Introduction	Random Excitation	Parametric Optimization	Conclusion

## Random Excitation by Optimized Pulse Inversion in Contrast Harmonic Imaging

### Sébastien Ménigot and Jean-Marc Girault



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April 26<sup>th</sup>, 2012



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Ultrasound Contrast Imaging

## Ultrasound Contrast Imaging

### Contrast Agents

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





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## Ultrasound Contrast Imaging

### Contrast Agents

- Injection of contrast agents ⇒ perfusion imaging
- Encapsulated microbubbles: mean diameter between 1 to 10 μm
- High nonlinear behavior





### Contrast to Tissue Ratio

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

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## Ultrasound Contrast Imaging





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

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## Ultrasound Contrast Imaging







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 Pulse Inversion Imaging
 Pulse Inversion Method
 Pulse Inversion Method
 Pulse Inversion Method



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## What is the best command to optimize the CTR?



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## **Random Excitation**

- Automatic
- Without hypothesis on the shape wave

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#### Principle

## Principle of Random Excitation



### Principle of Implementation

• Find the input signal x(t) of the pulse inversion imaging system

Optimize the CTR

3 Random search by Monte-Carlo method

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#### Principle

## Principle of Random Excitation



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• Find the input signal x(t) of the pulse inversion imaging system

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### Principle of Implementation

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

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#### Principle

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- Find the input signal x(t) of the pulse inversion imaging system
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### Simulation Properties

### • Transducer centred at $f_c = 3 \text{ MHz}$

### 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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### Simulation Properties

- Transducer centred at  $f_c = 3 \text{ MHz}$
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### Simulation Properties

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## Results for linear system



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Results for nonlinear pulse inversion imaging system

## Results for nonlinear pulse inversion imaging system



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Results for nonlinear pulse inversion imaging system

## Results for nonlinear pulse inversion imaging system



$$f_{opt} = 2.5 \text{ MHz}$$

CTR = 30.4 dB

(Ménigot, 2009)

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Results for nonlinear pulse inversion imaging system

## Results for nonlinear pulse inversion imaging system



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## Parametric Optimization

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#### Implementation

## Implementation of the Parametric Optimization



### Setting of Iterative Optimization

- ① Choice of the Cost Function  $J(\theta)$
- 2 Choice of the parameters heta
- 3 Choice of the optimization algorithm

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## Implementation of the Parametric Optimization



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## Implementation of the Parametric Optimization



### Setting of Iterative Optimization

- **O** Choice of the Cost Function  $J(\theta)$
- **2** Choice of the parameters  $\theta$

### Choice of the optimization algorithm

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## Implementation of the Parametric Optimization



### Setting of Iterative Optimization

- **O** Choice of the Cost Function  $J(\theta)$
- 2 Choice of the parameters  $\theta$
- S Choice of the optimization algorithm

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## Implementation of the Parametric Optimization



### Setting of Iterative Optimization

- **Q** Choice of the Cost Function  $J(\theta) \rightarrow CTR$
- 2 Choice of the parameters  $\theta$
- S Choice of the optimization algorithm

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## Implementation of the Parametric Optimization

### **Optimization Setting**

Maximization of the CTR

Input signal described by autoregressive model

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

### In the second state of the second state of

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## Implementation of the Parametric Optimization

### **Optimization Setting**

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In the second state of the second state of

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## Implementation of the Parametric Optimization

### **Optimization Setting**

Maximization of the CTR

Input signal described by nonlinear autoregressive model (NAR)

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

### 3 Nelder-Mead's Algorithm based on simplex

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## Implementation of the Parametric Optimization

### Optimization Setting

Maximization of the CTR

Input signal described by nonlinear autoregressive model (NAR)

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

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

### 3 Nelder-Mead's Algorithm based on simplex

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## Implementation of the Parametric Optimization

### Optimization Setting

Maximization of the CTR

Input signal described by nonlinear autoregressive model (NAR)

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Order K = 3 and memory  $M = 3 \Rightarrow 19$  parameters Drawback: what is the signal x(t) ?

### Nelder-Mead's Algorithm based on simplex

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## Implementation of the Parametric Optimization

### **Optimization Setting**

Maximization of the CTR

Input signal described by nonlinear autoregressive model (NAR)

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

Order K = 3 and memory  $M = 3 \Rightarrow 19$  parameters Drawback: what is the signal x(t)?  $\Rightarrow$  Optimal Input Signal obtained randomly

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## Implementation of the Parametric Optimization

### **Optimization Setting**

Maximization of the CTR

2 Input signal described by nonlinear autoregressive model (NAR)

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

Order K = 3 and memory  $M = 3 \Rightarrow 19$  parameters Drawback: what is the signal x(t)?  $\Rightarrow$  Optimal Input Signal obtained randomly

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Results wi <sup>.</sup>	th Parametric Op	otimization		
	Pulse	Random	Random	with
	$f_{opt} = 2.5 \text{ MHz}$	<u>r</u>	Parametri	ic

			Optimization
CTR	30.4 dB	31.4 dB	

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## Results with Parametric Optimization

	Pulse $f_{opt} = 2.5 \text{ MHz}$	Random	Random with Parametric Optimization
CTR	30.4 dB	31.4 dB	31.5 dB

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## Results with Parametric Optimization

	Pulse $f_{opt} = 2.5 \text{ MHz}$	Random	Random with Parametric Optimization
CTR	30.4 dB	31.4 dB	31.5 dB

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	Pulse $f_{opt} = 2.5 \text{ MHz}$	Random	Random with Parametric Optimization
CTR	30.4 dB	30.5 dB	
N <sub>test</sub>	-	15	

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	Pulse $f_{opt} = 2.5 \text{ MHz}$	Rar	ndom	Random with Parametric Optimization
CTR	30.4 dB	30.5 dB	31.3 dB	
N <sub>test</sub>	-	15	2165	

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	Pulse $f_{opt} = 2.5 \text{ MHz}$	Random	Random with Parametric Optimization
CTR	30.4 dB	30.5 dB	31.3 dB
N <sub>test</sub>	-	15	258

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	Pulse $f_{opt} = 2.5 \text{ MHz}$	Rar	ndom	Random with Parametric Optimization
CTR	30.4 dB	30.5 dB	31.3 dB	31.3 dB
N <sub>test</sub>	-	15	2165	258

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## **Conclusion & Prospects**

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## Conclusion & Prospects

### • Random process without a priori knowledge of the medium

• Decrease test number by combination between random process and parametric optimization

### • Prospects:

- Analysis the optimal excitation
- Find the optimal command by metaheuristic
- In NDE, test number is not a problem

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- Random process without a priori knowledge of the medium
- Decrease test number by combination between random process and parametric optimization
- Prospects:
  - Analysis the optimal excitation
  - Find the optimal command by metaheuristic
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## Conclusion & Prospects

- Random process without *a priori* knowledge of the medium
- Decrease test number by combination between random process and parametric optimization
- Prospects:
  - Analysis the optimal excitation
  - Find the optimal command by metaheuristic
  - In NDE, test number is not a problem

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## Conclusion & Prospects

# Thank you for your attention

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