Time reversal through a liquid-solid interface

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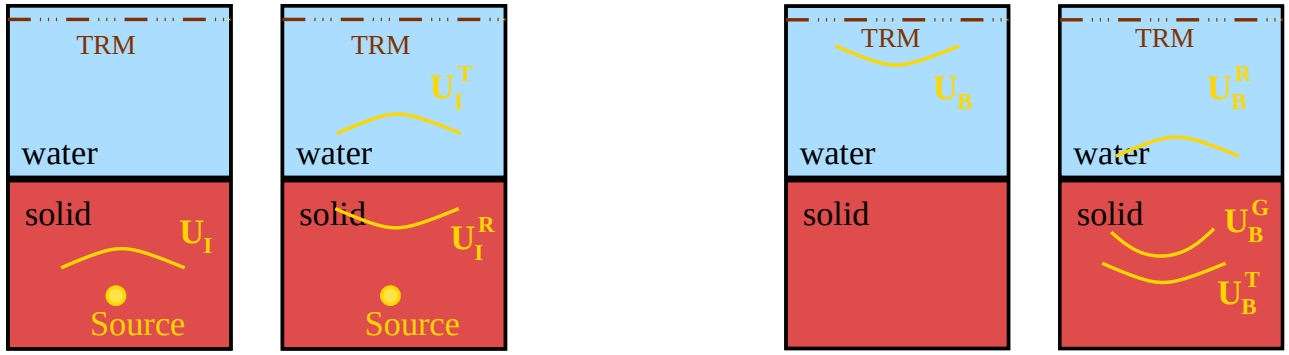
Outline

- Numerical simulation of time reversal through a liquid-solid interface. Is time-reversal focusing effective in the presence of an interface and for multimode (elastic) wave propagation?
- Spatial focusing in time reversal with strong multiple scattering. The super-resolution phenomenon can be used both for discrimination and for focusing energy very tightly on a target.
- Implications of tight spatial focusing in time reversal for imaging: Increased blurring. Robust estimation of TR super-resolution from array data. In imaging the array data are time reversed and back propagated through a homogeneous medium numerically
- Research agenda in imaging and time reversal through an interface
- Summary and conclusions

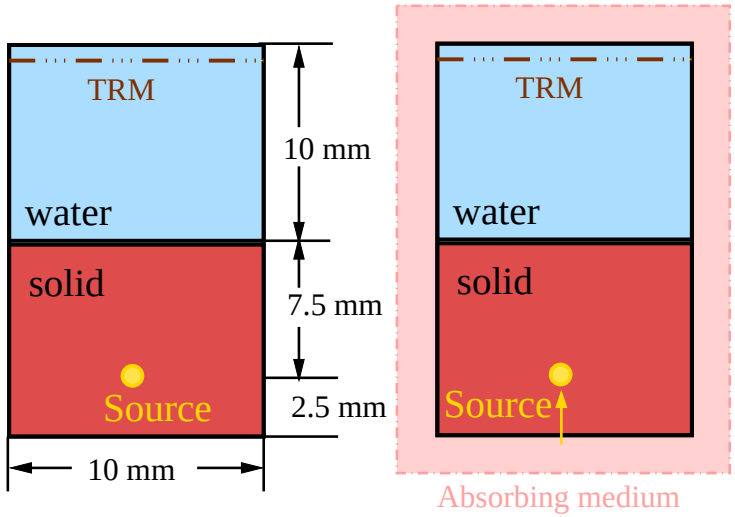
Time reversal through a solid-liquid interface



A point source emits a pulse in the solid, the waves are partially transmitted into the fluid and recorded by the Time-Reversal Mirror (TRM).

The time-reversed field is re-emitted by the TRM, back-propagates in the fluid and generates two wavefronts in the solid until it finally refocuses (approximately) onto the source.

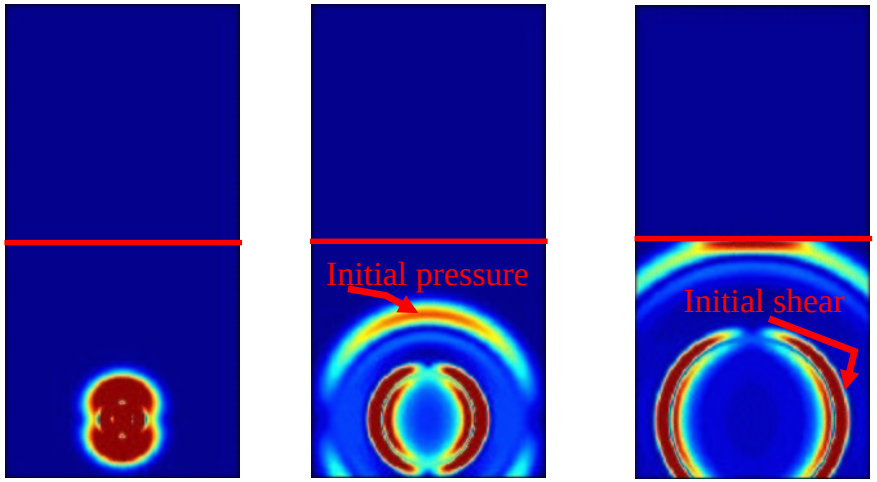
Numerical simulations



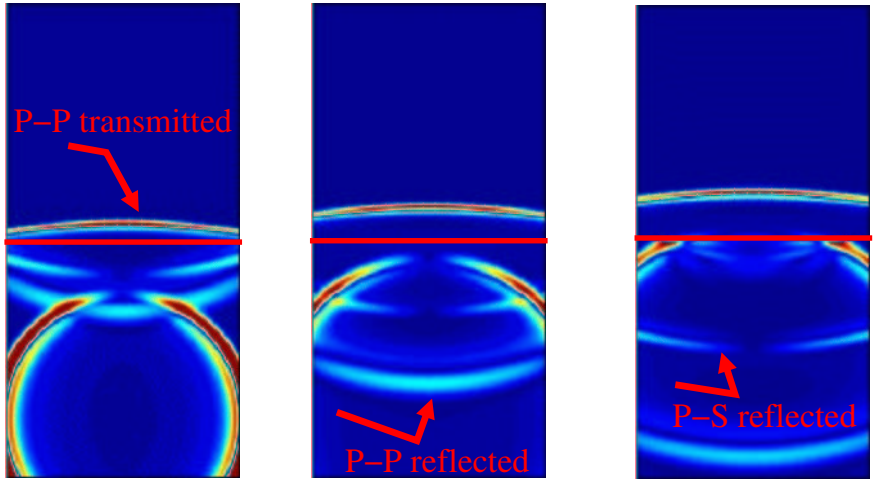
The computational setup: The dimensions of the problem are shown on the left and are from non-destructive testing experiments with ultrasuound (Fink 1998). The medium is infinite in all directions so in the numerical computations an absorbing layer surrounds the domain, shown on the right.

Numerical method: Finite element, time domain, elastic wave code, highly resolved (2D and 3D).

Forward wave propagation



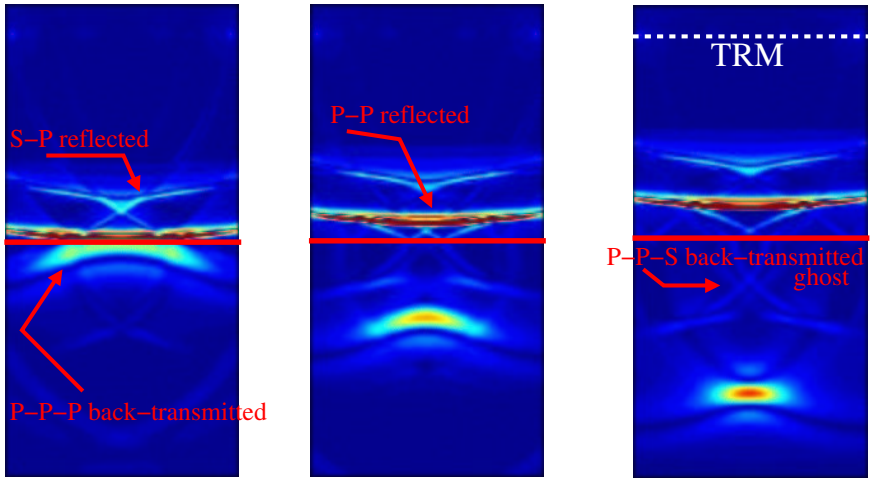
$t = 0.47\mu s$ $t = 0.94\mu s$ $t = 1.41\mu s$



$t = 1.88\mu s$ $t = 2.35\mu s$ $t = 2.82\mu s$

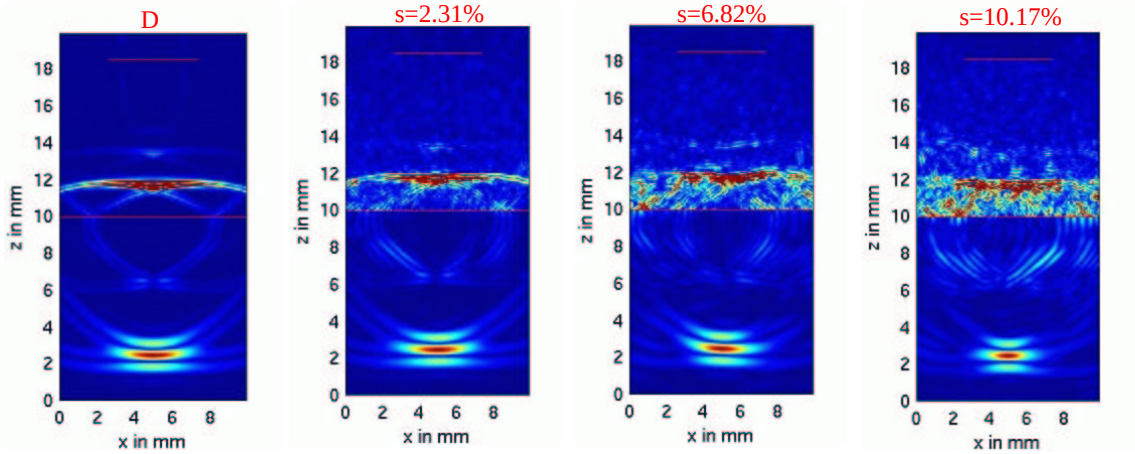
The source emits both a pressure (P) and a shear (S). The P wave arrives first at the interface. It generates a P-P wave in the fluid, and a P-P and P-S wave in the solid.

Back propagation after time reversal



The backward propagating P-P wave arrives second at the fluid-solid interface where it generates a reflected pressure wave P-P, the physical P-P-P back-transmitted wave, and the ghost P-P-S back-transmitted wave. This ghost wave has a smaller velocity and thus remains behind the source location when the two physical waves focus on it.

Time reversal in a random medium (the fluid)



The back-propagated, time-reversed field at the time of refocus for a deterministic (D) medium on the left and random media with different standard deviation of the sound speed fluctuations in the fluid (0.0%, 2.31%, 6.82% and 10.17% from left to right). The correlation length is shorter than the wavelength.

Note the tighter focusing, super-resolution, in the random media, and its statistical STABILITY. Note the complicated (very random) wave field at the interface.

Research agenda in imaging and TR through a liquid-solid interface

- Carry out energy calculations for TR through an interface, especially in random media and random interfaces

- Imaging through an interface. Establish relations between imaging and time reversal. Estimation of super-resolution in time reversal from array data has been done for scalar waves in a random medium without an interface. Will be done for EM and elastic waves through an interface

- Imaging through an interface from remote sensing arrays and assessment of the effect of inhomogeneities

- Carry out large scale 3D simulations for TR and imaging through an interface using an existing state-of-the-art 3D elastic code (developed by C. Tsogka in our group)

Summary and conclusions

- We have studied the role of interfaces and multi-mode (elastic) wave propagation on time-reversal refucusing

- We have quantified the phenomenon of super-resolution in TR through random media, especially its statistical stability in time domain (broadband)

- We have a well-developed and fully tested computational environment for elastic (as well as EM) wave propagation through interfaces that is appropriate for mine-detection research

- We have developed a detailed estimation theory for super-resolution from array data