Measuring CBF from Perfusion MRI by Wavelet Transform

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Introduction

Perfusion: Rate at which nutrient-supplying blood passes through tissue

Applications of Perfusion Assessment

- Stroke
- Alzheimer's Disease
- Assessment of Prognosis
- Tumor Characterization
- Monitoring of Cancer Therapy

Medical Imaging Modalities used in Perfusion Assessment

- **PET** (Positron Emission Tomography)
- **SPECT** (Single Photon Emission Computed Tomography)
- **MRI** (Magnetic Resonance Imaging)

Perfusion MRI

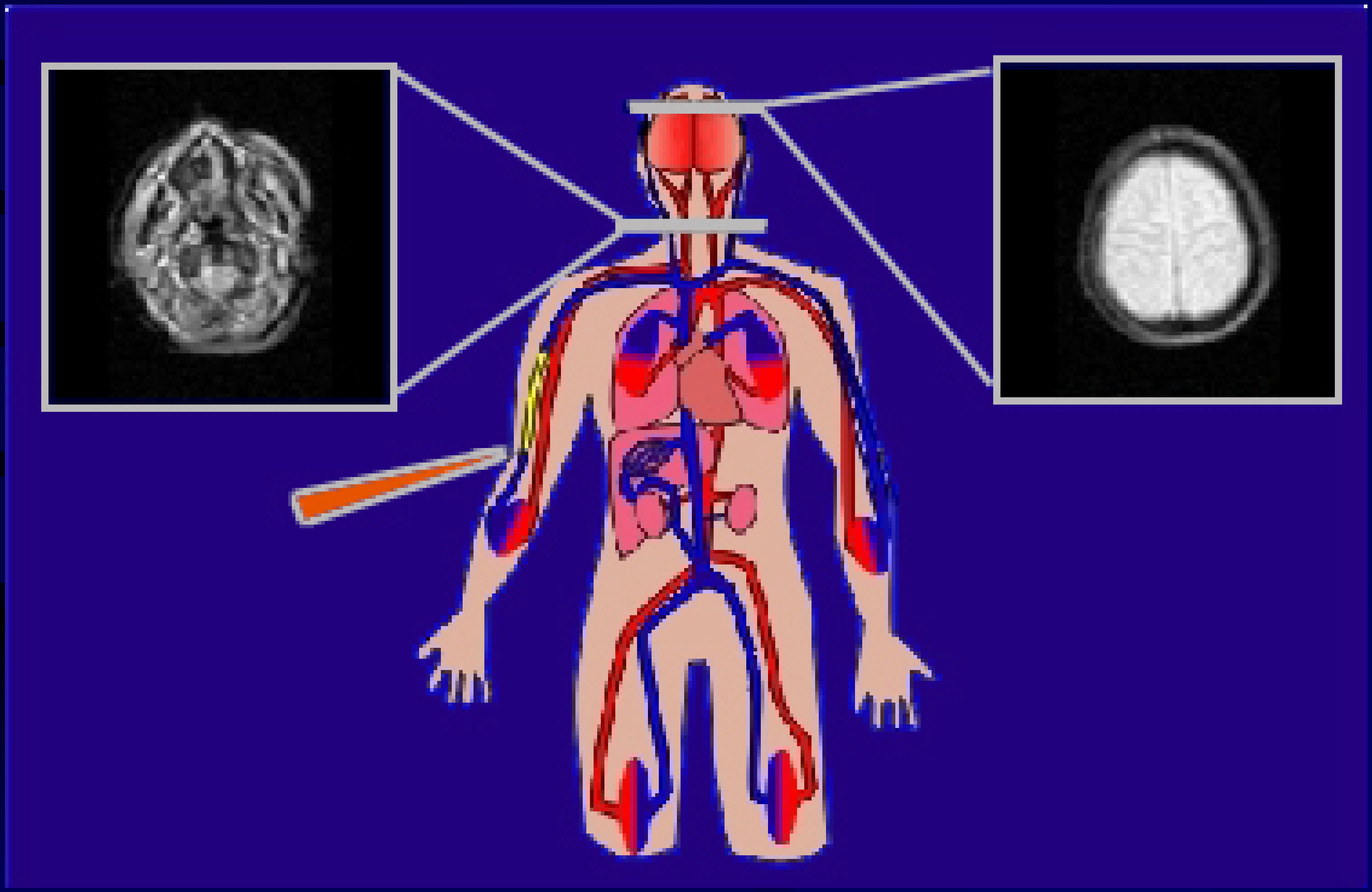
Observation of the passage of a contrast agent, e.g. Gd-DTPA, by Rapid MR Imaging Methods,

e.g. Echo Planar Imaging (EPI)

Advantages of Perfusion MRI (pMRI)

- Higher spatial resolution
- No patient exposure to ionizing radiation

Experiment of Perfusion MRI :

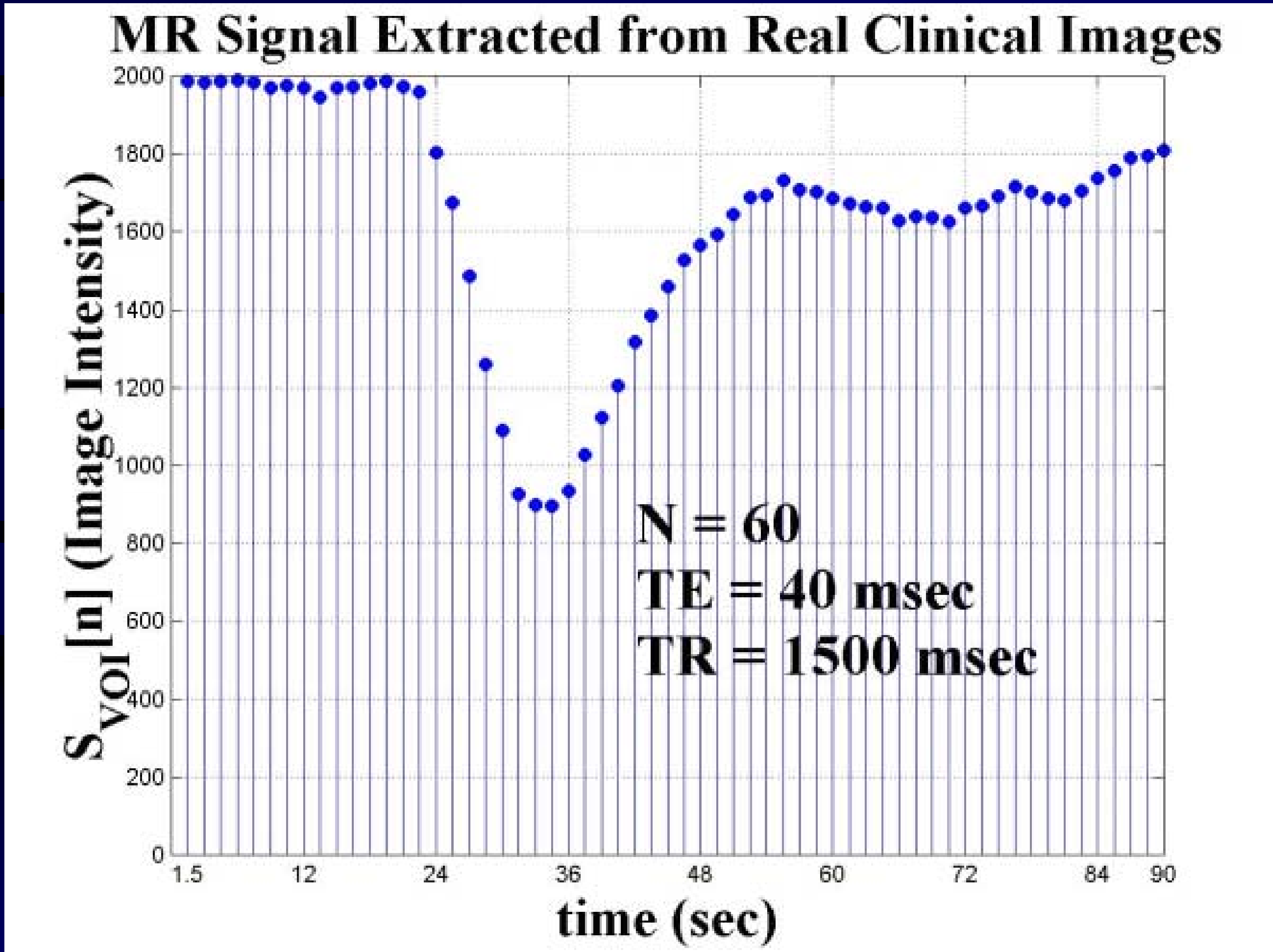


Theory

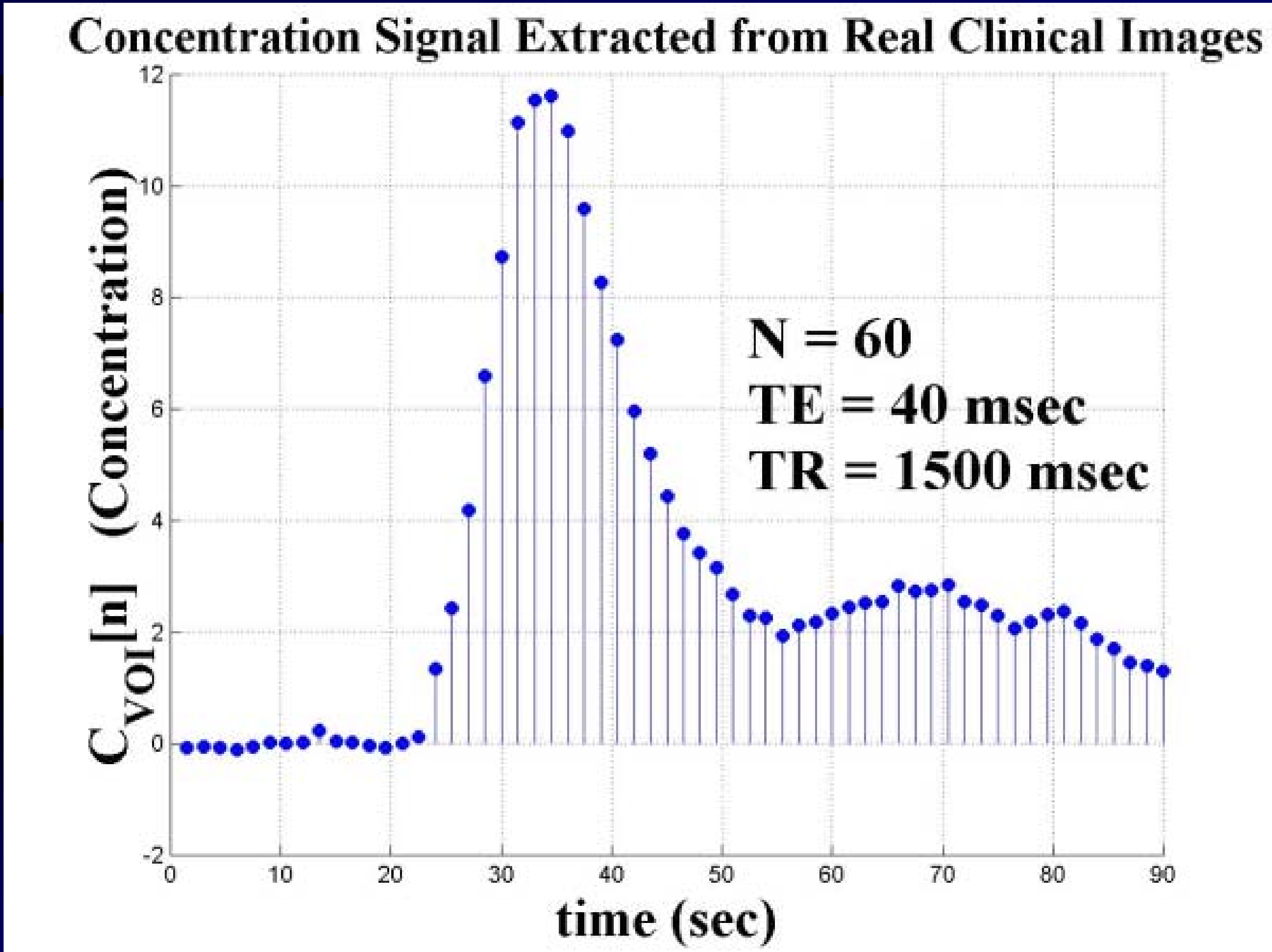
Changes in Transverse Relaxation Rate

$$C(t) = k \cdot \Delta R_2$$

$$= -\frac{k}{TE} \ln\left[\frac{S(t)}{S_0}\right]$$



MR Signal Extracted from Real Clinical Images
2000
1800
1600
1400
1200
1000
800
600
400
200
0
S_VOI[n] (Image Intensity)
N = 60
TE = 40 msec
TR = 1500 msec
1.5
12
24
36
48
60
72
84
90
time (sec)


Concentration Signal Extracted from Real Clinical Images
N = 60
TE = 40 msec
TR = 1500 msec
C_VOI[n] (Concentration)
time (sec)
12
10
8
6
4
2
0
-2
0
10
20
30
40
50
60
70
80
90

Essential Equation

$$C_{VOI}(t) = \frac{\rho}{k_H} F \int_0^t C_{AIF}(\tau) R(t-\tau) d\tau$$

k **: Correction Factor**

p **: Density of Brain Tissue**

F **: Cerebral Blood Flow (CBF)**

***C*(*t*) : Concentration of Contrast-Agent**

***R*(*t*) : Residue Function**

Discretization

$$
\begin{aligned}
C_{VOI}(t_n) &= \frac{\rho}{k_H} F \int_0^{t_n} C_{AIF}(\tau) \cdot R(t_n - \tau) d\tau \\
&= \frac{\rho}{k_H} F \cdot \left[\sum_{m=0}^{n} C_{AIF}(t_m) \cdot R(t_n - t_m) \right] \cdot \Delta t \\
&= \frac{\rho}{k_H} F \cdot \left[\sum_{m=0}^{n} C_{AIF}(m \cdot \Delta t) \cdot R((n-m) \cdot \Delta t) \right] \cdot \Delta t \\
&= \frac{\rho}{k_H} F \cdot \Delta t \cdot \left[\sum_{m=0}^{n} C_{AIF}[m] \cdot R[n-m] \right]
\end{aligned}
$$

Discrete-time Equation

$$C_{VOI}[n] = \frac{\rho}{k_H} F \cdot \Delta t \cdot C_{AIF}[n] \otimes R[n]$$

Model-Independent Methods

$$\left.\begin{array}{c}\text{Residue Function : Unknown} \\ \\ \text{Imaging Speed} \Rightarrow \text{Noisy Data}\end{array}\right\}$$

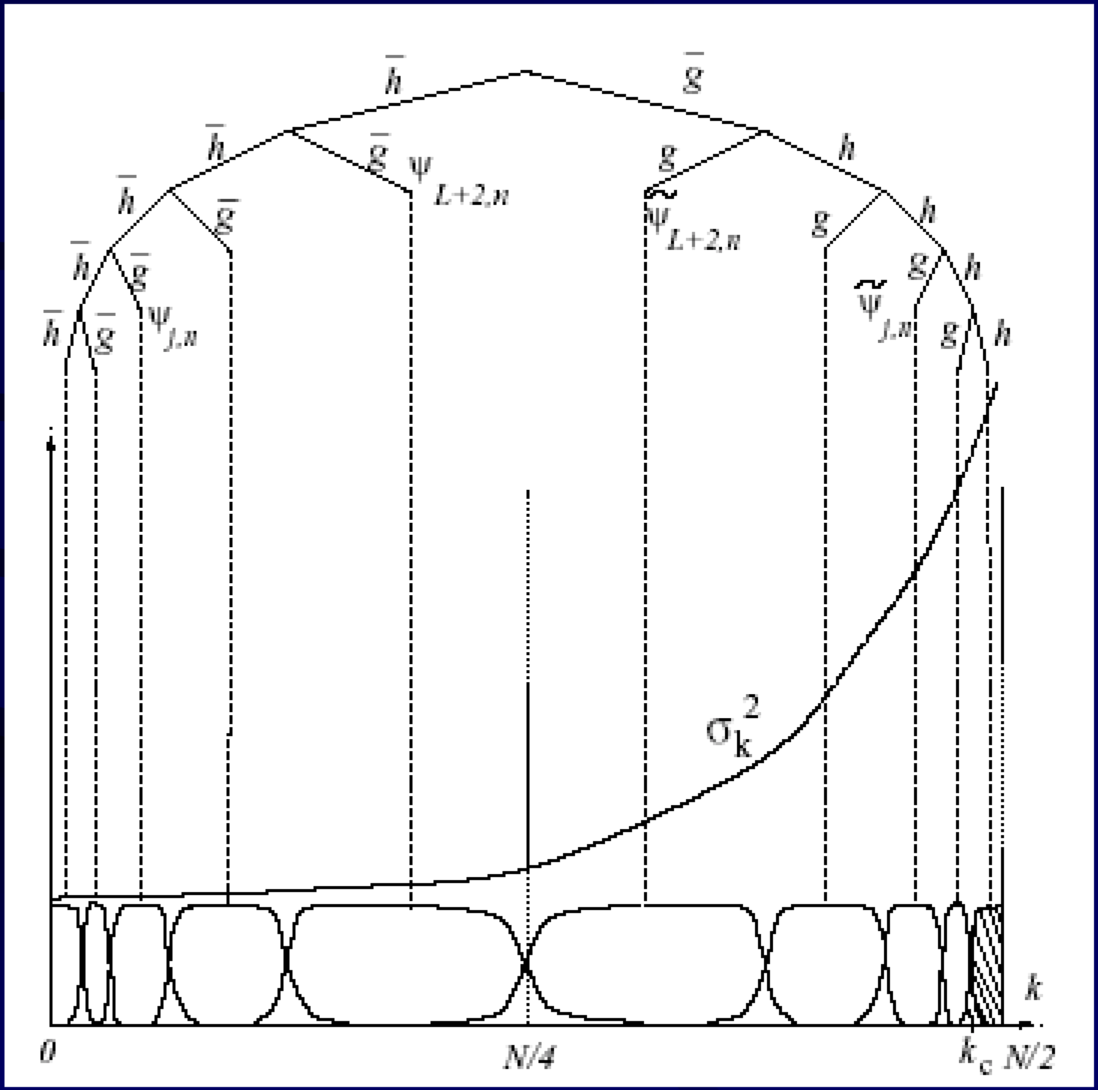
$$\Rightarrow \quad \textit{Deconvolution} \;\; \text{Problem}$$

Measuring CBF using Wavelet Transform

Deconvolution in Mirror Wavelet Basis

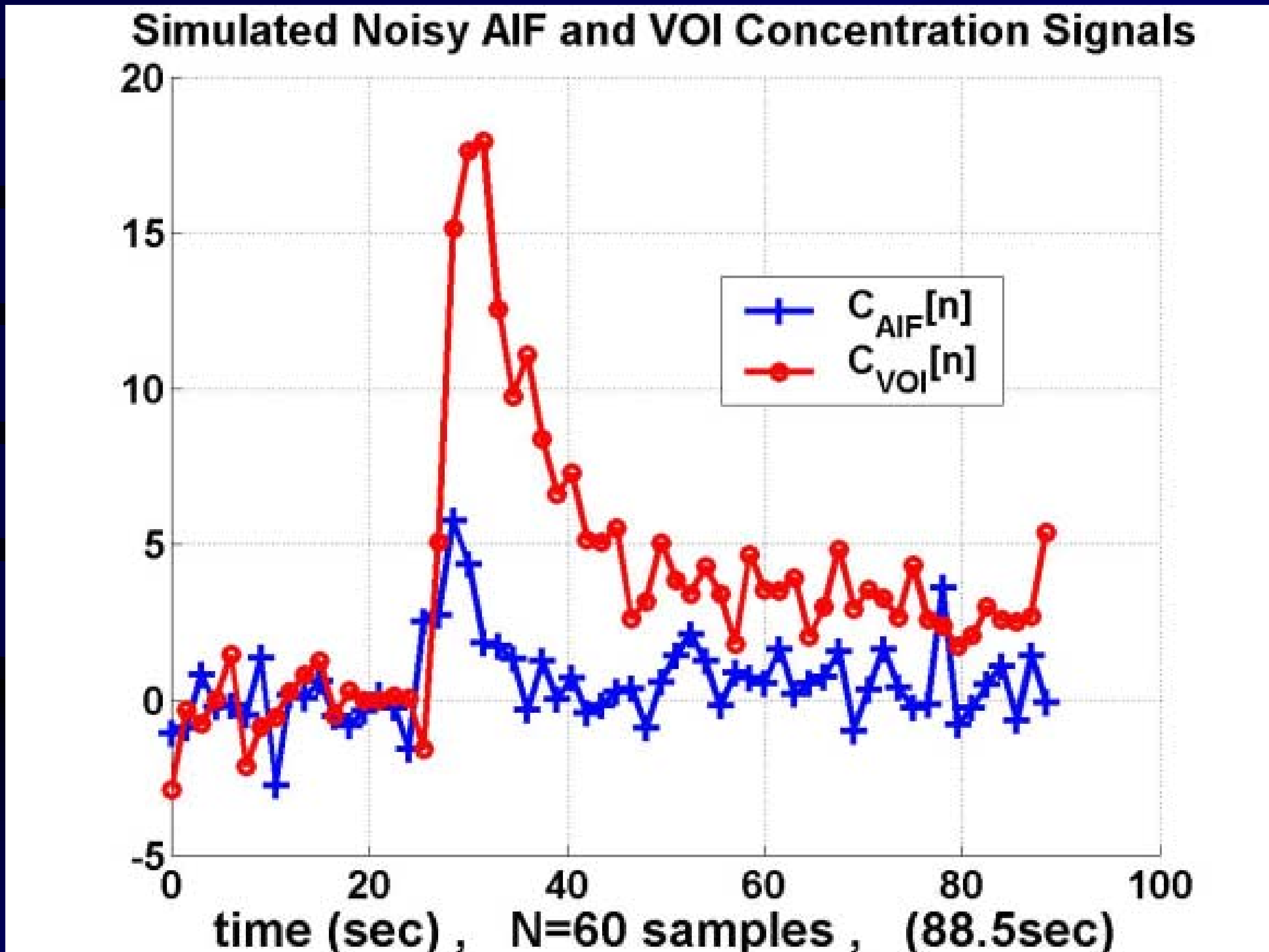
- Inverse Convolution in presence of noise
- Decomposition in Mirror Wavelet Basis
- Soft-Thresholding of Wavelet coefficients
- Hard-Thresholding of Finest Scale
- Reconstruction in Mirror Wavelet Basis
- Shift-Invariant Algorithm

Mirror Wavelet Basis

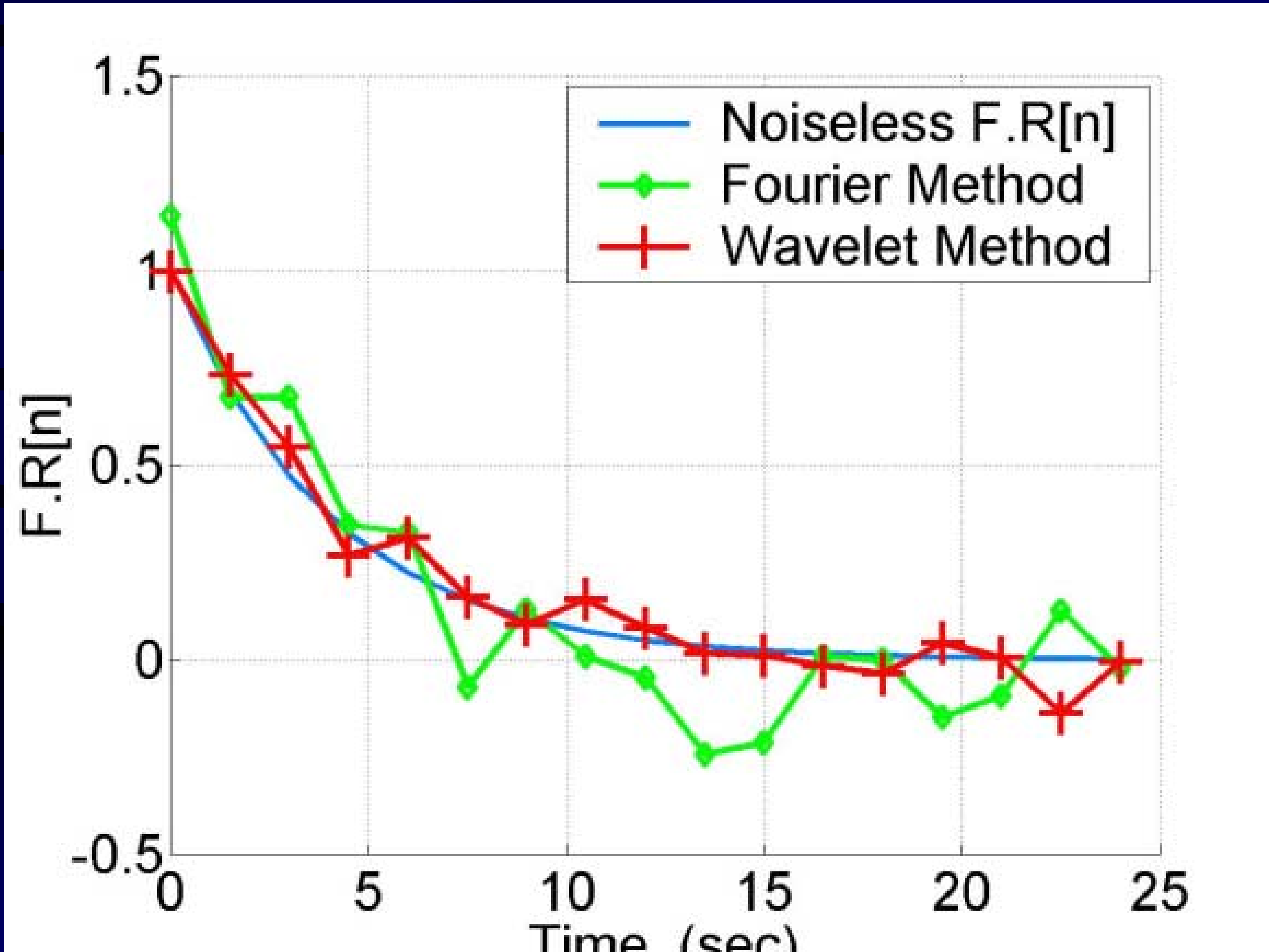


Simulations

- **Arterial Input Function (AIF):**
  Gamma-Variate Function
- **Residue Function:**
  Exponential Function
- **Recirculation:**
  Adding an Exponential to the AIF
- **Noise:**
  AGWN to MR signal


Simulated Noisy AIF and VOI Concentration Signals
$C_{AIF}[n]$
$C_{VOI}[n]$
20
15
10
5
0
-5
0
20
40
60
80
100
time (sec) ,   N=60 samples ,   (88.5sec)

Results



Noiseless F.R[n]
Fourier Method
Wavelet Method
F.R[n]
1.5
1
0.5
0
-0.5
0
5
10
15
20
25
Time (sec)

Conclusion

- The Mean Square Error is improved compared to the Fourier Method.

- The proposed method seems promising. It can be extended to clinical applications by choosing an appropriate thresholding parameter, i.e., the maximum amplitude of mirror wavelet coefficients.