High volume data acquisition and processing in electrocardiography (ECG)

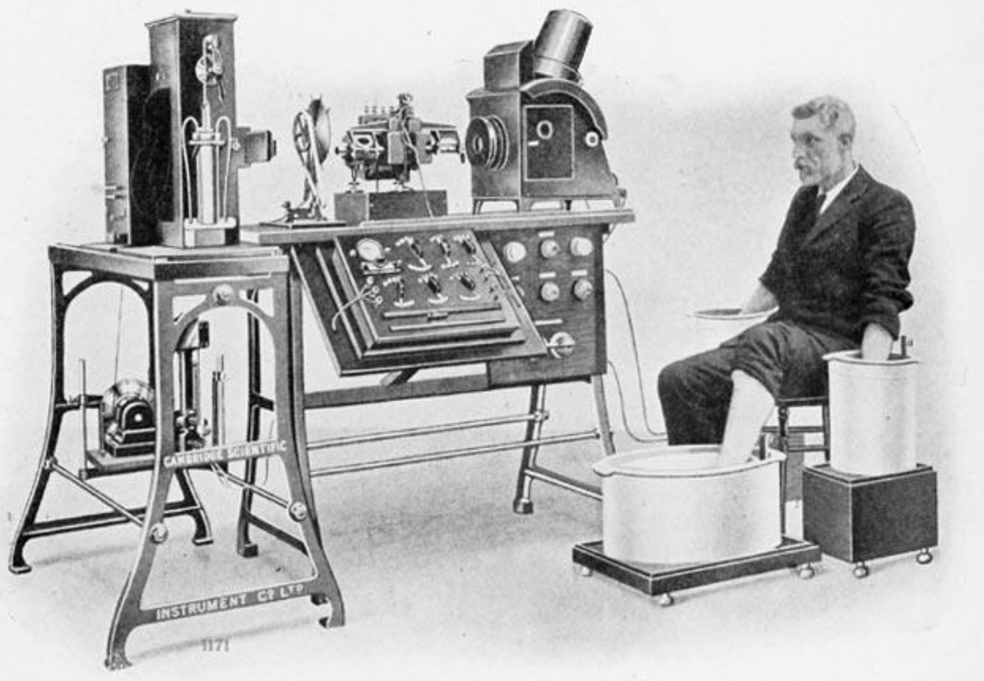
Bo Qiang

Disclaimer

- I am not affiliated with Mayo Clinic, Preventice, AliveCor, CardioSecur, 3DS and any other companies mentioned in these slides.
- All materials in this presentation are available publicly or have been approved to be used by authors and inventors.

Outline

- What is electrocardiography (ECG or EKG)?
- ECG data processing.
- Remote ECG monitoring by mobile device.
- Recent technology advancements.



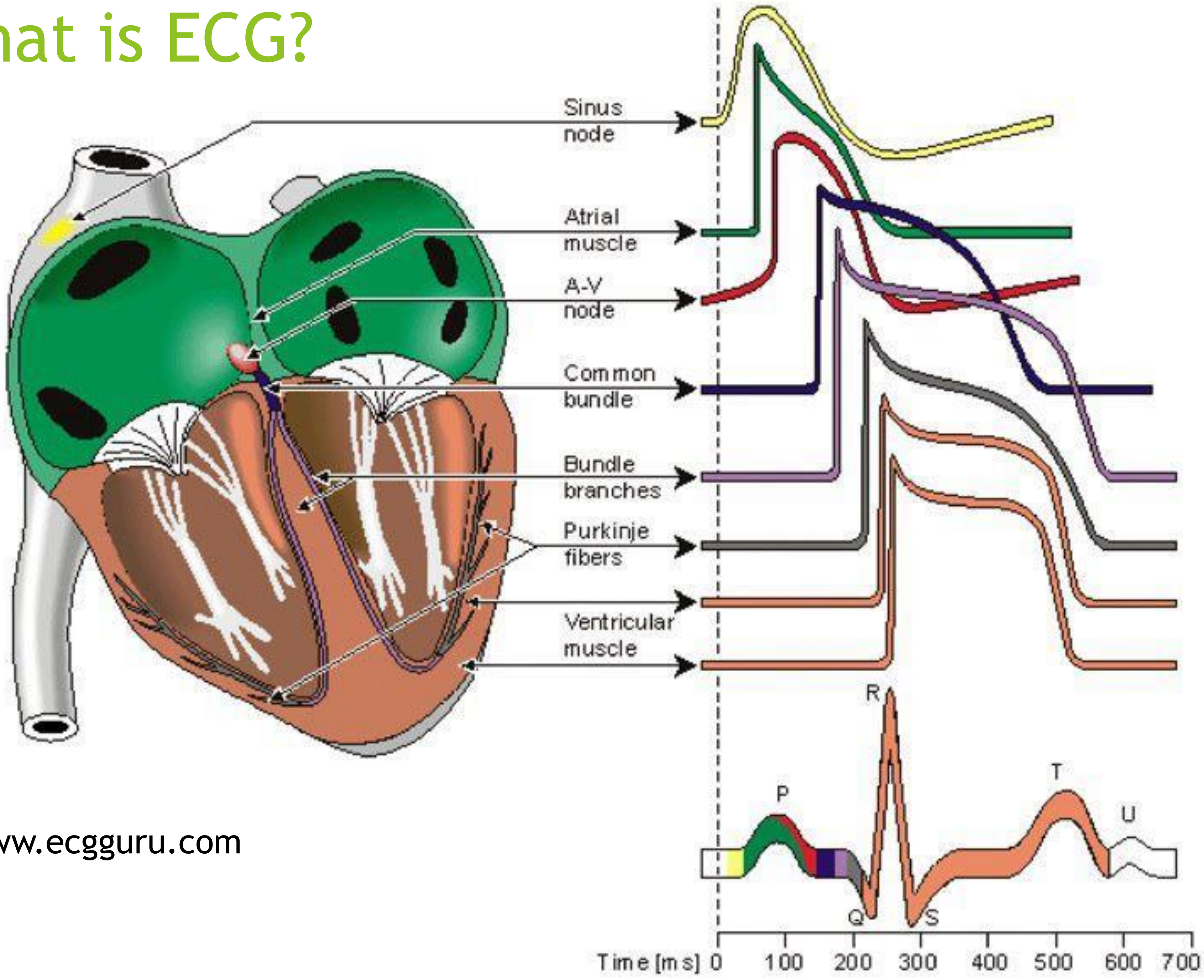
Photograph of a Complete Electrocardiograph, Showing the Manner in which the Electrodes are Attached to the Patient, In this Case the Hands and One Foot Being Immersed in Jars of Salt Solution

Early ECG

GE MUSE V8

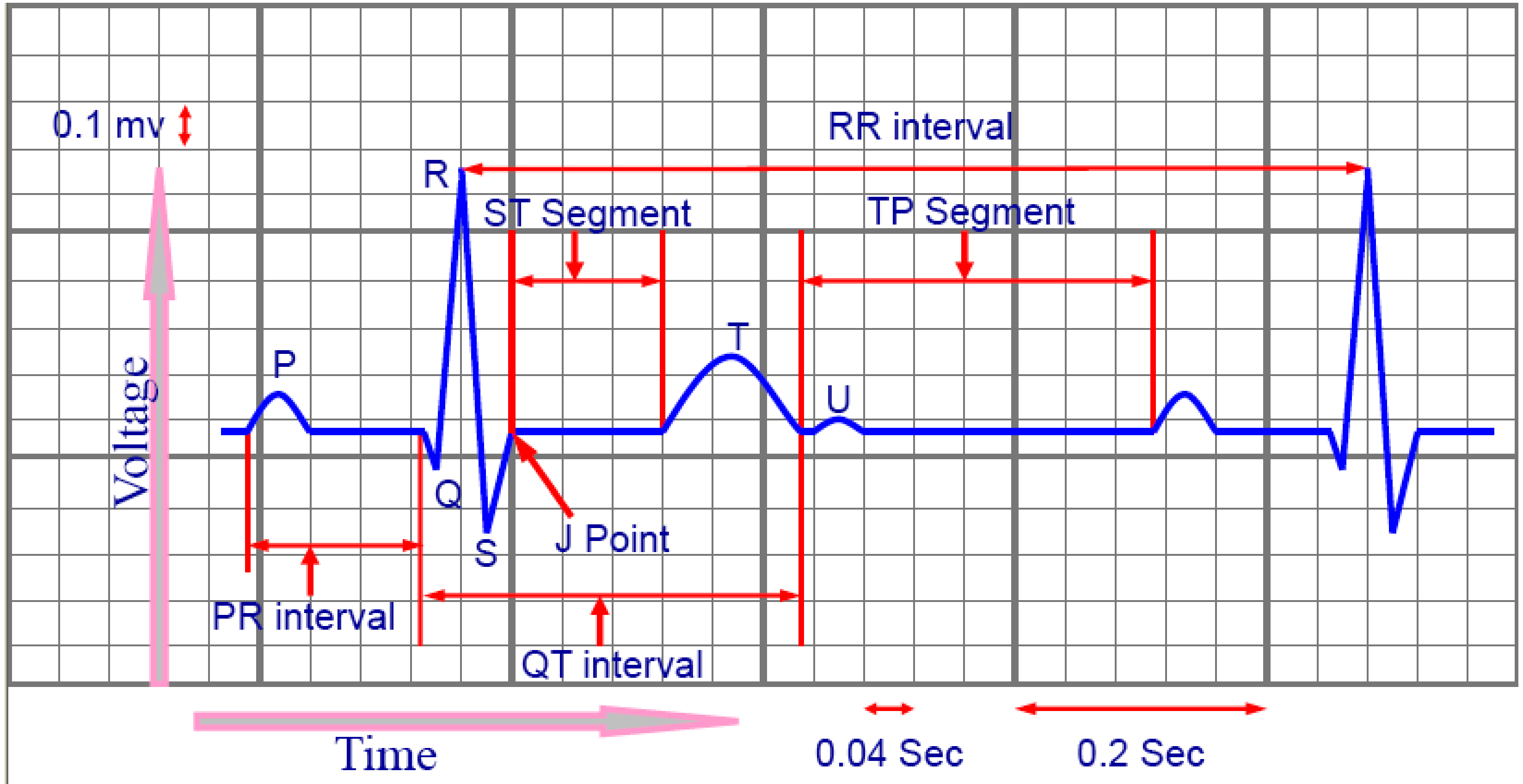
Electrocardiography (**ECG** or EKG*) is the process of recording the electrical activity of the heart over a period of time using electrodes placed on the skin.

What is ECG?



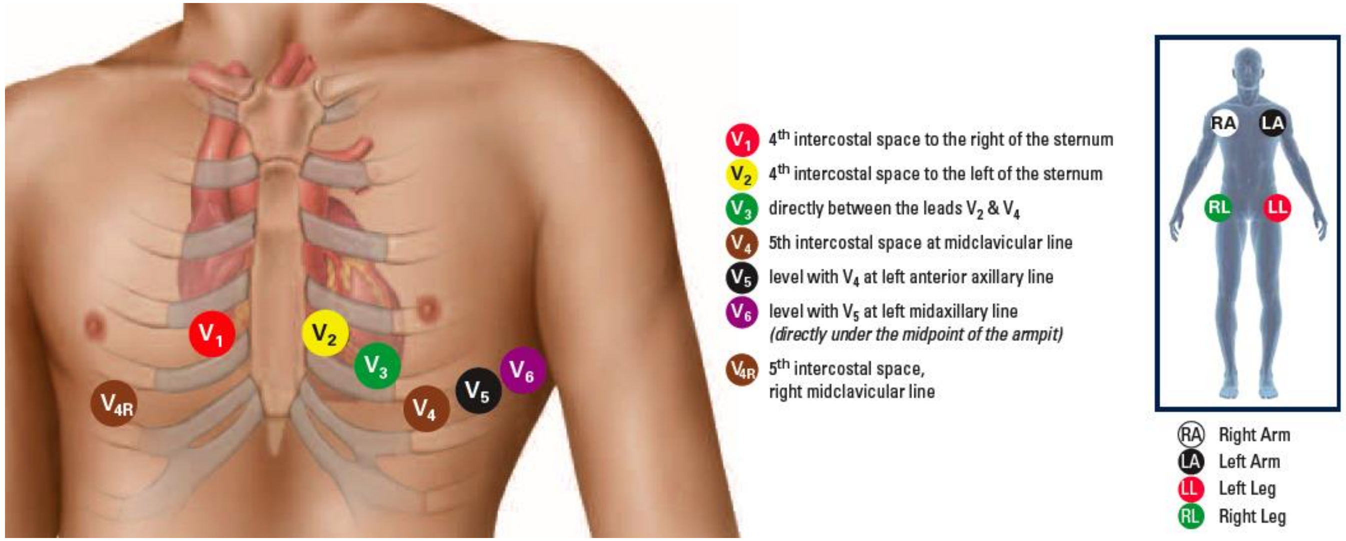
www.ecgguru.com

What is ECG?



- PR interval 0.12 – 0.20 sec
- QRS duration 0.08 – 0.10 sec

- QT interval 0.4 – 0.43 sec
- RR interval 0.6 – 1.0 sec



12-lead ECG

www.Wikipedia.com

Conventional clinical ECG

- Short duration: usually 10 seconds, ~3 seconds in reporting.
- Low repeatability, precision and accuracy, sometimes subjective.
- Data analysis is low efficiency and labor intensive.

MUSE_Interactive: A Software Tool for Automatic ECG analysis

- Read popular ECG formats.
- Automatic delineation: QRS complex, P- and T wave; peak, start and stop.
- Manual adjustments: Adjust positions, remove and add additional features.
- Automatic report generation.
- Visualization.

Peter Noseworthy, Bo Qiang, Alan Surgue, Paul Friedmen, patent pending 2015-252 (Fish 07039-1558P01) “ELECTROCARDIOGRAM ANALYTICAL TOOL”

Alan Sugrue, Peter A Noseworthy, Vaclav Kremen, J Martijn Bos, Bo Qiang, Ram K Rohatgi, Yehu Sapir, Zachi I Attia, Peter Brady, Samuel J Asirvatham, Paul A Friedman, Michael J Ackerman, Identification of Concealed and Manifest Long QT Syndrome Using a Novel T Wave Analysis Program, Circulation Arrhythmia and Electrophysiology 9(7):e003830 · July 2016

Software Overview

Load (MUSE Format) →

Preprocessing
- De-noising
- Baseline correction
- Power line interference

→

Feature Extraction
- R-Waves
- QRS Complexes
- P- and T-Waves

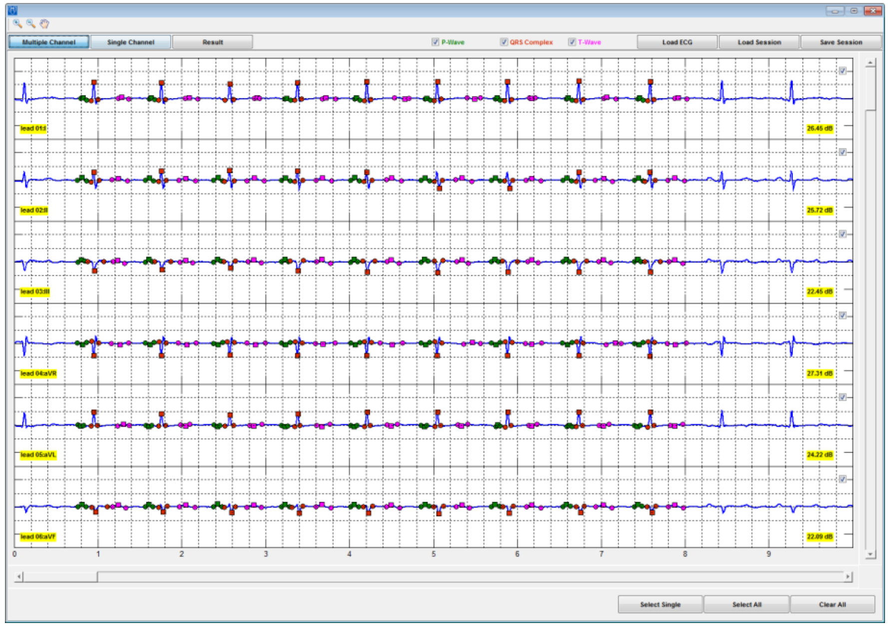
→

Manual Adjustments ↓

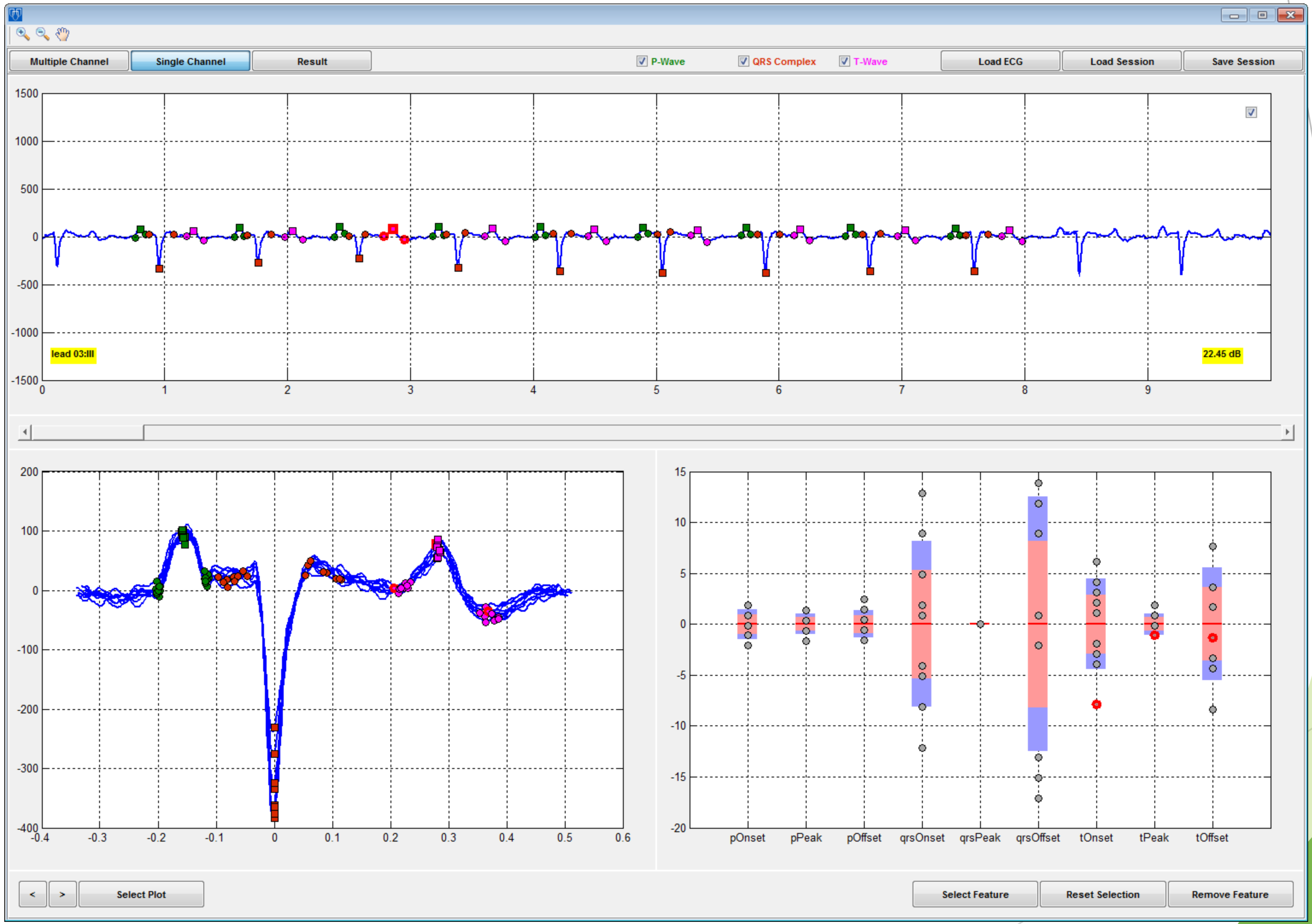
Report Generation →

Statistical Analysis

MUSE-Interactive



Single-Channel View



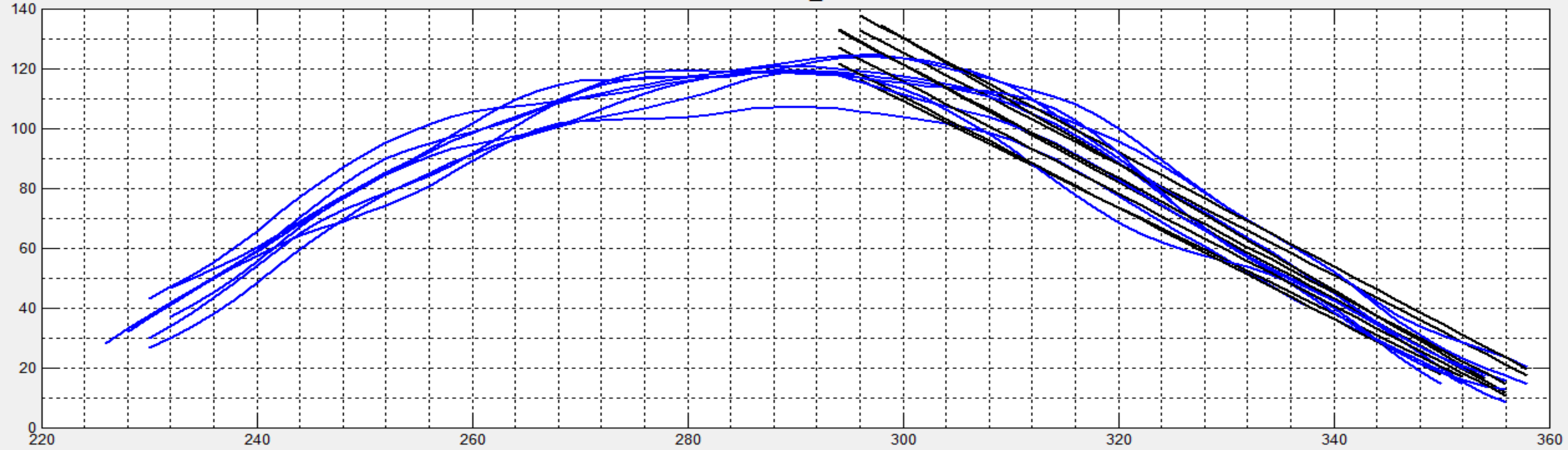
Report Generation

MUSE_20141124_090445_53000

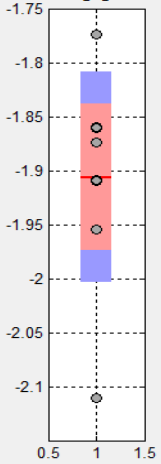
Multi-Channel | Single Channel | Results | Save | Load

	T_LSLOPE	T_RSLOPE	T_AMP	T_AREA	T_COG_X	T_COG_Y	T1_COG_X	T1_COG_Y	T4_COG_X	T4_COG_Y	QT	QTC	TPEAK_TEND
Lead 1: I	1.30 +/- 0.12	-1.91 +/- 0.10	118.24 +/- 5.76	5189.03 +/- 292.50	0.29 +/- 0.00	47.15 +/- 2.30	0.25 +/- 0.00	36.35 +/- 3.46	0.34 +/- 0.00	26.57 +/- 1.57	0.35 +/- 0.00	0.38 +/- 0.00	-29.88 +/- 1.55
Lead 2: II	0.86 +/- 0.12	-1.28 +/- 0.25	83.82 +/- 3.57	3934.76 +/- 131.15	0.28 +/- 0.00	34.56 +/- 1.18	0.24 +/- 0.00	27.42 +/- 2.53	0.33 +/- 0.00	21.30 +/- 1.98	0.35 +/- 0.00	0.37 +/- 0.00	-29.88 +/- 3.44
Lead 3: III	-0.42 +/- 0.16	0.52 +/- 0.12	-37.48 +/- 7.65	1393.09 +/- 273.83	0.31 +/- 0.01	-14.07 +/- 1.81	0.27 +/- 0.01	-12.13 +/- 2.18	0.36 +/- 0.01	-6.13 +/- 2.96	0.37 +/- 0.01	0.40 +/- 0.01	-30.25 +/- 3.11
Lead 4: aVR	-1.08 +/- 0.10	1.59 +/- 0.11	-101.93 +/- 4.24	4589.48 +/- 181.64	0.29 +/- 0.00	-40.81 +/- 1.34	0.24 +/- 0.00	-30.59 +/- 2.09	0.33 +/- 0.00	-25.57 +/- 2.02	0.35 +/- 0.00	0.37 +/- 0.00	-28.88 +/- 0.83
Lead 5: aVL	0.87 +/- 0.08	-1.27 +/- 0.14	77.25 +/- 4.05	3242.82 +/- 202.90	0.29 +/- 0.00	30.50 +/- 1.53	0.25 +/- 0.00	23.29 +/- 2.59	0.34 +/- 0.00	16.71 +/- 1.95	0.36 +/- 0.00	0.38 +/- 0.00	-28.63 +/- 0.52
Lead 6: aVF	0.51 +/- 0.13	-0.35 +/- 0.08	30.33 +/- 6.24	1263.45 +/- 325.75	0.25 +/- 0.01	12.00 +/- 2.42	0.21 +/- 0.01	10.84 +/- 2.67	0.30 +/- 0.01	6.24 +/- 2.92	0.32 +/- 0.01	0.34 +/- 0.02	-39.88 +/- 6.06
Lead 7: V1	-0.78 +/- 0.15	0.35 +/- 0.11	-31.55 +/- 5.08	1060.87 +/- 199.47	0.30 +/- 0.00	-11.34 +/- 1.81	0.27 +/- 0.00	-9.90 +/- 1.51	0.36 +/- 0.01	-2.55 +/- 4.61	0.38 +/- 0.00	0.40 +/- 0.00	-44.00 +/- 0.00
Lead 8: V2	1.15 +/- 0.18	-1.16 +/- 0.10	75.02 +/- 4.50	3010.98 +/- 318.90	0.23 +/- 0.00	29.57 +/- 2.32	0.19 +/- 0.01	19.26 +/- 3.39	0.27 +/- 0.01	18.29 +/- 2.53	0.29 +/- 0.01	0.31 +/- 0.01	-31.25 +/- 1.91
Lead 9: V3	1.56 +/- 0.26	-0.96 +/- 0.07	97.76 +/- 9.34	4230.98 +/- 497.88	0.25 +/- 0.00	36.50 +/- 3.58	0.21 +/- 0.00	33.71 +/- 2.99	0.30 +/- 0.00	19.94 +/- 4.28	0.32 +/- 0.00	0.34 +/- 0.00	-42.25 +/- 1.04
Lead 10: V4	1.24 +/- 0.34	-0.61 +/- 0.21	72.15 +/- 22.91	3052.64 +/- 896.11	0.38 +/- 0.30	26.07 +/- 7.17	0.33 +/- 0.30	22.03 +/- 6.73	0.43 +/- 0.30	16.61 +/- 3.88	0.45 +/- 0.30	0.49 +/- 0.34	-42.63 +/- 0.74
Lead 11: V5	1.19 +/- 0.22	-0.39 +/- 0.11	63.00 +/- 7.01	3290.89 +/- 383.07	0.29 +/- 0.00	27.60 +/- 2.28	0.24 +/- 0.01	18.13 +/- 5.99	0.33 +/- 0.01	24.11 +/- 2.62	0.35 +/- 0.01	0.37 +/- 0.01	-39.50 +/- 6.21
Lead 12: V6	0.91 +/- 0.20	-1.01 +/- 0.19	75.99 +/- 6.38	3483.14 +/- 308.06	0.29 +/- 0.00	30.47 +/- 2.28	0.25 +/- 0.00	25.52 +/- 2.84	0.34 +/- 0.00	17.84 +/- 2.37	0.36 +/- 0.00	0.38 +/- 0.00	-35.38 +/- 3.62

Lead 1: I -- T_RSLOPE

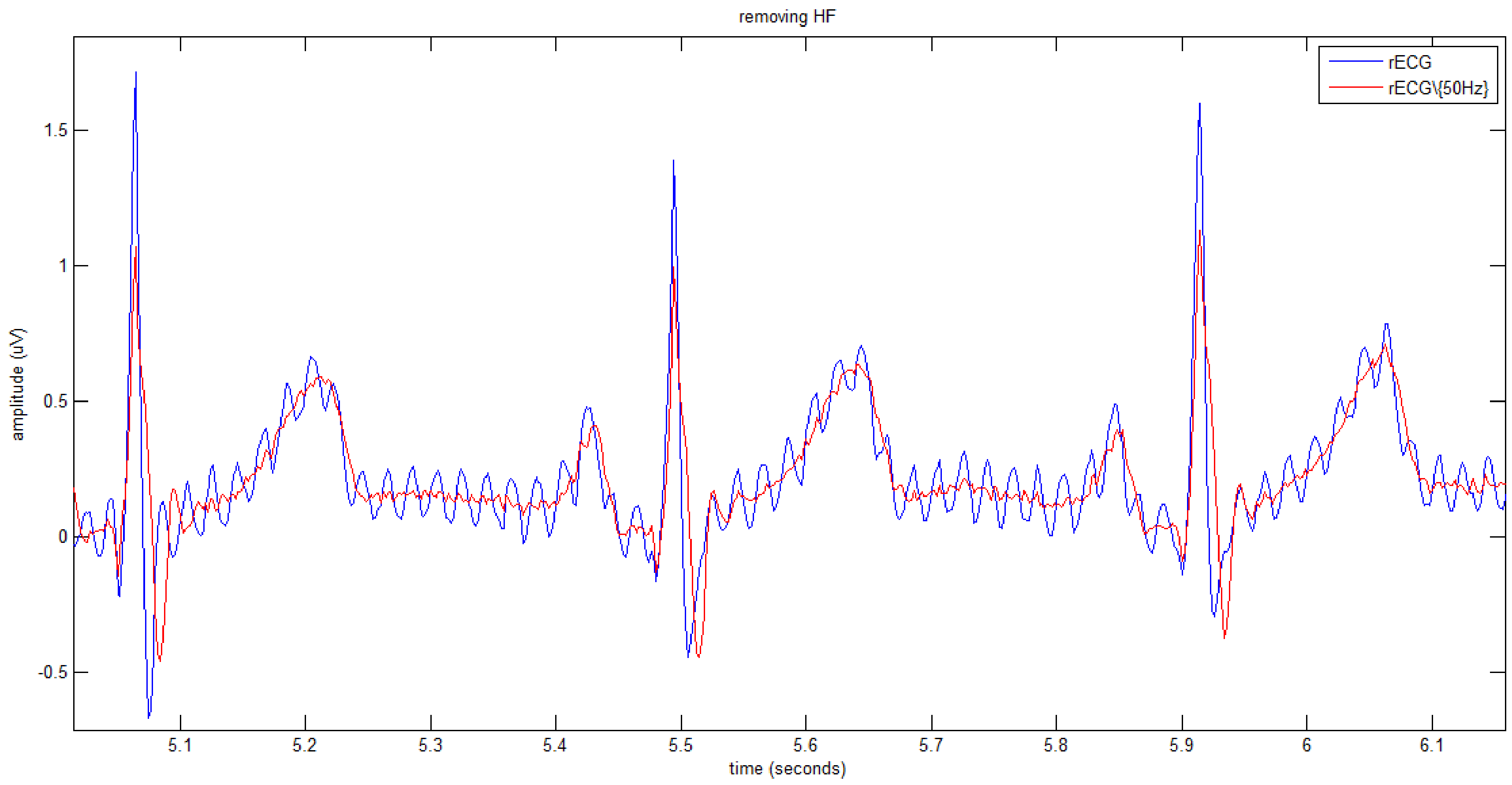


[8]



< | 0 | > | Remove | Build Report

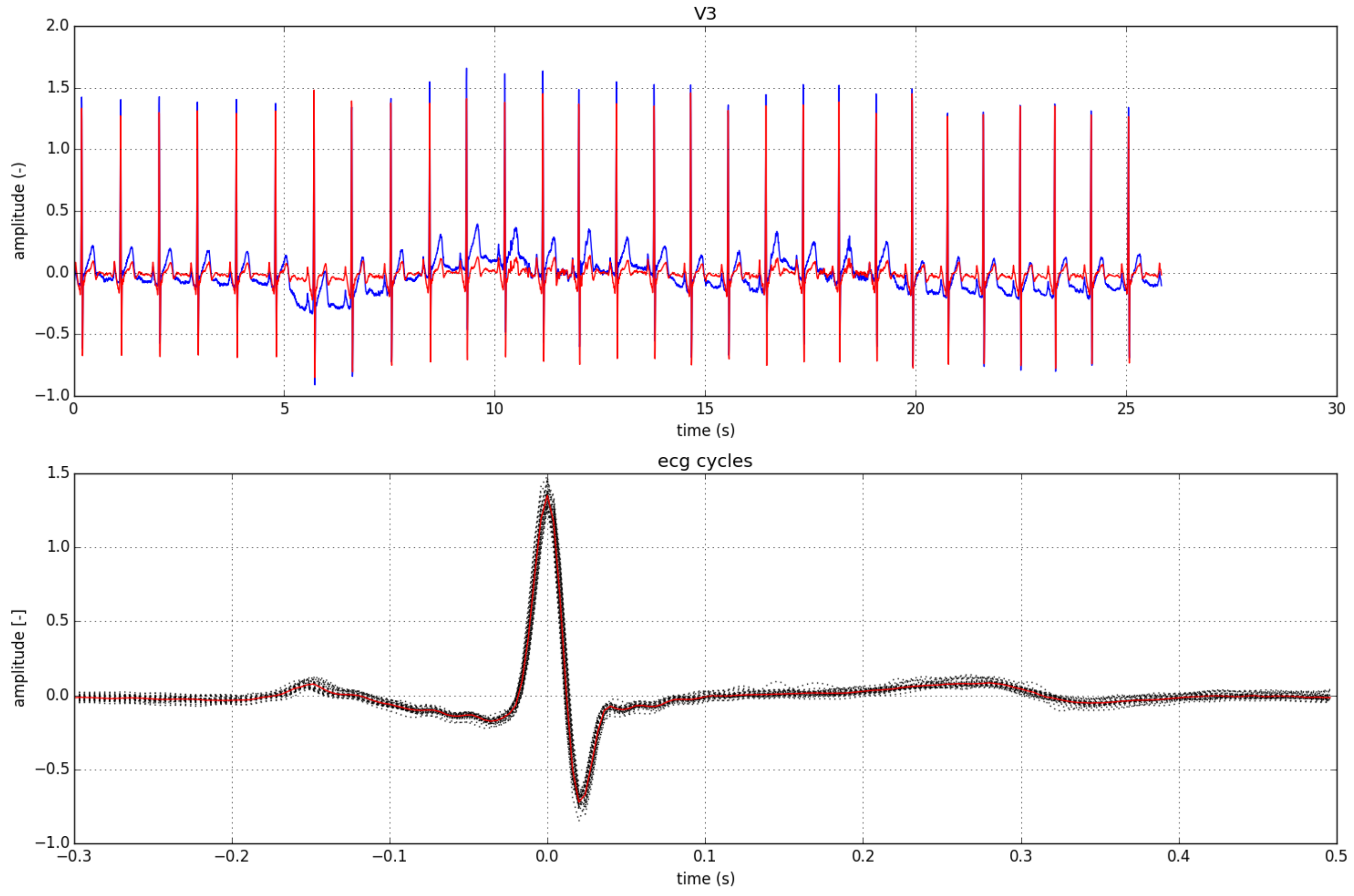
Preprocessing - denoising



- Powerline interference
- Random noise
- Motion noise

- Low pass filtering
- Wiener filtering
- Wavelet based methods

Preprocessing – baseline removal

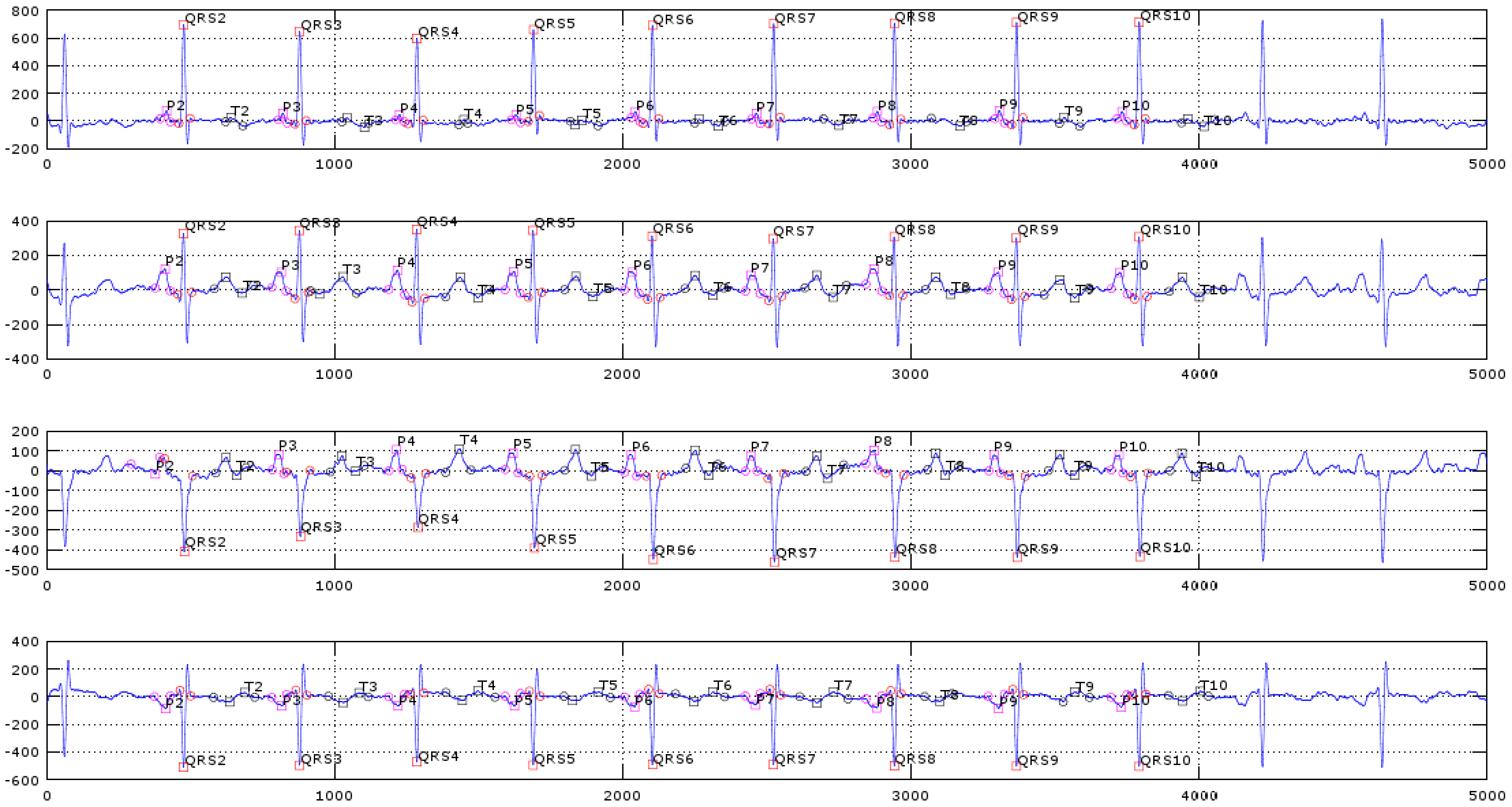


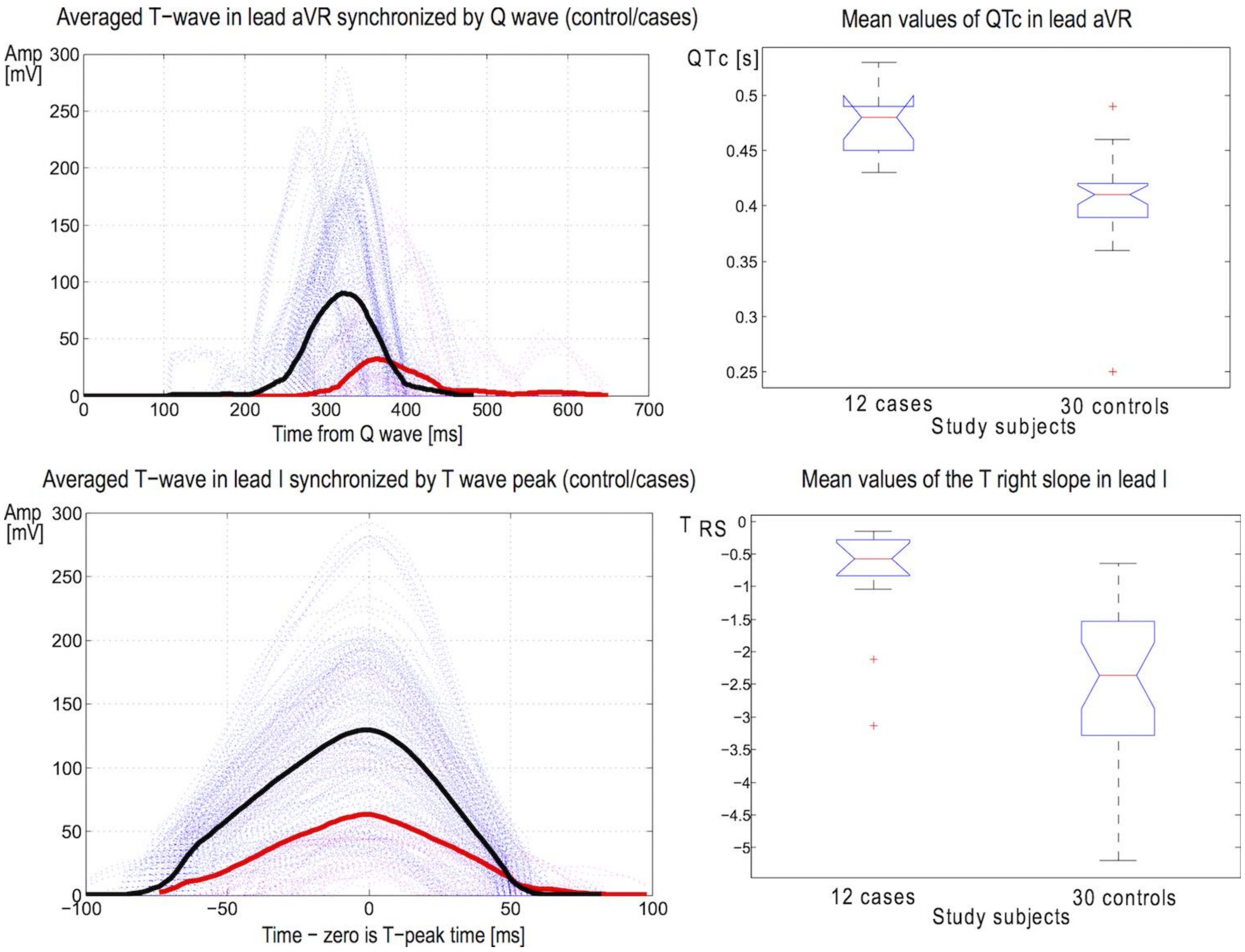
- Slow motion, breathing

- High pass filtering
- Polynomial fitting
- Wavelet decomposition

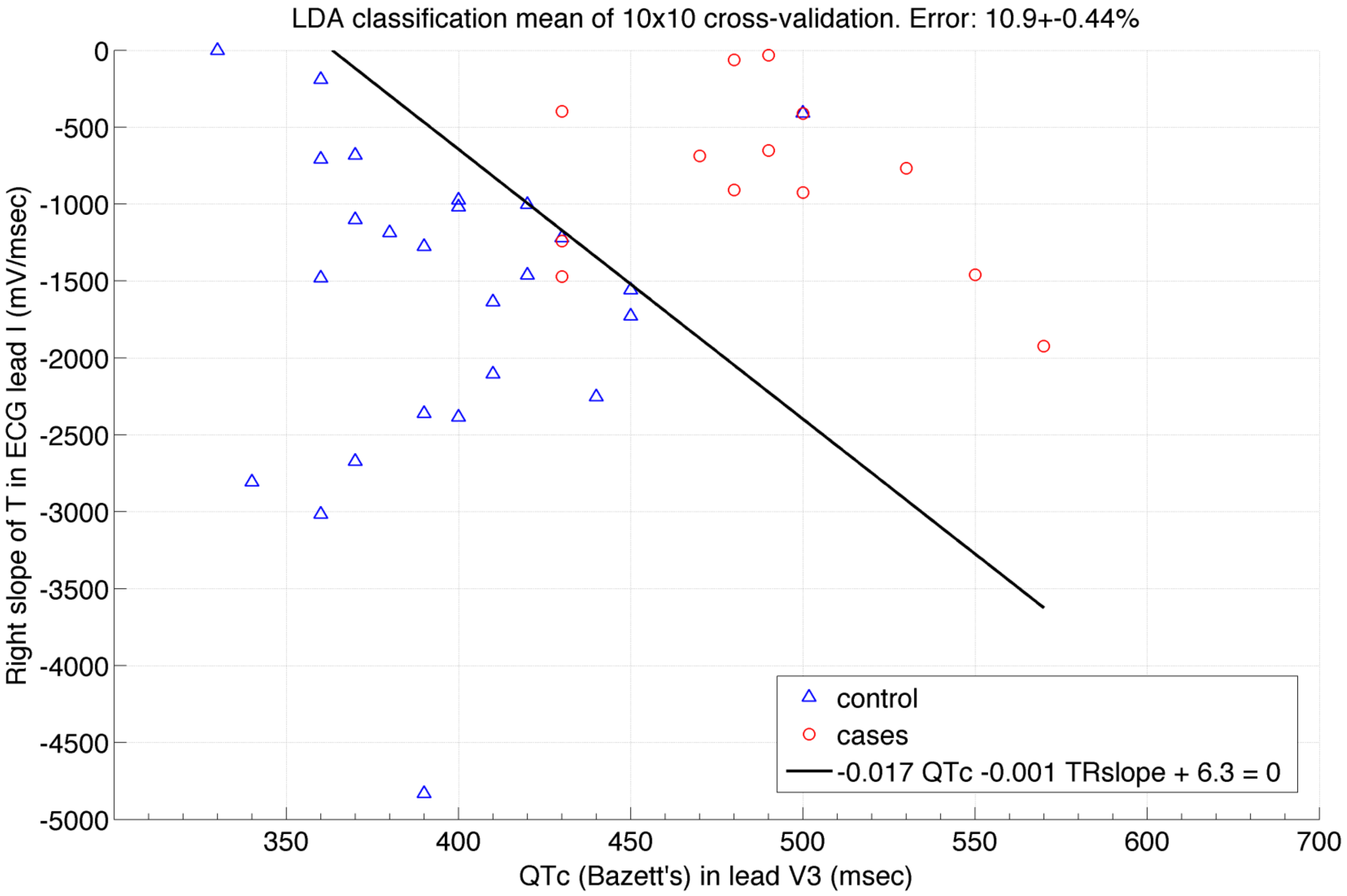
Feature extraction

- Wavelet decomposition.
- Adaptive thresholding in multiple decomposition levels.
- Automatic validation.
- Cross-channel correlation.
- Optional template matching and Bayesian method.





Sugrue, Alan, et al. "Electrocardiographic predictors of torsadogenic risk during dofetilide or sotalol initiation: utility of a novel T wave analysis program." *Cardiovascular Drugs and Therapy* 29.5 (2015): 433-441.



Sugrue, Alan, et al. "Electrocardiographic predictors of torsadogenic risk during dofetilide or sotalol initiation: utility of a novel T wave analysis program." *Cardiovascular Drugs and Therapy* 29.5 (2015): 433-441.

Cardiovasc Drugs Ther
DOI 10.1007/s10557-015-6620-7

CrossMark

EDITORIAL

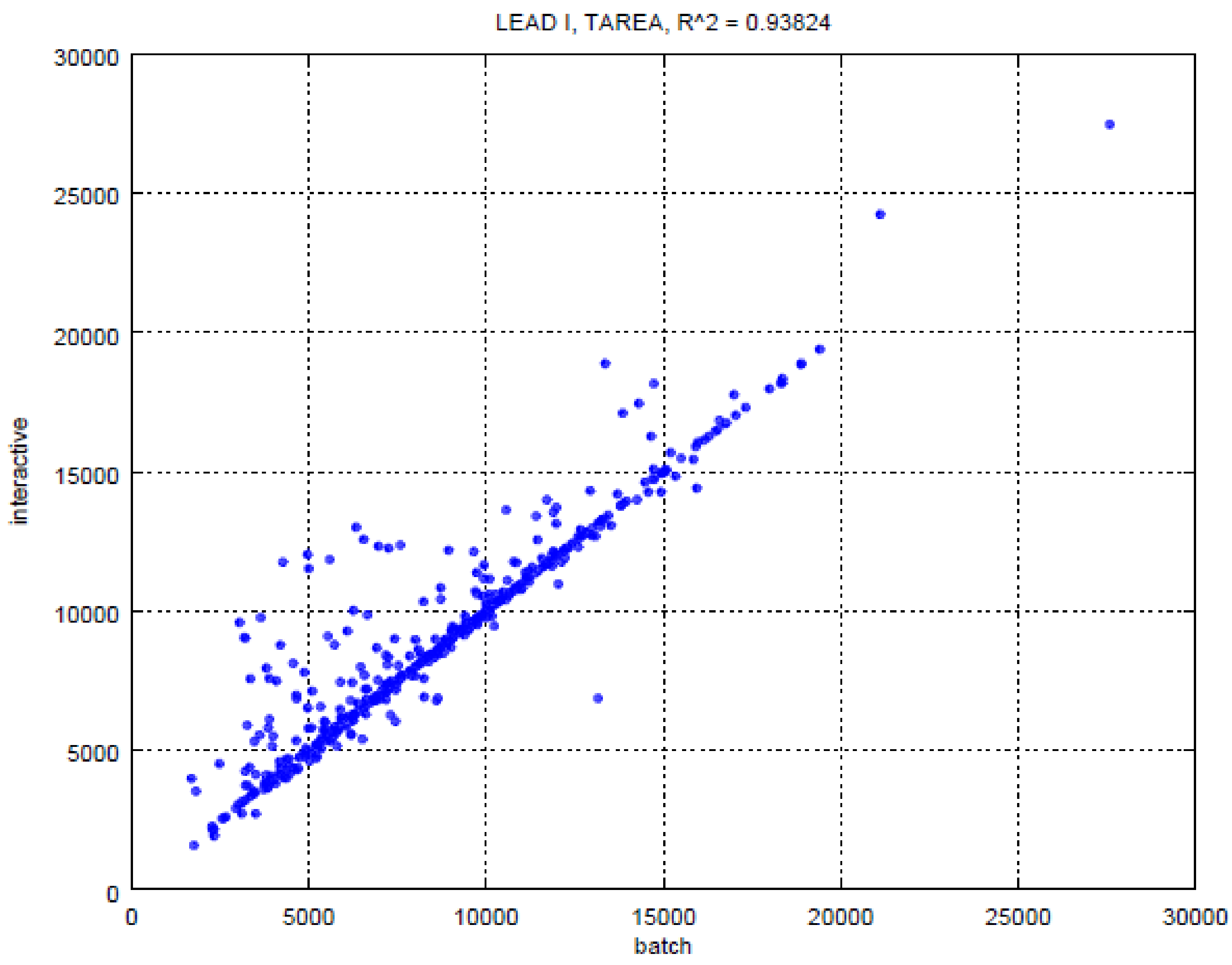
T-wave Right Slope Provides a New Angle in the Prediction of Drug-Induced Ventricular Arrhythmias

Editorial to: "Electrocardiographic Predictors of Torsadogenic Risk During Dofetilide or Sotalol Initiation: Utility of a Novel T Wave Analysis Program" by Sugrue A. et al.

Jordi Heijman[1] · Harry J. G. M. Crijns[1]

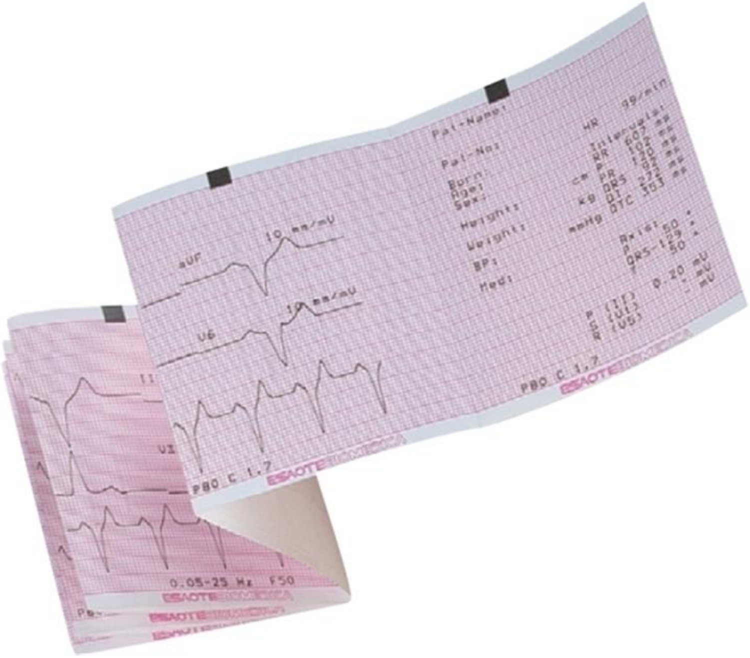
Benefit of MUSE_Interactive

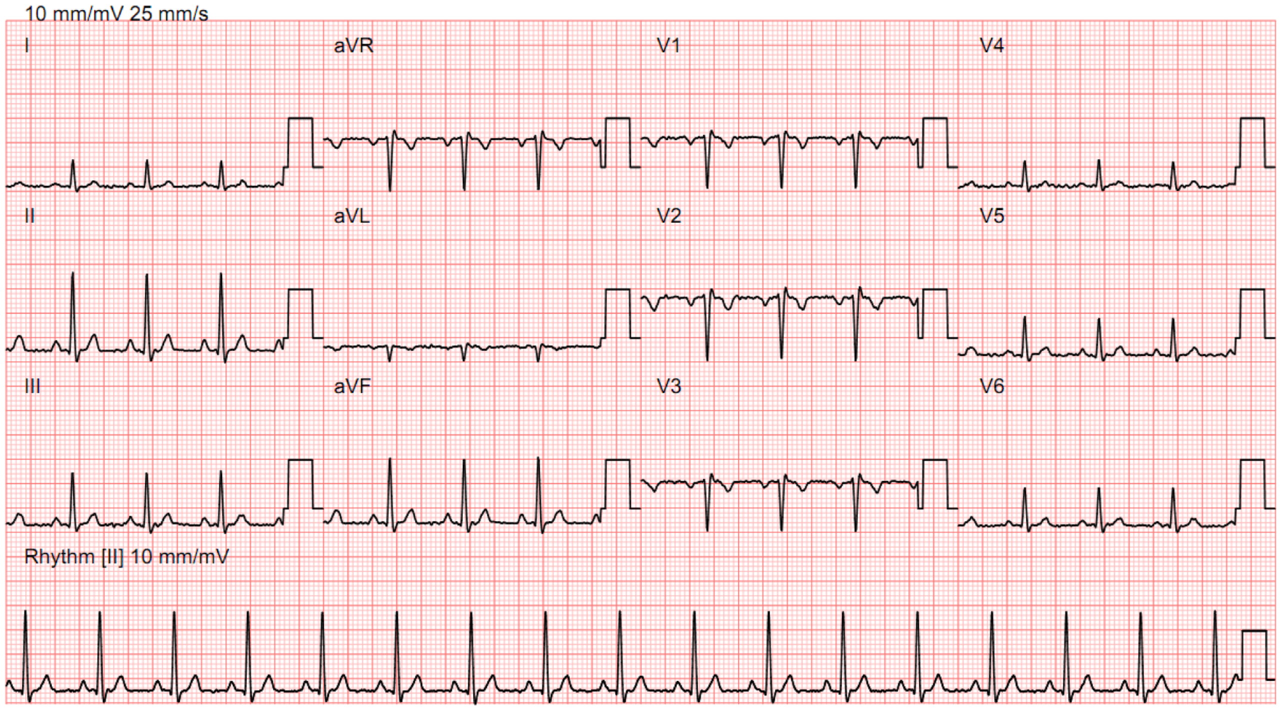
- Greatly improved the efficiency
  - QRS, T- and P- Waves are automatically detected, speedup the process minutes to seconds.
  - Batch processing without intervention.
- Better confidence and repeatability
  - Visualization provide a direct view of analysis.
  - Self-learning capability: the more analysis performed, the better the program will be.


LEAD I, TAREA, R^2 = 0.93824
interactive
batch
0
5000
10000
15000
20000
25000
30000

Historic Paper Base ECG

- There are great amount of historic paper based ECG data.
- They are of great values for training diagnostic models.
- On-going effort for converting them to digital form.

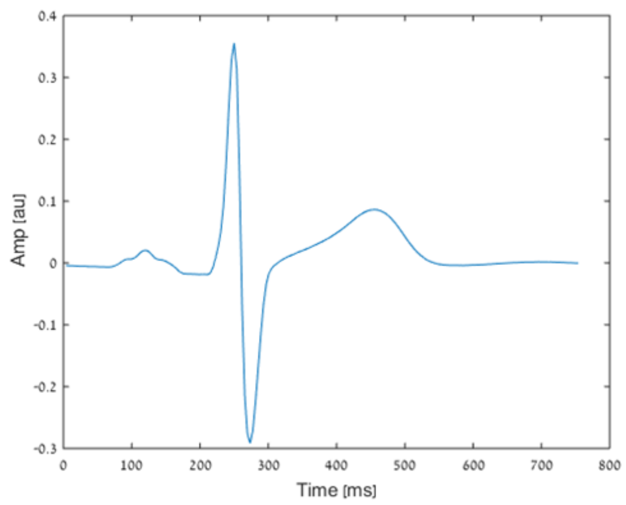



10 mm/mV 25 mm/s
I
aVR
V1
V4
II
aVL
V2
V5
III
aVF
V3
V6
Rhythm [II] 10 mm/mV

ECG on mobile devices

- Traditional ECGs are performed in clinic setting.
- ECG can be collected with mobile devices to continuously monitor heart health remotely.
- Mayo clinic and a medical device startup Preventice has been working together to develop a portable ECG technology.
- Currently the technology has been used in patients.

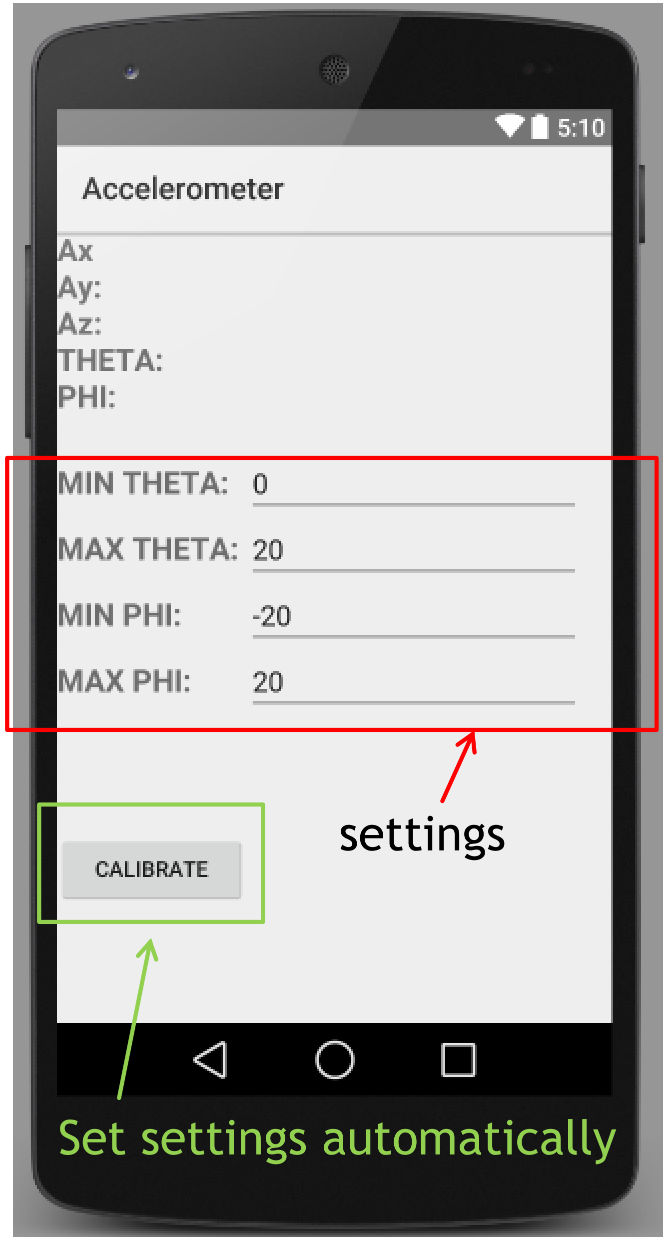
BodyGuardian Sensor

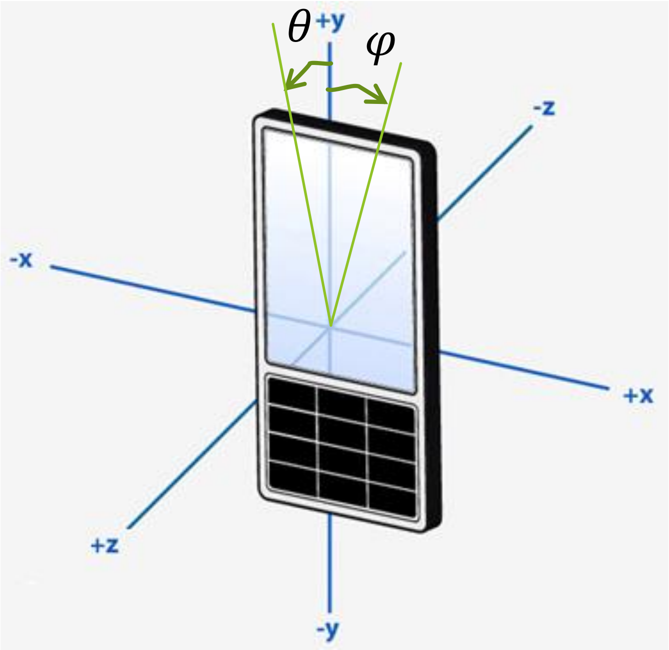



bodyguardian
cellular
Internet
Patient
BodyGuardian control unit + SnapStrip on chest communicates with phone.
Secure database
BodyGuardian Connect sends cardiac data to secure database servers.
Doctor
Doctor views patient data via secure Internet connection.
Preventice

Technical Challenges

- Large volume of data transmission.
  - Connection problems.
  - Bandwidth problem.
  - Data loss and duplication.
- Noise removal.
  - Motion artefacts, activity, breathing, random noise…
- Data interpretation.
  - Body positions.





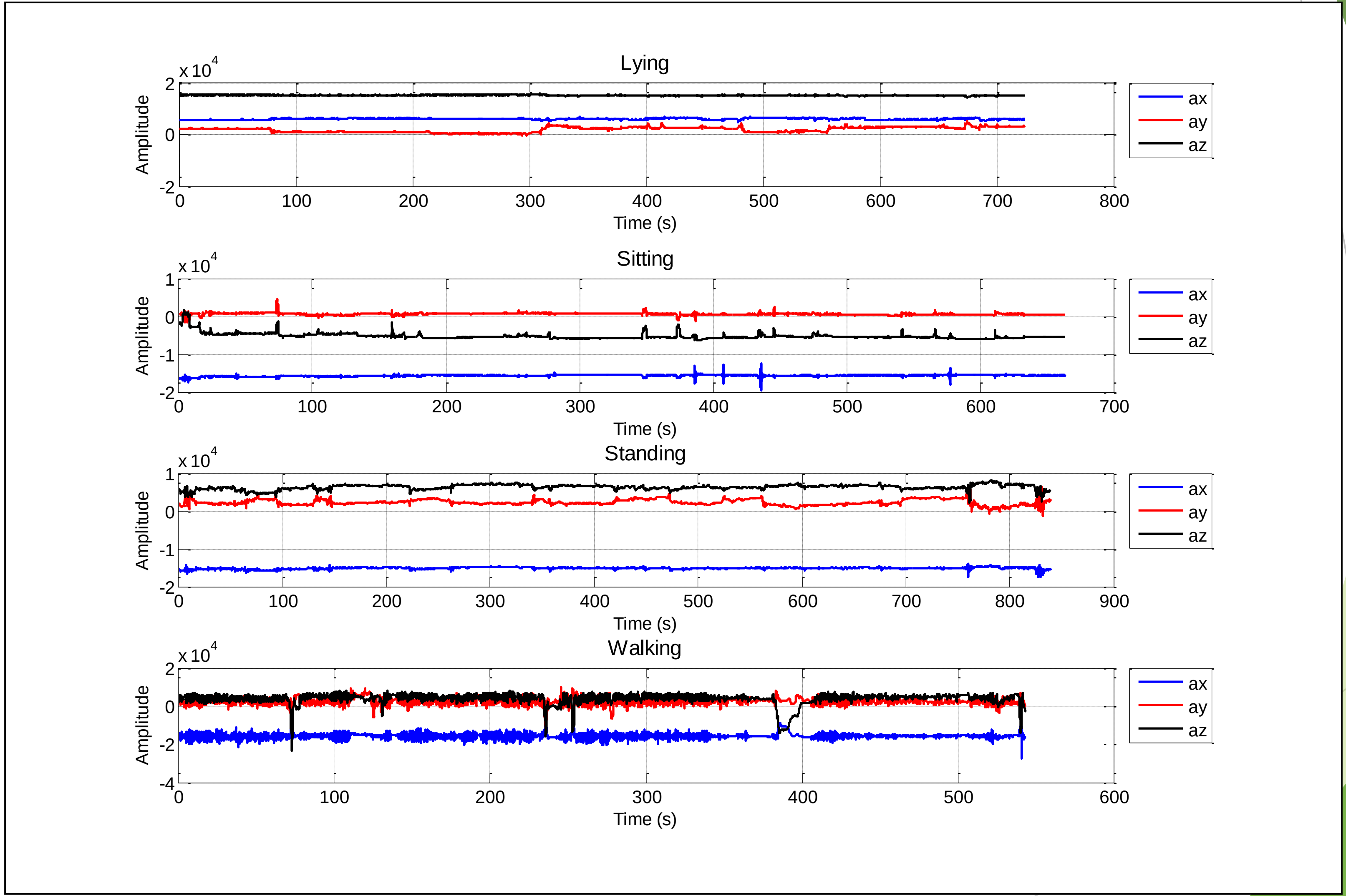
Ax: accelerometer reading in x direction
Ay: accelerometer reading in y direction
Az: accelerometer reading in z direction
THETA: angle between phone face and +y
PHI: angle between phone side and +y

$$\theta = atan\left(\frac{Az}{Ay}\right) \qquad \varphi = atan\left(\frac{Ax}{Ay}\right)$$

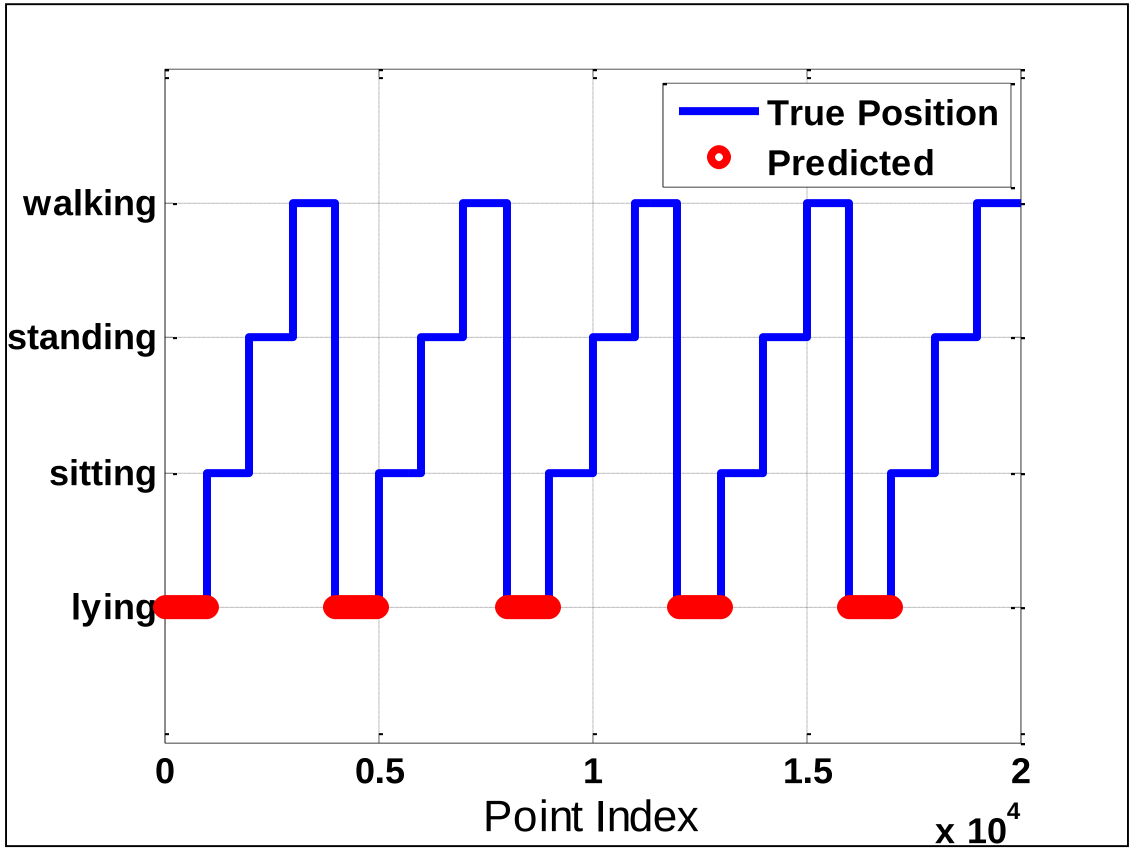
Estimate body activity

- Break up the 5000 data points in each activity into 1000 data-point sections and mix them.
- Using machine learning algorithms, randomly select 80% of the data for training.
- Test the model with the rest 20% of the data.

Raw Accelerometer Signal



Result: Lying

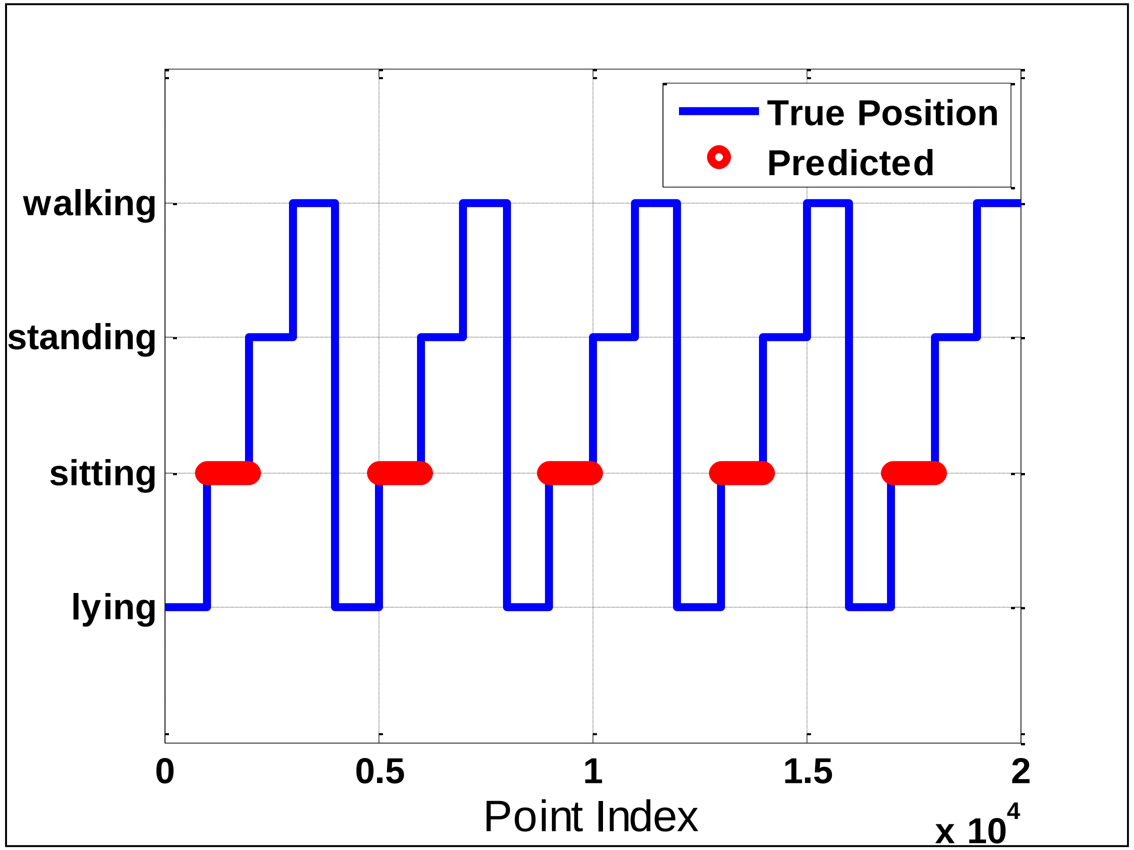


Features Used: x, y and z accelerations and their mean. and standard deviations.

Machine Learning Algorithm: support vector machine

- Predict when the person is lying.
- All the data points are correctly predicted (0% error).

Result: Sitting

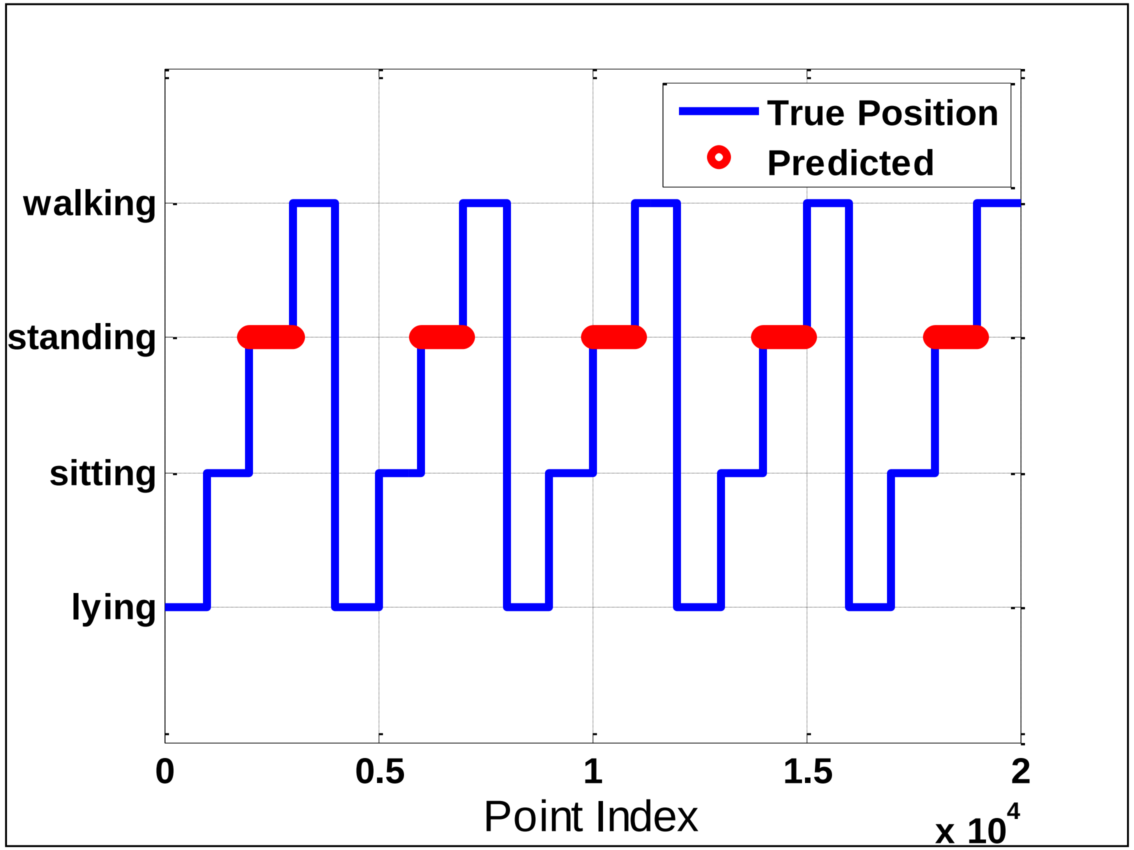


Features Used: x, y and z accelerations and their mean. and standard deviations.

Machine Learning Algorithm: support vector machine

- Predict when the person is sitting.
- All the data points are correctly predicted (0% error).

Result: Standing

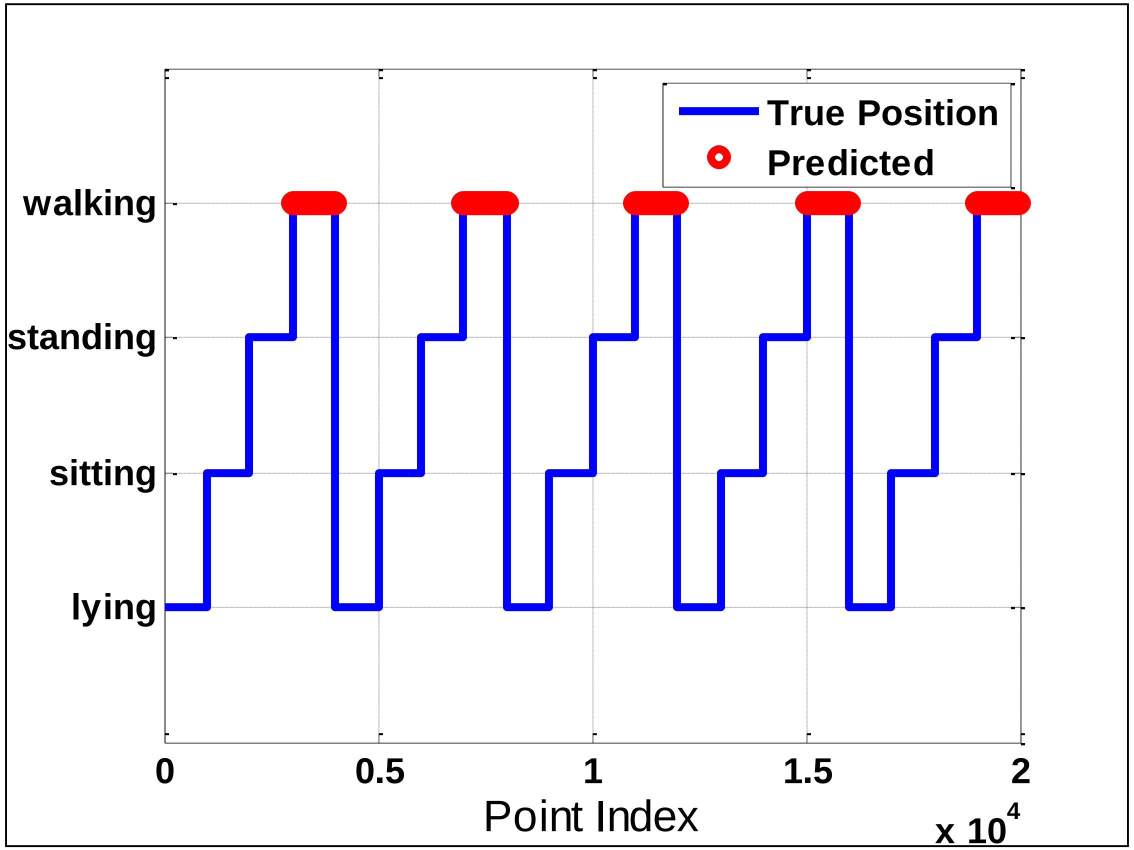


Features Used: x, y and z accelerations and their mean. and standard deviations.

Machine Learning Algorithm: support vector machine

- Predict when the person is standing.
- All the data points are correctly predicted (0% error).

Result: Walking

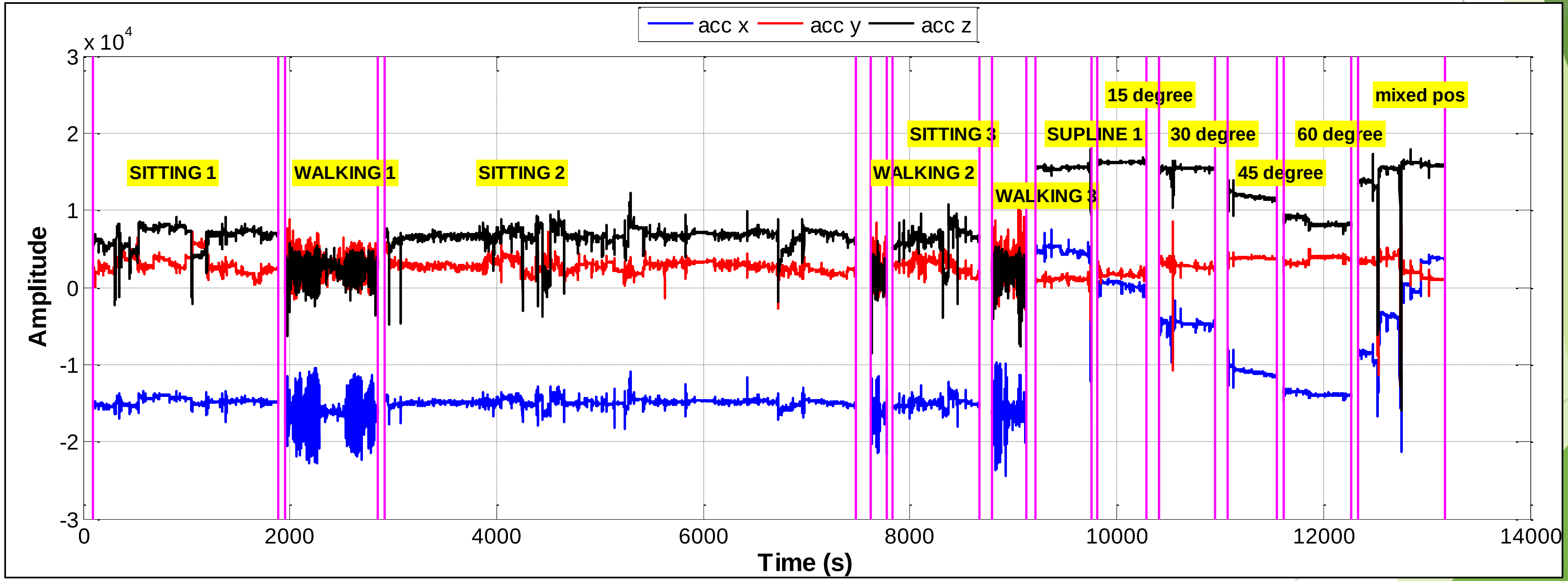


Features Used: x, y and z accelerations and their mean. and standard deviations.

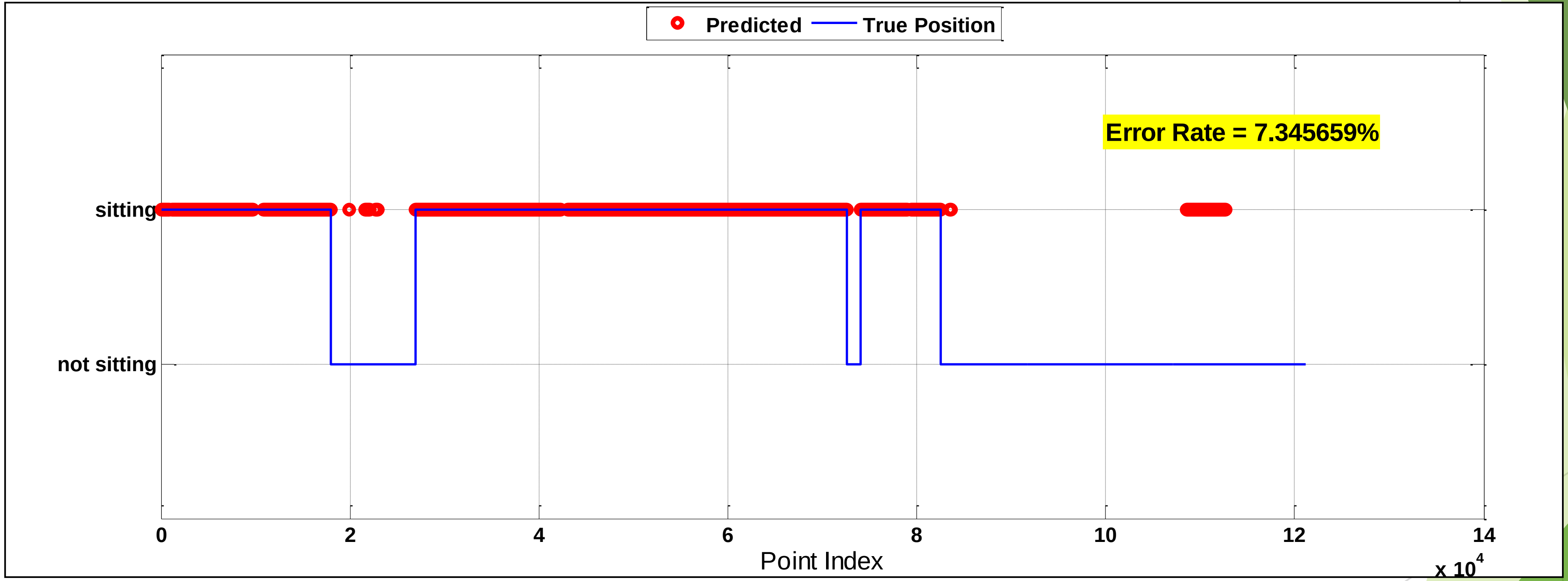
Machine Learning Algorithm: support vector machine

- Predict when the person is walking.
- All the data points are correctly predicted (0% error).

- 80% of points are used for training.
- 20% of points are used for testing.
- Support vector machine for learning algorithm.
- Features used: ax, ay, az, mean(ax), mean(ay), mean(az), std(ax), std(ay), std(az)

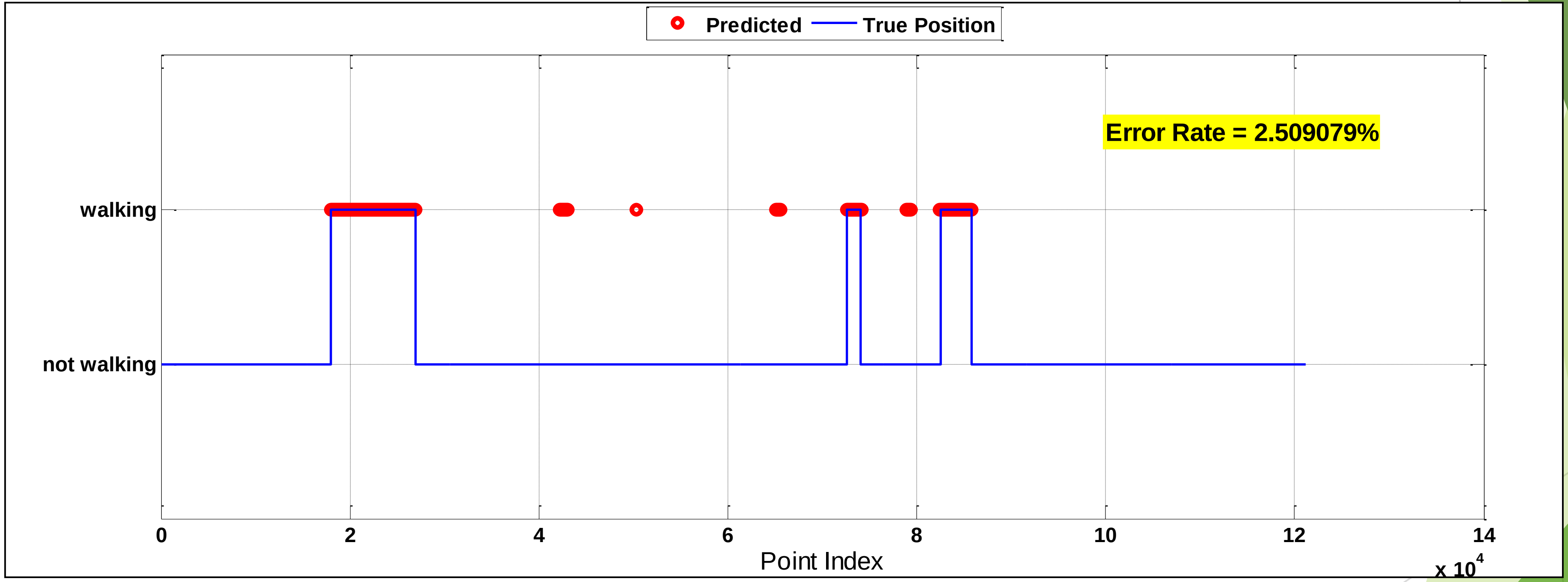


Sitting



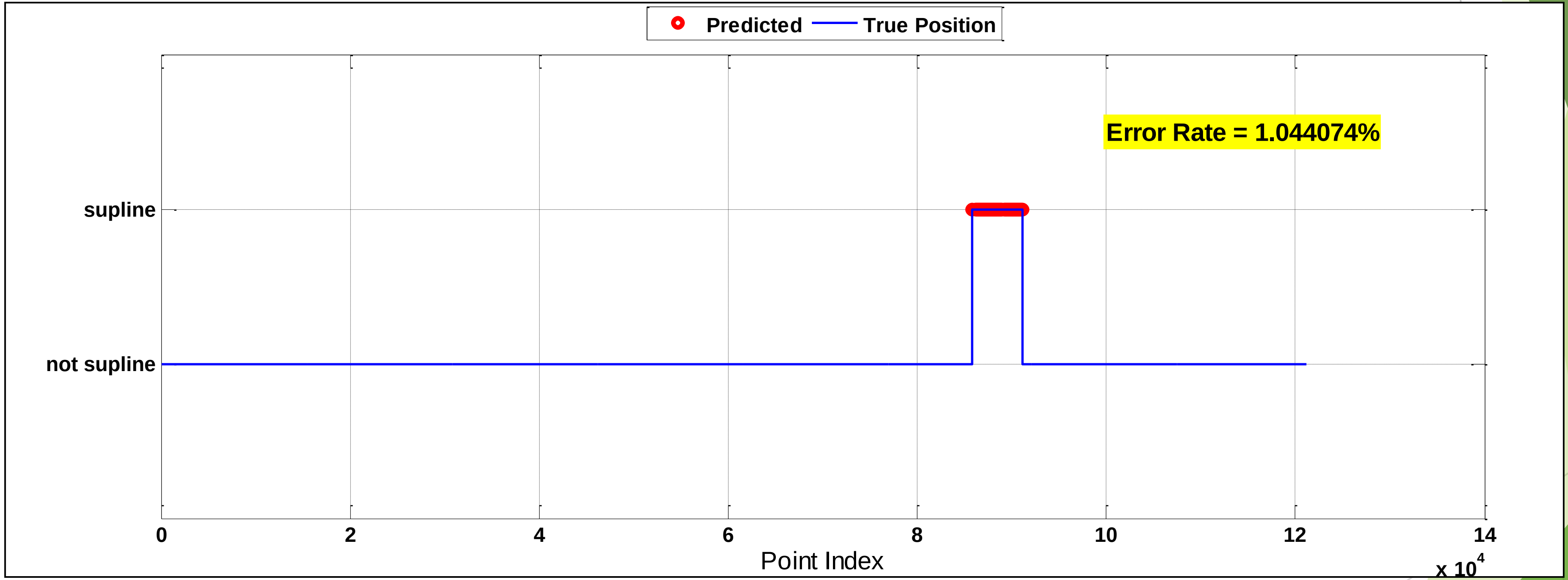
Predicted
True Position
Error Rate = 7.345659%
sitting
not sitting
0
2
4
6
8
10
12
14
Point Index
x 10^4

Walking



Predicted
True Position
Error Rate = 2.509079%
walking
not walking
0
2
4
6
8
10
12
14
Point Index
x 10^4

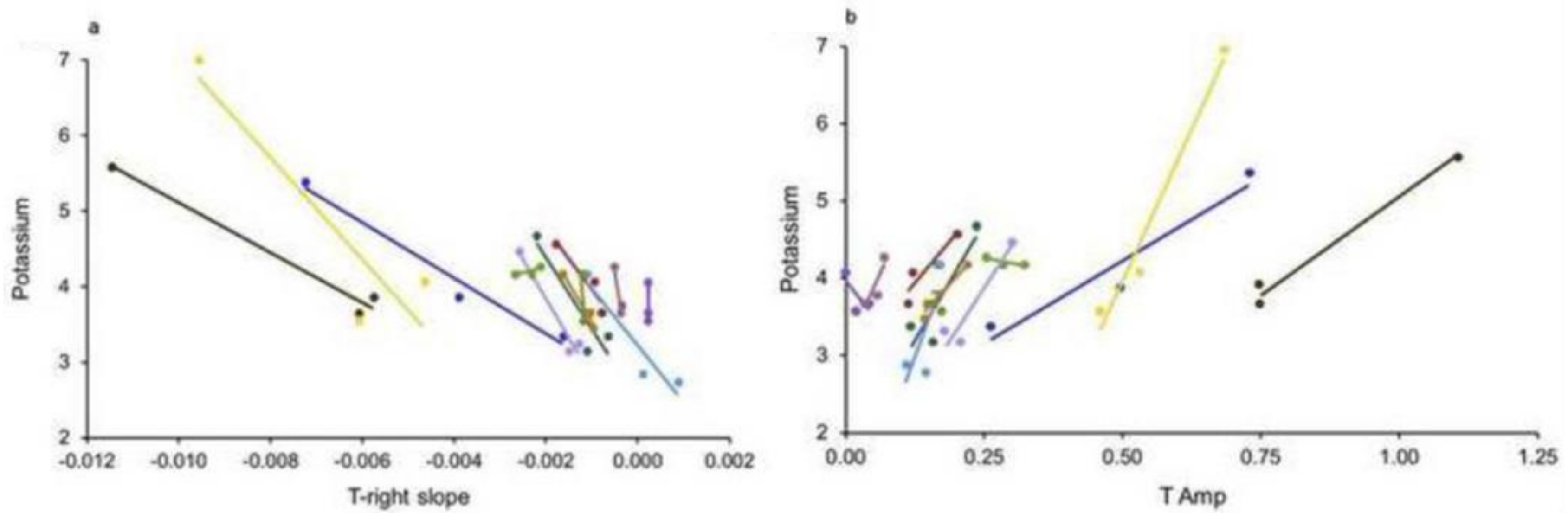
Supine



Predicted
True Position
Error Rate = 1.044074%
supline
not supline
0
2
4
6
8
10
12
14
Point Index
x 10^4

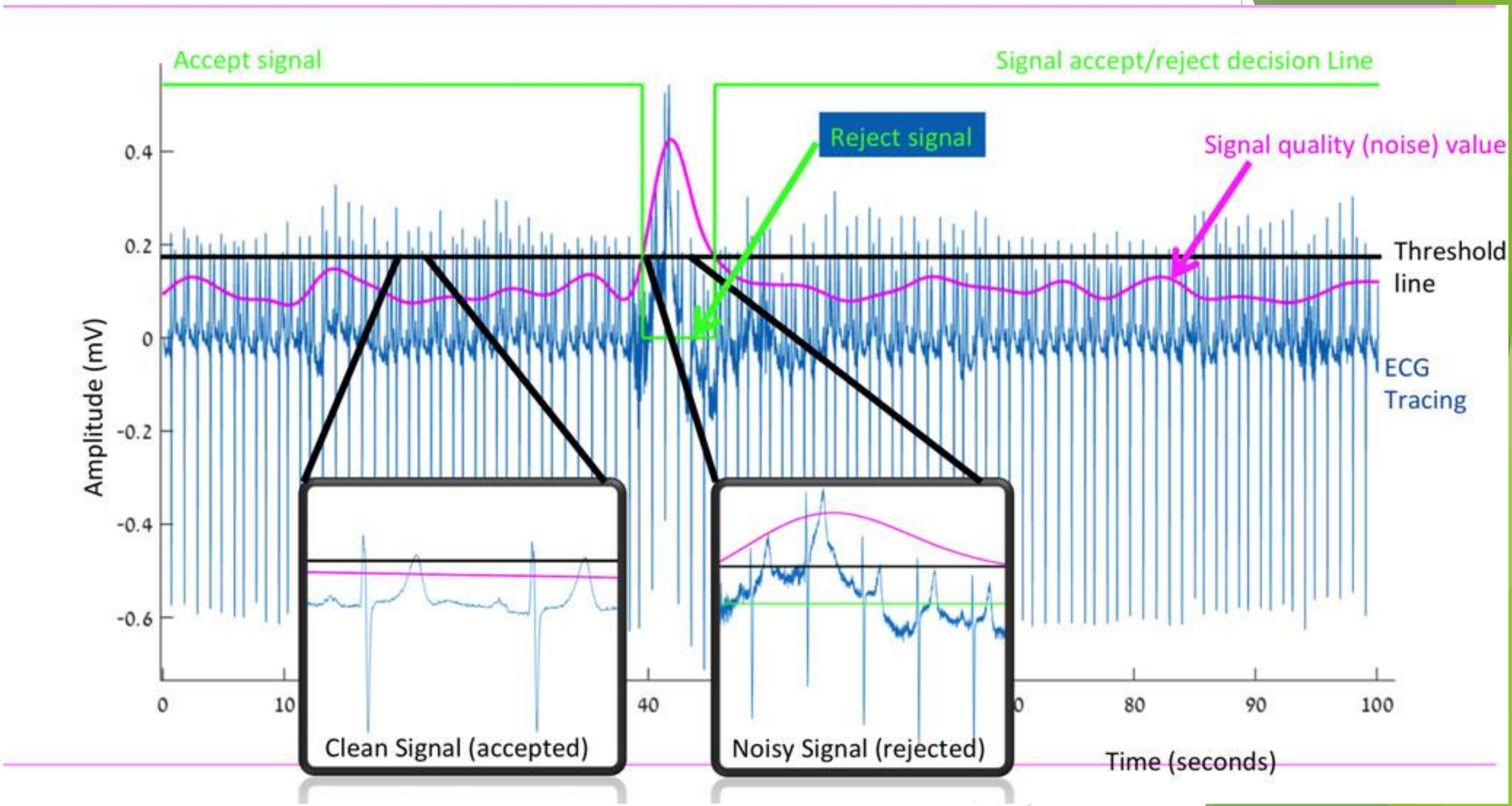
Application: Bloodless Potassium Determination

- It is found that T wave right slope is closely correlated with K+ concentration in blood.
- Dialysis patients need to have their blood potassium regulated within a healthy range.
- With mobile ECG measurements, we will know their K+ concentration remotely.

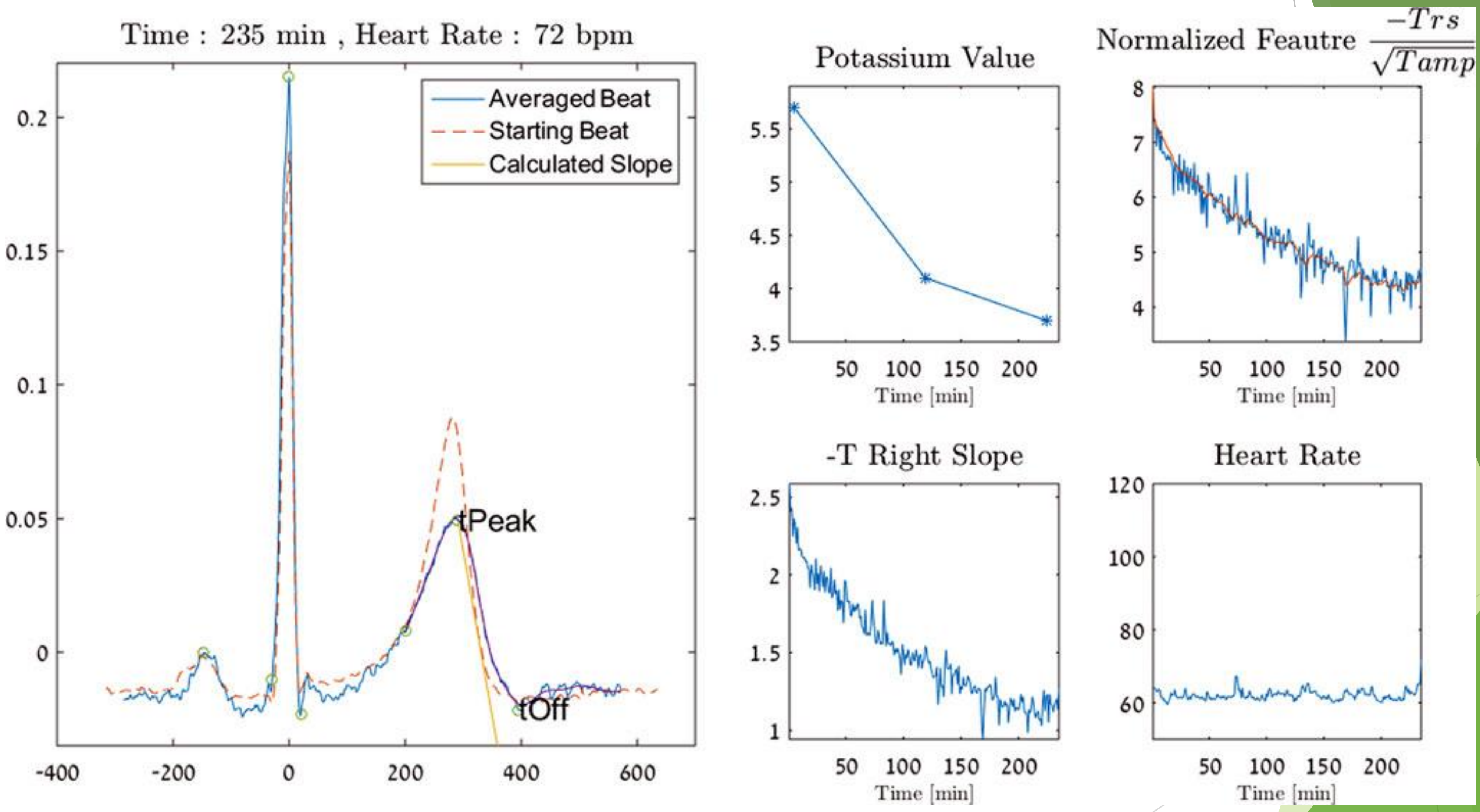


Dillon, John J., et al. "Noninvasive potassium determination using a mathematically processed ECG: Proof of concept for a novel “blood-less, blood test”." *Journal of electrocardiology* 48.1 (2015): 12-18.

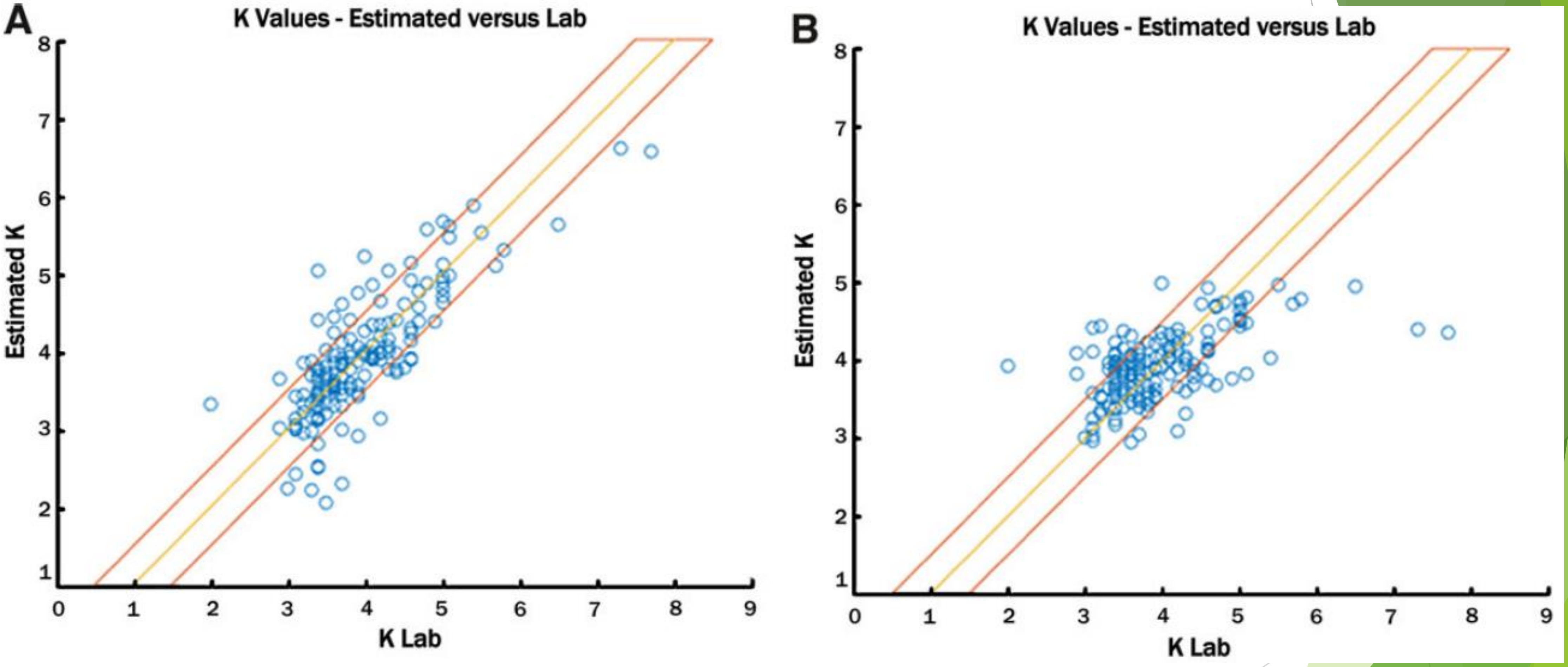
Attia, Zachi I., et al. "Novel Bloodless Potassium Determination Using a Signal-Processed Single-Lead ECG." *Journal of the American Heart Association* 5.1 (2016): e002746.



Accept signal
Signal accept/reject decision Line
Reject signal
Signal quality (noise) value
Threshold line
ECG Tracing
Amplitude (mV)
0.4
0.2
0
-0.2
-0.4
-0.6
0
10
40
80
90
100
Clean Signal (accepted)
Noisy Signal (rejected)
Time (seconds)

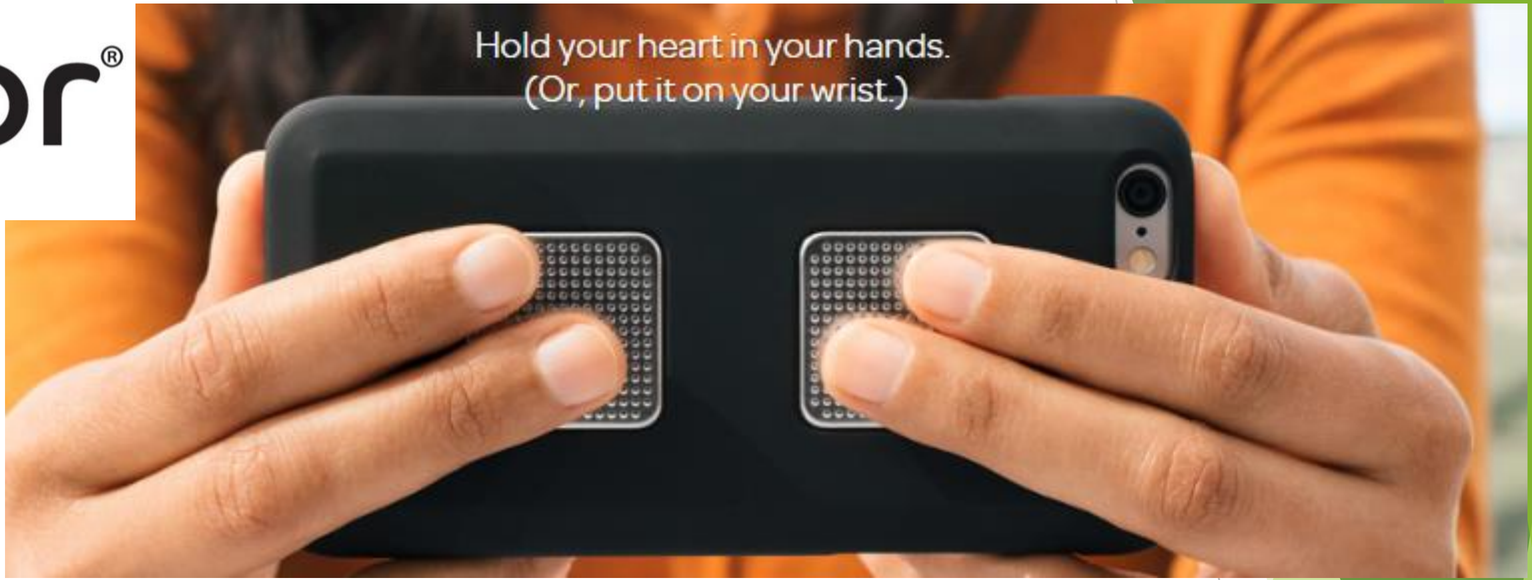


Time : 235 min , Heart Rate : 72 bpm
Averaged Beat
Starting Beat
Calculated Slope
tPeak
tOff
0.2
0.15
0.1
0.05
0
-400
-200
0
200
400
600
Potassium Value
5.5
5
4.5
4
3.5
50
100
150
200
Time [min]
Normalized Feautre $\frac{-Trs}{\sqrt{Tamp}}$
8
7
6
5
4
50
100
150
200
Time [min]
-T Right Slope
2.5
2
1.5
1
50
100
150
200
Time [min]
Heart Rate
120
100
80
60
50
100
150
200
Time [min]


A
K Values - Estimated versus Lab
Estimated K
K Lab
B
K Values - Estimated versus Lab
Estimated K
K Lab

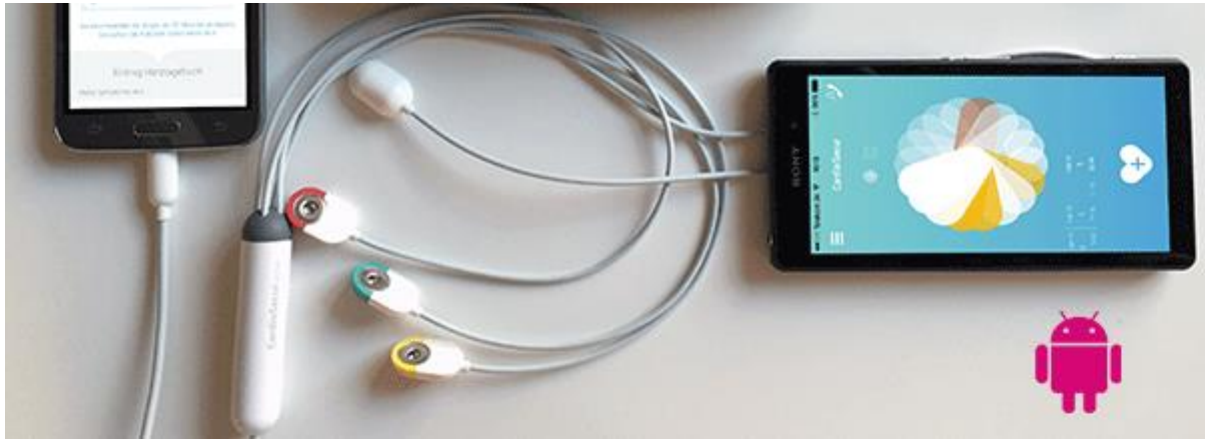
AliveCor®

AliveCor ECG Sensor



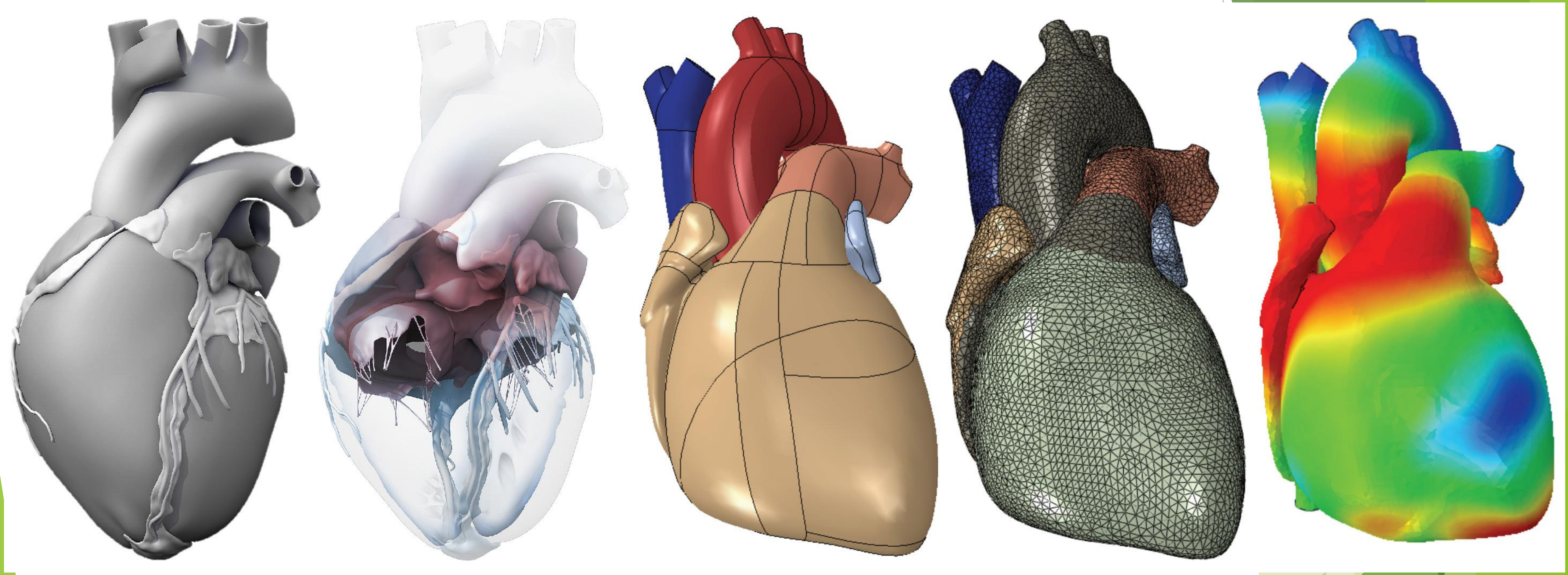
CardioSecur®
Knows your Heart

CardioSecur 22 lead ECG



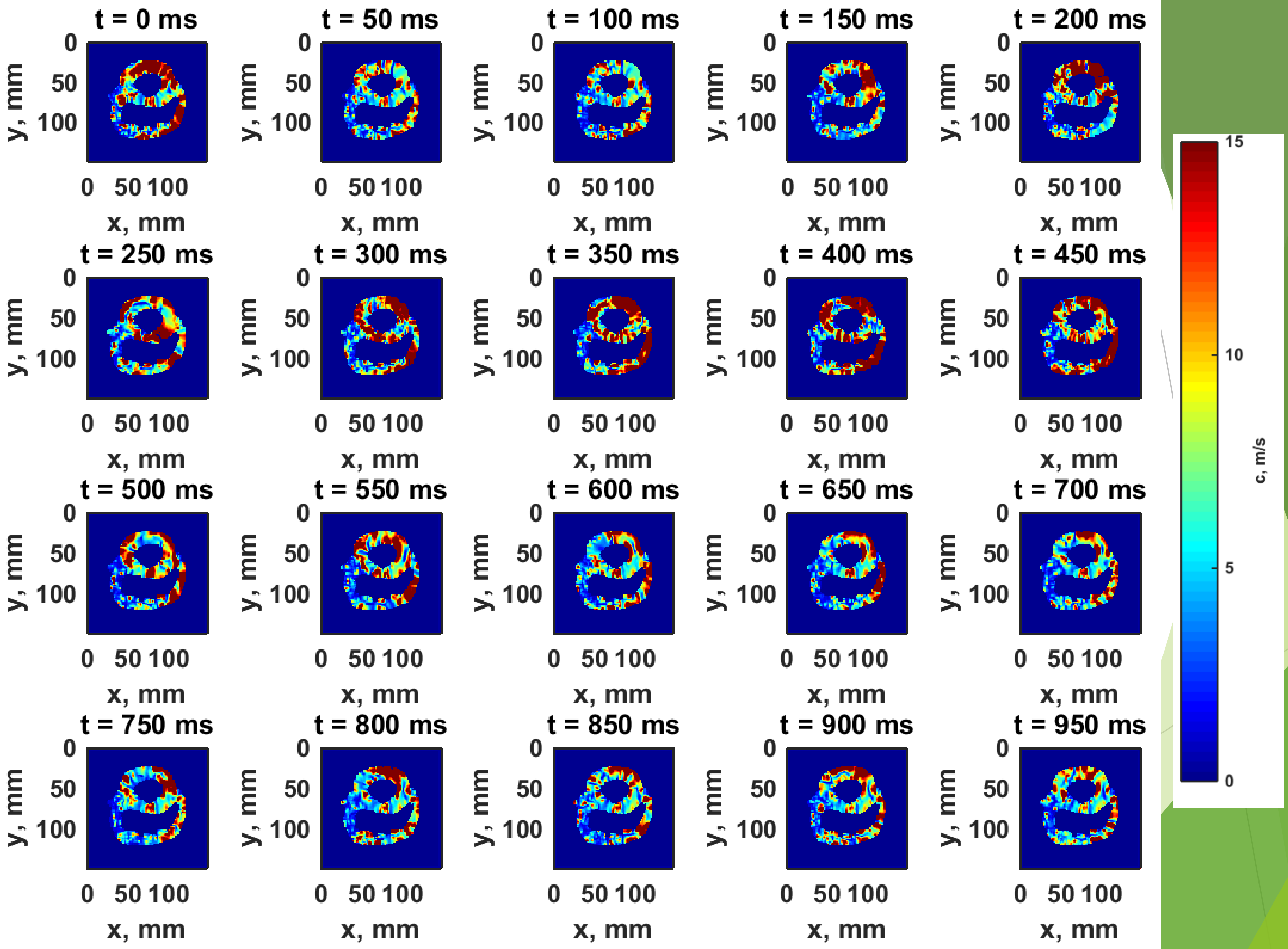
FEM Simulation of Heart Cycle

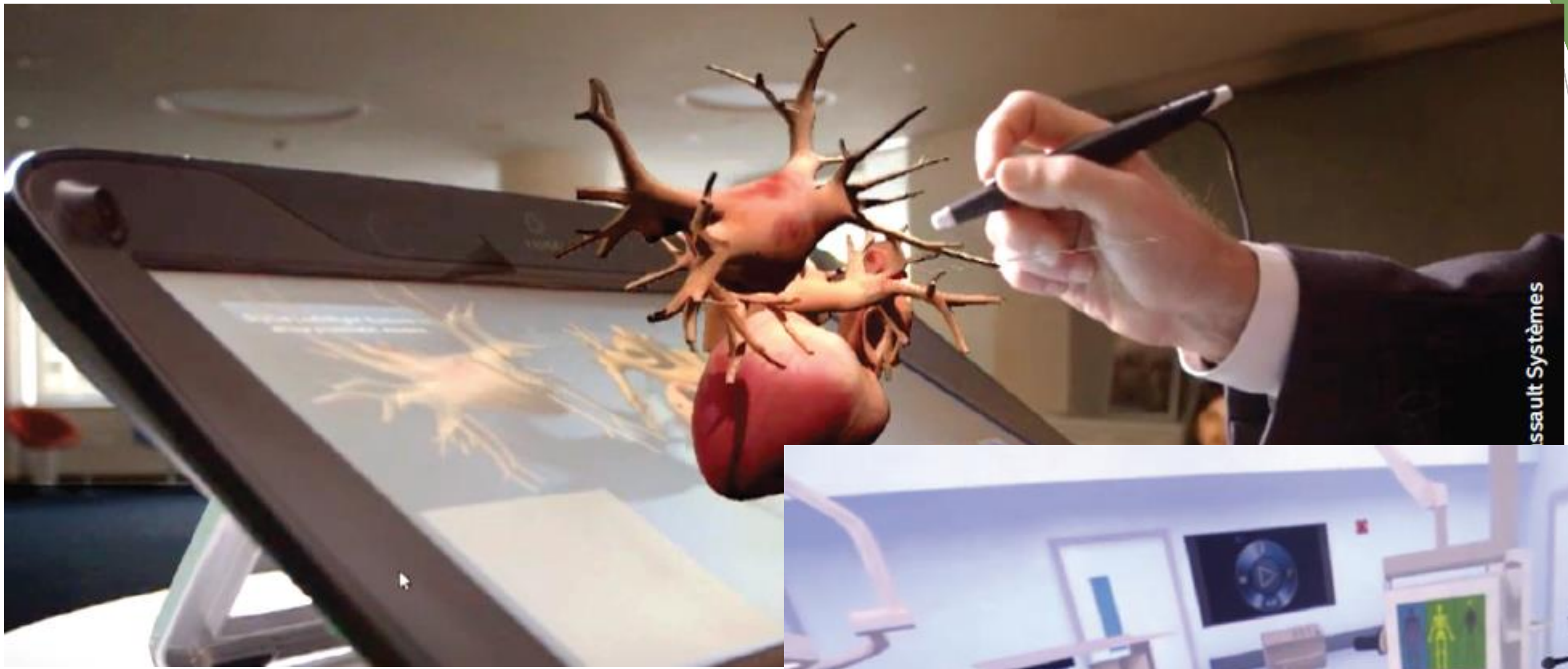
- Finite Element Modeling can be used to simulate the electrical and mechanical activities of the heart.
- Collaborating with 40+ medical and research institutions (including Mayo Clinic), 3DS has launched a product called “living heart project” to simulate complete heart cycles.
- It can simulate ECG signals under different cardio conditions.



biomechanics.stanford.edu

Tissue stiffness




ssault Systèmes

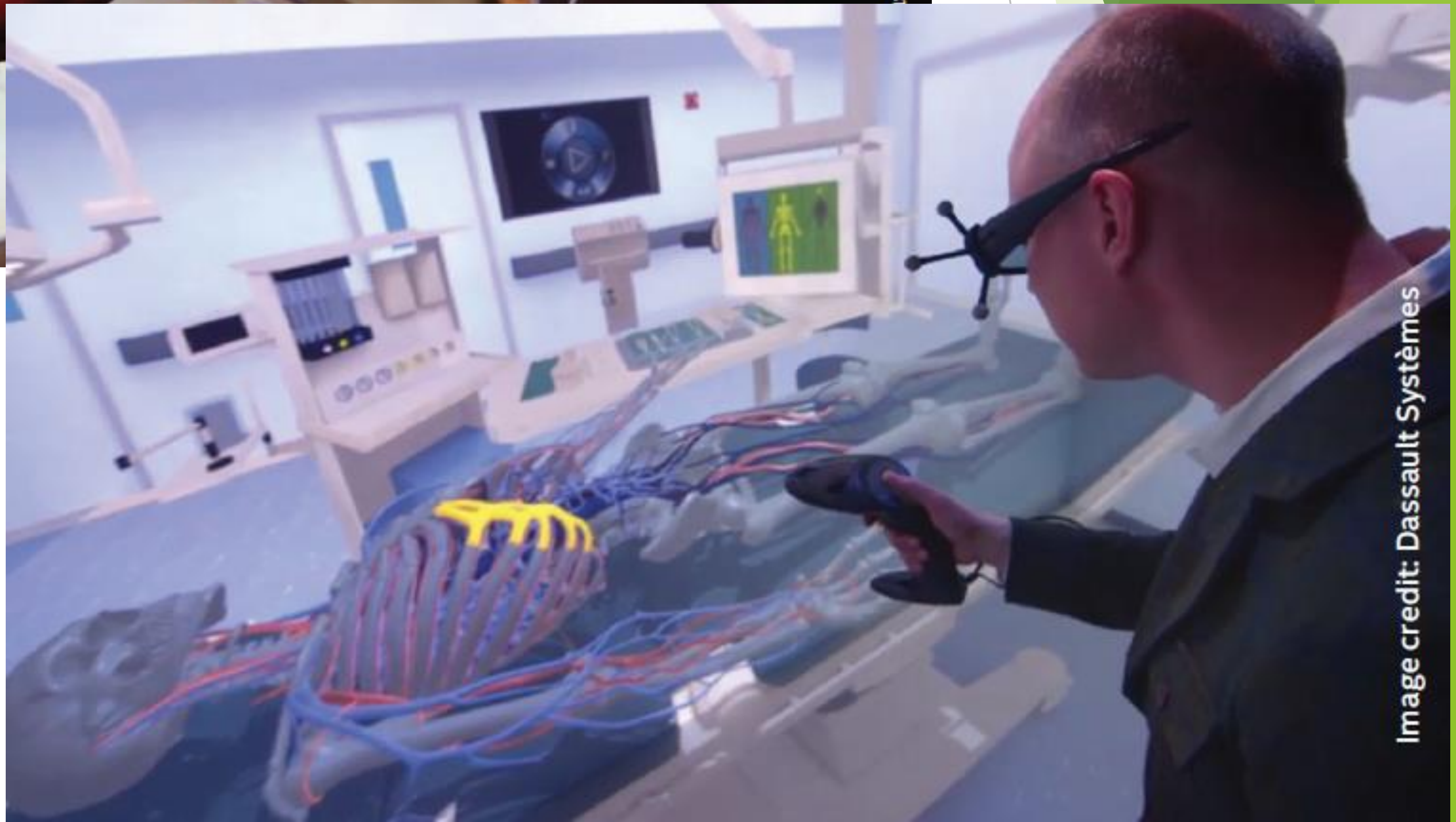


Image credit: Dassault Systèmes

Conclusion

- ECG automatic analysis software: MUSE_Interative
- Mobile ECG collection and data processing
- Advanced cardio simulation

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