Dual-Frequency Alias-Free Color Doppler using Chirping and Pulse Compression

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Background, Motivation, Hypothesis and Objectives

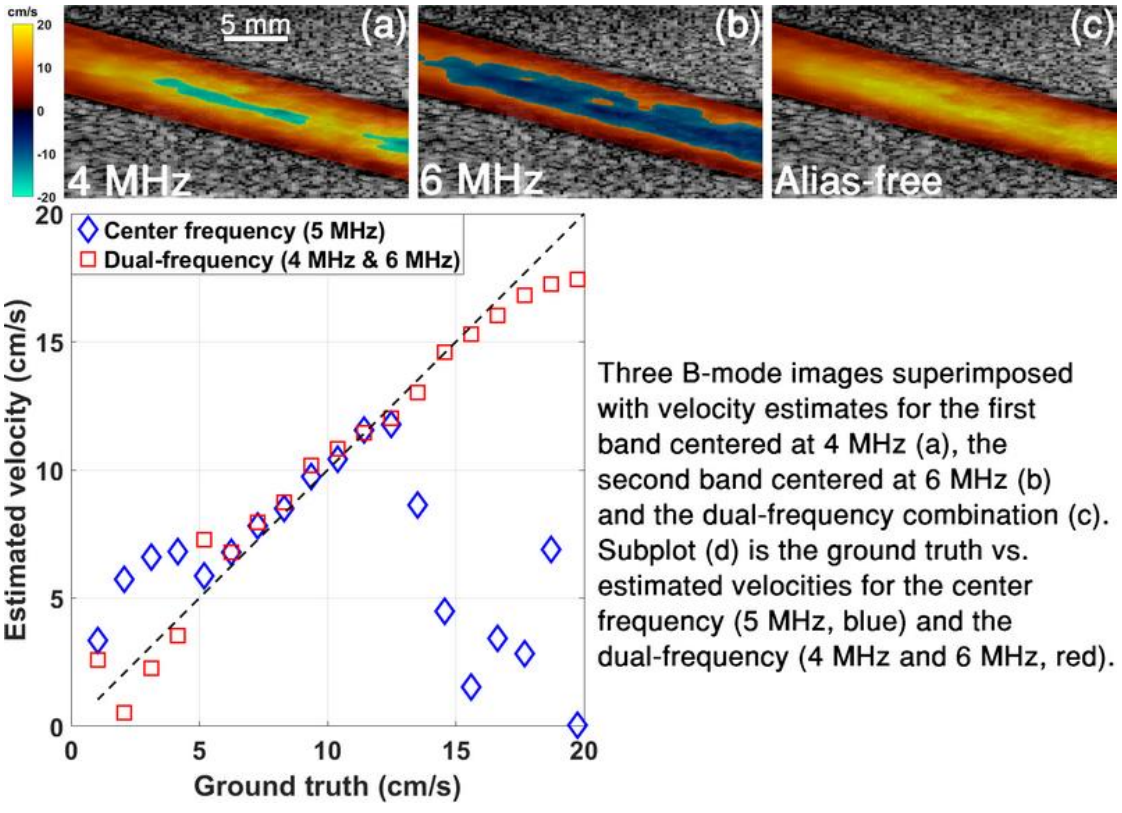
Color Doppler is one of the most popular non-invasive technique for blood flow analysis and visualization. Plane-wave ultrasound can be used to yield high frame rates and broaden the clinical perspectives of color flow imaging. As with conventional ultrasound, however, aliasing may occur if the flow information is time-sampled insufficiently. The Nyquist velocity limit depends upon PRF (pulse repetition frequency) and center frequency. One approach for extending this Nyquist limit is to transmit signals using a dual-PRF scheme (Posada *et al.*, *IEEE TMI*, 2016) and combine the two aliased estimates to recover alias-free velocities. Instead of transmitting at dual PRFs, it is similarly possible to use a dual-frequency approach to increase Nyquist velocity. Our objective was to increase the Nyquist limit while increasing range resolution. To this end, we used chirp signals and matched filtering to obtain a spread spectrum for dual-frequency dealiasing.

Methods and Materials

A 20° slanting vessel (Gammex Doppler 403) was scanned with a Verasonics Vantage system and a linear array probe. Poiseuille flows with velocities ranging between 2-20 cm/s were analyzed. Linear up-chirps were transmitted with plane wavefronts in the 3-7 MHz band. The received signals were matched-filtered through pulse compression to recover a wide frequency band. The delayed-and-summed signals were then bandpass filtered at 4 and 6 MHz, respectively, to provide two signals at different center frequencies. Two series of Doppler velocities were finally obtained by using a slow-time autocorrelator. These Doppler fields were combined to extend the Nyquist velocity and return alias-free color Doppler images.

Results, Discussion and Conclusion

Our results show (Fig. 1a-b) that aliasing was present in the two Doppler estimates (20 cm/s), at 4 and 6 MHz. After dual-frequency combination, an alias-free velocity map was extracted (Fig. 1c). Fig. 1d also shows that there was a good concordance between the dealiased estimated velocities and the ground-truth velocities, up to 20 cm/s. These findings demonstrate that the dual-frequency method with pulse compression allows extending the Nyquist velocity limit with a good range resolution. Further improvements are expected with the use of CMUT probes and wider frequency bands.



Three B-mode images superimposed with velocity estimates for the first band centered at 4 MHz (a), the second band centered at 6 MHz (b) and the dual-frequency combination (c). Subplot (d) is the ground truth vs. estimated velocities for the center frequency (5 MHz, blue) and the dual-frequency (4 MHz and 6 MHz, red).