Detection of R Waves in ECG Signals

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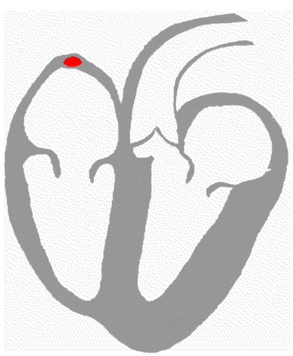
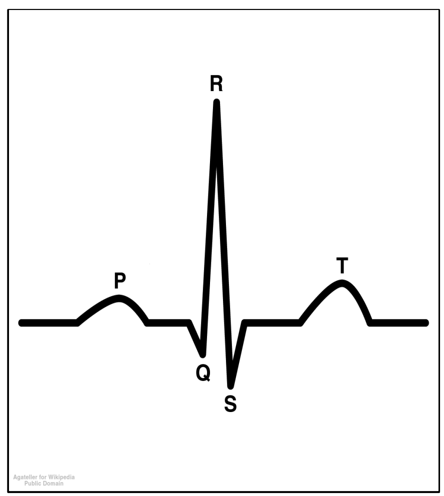
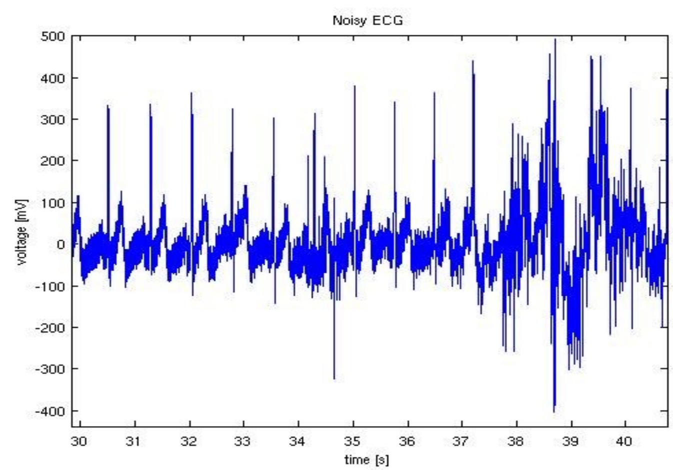
Introduction: The Heart, ECG, and R Waves

- the heart produces a wave of electrical activity to contract and pump blood throughout the body
-the electrical field produced by this wave is detected by the ECG
-the problem is to detect R wave times in order to calculate instantaneous heart rate.
-this is non-trivial because the signals are heterogeneous and noisy

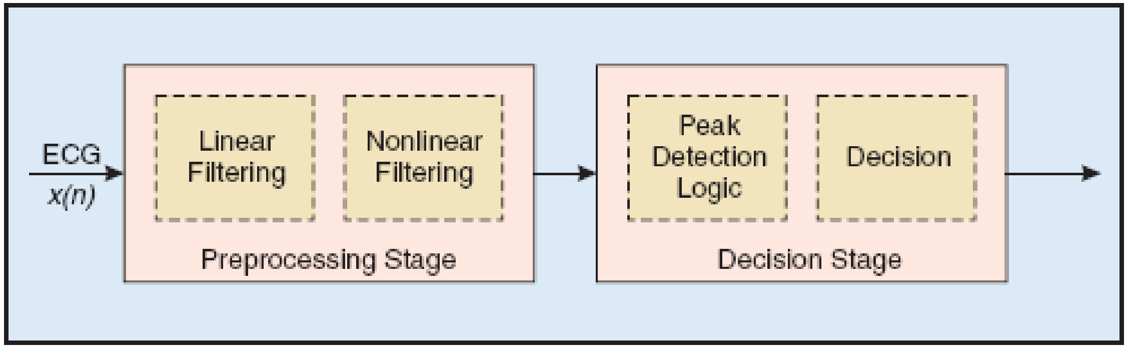






Overview of Methodologies

- historically the QRS complex detection was done manually but in the last 30 years many software algorithms have been designed to automate the process.
- the preprocessing stage can be approached in many ways:
    - linear filtering
    - neural network-based transformations
    - Hilbert transformation
    - Wavelet coefficient estimation
    - Model-based approaches
    - etc.
- the decision stage usually consists of some form of threshold detection.



The Hilbert and Wavelet Transforms

- Given a signal f , we can define it's Hilbert Transform as follows:

$$\hat{f}(t) = \frac{1}{\pi} \int f(s) \frac{1}{(t-s)} ds$$

- The Hilbert transform is used to define the Analytic Representation of a signal

$$A(t) = f(s) + i\,\hat{f}(s) = R(t)\,\mathrm{e}^{\phi(t)}$$

- The amplitude of A(t) gives the signal's amplitude and slope information, but the measure is still susceptible to noise
- A wavelet transform convolves a signal with a wavelet, $\phi_{a,b} = \frac{1}{\sqrt{a}} \phi\left(\frac{(t-b)}{a}\right)$ such that

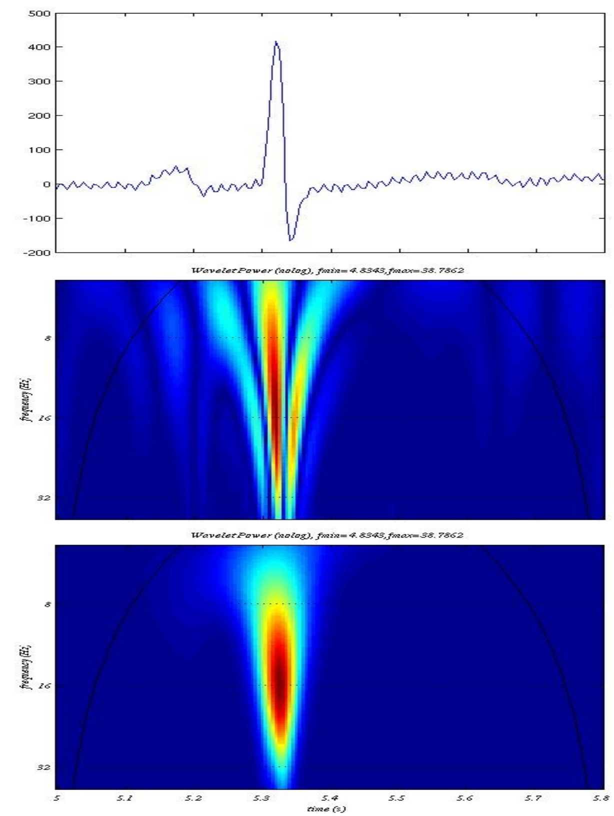
$$w(a,b) = f * \phi = \int f(s)\,\overline{\phi_{a,b}}(s)\,ds$$

- w(a,b) gives information about frequency variations in time, but this projection depends on the wavelet used.

Analytic Wavelets

- We can combine the advantages of the Hilbert and wavelet transforms by using a complex analytic wavelet

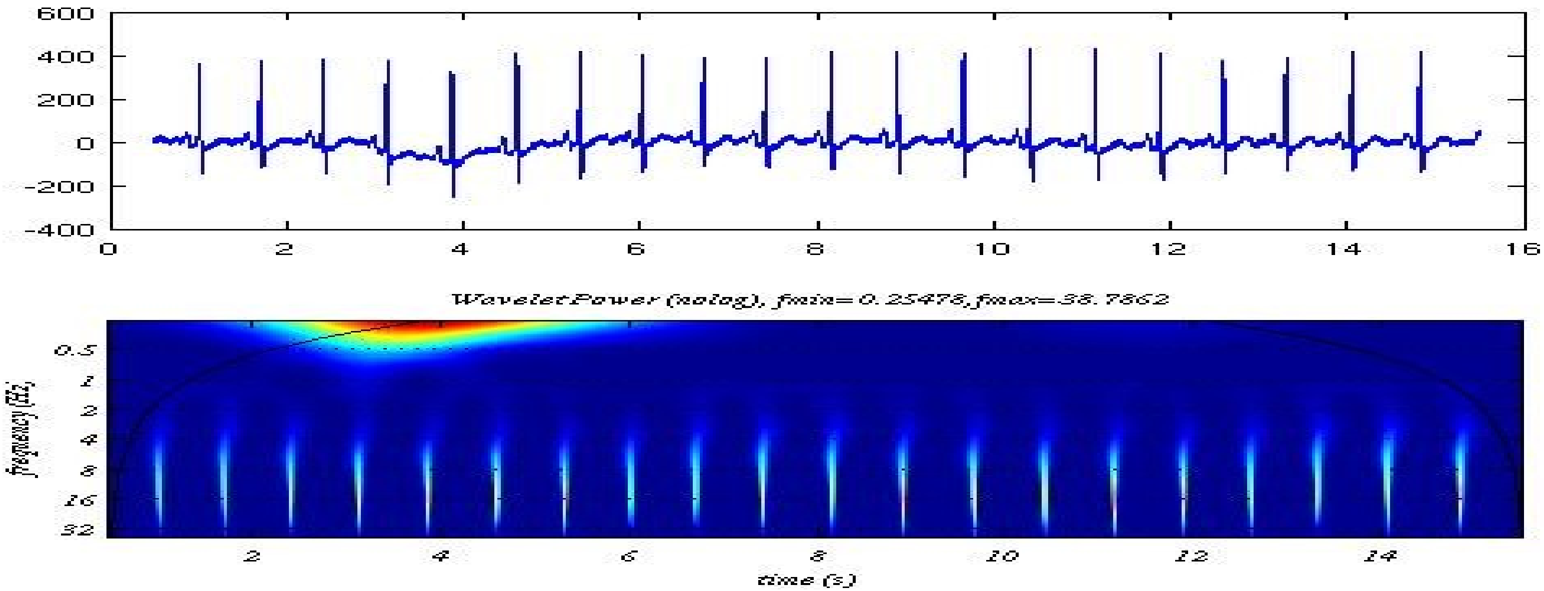
$$\phi(\omega)=\omega^{n} e^{-\omega}, \omega \geq 0$$
$$\phi(\omega)=0, w<0$$



- This has the advantage of combining the time frequency localization of a wavelet transform with information about the local slope of the signal.

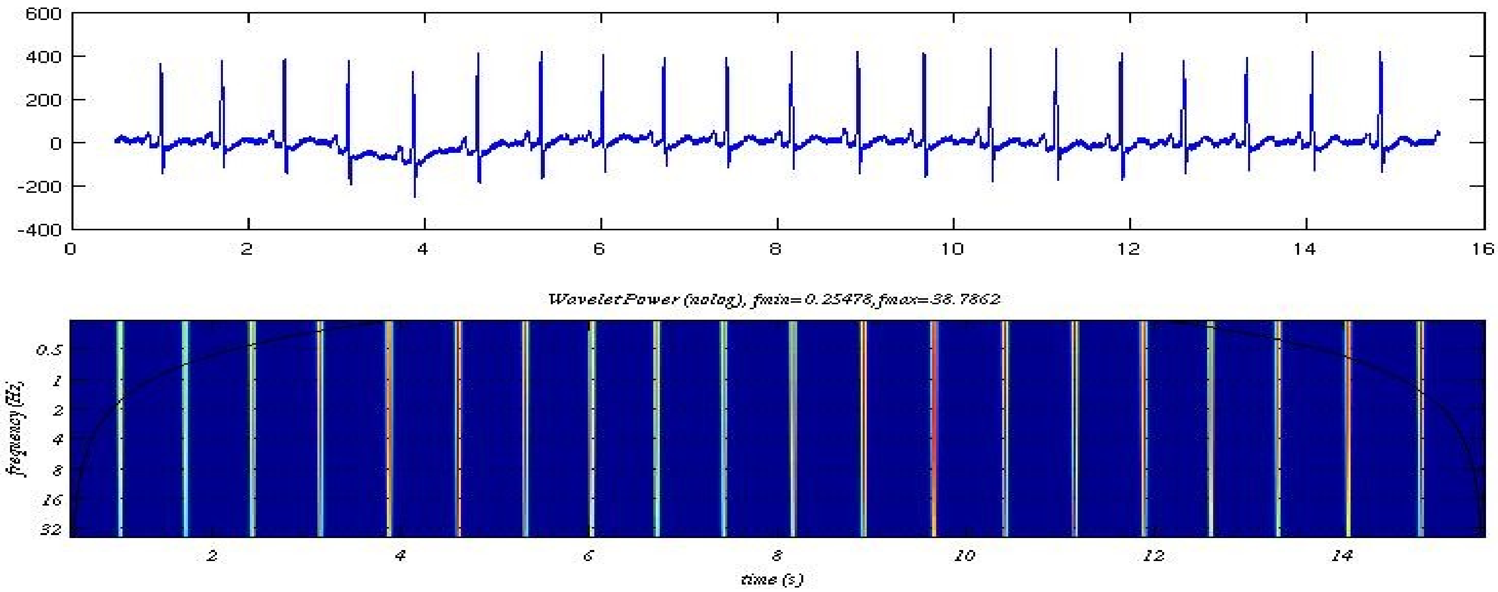
METHODOLOGY:

1. Compute analytical wavelet transform



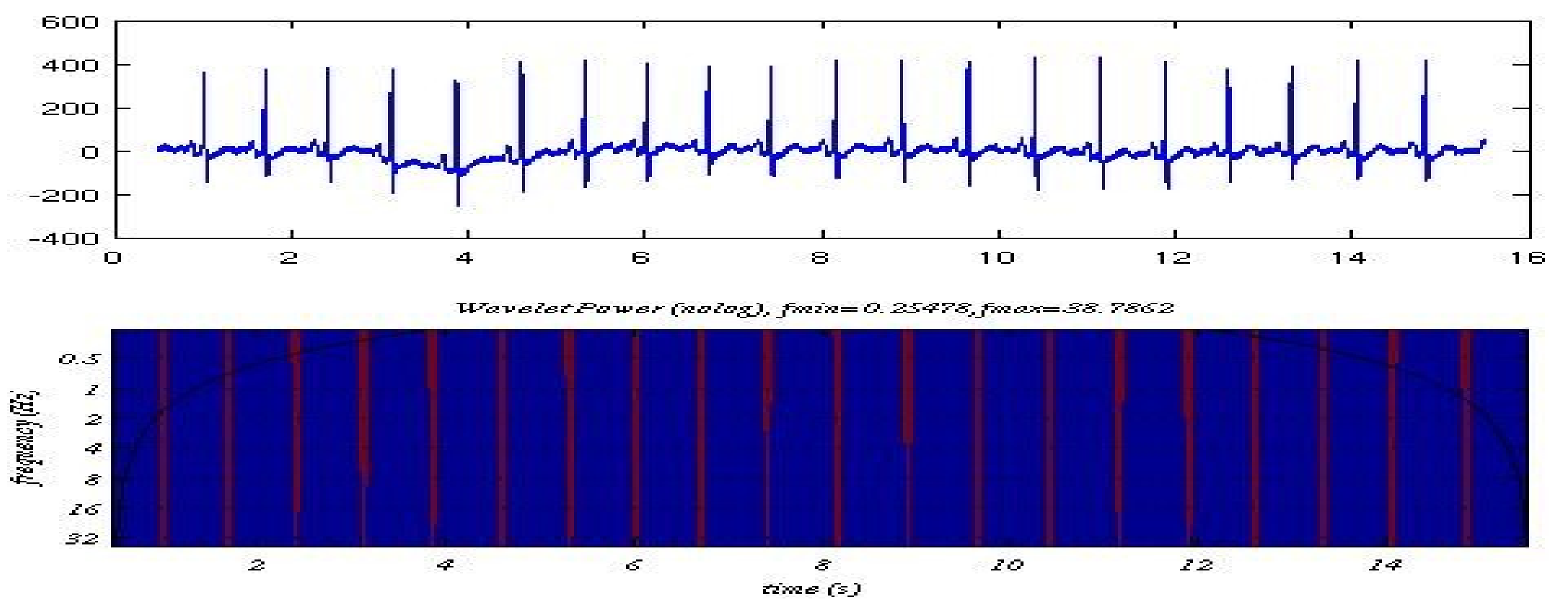
METHODOLOGY:

1. Compute analytical wavelet transform
2. Select band of interest (8Hz-16Hz)



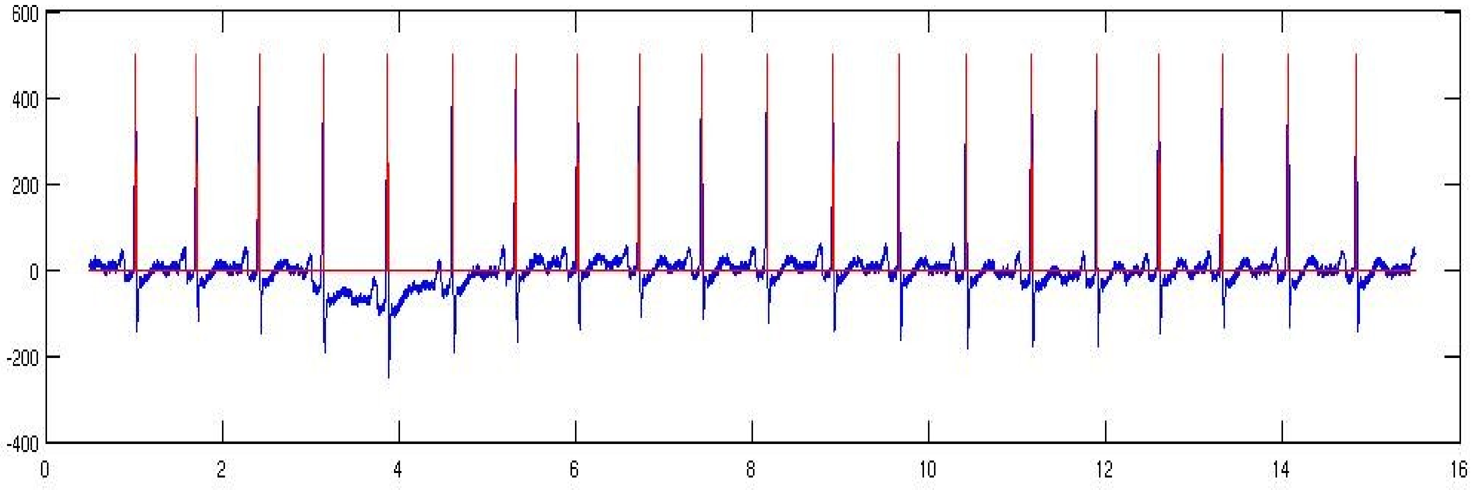
METHODOLOGY:

1. Compute analytical wavelet transform
2. Select band of interest (8Hz-16Hz)
3. Threshold and look for persistent lines



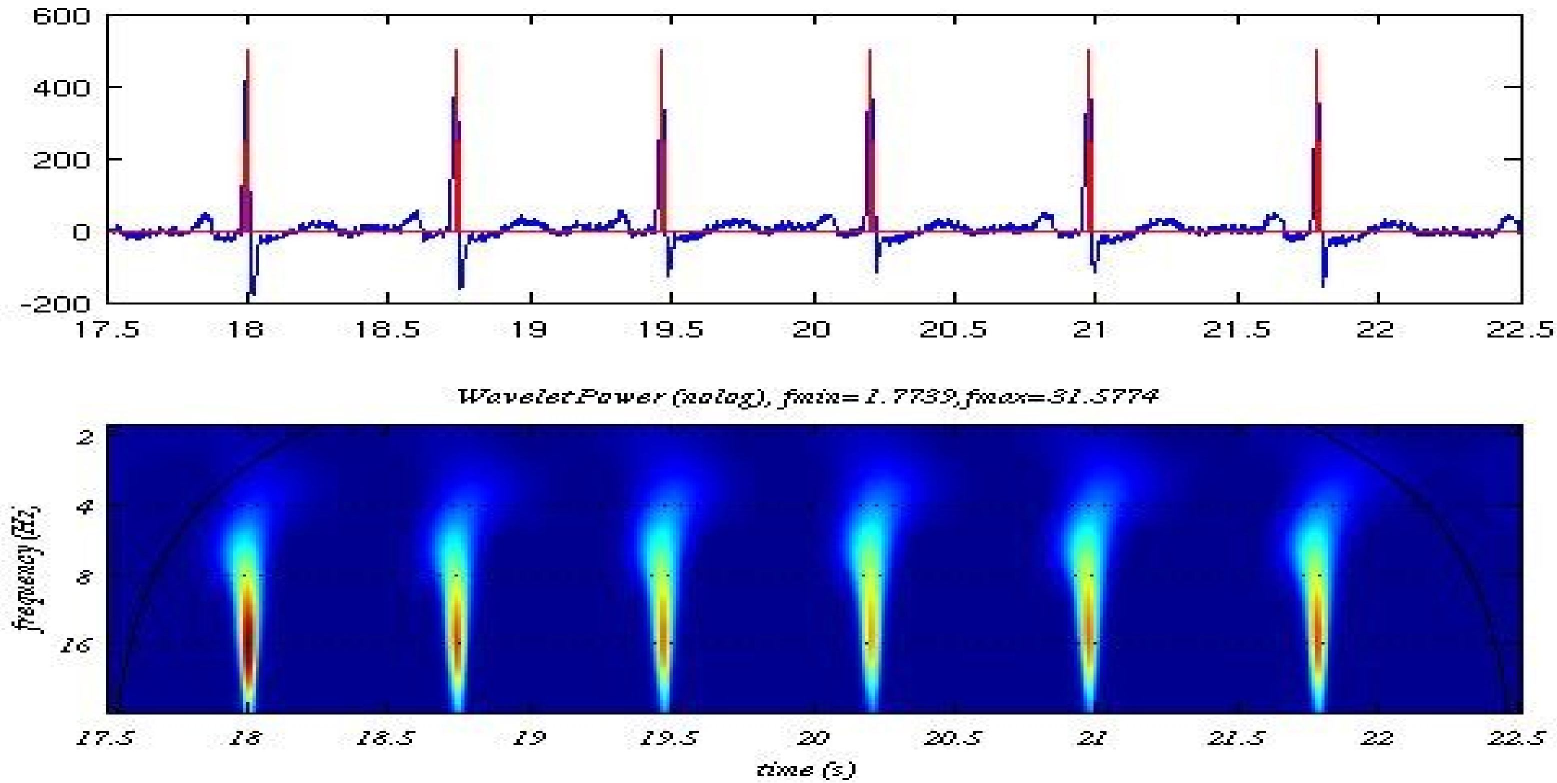
METHODOLOGY:

1. Compute analytical wavelet transform
2. Select band of interest (8Hz-16Hz)
3. Threshold and look for persistent lines
4. Locate the local maximums of the wavelet transform



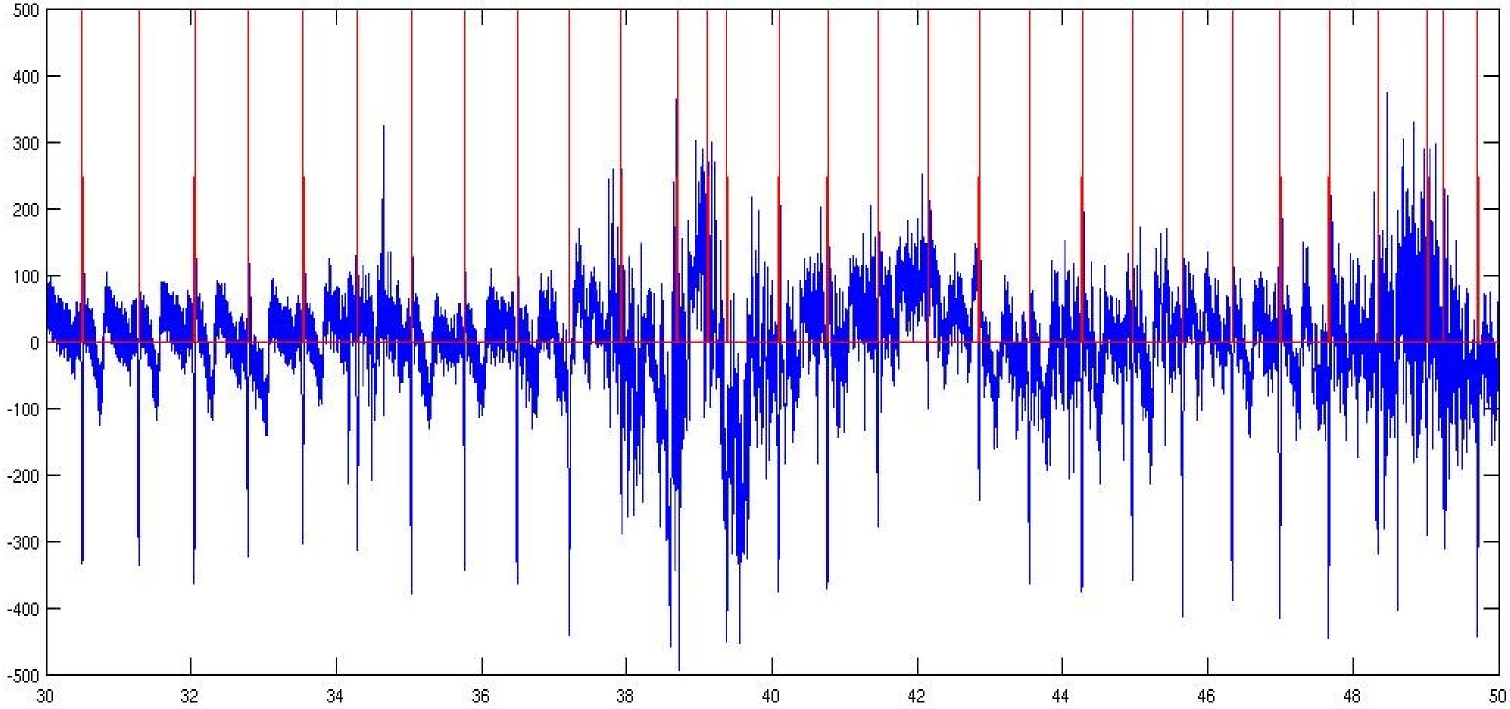
RESULTS:

Clean signal:



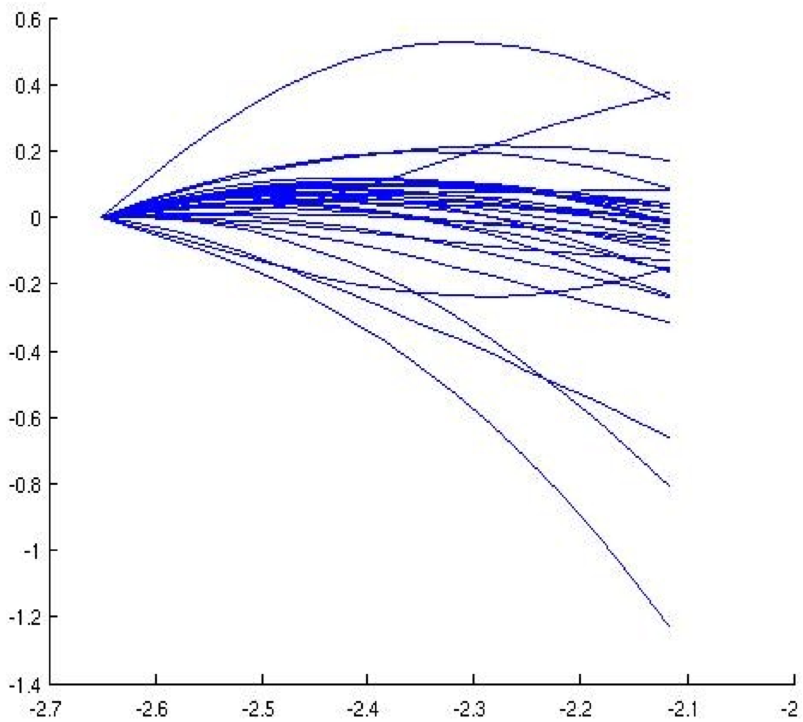
RESULTS

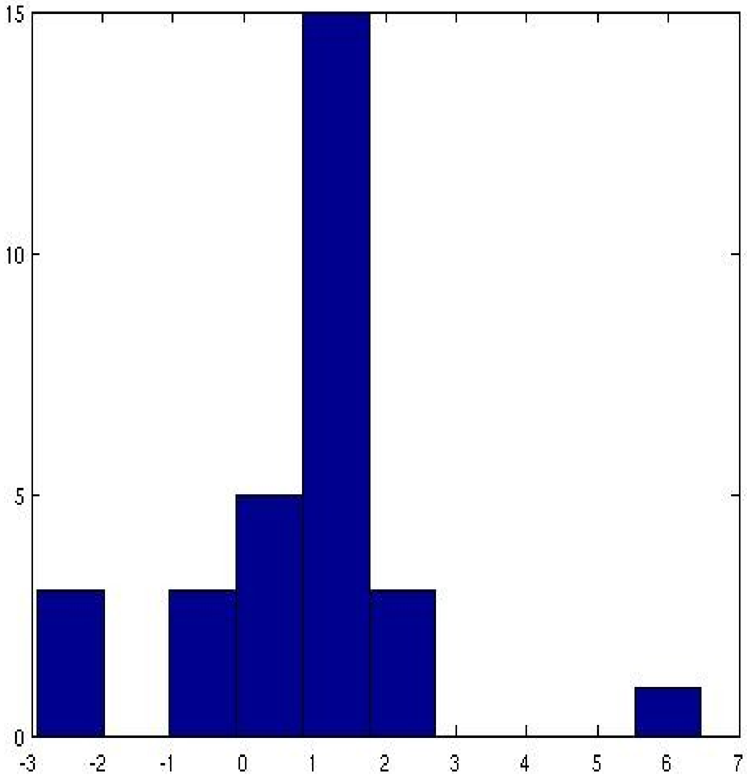
Noisy signal:



RESULTS

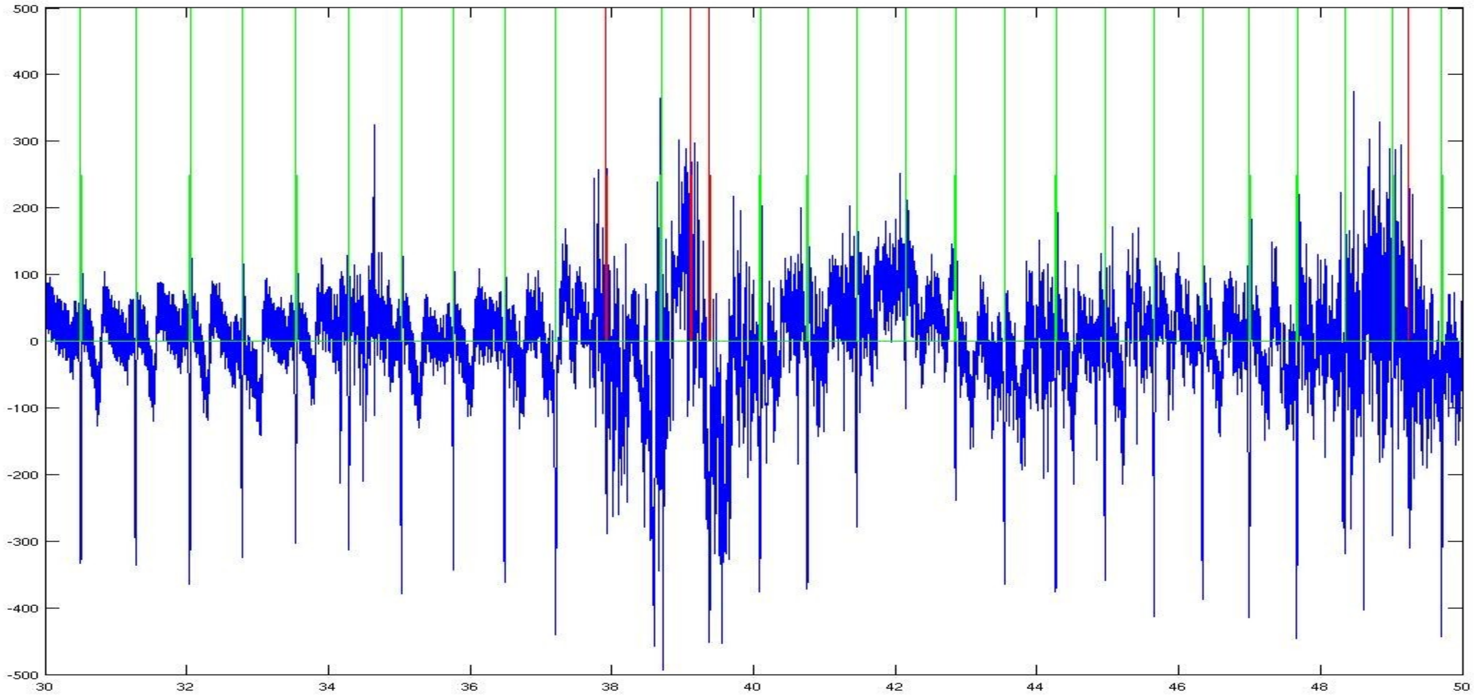
Noisy signal:





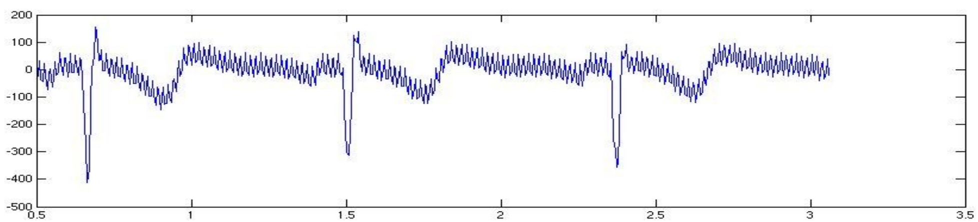
RESULTS

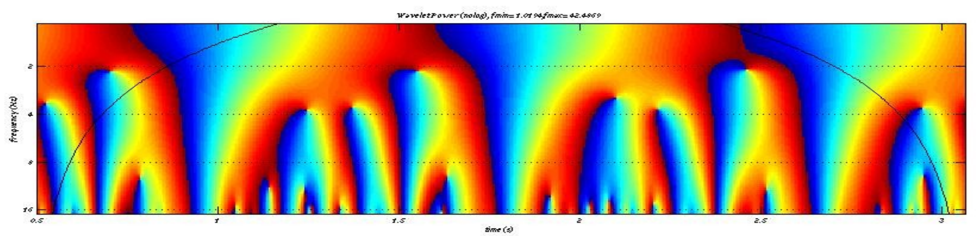
Noisy signal:



Validation of QRS complex localization

- Rate of coefficient change with respect to frequency signature
- Phase spectrum signature of the signal
- Robustness to detection parameter variation

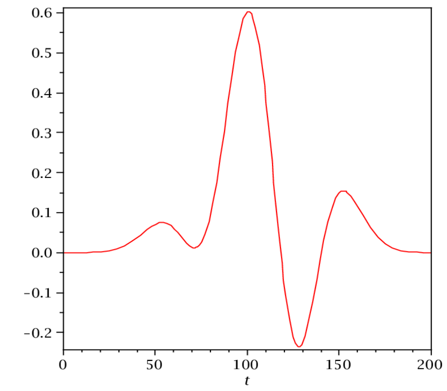




A constructed Wavelet

- We can define a projection into a subspace of functions that have desired characteristics.
- There are models to describe the heart beat
- Using the frequency function obtained by one of this simulations we define a wavelet
- Then we see how well this function match the data collected

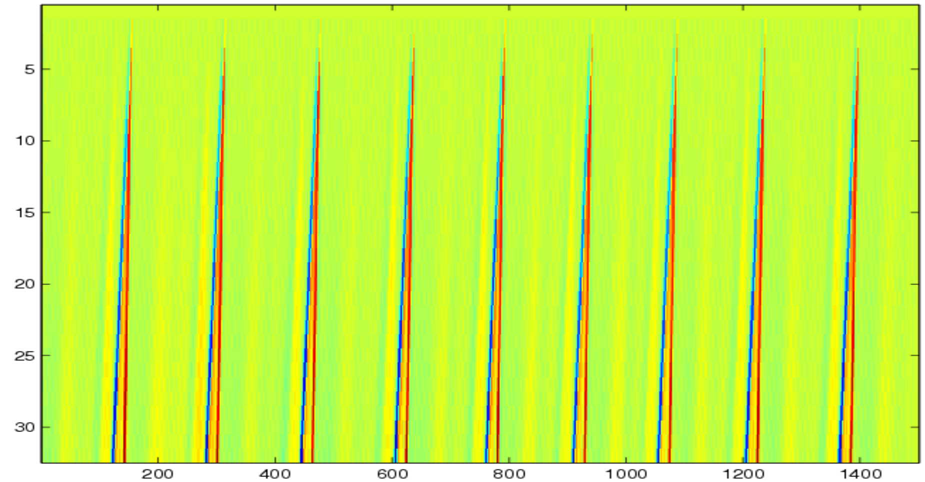
$$\phi_{a,b} =$$

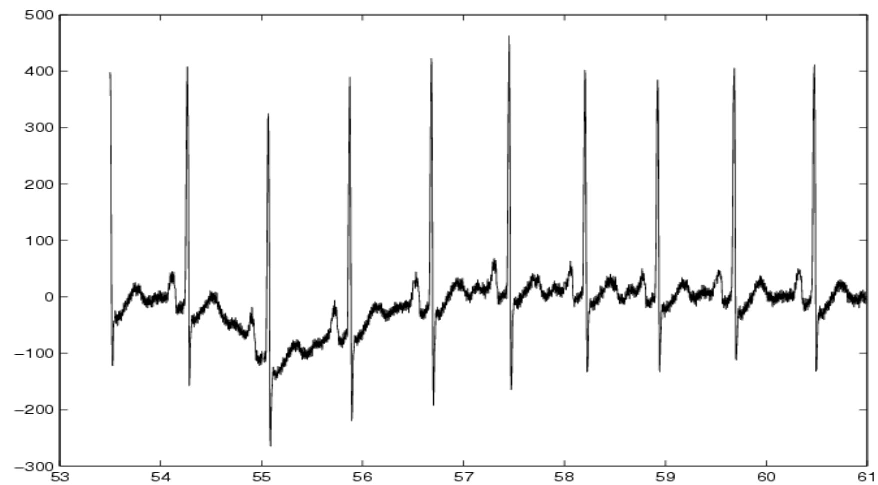


$$\langle f, \phi \rangle_{a,b} = f * \phi = \int f(s) \overline{\phi_{a,b}}(s)\, ds$$

Clean signals

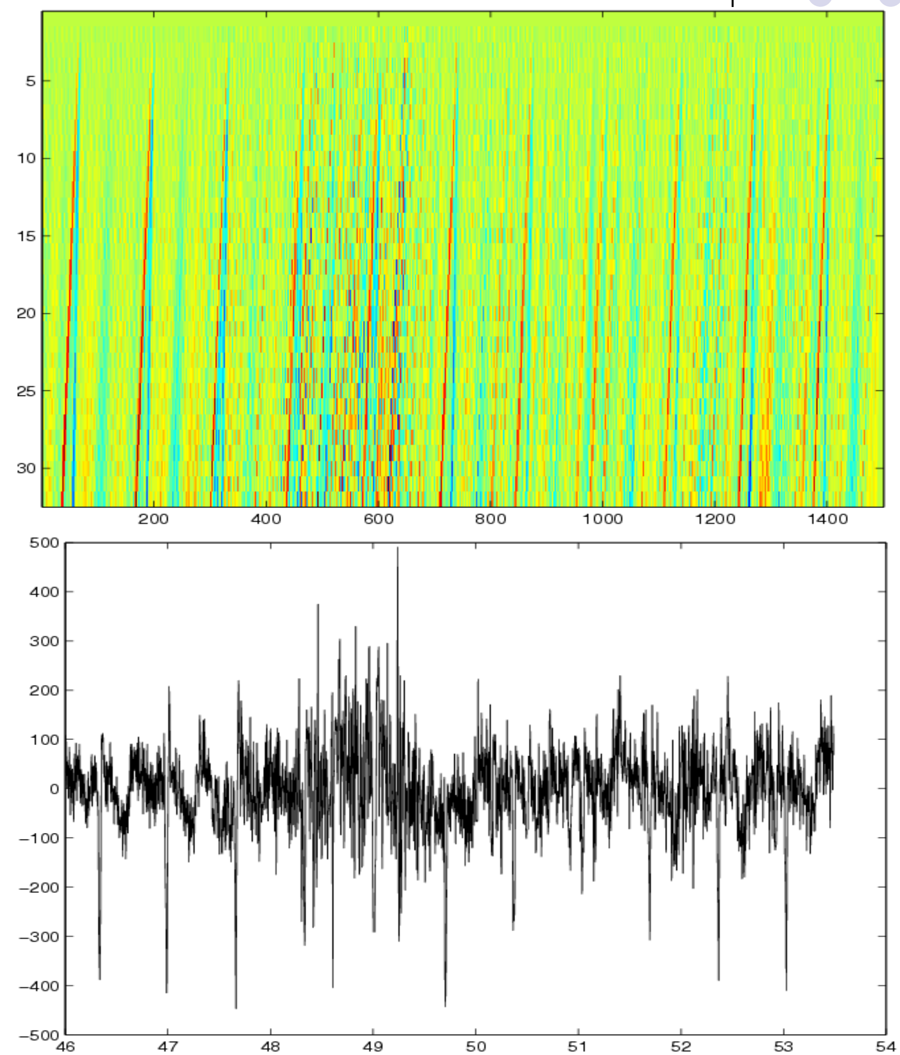
- Here we compare the wavelet coefficients vs. time
- The red lines indicate a hight correlation of the signal collected
- Low amplitude noise will vary the color of the back





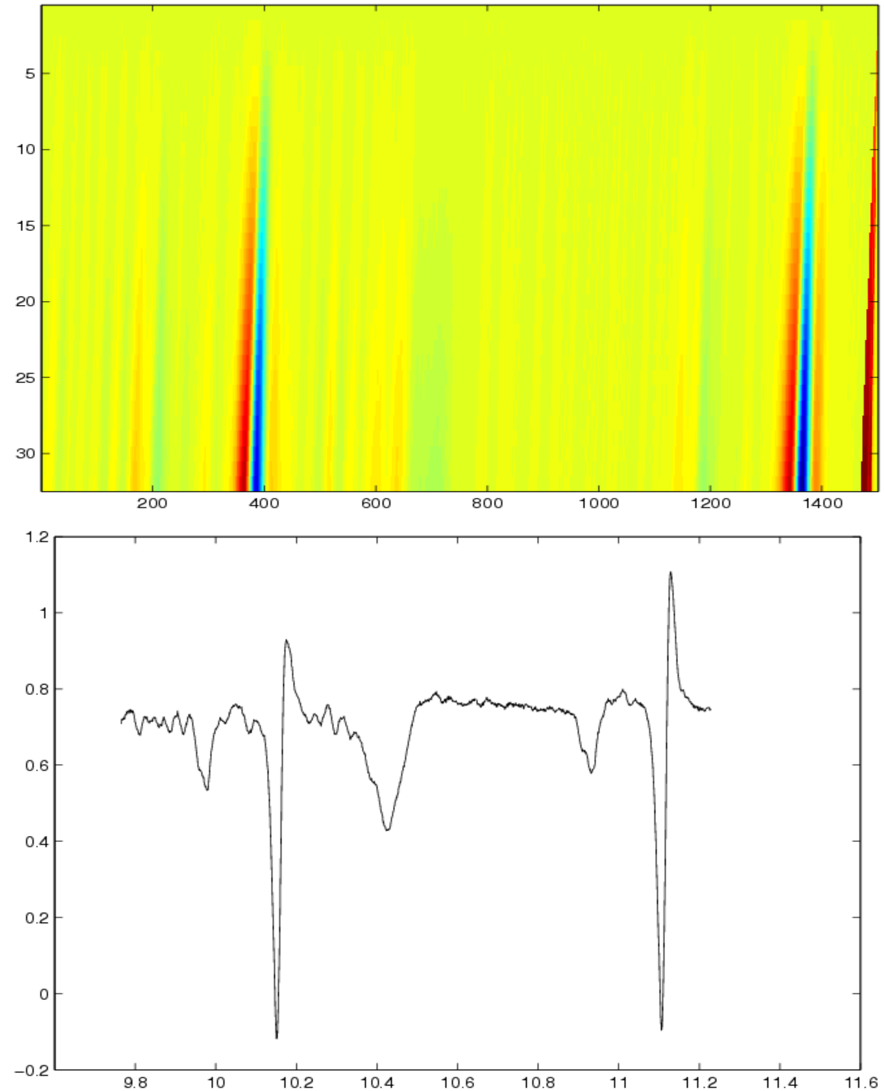
Some Noise

- This method is good cleaning noise that has a similar frequency and amplitude.



A weakness

- The signal has a jump, this method is not effective very effective.
- Whoever, there are better methods, to eliminate this kind of noise.

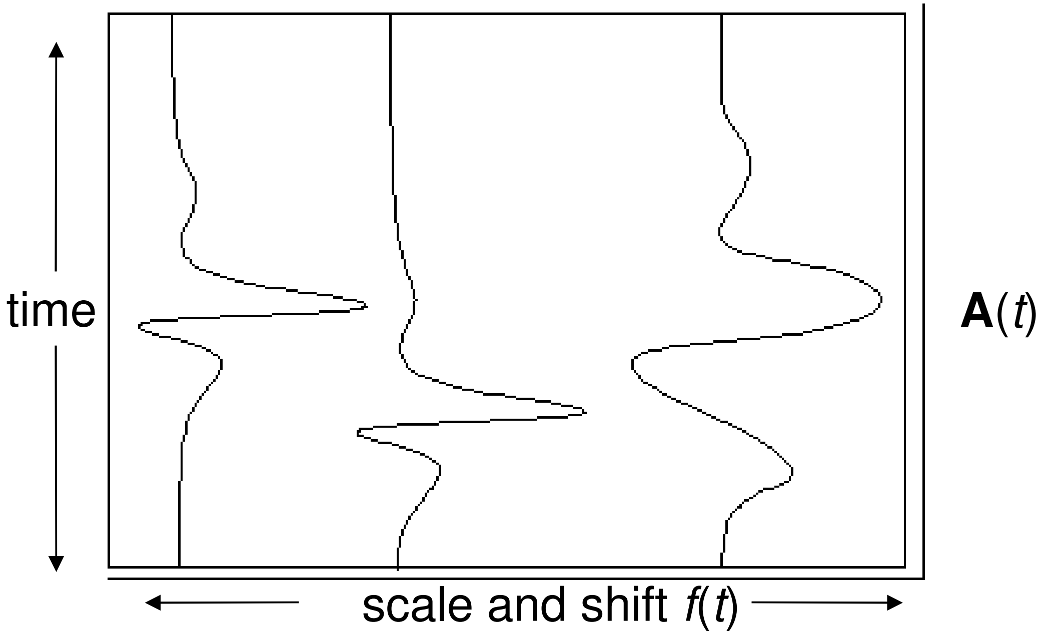


A 'Dictionary' Method

- Suppose we can write the signal as

$$s(t) = \mathbf{A}(t)\,\mathbf{c} + \text{residuals}$$

where **A**(t) is a “dictionary” of functions and **c** is a vector of coefficients



- Functions $f(t)$ are analytical models of QRS Complex

Optimization Problem

- What coefficient vector, **c**, gives the least residual?

- Convert to least squares optimization problem

$$\min_{c} \|s(t) - \mathbf{A}(t)\mathbf{c}\|^2$$

- This problem alone does not have a unique solution

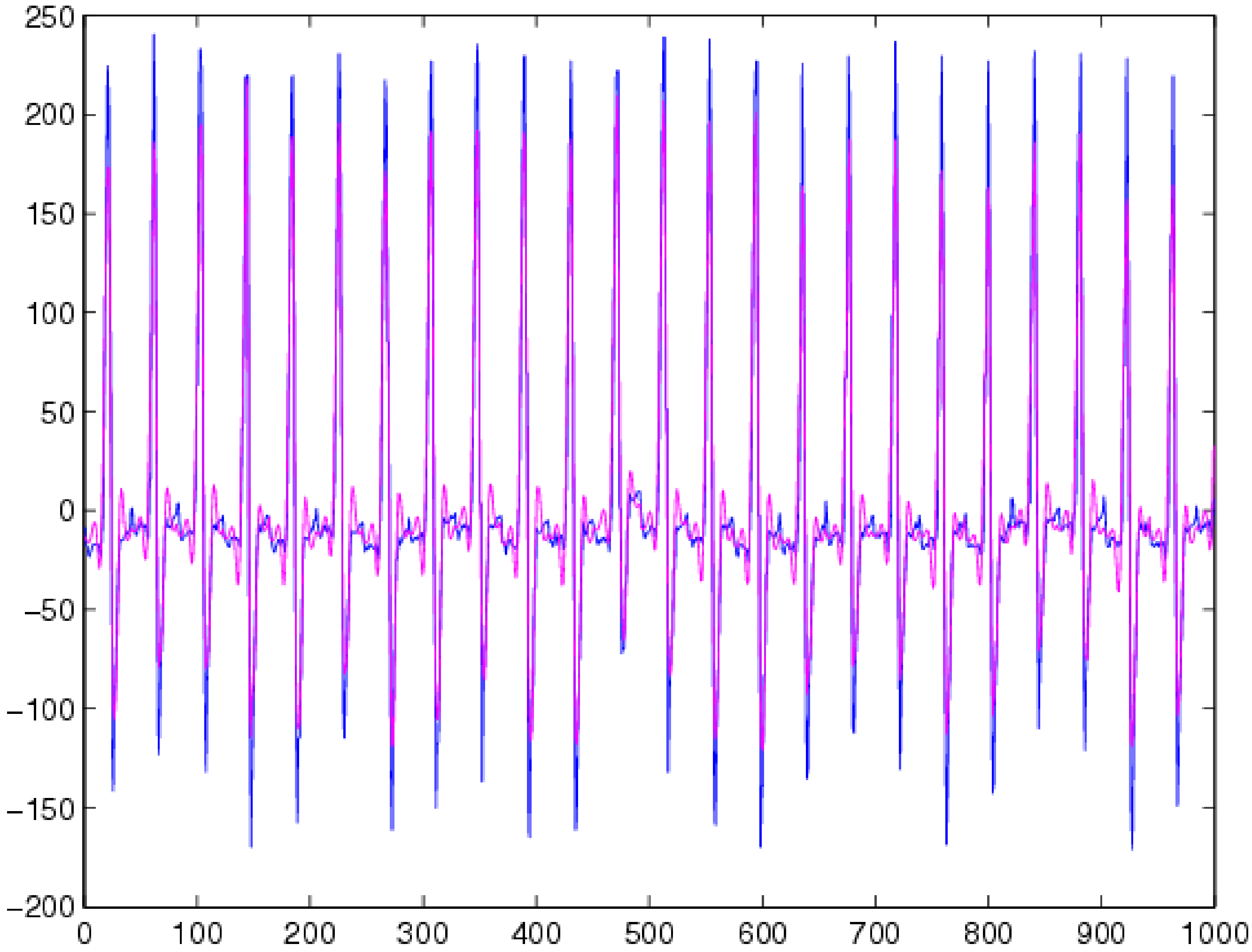
- Add the condition

$$\|\mathbf{c}\|_1 = |c_1| + |c_2| + ... \leq \gamma$$

with γ as small as possible for reasonable solutions

- This allows minimal number of coefficients

Results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