# High-contrast ultrafast microvascular imaging using delay-multiply-and-sum based nonlinear compounding: phantom and *in vivo* studies

**Jinbum Kang**[1], Dooyoung Go[1], Yangmo Yoo[1,2], [1]Department of Electronic Engineering, Sogang University, Seoul, Korea, [2]Department of Biomedical Engineering, Sogang University, Seoul, Korea

## Background, Motivation and Objective

Ultrafast power Doppler imaging enables non-contrast, high-sensitivity microvascular imaging by collecting a large number of spatiotemporal samples within a short acquisition time. However, conventional plane wave or diverging wave compounding based power Doppler imaging techniques (CCC-PD) suffer from low-contrast resolution induced by side-, grating- and axial-lobe artifacts. In this study, we propose a new ultrafast power Doppler imaging method based on delay-multiply-and-sum nonlinear compounding (DMSC-PD) to improve the contrast resolution of microvascular imaging.

## Statement of Contribution/Methods

In the DMSC-PD method, the singular value decomposition (SVD) clutter filtering is preferentially applied to individual spatiotemporal angle data set, and pre-clutter filtered RF data are coupled and multiplied in pairs prior to summation to emphasize coherent flow signals between the angle frames. To evaluate the performance of the DMSC-PD method, flow phantom (Model 1430, Gammex Inc., Middleton, WI, USA) and *in vivo* (i.e., kidney vessels) studies were conducted using an ultrasound research platform (Vantage, Verasonics Inc., Kirkland, WA, USA) with a C5-2 curved array transducer. For ultrafast Doppler imaging, 10-titled diverging waves ($\pm 12^{\circ}$) were transmitted, and each post-compounding set of 50 and 250 frames (both 250 Hz PRFs) were obtained for the phantom and *in vivo* study.

## Results/Discussion

Fig. 1(a) and 1(b) represent the results of power Doppler imaging for the phantom and *in vivo* studies, respectively. In the phantom study, the DMSC-PD method has a relatively higher flow intensity across the axial dimension at the similar background noise level compared to the CCC-PD method, as shown in the Fig. 1(a.1). For the flow signal-to-clutter ratio (SCR) measurement with varying the number of angles ($N$=3, 5, 7, 10 and 15), the DMSC-PD method showed higher SCR values for all angle cases than the CCC-PD method, i.e., 22.02 vs. 16.64 dB at $N$=10, as illustrated in the Fig. 1(a.2). In the *in vivo* study, the DMSC-PD method provided the increased conspicuity of microvasculature for the kidney vessels while the incoherent electronic noise and off-axis interference are effectively suppressed, as shown in the Fig. 1(b). These results demonstrate that the proposed DMSC-PD method can effectively improve the contrast resolution of ultrafast microvascular imaging.

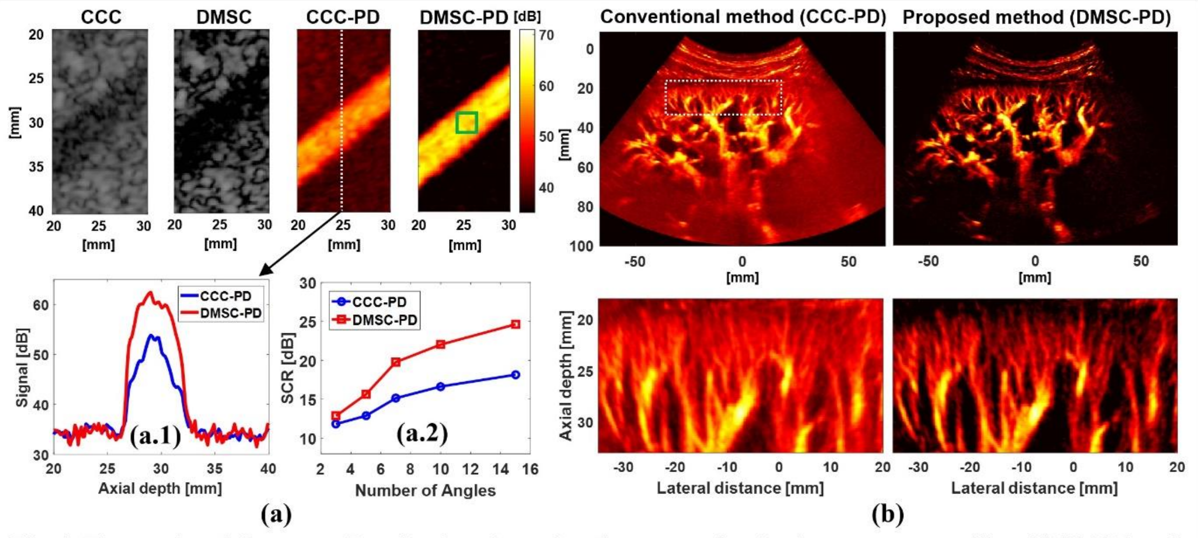


**Fig. 1. The results of the power Doppler imaging using the conventional coherent compounding (CCC-PD) and delay-multiply-and-sum compounding (DMSC-PD) for (a) the flow phantom (*v*=8 cm/s) and (b) the *in vivo* kidney vessels. (a.1) Center axial profiles from the CCC-PD and DMSC-PD. (a.2) The measured SCR values according to the different number of diverging wave angles (3, 5, 7, 10 and 15) using the CCC-PD and DMSC-PD method.**