Laboratory of Bioelectric and Bioenergetic Systems

TECHNION
Israel Institute of Technology

# Smart medical IoT


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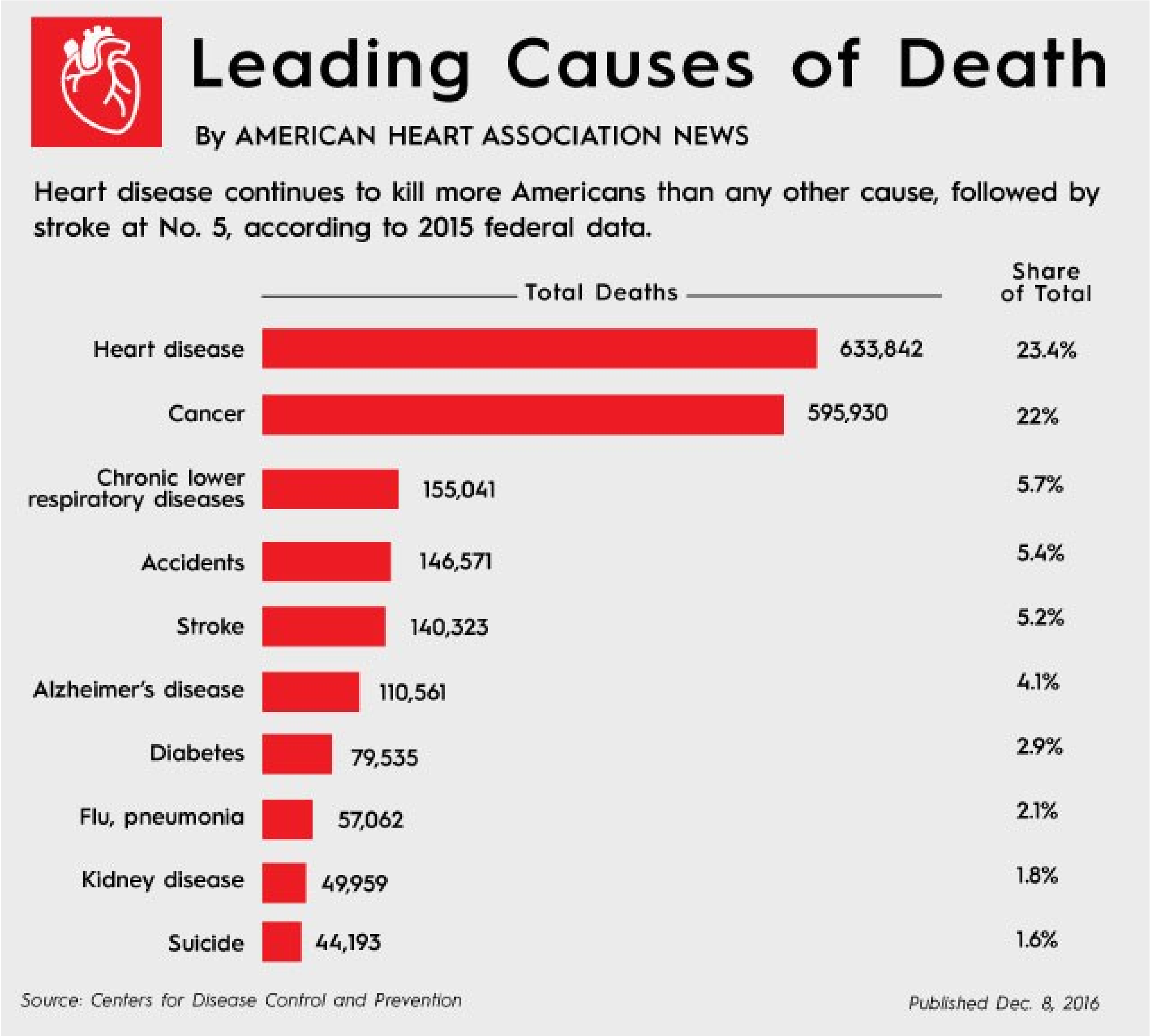
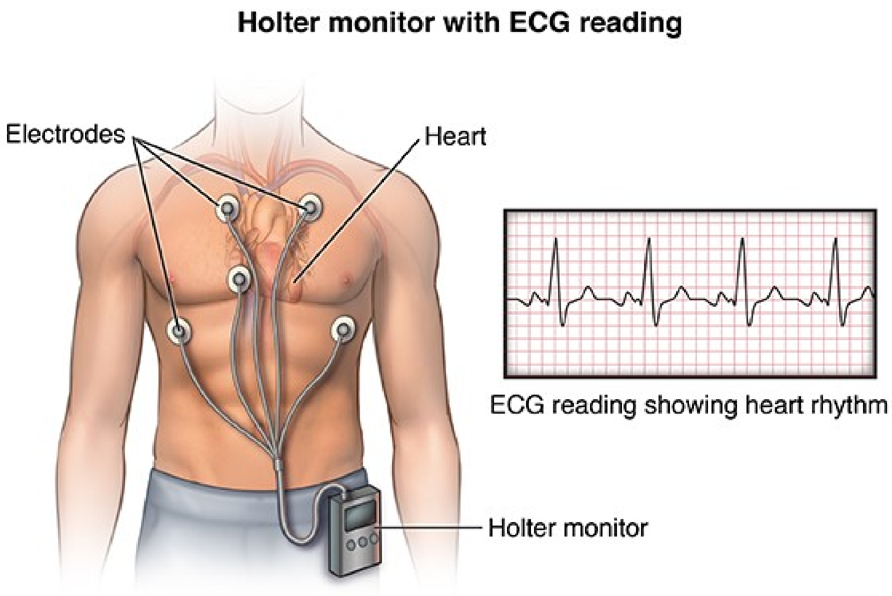
http://bioelectric-bioenergetic-lab.net.technion.ac.il/

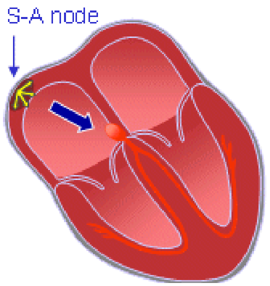
# MOTIVATION: Heart disease and unsatisfied treatment

- Heart diseases are the number 1 killer in the western world.
- Up to date, there is not satisfactory drug treatments.
- "No change in the number of deaths attributed to heart failure has been observed between 1995 and 2011."



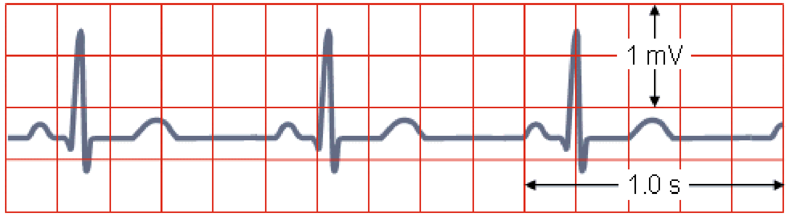
# How are cardiac diseases diagnosed today?



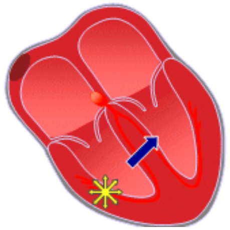




Normal sinus rhythm

Impulses originate at SA node at normal rate

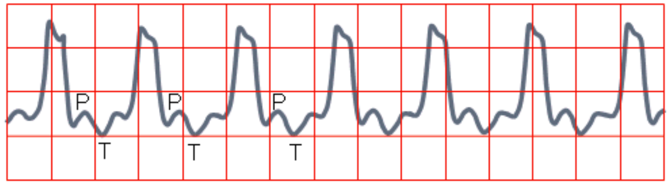



All complexes normal, evenly spaced, Rate 60-100/min

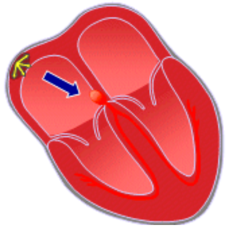


Ventricular tachycardia

Impulses originate at ventricular pacemaker

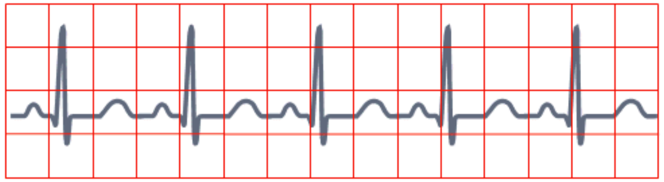



Wide ventricular complexes. Rate>120/min



Sinus tachycardia

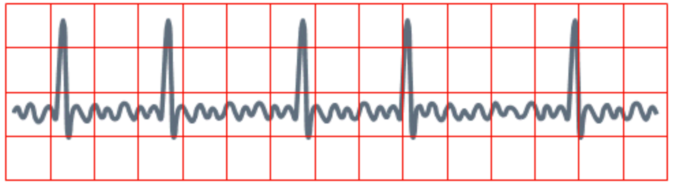
Impulses originate at S-A node at rapid rate



All complexes normal, evenly spaced. Rate >100/min

Atrial Fibrillation

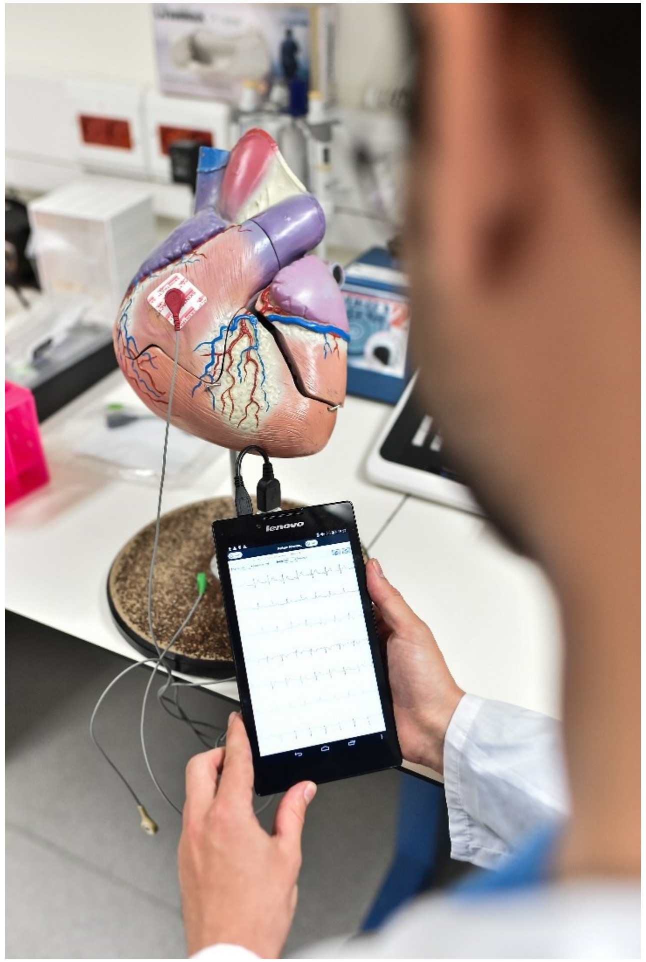
Impulses have chaotic, random pathways in atria



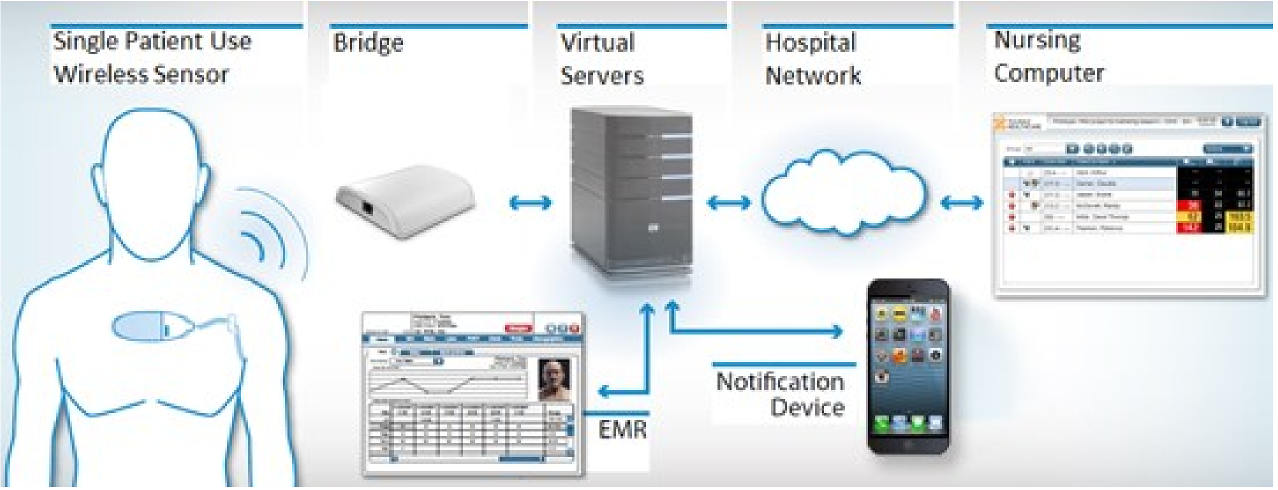
Baseline irregular, ventricular response irregular

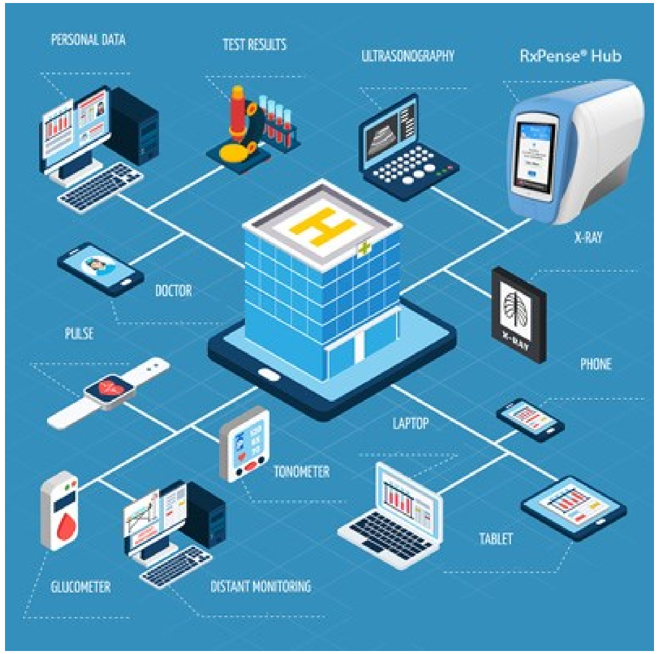
http://www.bem.fi/book/19/19.htm

# Future cardiac diseases detection

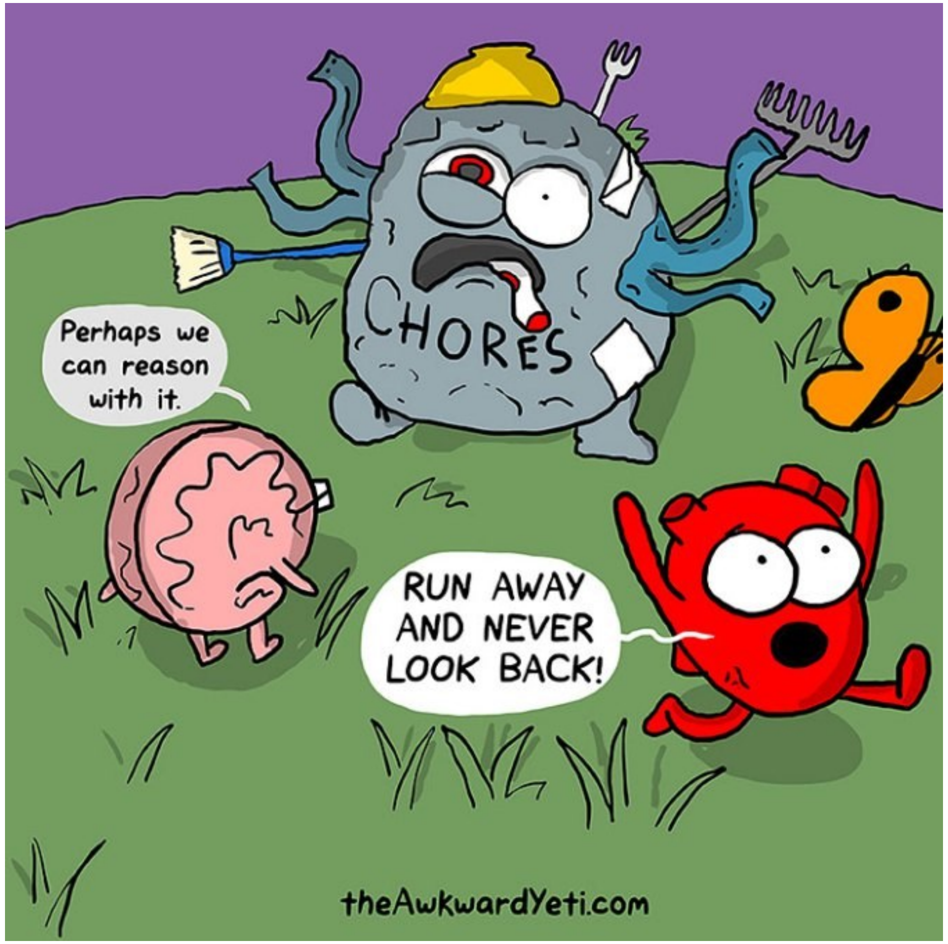



# Medical IoT description in the internet

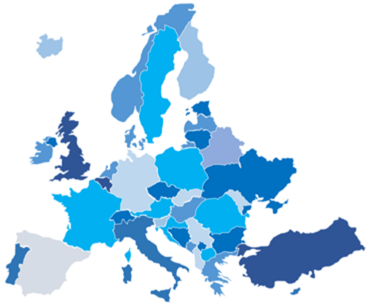


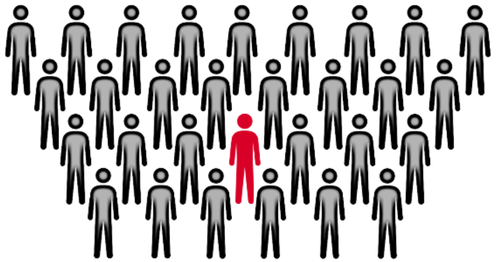




# Making smart IoT



# AF increases stroke incidence





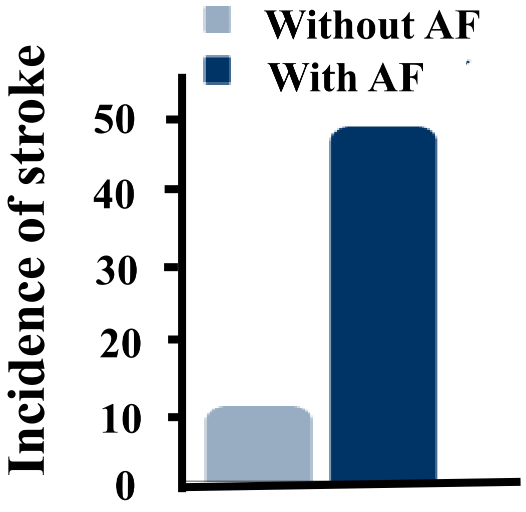
**9.7M**
Europeans diagnosed with AF

**2.7-3.3%**
Prevalence of AF in 2030 in EU

**€10 billion**
Annual direct-cost in EU

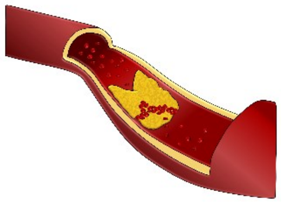
Zoni-Berisso et al. Clin Epidemiol 2014

Center of Health Protection 2016



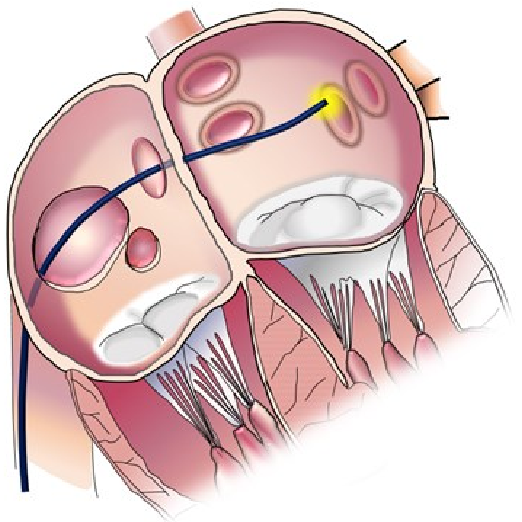

**Increases stroke risk by 480%**

**200,000**
**AF induced cases a year in EU**

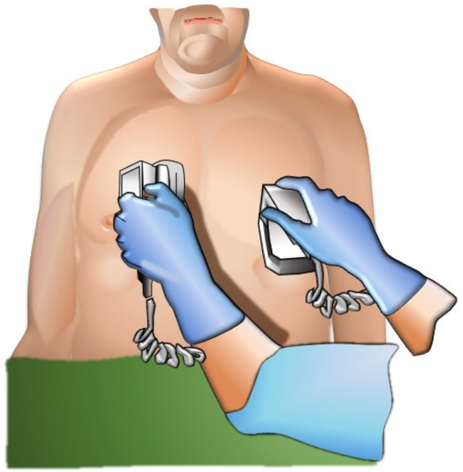


# Existing treatments for AF are limited in their outcome

## Catheter ablation

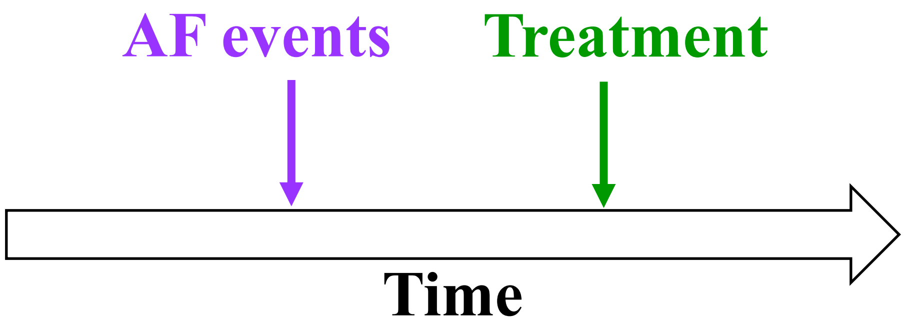


## Cardioversion



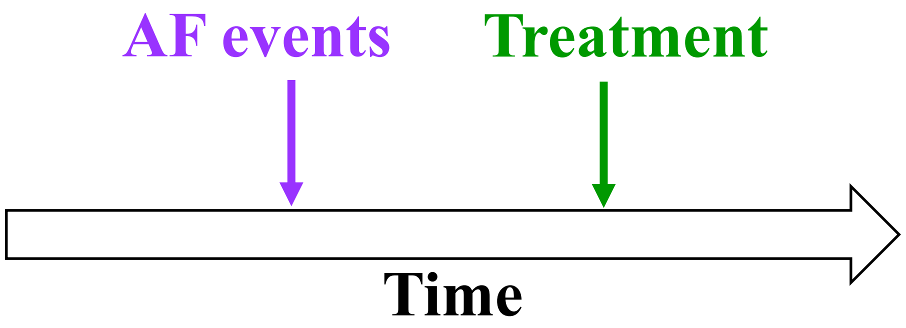
## Drug treatments

- 30% are repeated procedure
- 25% of the procedures have less than 15% success



# Mindset Change:

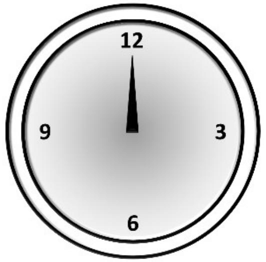
## Treat AF associated effects when AF event is predicted



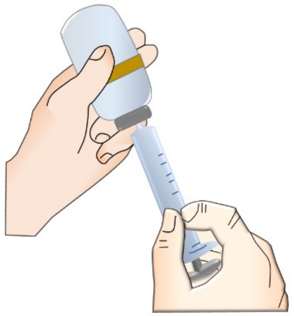
# Timing is everything:
# Eliminating AF events and their side effects

**User target:** Paroxysmal AF patients (2-3 episodes per day)

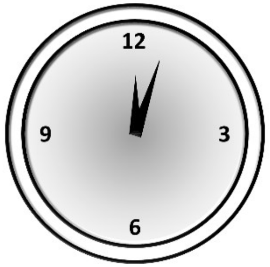
Time = **12:00 pm**



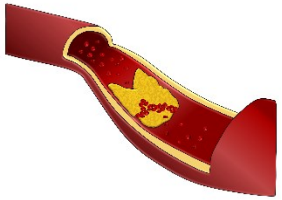

Normal ECG



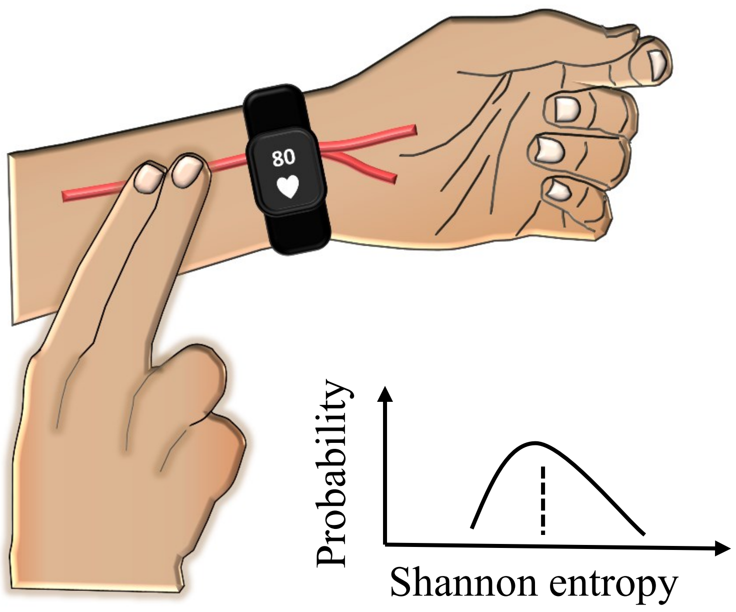

Time = **12:05 pm**

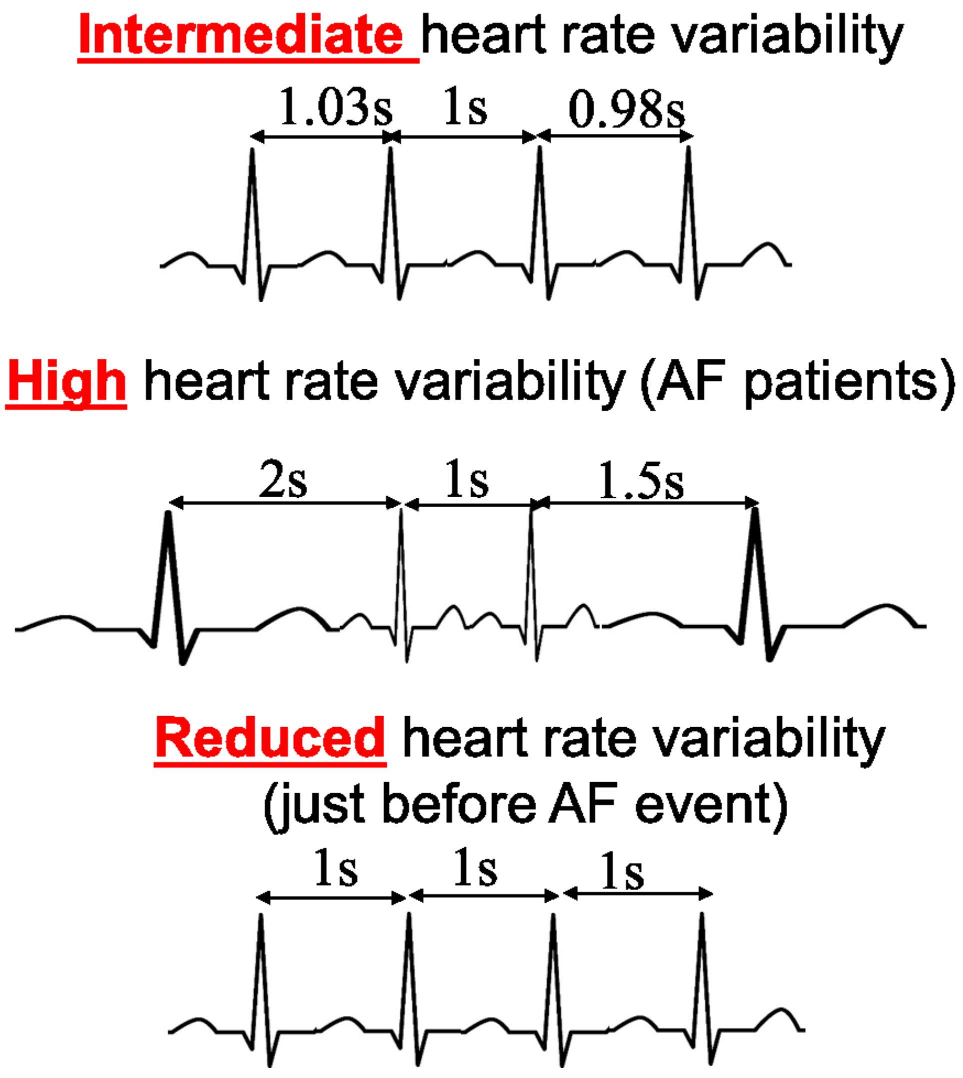



Normal ECG



# Beat to beat variability changes before AF event

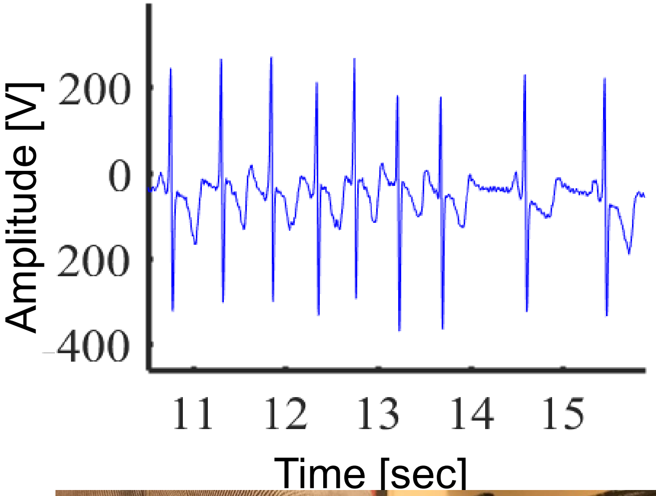


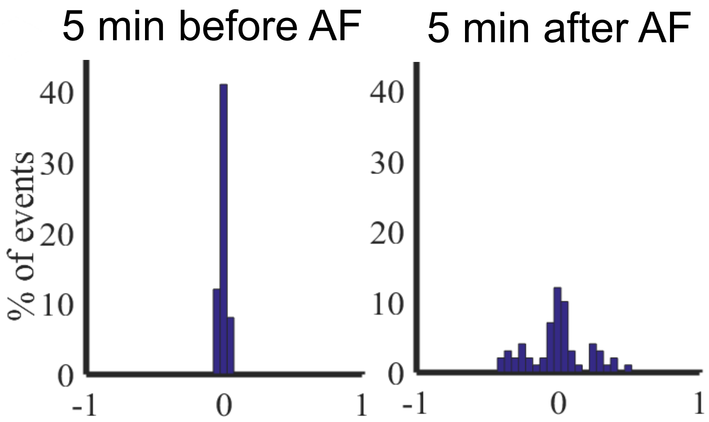



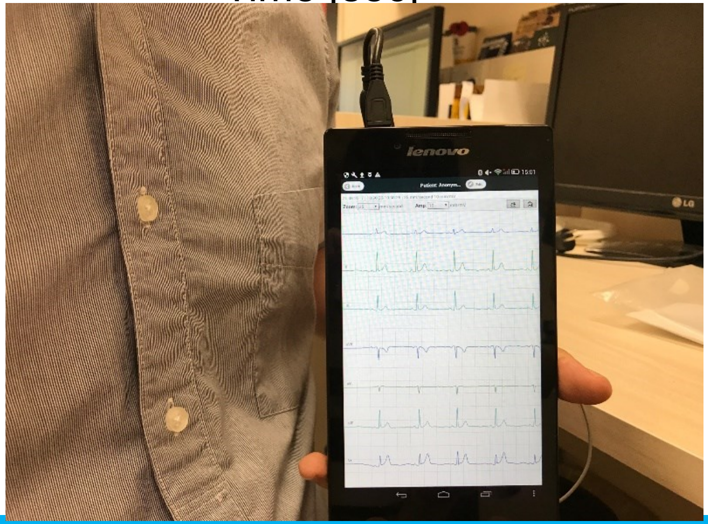

**Submitted patent:** Yaniv Y.
Early prediction and detection of
arrhythmogenic events #1863

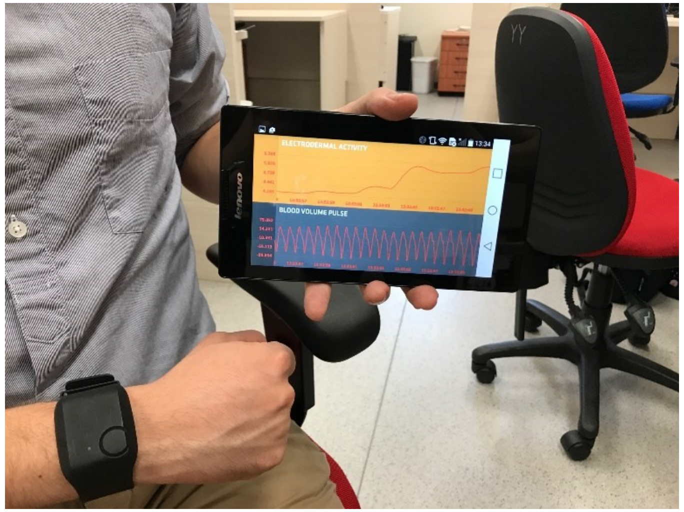
Vaziri, S. M et al. Circulation, 1994.
Bettoni, M et al. Circulation, 2002.
Shin, D. G. et al. Circ J, 2006.
Chesnokov, Y. V. Artif Intell Med, 2008.
Mohebbi, M. & Ghassemian, H. Comput Methods Programs Biomed, 2012.
Seaborn, G. E. et al. Ann Noninvasive Electrocardiol, 2014.

# Predicting AF events



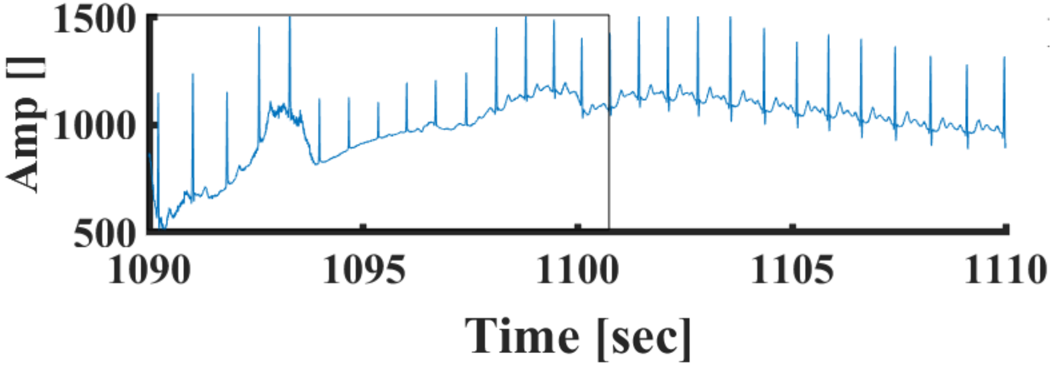




**Challenge:** Designing a patient-tailored wearable device based on real time heart rate variability analysis that can predict AF events with low false-negative and false-positive alerts

High Risk

# Challenges for IoT solution

**Challenge 1:**
Limited automated detection of R peaks (QRS)



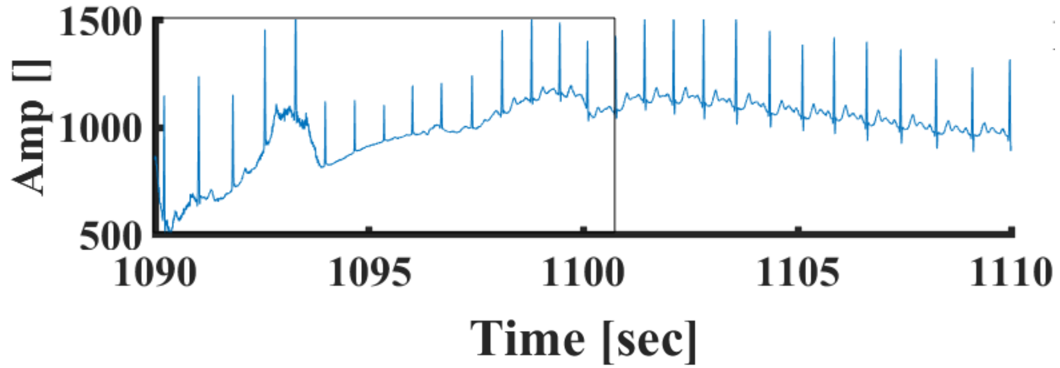

**Challenge 2:** Embedding complex algorithms on mobile devices

*http://techno-adviser.blogspot.co.il*

**Challenge 3:**
Automated diagnosis

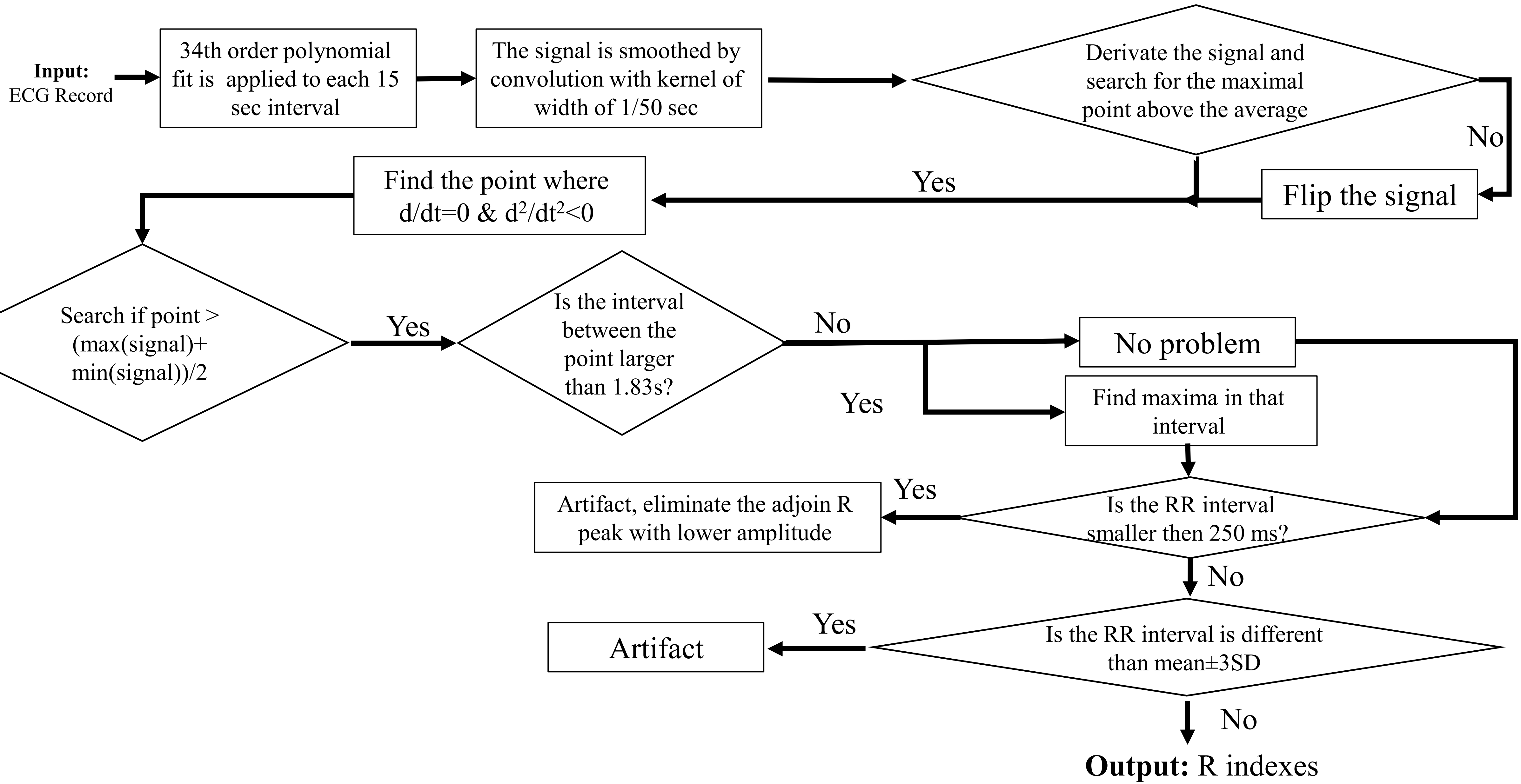
*https://www.infineon.com*

# Aim 1

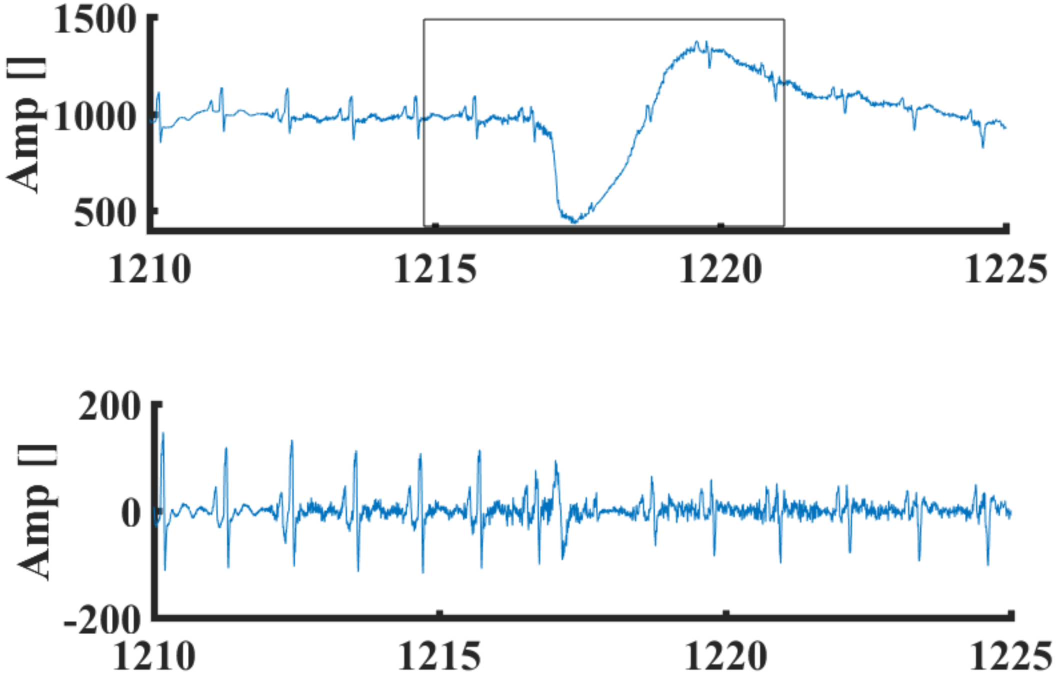


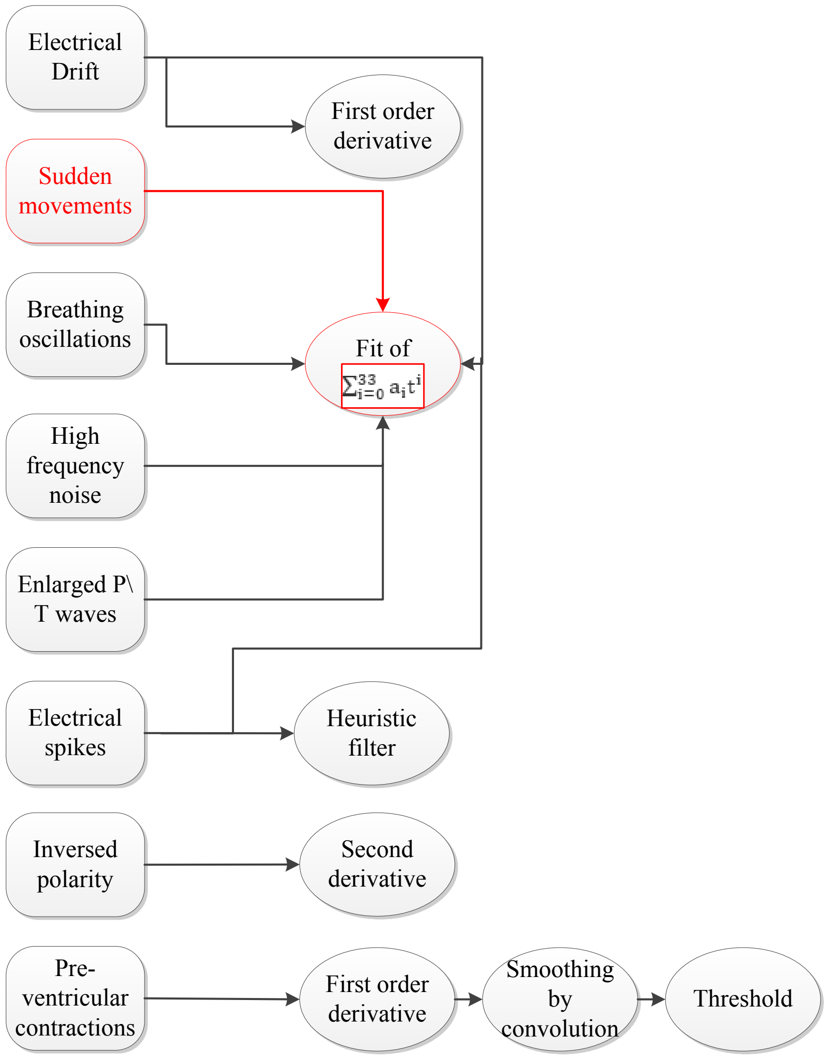

To develop a robust R-peak detector for low quality ECG of patients with cardiac diseases.

# Results 1-The R peak detector algorithm



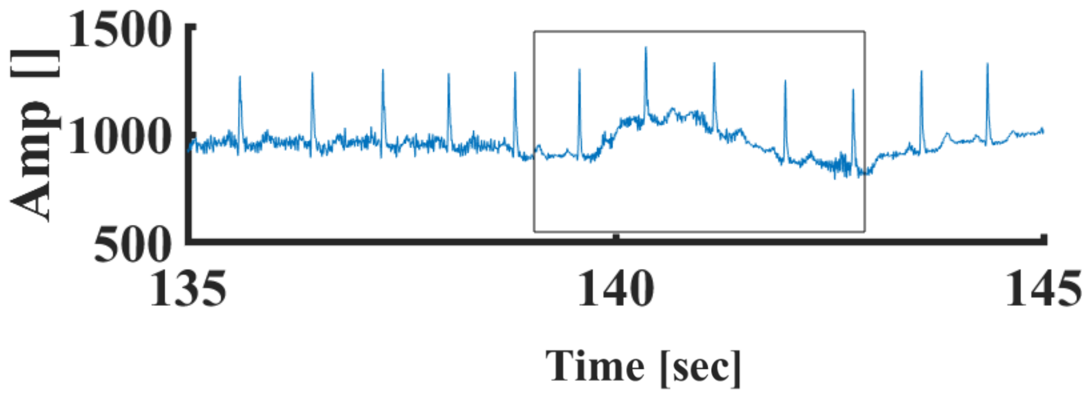
# Results 1: Detecting the R interval in the presence of sudden patient movement

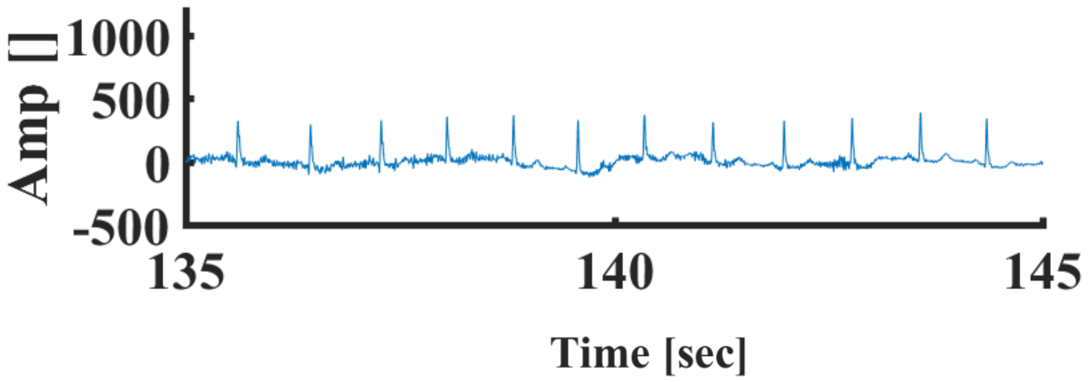


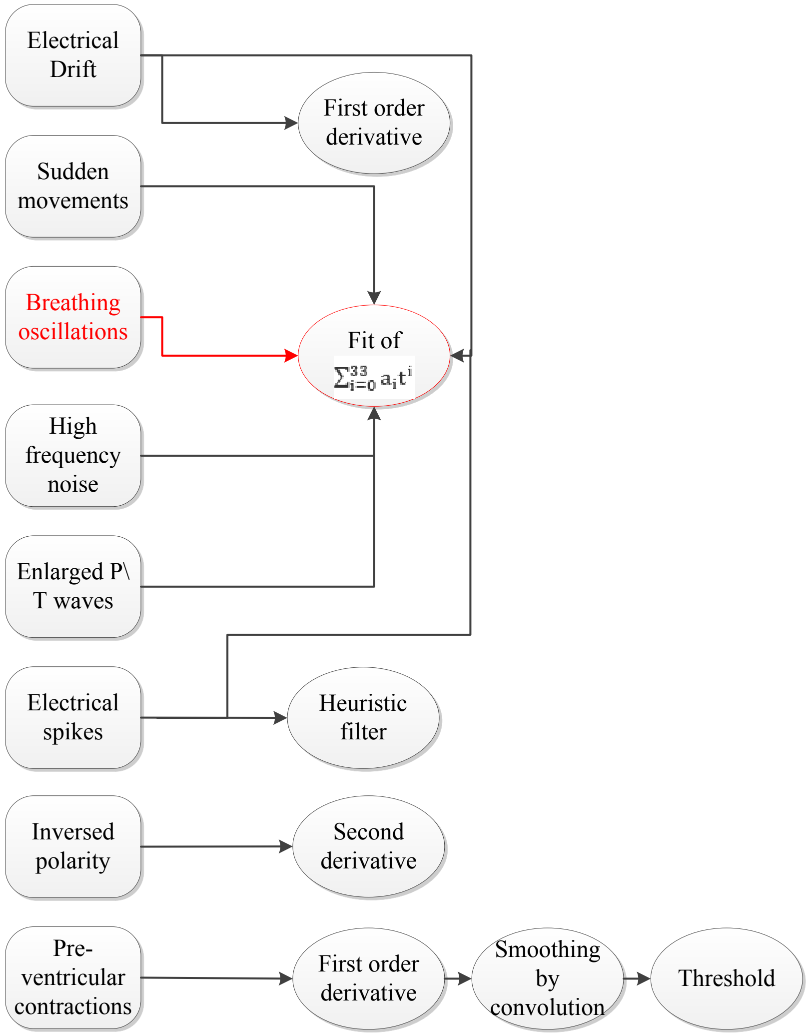

Gliner et al. *Under Review*

# Results 1: Decoding the R interval in the presence of breathing oscillations

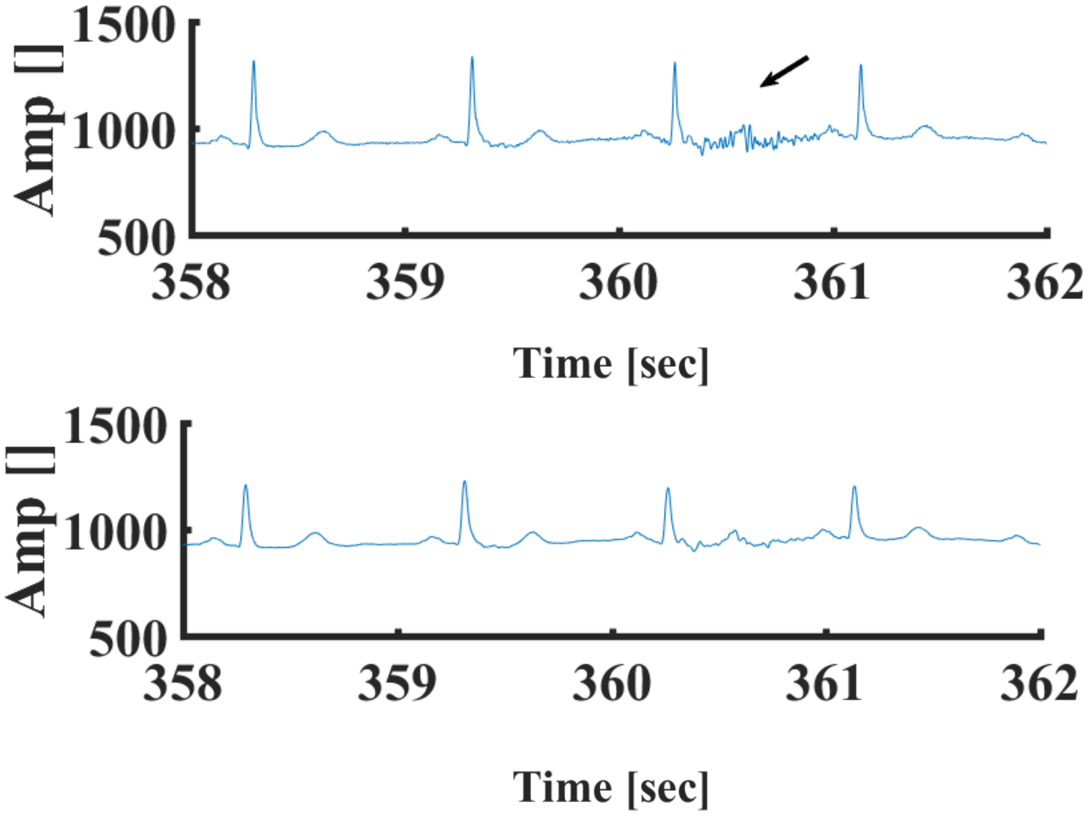


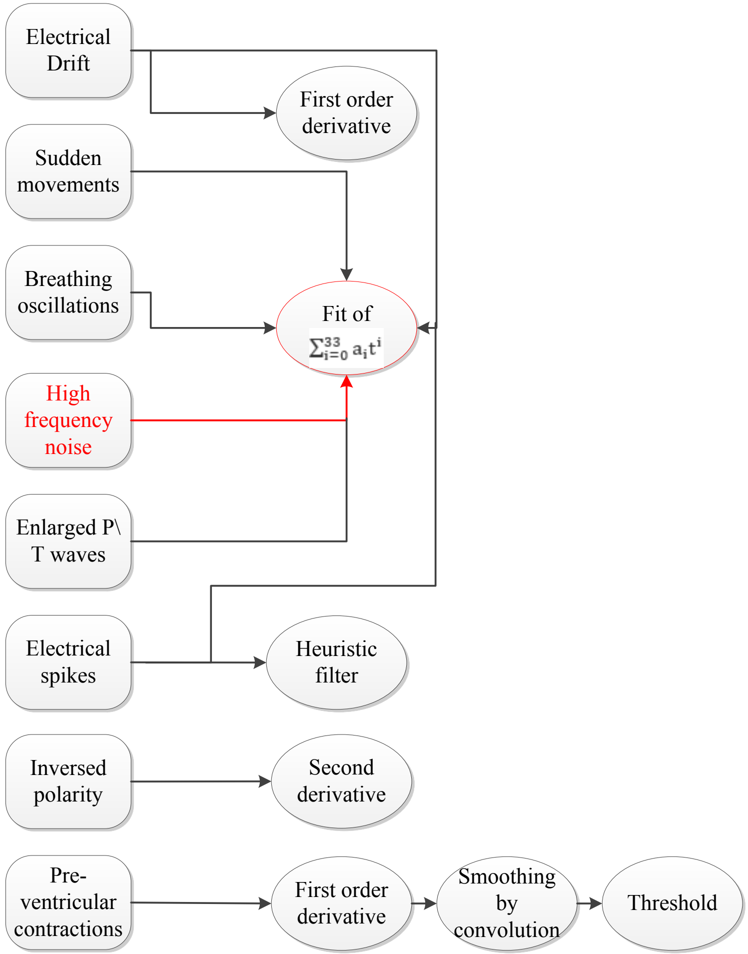




Gliner et al. *Under Review*



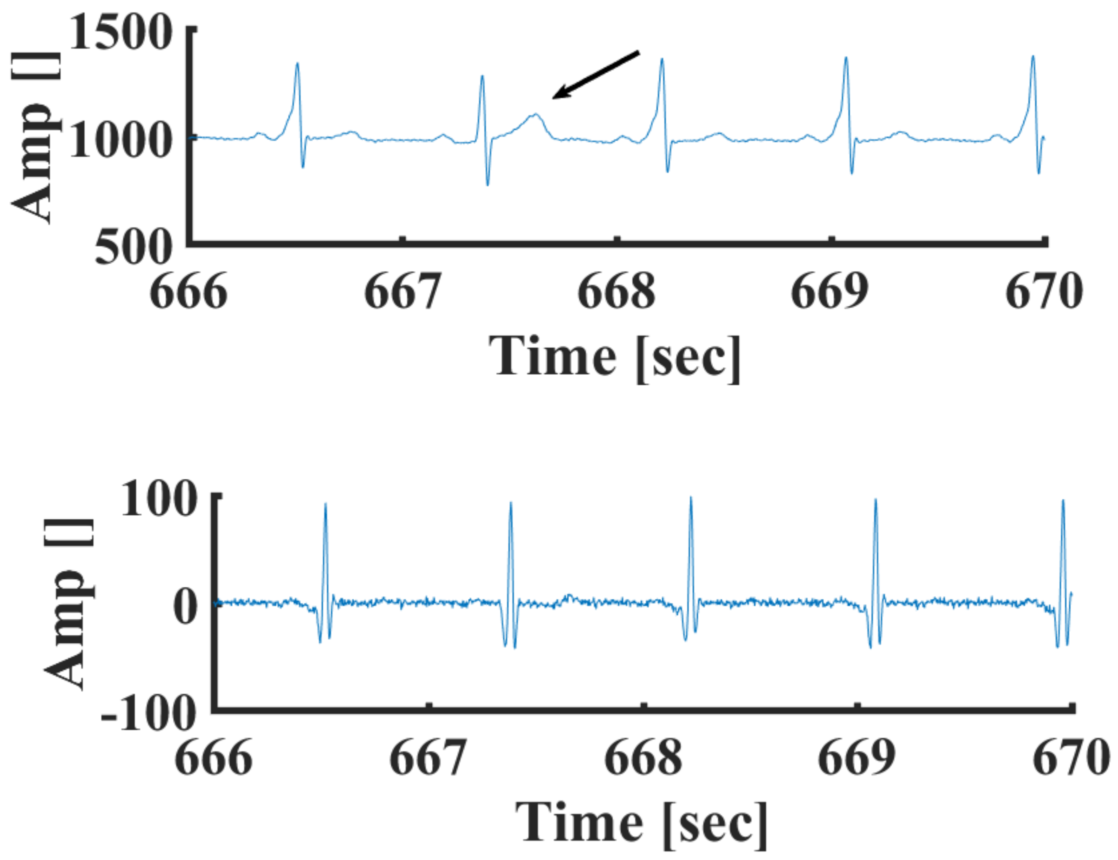
# Results 1: Detecting the R peak in the presence of high frequency environmental noise

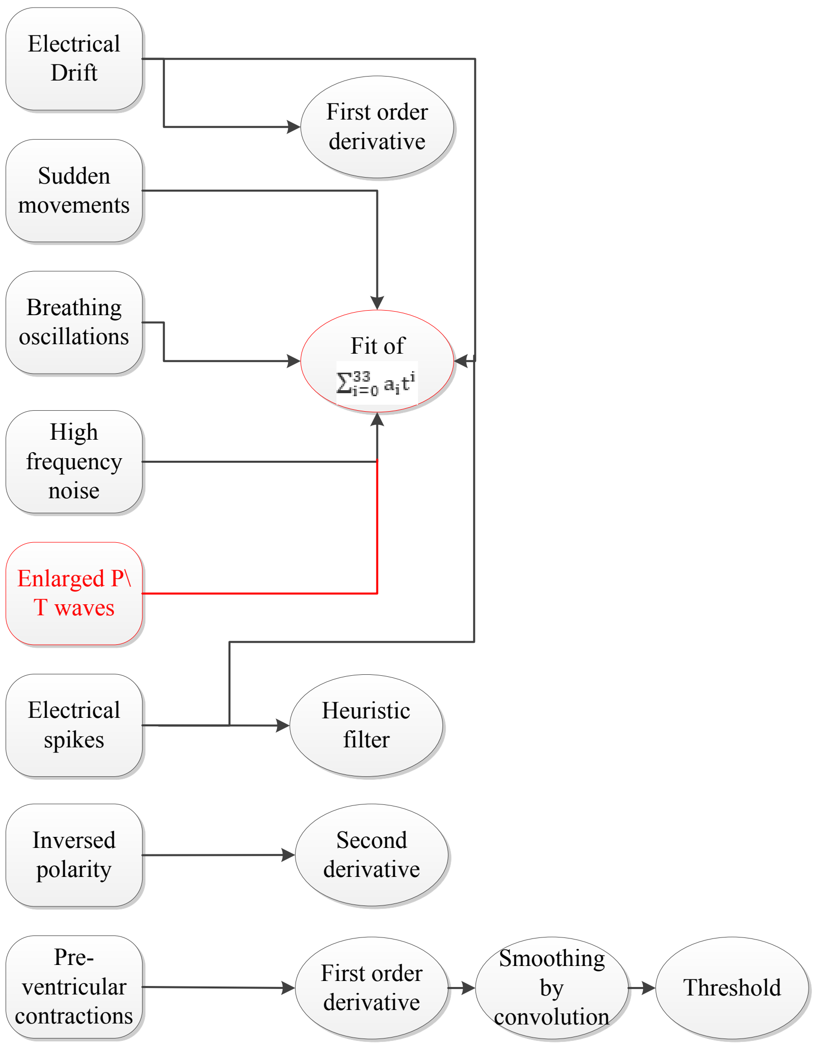



Gliner et al. *Under Review*

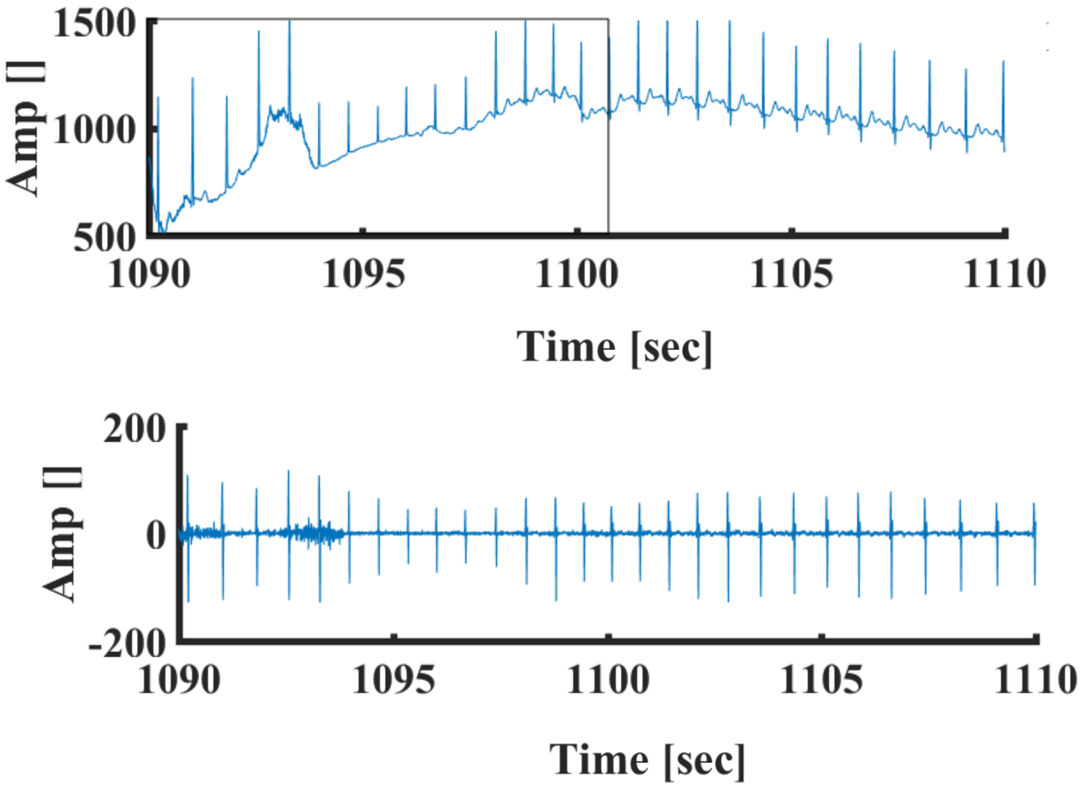
# Results 1: Detecting the R peak in the presence of enlarged P or T waves

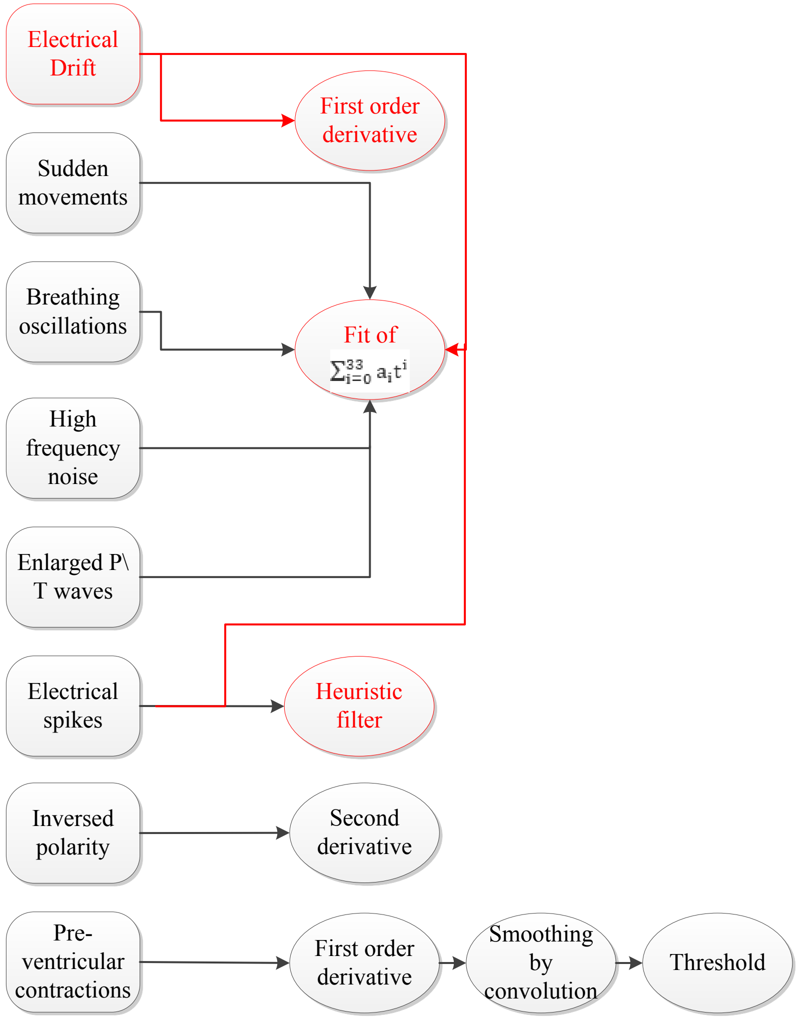



Gliner et al. *Under Review*

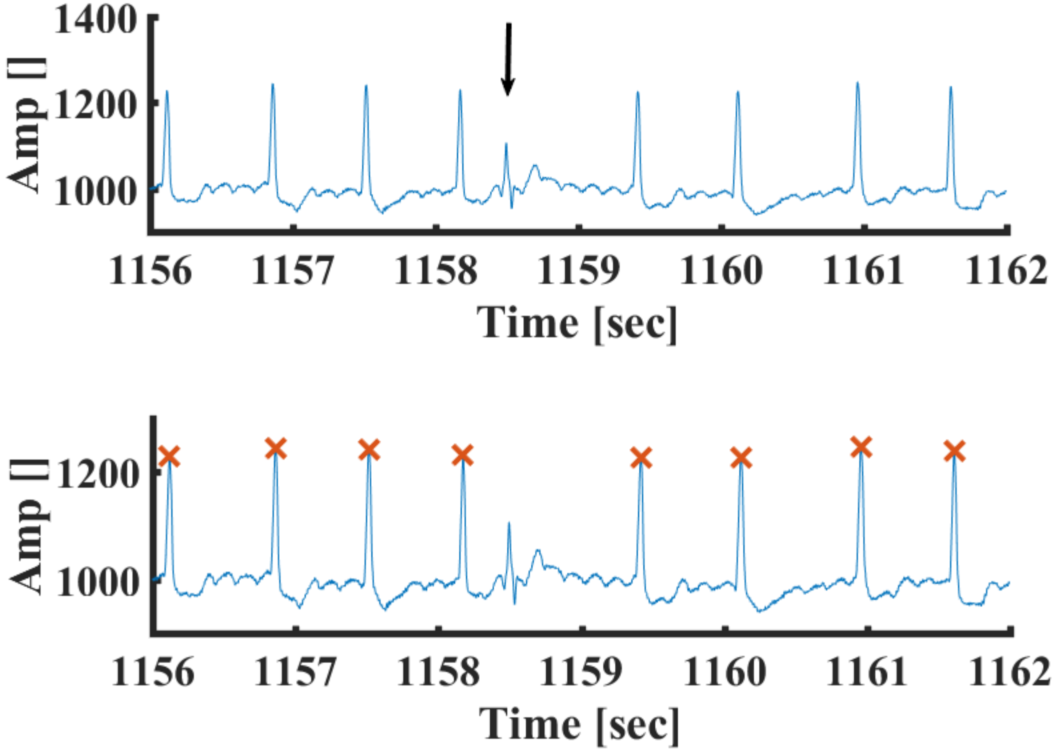
# Results 1: Detecting the R peak in the presence of electrical drift

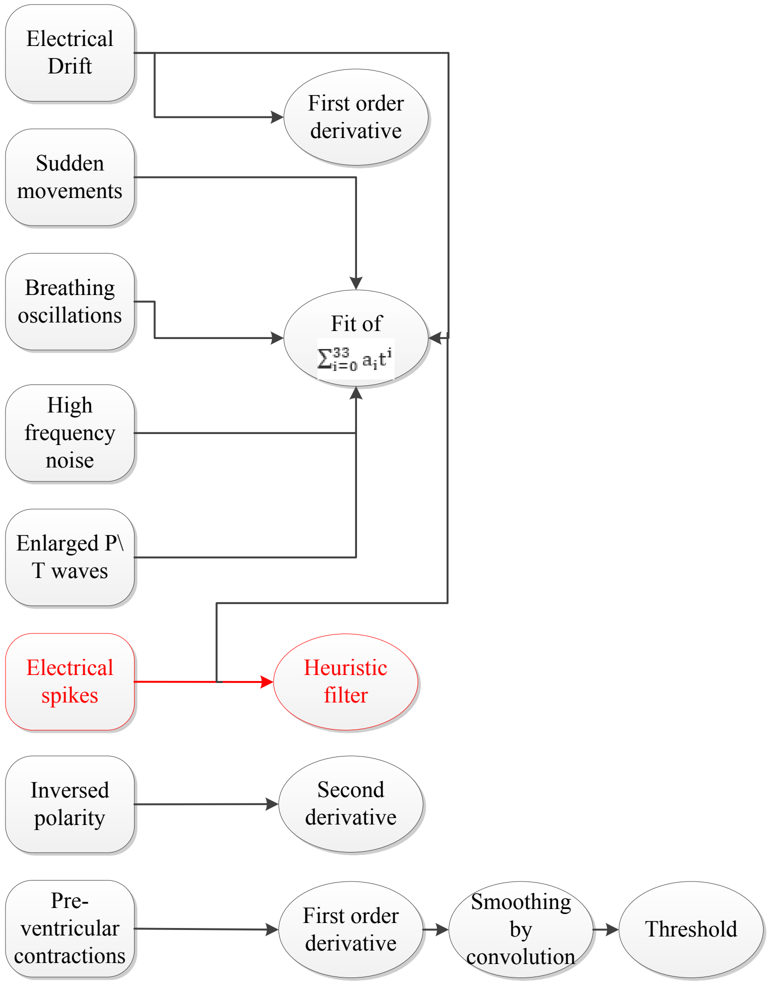



Gliner et al. *Under Review*

# Results 1: Detecting the R peak in the presence of electrical spikes

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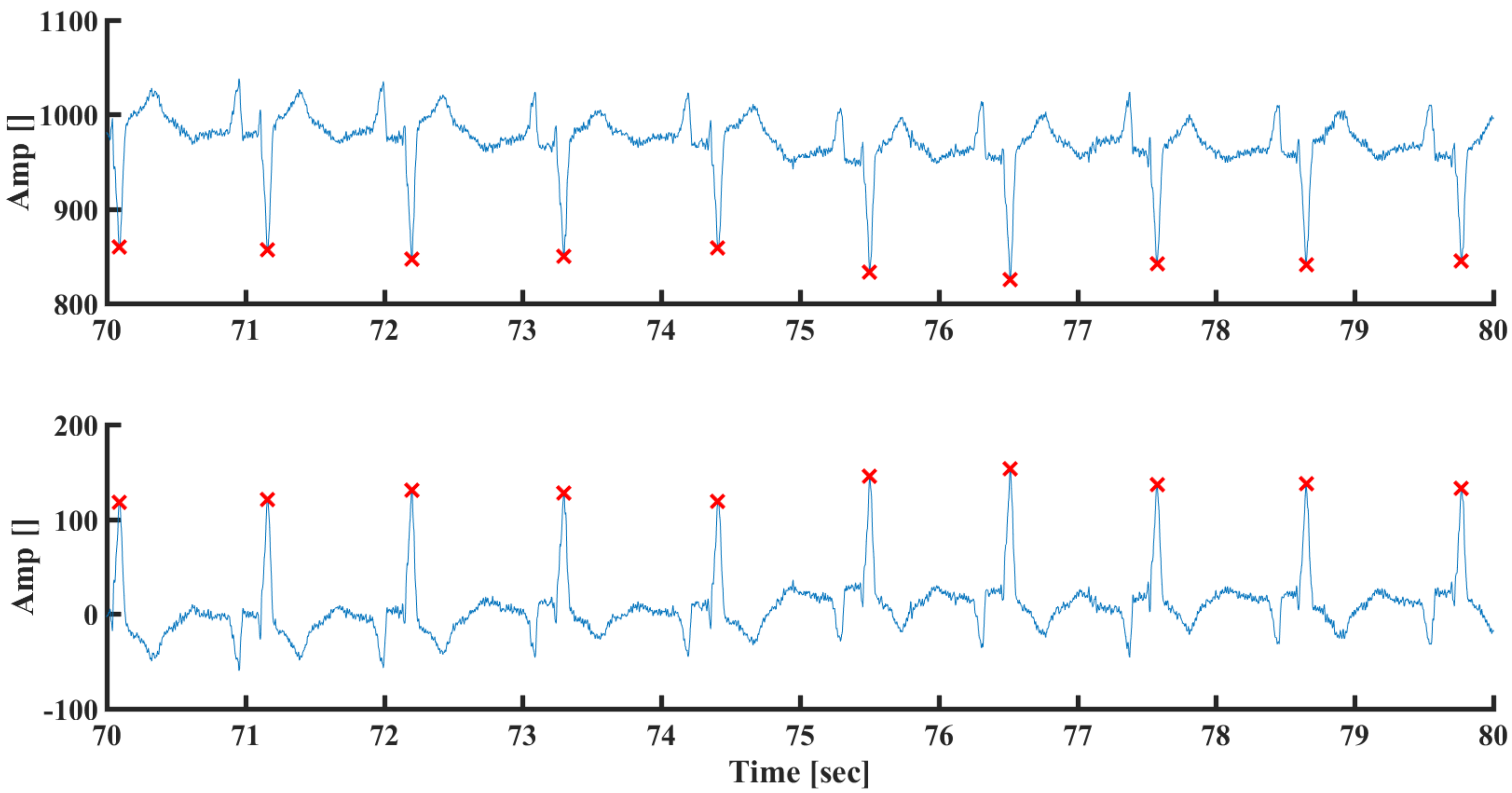
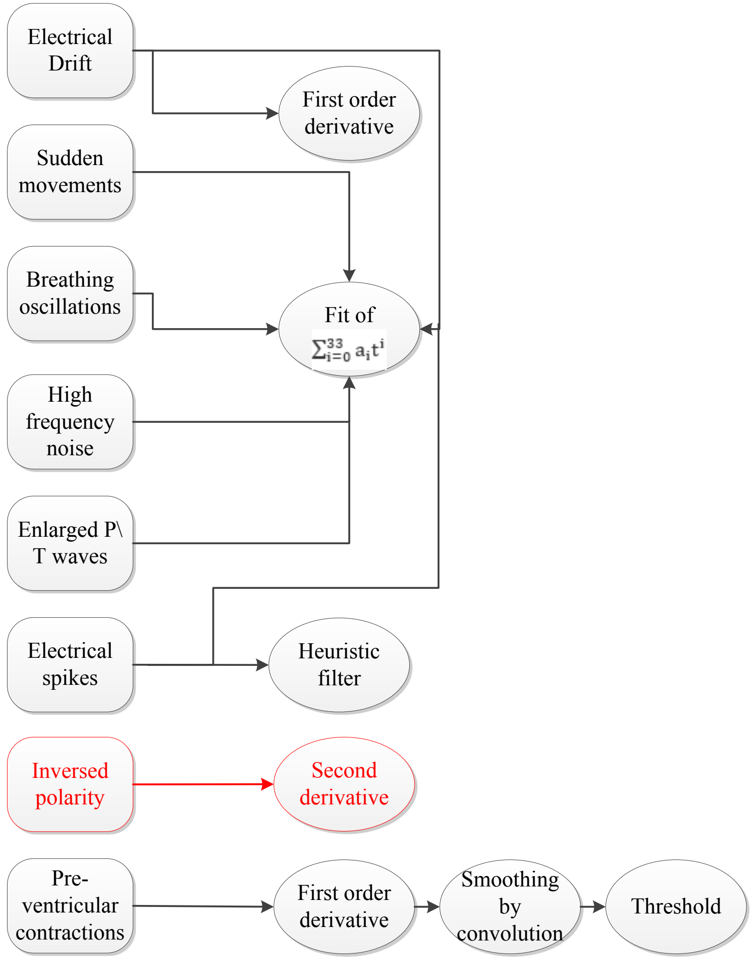
# Results 1: Detecting the R peak with reverse ECG polarity

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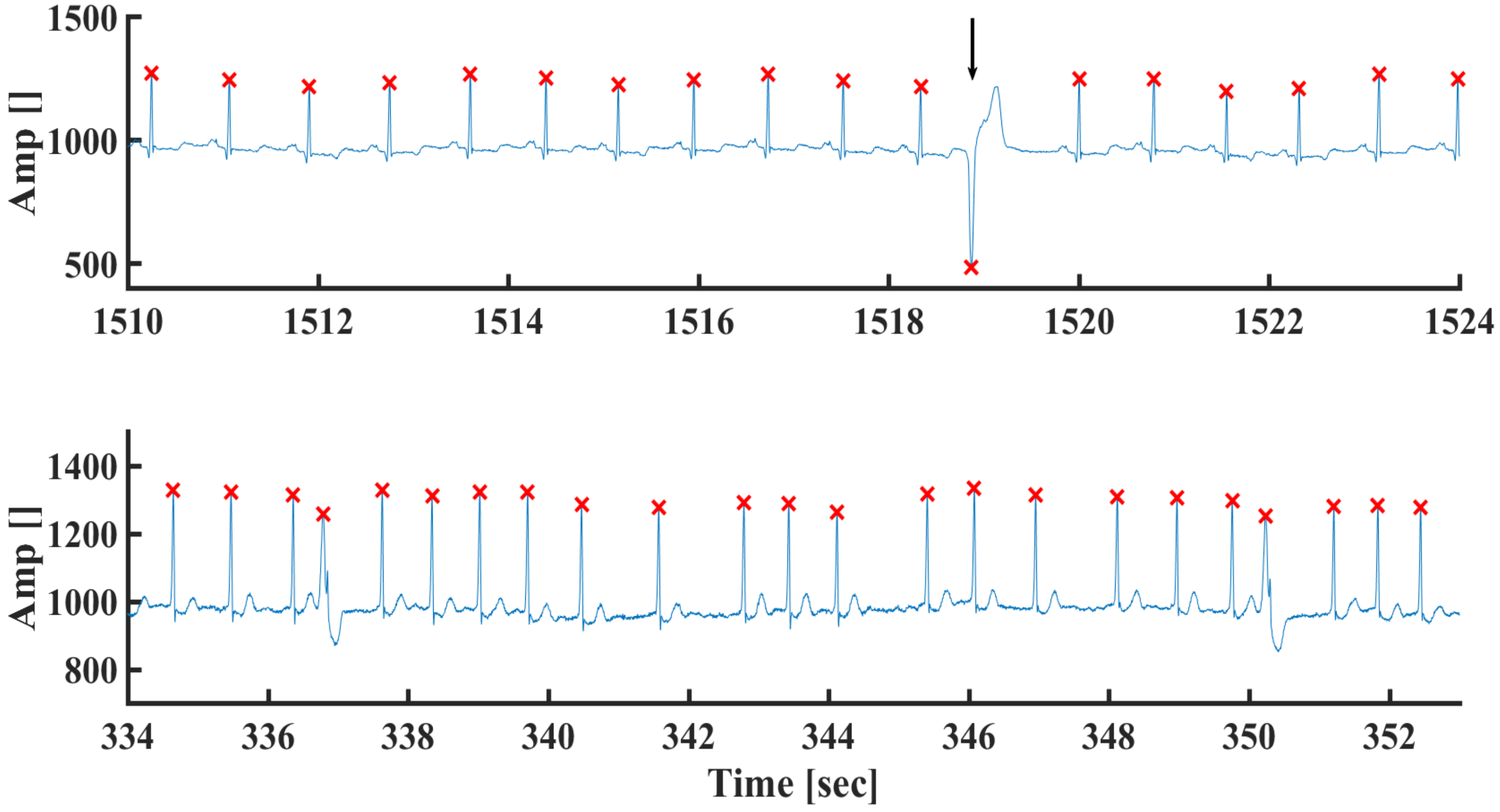
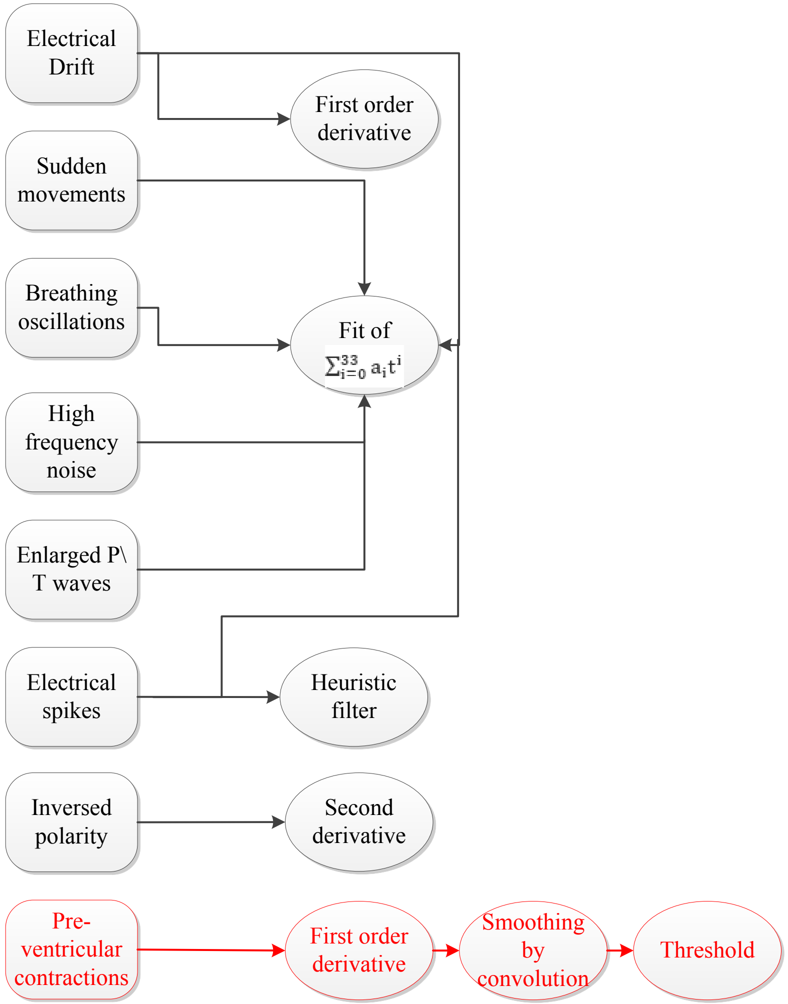
# Results 1: Detecting the R peak in the presence of premature ventricular contraction

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# Results 1: Peak detector performance

| Non-AF (%) | gqrs algorithm | Pan et al. algorithm | Behar et al. algorithm | Current algorithm |
|---|---|---|---|---|
| False negative | 0.15 | 0.49 | 0.47 | **0.14** |
| False positive | 0.39 | 0.33 | 1.19 | **0.28** |
| Positive prediction | 99.6 | 99.7 | 98.8 | **99.7** |

| AF (%) | gqrs algorithm | Pan et al. algorithm | Behar et al. algorithm | Current algorithm |
|---|---|---|---|---|
| False negative | 0.42 | 0.72 | 2.09 | **0.34** |
| False positive | 0.79 | 0.67 | 5.45 | **0.25** |
| Positive prediction | 99.2 | 99.3 | 95.7 | **99.7** |

| Total (%) | gqrs algorithm | Pan et al. algorithm | Behar et al. algorithm | Current algorithm |
|---|---|---|---|---|
| False negative | 0.30 | 0.30 | 1.21 | **0.24** |
| False positive | 0.62 | 0.62 | 3.91 | **0.27** |
| Positive prediction | 99.4 | 99.4 | 97.2 | **99.7** |

# Aim 2

*http://techno-adviser.blogspot.co.il*

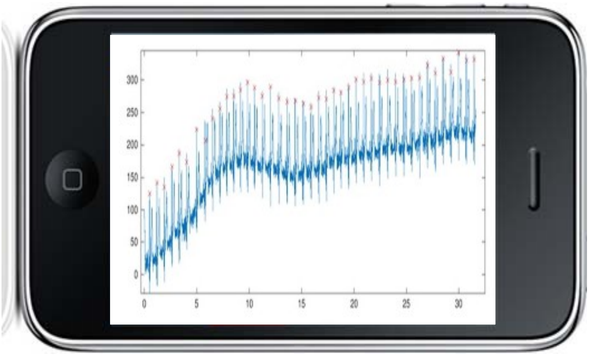
Embedding complex algorithms on mobile devices.

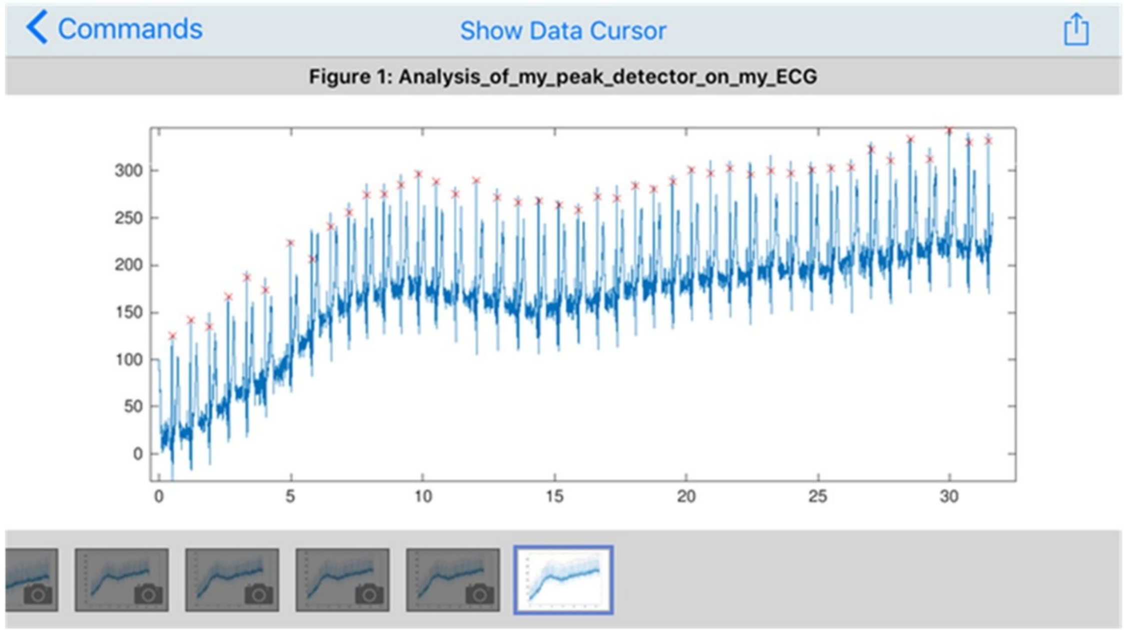
# Results 2: Mobile system

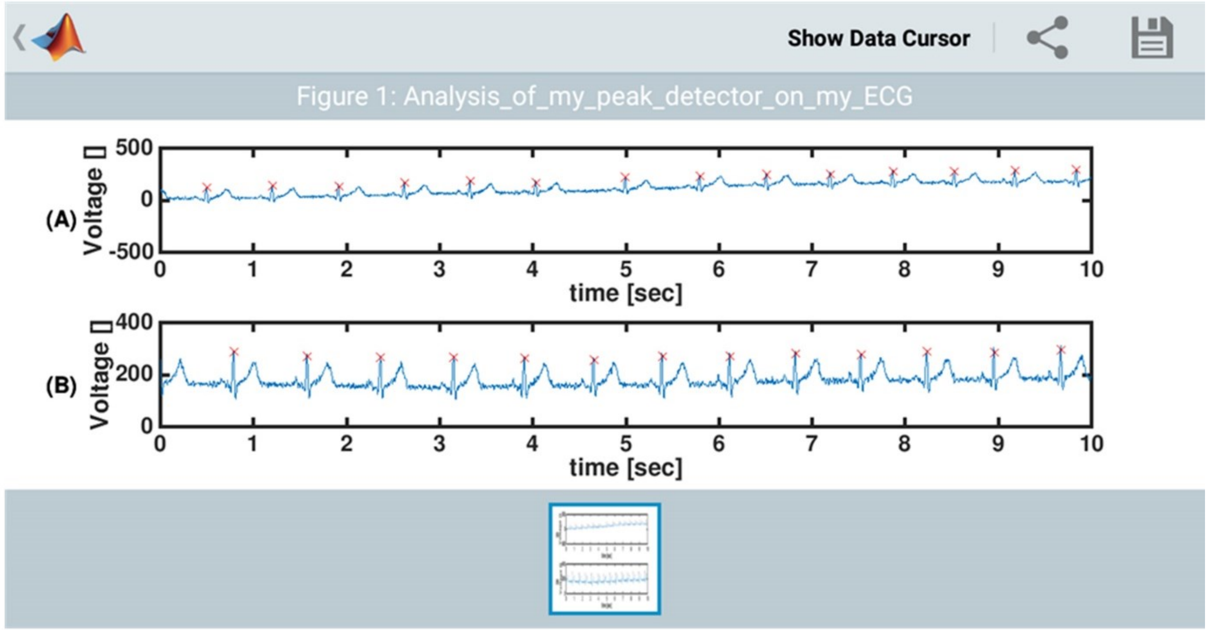

Acquire data using the ECG device and upload to the cloud

Download the Matlab Mobile application and install it on the cell phone or tablet → Connect to your Matlab Cloud account and download the source code → Download the ECG data from the cloud using Matlab Mobile → Process the data and annotate R- peaks

# Results 2: Peak detection on mobile phones






Gliner et al. *Under Review*

# Aim 3

*https://www.infineon.com*

Automated diagnosis

# Aim 3- Database


- 2 datasets: a training set of 8,528 single lead ECG recordings from 9s to just over 60s and a test set containing 3,658 ECG recordings of similar length.
- All recordings consisted of one bipolar channel recorded by an AliveCor device.
- The data was sampled at 300 Hz and filtered by a band pass filter in the device itself.
- The training set data was annotated by a cardiologist to one of the four types: normal (~59.5% of the recordings), AF (~10% of the recordings), other rhythm (~30% of the recordings), and noisy (~0.5% of the recordings).
- 10 trials on the hidden set were allowed

# Results 3: Learning strategy and algorithm

ECG Record (Input)

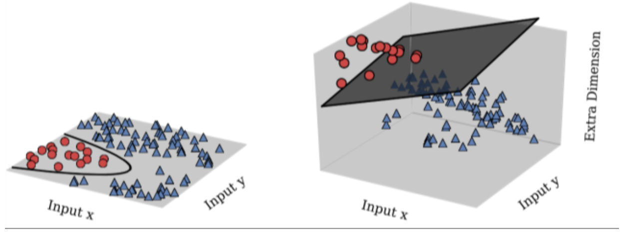
R Peak Detection

P,Q,S,T Peaks Detection

Average Beat Morphology Calc.

62 features calculation from the following categories:

1. Time-frequency domain features
2. Heart rate and heart rate variability
3. Signal entropy
4. Intra-beat temporal intervals variability
5. QRS morphology
6. Average beat morphology




Quadratic SVM Classifier

Normal\Other\AF\Noise

Is classified as "Normal" ?

Yes

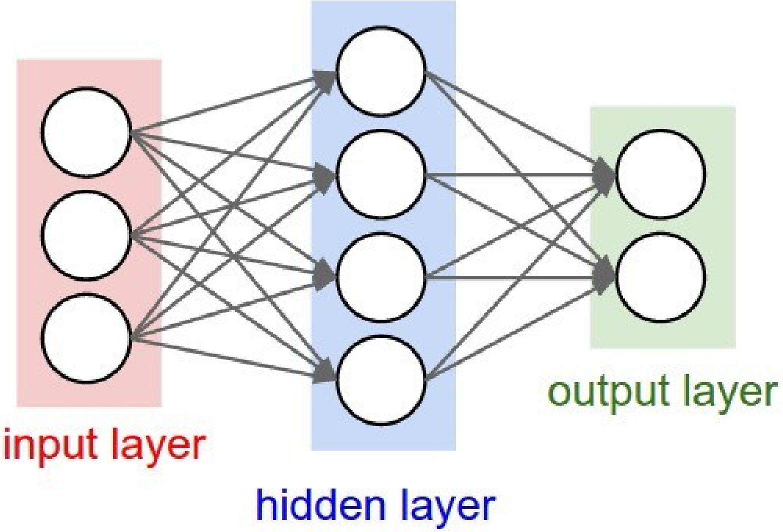
Neural Network Binary Classifier

No

Other\AF\Noise

Normal\Other

Output (Normal, Other, AF, Noise)



# Aim 3 Results: CinC 2017 challenge classifier results

Cross-validation matrix on the training set:

| Ours | Normal | AF | Other | Noise |
|---|---|---|---|---|
| Normal | 4772 | 9 | 244 | 4 |
| AF | 17 | 650 | 70 | 0 |
| Other | 455 | 51 | 1960 | 10 |
| Noise | 35 | 5 | 21 | 225 |

Results on the hidden set:

Normal rhythm: $$F_{1n} = \frac{2N_n}{\sum N + \sum n}$$

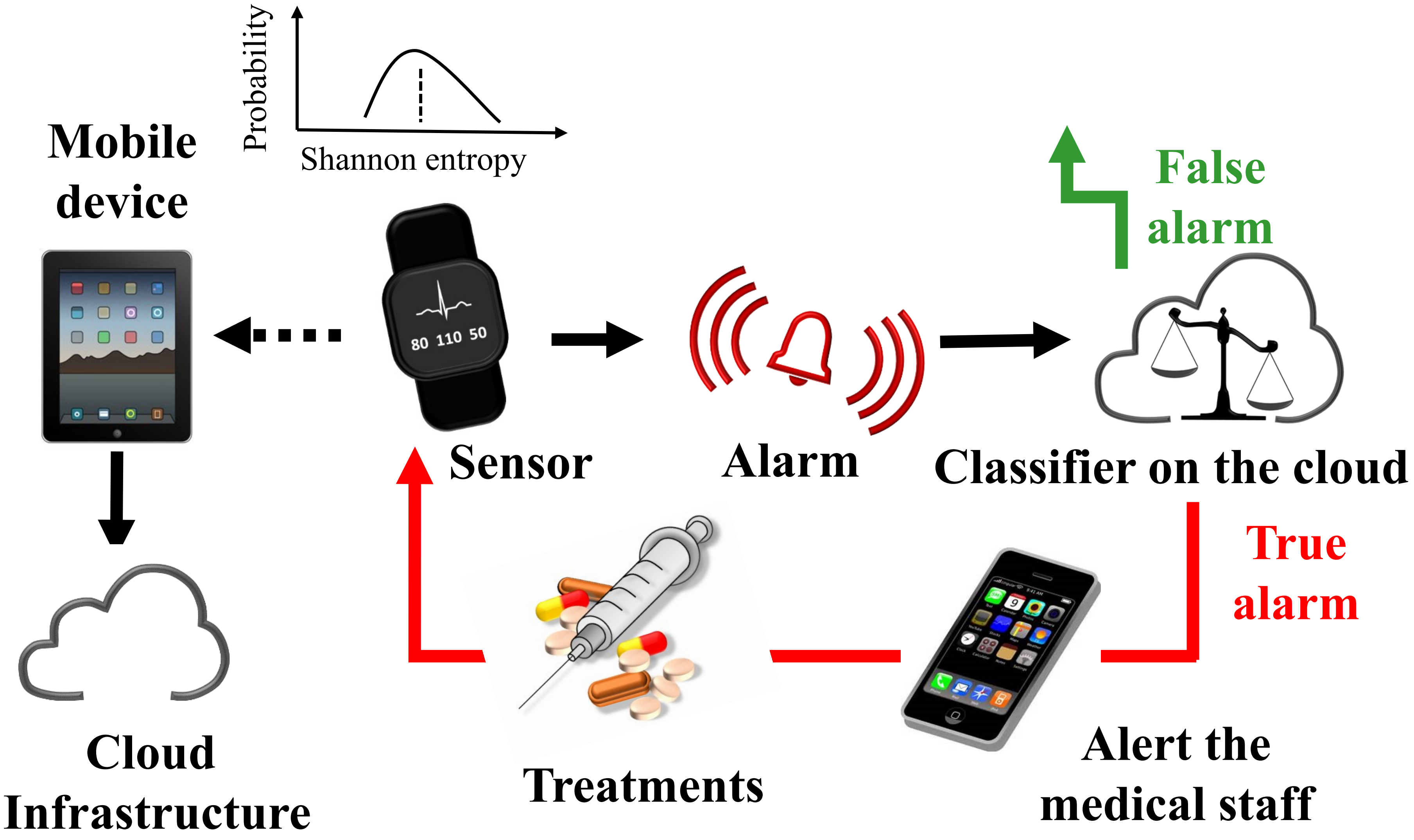
AF rhythm: $$F_{1a} = \frac{2A_a}{\sum A + \sum a}$$

Other rhythm: $$F_{1o} = \frac{2O_o}{\sum O + \sum o}$$

| | $F_1$ |
|---|---|
| Normal | 0.9 |
| AF | 0.81 |
| Other | 0.7 |
| Total | 0.8 |

$$F_1 = \frac{F_{1n} + F_{1a} + F_{1o}}{3}$$

# Summary


Probability
Shannon entropy
Mobile device
80 110 50
Sensor
Alarm
False alarm
Classifier on the cloud
True alarm
Cloud Infrastructure
Treatments
Alert the medical staff

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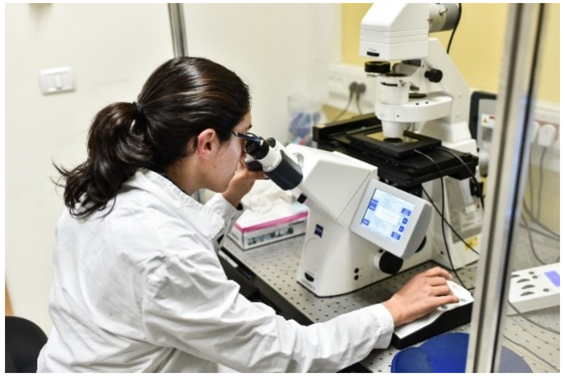
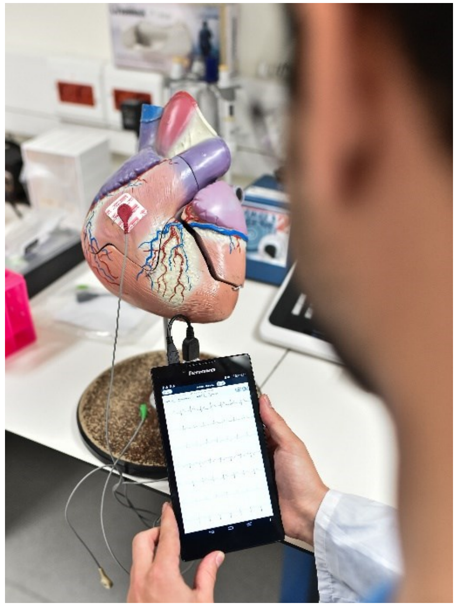
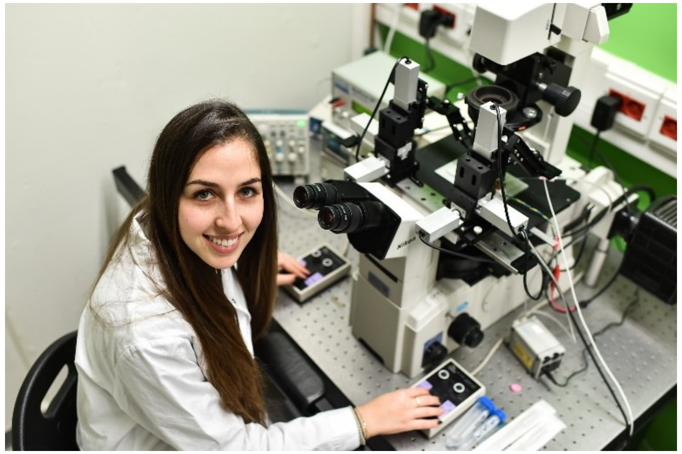
# Thanks for your attention!







# Questions?