

# Transmit frequency optimization for ultrasound contrast agent response

S. Ménigot, A. Novell, I. Voicu, A. Bouakaz and J.-M. Girault

François Rabelais University  
Inserm U930, CNRS ERL 3106 - Team 5  
Tours - FRANCE

September 24, 2009



MediTech 2009, Cluj-Romania



**Inserm**

Institut national  
de la santé et de la recherche médicale



## 1 Introduction

## 2 Method

- Method: Gradient ascent

## 3 Results & Discussion

- Simulations
- In vitro experiments
- Discussion

## 4 Conclusions

# Introduction

# Problematic in Ultrasound Contrast Imaging

## Objectives

### 1 Objectives:

- Increase the Contrast Tissue Ratio (CTR) :

$$CTR = \frac{\int_{T_0}^{T_1} s^2 dt}{\int_{T_2}^{T_3} s^2 dt};$$

- keep the axial resolution.

### 2 Difficulties:

- Non-stationarity of the perfused medium;
- Non-linearity of the non-perfused medium.

# Problematic in Ultrasound Contrast Imaging

## Objectives

### 1 Objectives:

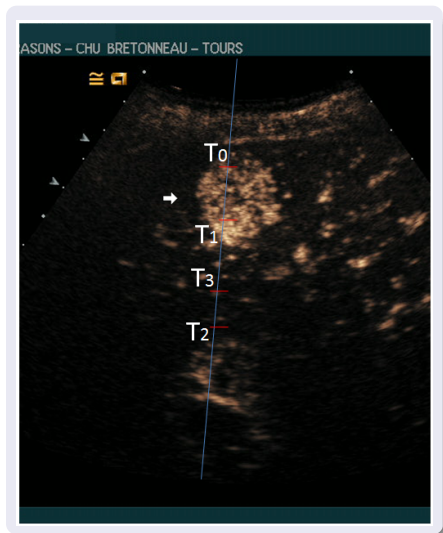
- Increase the Contrast Tissue Ratio (CTR) :

$$CTR = \frac{\int_{T_0}^{T_1} s^2 dt}{\int_{T_2}^{T_3} s^2 dt};$$

- keep the axial resolution.

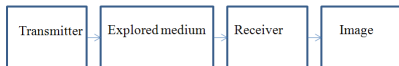
### 2 Difficulties:

- Non-stationarity of the perfused medium;
- Non-linearity of the non-perfused medium.



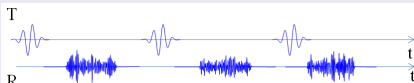
# Existing US Imaging System: standard echography

## Standard echograph



- Non closed loop

## Non closed loop system

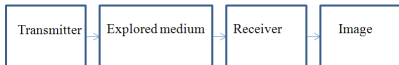


Standard Imaging

## Transmitting sequences

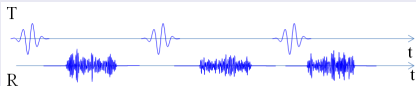
# Existing US Imaging System: standard echography

## Standard echograph



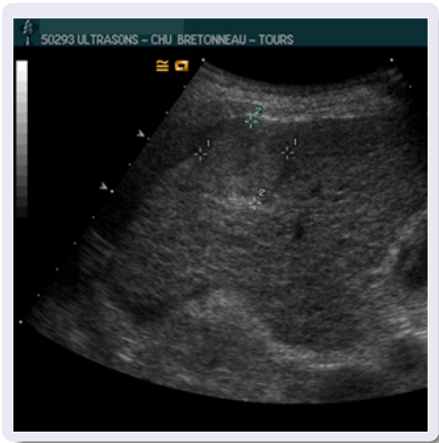
- Non closed loop

## Non closed loop system



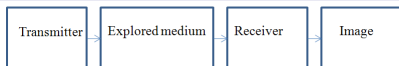
Standard Imaging

## Transmitting sequences



# Existing US Imaging System: Contrast imaging

## Contrast imaging



- Non closed loop

## Non closed loop system



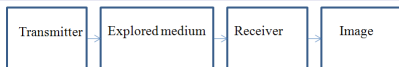
Harmonic Imaging

## Transmitting sequences



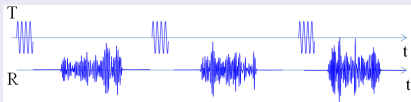
# Existing US Imaging System: Contrast imaging

## Contrast imaging



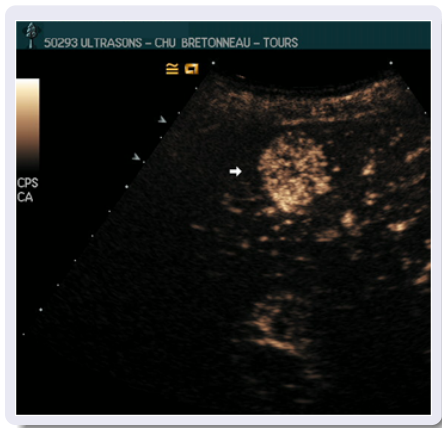
- Non closed loop

## Non closed loop system



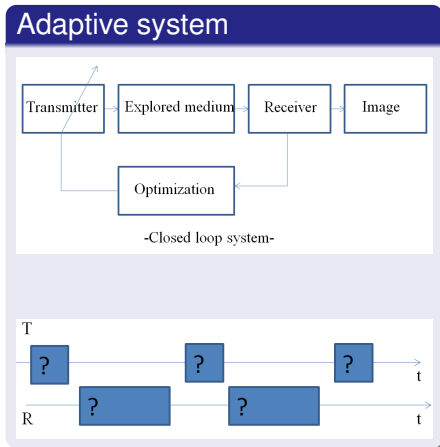
Harmonic Imaging

## Transmitting sequences

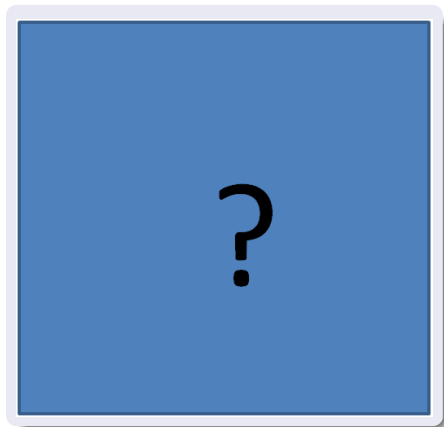
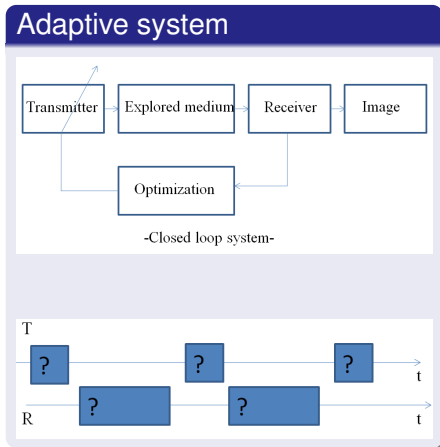


# Method

# Adaptive US imaging system



# Adaptive US imaging system



# Optimal Control

Backscattered signal  
By the  $\mu$ bubble

Lagrange  
multiplier

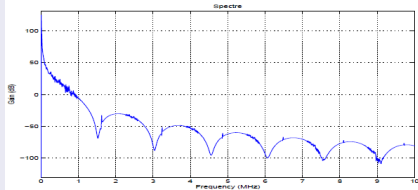
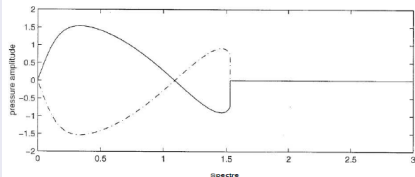
Non-linear Equation  
of the  $\mu$ bubble

$$CTR = \frac{\int_0^T s^2(t) - \lambda(t) G(t) dt}{\int_0^T \sigma_n^2(t) dt}$$

Backscattered signal  
By the tissue

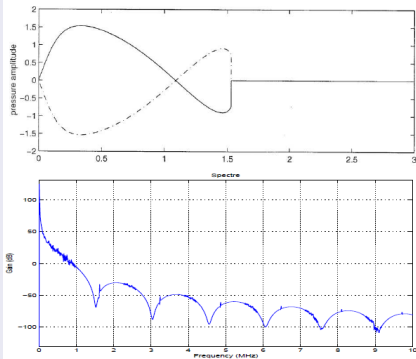
# Optimal control

## Optimal solution

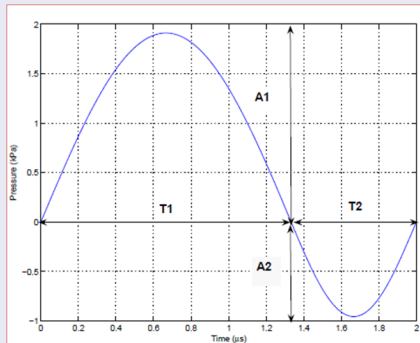


# Optimal control

## Optimal solution

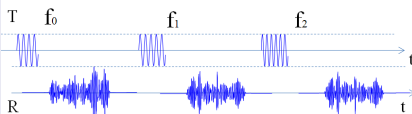
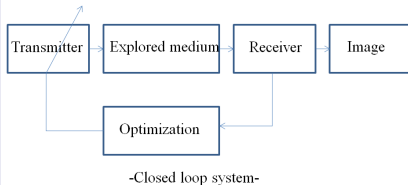


## sub-optimal solution



# Adaptive system: Transmitting frequency optimization

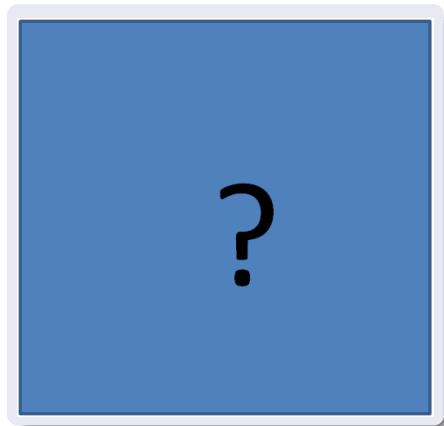
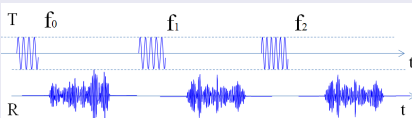
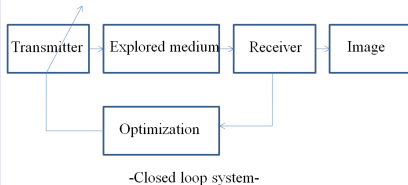
## Transmitting frequency optimization





# Adaptive system: Transmitting frequency optimization

## Transmitting frequency optimization



# Gradient ascent

## Recurrence relation

$$f_{k+1} = f_k + \alpha_k \cdot \nabla E(f_k),$$

$$\nabla E(f_k) = \frac{E_k - E_{k-1}}{f_k - f_{k-1}},$$

The gain  $\alpha_k$  is constant.

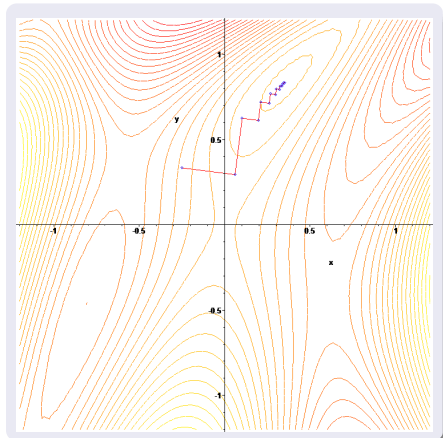
# Gradient ascent

## Recurrence relation

$$f_{k+1} = f_k + \alpha_k \cdot \nabla E(f_k),$$

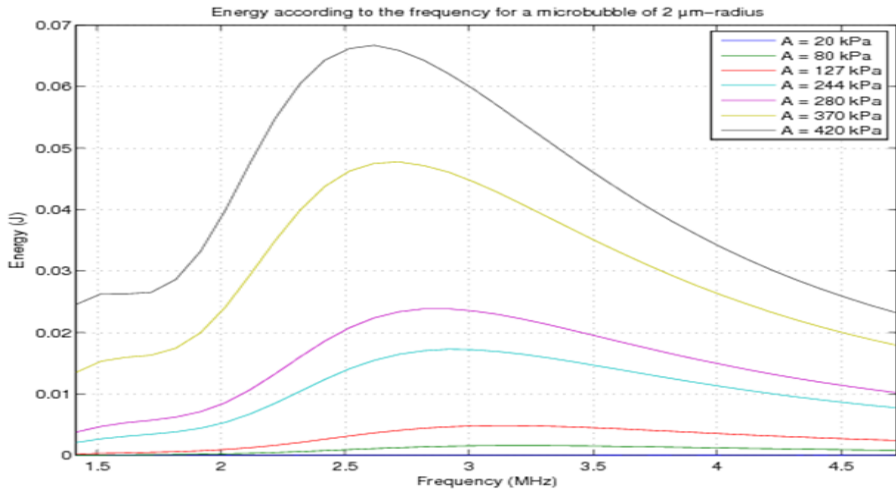
$$\nabla E(f_k) = \frac{E_k - E_{k-1}}{f_k - f_{k-1}},$$

The gain  $\alpha_k$  is constant.



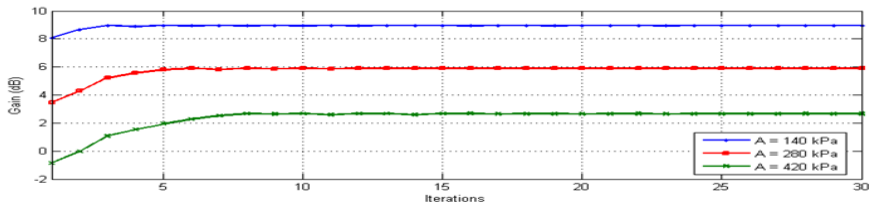
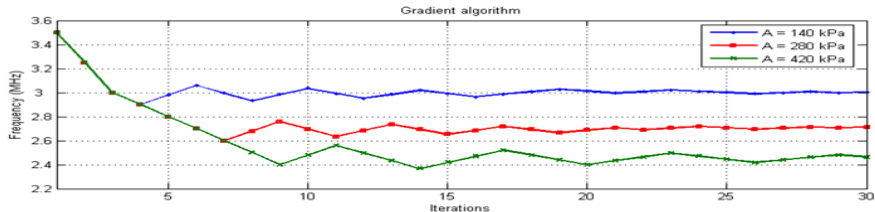
# Results & Discussion

# Backscattered energy of the microbubble



# Frequency & Gain

- Sinusoidal transmitting burst;
- Ascent Method



# Experimental setup

## Materials

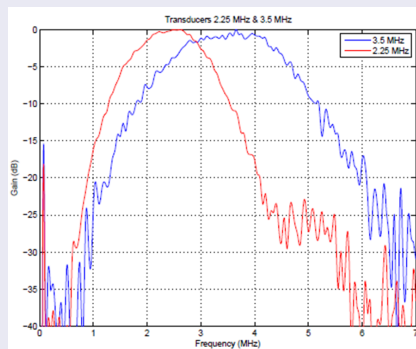
- 1 Sonovue TM (Bracco Research, Geneva, Switzerland);
- 2 Orthogonal positions of transducers;
- 3 Transducer properties:
  - PZT;
  - single-element;
  - Transmitter (2.25 MHz - BW:74%);
  - Receiver (3.5 MHz - BW: 63%).

# Experimental setup

## Materials

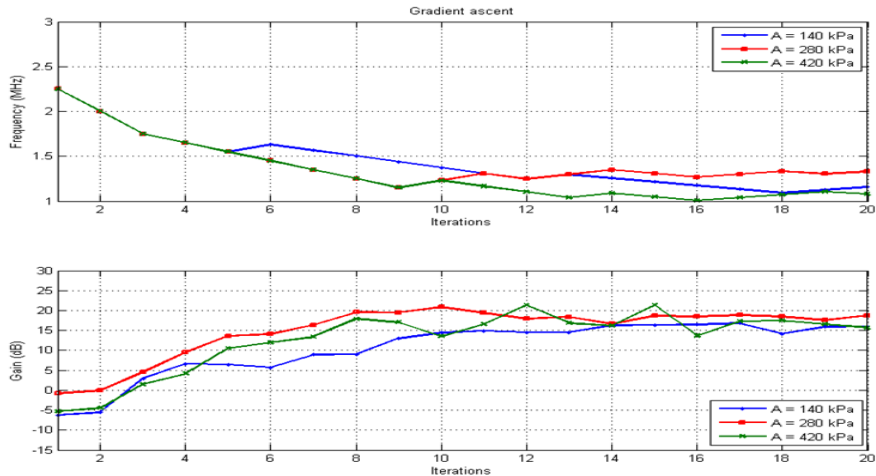
- 1 Sonovue TM (Bracco Research, Geneva, Switzerland);
- 2 Orthogonal positions of transducers;
- 3 Transducer properties:
  - PZT;
  - single-element;
  - Transmitter (2.25 MHz - BW:74%);
  - Receiver (3.5 MHz - BW: 63%).

## Transfert function





# In vitro experiments: Results



# In vitro experiments: Results

- 1 Adaptive technics permit to obtain non-negligible gain;
- 2 The price to pay is a higher complexity of the system;
- 3 The gain for the clinician:
  - For the same examination duration: the amount of contrast agent is reduced;
  - Improving of the CTR.

# Conclusions

# Conclusions

## Conclusions & Prospects

- 1 Adaptive imaging systems constitute a new promising way;
- 2 In short term: explore multivariate optimization;
- 3 In short term: RLS adaptive technique;
- 4 In mean term: explore new techniques such as adaptive pulse inversion;
- 5 In mean term: implement our techniques in a programmable imaging system.

# The End !