Real-time Refocusing Algorithms for Acoustic Neurostimulation

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Background and Aims

- Focused ultrasound is non-invasive and non-ionizing
- During a transcranial ultrasound session, potential movements of patient's head require real time refocusing of the ultrasound beam
- Previous research has shown using a single-element covered with acoustic lens could moderate steer and refocus the ultrasound beam up to 11mm and 10mm in the transverse direction and longitudinal direction
- Precise focusing requires time consuming simulations unsuitable for real time applications
- Evaluate real time refocusing using approximate geometric delays (beamforming)
- Make datasets for possible future use in neural network

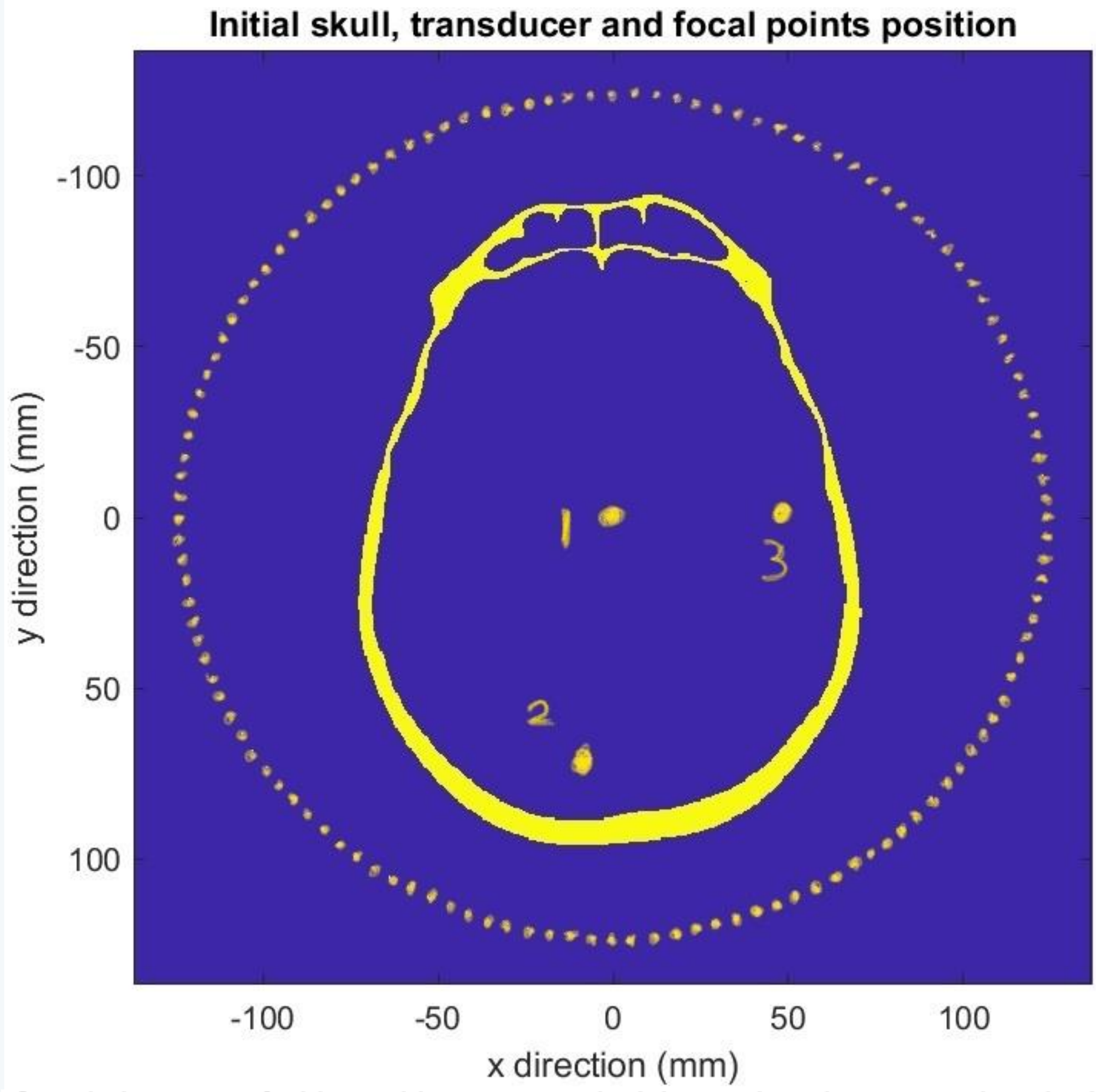
Methods

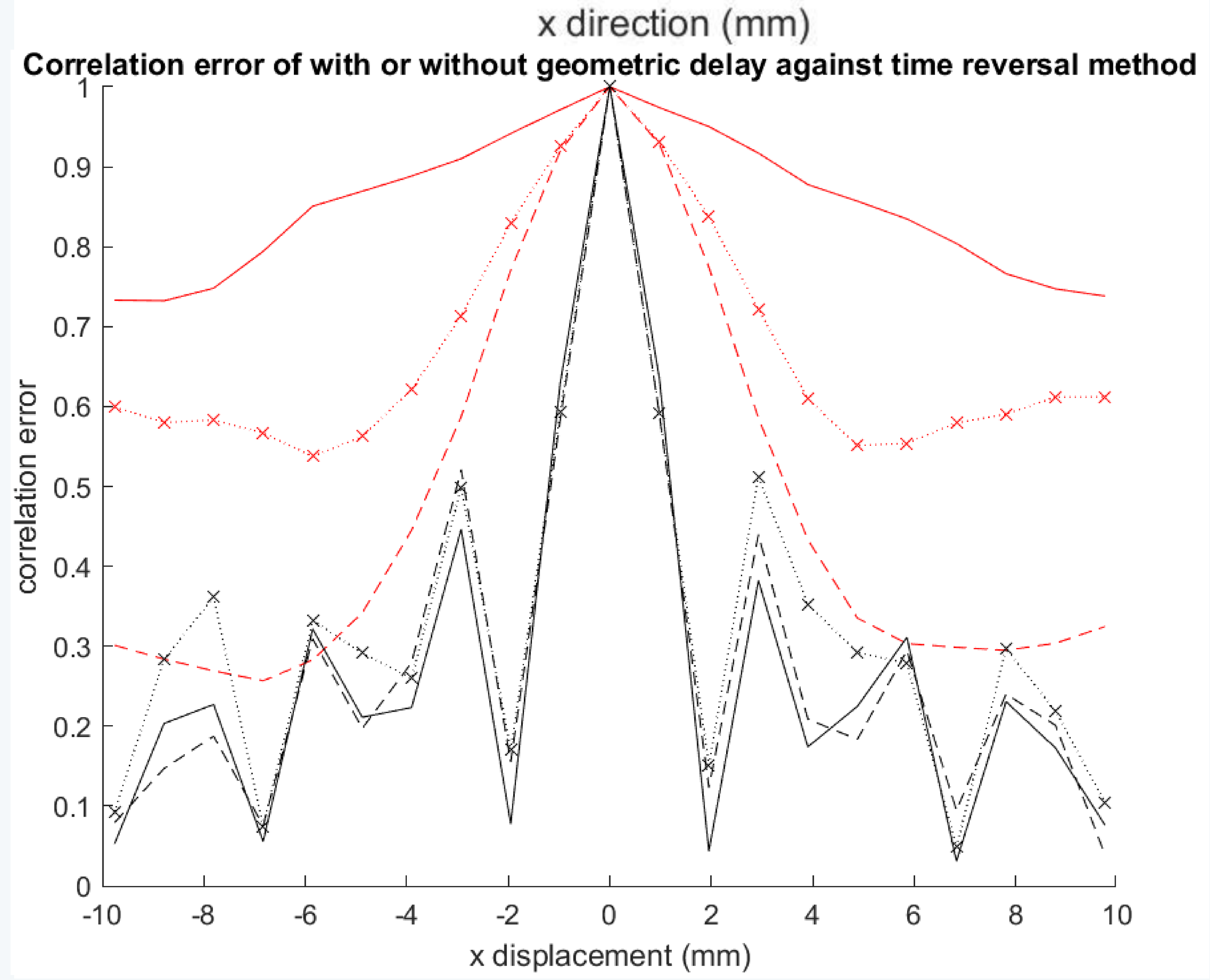
- First use time reversal method to calculate the transmit phases of three fixed targets. Then use geometric beamforming method, to calculate the extra phases of the transmitted wave due to head's movements for the three targets
- Compare the focal properties with and without geometric correction, which includes ultrasound amplitude, full width half maximum (FWHM), position error (targets' position difference between simulation results and theoretical results) at the three targets
- Assume the phases results got from time reversal method is the standard, calculate the correlation error between phases from time reversal and phases from with or without using geometric beamforming (correlation error between phase series 1 and series 2:

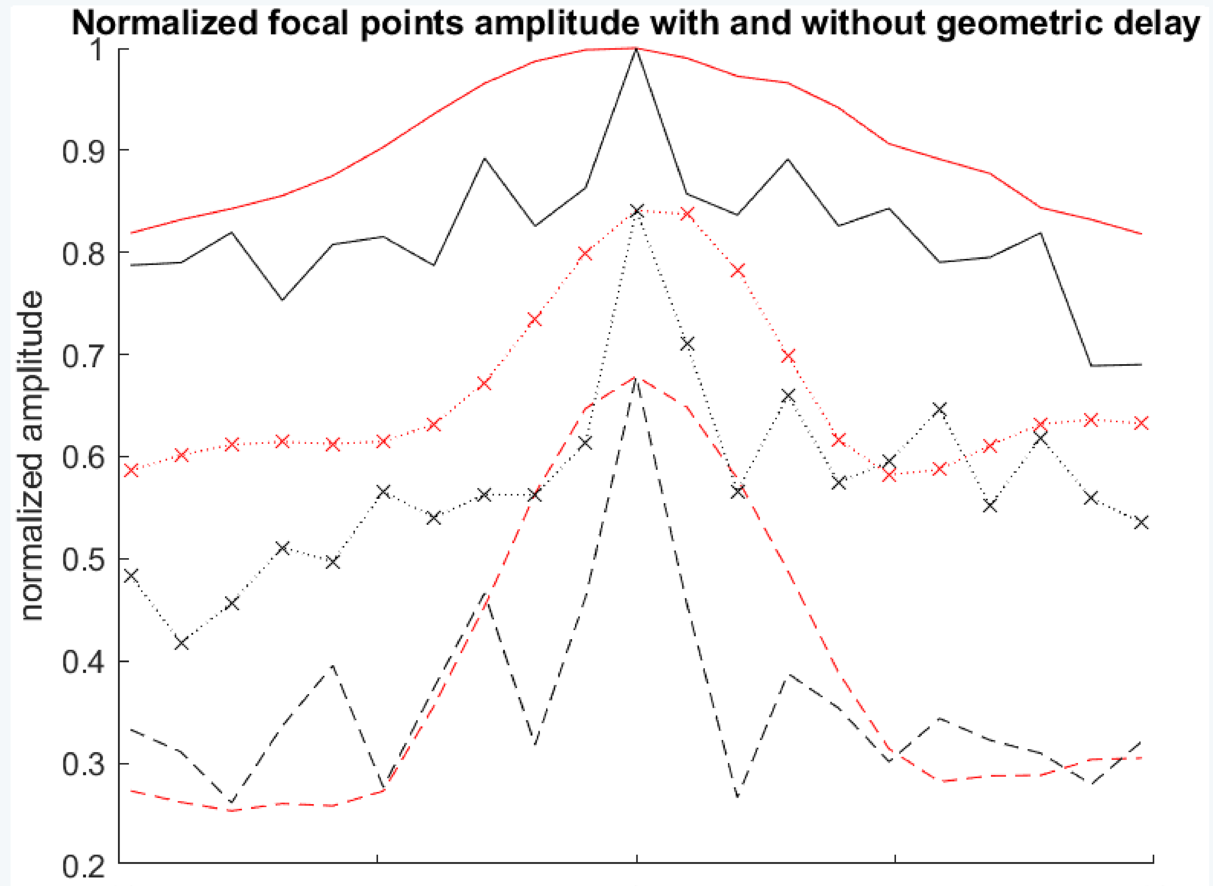
$$apod_1 = exp(i * phase_1)$$
$$apod_2 = exp(i * phase_2)$$
$$error = \frac{|\sum_{i=1}^{n} apod_1^* .* apod_2|}{||apod_1.^2||}$$

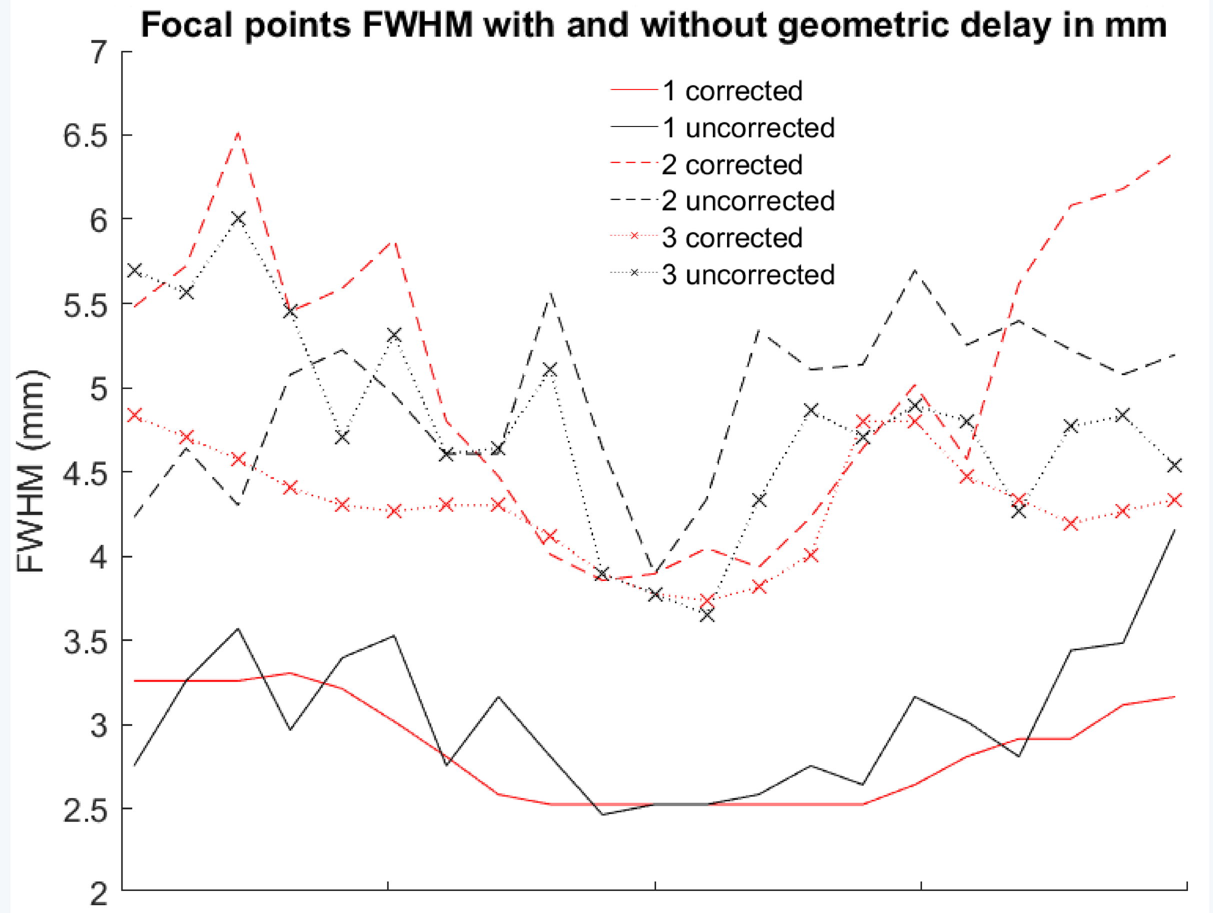
- Evaluate the influence of skulls' position to the focal point's position when keep phases of transmitted wave fixed, which will help decide whether the information of each skull is needed in the dataset
- Use time reversal method, make a dataset which includes totally 50 different skulls, 50 random targets for each skull and 10 sets of transformations (including displacements and rotations) for each target
- The neural network will take target positions, skull displacements and rotations as input and outputs corresponding phases

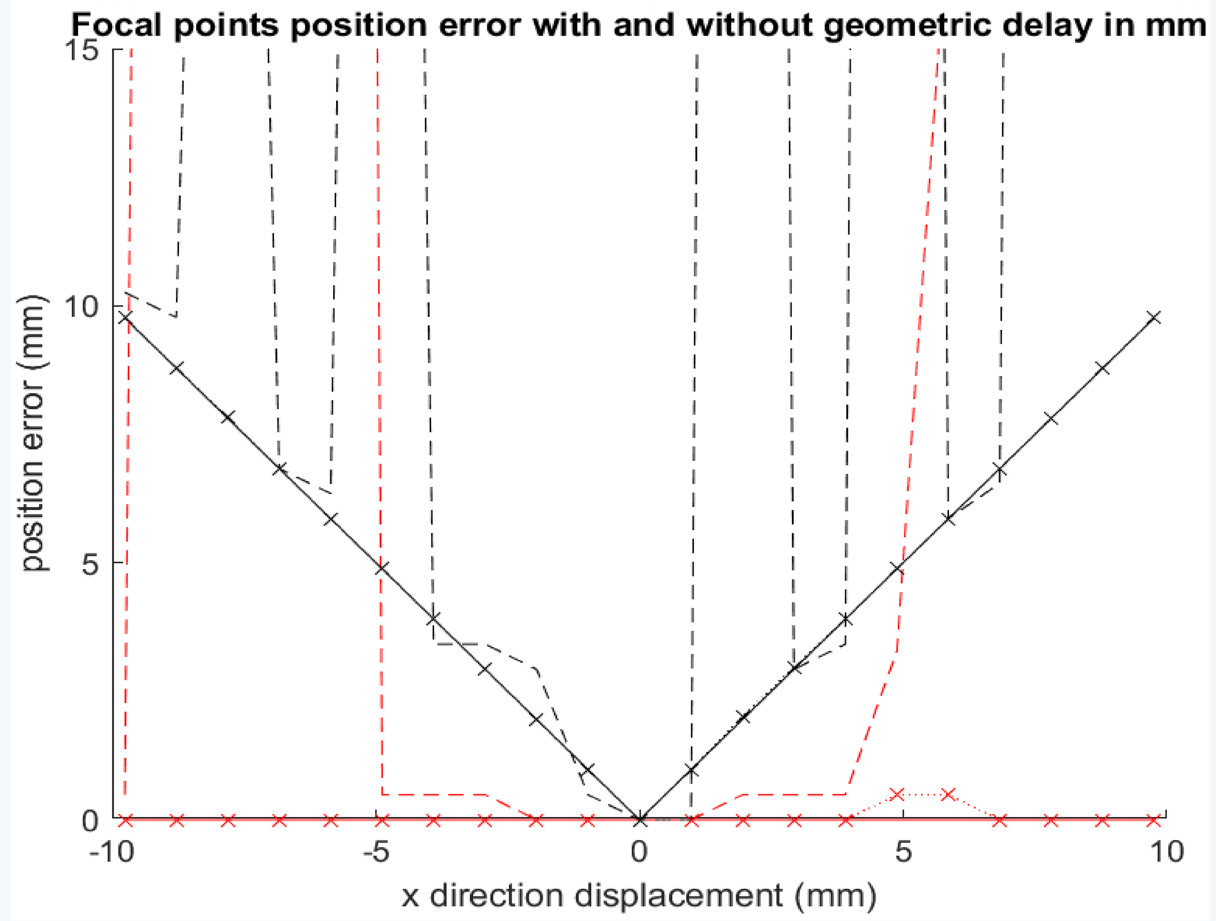
Results











Discussion

- Correlation error and quality metrics shows the result is not symmetric. Correlation error and amplitude at focal point are the higher the better. In contrast, FWHM and position error are the lower the better.
- Results of correlation error show that compared with not using geometric beamforming method, with this method the correlation error increases when the focal point is at the center and at the side. The error grows from 0.225 to 0.857 for targets at the center when the x displacement is 4.88mm. When the displacement is 7.81mm, the error increases from 0.299 to 0.590, which increases about 97.3%
- Results of quality metrics with geometric beamforming show improvement than not using this methods at least in a range of +- 10mm when target is at the center and at the side. When the displacement is 4.88mm, the amplitude can be improved from 0.815 to 0.903, and FWHM is reduced from 3.53mm to 3.02mm, position error is reduced from 4.88mm to 0 for target at centre
- Results for targets at the back shows improvement in a range of +- 4mm. In this range, the position error is about 0.5mm while the FWHM is between 4mm-5.5mm, which is much larger than the position error. So error can be neglected in this range. The wavefield will lack focusing when displacements is larger than this range.
- Results of displacements in y direction and rotation are similar with the results above but will not be included here for limited space

Conclusion

- Geometric beamforming works when focal point is at the center and at the side but focus at the back is the worst scenario.
- The back area of the head contains the visual cortex that is very important in neurostimulation. Thus, further works exploring neural networks could provide some methods for improving the results

Reference

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- Maimbourg, Guillaume et al. "**Steering Capabilities of an Acoustic Lens for Transcranial Therapy: Numerical and Experimental Studies.**" *IEEE transactions on bio-medical engineering* vol. 67,no 1, p. 27-37, 2020.

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