approximately 900mm. For this study, all the data correspond to areas of skin located on the front arm. These images present two layers, successively the epidermis and the dermis. In the epidermis, the layer of the stratum corneum is a fine irregular band which constitutes the surface of the skin. The data on which we undertook our study were submitted beforehand to experts from the ANONYMOUS laboratory which manually delimited the external surface of the skin, the stratum corneum and the junction between the epidermis and dermis (JED). The observed variability of the delineation testifies the difficulty of interpretation of the OCT images and the need for semi-automatic classification methods (Fig. 1). The data provided by the experts constitute the ground truth used for experimentations.

3.2 Empirical Data Fitting

The parameters of each distributions are estimated over the data of the stratum corneum and the data of the other part of the epidermis delineated by the experts. Figures 2 and 3 present the fitting of the distributions over the empirical data of each of these layers. The pdf were scaled so that the area under the curves matched the total area under the histogram.

On both layers, the best fit was obtained with the Nakagami distribution. The Rayleigh distribution leads to the poorer result while the Lognormal distribution goodness of fit is close but less precise than the Nakagami distribution. This is confirmed by the KS goodness of fit test that we performed over 30 images for both the stratum corneum and epidermis layers. Figures 4 and 5 present the KS values for each distributions.

Quantitative measurements using the KS criterion show that the nakagami distribution is the most precise for speckle characterization. It obtains the best KS scores on each layer, on all the 30 images. We performed the experimentations on the separability of the layers with this distribution.

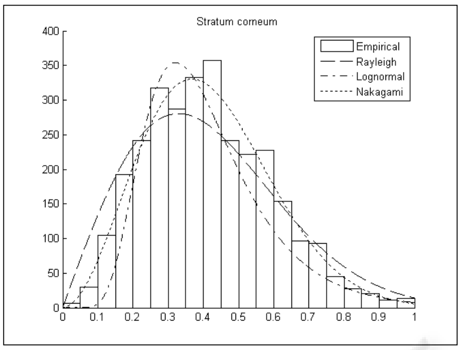

Figure 2: Fitting of the three distributions over the empirical OCT data of the stratum corneum.

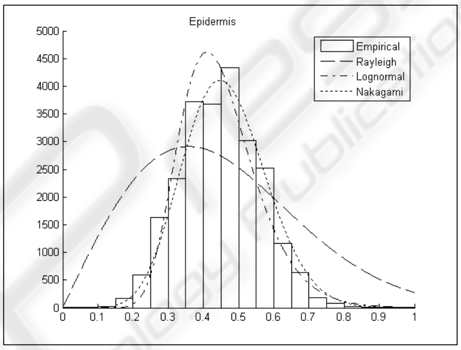

Figure 3: Fitting of the three distributions over the empirical OCT data of the epidermis.

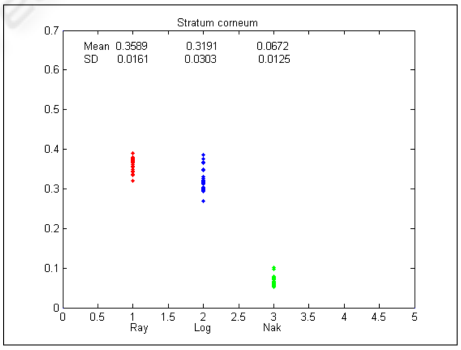

Figure 4: KS values of the fits of the stratum corneum data over 30 images.

3.3 Separability of the Skin Layers

We estimated the parameters of the Nakagami distribution over the two layers of the 30 images, for each of the five experts. Figure 6 presents the vectors of parameters for each layers, on the 30 images, projected

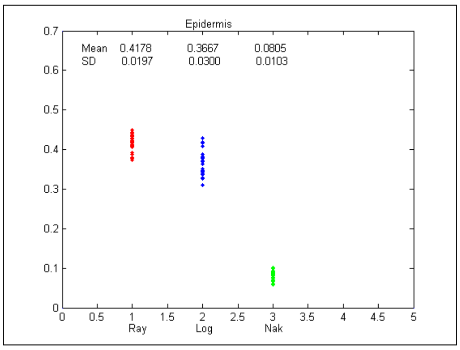

Figure 5: KS values of the fits of the epidermis data over 30 images.

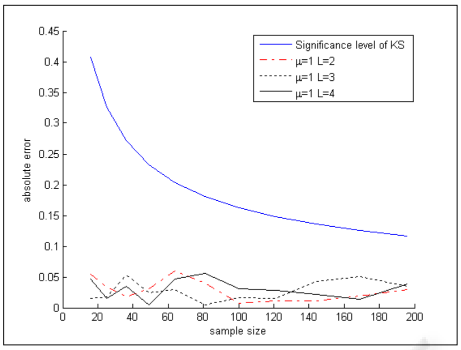

Figure 7: KS value of the Nakagami distribution for various sizes of the data sample and several parameters values.

onto the parameter space. It shows that the speckles that affect the two layers have different caracteristics. The two layers can thus be classified upon the caracterization of the speckle that affects their corresponding tissue. This confirm both the fact that the local speckle caracteristics depends on the visualised tissue, and that this caracterization brings richfull information for the segmentation of the layers of the skin.

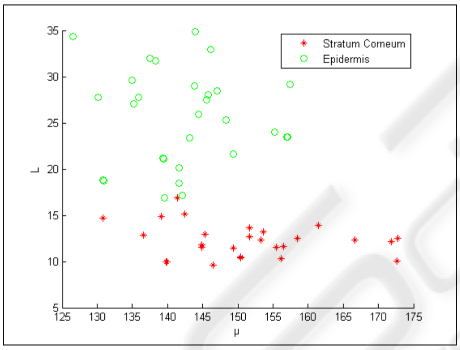

Figure 6: Parameters vectors of the Nakagami distribution estimated over 30 images, for both layers.

3.4 Stability of the Estimator

We analysed the KS criterion of the Nakagami distribution on synthetic data samples of various sizes, to study the stability of the estimator on small samples. Figure 7 presents the KS values of the Nakagami distribution calculated for various sizes of the synthetic data samples.

The results shows the stability of the estimator. This is relevant for image processing matters, as during segmentation or classification the speckle has to be caracterized locally on small data samples.

4 CONCLUSIONS

In OCT images of the skin, it is often difficult to distinguish the various layers and the various lesions. The statistical study of the distribution of speckle in OCT images can be the clincher for successful distinction of these elements. In this paper, we analyzed the performances of three models of distribution for the speckle characterization in the stratum corneum and the remainder of the epidermis. The results show that the nakagami distribution leads to a better classification. The probability density functions that were studied have one or two parameters. This number is of primary importance in the capacity of a pdf to precisely characterize the speckle and differentiate the layers. We currently work on the study of the Generalized Gamma distribution with three parameters, which should produce more precise results.

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