Random Excitation by Optimized Pulse Inversion in Contrast Harmonic Imaging

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Outline

1. Introduction
   - Ultrasound Contrast Imaging
   - Pulse Inversion Imaging
   - Problematic

2. Random Excitation
   - Principle
   - Simulation Model
   - Results for linear system
   - Results for nonlinear pulse inversion imaging system

3. Parametric Optimization
   - Implementation
   - Results

4. Conclusions & Prospects
Introduction
Ultrasound Contrast Imaging

Contrast Agents

- Injection of contrast agents $\Rightarrow$ perfusion imaging
- Encapsulated microbubbles: mean diameter between 1 to 10 $\mu$m
- High nonlinear behavior

Contrast to Tissue Ratio

$$CTR = \frac{E_{\text{microbubbles}}}{E_{\text{tissue}}}$$

[F. Tranquart]
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Ultrasound Contrast Imaging

Ultrasound Contrast Harmonic Imaging

- Transmitted Signal
- Emission Tx
- Medium
- Reception Rx
- Image

Ultrasound Harmonic Imaging using post-processing

Transmission

Reception

Image

Criterion
Ultrasound Contrast Imaging

Ultrasound Contrast Harmonic Imaging

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Encoding Harmonic Imaging

Transmitted Signal → Emission Tx → Medium → Reception Rx → Image

Post-processing

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Transmission

Reception

Image

Criterion

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Pulse Inversion Imaging

Pulse Inversion Method

- Emission (Tx)
- Delay $\tau$
- Phase Inversion
- Medium
- Reception (Rx)
- Image

Transmission

Reception

Pulse Inversion

Extraction of even harmonic components

Criterion

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What is the best command to optimize the criterion?
Random Excitation
**Principle of Random Excitation**

**Principle of Implementation**

1. Find the input signal $x(t)$ of the pulse inversion imaging system
2. Optimize the $CTR$
3. Random search by Monte-Carlo method
**Principle of Random Excitation**

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Simulation Model

Simulation Properties

- Transducer centred at $f_c = 3$ MHz
- Microbubble
  - Free simulation software Bubblesim [Hoff, 2001]
  - Modified Rayleigh-Plesset Equation
  - Diameter: 2.5 $\mu$m
  - Shell thickness: 1 nm
  - Resonance Frequency: 3.1 MHz
- Tissue: Rayleigh diffusion
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Results for linear system: Optimization of microbubble power
Results for nonlinear pulse inversion imaging system
Results for nonlinear pulse inversion imaging system

- Normalized Pressure
- Time (μs)

- $f_{opt} = 2.5$ MHz
- $CTR = 30.4$ dB
Results for nonlinear pulse inversion imaging system

\[ f_{opt} = 2.5 \text{ MHz} \]
\[ CTR = 30.4 \text{ dB} \]

\[ CTR = 31.4 \text{ dB} \]

1 million of tests
Parametric Optimization
Implementation of the Parametric Optimization

1. Choice of the Cost Function $J(\theta)$
2. Choice of the parameters $\theta$
3. Choice of the optimization algorithm
Implementation of the Parametric Optimization

Setting of Iterative Optimization

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2. Choice of the parameters $\theta$
3. Choice of the optimization algorithm

Setting of Iterative Optimization
Implementation of the Parametric Optimization

Optimization Setting

1. Maximization of the CTR
2. Input signal described by autoregressive model

\[ \hat{x}(t) = \sum_{i=0}^{M-1} h_1(i)x(t - i) \]

3. Nelder-Mead’s Algorithm based on simplex
Implementation of the Parametric Optimization

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\[ \hat{x}(t) = \sum_{i=0}^{M-1} h_1(i)x(t - i) + \sum_{i=0}^{M-1} \sum_{j=i}^{M} h_2(i, j)x(t - i)x(t - j) + \cdots \]

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Order $K = 3$ and memory $M = 3 \Rightarrow 19$ parameters

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Drawback: what is the signal $x(t)$?

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\( \Rightarrow \) Optimal Input Signal obtained randomly

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# Results with Parametric Optimization

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Conclusion & Prospects
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- Know the optimal shape of the optimal command
- Random process without *a priori* knowledge of the medium
- Suboptimal excitation by combination between random process and parametric optimization
- Decrease test number
- Prospects:
  - Analysis the optimal excitation
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Thank you for your attention

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