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A Reconfigurable Architecture of a Scalable, Ultrafast, Ultrasound, Delay-and-Sum Beamformer

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I. Introduction

In recent decades, increasing ultrasound frame rates has been the main motivation behind many novel ultrasound imaging applications [1–3]. With this work, we propose an efficient ultrafast FPGA beamformer that applies coherent compounding, through a delay-reuse optimization.

II. Architecture Design & Implementation

An abstract view of the DAS equation is the following:

$$s_{bf}(X_s) = \sum_{\theta \in \text{angle\_set}} \sum_{i \in \text{element\_set}} s_i(\tau(X_s, X_i, \theta)) \quad (1)$$

where X_s is a pixel, X_i is a channel. By replacing the variable $\Delta x_{i,s} = x_i - x_s$ in equation (1), a delay-value reuse algorithmic transformation is enabled [4], reducing the memory complexity from O(N^3) to O(N^2). To beamform each image row, the ultrasound values are summed diagonally; see Figure 1. The illustrated array is divided into segments, that are processed in a **pipeline**. We applied two interpolation methods, a mean interpolation and the standard linear interpolation.

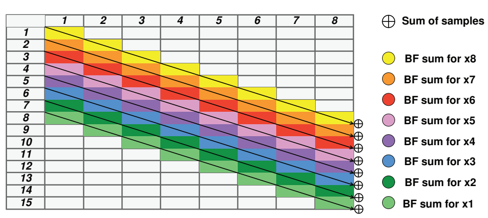

Fig. 1: Sample-summing process of the DAS algorithm.

III. Evaluation

We implemented two beamforming kernels (mean / linear interpolation) on an Alveo U200 Data-Center Accelerator Card. As input for our kernels, a dataset from the IEEE Imaging Challenge (PICMUS) was utilized [5]. Figure 2 illustrates the beamformed images, while Figure 3 describes the scalability of our design.

IV. Conclusion

The contribution of our ultrafast FPGA beamformer is the preservation of high frame rates, the high aperture size, and the design's scalability. Specifically, the two versions of the proposed architecture achieved a PRF_{max} of more than 11 KHz and 10 KHz, respectively, and a beamforming rate of around 2 GSamples/sec.

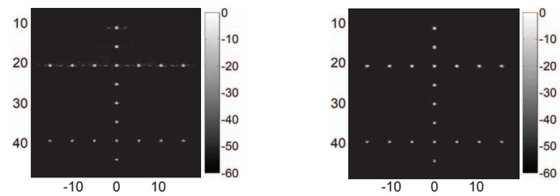

Fig. 2: Reconstructed image. mean interp (L), linear interp (R)

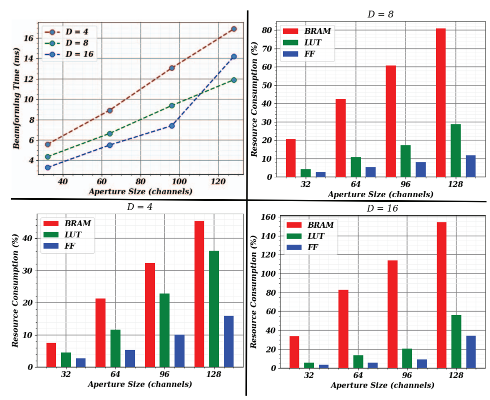

Fig. 3: Scalability graphs, while tuning the channel amount.

References

1. Hager, P. A., Speicher, D., Degel, C. & Benini, L. *Ultra-Light: An ultrafast imaging platform based on a digital 64-channel ultrasound probe* in *2017 IEEE International Ultrasonics Symposium (IUS)* (2017), 1–5.
2. Zhang, C. *et al.* The Ultrasound Signal Processing Based on High-Performance CORDIC Algorithm and Radial Artery Imaging Implementation. *Applied Sciences* **13.** ISSN: 2076-3417. https://www.mdpi.com/2076-3417/13/9/5664 (2023).
3. Kidav, J. U. & G, S. S. An FPGA-Accelerated Parallel Digital Beamforming Core for Medical Ultrasound Sector Imaging. *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control* **69,** 553–564 (2022).
4. West, B. L., Zhou, J., Chakrabarti, C. & Wenisch, T. F. *Delay Compression: Reducing Delay Calculation Requirements for 3D Plane-Wave Ultrasound* in *2019 IEEE International Ultrasonics Symposium (IUS)* (2019).
5. Liebgott, H., Rodríguez-Molares, A., Cervenansky, F., Jensen, J. & Bernard, O. *Plane-Wave Imaging Challenge in Medical Ultrasound* in (Sept. 2016), 1–4.