Real-time, high frame rate, tri-plane ultrasound imaging for cardiac applications based on spiral arrays

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Background, Motivation and Objective

Tri-plane echocardiography has been introduced as a compromise between 2D and 3D imaging; it simultaneously acquires apical 2-, 3-, and 4-chamber views, thus visualizing all the segments of the left ventricle in a single recording. However, scanning the region of interest line-by-line results in unacceptably low frame rates. The aim of this work was to implement a real-time high frame rate (HFR) tri-plane echocardiographic system based on spiral arrays with low-element count, coupled to the ULA-OP 256 scanner.

Statement of Contribution/Methods

Two 256-element sparse arrays (PA and PB), both based on 10.4-mm-wide spirals, were designed by selecting 256 elements out of those available on the 3.7 MHz, 32×32-element probe by Vermon (France). PA and PB were connected to 2 synchronized ULA-OP 256 systems so that 5 different transmission/reception (TX/RX) configurations could be tested:

A) PA used in TX and RX;
B) PB used in TX and RX;
C) PA used in TX and PB in RX;
D) PB used in TX and PA in RX;
E) PA and PB simultaneously used in TX and RX.

Tri-plane images were reconstructed at rotational angles of 0, 45 and 90°; 4 scan modes were implemented: 2 focused, single-line transmission (SLT) and multi-line transmission (MLT); and 2 defocused, single-plane transmission (SPT), and multi-plane transmission (MPT).
Experiments were conducted on a univentricular phantom and on the CIRS 055A. Images were displayed in real-time (Fig. 1), while beamformed data were acquired for image quality assessment in terms of lateral resolution, contrast ratio (CR) and signal-to-noise ratio (SNR).

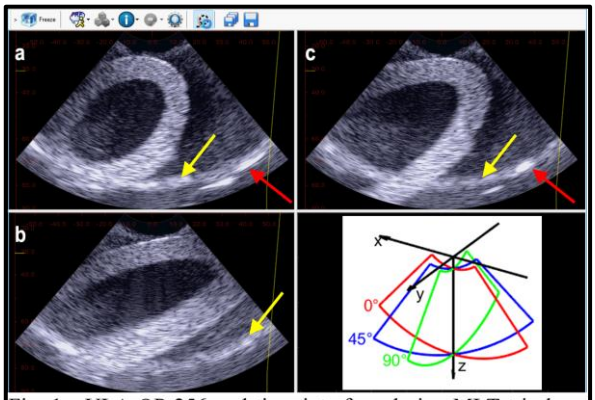

Fig. 1 - ULA-OP 256 real-time interface during MLT tri-plane imaging; here, the TX/RX configuration was A. The different panels show the B-mode images reconstructed at different rotation angles: 0° (a), 45° (b), and 90° (c). Yellow arrows indicate the artifacts due to the echoes pointed by red arrows.

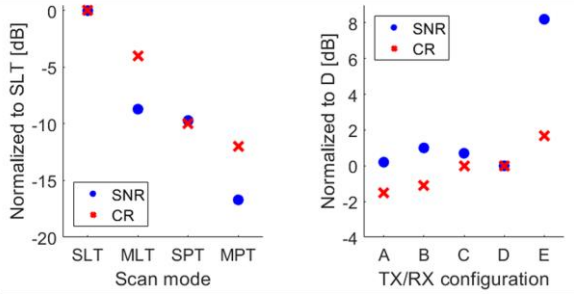

Fig. 2 – Average SNR (blue) and CR (red) for different scan modes (left) and different TX/RX configurations (right).

Results/Discussion

As shown in Fig. 2, the best CR was obtained for SLT; CR was 4, 10, and 12dB lower for MLT, SPT and MPT. The TX/RX configuration also impacted on CR: C and D perform better than A and B (+1.3dB), but worse than E (−1.7dB). The best SNR was obtained for SLT; SNR was 9, 10, and 17dB lower for MLT, SPT and MPT. Configuration E achieved the highest SNR +8dB than the other configurations. Lateral resolution was similar in SLT and MLT, while it was 50% worse in SPT and MPT.
HFR tri-plane imaging is feasible in real-time with sparse arrays and low-element count scanners: the TX/RX configuration E, using 512 elements, offers the best performance. MLT offers a similar frame rate with existing 2D echocardiography methods, while SPT and MPT boosts the frame rate up to 250 Hz and may enable real-time functional analysis of the human heart.