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Deep-Learned Beam Imputation for Cardiac Color Doppler

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Introduction/Background

Color Doppler is an important component of clinical echocardiography, used in the diagnosis of valvular disease and septal defects. However, enabling color Doppler reduces frame rate because it requires serially sending ultrasound pulses for multiple scan lines, each of which adds to the time per frame. The reduction in frame rate can be ameliorated by reducing number of beams, but this in turn reduces the angular resolution of the color Doppler. To address this issue, we present a deep learned model for reconstructing missing Doppler beams to allow for low beam count, high frame rate color Doppler without sacrificing angular resolution.

Methods/Intervention

Using a random subselection of 98 echocardiography studies from the EchoXFlow dataset, we removed beam information from color Doppler in a checkerboard pattern: even-numbered beams were dropped from even-numbered frames and odd-numbered beams from odd-numbered frames, such that each beam was present in 50% of frames. We evaluated three methods for infilling the missing beams: linear interpolation, a 2D U-Net, and our novel model. Our novel model consists of three parts: First, a 1D CNN extracts latent features from each beam individually. Second, the concatenated latents are forwarded to a 2D CNN which computes latents for the missing beams. Finally, a 1D decoder CNN reconstructs missing beams from the latents. The data was split into nonoverlapping subsets of 75 studies for training and 23 for testing. Each model's output was compared to the ground truth using L1 distance. Statistical significance was assessed with the Wilcoxon signed-rank test.

Results/Outcome

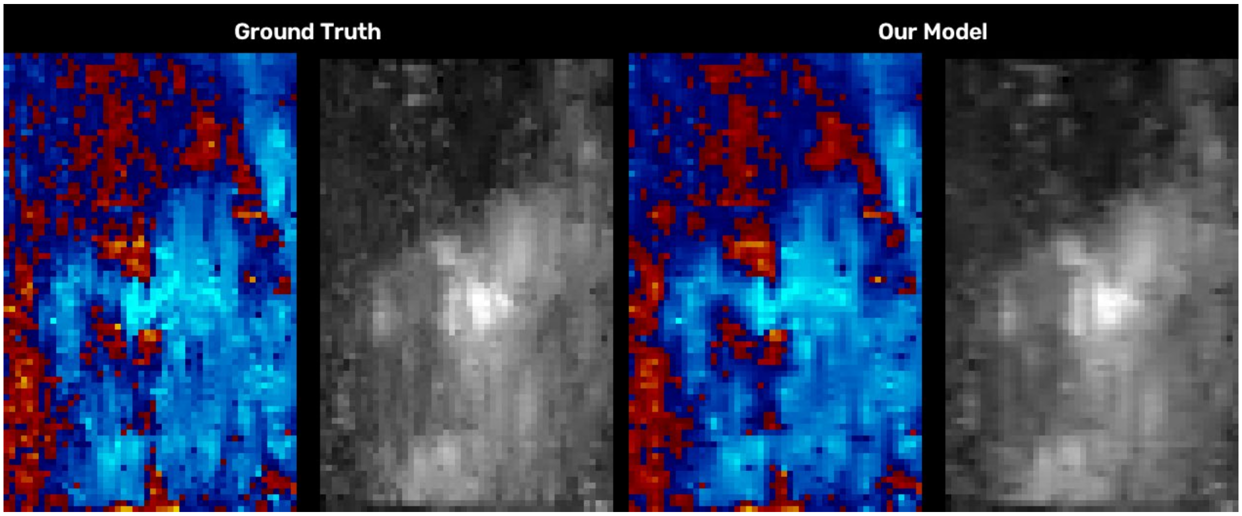
Over the 23 studies in the test set, linear interpolation reconstructed missing beams with a mean error of 0.2635. The 2D U-Net achieved a mean error of 0.2583 (1.99% improvement relative to linear interpolation, $p=0.00075$), and our novel model achieved a mean error of 0.2543 (3.49% improvement relative to linear interpolation, $p=0.015$ versus 2D U-Net).

Conclusion

Explicitly separating per-beam and inter-beam processing in a multi stage pipeline improves beamspace reconstruction relative to a standard U-Net.

Statement of Impact

Our method has the potential to increase the angular resolution of color Doppler in low beam count regimes, allowing higher frame rates without significant loss of visual quality.



Visual Comparison of Interpolated Color Doppler with Ground Truth

Keywords

echocardiography; ultrasound; Doppler; video; interpolation; super-resolution