MIST: Multi-stage Transcranial Artifact Suppression Network for Brain Ultrasound Localization Microscopy

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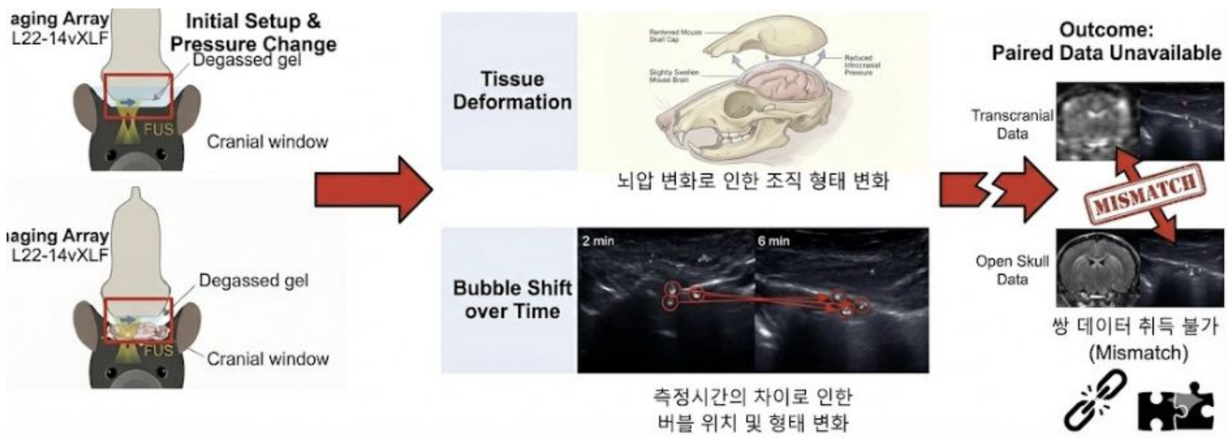
<Our Goal>

- 왜곡이 심한 데이터의 실제 참값을 알 수 없는 임상 데이터의 한계를 **Pseudo Pair 합성 데이터를 활용하여 지도학습을 가능**하게 구성
- Pseudo Pair 합성 데이터만을 학습해도 **PSNR이 7~8dB 향상**되고, 희미한 혈관들이 선명하게 강화

Background & Limitation

- Ultrasound signals become blurred and distorted as they pass through the skull, making it difficult to clearly visualize cerebral vasculature.
- **Open-skull and transcranial image pair cannot be acquired under identical conditions**, resulting in the absence of ground-truth data for AI training—a major bottleneck in transcranial ultrasound research.



Objectives

- To overcome the absence of ground-truth open-skull and transcranial observation pairs in clinical data, we generate structure-preserving pseudo pairs and train a model to restore transcranial images to open-skull quality.

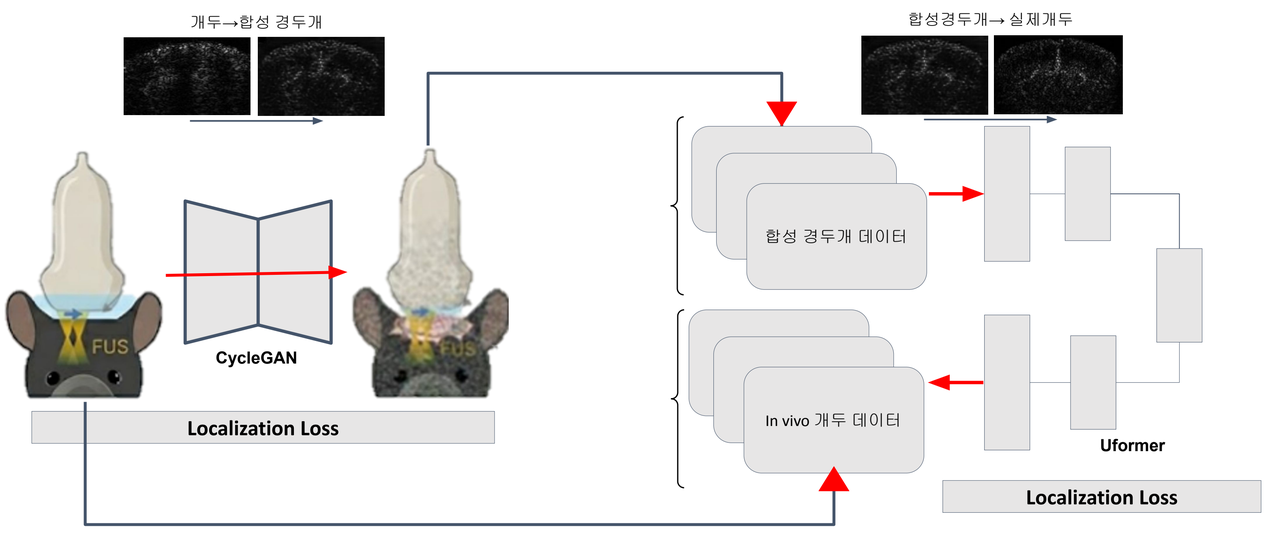
Methods and Materials

Stage 1: CycleGAN + Localization Loss

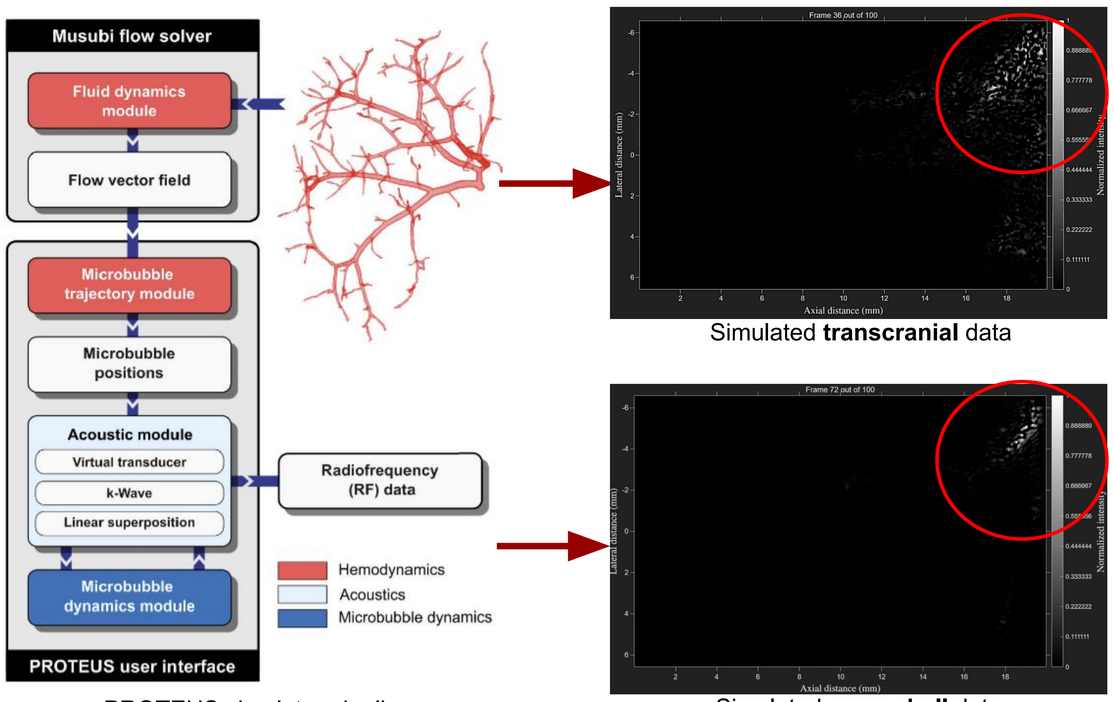
- Convert open-skull images into transcranial-style images to build paired data (open-skull → synthetic transcranial)
- Localization Loss preserves microbubble spatial information

Stage 2: Uformer Restoration

- Train a supervised model to restore synthetic transcranial images back to open-skull quality using pseudo pairs
- Performs denoising, resolution enhancement, and PSF restoration



Generation of simulation data for testing model performance



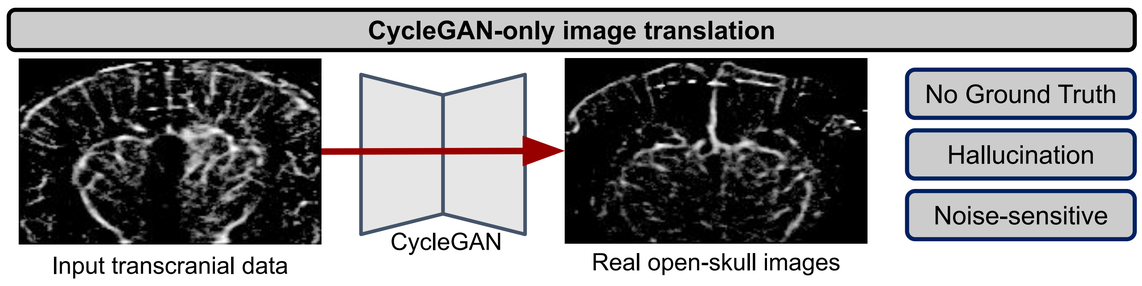
PROTEUS simulator pipeline

Simulated **transcranial** data

Simulated **open-skull** data

Motivation

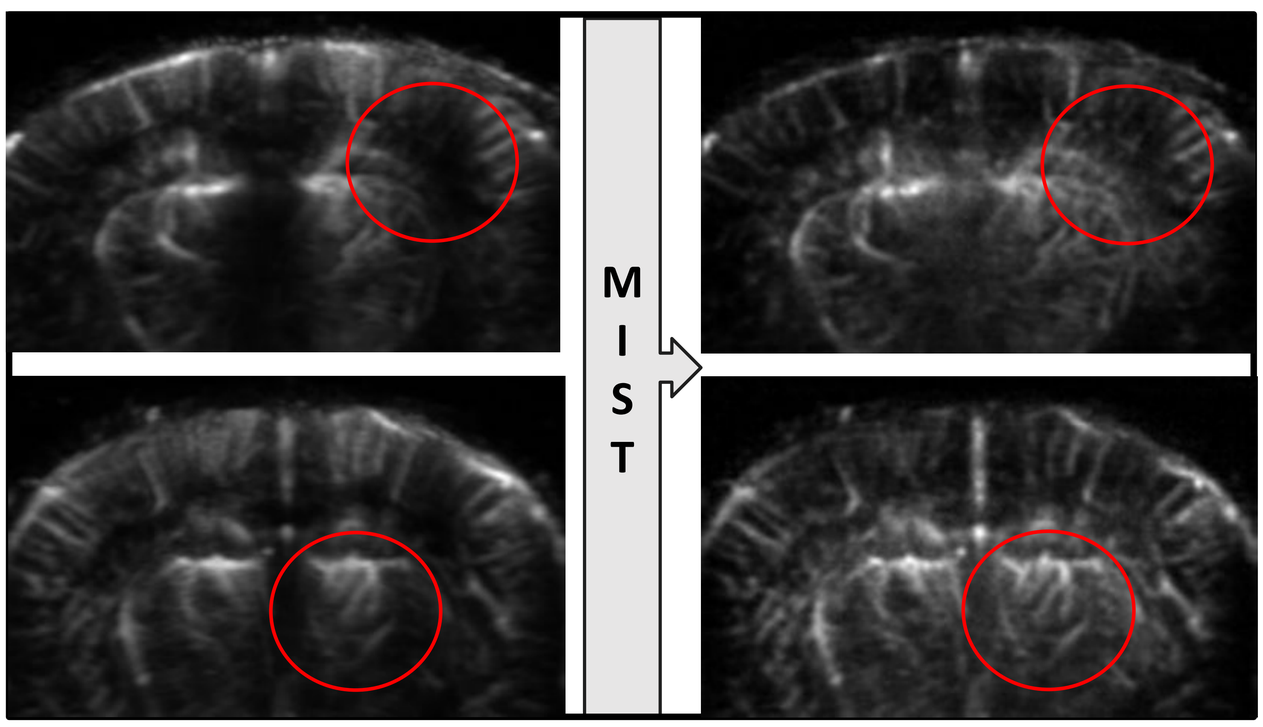
- CycleGAN alone can distort structures and cause hallucinated artifacts
- Pseudo-data should preserve microbubble dynamics and apply only transcranial degradation pattern



Results

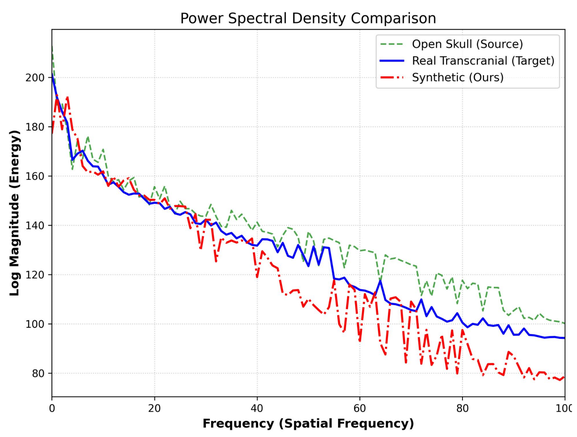
Qualitative evaluation

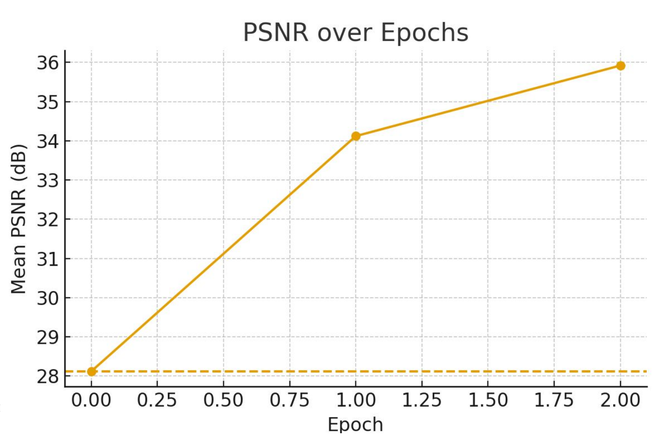
- Clearer vascular structures are observed even in real transcranial data



Quantitative evaluation

- Uformer restoration improves PSNR by 7–8 dB (up to 35.92 dB)
- The 2D FFT of the restored B-mode images shows a frequency pattern closer to real transcranial data, although it does not fully replicate skull-induced attenuation





Comparative Evaluation

- Achieves significantly higher PSNR compared to Richardson–Lucy and CycleGAN-only baselines

Richardson-Lucy	**23.89dB**
CycleGAN Only	**30.5dB**
Ours (MIST)	**35.92dB**

Conclusion and Future Work

- MIST restores severely degraded transcranial ultrasound into clear cerebrovascular images without invasive craniotomy.
- MIST delivers vascular enhancement, improved image quality and PSNR
- Future work will expand quantitative and qualitative evaluations to verify its physical fidelity.

Reference

- [1] Wang, Zhendong, et al. "Uformer: A general u-shaped transformer for image restoration." *CVPR* 2022.
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- [3] Blanken, Nathan, et al. "PROTEUS: A physically realistic contrast-enhanced ultrasound simulator—Part I: Numerical methods." IEEE Trans. Ultrason., Ferroelectr., Freq. Control 72.7 (2024): 848-865.
- [4] Errico, C.; Pierre, J.; Pezet, S.; Desailly, Y.; Lenkei, Z.; Couture, O.; Tanter, M. (2015). Ultrafast ultrasound localization microscopy for deep super-resolution vascular imaging. Nature, 527(7579), 499–502. DOI: 10.1038/nature16066