SPECKLE IMAGE ANALYSIS OF CORTICAL BLOOD FLOW AND PERFUSION USING TEMPORALLY DERIVED CONTRASTS

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ABSTRACT

Contrast values estimated from temporal statistics is used for Laser Speckle Contrast Analysis (LASCA) of cortical blood flow and perfusion. Using temporal statistics, we are able to reliably estimate the blood flow and perfusion by processing only a selected number of pixels from the raw speckle images. For the number of frames ($N > 6$) for estimating the temporal contrast, the Root Mean Square (RMS) of the inverse decorrelation time (τ_c) is found to be relatively constant with a variance of ± 3.52%. For a given window size used for estimation of τ_c, it is observed that the RMS of $1/\tau_c$ values exhibit a low variance of ± 4.62% as compared to spatially derived contrasts (SDC) with/without averaging. For a given reduction in binning size, the image processing using the temporally derived contrasts (TDC) is found to be 1.41 times faster as compared to obtained using SDC.

1. INTRODUCTION

Laser Speckle Imaging is becoming an important tool for real time monitoring of blood flow surges and vascular perfusion during neurosurgical interventions and deep brain implantations. The signal processing involved in the translation of the intensity maps into a reliable estimate of blood flow is usually spatially derived from the raw intensity values. In this paper, we demonstrate the performance of temporally derived contrast images acquired from the rat cortex under baseline conditions.

Laser speckle contrast analysis (LASCA) is a means of providing full-field and real time measurement of blood flow using first order statistics of the time-integrated speckle as suggested by Briers et al. A 2-D array CCD camera with focusing optics was used to detect the speckle pattern formed by light reflected from tissue illuminated by a divergent laser beam. Analyses of the speckle pattern contrast provided information about the concentration and average velocity of red blood cells. LASCA has been used as a minimally non-invasive method of imaging transport in biological tissues such as cerebral blood flow in rats [1] as well as capillary blood flow in a human hand [2]. The main disadvantage of LASCA is the loss of resolution caused by the need to average over a block of pixels to obtain the spatial statistics used in the analysis. However despite of that, it still has higher resolution.

This paper is an extension on the study validated by [3], on the modified laser speckle imaging method (LSI) that uses temporal statistics of the time-integrated speckle to measure the rat cerebral blood flow (CBF). That was done matching the velocity obtained from laser Doppler readings with the temporal contrast. In this paper, it is shown that temporally derived contrast images provide a clearer approximation to the spatiotemporal profile of vascular perfusion. Since our method gives a frame spatial resolution for binning from 1 to 6, the temporally derived method is proven to be better suited for real time applications such as flow monitoring during surgical intervention.

2. MATERIALS AND METHODS

2.1. Method

Male Sprague-Dawley rats (250-300gm) were used for the imaging. Animal care and experimental procedures were carried out in accordance with the University guidelines laid out adhering to the Basic Principles of the International Guiding Principles for Biomedical Research Involving Animals (1985). Animals were anaesthetized with urethane (1.25mg/kg) and mounted onto a stereotaxic frame (Stoelting). A burr hole of 6mm was drilled into the skull and thinned to the dura mater. The site of 3mm diameter was made 2mm anterior to Bregma and 3mm lateral to the midline. Saline was used to keep the exposed surfaces moist till imaging was commenced.

A diode laser (Sanyo, 782.6nm) was used to irradiate the imaging site and controlled with a shutter (UniBlitz). The

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laser operation was controlled. The frequency was adjusted to be 10Hz. A monochrome 12-bit cooled CCD with 1392x1040 pixels (Roper Scientific) was positioned over the imaging site. Images were acquired using Metamorph and LASCA was performed on an Intel 2.8GHz Xeon Processor with 256Mb RAM using MatLab 6.5. The exposure time of the CCD was adjusted to be at 10ms and the images were acquired for a period of 6 seconds. 60 images were acquired in the process.

2.2. Laser Speckle Contrast Analysis (LASCA)

The speckle contrast of a time-integrated speckle over time T is given by

$$K=\left\{\left(\tau_c/2T\right)\left[1-\exp\left(-2T/\tau_c\right)\right]\right\}^{1/2}$$

where τ_c is the decorrelation time of the intensity fluctuations [4]. The relationship between τ_c and mean velocity, υ_c is given by

$$\upsilon_c=\lambda/2\pi\tau_c$$

where λ is the wavelength of the laser light used. Hence we can conclude that $1/\tau_c$ is proportional to mean velocity.

2.3. LASCA using Spatially Derived Contrasts (SDC)

In this method, the speckle contrast K for a pixel is computed using the intensity distribution obtained from a group of neighbouring pixel values.

$$K=\frac{\sigma_s}{<I>}$$

where K, σ_s and < I > represent the speckle contrast, the spatial standard deviation and the spatial mean light intensity respectively. In practice, a 5x5 or 7x7 window of pixels is used [4]. In this study, a 5x5 pixel window was used in the computation of spatial contrast for the comparison purposes.

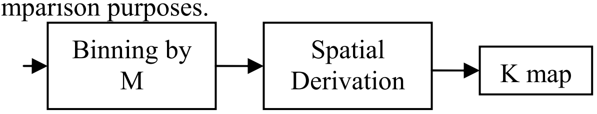

Figure 1. Flow Chart of the Processing of SDC

2.4. LASCA using SDC with Averaging

In this method, the speckle contrast K for a pixel is computed using the intensity distribution obtained from a group of neighbouring pixel values. Using K_1, K_2 …… K_N to be the pixel contrasts obtained using method 2.3, the contrast $K_{SDC(Averaging)}$ corresponding to SDC with averaging is given by,

$$K_{SDC(Averaging)}=\frac{K_1+K_2+K_3+......+K_N}{N}$$

where K_1, K_2, K_3 …. K_N are the respective consecutive contrast values and N is the number of frames averaged.

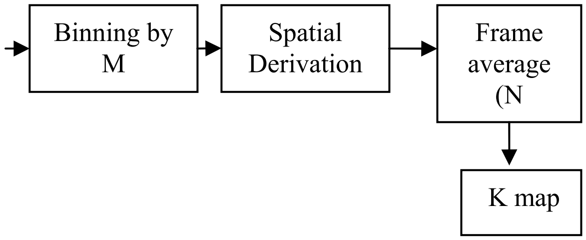

Figure 2. Flow Chart of the Processing of SDC with Averaging

2.5. LASCA using Temporally Derived Contrasts (TDC)

The first order temporal statistics of time-integrated speckle pattern can be used to obtain velocity information [3]. TDC can be measured by using this method

$$K_{i,j}=\frac{\sigma_{i,j,t}}{\left\langle I\right\rangle_{i,j,t}}$$

where K is the pixel speckle contrast, , $\sigma_{i,j,t}$ is the standard deviation of the (i'th, j'th) pixel intensity in time t and $<I>_{i,j,t}$ is the mean intensity of the (i'th, j'th) pixel intensity in time t. The notation t is used to denote N successive frames used for the temporal filtering. The TDC is computed for each pixel and placed together according to (i'th, j'th) coordinates to form a temporal contrast map K_{TDC}.

$$K_{TDC}=\begin{bmatrix} K_{1,1} & K_{2,1} & K_{3,1}\ ....\ K_{i,1} \\ K_{1,2} & K_{2,2} & K_{3,2}\ .....K_{i,2} \\ K_{1,3} & K_{2,3} & K_{3,3}\ .....K_{i,3} \\ \vdots & \vdots & \vdots \\ K_{1,j} & K_{2,j} & K_{3,j}\ .....K_{i,j} \end{bmatrix}$$

The results are given as a 2D gray scale and subsequently converted to pseudo colour using Matlab and displayed as an image.

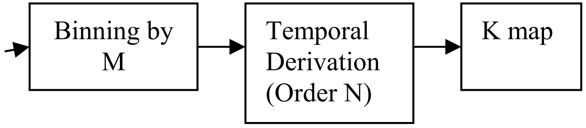

Figure 3. Flow Chart of the Processing of Temporally Derived Contrasts (TDC)

2.6. Binning

In this method, pixels from the laser speckle image are selected for processing according to the binning size, M. The selected pixel $I_{x,y}$ is given by,

$$I_{x,y} = I_{i_1 * (i/M), j_1 * (j/M)}$$

where i, j are the original coordinates of the pixel, i_1 range from 1 to i/M and j_1 range from 1 to j/M. Binning is carried out in order to cut down processing time as pixels are selectively processed. The processing time decreases by a factor of ¼ with increasing M.

3. RESULTS AND DISCUSSION

The images were acquired under baseline conditions with no external stimulations applied to the test animal. Under such conditions, it is expected to observe a steady blood flow resulting in a fairly constant value of $1/\tau_c$. Baseline values are compared using the Root Mean Square (RMS) of the estimates of τ_c (obtained from lookup tables prepared using the relationship between K and τ_c [4]). In Spatially Derived Contrast with averaging, the number of frames N included in the averaging is shown to affect the RMS of $1/\tau_c$. In the Temporally Derived Contrast approach, the contrasts are estimated using the temporal mean and standard deviation of 'N' pixel values. For the latter case, the RMS of $1/\tau_c$ variations are shown to decrease with increasing N.

The region used to monitor the blood flow was located in the middle of a major blood vessel spanning the image from bottom left to top right as shown in Figure 4. The number of contrast maps used for averaging ranged from N = 0 (corresponding to SDC without averaging) to N = 10.

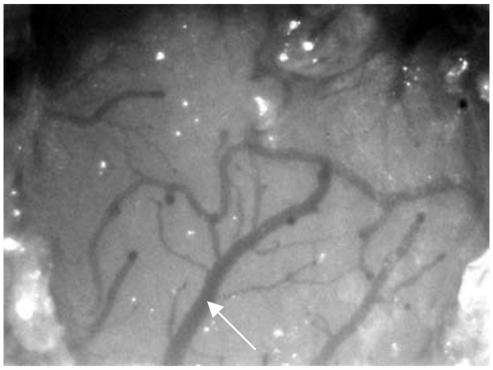

Figure 4. Image of Rat Cortex under White Light Conditions

Figure 5 shows the variations of the RMS $1/\tau_c$ values for a window of 10 by 10 pixels chosen over the blood vessel. The window size chosen corresponds to the width of the blood vessel. We observe that the RMS $1/\tau_c$ values for both TDC and SDC with averaging decreases with increasing N. It is also observed that for N > 6, the RMS $1/\tau_c$ for TDC is relatively steady with a variance of ± 3.52%.

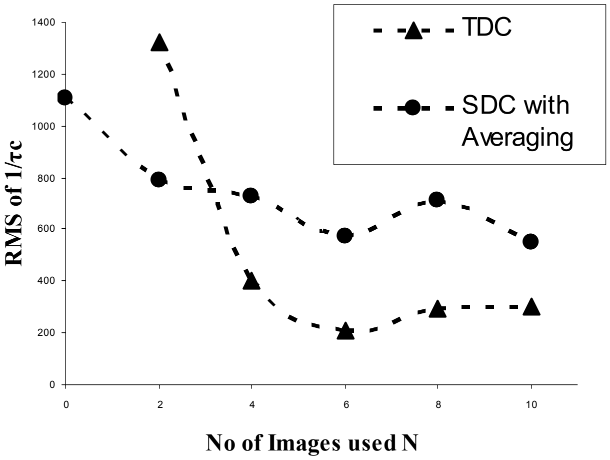

Figure 5. RMS of $1/\tau_c$ values for SDC with/without Averaging and TDC for varying N

Figure 6 shows the variations of RMS $1/\tau_c$ values for a window of 3x3 pixels chosen in the region of the blood vessel for binning sizes (M) varying from 1 to 6. Since the diameter of blood vessel as seen in the image decreases with increasing M, a window of 3x3 pixels was used so as to correspond to the width of the blood vessel for a binning size M=6. We observe that the RMS $1/\tau_c$ values of both SDC with/without averaging decrease with increasing M and that the RMS fluctuations for the $1/\tau_c$ values for TDC exhibit a low variance of ± 4.62 %.

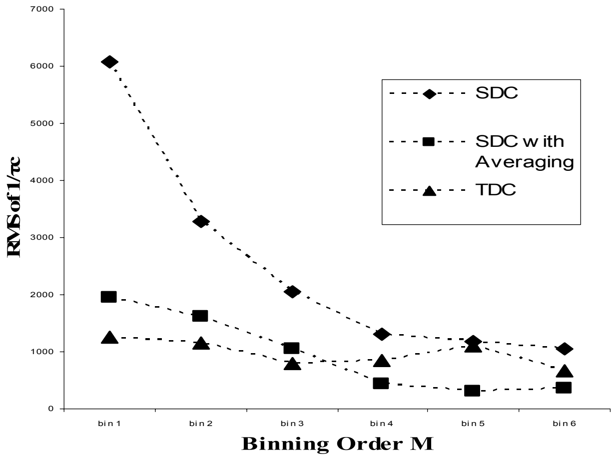

Figure 6. RMS of $1/\tau_c$ values of SDC with/without Averaging and TDC with varying M

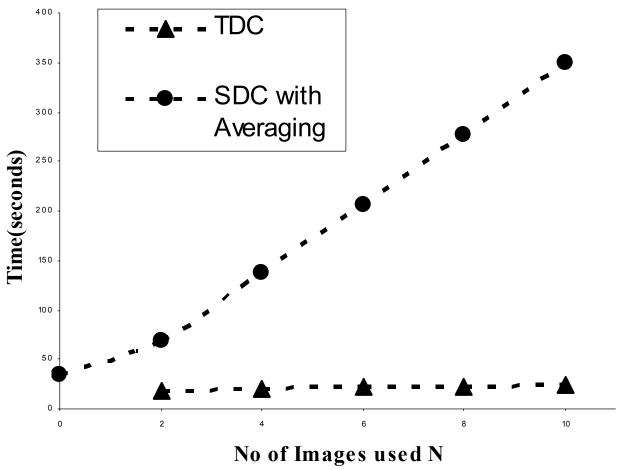

Figure 7. Processing Time of SDC with Averaging and TDC

Figure 7 shows the variations in processing time for SDC with Averaging as compared to TDC for binning size M=2. It is observed that the processing time of SDC with Averaging increases linearly with increasing number of images used for averaging. The processing time for TDC is observed to be relatively constant with a variance of ± 1.16%. When N=10, image processing using TDC is 10 times faster compared to SDC with Averaging and 1.41 times faster compared to SDC.

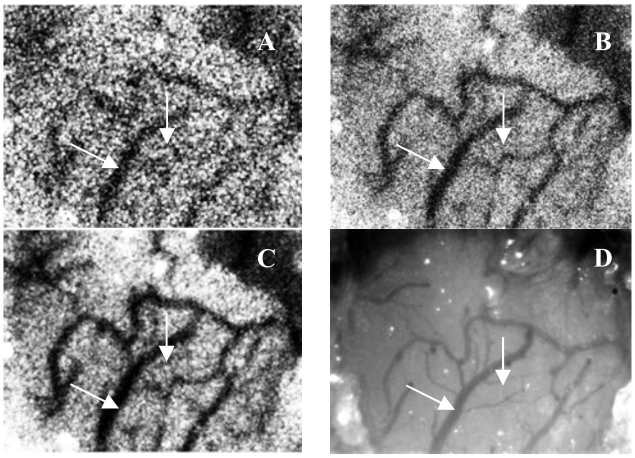

Figure 8 A) SDC, B) TDC, C) SDC with Averaging D) White Light

Figure 8 shows the speckle maps corresponding to the various processing methods. Fig (A) is the contrast map processed using SDC (M=2, window size=5x5), Fig (B) is the contrast map processed using TDC (M=2, N=10), Fig (C) is the contrast map processed using SDC with averaging (M=2, window size=5x5, N=10) and Fig (D) is the white light image. White arrows are used to indicate the major and minor blood vessels. It is observed that SDC with averaging and TDC provide greater spatial resolution and detail compared to SDC.

4. CONCLUSION

Speckle image processing with temporally derived contrast (TDC) was seen to be able to reduce contrast intensity fluctuations over time. For binning size in the range of 2-6, this method provides a reliable estimate of blood flow and vascular perfusion with reduced processing times significantly to almost real time. With Laser Speckle Imaging becoming an important tool for real time monitoring of blood flow surges and vascular perfusion during neurosurgical interventions and deep brain implantations, this method could be used for real time assessment of flow in major vessels and regions of perfusion surrounding the region of intervention.

6. REFERENCES

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