Adaptive Transthoracic Targeting Using Dual-Mode Ultrasound Arrays: A simulation and experimental study

Andrew Casper, John Ballard & Emad S. Ebbini

Ultrasonic Imaging and Signal Processing Laboratory (UISPL)
Department of Electrical and Computer Engineering
1) Locate structures using the imaging modality
2) Calculate driving pattern to refocus around structures and target deep seated focus
3) Use driving pattern to deliver therapy

Overview

- Implementation
  - Equations
  - Computing Hardware
- Validation
  - Model Registration
  - Ability to Refocus
  - Accuracy of FDTD Simulations
- Comparison with Other Methods
Implementation: FDTD

Discretizes the following coupled PDE’s

\[
\frac{\partial}{\partial t} \hat{u}(x, y, t) = \frac{-1}{\rho(x, y)} \nabla p(x, y, t)
\]

\[
\frac{\partial}{\partial t} p(x, y, t) = -\rho(x, y) \cdot c(x, y)^2 \nabla \cdot \hat{u}(x, y, t) + \sigma \cdot p(x, y, t)
\]

Accuracy of simulation depends heavily on size of discretization

Spatial: 100 μM or λ/15
Temporal: ≈ 21 nS
Each update equation contains only first order differences and can be made highly parallel. However, the result of each particle velocity update is needed before updating pressures and vice versa.

Ideal implementation has a large number of processors with large memory bandwidth.

- Nvidia GTX 285
  - 240 Processors
  - 100 Gb/Sec
  - 1 Gb Onboard Memory
  - Retails <$300
\[ \hat{u} = W_C h^* T \left( h_T W_C h^*_T \right)^{-1} p \]

\[ W_C = \left( H_C H^*_C + \gamma I \right)^{-1} \]
Validation: Setup

- 64 Element Concave Array
- 1 MHz Excitation
- 2.0 mm Pitch

- Plexiglass Ribs
Validation: Model Registration

Synthetic Aperture Image (45 dB)

Speed of Sound Distribution

Axial (mm)

Lateral (mm)
Refocused Patterns

5 times less energy on ribs
Validation: Focal Point Comparisons

No Refocusing

Refocusing

Measured

Simulated
Refocused and Geometric

Temperatures at Focus

Limitations of Temperature Prediction

1) FDTD assumes linear propagation
2) No secondary effects (cavitation, mode conversion, etc)
3) Assumptions of 2d heat diffusion unrealistic
Simulation: Region of Interest

<table>
<thead>
<tr>
<th>Medium</th>
<th>SOS (m/s)</th>
<th>Density (Kg/m³)</th>
<th>Attenuation (dB/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscera</td>
<td>1480</td>
<td>1000</td>
<td>0</td>
</tr>
<tr>
<td>Skin</td>
<td>1537</td>
<td>1040</td>
<td>0.87</td>
</tr>
<tr>
<td>Muscle</td>
<td>1547</td>
<td>1038</td>
<td>0.3</td>
</tr>
<tr>
<td>Bone</td>
<td>3200</td>
<td>2100</td>
<td>15.0</td>
</tr>
</tbody>
</table>
Field Patterns

Refocused

Time Reversed
Comparison

Energy Incident on Ribs

Energy at Focus
Conclusion and Future Work

FDTD simulation allows for accurate estimation of directivity vectors needed to refocus through inhomogeneous media

Future Work:
1) Quantitative imaging to “fill in” images generated by DMUA
2) Faster forward modeling
Refocused Field
Time Reversed Field
Shadowed Field
No Compensation
Driving Patterns TR and Ref
Field Patterns

Refocused

Time Reversed
Field Patterns

Shadowed

No Compensation