Parametric study of a shape based inversion for detection HIFU lesion
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ABSTRACT: A key problem in the practical use of high intensity focused ultrasound (HIFU) as a tool for cancer treatment is the non-invasive characterization of the regions of tissue that have successfully been necrosed. Previously, we proposed an approach to image guidance based on the use of RF data obtained from a diagnostic ultrasound transducer and a shape-based inverse scattering approach. Specifically, it was assumed that the lesion has an ellipsoidal shape defined by its center, size, orientation, and contrast (in sound-speed and attenuation) compared to the background. An inverse-type method was used to identify the ellipsoid parameters from the RF data. Experiments using a clinical scanner and tissue phantoms are reported and evaluation of the method's efficiency to ellipsoids of different sizes is done.

Shape: 
- Cigar (without cavitation)
- Tadpole (with cavitation)

Characteristics: 
- 2-5 times higher attenuation than in original tissue
- Only sound speed and attenuation differ between background tissue and lesion

Hypothese:
- Lesion is ellipsoidal (cigar shape, no cavitation)
- Background tissue and lesion are homogenous
- Only sound speed and attenuation differ between background tissue and lesion

Method

Acquisition

Unbeamformed acquisition using single elements for either emission and reception.

3D achieved using:
- Elements (y)
- Probe displacements (z)

Forward model

\[ u_0(\omega, E_{Tx}, E_{Rx}) = \int_{V} K_c(\omega, r, E_{Tx}, E_{Rx}) c(\omega, r) + K_a(\omega, r, E_{Tx}, E_{Rx}) a(\omega, r) \, dr \]

Gives received signal \( u_0 \) considering the attenuation \( a \) and sound speed \( c \) of any point of space.

\[ K_c(\omega, r, E_{Tx}, E_{Rx}) = e_{p_0}(\omega) R(k_b(\omega)) \]
\[ g(\omega, r, E_{Tx}) \]
\[ g(\omega, r, E_{Rx}) \]

\( g \) is the Green's function integrated over the element \( E \):

\[ g(\omega, r, E_{Tx}) = \int_{V} e^{iw0}/4\pi r \, dr \]

The non linear shape based inversion is used to find the correct location of the lesion. The shape used is an ellipsoid defined by 9 geometrical parameters.

Phantom

Three phantoms with scatterers were made of agar with lesions made of polyurethane.

<table>
<thead>
<tr>
<th>Phantom</th>
<th>Attenuation (Np/m²*MHz⁻¹)</th>
<th>Sound speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lesion</td>
<td>77</td>
<td>1530</td>
</tr>
<tr>
<td>Background tissue</td>
<td>8</td>
<td>1525</td>
</tr>
</tbody>
</table>

Both lesion and background tissue backscatter signal (due to their structure, i.e. the scatterers).

Results of the algorithm:

<table>
<thead>
<tr>
<th>Lesion</th>
<th>Small (mm)</th>
<th>Medium (mm)</th>
<th>Big (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>True</td>
<td>Result</td>
<td>True</td>
<td>Result</td>
</tr>
<tr>
<td>L₁</td>
<td>2.9</td>
<td>4.0</td>
<td>4.8</td>
</tr>
<tr>
<td>L₂</td>
<td>3.8</td>
<td>4.8</td>
<td>5.4</td>
</tr>
<tr>
<td>L₃</td>
<td>20.5</td>
<td>15</td>
<td>20.6</td>
</tr>
<tr>
<td>Max₂</td>
<td>5.5</td>
<td>0.3</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Conclusion

Good results for finding lesion size and location for lesions whose smallest axis exceeds 4 mm. 
Future effort: smaller and multiple lesions, non ellipsoidal shape.

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