Heart Sound Segmentation: A Stationary Wavelet Transform Based Approach

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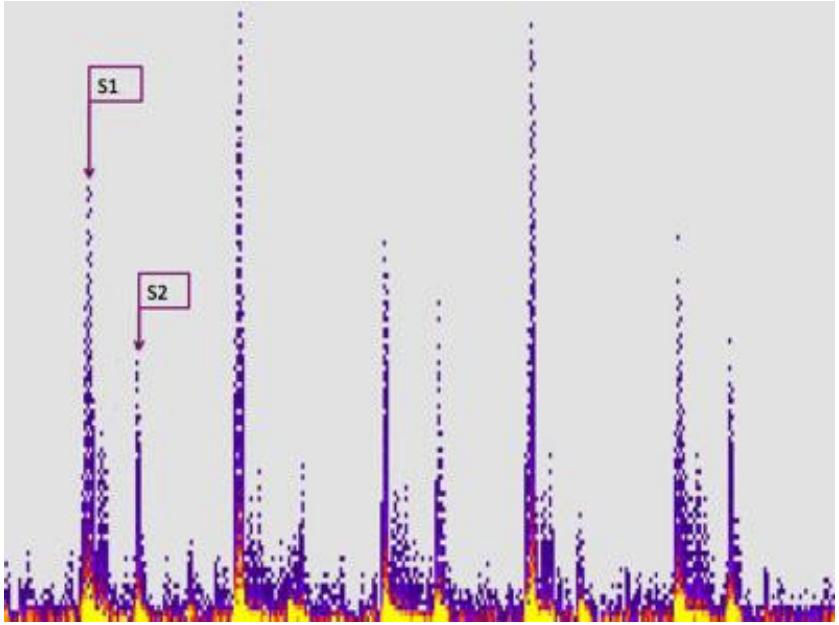
Classifying Heart Sounds PASCAL Challenge

The challenge had 2 tasks:
Segmentation and Classification
and Anomaly Detection

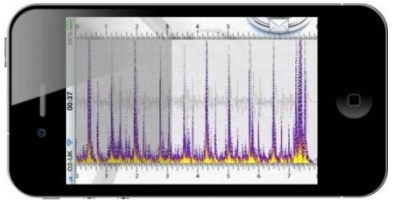


This work describes what i did in the first task: Segmentation and Classification

Datasets

44100 Hz
20 auscultations

iStethoscope



- Non-controlled environment
- No expert!
- Who was auscultated ?

4000 Hz
80 auscultations

Digiscope

- Controlled environement
- Done by expert!
- Auscultation were performed on infants exclusively!

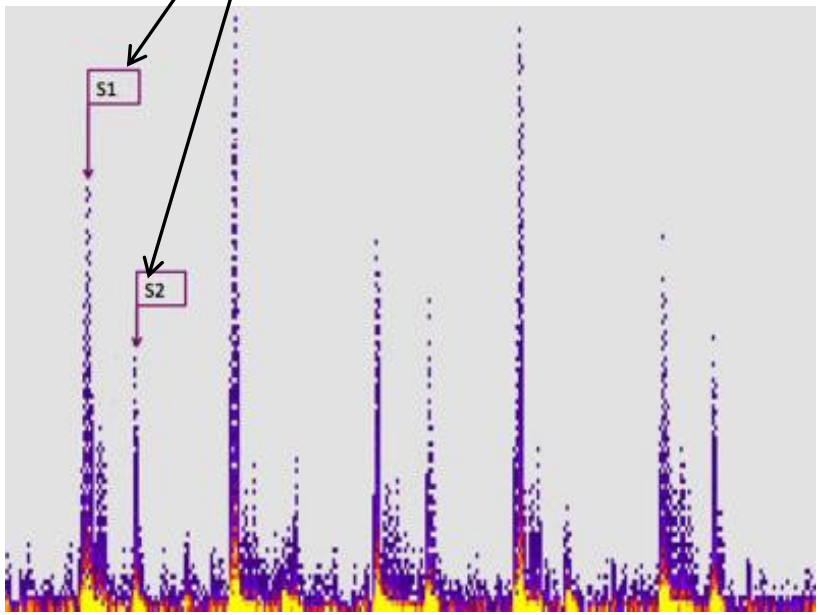
Heart Sounds

Normal Heart Sounds

Normal S1 and S2

Best with headphones.

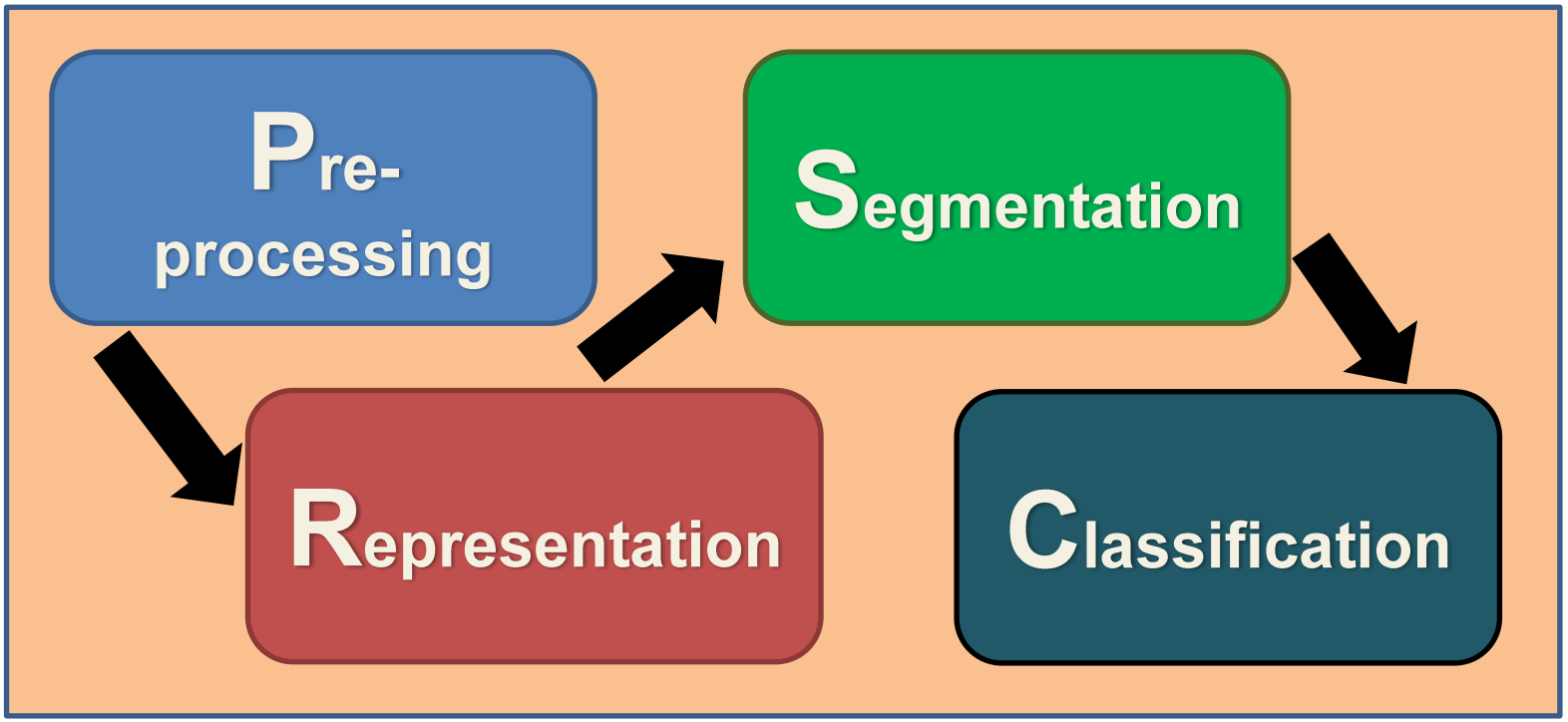
We want to detect and distinguish these two peaks ! (which are the heart sounds!)



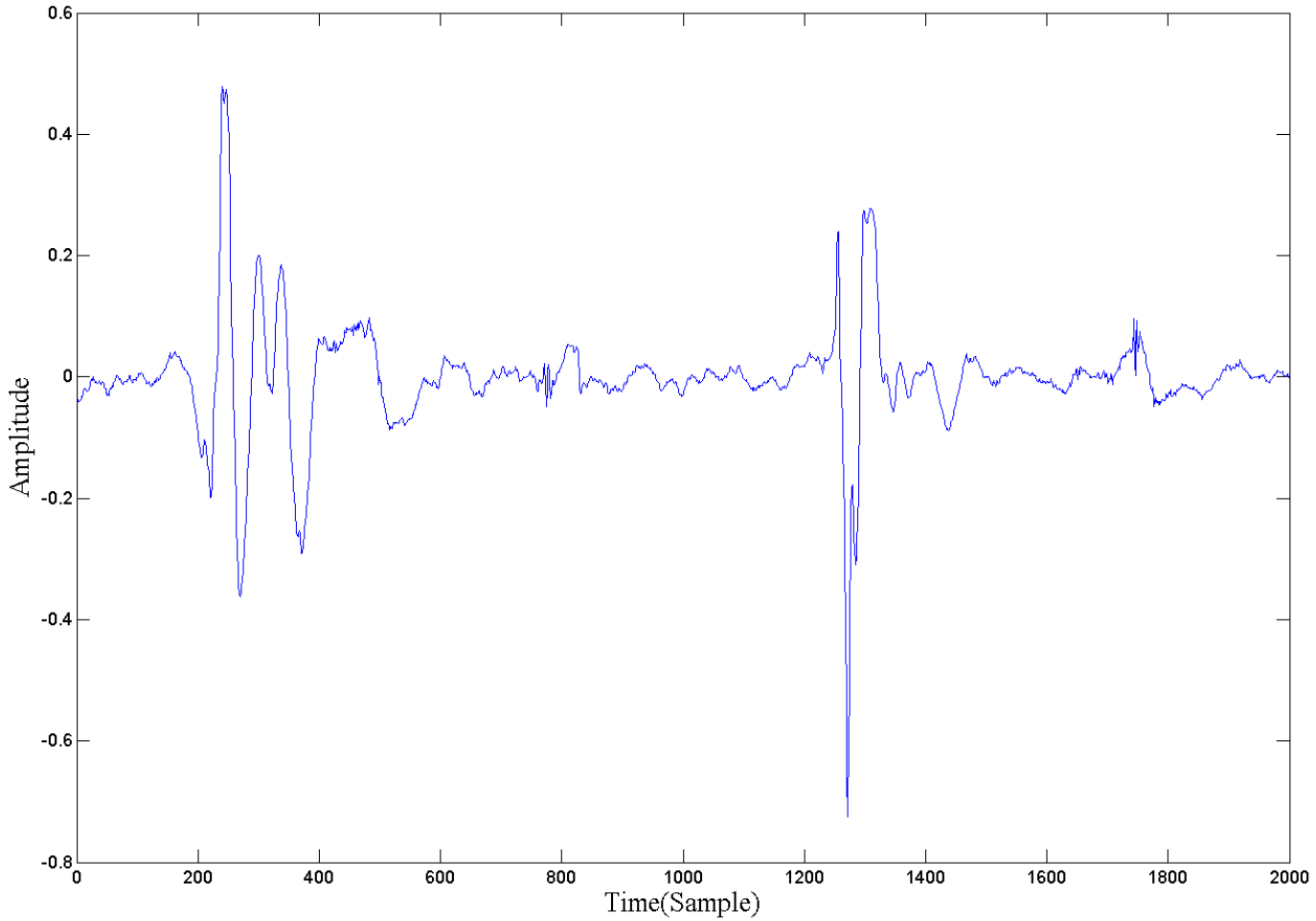
How do you detect and distinguish heart sounds ?

Heart Sound Segmentation

Cardiac Segmentation algorithms can be successfully divided in 4 phases:

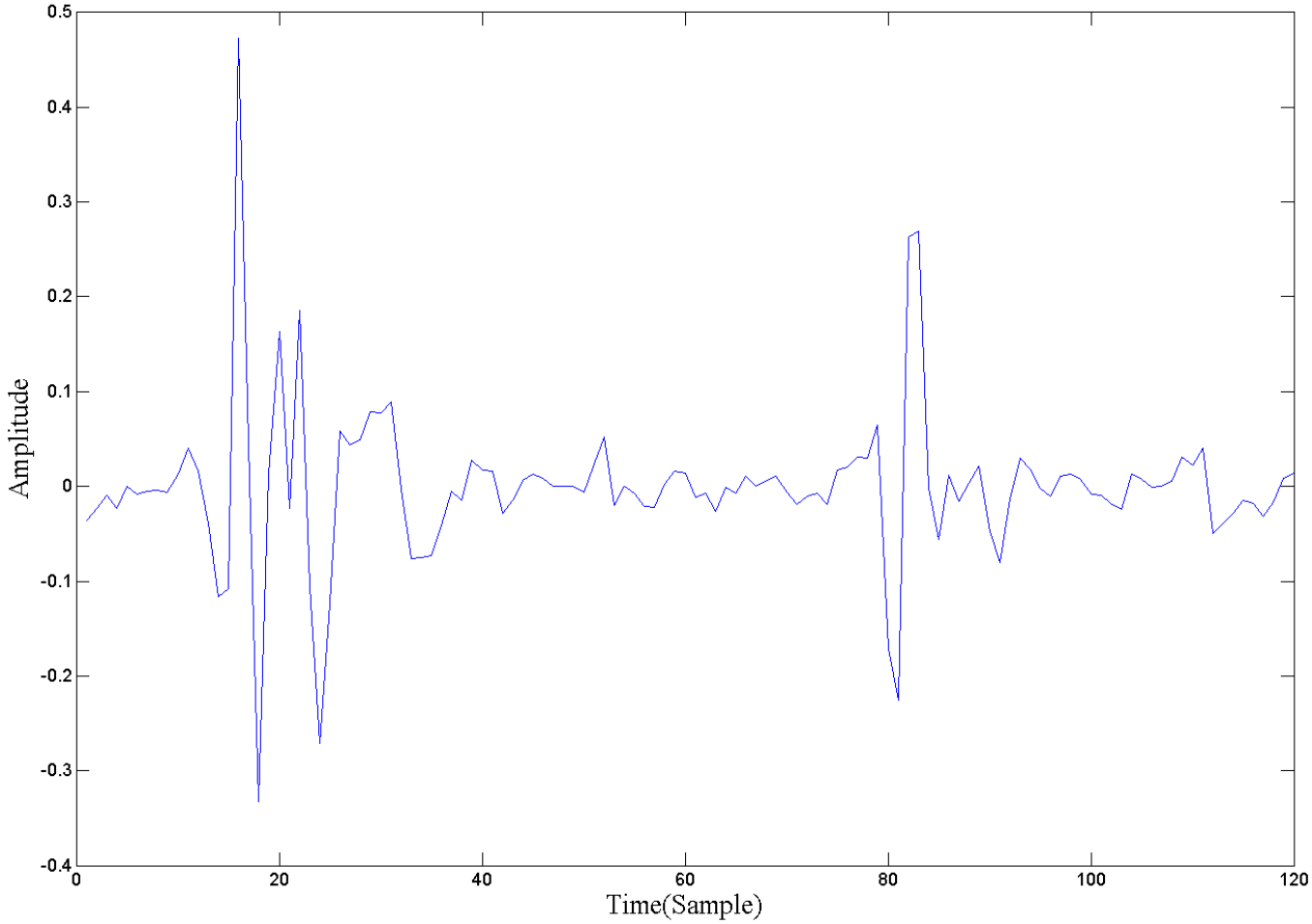


Pre-processing



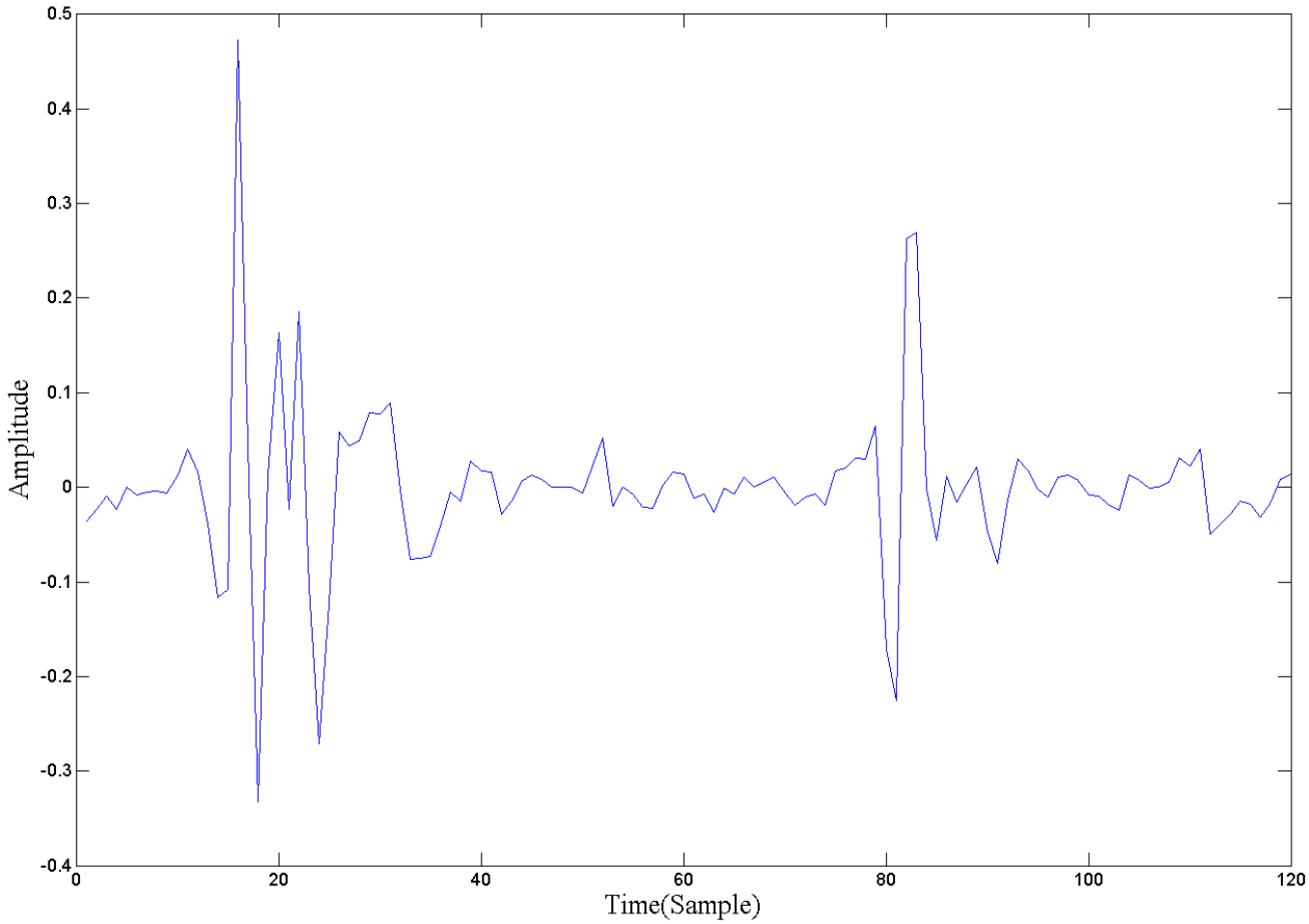
P

Pre-processing



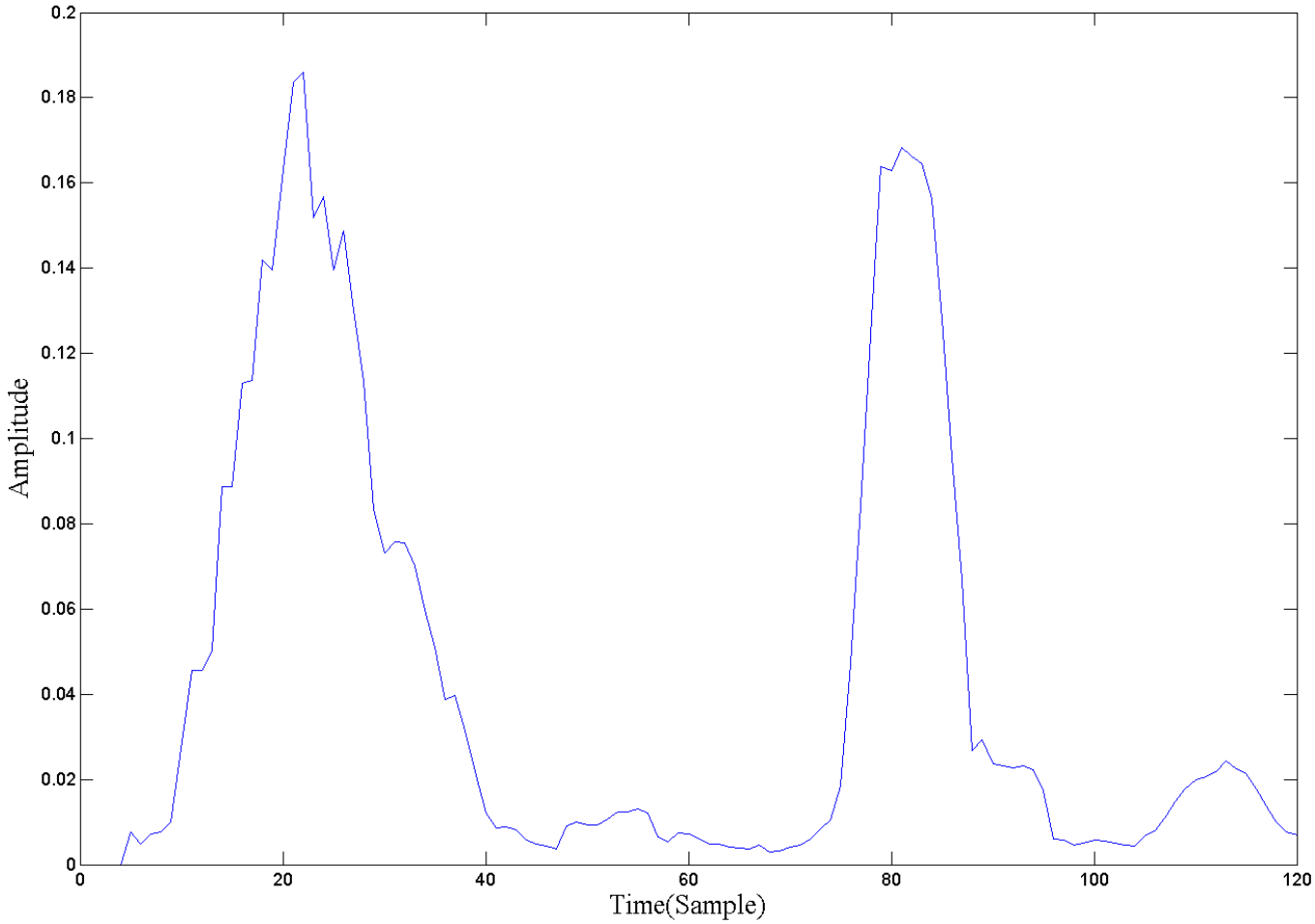
P

Representation



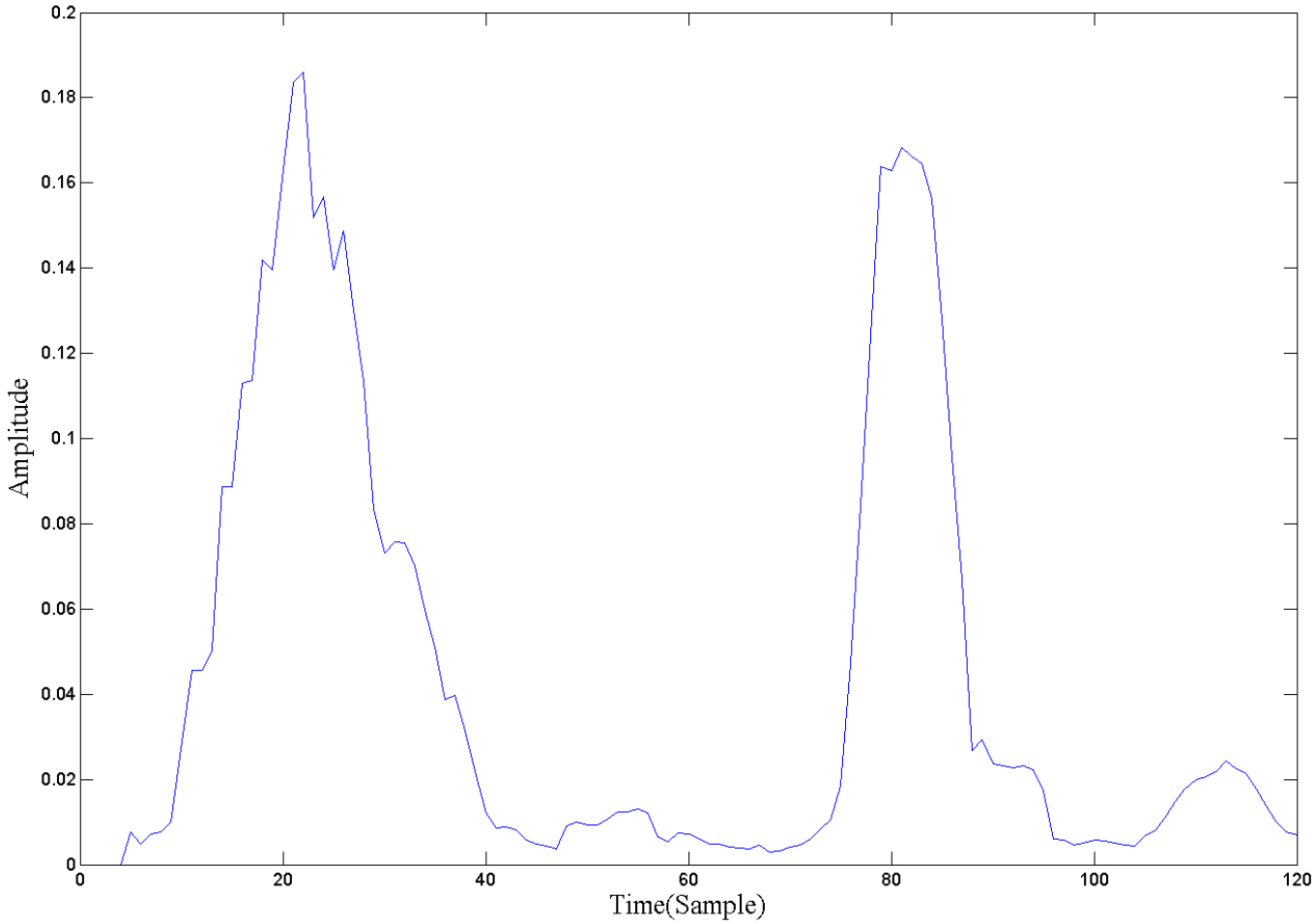
R

Representation



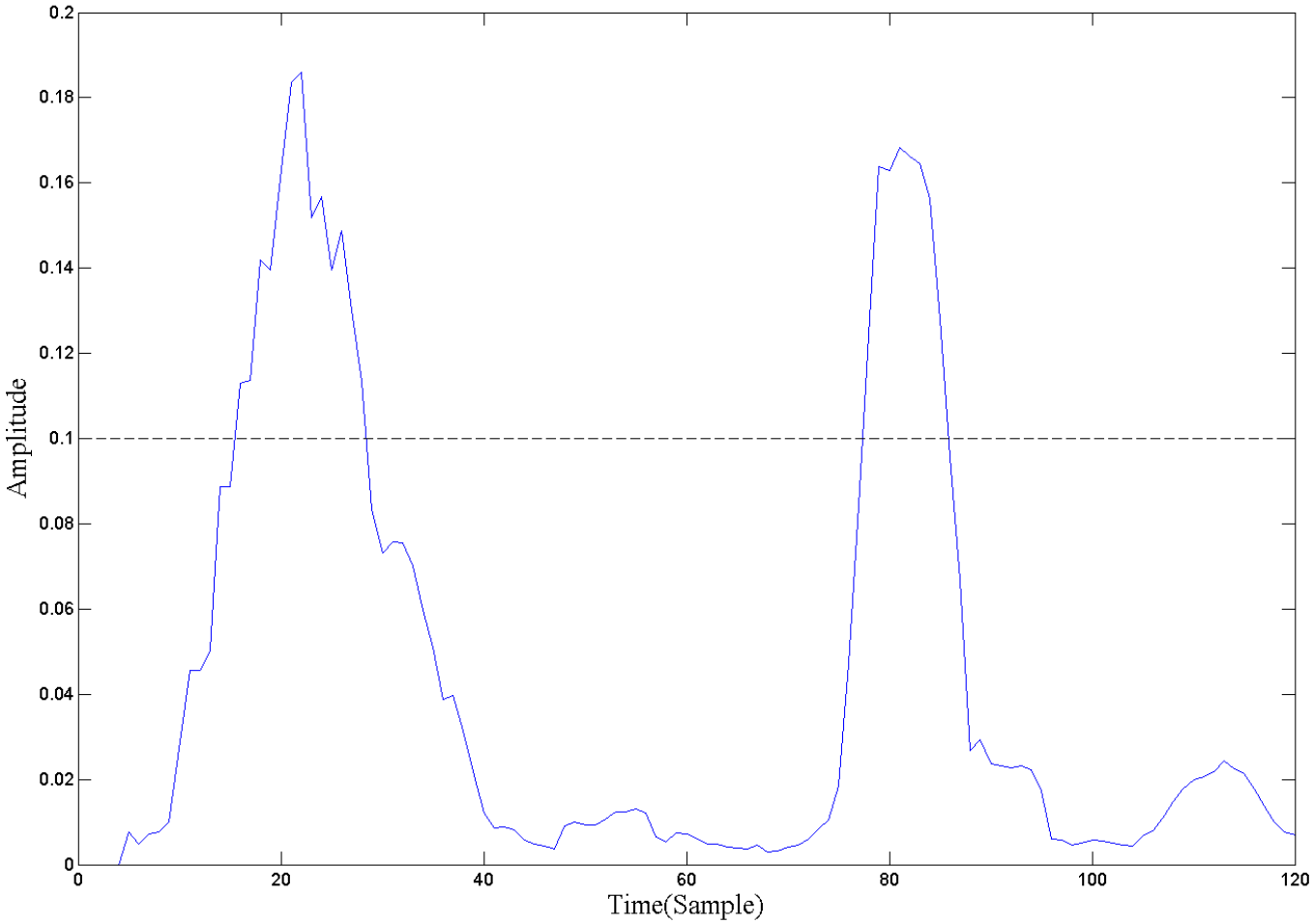
R

Segmentation



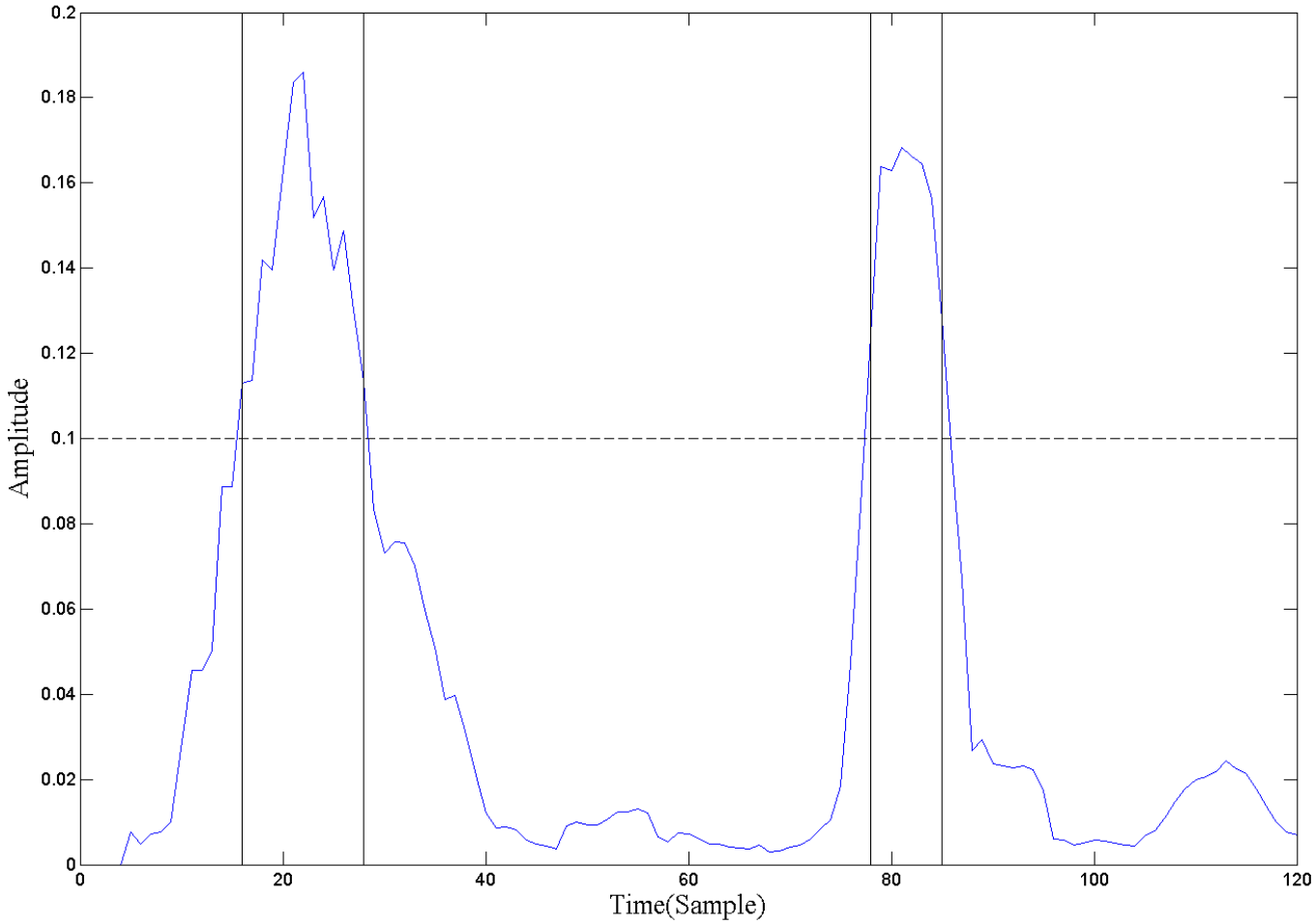
S

Segmentation

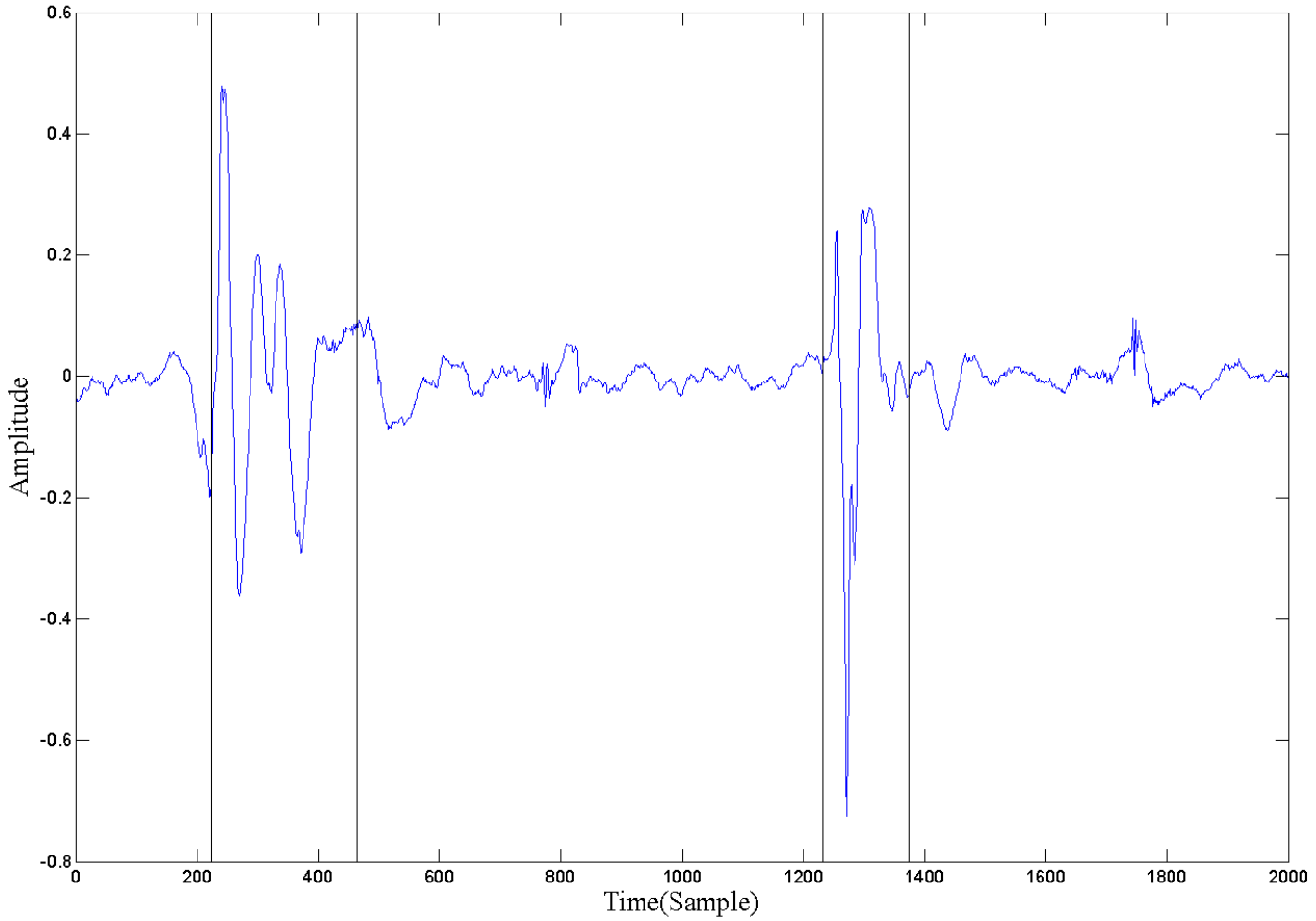


S

Segmentation



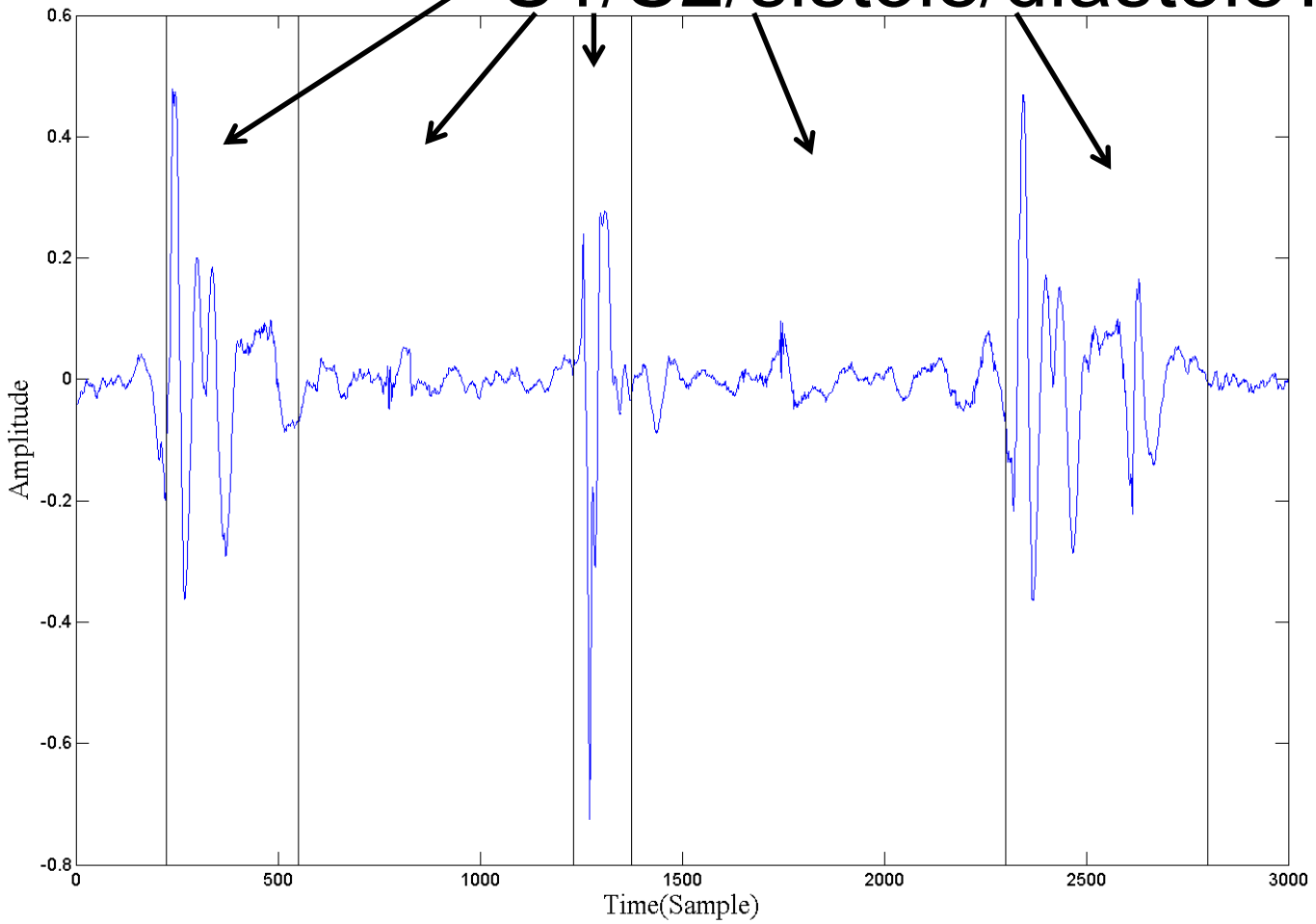
Segmentation



S

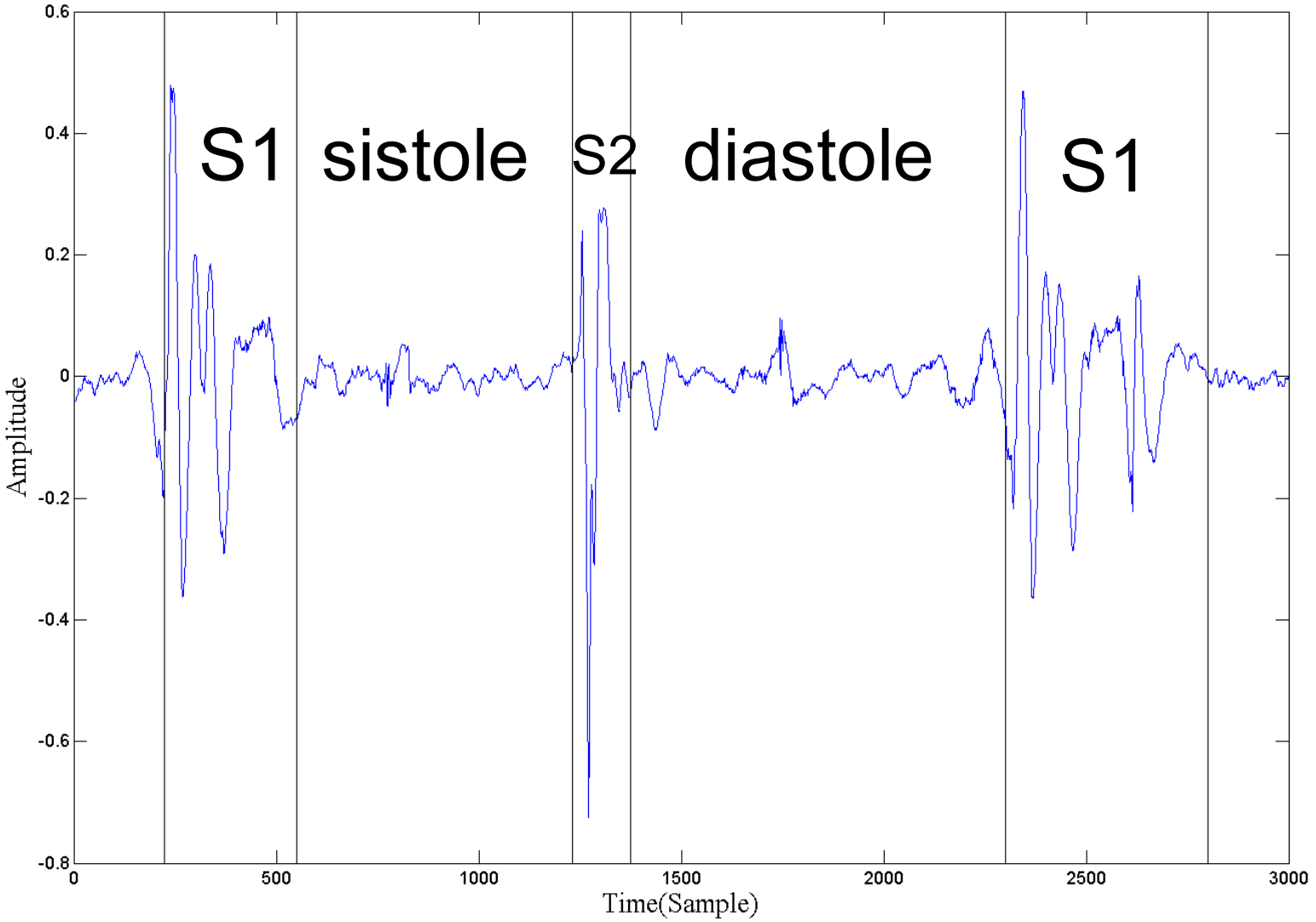
Classification

S1/S2/sistole/diastole?!



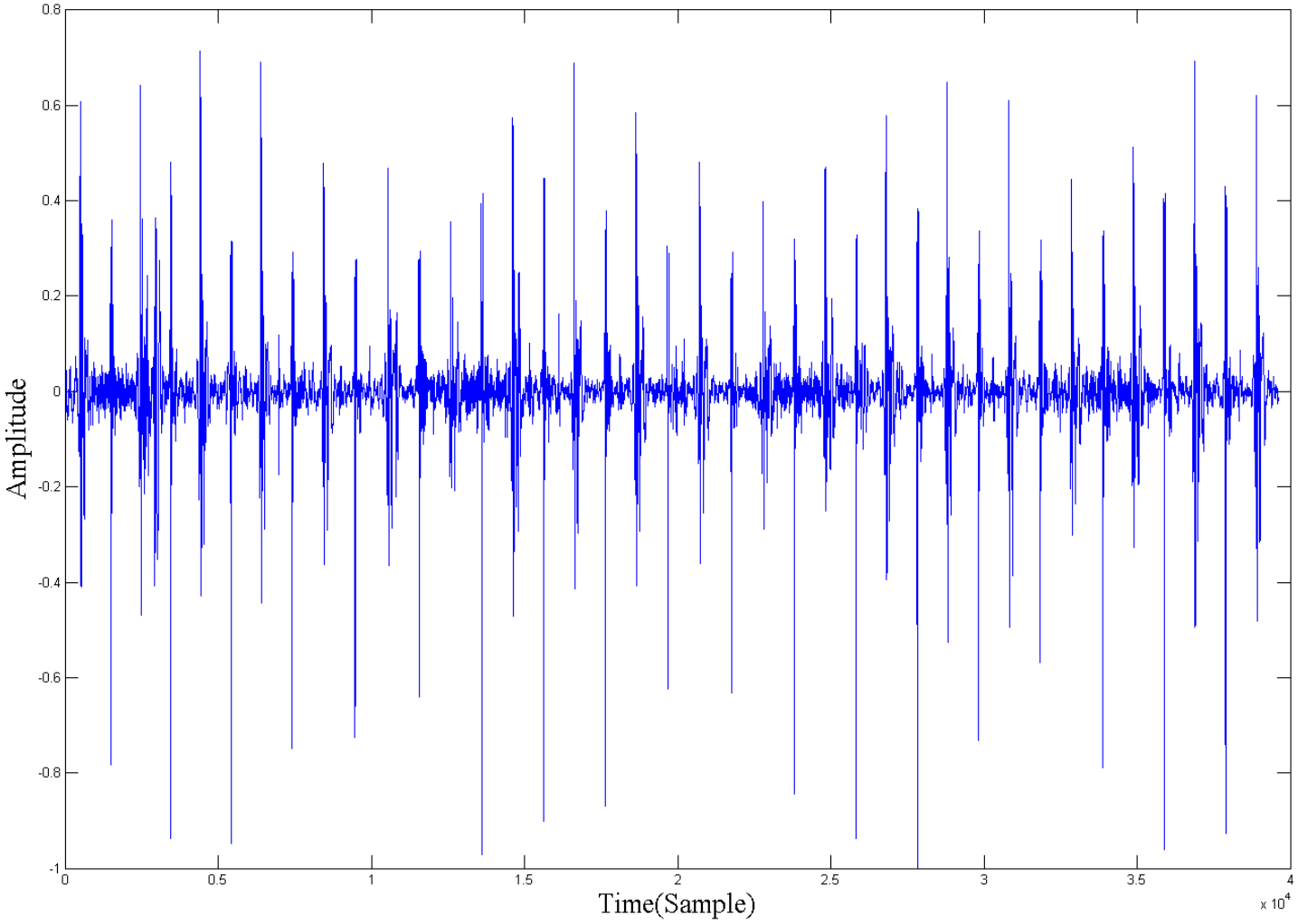
C

Classification

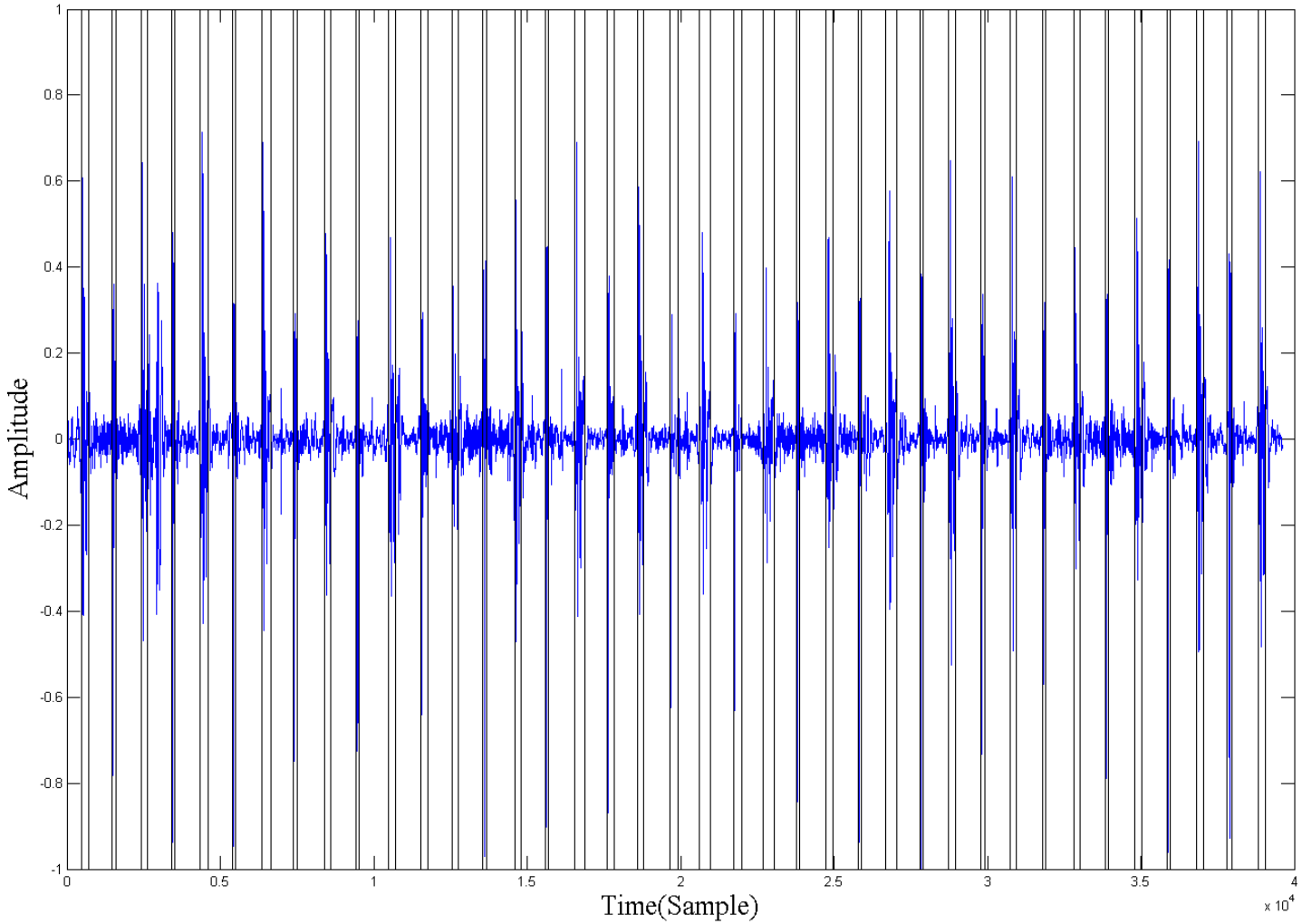


C

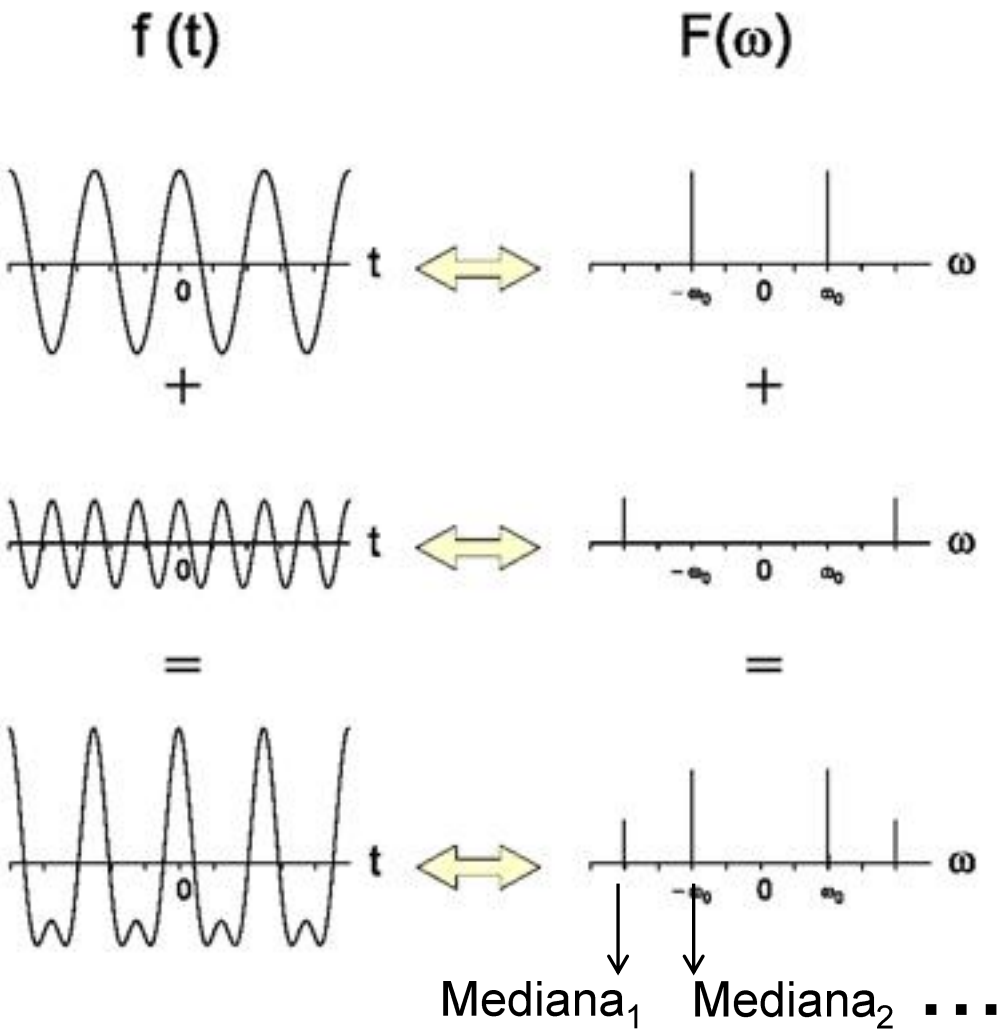
Manual Annotation



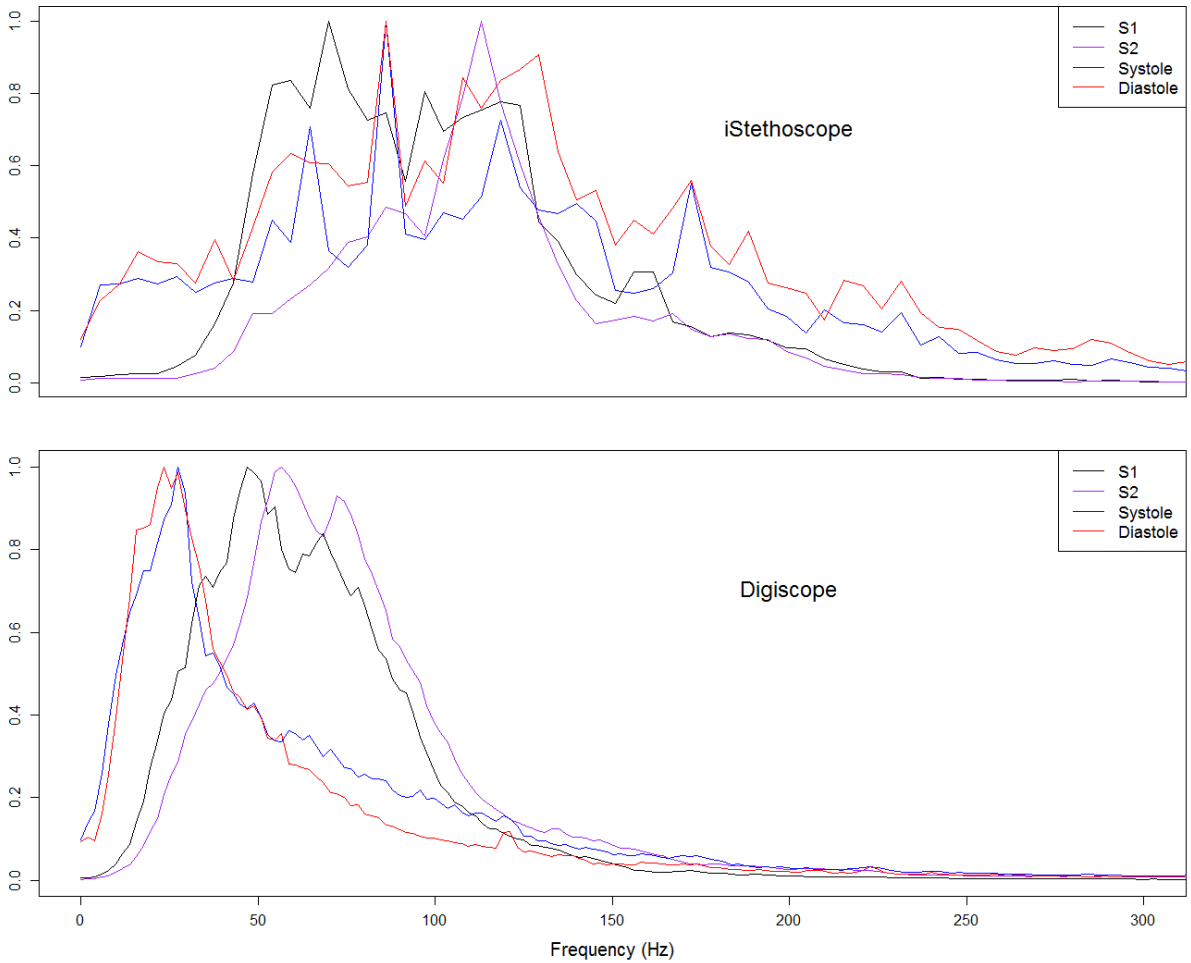
Manual Annotation



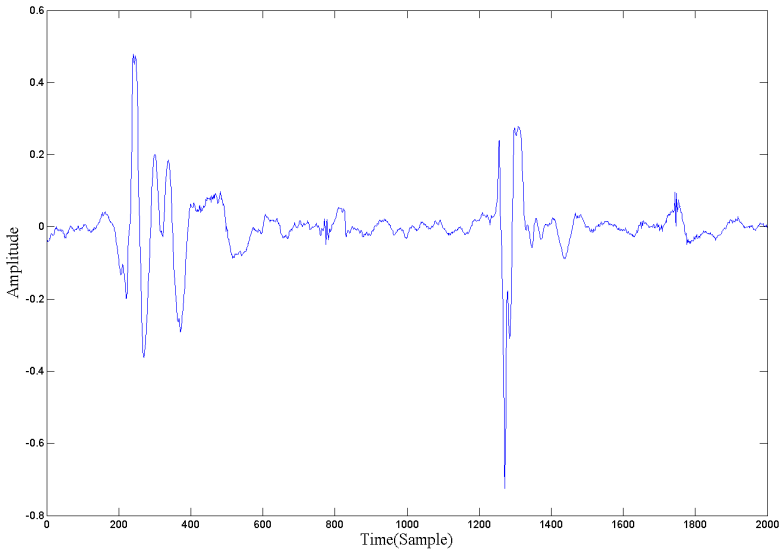
Fourier Transform

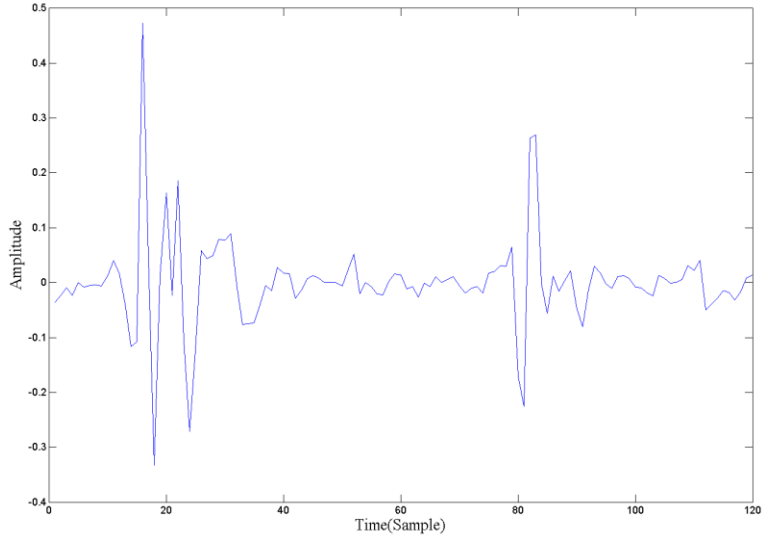


Spectral Analysis



Pre-Processing





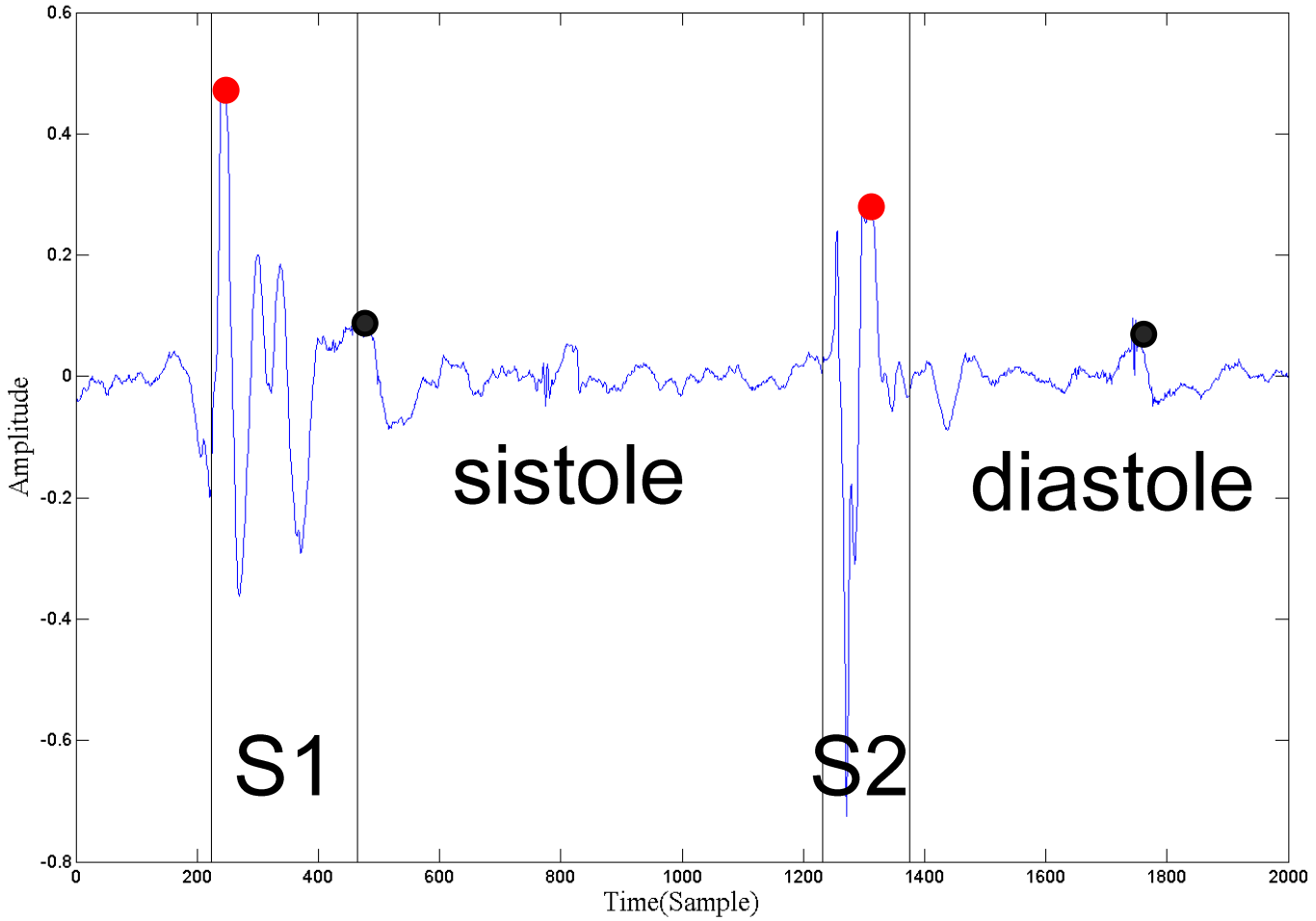
Just downsampled iStethoscope!

Representation

A good cardiac signal representation should have 2 characteristics g_1 e g_2

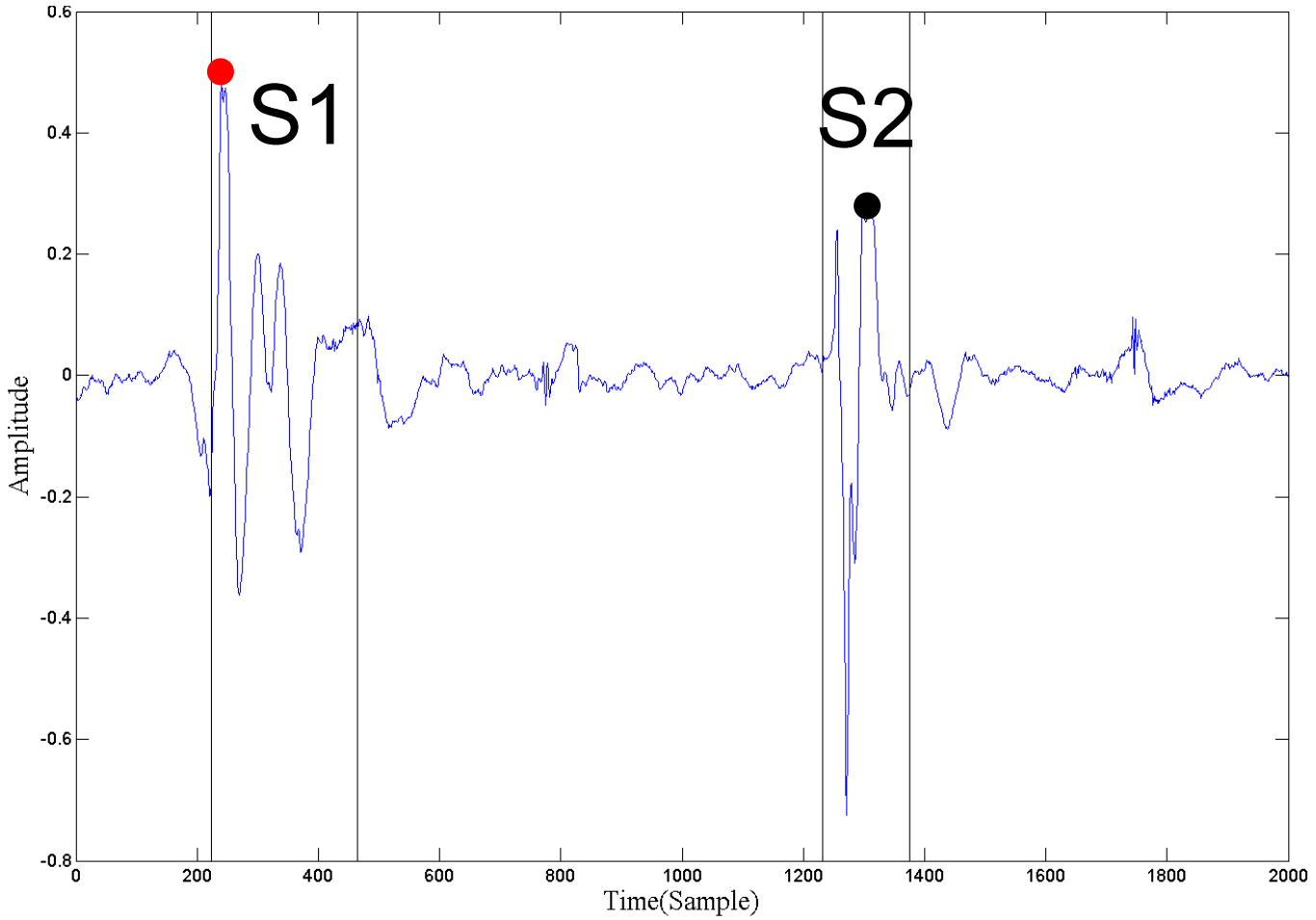
g_1. Accentuate the difference between S1/S2 and sistole/diastole

$$g_1 = |median(max(w_{S1,S2}(t))) - median(max(w_{Systole,Diastole}(t)))|$$



g_2. Accentuate the difference between S1 and S2

$$g_2 = |median(max(w_{S1}(t))) - median(max(w_{S2}(t)))|$$

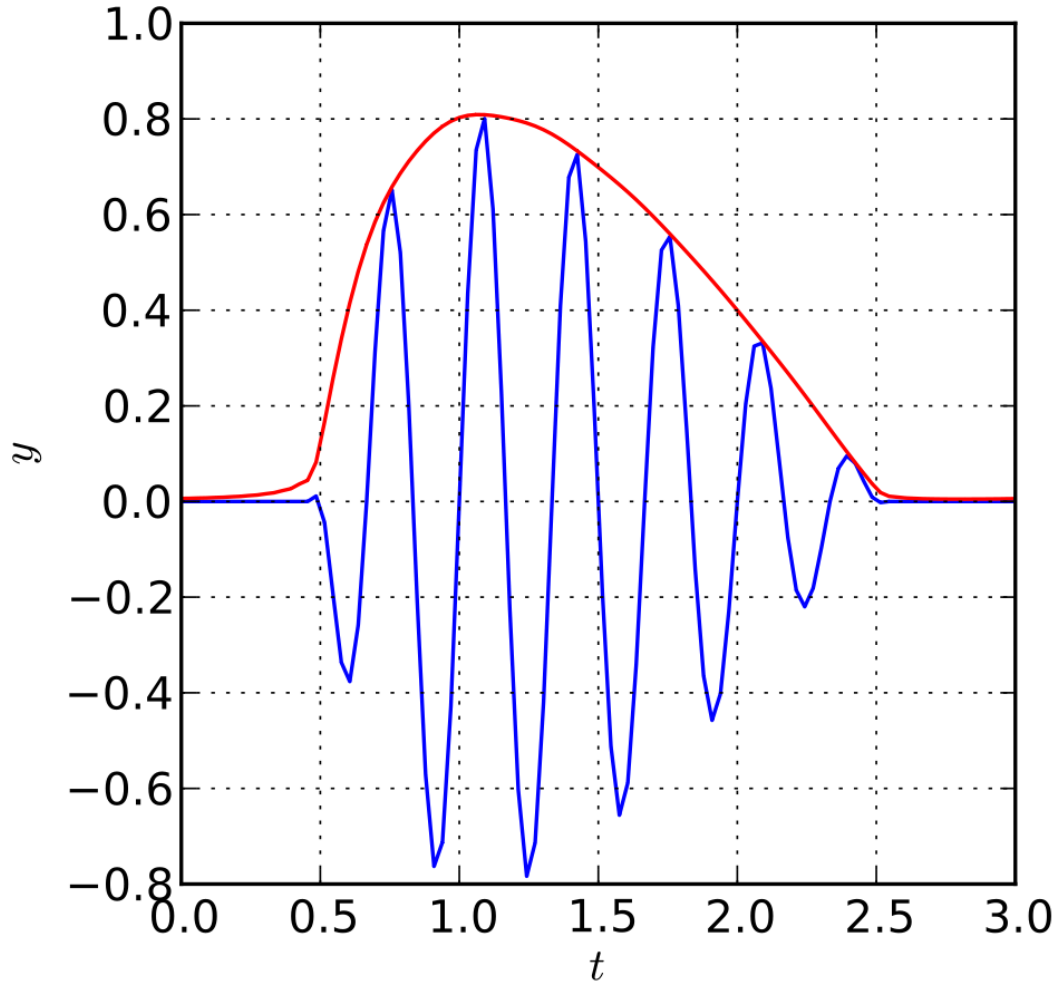


Representation

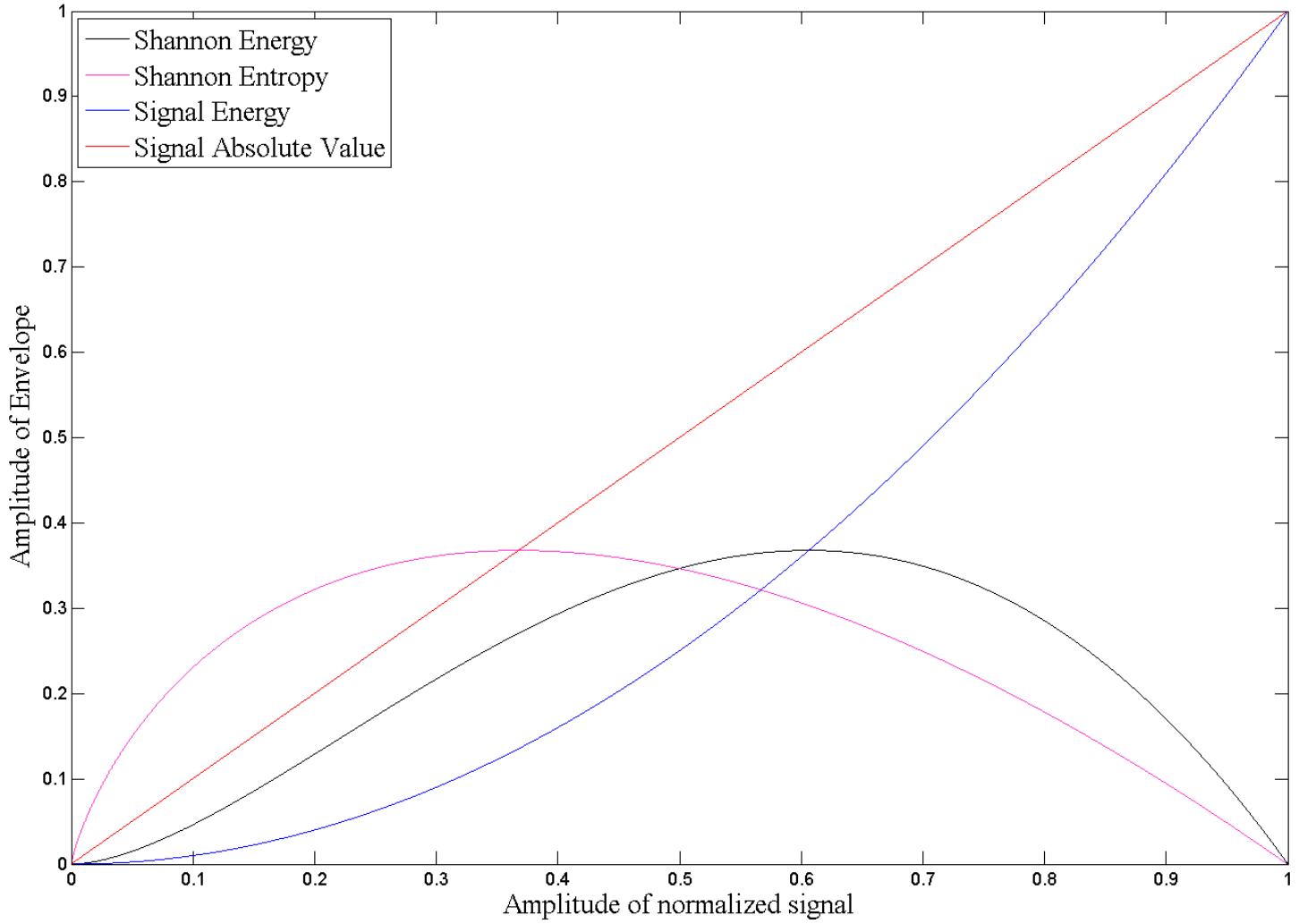
- Shannon Energy Envelope
- Shannon Entropy Envelope

Domínio do tempo

Shannon Energy Envelope



Shannon Energy/Entropy



Representations

- Continuous Wavelet Transform
- Discrete Wavelet Transform
- Stationary Wavelet Transform
- S-Transform

- Empirical Mode Decomposition
- Hilbert-Huang Transform

Time-Frequency Domain

Digiscope Results

Representation	Order	Scale	Coef	g_1	g_2
DWT	38	3	c_a	0,63	0,014
SWT	1	3	c_a	0,59	0,26
CWT	2	60(*)		0,57	0,22
S-T		380(*)		0,42	0,25
Original Signal				0,57	0,2875
Shannon Energy				**0,70**	0,18
Shannon Entropy				0,35	0,03
HHT				0,28	0,17
EMD				0,31	0,17
DWT	5	3	c_d	0,32	0,42
SWT	15	3	c_d	0,36	0,48
CWT	13	240(*)		0,40	**0,50**
S-T		500(*)		0,42	0,33

iStethoscope Results

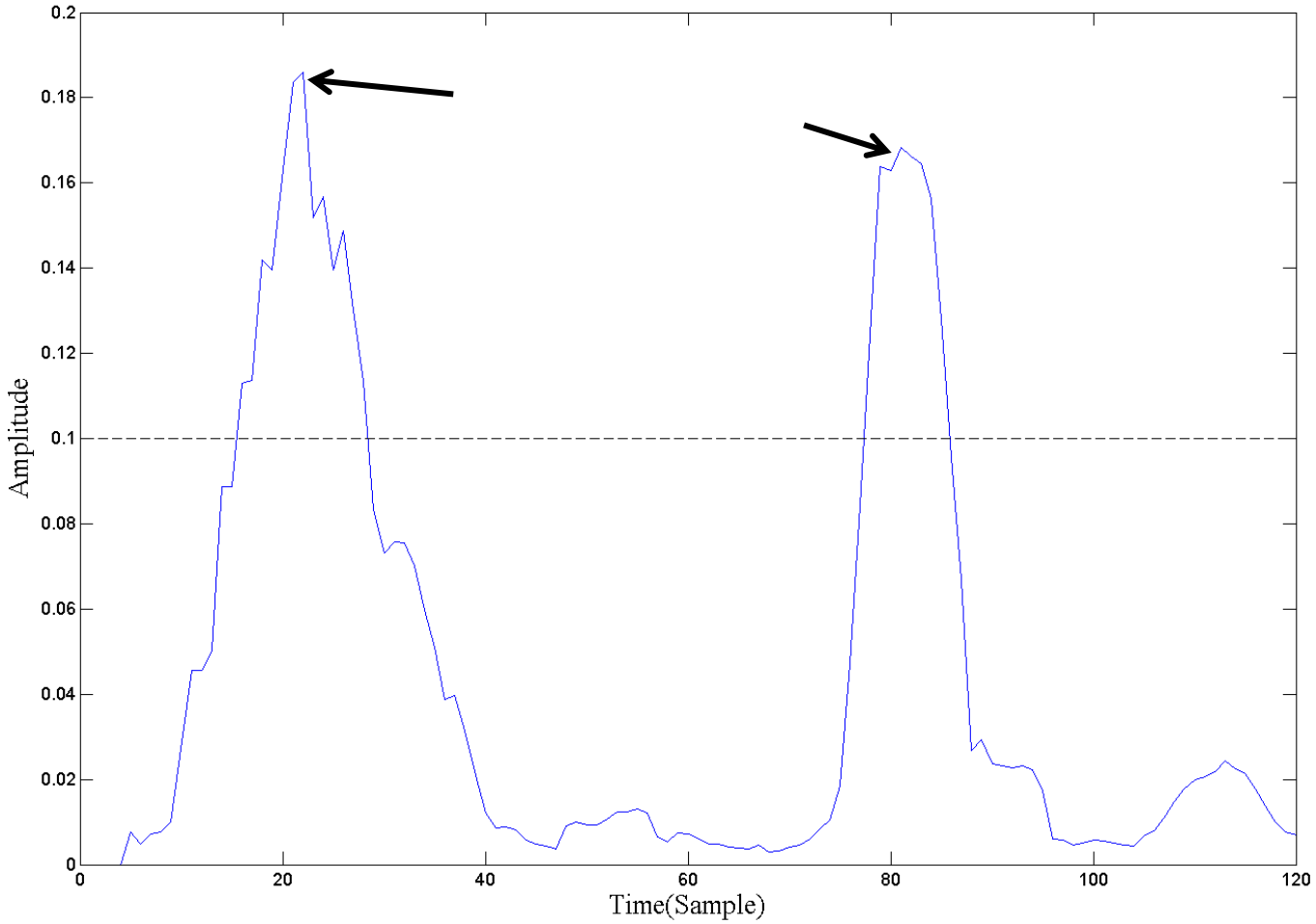
Representation	Order	Scale	Coef	g_1	g_2
DWT	23	3	c_a	0,49	0,02
SWT	2	5	c_d	0,48	0,25
CWT	4	60(*)		0,49	0,29
S-T		500(*)		0,40	0,27
Original Signal				0,40	0,34
Shannon Energy				**0,61**	0,31
Shannon Entropy				0,45	0,09
HHT				0,12	0,13
EMD				0,12	0,15
DWT	23	4	c_a	0,11	**0,41**
SWT	2	5	c_a	0,41	0,39
CWT	4	20(*)		0,31	**0,41**
S-T		380(*)		0,37	0,38

Segmentation

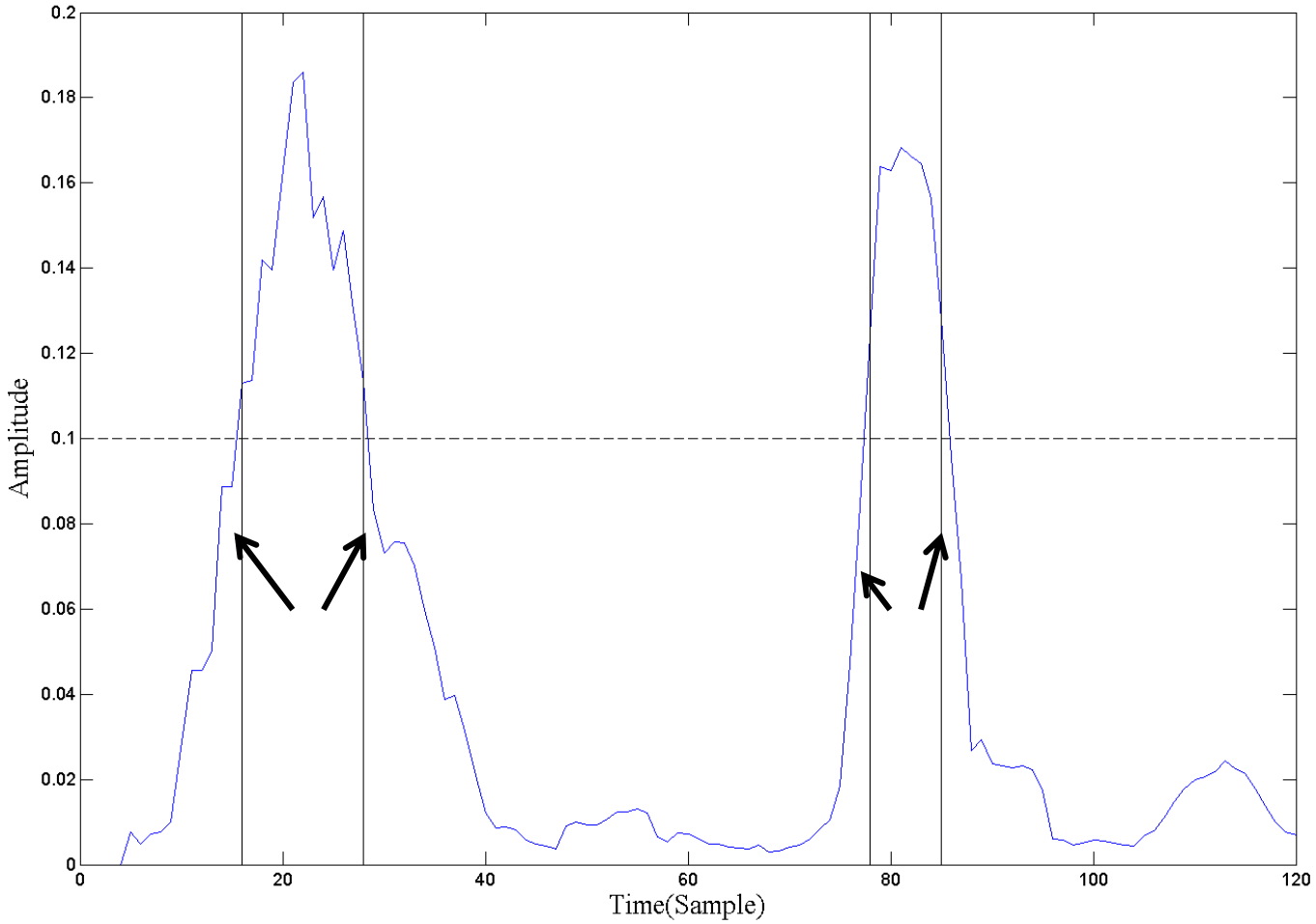
We can divide the Segmentation phase into 2 sub-phases:

- Peak Detection
- Boundary Detection

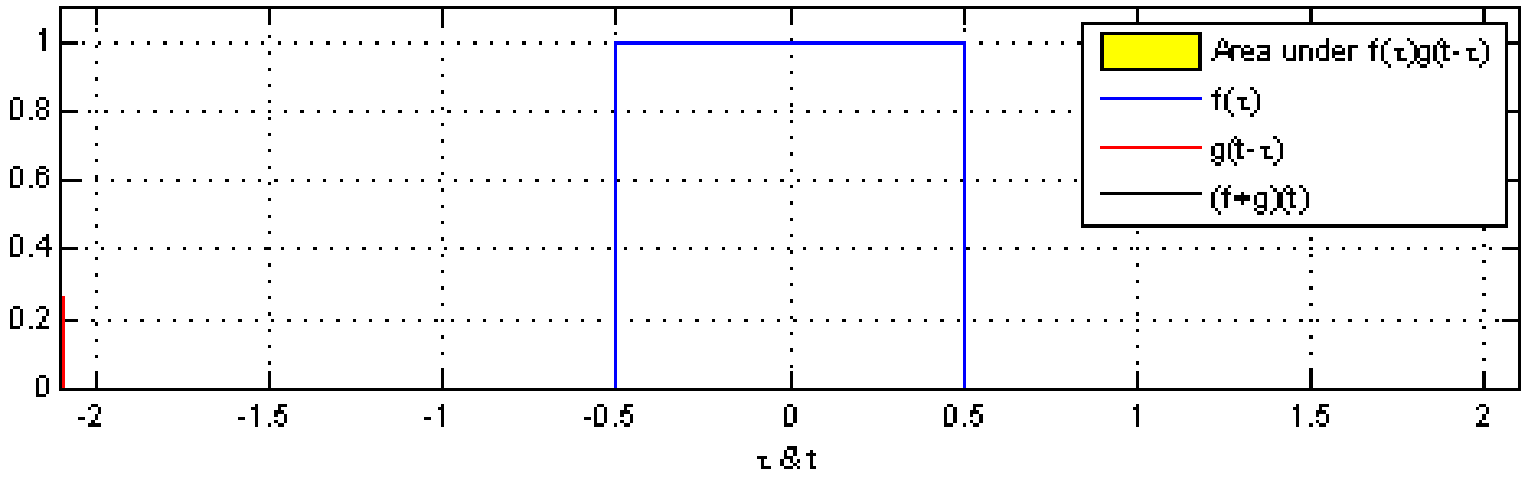
Peak Detection



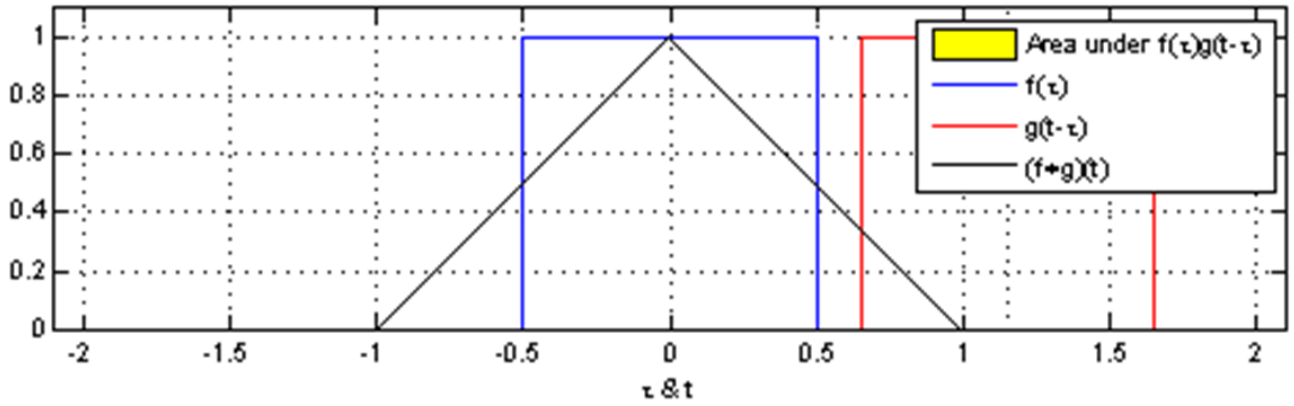
Boundary Detection



Convolution

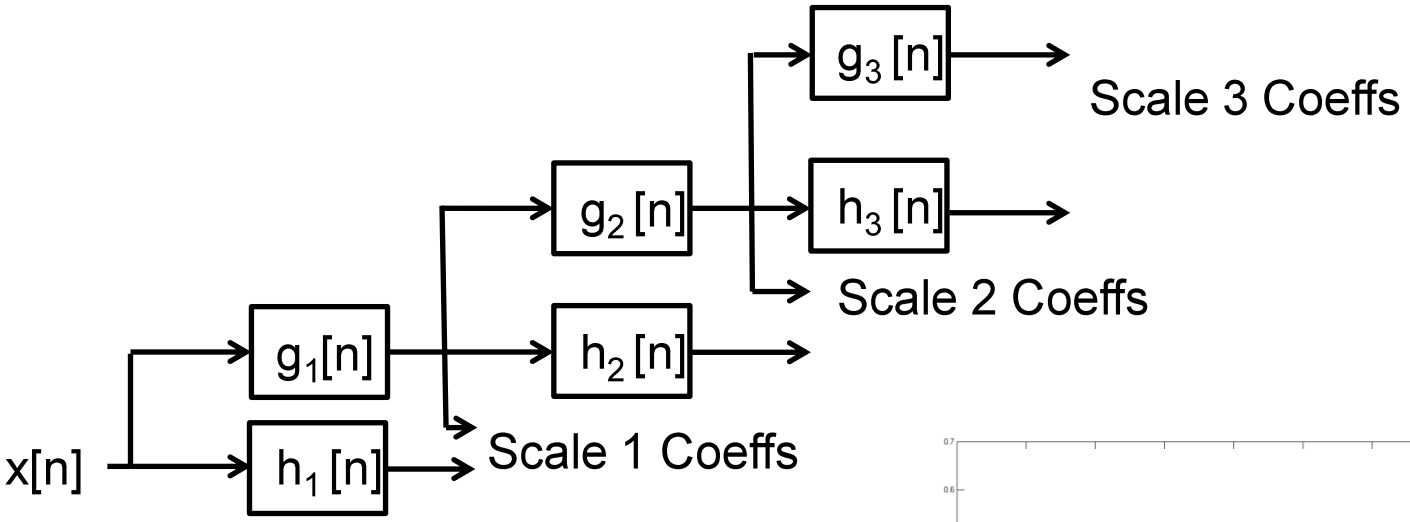


Idea!



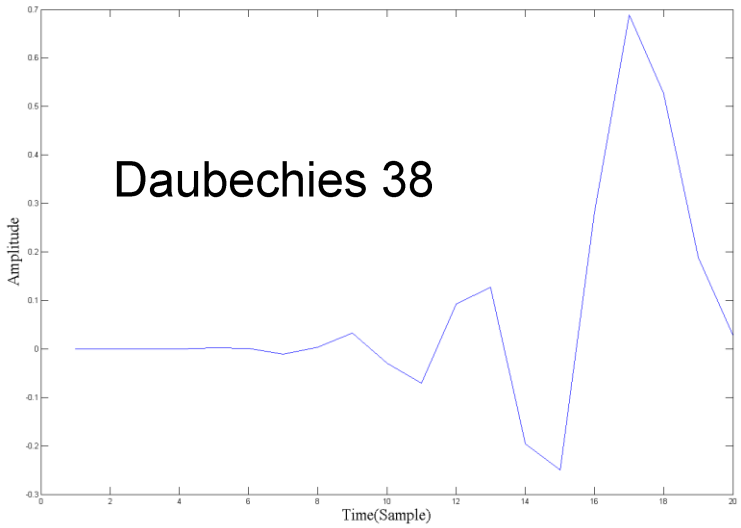
Use a filter in the SWT that looks like the S1/S2 in order to determine their boundaries!

Stationary Wavelet Transform

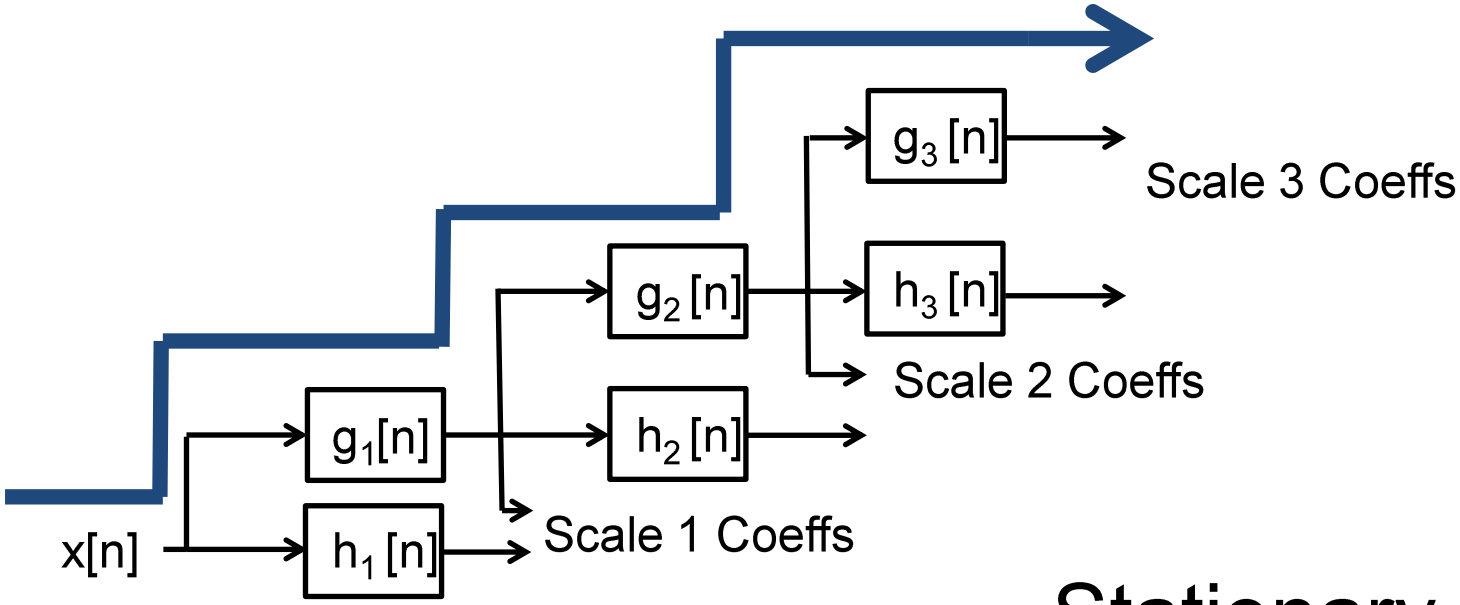


$g_j[n] \rightarrow (\uparrow 2) \rightarrow g_{j+1}[n]$

$h_j[n] \rightarrow (\uparrow 2) \rightarrow h_{j+1}[n]$



Problem

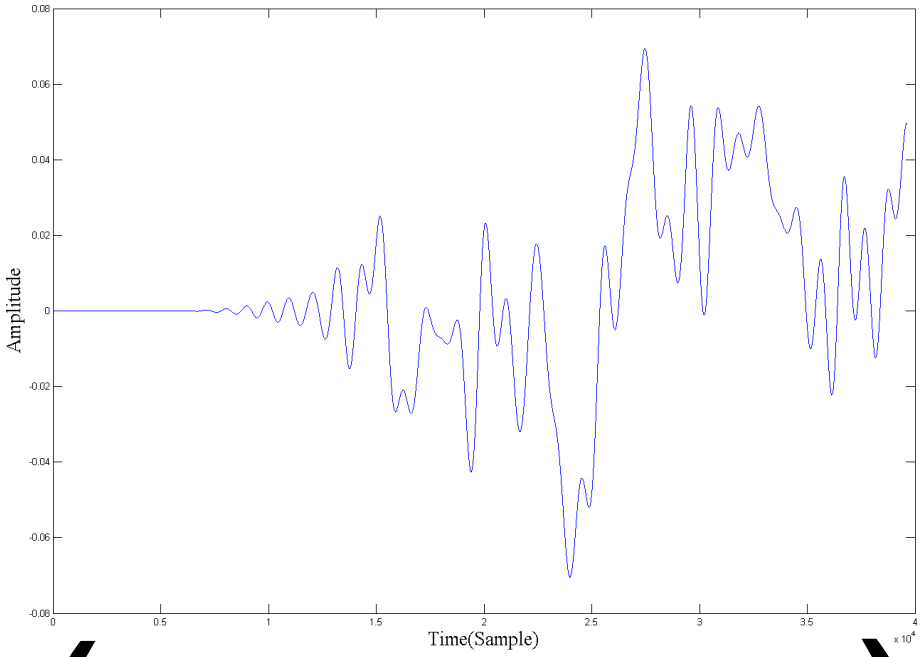


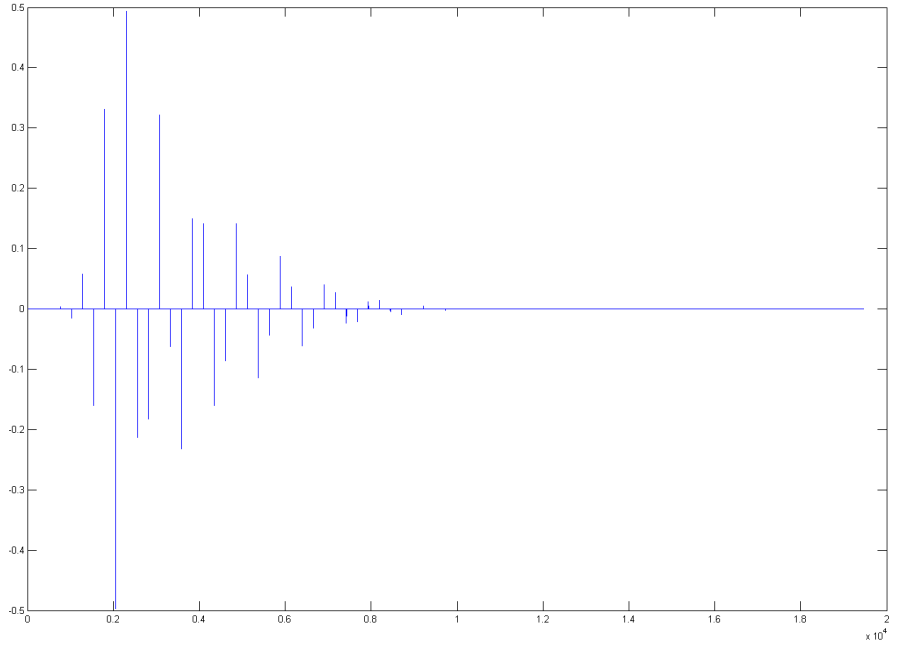
$g_j[n] \rightarrow \uparrow 2 \rightarrow g_{j+1}[n]$

$h_j[n] \rightarrow \uparrow 2 \rightarrow h_{j+1}[n]$

Stationary Wavelet Transform

Problem



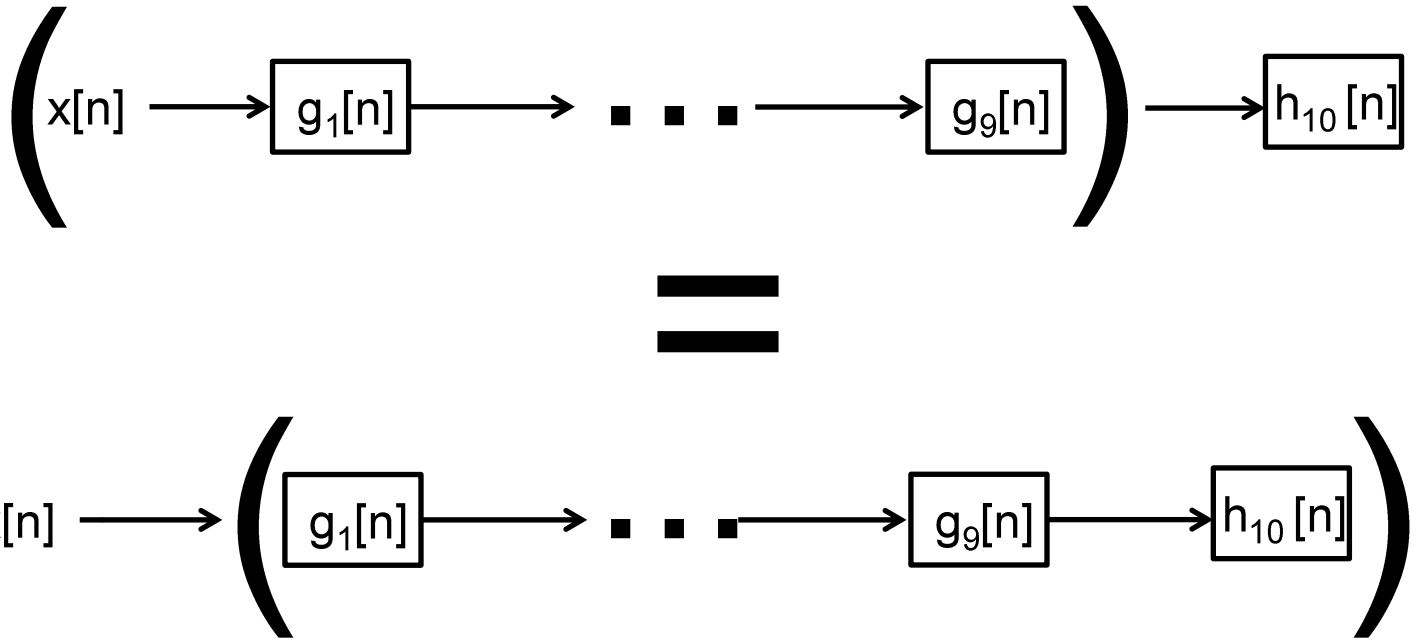


$$\left(x[n] \rightarrow g_1[n] \rightarrow \blacksquare \blacksquare \blacksquare \rightarrow g_9[n] \right) \qquad h_{10}[n]$$

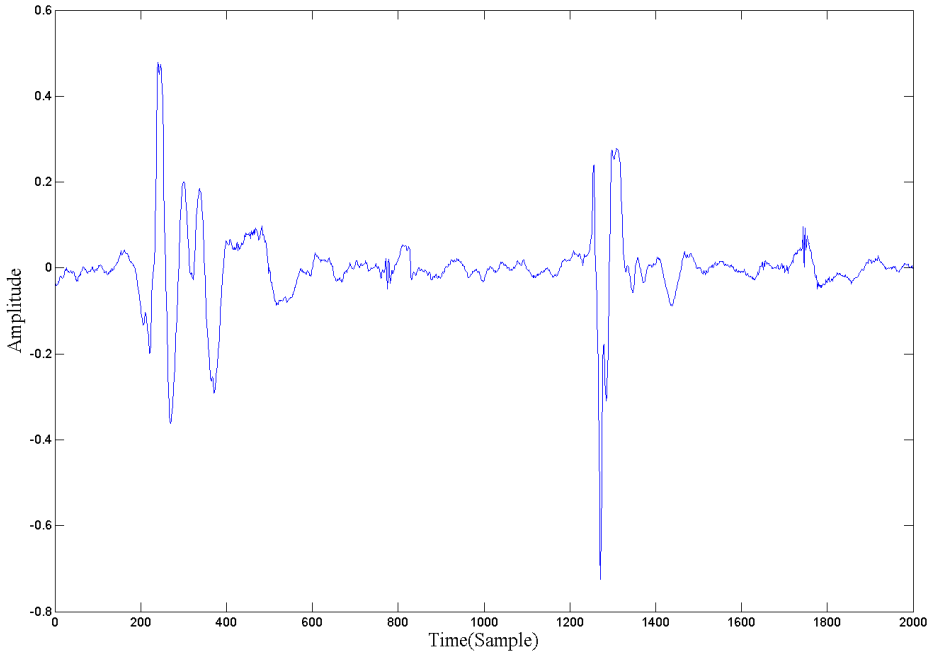
Signal becomes completely deformed!

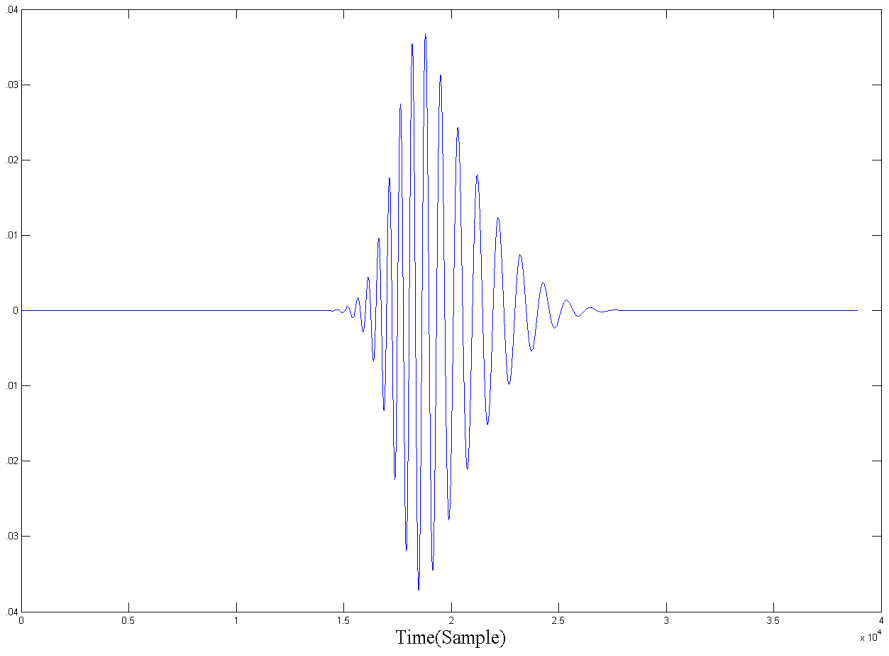
Solution

Lets use the Convolution‘s Associative Property!

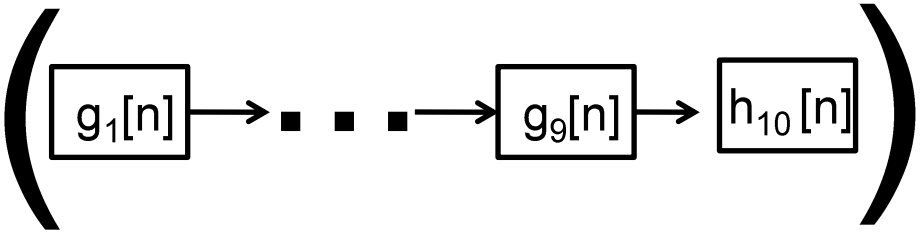


Solution

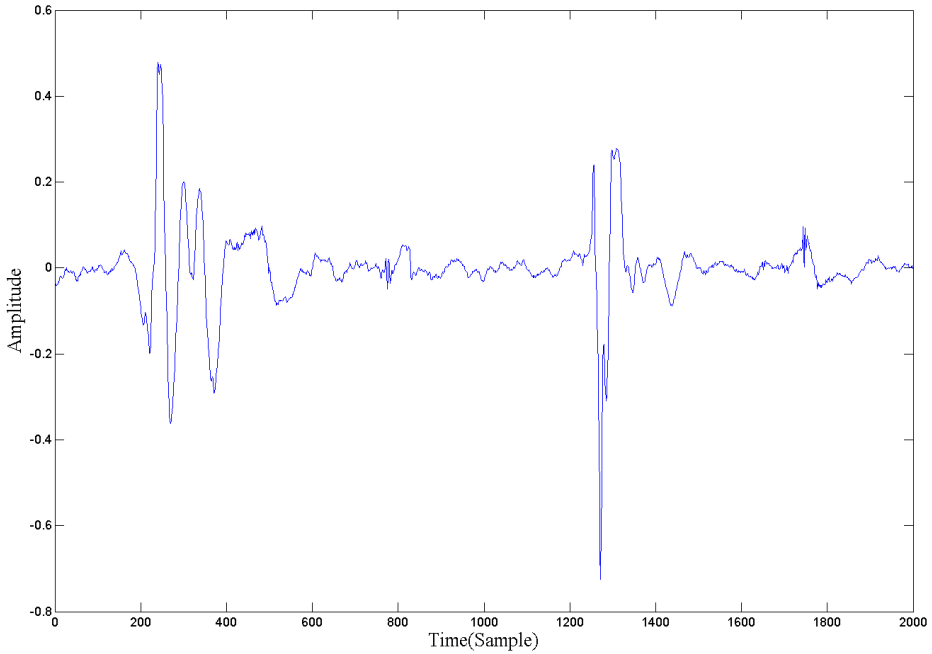


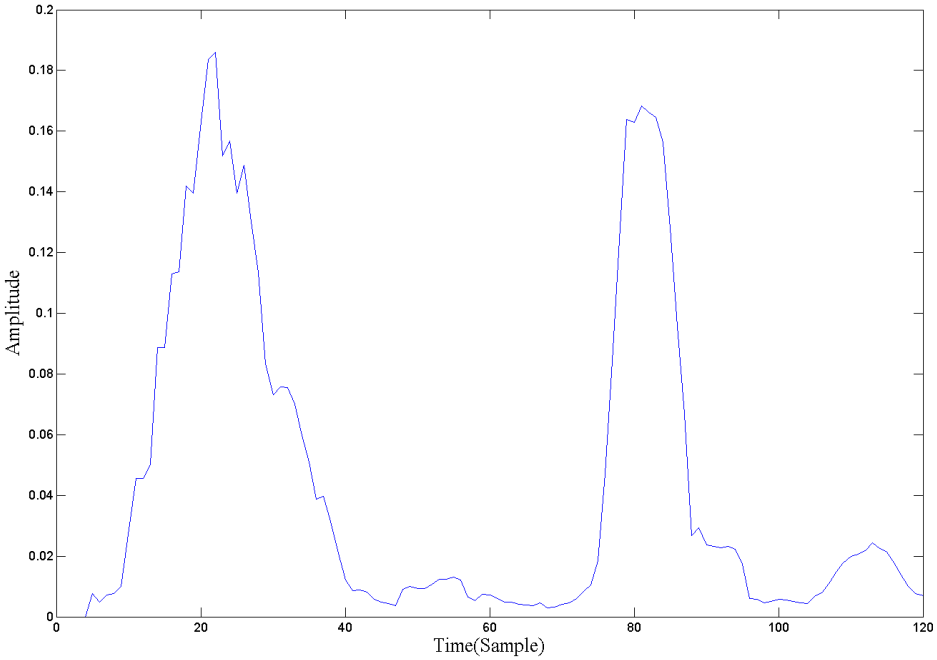


x[n]



Signal Transformation: Digiscope

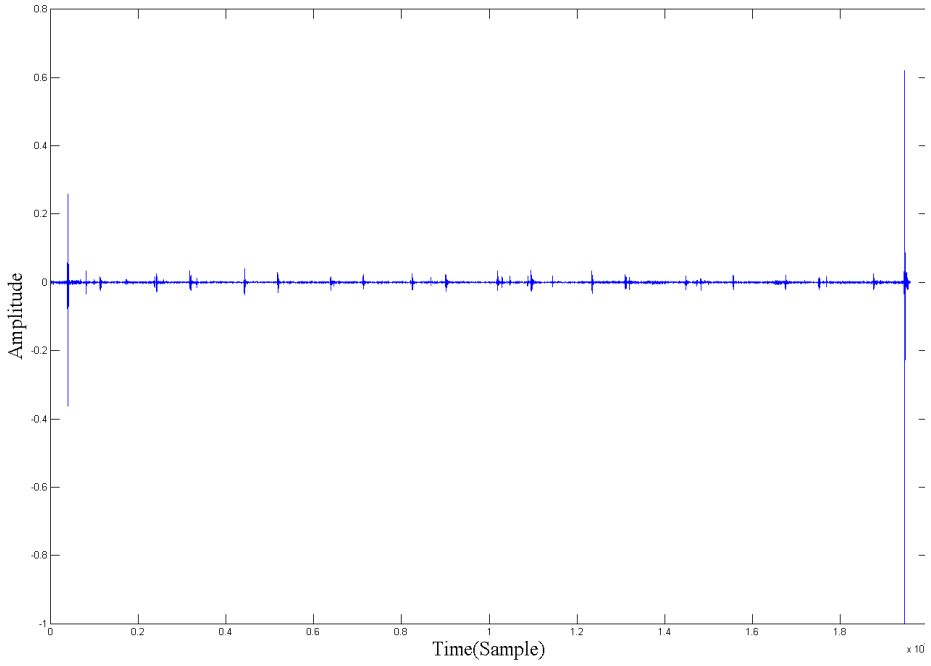


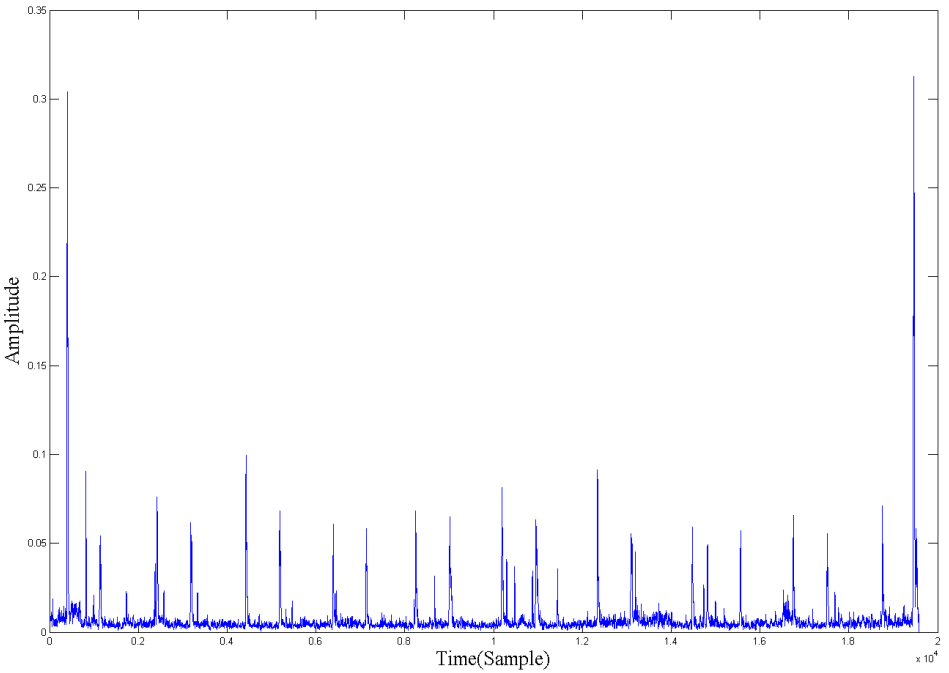


x[n]

$Shannon_{energy}(x[n])$

Signal Transformation: iStethoscope

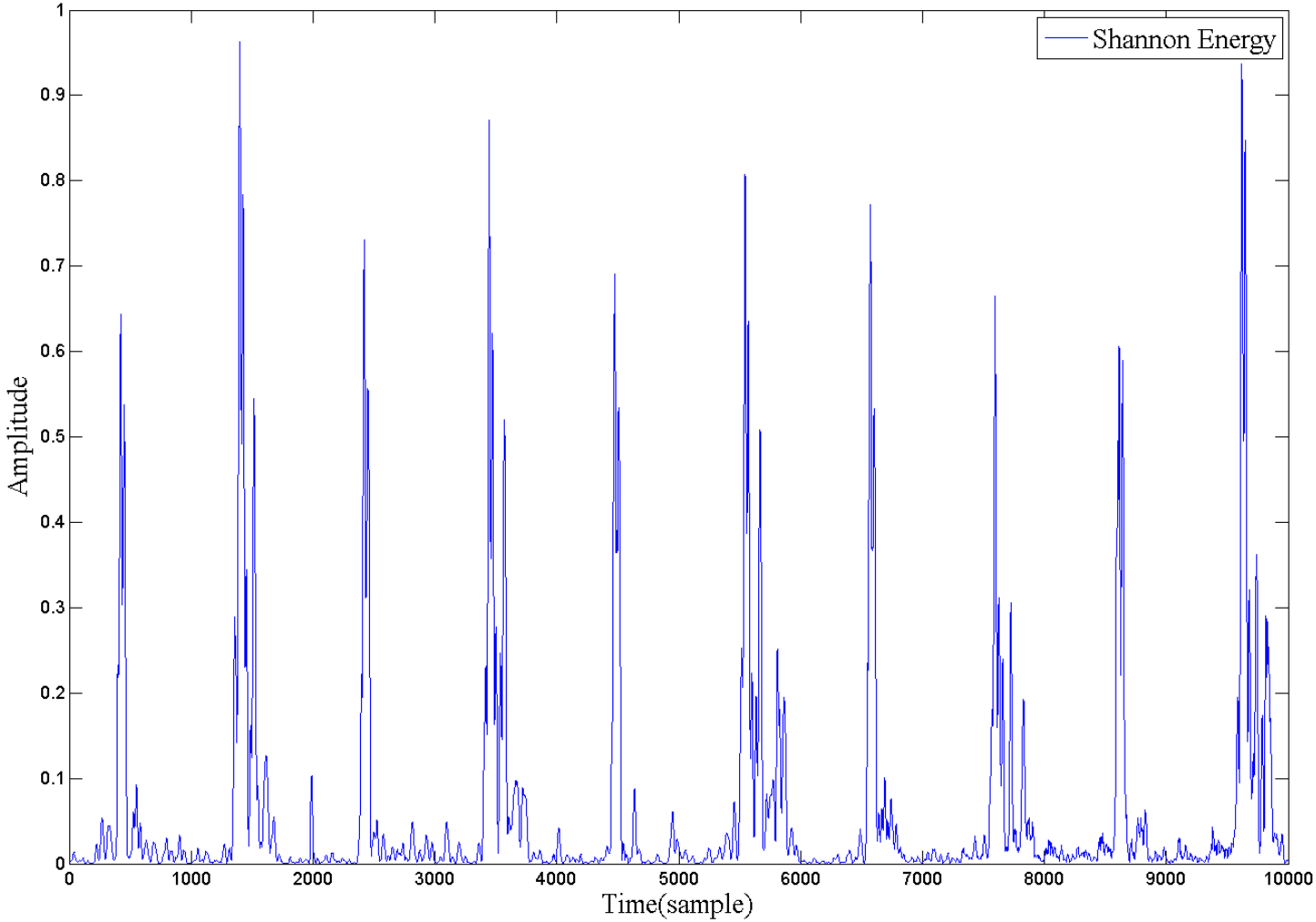




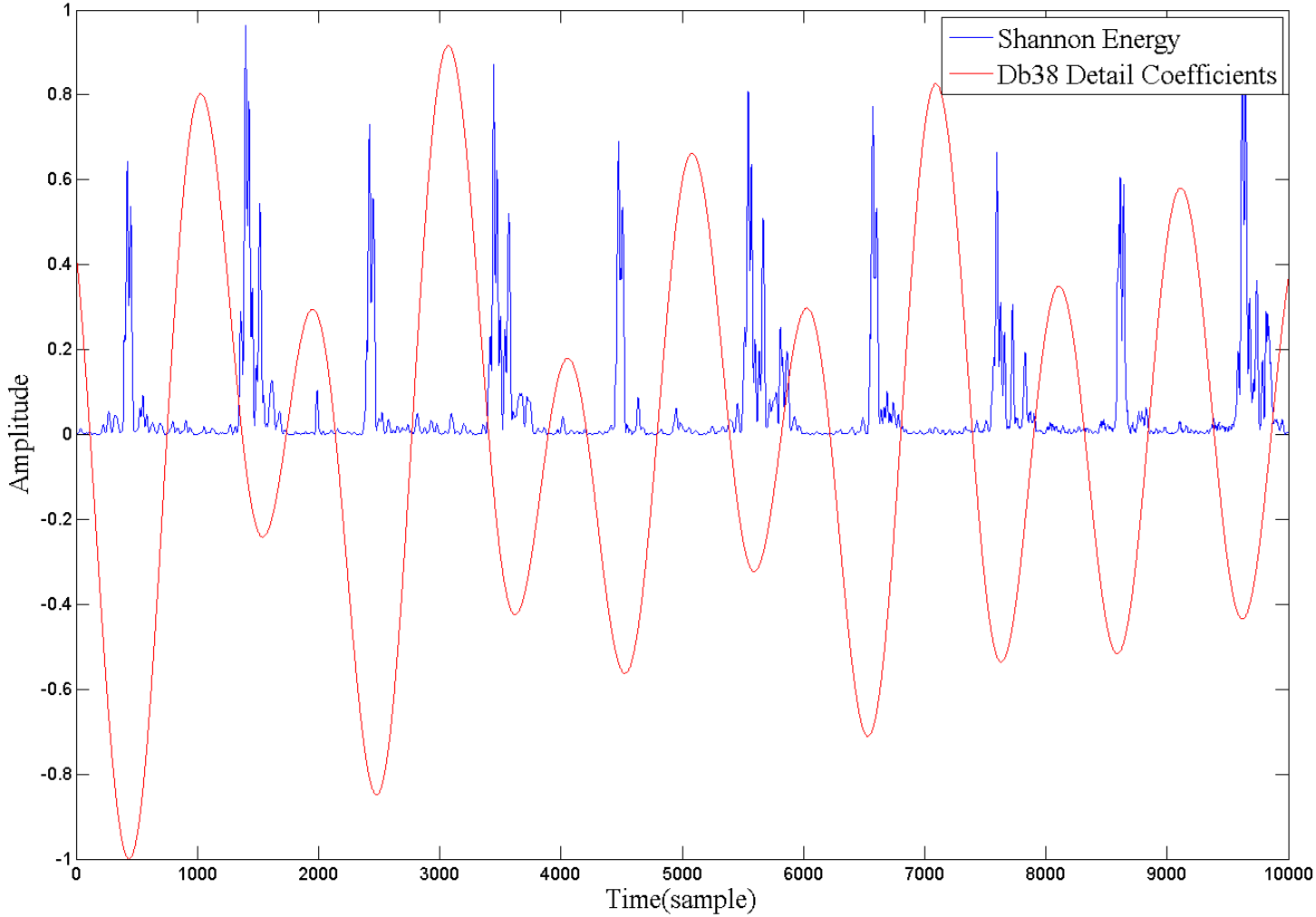
x[n]

$Shannon_{entropy}(x[n])$

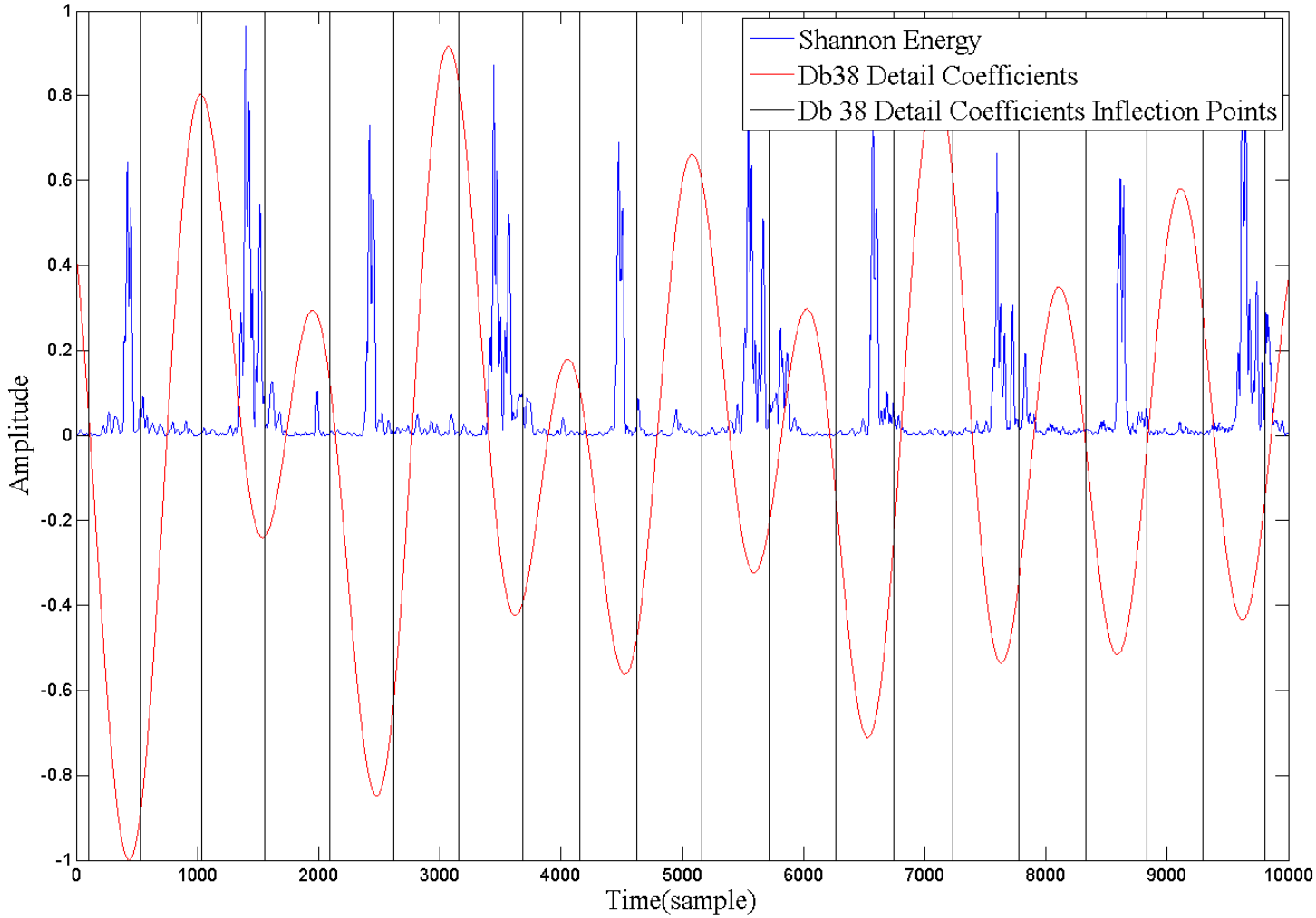
Shannon Energy



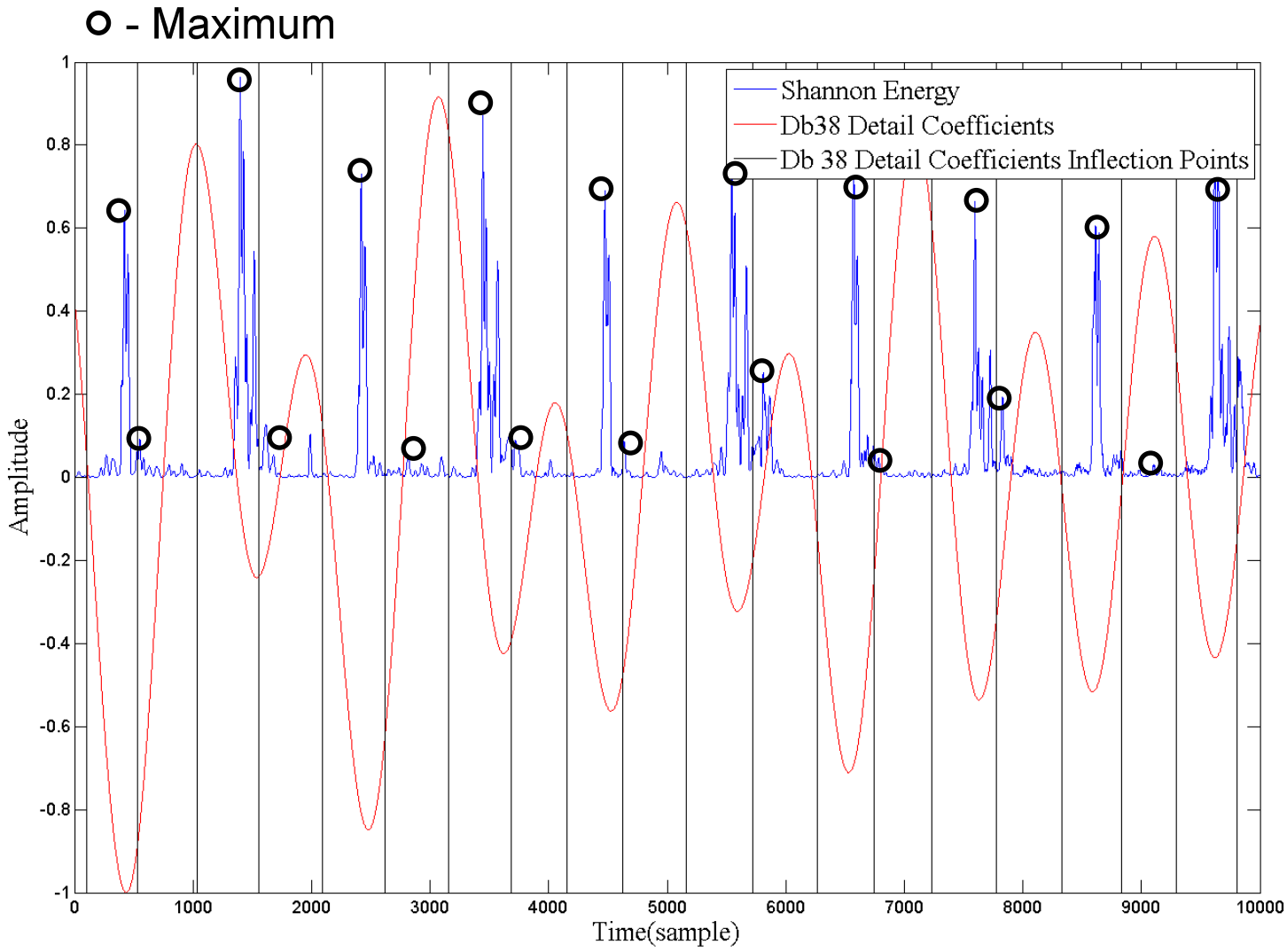
Wavelet Coefficients



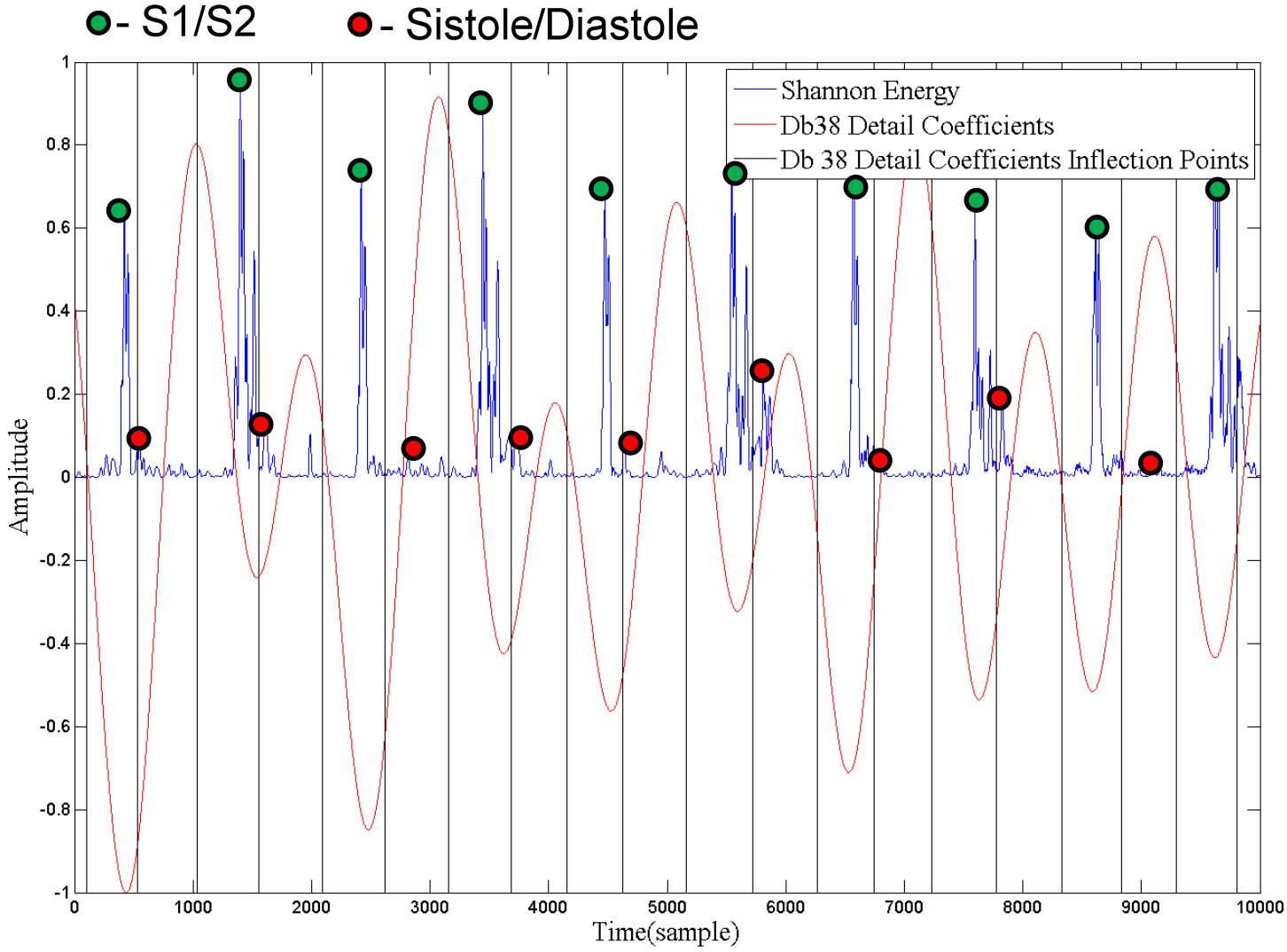
Inflection Points

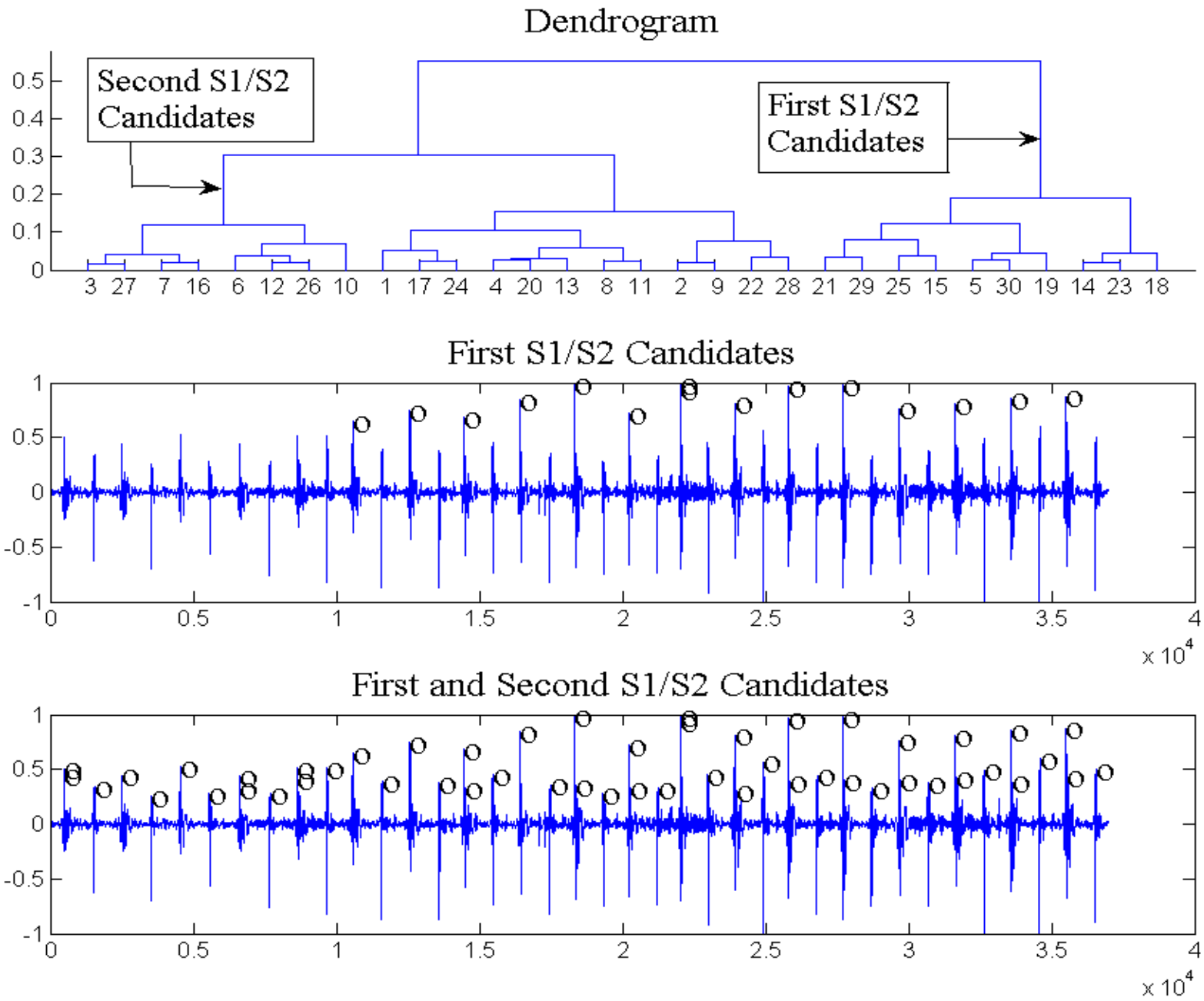


Segment Descriptors



Segment Descriptors




Dendrogram
Second S1/S2 Candidates
First S1/S2 Candidates
0.5
0.4
0.3
0.2
0.1
0
3 27 7 16 6 12 26 10 1 17 24 4 20 13 8 11 2 9 22 28 21 29 25 15 5 30 19 14 23 18
First S1/S2 Candidates
1
0.5
0
-0.5
-1
0 0.5 1 1.5 2 2.5 3 3.5 4
x 10^4
First and Second S1/S2 Candidates
1
0.5
0
-0.5
-1
0 0.5 1 1.5 2 2.5 3 3.5 4
x 10^4

PASCAL Challenge Results

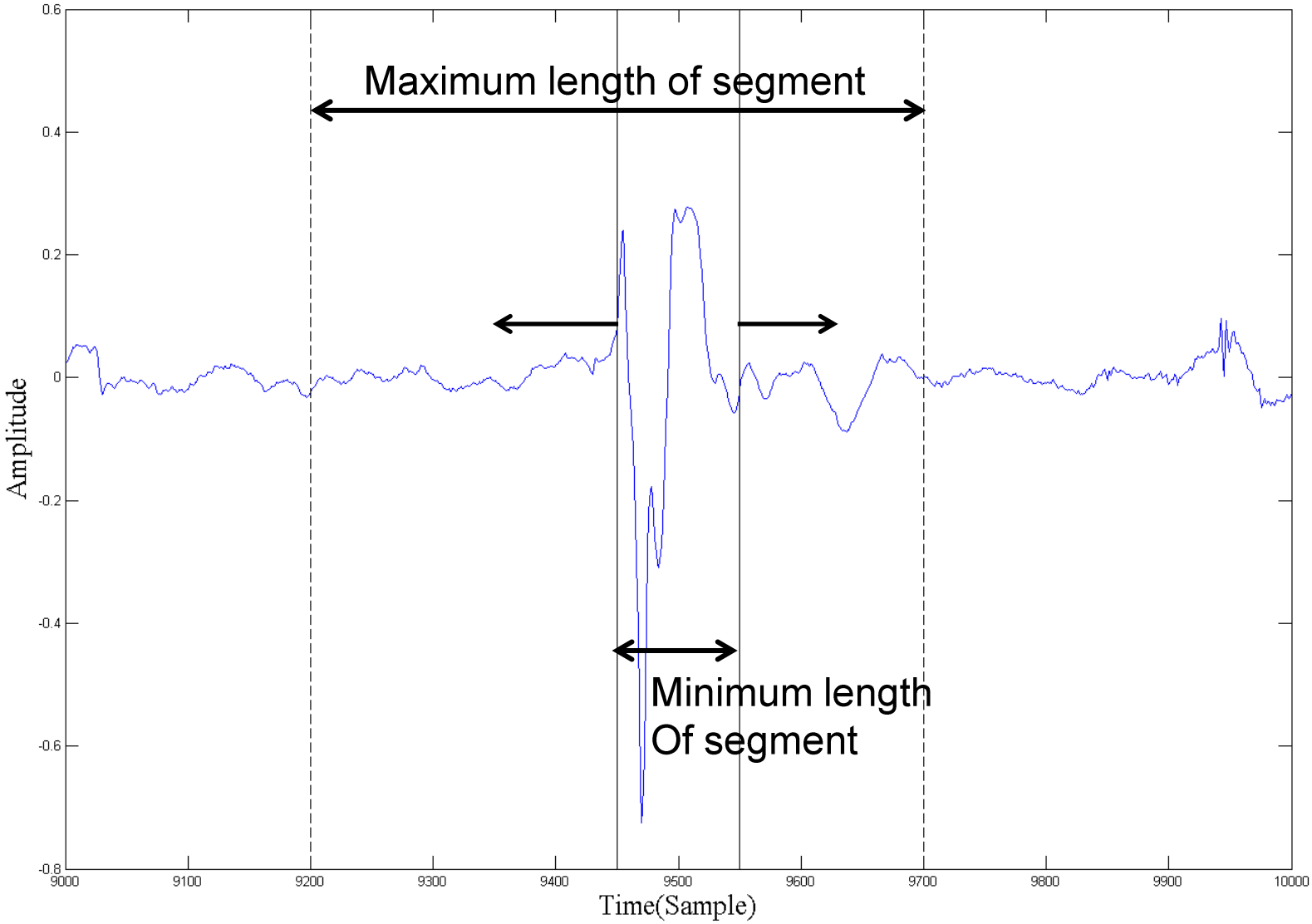
Approach	Total Error	
	Digiscope	iStethoscope
Our Proposed Method	56732	706535
Stanford	76444	1243640
UCL	75569	3394378
ISEP	72242	3905581

Determining Boundaries

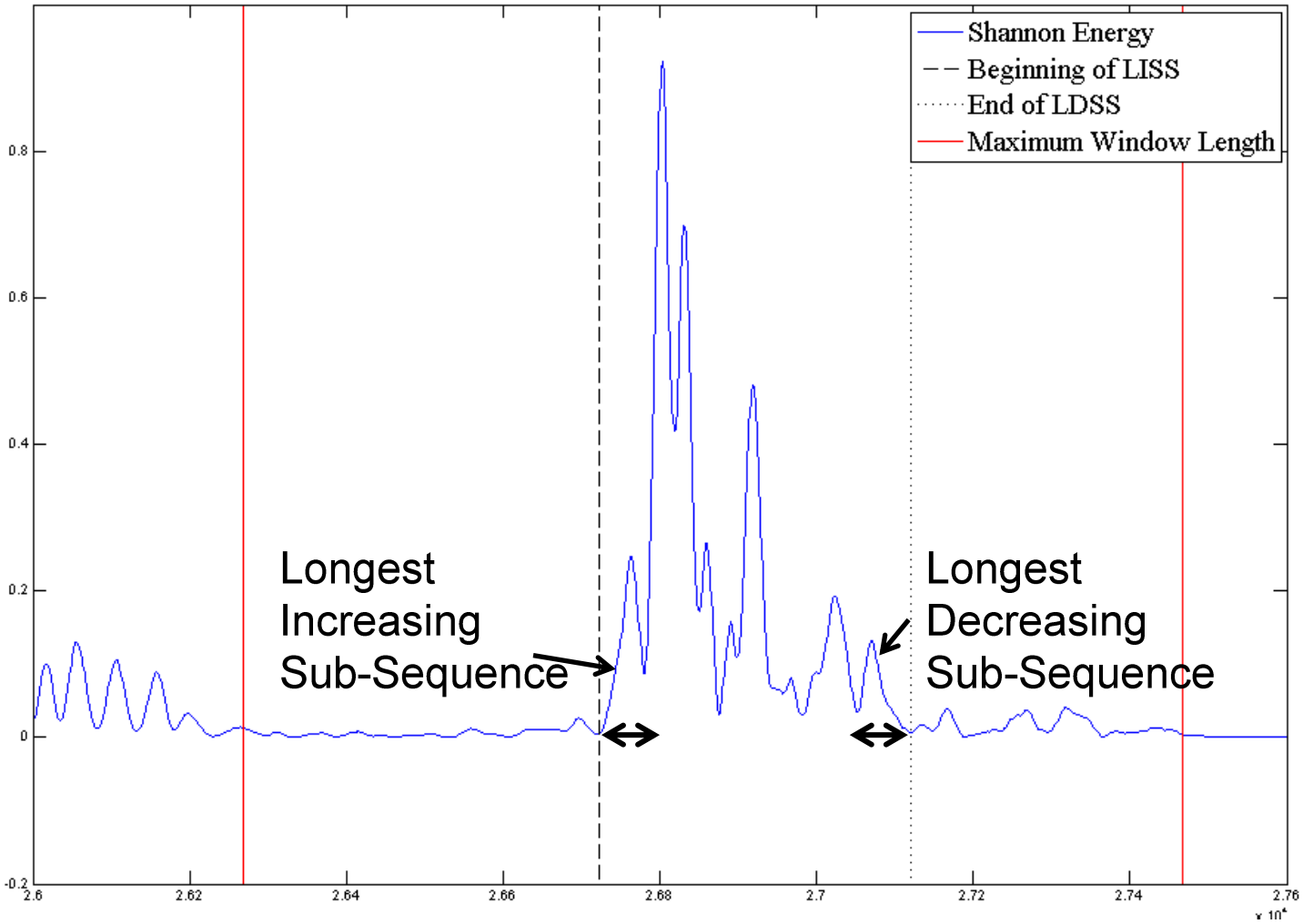
Determining Boundaries

- Variation between Segments
- Longest Increasing/Decreasing Sub-sequence

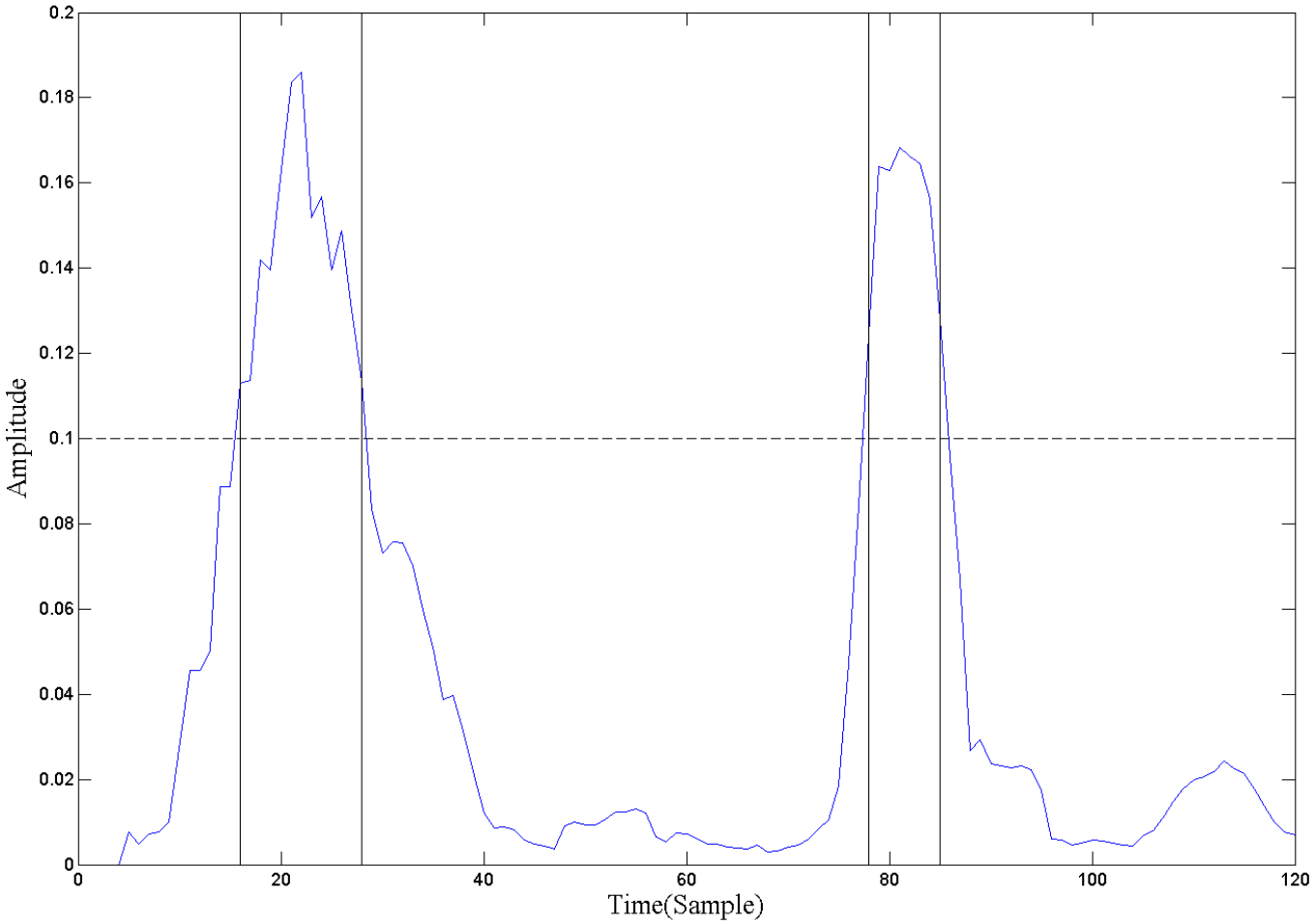
Variation Between Segments(a_1)



Longest Increasing/Decreasing Sub-sequence(a_2)



Baseline Method(a_3)



Results

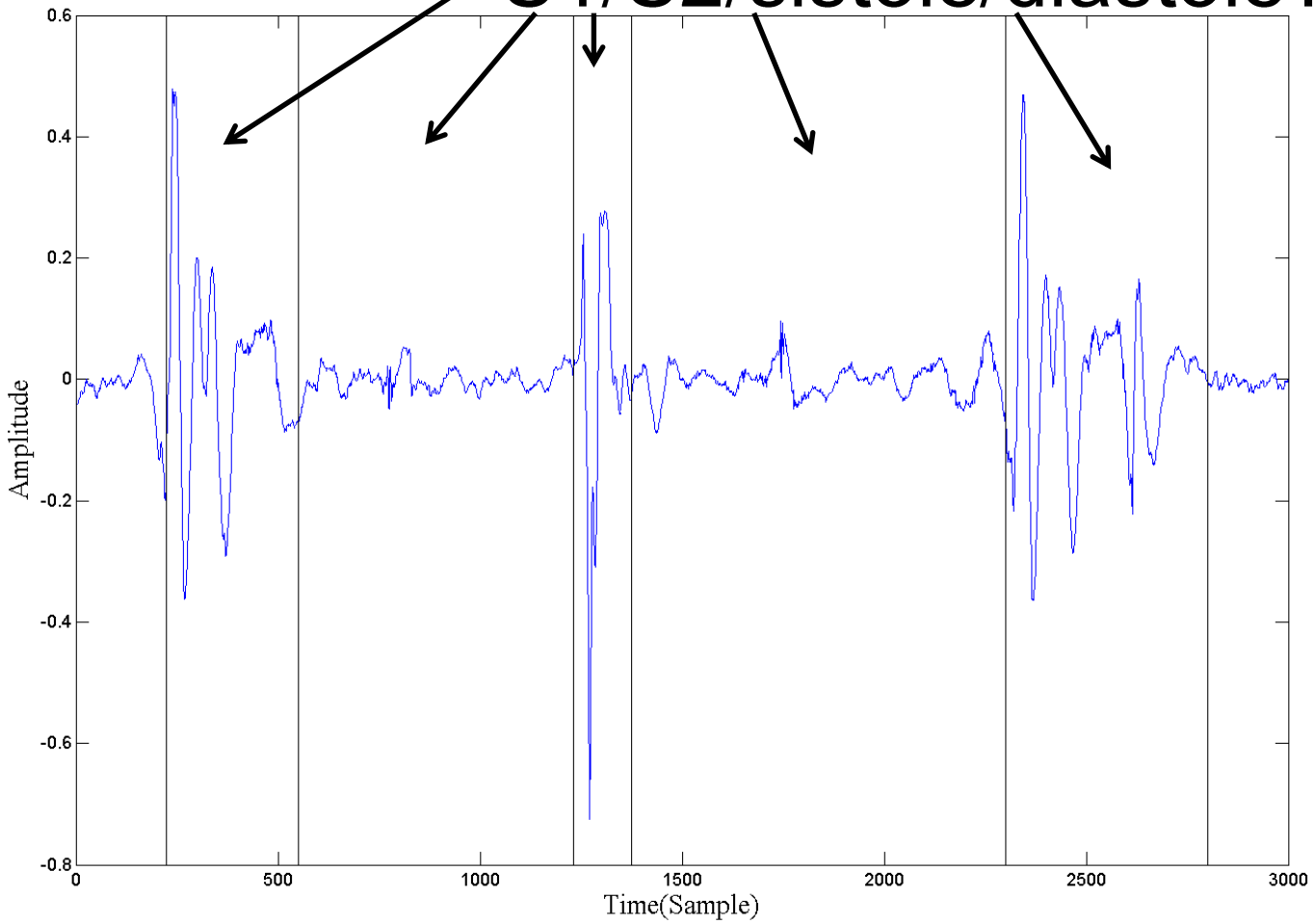
Approach	Annotation Error	
	Digiscope	iStethoscope
a_1	29,1±14,3	37,1± 13,4
a_2	41,4± 10,8	67,1±15,2
a_3	46,8± 15,2	83,2± 20,4

Média +- desvio padrão (ms)

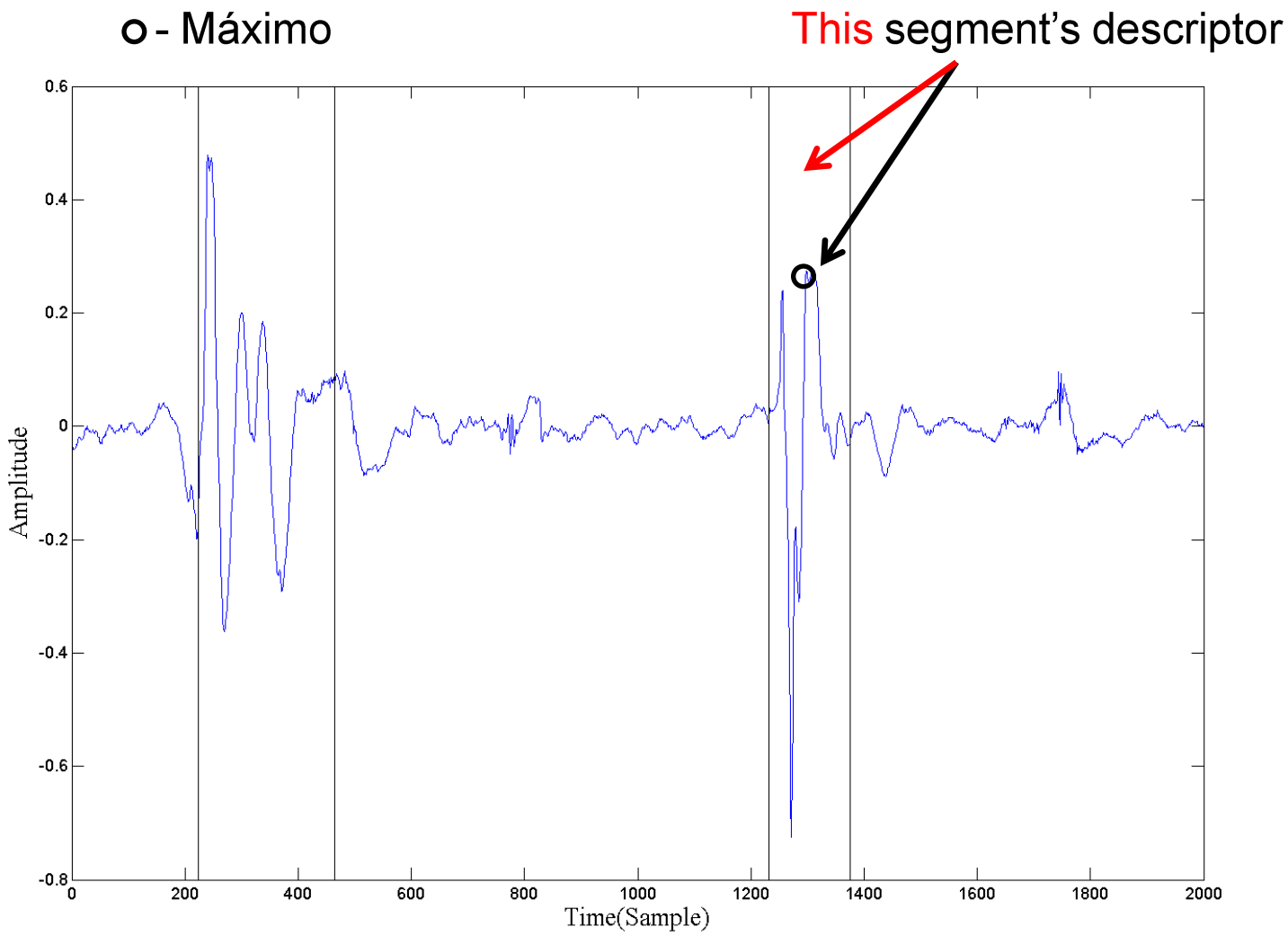
Classification

Classification

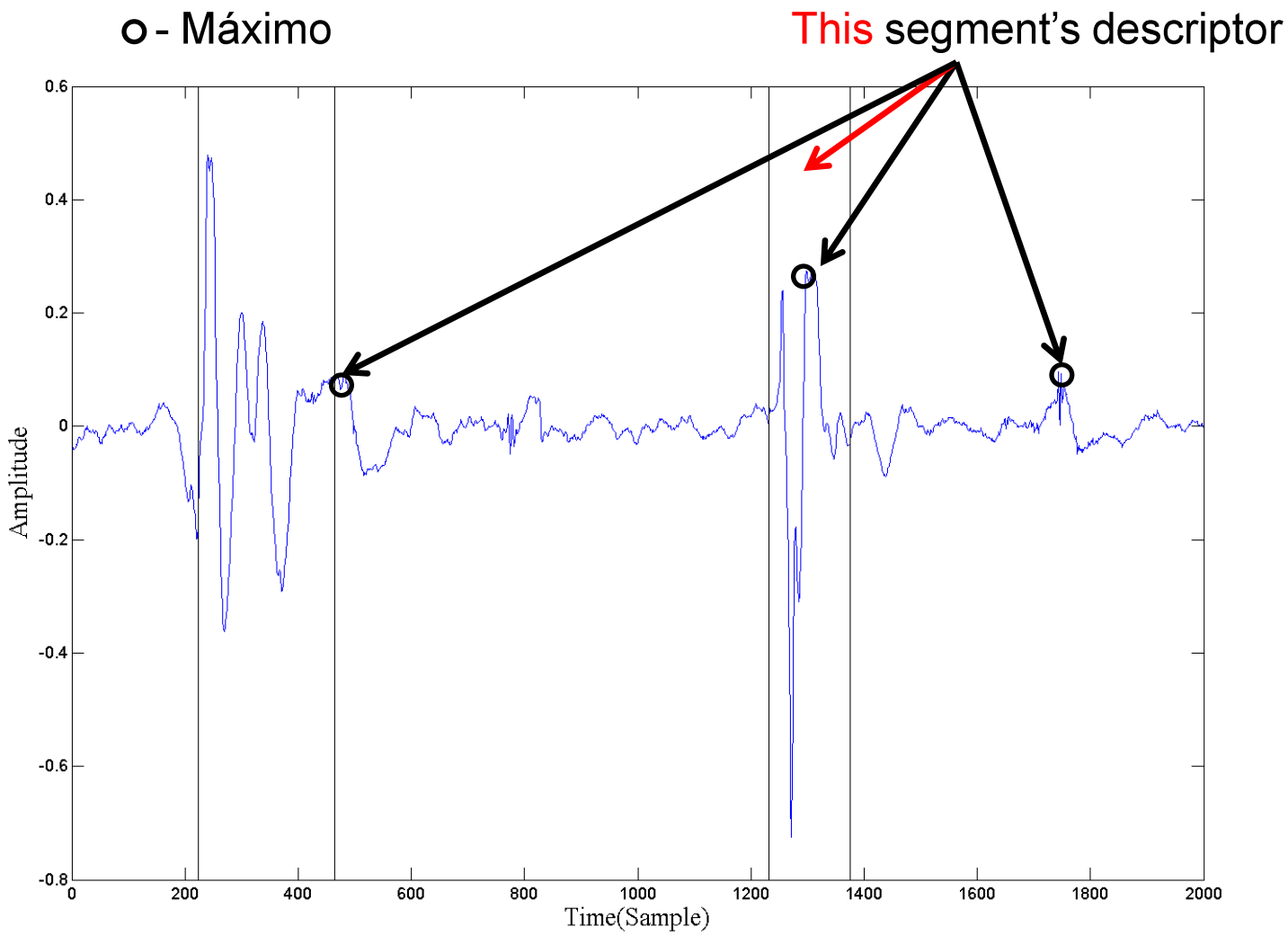
S1/S2/sistole/diastole?!



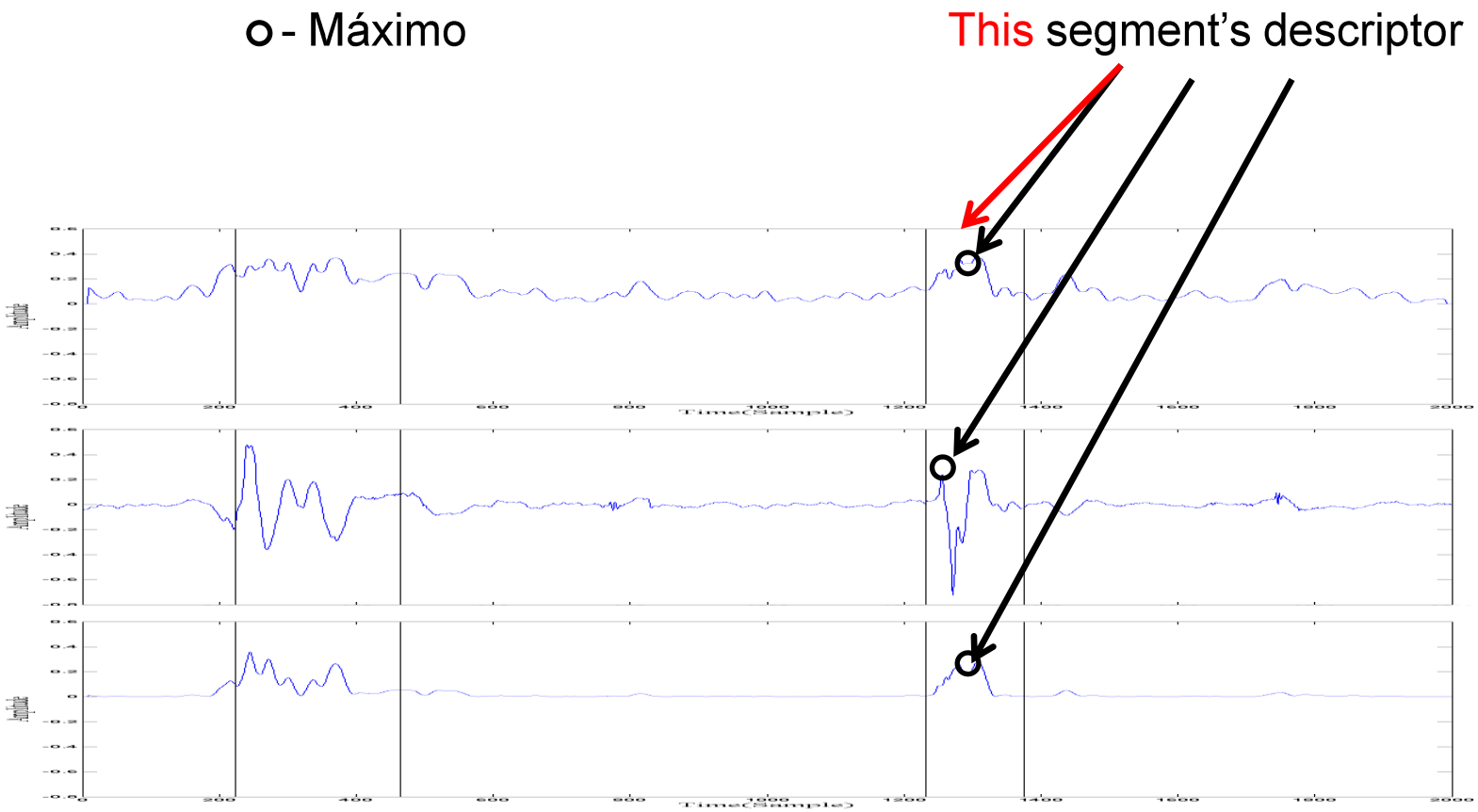
Individual descriptor



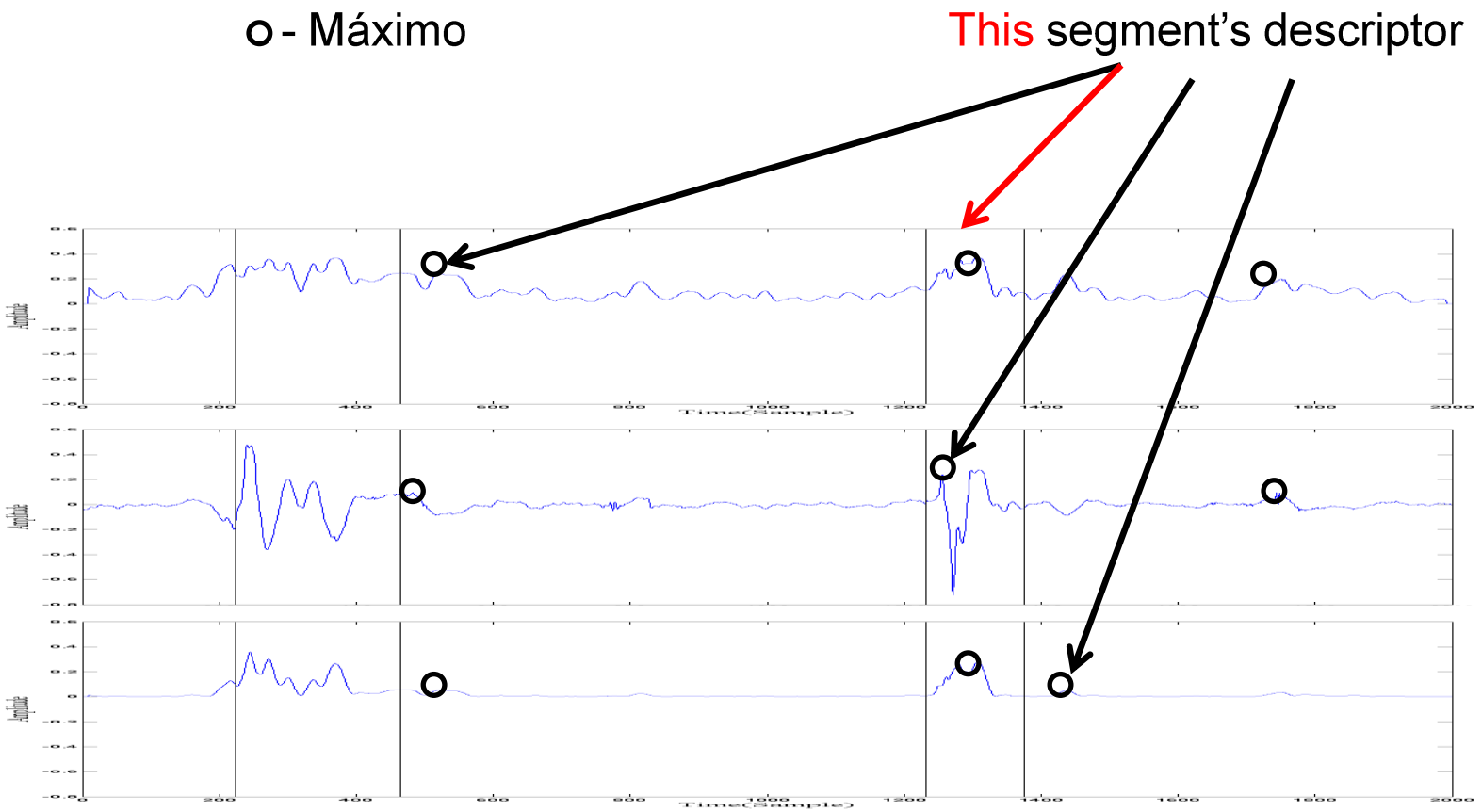
Expanded Descriptor



Combination of descriptors: Individual



Combination of descriptors: Expanded



Results: Combination of Descriptors

Type of Feature	Approach	Accuracy	Sensitivity	Specificity
Individual	CWT+ST	0.86	0.88	0.84
Neighbourhood	SWT+DWT+ST	0.83	0.86	0.80
	Digiscope			
Individual	CWT+DWT+HHT+ST+EMD	0.90	0.91	0.89
Neighbourhood	CWT+DWT+ST	0.92	0.90	0.94
	Istethoscope			

Conclusion

Conclusion

- Spectral Analysis
- Evaluation of different types of Representations
- New peak detection algorithm
- 2 new boundary detection algorithms
- Article publication in Computing in Cardiology 2013

Thank you!