Performance Descriptor for Contrast-free Ultrasensitive Power Doppler Imaging Using Spatio-temporal Correlation Matrix

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Despite effective clutter filtering, even small amount of motion can lead to incoherent integration of the power Doppler (PD) ensemble, especially in small vessel imaging, resulting in poor visualization of blood flow. A motion corrupted PD ensemble can either result in over- or under-estimation of blood vessels [1], without any indication or forewarning. We hypothesize that the proposed spatiotemporal correlation matrix as a reliable indicator of coherency of the PD ensemble to (1) determine if the acquired Doppler ensemble (DE) is corrupted by motion, (2) identify frames that needs motion correction (MC) or rejection, and (3) determine the efficacy of MC of *in vivo* patient data, where ground truth is unavailable.

To test this hypothesis, we conducted *in vivo* PD imaging on 10 human thyroid nodules. Thyroid is typically prone to motion due to its proximity to the pulsating carotid artery. Thyroid displacements were estimated using normalized 2D cross-correlation and were motion corrected [1]. The pixels associated with the thyroid nodule in the DE were rearranged in the Casorati form and their correlation matrices were estimated [2].

The results demonstrated that the visualization of the blood vessel substantially improved upon MC **(Fig. 1 a-d)**. Correspondingly, the mean correlation of the DE **(e,f)** increased by 33 % upon MC, which is important for coherent PD integration [2]. Further, it can be observed that frames 1580 - 1848 displayed relatively lower correlation even after MC, which indicated out-of-plane motion that cannot be motion corrected, and thus should be rejected prior to PD integration. Further, a mean-correlation-image estimated using overlapping 3x3 kernels was useful in assessing the quality of the PD image, and in identifying regions that lacked visualization of the blood flow signal due to incoherency of the DE.

The proposed metric is easy to compute, and can be useful in obtaining robust feedback on the quality of the acquired data. These preliminary results were encouraging for further *in vivo* validation.

[1] Nayak R. *et. al.* Non-contrast agent based small vessel imaging of human thyroid using motion corrected power Doppler imaging. *Scientific reports*, *8*(1), 2018.
[2] Nayak, R *et. al.* Non-invasive Small Vessel Imaging of Human Thyroid Using Motion-Corrected Spatiotemporal Clutter Filtering. *UMB*, 2019.

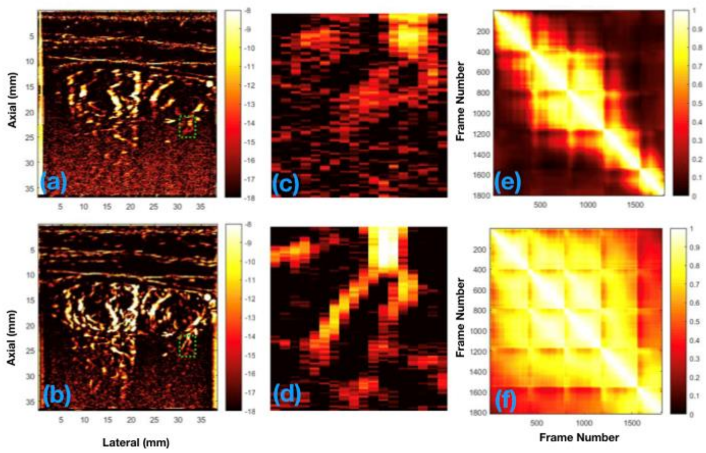

Figure 1: (a, b) displays PD images before and after MC. (c, d) displays zoomed insets corresponding to the green ROIs in (a,b) respectively. (e, f) displays the spatio-temporal correlation matrix for (a,b), respectively. The correlation matrix is displayed in scale of 0-1, which indicated low and high coherency, respectively.