TOWARDS ULTRASOUND LOCALIZATION MICROSCOPY CLINICAL APPLICATION

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Background

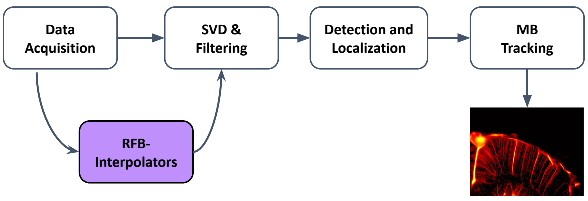
- **Ultrasound Localization Microscopy (ULM):**

  A technique to generate density and dynamic maps of the vasculature at a microscopic resolution.
- Many diseases correlate with changes in the properties of the vascular system (e.g. cancer, Parkinson and Alzheimer).
- **The main challenges in ULM clinical application:**
  1. **High frame rate requirement** to coherently match microbubbles in the tracking step (1kHz), not reachable by commonly used clinical scanners (sub-100Hz).
  2. **Long acquisition times** to accumulate enough MBs signals to generate the super-resolved image
  3. **Lack of ground truth** for *in vivo* ULM's reconstructed images.
- **Main Objective:**

  Relaxing the ULM requirements toward the clinical applicability of Ultrasound Localization Microscopy.

Methodology

1. **Relaxing ULM high frame rate requirement:**
   - Introducing upstream of the ULM framework an RFB-interpolation technique [3], which recovers the information lost when acquiring data at low frame rates.
   - Two *In vivo* datasets [2], Dataset A: **Rat Brain** (1KHz) and Dataset B: **Mammary Tumor** (500Hz).
   - Apply a downsampling up to 10.
   - Generate the reconstructed maps using the dow-sampled data, **with** and **without** the **interpolation**.
   - Compare the results considering the original high frame rate super-resolved images as ground truth.
   - Metrics: Dice Score and Root Mean Squared Error, and, Fourier Ring Correlation

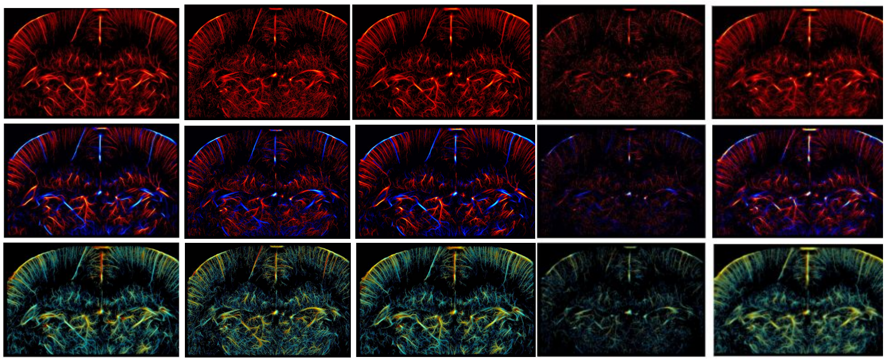


Block diagram of the proposed technique.

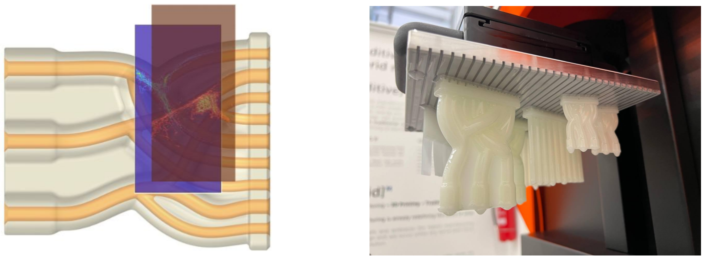
2. **Relaxing ULM long acquisition times:**
   - Through **separation** of two distinct **monodisperse MBs** (2.5 and 4.1 um), each characterized by a specific resonance behavior.
   - We acquired and analyzed ultrasound data first in water, and then, in a flow phantom, where we singularly inject the two monodisperse MB populations.
   - **MB localization and tracking for each sub-population** allows ULM imaging of the different monodisperse MB injections

3. **3D printed vascular phantom of an organ**:
   - 3D printed vascular structures offer the possibility of quantitative technical evaluations on imaging devices.
   - To create the 3D model, we use a publicly available 3D *in vivo* Rat's Brain dataset [4].
   - The vessels are isolated through manual thresholding and segmentation.
   - Print using TPU as material, and, the Selective Laser Sintering as printing technology

Results



Results of the proposed technique in comparison to ULM when applying to Dataset A.



Reconstructed density maps of the two monodisperse MBs populations using a 3D printed model.

3D printed vascular model of a Rat's Brain.

Conclusion

- Reconstructed density maps (even below 100Hz) using the interpolation technique show **high similarity with the high frame rate** reconstructed images (Dice score of 80% for dataset A and 68% for dataset B [1]).
- Results demonstrate the feasibility of monodisperse MBs uncoupling, enabling the use of higher microbubble concentrations for ULM, and thus reducing acquisition time.
- We can use 3D printing to obtain a highly controllable vascular structure.

References

[1] G. Tuccio, S Afrakhteh, G.Iacca, and L. Demi. "Time Efficient Ultrasound Localization Microscopy Based on A Novel Radial Basis Function 2D Interpolation." IEEE Transactions on Medical Imaging (2023).

[2] B. Heiles, A. Chavignon, V. Hingot, P. Lopez, E. Teston, and O. Couture,"Performance benchmarking of microbubble-localization algorithms for ultrasound localization microscopy,"Nature Biomedical Engineering vol. 6, 05 2022.

[3] H. Jalilian, S. Afrakhteh, G. Iacca, and L. Demi. "Increasing frame rate of echocardiography based on a novel 2D spatio-temporal meshless interpolation." Ultrasonics 131 (2023): 106953.

[4] Chavignon, Arthur & Heiles, Baptiste & Hingot, Vincent & Orset, Cyrille & Vivien, Denis & Couture, Olivier. (2023). Deep and Complex Vascular Anatomy in the Rat Brain Described With Ultrasound Localization Microscopy in 3D. IEEE Open Journal of Ultrasonics Ferroelectrics and Frequency Control. PP. 1-1. 10.1109/OJUFFC.2023.3342751.

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