Transcranial ultrasound focusing with reduced cranial invasivaness

Giovanni Angelo Meles[1] [1], Joost van der Neut[2], Koen W. A. van Dongen[2] and Kees Wapenaar[1]

[1]Faculty of Civil Engineering & Geosciences, Delft University of Technology, Delft, The Netherlands
[2]Faculty of Applied Sciences, Delft University of Technology, Delft, The Netherlands

Background

Wavefield focusing, as required in Ultrasound Neuromodulation, can be achieved by Time Reversal Mirrors (TRM). Theoretically, to achieve proper mirroring wavefields emitted by a source at the focal point are first evaluated at a boundary enclosing that focal point. Next, the wavefields are reversed in time and sent back into the medium. Unfortunately in TRM the resulting wavefields are infinite in time and propagate through the entire medium.

Methods

To overcome the problems associated with TRM we propose a Finite Time Focusing (FTF) method where the wavefields are focused using Marchenko focusing functions. In FTF series of wavefronts are emitted into the medium from the surrounding boundary in such a way that only the first wavefronts reaches the focal point [Meles et al., 2019]. In contrast to TRM, Marchenko focusing functions have the advantage that they are confined in time and space by the direct propagation path from the boundary to the focal point [Wapenaar et al., 2014].

Results

Both methods have been numerically tested by focusing the wavefield in the brain from outside the skull. Results show that the proposed finite time focusing method (FTF), as compared to TRM, leads to less exposure of the brain outside the focal point. This is beneficial as it would provide focusing with reduced level of cranial invasiness. In conclusion, the proposed FTF method has the potential to outperforms standard TRM when used for wavefield focusing inside the brain.

References

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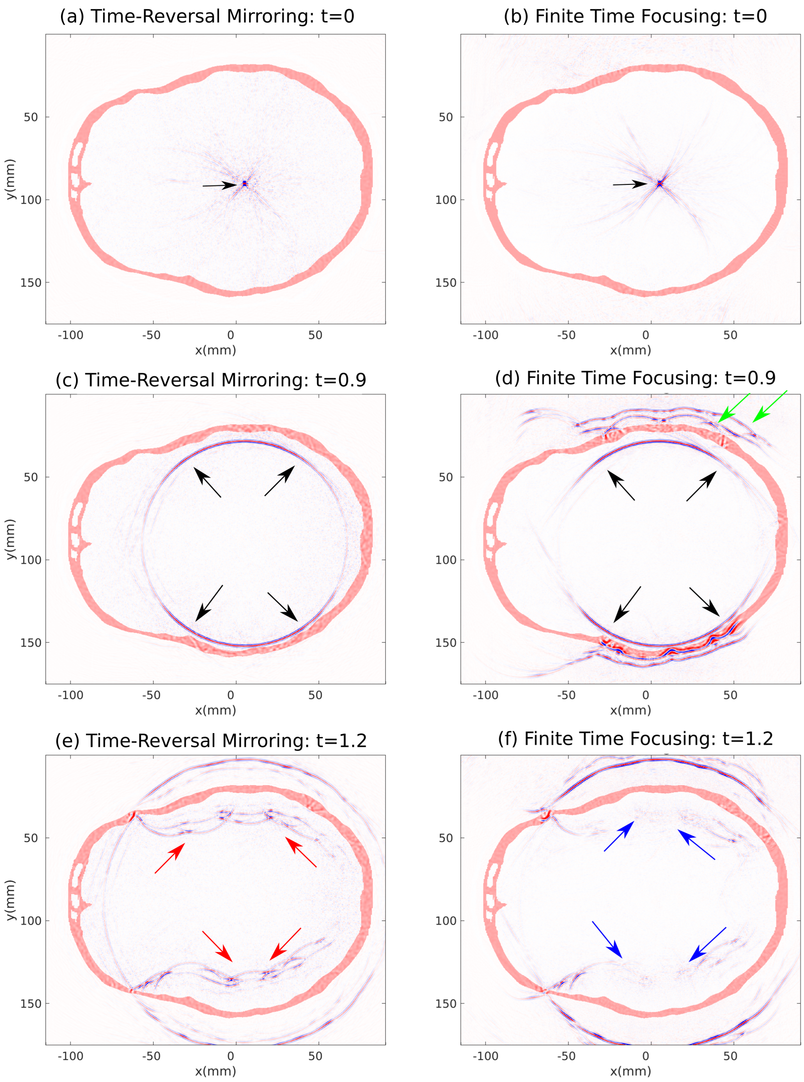

Figure 1: Focusing properties of TRM and FTF solutions. Left column: Snapshots of the TRM solution when partial boundaries are considered. Due to the finite extent of the injection boundaries, small amplitude artefacts contaminate the wavefield at time $t = 0$, but good focusing ia achieved (black arrow in (a)). At times $t > 0$ the wavefield is seen propagating inside the skull (black arrows in (c) indicate the direct wavefronts) until it gets reflected by the skull (red arrows in (e) point at strong scattering events being sent back into the skull). Right column: Snapshots of the FTF solution. A focusing comparable to what provided by TRM is achieved at time $t = 0$ (black arrow in (b)). As for the TRM case, at times $t > 0$ the wavefield is also seen propagating inside the skull (black arrows in (d) indicate the direct wavefronts). However, in the meantime the coda of the focusing function is approaching the skull (green arrows in (d)). As the wavefield emanating from the focal point reaches the skull, it destructivly interferes with the coda of the focusing function, resulting in small amplitude reflections (compare the wavefronts indicated by blue and red arrows in (f) and (e), respectively).

[1]e-mail: G.A.Meles@tu.delft.nl