LABORATORY FOR Computational Sensing + Robotics THE JOHNS HOPKINS UNIVERSITY

ERC | CISST

MUSiiC Research Laboratory

Ultrasound Imaging of Brain Shunts

Paper Seminar Presentation

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Project Summary

Photoacoustic excitation on the occlusion material induced by laser systems will generate acoustic waves to propagate to all the directions, which can be further collected by an external ultrasound probe, making the occlusion and the shunts visible.

- Able to distinguish different level of occlusions
- Able to identify the distance between the end of the fiber and the occlusion by the output image intensity.

Paper Selection

"Time reversal of ultrasonic fields-Part I: Basic principles".

- M. Fink, *IEEE Trans. Sonics Ultrason. 39(5), 555–566 (1992).*

"Time reversal operator decomposition with focused transmission and robustness to speckle noise: Application to microcalcification detection".

- J.-L. Robert, M. Burcher, C. Cohen-Bacrie, and M.Fink, *J. Acoust. Soc. Am., 119:3848-3859 (2006).*

Paper Selection

- Reasons for selecting the paper
  - Major challenge of the project:
    - Attenuation and reflection of the skull
    - Variation of time delays and poor spacial focusing

Paper I

- Introduce time reversal method to solve this problem

Paper II

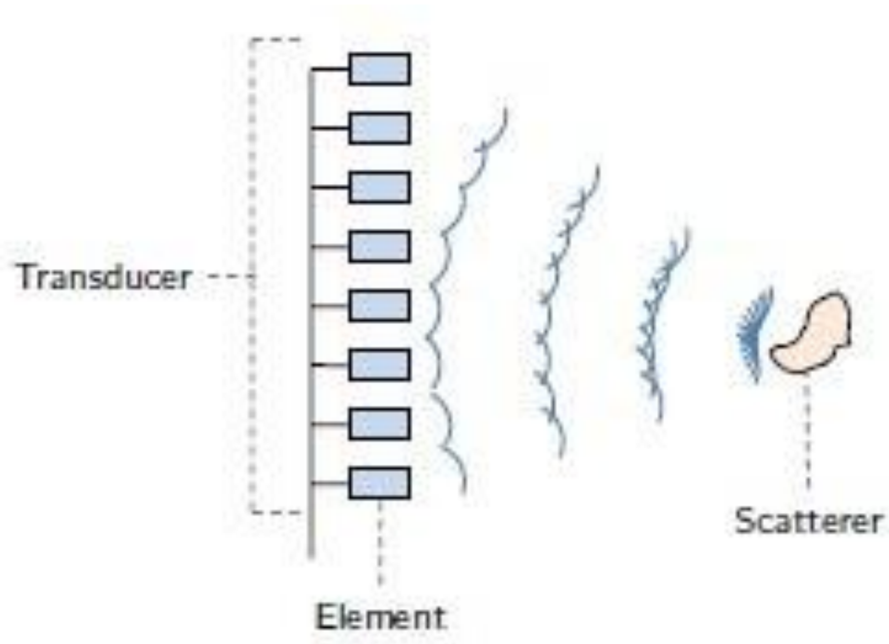
- Solve the weakness in Paper I
- Propose associated time reversal operators to achieve dynamic focusing

Key results and Significance

- Time-reversal mirror(TRM) is used to focus through an inhomogeneous medium, instead of the classical techniques
- Pressure at the selected target location is maximized, optimal solution for focusing on the scatter is provided
- Spatial-temporal matched filter is realized through an inhomogeneous propagation transfer function
- Automatic target selection is enabled by iterative time-reversal processing

Background

- Time-delay focusing
  - Transmitted wave interfere at the target location
  - Improves resolution and contrast



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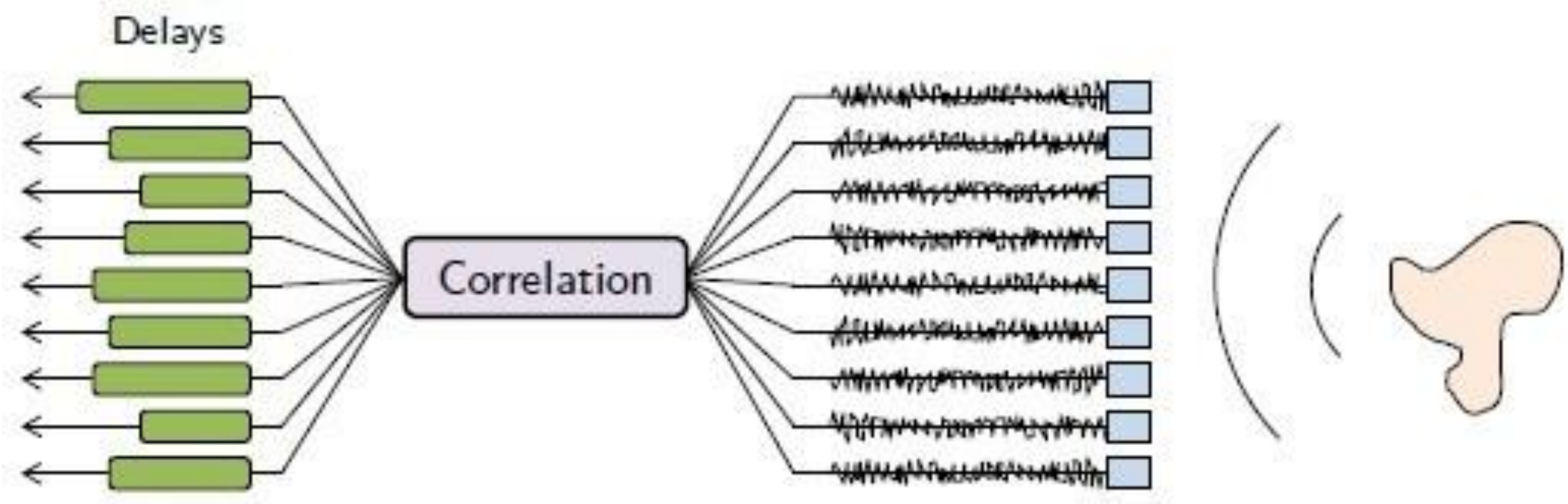
Background

- Classical techniques: adaptive time-delay focusing



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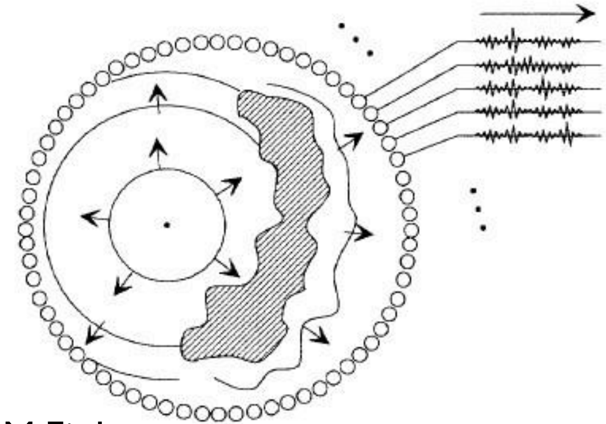
- Drawbacks:
  - Shape of scatter is not point-like
  - Speed of sound is not constant
  - Inhomogeneity in the medium causes that the received signal to vary in shape and size.

Time reversal processing

- Time-reversal: the reversal of the final conditions of a process will elicit the initial conditions
- Time-reversal cavity
  - Transducer sphere
- Time-reversal mirror(TRM)
  - An array of transmit-receive transducers



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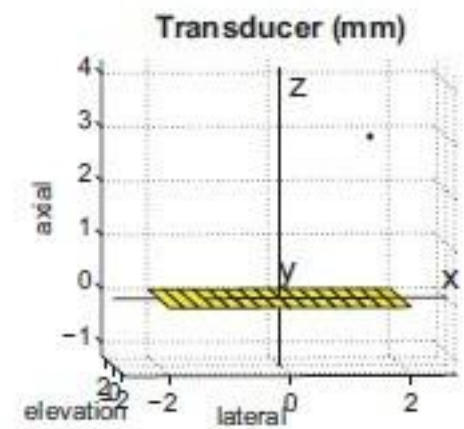

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Reciprocity

- The reception of a signal at a location r from a source at location r_0 is identical to the reception of a signal at r_0 from a source at r.
- Green's Function

$$G(r_0, t_0 | r, t) = G(r, t_0 | r_0, t)$$

- Impulse response

$$h_i^r(r_0, t) = \int_{S_i} G(r_0, t_0 | r, t) dr$$

$$h_i^t(r_0, t) = \int_{S_i} G(r, t_0 | r_0, t) dr$$

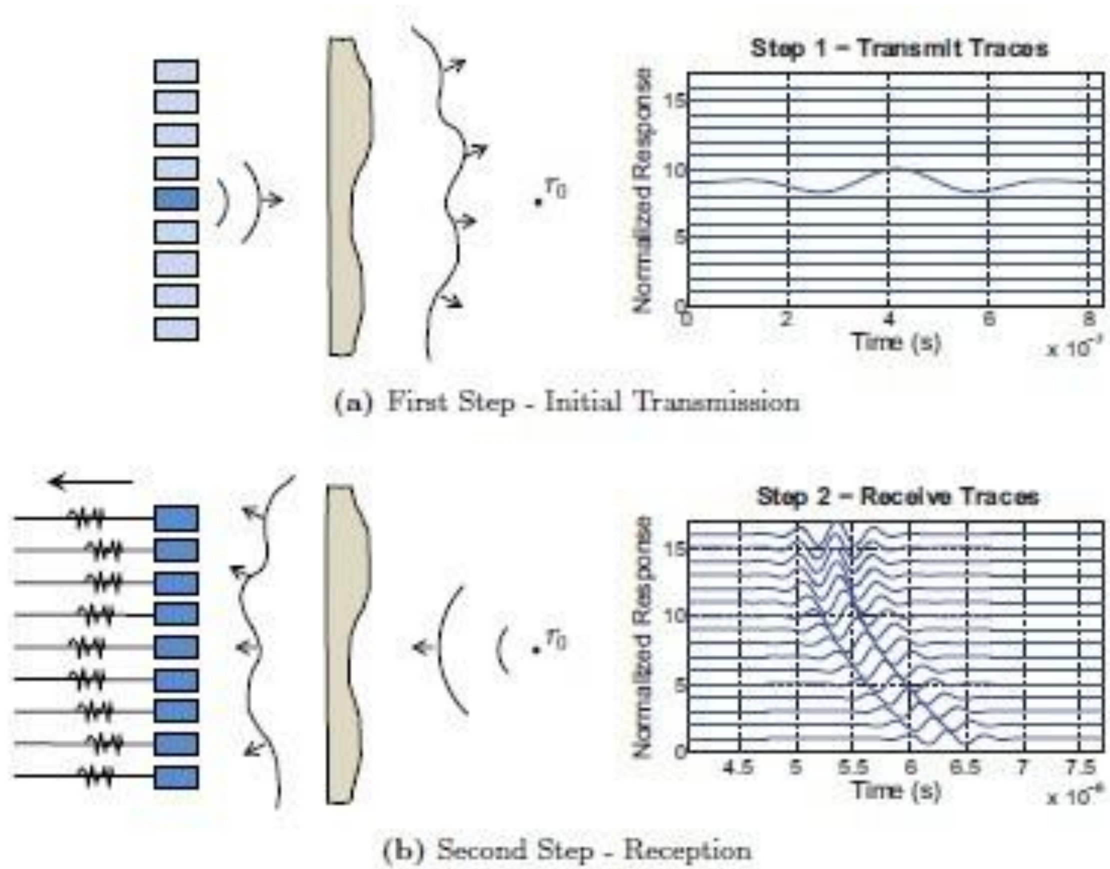
Time-reversal Focusing of Single Scatterer

- Step 1
  Send pulse from a single element

  $x(t)$

- Step 2
  Collect signal from all the elements

  $h_i(r_0, t) \otimes x(t)$



(a) First Step - Initial Transmission

(b) Second Step - Reception

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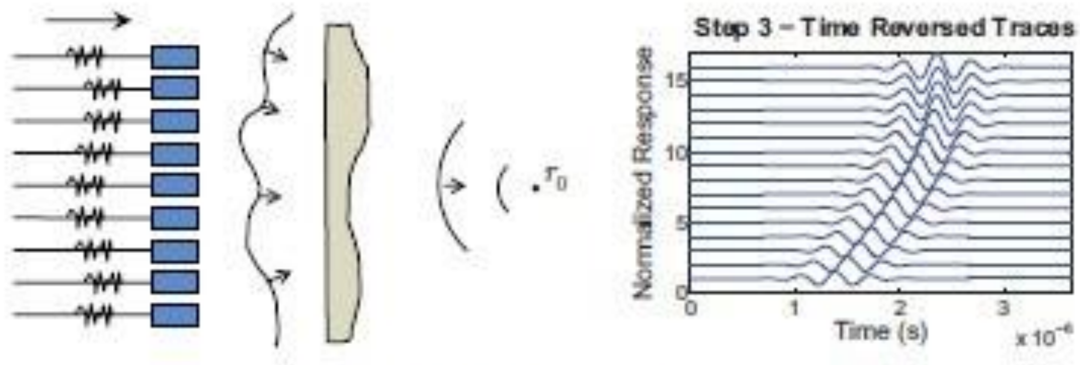
Time-reversal Focusing of Single Scatterer

- Step 3
  Time-reversal the signal and remit at all elements

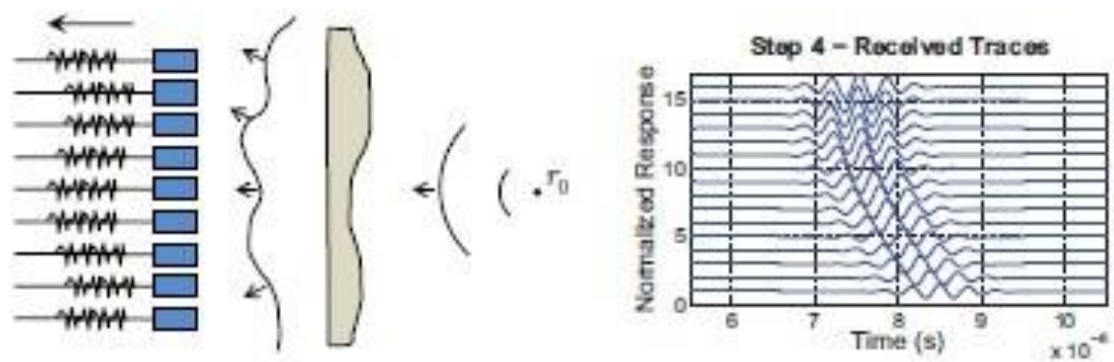
  $h_i(r_0, -t) \otimes x(-t)$

  Energy is maximized at location r_0



(c) Third Step - Time Reversal

- Step 4
  Collect the signal again



(d) Fourth Step - Second Reception

$$\left[\sum_{i=1}^{M} h_i(r_0, -t) \otimes x(-t) \otimes h_i(r_0, t)\right] \otimes h_j(r_0, t)$$

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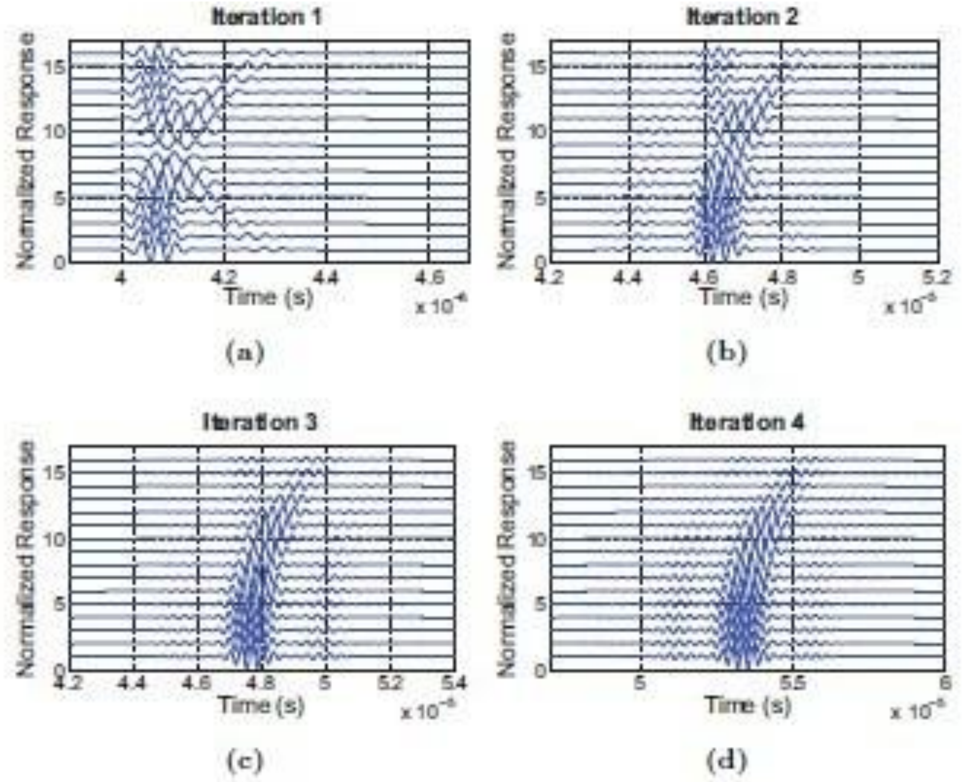
Target Selection

- Complete time-reversal operation
  - A closed time-reversal cavity
  - A long enough recording time
- In pratice
  - A finite spacial aperture
  - Short temporal windows
- Information lost enables the target selection capabilities

Multiple Scatterers

- The time-reversal process focuses energy on the most reflective scatterer after some iterations automatically
- The larger the contrast between the most reflective and the second scatter, the quicker the algorithm focuses on the most reflective one.



Evaluation

- Positive
  - The time-reversal process does not suffer from the cross-correlation related problems, since it does not depend on the transmission signals.
  - No assumptions have been made regarding the medium or the properties of the ultrasound transducer elements, so the inconsistencies of these won't affect the process.
  - The ability of TRM to choose the origin and the duration of the signals to be time reversed is one of its major advantages, that enables the automatic target selection.
- Negative:
  - Only focusing on the strongest scatterer.

Followed work

"Time reversal operator decomposition with focused transmission and robustness to speckle noise: Application to microcalcification detection".

- J.-L. Robert, M. Burcher, C. Cohen-Bacrie, and M.Fink, *J.Acoust. Soc.Am., 119:3848-3859 (2006).*

- Solve the weakness of the above method
- Propose associated time reversal operators to achieve dynamic focusing

Time reversal operators

- Decomposition of the time reversal operator (DORT)
  - Define time reversal operator as $K^*(\omega)K(\omega)$, $K(\omega)$ is the transfer matrix of the array
  - The operator can be diagonalized
  - Its eigenvectors of nonzero eigenvalue provides the phase law to be applied to the transducers regarding scatters of different reflectivities
  - Each of the scatters will be focused individually
  - Determine these eigenvectors and using them for the selective focusing.

Time reversal operators

- DORT
  - Inheres all the advantages of TRM
  - Impossible to collect a full data set
  - Sensible to speckle noise
- FDORT
  - Using focused pulse for initial transmission
  - Resolution is lower, limited by the size of transmit aperture
  - Detection of small microcalcifications embedderd in speckle

Current limitations and Future work

- Not many scatterers can be detected after some iterations
- Unable to focus on spacially closed scatterers(or to speckle) individually , due to the overlap of their response.
- Unable to distinguish scatterers with the same magnitude, due to the theoretic calculation approaches.

Utilization in our project

- Depends on the result of the occlusion imaging with skull
- Single iteration
  - Collect data
  - Time-reverse
  - Simulation in MATLAB

Thank you !

Questions ?