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Noise Reduction of a Photoacuoustic Microscopy Image According to Reorganizing of Ultrasound Signals

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Abstract. Photoacoustic microscopy (PAM) is an innovative imaging technology due to its distinctive physical features comparing with optical or acoustic systems. The biggest issues for this technology are to improve operating speed, spatial resolution, signal-to-noise ratio (SNR) and equipment's volume for commercialization. Herein we propose a noise reduction algorithm by reorganization of ultrasound signal without sacrificing any spatial resolution or operating speed. This algorithm was implemented by using LabVIEW software and then evaluated with actual PAM data. The results show that maximum 74% of noise could be reduced. Based on the results of the noise analysis, we has been reconstructed the PAM images, analyzed these. Finally, we confirmed that the proposed method can improve the sharpness of the image and reduce the noise.

Keywords; Photoacoustic; SNR; reorganization; ultrasound; real-time system

1. Introduction

PAM is an emerging imaging technology for in vivo preclinical research and clinical practice due to its unique physical characteristics. PAM is an innovative imaging technology due to its distinctive physical features comparing with optical or acoustic systems. For example, it can noninvasively provide label-free images

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containing various information such as oxy-hemoglobins, decoxy-hemoglobins [1], DNA/RNA in cell nuclei [2], etc. Thanks to these advantages, PAM has been widely used in many research area, such as oncology [3], neuroscience [4], cardiology [5], etc. Despite the significant enhancement on the system performance, previously introduced PAM systems show the limited performance in imaging speed, spatial resolution, SNR compared with recent optical or acoustic systems for commercialization [6].

Here, we present a noise reduction technique based on signal processing which can be applied in any PAM systems without sacrificing spatial resolution or operating speed. The proposed algorithm based on reorganizing pixel signal had been implemented by using LabVIEW software and then evaluated with actual PAM data of blood vessels in mouse ear.

2. Methods

A. Obtaining of a PAM image

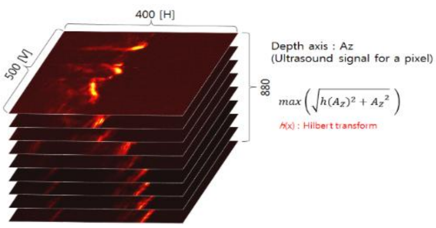
The evaluated PAM data had been obtained by using the system in [6]. This system is implemented based on a fully integrated 2-axis water-proofing microelectromechanical system (MEMS) scanner. Thanks to the high performance scanner, this system shows enhanced performance in imaging speed, scanning range, cost-effective productivity and small system volume without SNR degradation. Refer to [6] for details on the system configuration. The acquired raw data for an image has 400×500 pixels which is its spatial resolution. Each pixel data consists of 880 sampled ultra-sound signal which is center frequency 50 MHz. In this reference, Hilbert transform method had been applied for image reconstruction.

B. Reconstruction of PAM images

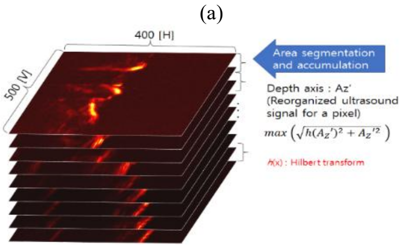
In order to reconstruct an ultrasound signal into an image in PAM system, delay and sum algorithm, fast Fourier transform (FFT) algorithm, time reversal approach and Hilbert transform are used [6, 7]. The delay and sum algorithm has a limitation that it should be known a proper delay and amplitude correction. If, the source position is unknown, a measurement method can be built to locate the source itself. The FFT algorithm can be applied in the case using homogeneous medium. Other case, it only work for single point sources. The time reversal algorithm is limited in real-time operation, because of its ridiculous high computational time. Hilbert transform algorithm is a method to calculate a most strong amplitude of an ultrasound signal for a pixel. This is simple enough for a real-time operation, but cannot cancel noise due to the inherent signal fluctuation from hardware. In this paper, we quantitatively analyzed the noise improvement of the proposed algorithm using a Hilbert transform - based algorithm which is suitable for real - time systems.

C. Denoising by reorganizing ultrasound signal

Generally, in order to reduce the noise of the image, this is done by analyzing the relationship between spatial or temporal values and computing it according to analyzed relationship. These approaches, however, result in loss in spatial resolution or operating speed. Herein, we propose a method while minimizing these mentioned losses by reorganizing the ultrasound signal of a pixel itself. The basic concept is to equally divide an ultrasonic signal of each pixel into several sub-region and to reorganize a new signal by accumulating these divided sub-regions. By applying this reorganized signal to the existing Hilbert transform algorithm, it was possible to obtain images with reduced noise. Fig. 1 show conceptual diagrams of the existing and proposed image reconstruction algorithms. In the Fig. 1 (a), A_z represents the raw ultrasound signal of a pixel, and the final pixel value of pixel in the reconstructed image is the maximum value obtained from the equation in the given figure. The proposed method, shown in Fig. 1 (b), divides into a uniform range of A_z and performs accumulating values in these sub-regions to create a new array A_z ', and applies this reorganized array to the existing Hilbert transform algorithm. Since the proposed method does not use multiple images, there is no loss in operation speed. In addition, there is no loss of spatial resolution because there is no merge calculation between spatially neighboring pixel values. This approach has big advantage of being suitable for a real-time image system because it calculates final pixel value using only the corresponding pixel signal.



(a)



(b)

Figure 1. Concept diagrams for PAM reconstruction algorithm; (a) conventional Hilbert transform algorithm, (b) the proposed algorithm based on reorganizing an ultrasound signal.

3. Evaluation and Discussion

Figure 2(a) shows the reconstructed image using the existing method (top) and the proposed method (bottom). When the proposed method is applied, it can be seen that there is almost no visible point or line noise when the conventional method is applied. In order to analyze the degree of noise improvement, first of all, we calculated the standard deviation of the black area shown as ROI in the Fig. 2(a). Fig. 2 (b) is a histogram analysis of the reconstructed images according to the number of sub-regions. For example, the number of sub-regions 220 means that a total of 4 sampled values in an ultrasonic signal are accumulated over one divided region. As the number of sub-regions increases, the shape of the graph by the proposed method becomes sharp, and the sharp shape of the graph means that the value of the entire pixel becomes uniform. Therefore, that it can be confirmed that the noise is reduced. Fig. 3 (c) is a graph of the standard deviations according to the number of sub-region. The dotted line is the normalized standard deviation value when the conventional method is applied. Normalization was performed using the maximum amplitude represented in an image. When conventional method is applied, it appears as the same value regardless of the number of sub-regions, so it is displayed as a straight line. Compared with the conventional method, the proposed method greatly changes the standard deviation value according to the number of sub-regions. The graph shows that the standard deviation was minimized when divided into 35 sub-regions. This is equivalent to accumulating approximately 25 near-sampled values in a raw ultrasound signal. At this condition, the standard deviation value was 0.0345, which corresponds to 26% of the conventional approach. However, in this condition, the reconstructed image itself has been distorted and the signal loss, such as microvessel, has been large. Considering the information loss and noise reduction rate in a reconstructed image, the optimum value is considered to be 100 divisions. This is the result of accumulating 7 sampled values in the ultrasound signals. The standard deviation value at this time is 0.00463, which corresponds to 35% of the conventional method.

Figure 3 compares the reconstructed images. Fig. 3 (a) shows the general microscope image of the mouse ear used in the experiment. Fig. 3 (b) and (c) show the reconstructed images by applying the conventional and proposed methods. In particular, Fig. 3 (c) shows the result image when the number of sub-regions is 100. In general, PAM images are more advantageous for observation of blood vessels that do not appear in general microscopic images because more depth direction signals are displayed compared to general microscopic images due to its inherent physical feature. For this reason, as shown in the Fig. 3(b) and (c), the reconstructed PAM image shows additional blood vessels compared with the microscopic image, as shown in the Fig. 3(a). Comparing Fig. 3(b) and (c), it can be confirmed that the boundary of the blood vessel is clearer and that 3(b) and (c), it can be confirmed that the boundary of the blood vessel is clearer and that the dot-like noise spreading over the entire image is much reduced. Since this method does not require multiple image capturing and merging operations with spatially neighboring pixels, there is no reduction in spatial resolution and system operation speed. Problem has been also found. As the number of sub-regions increases, the streaks increase in parts such as blood vessels. This is due to the loss of information resulting from the segmentation and accumulation process of sub-regions, and we hope to find a way to compensate.

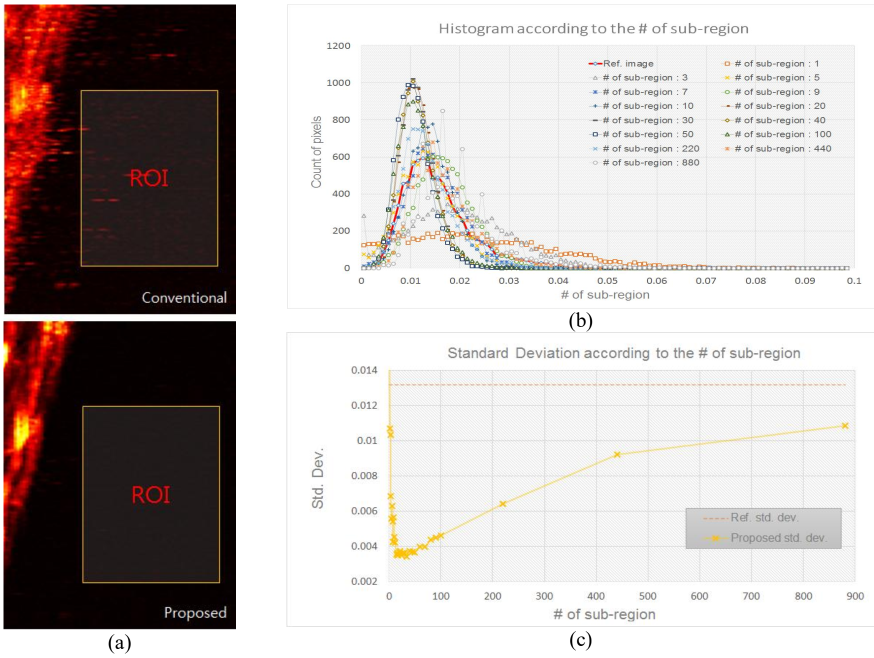
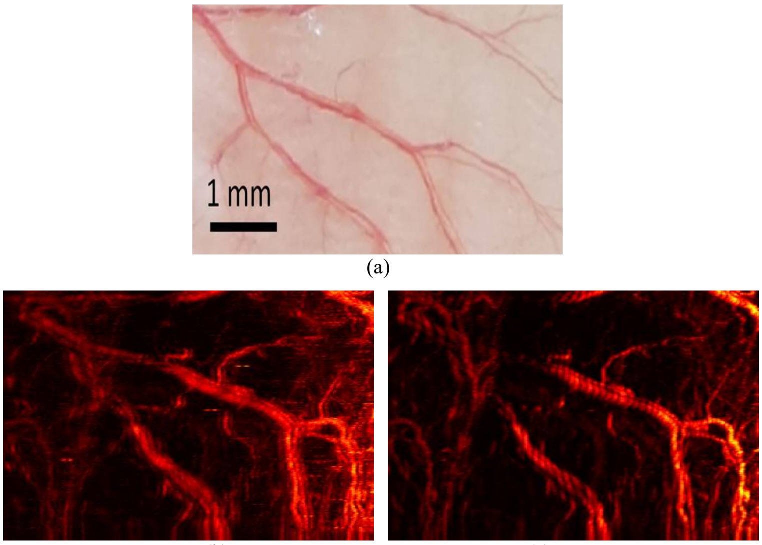


Figure 2. Noise analysis using a simple black area; (a) image comparison between conventional and proposed approaches, (b) histograms and (c) standard deviation graph according to the number of sub-regions.



(a)

(b) (c)

Figure 3. Image comparison; (a) photograph of the mouse ear showing blood vessels, reconstructed images using (b) conventional Hilbert transform and (c) proposed approaches.

4. Conclusion

In this paper, we proposed a signal processing technique for noise reduction which can be applied in general PAM systems without sacrificing spatial resolution or operating speed. The proposed method has been implemented by reorganizing each ultrasound signal of the corresponding pixels by equally dividing values in the raw ultrasound signal into sub-regions and accumulating them, and applying this reorganized signal to the existing image reconstruction algorithm. Since it uses only the signal of the corresponding pixel to calculate the final pixel value, it is suitable for a real-time application. In order to confirm the improvement of the noise, the standard deviation variation in the black image has been evaluated. Through this, it has been analyzed that the reduction ratio of noise according to the number of divided sub-regions and analyzed the optimal conditions, quantitatively. Based on the results of the analysis, we has been reconstructed the PAM images, analyzed these. Finally, we confirmed that the proposed method can improve the sharpness of the image and reduce the noise.

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