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Second Order Features for Laser Speckle Imaging

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Abstract. Laser speckle imaging (LSI) has been proposed as a non invasive imaging modality for studying brain activity and blood flow circulation. The spatial and temporal analysis of contrast, defined as the ratio of standard deviation to mean intensity over a spatial window and/or over a number of frames, has been used for LSI processing. In the present work, the second order statistical properties of laser speckle pattern have been proposed as an alternative to contrast analysis for blood flow imaging. These properties, which we call second order features (SOFs), were derived from the co-occurrence matrix that in turn was calculated over the same spatial and temporal window than for the contrast. The image quality metrics - equivalent number of looks, entropy and objective quality – showed superior performance of the SOFs comparing to the contrast analysis. Besides, the SOFs describe analogous variations with the contrast over time, so that they could be studied in CBF imaging.

Keywords: Laser Speckle Imaging (LSI), Briers Contrast, Cerebral Blood Flow (CBF), Co-occurrence Matrix, High Order Statistics

1. Introduction

The association of the brain neural activity with the changes in cerebral blood flow (CBF) has been studied thoroughly [Wang et al., 2007] as it is of crucial importance for clinical diagnosis as well as for microcirculation studies and angiogenesis research [Murari et al., 2007]. Among many neuro-imaging modalities such as functional Magnetic Resonance Imaging (fMRI), laser-Doppler flowmetry and emission tomography, the Laser Speckle Imaging (LSI) has been proposed as a simple, cheap and effective alternative technique for real-time imaging of blood flow changes. It has also been proposed, though not yet applied, to vascular structural imaging in order to study connectivity and morphologies of vascular networks [Murari et al., 2007].

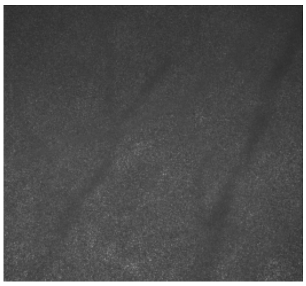

Figure 1 Raw Laser Speckle Image

Previous studies on LSI are mainly employing a first order statistic of the image texture (i.e. the contrast) in order to decipher the speckle pattern and translate it into useful information related to the CBF. In the present work the temporal properties of second order statistics, or features are examined.

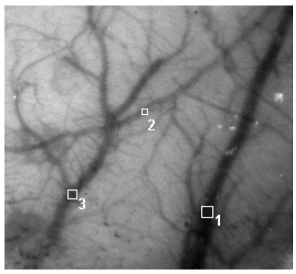

Figure 2 White light image of the barrel cortex, and three selected Regions of Interest (ROI).

2. Material and Methods

2.1. Animal Preparation

A male Sprague–Dawley rat (325 g) was used for the imaging. It was anaesthetized with pentobarbital (40mg/kg, IP) and mounted onto a stereotaxic frame (Benchmark, myNeurolab.com). A midline incision was made to expose the surface of the skull. The temporal muscle was freed and retracted with suture line. A window (6.5x6.5 mm) overlying the left barrel cortex (3.0 mm lateral, 4.3 mm caudal from bregma) was thinned with a high speed dental drill. The thinned area was filled with glycerine to avoid the glaring in imaging.

2.2. Imaging Procedures

A 20mW semiconductor laser diode (635 nm) was used to illuminate the imaging site. A monochrome 12-bit CCD camera (Pixelfly QE, PCO, Germany) with resolution of 1024x1392 pixels was positioned over the thinned skull and focused on the blood vessels overlying the cortical surface. A 2 by 2 hardware binning was performed by the camera, and the resulting image of size 512 by 696, was output to the PC for software processing. The acquisition began with 4 s of baseline activity, followed by 4 s of activity collected during right hind limb and 10 s of activity collected post-stimulus offset for a total of 18 s. Camera exposure time was set at 5 ms and images were acquired at a rate of 23 frames per second, resulting in 414 images. In addition, a white light image was acquired for comparison.

2.3. Data Analysis

Speckle is a random field intensity pattern produced by the mutual interference of partially coherent beams that are subject to instant temporal or spatial fluctuations. These patterns are seen when monochromatic coherent light is incident on a rough surface or a field of scattering particles. If the field of particles is non-static, photographing the pattern results in an image that is blurred over the exposure time of the recording device (see Fig. 1).

Temporal Contrast (tK)

One measure is the local speckle contrast which is defined as the ratio of the standard deviation to the mean intensity in a small window of the image [Briers, 2001]. The depiction of the vascular structure can be improved by using several consecutive frames; thus the statistics of the standard deviation and mean intensity are computed in a small box of the dataset, leading to the temporal contrast *tK* [Murari et al., 2007; Le et al., 2007]. Here we use a box of size 3 by 3 pixels by 23 frames (one second in our dataset).

Second Order Features (SOF)

The texture of an image region has been associated with the structural arrangement of pixel's intensities within the region [Haralick et al., 1973]. The most customary approach utilizes the concept of the grey level co-occurrence matrix that provides statistics for the probability of joint relationship of grey level intensities between neighbour pixels. Using the same small box than for *tK*, the Inverse Difference Moment, Difference Entropy, and Difference Variance were computed as in [Mahmoud-Ghoneim et al., 2003].

Assessment

Three measurements were used to assess the quality of the four second order features:

- the Equivalent Number of Looks (ENL), which measures smoothness in areas that should have a homogeneous appearance [Adler et al., 2004]. It is an average ENL calculated over the three ROIs;
- the image Entropy, which describes the information content in an image;
- and an objective quality criterion called the difference of Peak Signal-to-Noise Ratio (ΔPSNR) which is an objective measure of sharpness [Le et al., 2007]. For the ΔPSNR, a reference ground truth image (white light image) was needed as well as a classification of its foreground and background pixels (respectively blood vessels and non blood vessels). The blood vessels were segmented in the white light image, using Otsu's global image thresholding method, while the image was initially enhanced by the Contrast-Limited Adaptive Histogram Equalization (CLAHE) technique.

3. Results

The temporal-contrast and the three SOFs have been computed for each second of the same dataset. Three regions of interest (ROI, as in Fig. 2), have been picked up and their average value plotted against time, Fig. 3.

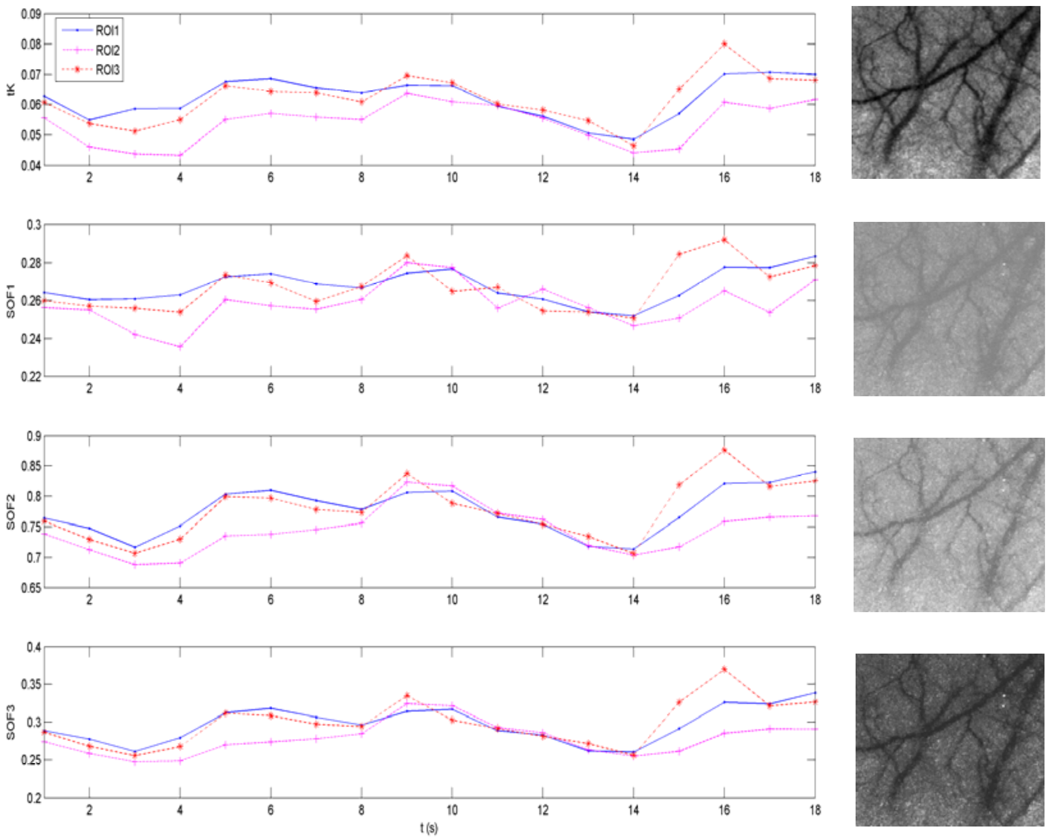

Figure 3 Left, top to bottom: time-course plot of averaged features: Contrast (tK), Inverse Difference Moment (SOF1), Difference Entropy (SOF2), and Difference Variance (SOF3). On each of the four plots are displayed the three Regions of Interest (".", "+", ""). Right, top to bottom: corresponding images of the same features calculated over one second (23 frames).*

The four different features are assessed by different quality metrics as in Table 1.

Table 1 Comparison of the different statistics and their quality.

Statistic	*ENL*	*Entropy*	*ΔPSNR*
K	101.09	4.29	1.63
SOF1	149.44	5.61	2.23
SOF2	147.84	4.88	4.11
SOF3	56.46	6.58	9.28

4. Discussion and Conclusions

We investigated Second Order Features, i.e. higher order statistics than the previously established temporal contrast. These SOFs, which are the Inverse Difference Moment, Difference Entropy, and Difference Variance, are found to contain more information than the contrast, as assessed by the following quality metrics: the Effective Number of Looks (ENL), the Entropy, and the objective quality (ΔPSNR). The ENL is higher for *SOF1* and *SOF2*, the Entropy is higher for all three, as well as the Objective Quality, as shown in Table 1.

Besides, it has been demonstrated previously that there exists a mathematical relationship between the contrast and the cerebral blood flow. If our proposed high-order statistics are themselves proportional to the contrast, we prove that they are also related to CBF. Indeed it is the case, since as shown in Fig. 3, the Inverse Difference Moment (SOF1), Difference Entropy (SOF2), and Difference Variance (SOF3) all follow closely the time-scale plot of contrast.

Our ongoing research is about finding the exact mathematical relationship between each SOF and the blood flow, upon which we will definitively suggest those as an alternative to the contrast.

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