Modified Laser Speckle Imaging with Adaptive Window

Ho-young JIN[1], Hyun-chool SHIN[1], Kab-mun CHA[1], Ki-won RHEE[1], Nitish Thakor[2]
(1. *Soongsil University*, *Seoul* 156-743, *Korea*; 2. *Johns Hopkins University*, *Baltimore* 21218, *USA*)

Abstract – One of the advantages of laser speckle is detecting micro-vascular through image processing. This paper proposes a new image processing method for laser speckle, adaptive window method that adaptively processes laser speckle images in the space. Disadvantage of conventional fixed window method is that it uses the same window size regardless of target areas. Inherently laser speckle contains undesired noise. Thus a large window is helpful for removing the noise, but it results in low resolution of image. Otherwise a small window may detect micro vascular but it has limits in noise removal. To overcome this trade-off, the concept of adaptive window method is newly introduced to conventional laser speckle image analysis. In addition, the modified adaptive window method applied to other selection images. We have compared conventional Laser Speckle Contrast Analysis (LASCA) and its variants with the proposed method in terms of image quality and processing complexity. Moreover compared the result of the accompanied changing selection images have also been compared.

Key words – *Laser Speckle Contrast Analysis* (*LASCA*); *adaptive window*; *laser speckle*; *selection image*

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1 Introduction

Lately, a considerable amount of researches concerning this study have been researched as industry develops and medicine progresses. Among these studies, various medical instrument which observe parts of human body such as Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET), and X-ray have been invented and developed. Laser speckle technology have been actively studied even though the technology have not popularizated because its potential of development is considerable[1].

A laser speckle is created when laser light illuminates an object, and the speckle contrast values are calculated from the time-varying statistics. The Laser Speckle Imaging (LSI) technique can detect vascular and blood flow changes in the underlying medium[2]. The detection of blood flow is an important in medical diagnosis. Using LSI, it is possible to observe of skin capillary flow and retinal flow in a noninvasive way. Also LSI is a relatively simple and inexpensive technique but it may support the investigation of complex interactions between neuronal activities and hemodynamic affairs[3].

Investigation of the spatiotemporal characteristics of blood flow is important in understanding the interest region of tissues. Various signal processing techniques for LSI exist but mostly they are based on LASCA. As variants, Spatial way[5], temporal way[6], spatial-temporal[7] and adaptive spatial mean filter[8] and temporal mean filter[2] have been studied to see micro vascular better.

Conventional fixed window based LASCA has shortcoming in that it uses the same window size regardless of target areas. Inherently LSI contains speckle noise. Thus a large window is helpful for removing the noise but it results in low resolution of image. Otherwise a small window may detect small vascular but it has limits in noise removal. To overcome this trade-off, we newly introduce the concept of adaptive windowing to conventional laser speckle image analysis. Adaptive windowing is applied to both spatial processing.

This paper is organized as follows. The experimental setup and techniques, laser speckle imaging of various LASCA and adaptive windowing LASCA are described in section 2,3. In section 4, the result images are presented. Finally, section 5 deals with the conclusion and observations.

2 Material and methods

2.1 Laser speckle imaging

A laser speckle is an interference pattern that has a granular appearance produced by reflected light when a coherent laser fell on an irregular course surface. Goodman asserts that useful information can be attained by examining the statistical properties of laser speckle patterns defined after storing the granular image in a Charge-Coupled Device(CCD) camera[4].

Fig. 1 shows the experimental system setup used to

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Corresponding author: Ho-young JIN(miyabbang@gmail.com)

obtain laser speckle images. When a He-Ne Laser (655 nm) illuminates the target region, the light is reflected by the surface of the target region, then a microscope magnifies the image. Finally, CCD camera captures the image and the images are stored in the computer.

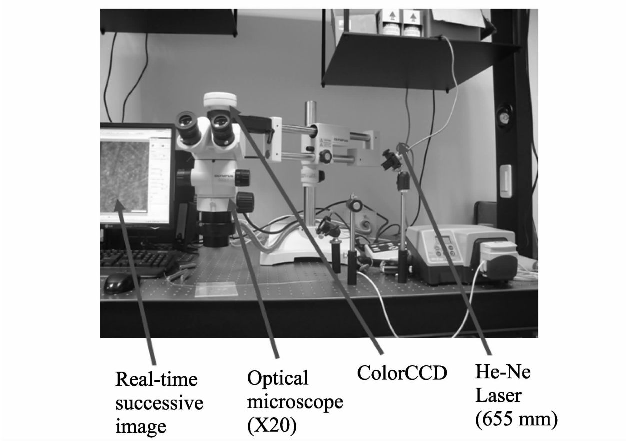

Fig. 1 Experimental system setup

2.2 Speckle Contrast K

The definition of the speckle contrast is

$$K = \sigma_s / \langle I \rangle, \tag{1}$$

where K is the speckle contrast, σ_s is the spatial standard deviation, and $\langle I \rangle$ is the spatial mean intensity of a window of pixels. The range of the contrast K is $0 \leqslant K \leqslant 1$. When an object moves, the speckle pattern it produces changes. It is cause of changing the speckle contrast value. The contrast value is low when an object moves quickly, on the other hands the value is high when an object moves slowly.

Applying this definition, vascular and non-vascular areas can be distinguished since the contrast is low where blood flow occurs, whereas it is high when no blood flow occurs.

3 Spekle image processing

3.1 Conventional LASCA based techniques

LASCA based techniques can be divided into two categories. They are spatial direction LASCA and temporal direction LASCA. Generally, spatial direction LASCA is known as LASCA[5].

In spatial direction LASCA, a square-shaped fixed window is used around a target pixel to calculate the contrast value in Eq. (1).

Fig. 2 shows the spatial direction LASCA operation, where W is $M \times M$ window, R. I is the raw speckle image, and C. I is speckle contrast image. As the sliding window W is moving by one pixel, the contrast is calculated.

Fig. 3 shows the temporal LASCA operation where n is the image frame number. Temporal direction LASCA can be defined according to Eq. (2)[6]

$$K_t(i,j) = \sigma_{i,j,n} / \langle I_{i,j} \rangle_n . \tag{2}$$

Where i, j is pixel number, $\sigma_{i,j,n}$ is temporal standard deviation, $\langle I_{i,j} \rangle_n$ is temporal mean intensity and $K_t(i,j)$ is the temporal contrast value. Temporal window size is $1 \times 1 \times n$.

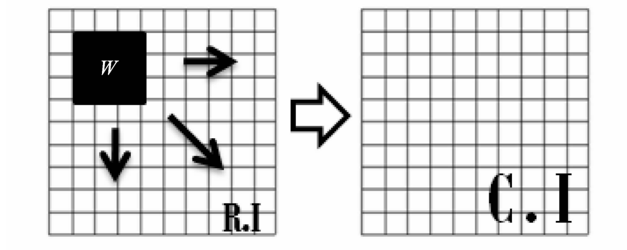

Fig. 2 Spatial direction LASCA operation

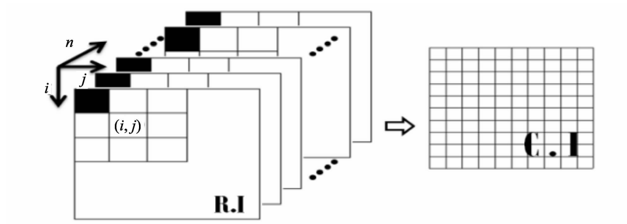

Fig. 3 Temporal direction LASCA operation

3.2 Proposed adaptive window LASCA

Fig. 4 is the spatial direction adaptive window LASCA operation. The proposed method attempts to improve spatial resolution over the basic variable LASCA techniques. The key is that the window size for calculating speckle statistics adaptively changes. The propose of our method is that we apply small size spatial window to in blood-vessel region pixels. On the other hand we apply large size spatial window to non-blood-vessel region pixels. Therefore most important thing in our proposed method is the distinguish blood-vessel and non-blood-vessel. This distinguish processing, we called Window selection.

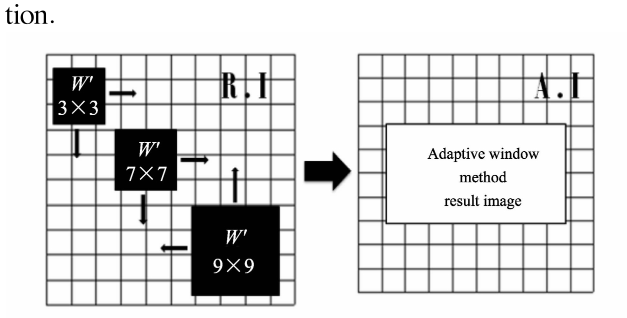

Fig. 4 Spatial direction adaptive window LASCA operation

Fig. 5 is the block diagram of our proposed method. In window selection, from the raw image, K are calculated using $M = 5$, $n = 15$. This process is the same peration as conventional LASCA. Then based on LASCA image, we draw a contrast histogram. Then it was devided the histogram as same interval. At this point is the threshold of the deciding window size. The window size number are adaptively changed among $M = 3, 5, 7$, and 9. Then this window selection image was applied to the last step in adaptive window method. The measure for applying variable-sized square windows is K, where K is speckle contrast, of raw images.

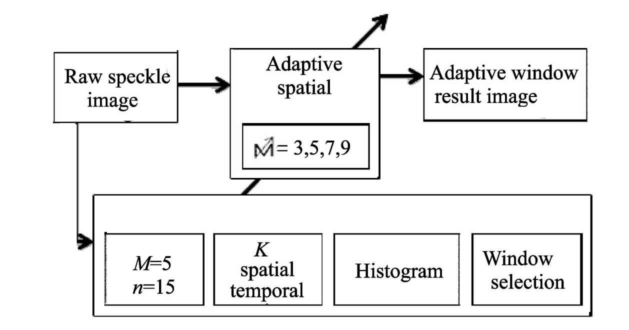

Fig. 5 Block diagram of adaptive window LASCA

4 Results

4.1 Raw laser speckle image

Fig. 6 is the speckle image of Rat barrel cortex. The width and length are 5 mm, the image is saved in 384 × 384 pixel, and the width and the length are about 13 m per pixel. In Fig. 6, the actual size of micro-blood-vessel that is underlined is about 0.85 mm. And Matlab is used for image processing of speckle image.

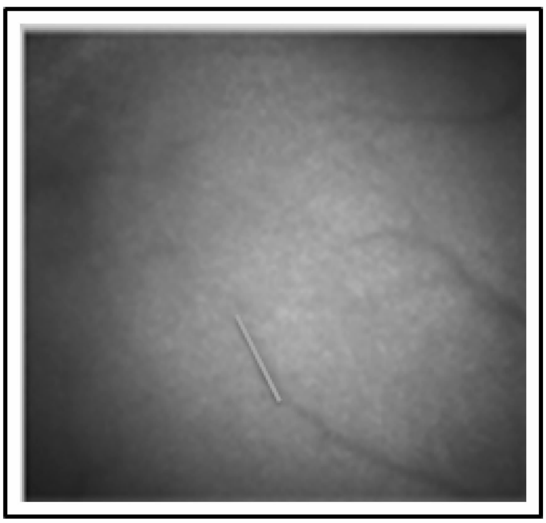

Fig. 6 Raw speckle image of Rat barrel cortex

4.2 Conventional LASCA result images

Fig. 7 presents the conventional LASCA images. Fig. 7(a), (b), (c) are the spatial direction LASCA and (d) is temporal direction LASCA. First of all, as moving from Fig. 7(a) ~ Fig. 7(c) window size M is larger than the former. When the size is the smaller window, blood-vessel can be seen more clearly than the bigger window. However, as a result of speckle noise, more black points are appeared. That means that although spatial resolution is better as the window size is small, the other hand, image of small window is influenced more by speckle noise. And compare with Fig. 7(c) and Fig. 7(a), we confirm that Fig. 7(c) is more blur than Fig. 7(a), however its speckle noise is removed than Fig. 7(a). That means that the effect of noise can be reduced by reducing window size but, spatial resolution is also decreased. However, compare with Fig. 6 and Fig. 7, blood-vessel can be seen more clearly using LASCA.

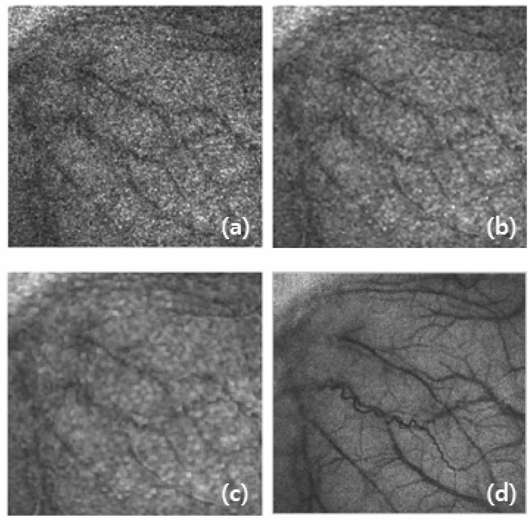

Fig. 7 Conventional LASCA images: (a), (b), (c) are spatial direction LASCA image ((a) $W = 3 \times 3$, (b) $W = 5 \times 5$, (c) $W = 7 \times 7$); (d) temporal direction LASCA image ($n = 15$)

And, Fig. 7(d) is the temporal direction LASCA. Contrast was calculated by using 15 frames ($n = 15$) and it shows high quality of image comparing with spatial method. However, temporal resolution was decreased due to using 15 frames.

4.3 Proposed adaptive window method

Fig. 8 shows window selection images and adaptive window method result images. (a) and (b) of Fig. 8 are the selection images using (b) and (d) of Fig. 7. We have estimated blue parts as blood-vessel and red parts as non-blood-vessel in (c) and (d) in Fig. 8. Blue parts have been applied to window 3×3 and red parts have been applied to window 9×9. As comparing Fig. 8(a) with Fig. 8(b), extracting blood-vessel of Fig. 8(a) is better than Fig. 8(b). And, speckle noise is reduced as shown in Fig. 8(c) and Fig. 8(d) but blood-vessel is more clear.

Fig. 9 presents the zoomed images of (c) and (d) in Fig. 8. As seen in the circle, in Fig. 9(b), there are black points considered as noise, but these black points are less clear in Fig. 9(c). And, part of blood-vessel that is unclear in Fig. 9(b) can be seen more clearly in Fig. 9(c). This appearance has been seen in a whole image.

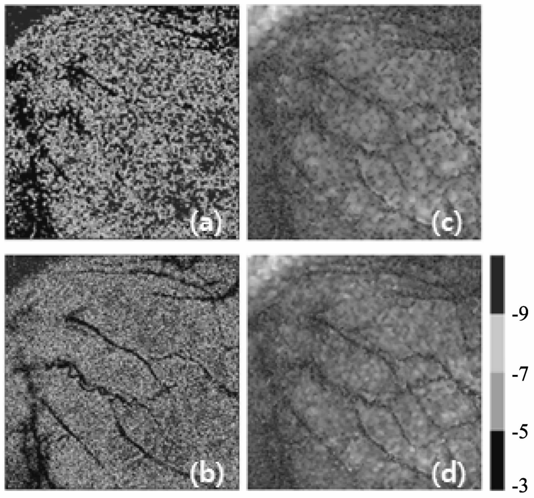

Fig. 8 Proposed adaptive window methods: (a) Window selection images using spatial direction LASCA($W = 5\times5$); (b) Using temporal direction LASCA $n = 15$; (c) Result images using Fig. 7(a); (d) Result image using Fig. 7(b) , M = 3,5,7,9

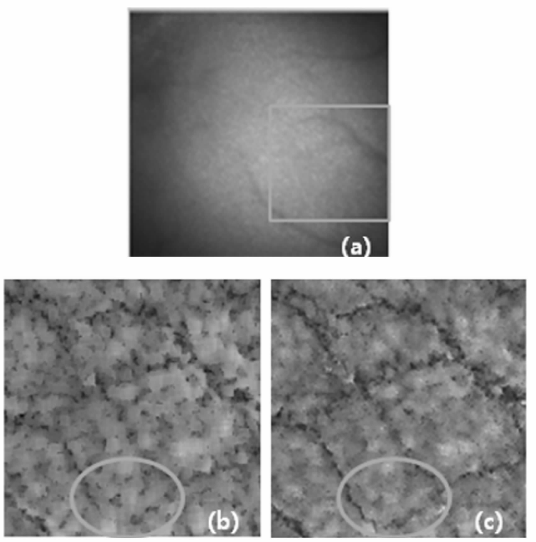

Fig. 9 Zoomed image of local adaptive window results: (a) Raw speckle image, (b) Using spatial LASCA as selection image, (c) Using temporal LASCA as selection image

5 Conclusion

We could have verified that our adaptive window method shows better performances comparing with conventional fixed window LASCA Moreover, in adaptive window method, we have certificated that image quality was improved when selection image has more good quality than the other. We have enhanced spatial resolution by applying adaptive window method to spatial direction. Later, we expect to enhance temporal resolution by applying it to temporal direction.

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