ReBeatICG: Real-time Low-Complexity Beat-to-beat Impedance Cardiogram Delineation Algorithm

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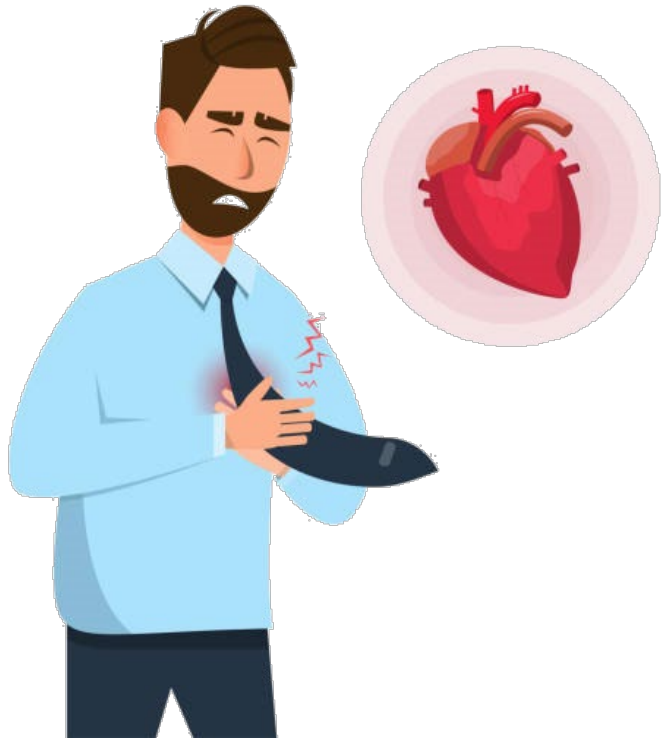
Cardiovascular deseases

- Cardiovascular diseases (CVDs) are globally the highest cause of death

- Hemodynamic parameters are vital to estimate cardio-respiratory activity and evaluate the subject's condition
  - An unobtrusive monitoring of such parameters is highly useful

- Noninvasive techniques to obtain the hemodynamic parameters
  - Doppler echocardiography, CO2 breath analysis, seismocardiography, phonocardiography
  - Impedance cardiography (ICG)

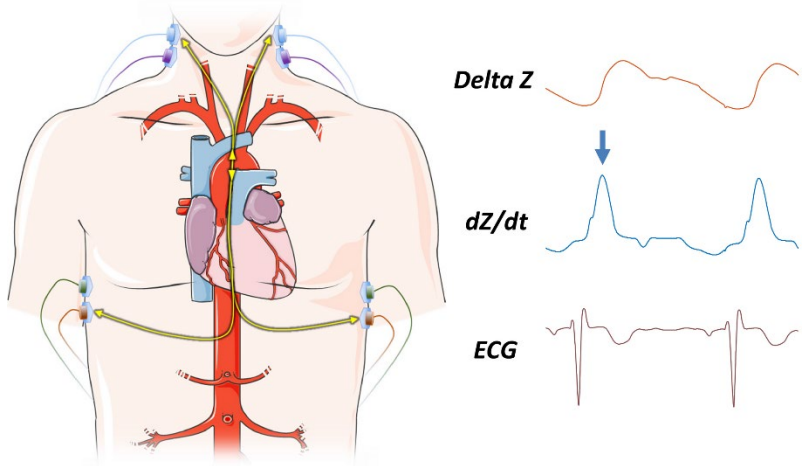


Impedance cardiography (ICG)

- Impedance based technique
  - Decrease in impedance is related to an increase in blood flow
  - First derivative of the impedance signal
- A noninvasive, simple, and low-cost technique

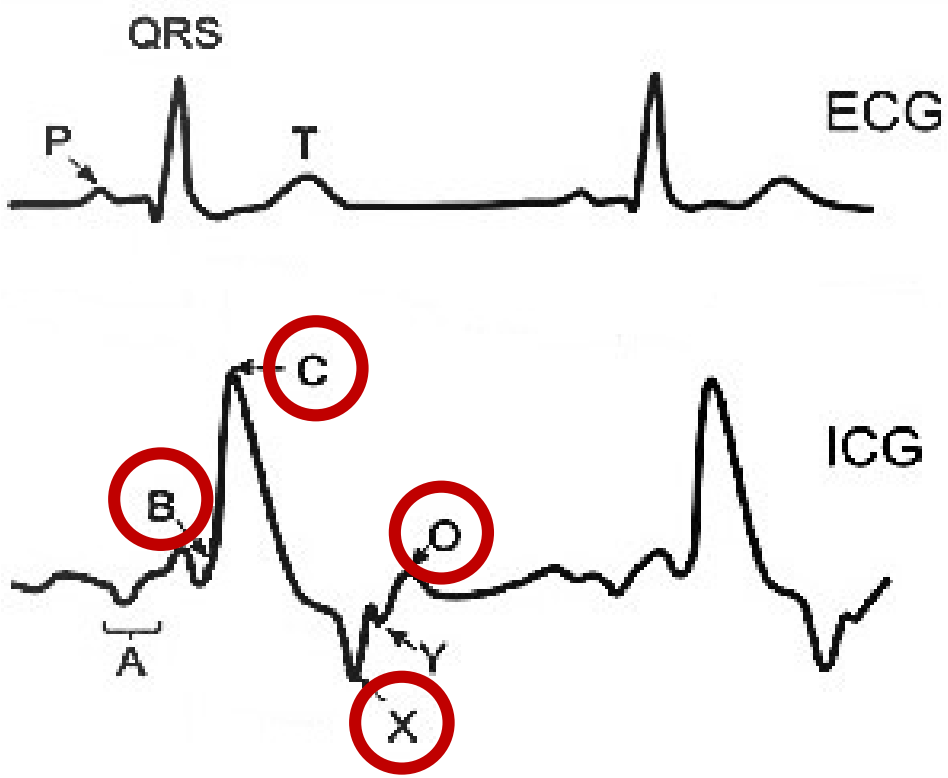
- Many useful hemodynamic parameters can be determined from the ICG signal
  - Cardiac output (CO), stroke volume (SV), systolic time intervals, thoracic fluid content ...

- Promising technique for monitoring hemodynamic parameters using wearable devices
  - Requires an accurate and real-time detection of the ICG's characteristic points



https://doi.org/10.1161/JAHA.118.009259

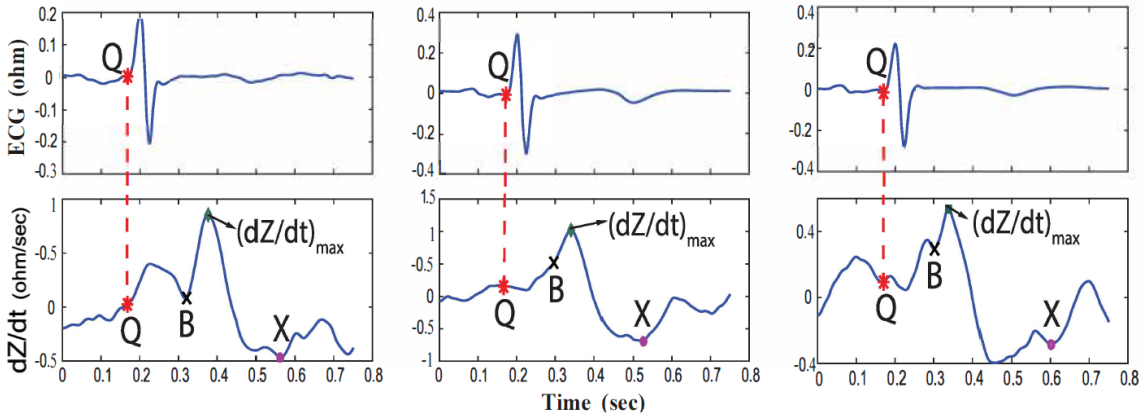
ICG characteristic points



A – Contraction of atrium
B – Opening of aortic valve
C – Max systolic flow
X – Closing of aortic valve
Y – Closing of pulmonar valve
O – Opening of mitral valve

https://pubmed.ncbi.nlm.nih.gov/27014612/

- Delineation is challenging due to many variations in the morphology of the ICG signals



https://pubmed.ncbi.nlm.nih.gov/30443441/

Identified Gaps and Solutions

- SoA delineation algorithms
  - Ensemble averaging [1]
  - More complex techniques (adaptive filtering [2], wavelet decomposition [3], etc)
  - Rely on the synchronously measured ECG signal

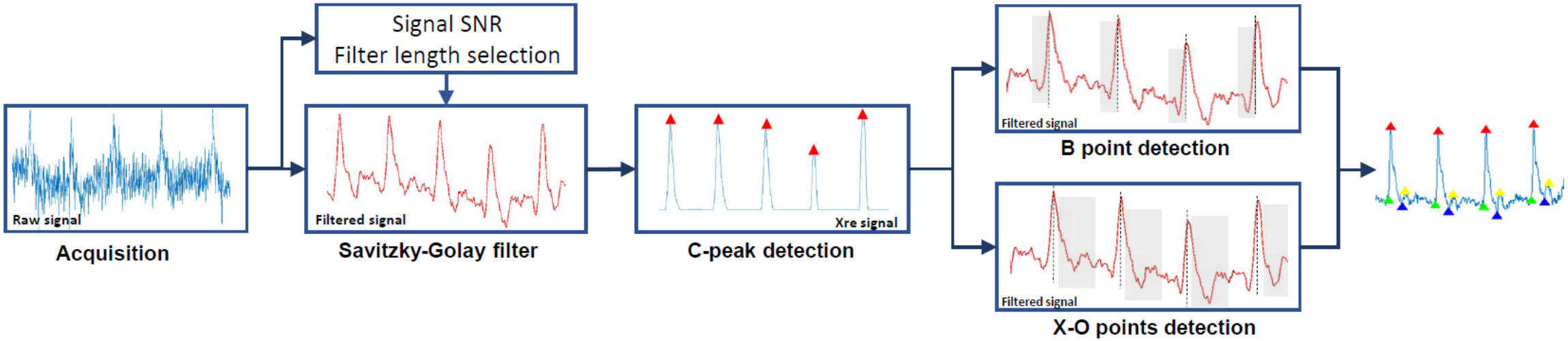
A new delineation methodology implemetable on wearable devices

- No standardized evaluation metrics for evaluation
- No open source databases that allow the assessment and comparison with previously proposed methods

A new open-access database of annotated ICG signals

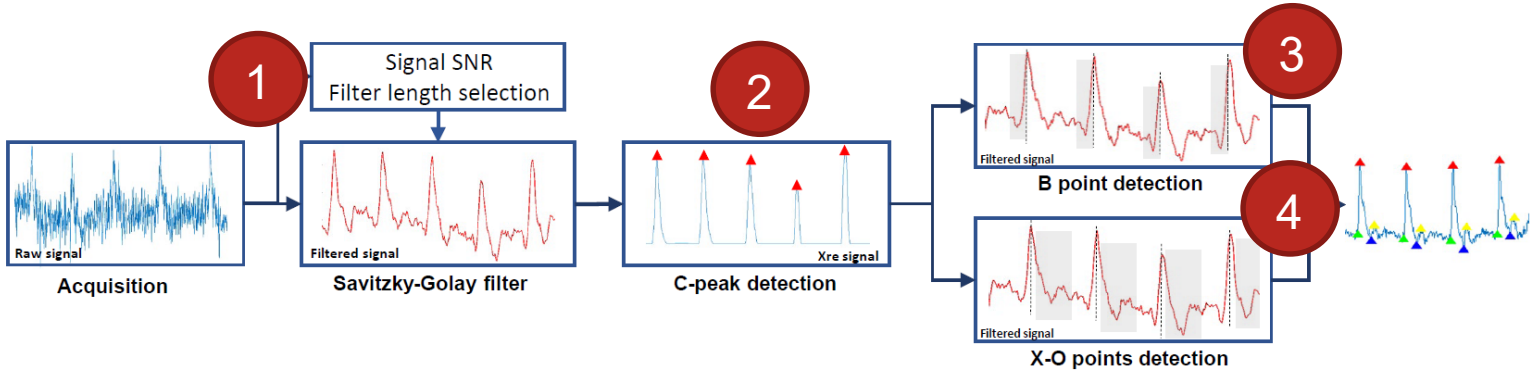
[1] A. Sherwood et al., “Methodological Guidelines for Impedance Cardiography,” Psychophysiology, 1990
[2] U. R. Zia et al., “Adaptive Noise Cancellation Techniques for Impedance Cardiography Signal Analysis,” IJITEE, 2019.
[3] L. Y. Shyu et al., “The detection of impedance cardiogram characteristic points using wavelet transform,” Computers in Biology and Medicine, 2004.

A new delineation methodology



- Real-time and low-complexity beat-to-beat delineation
- Relying only on the ICG signal
- Hemodynamic parameters monitoring on wearable devices

A new delineation methodology



Filtering

1

- Savitzky-Golay filter [4]
- Adaptive filter lenght selection

B peak detection

3

- Defining possible time window for B point
- Search based on derivative anaylsis together with condition checks

C peak detection

2

- „Relative energy" preprocessing method
- An adaptation of the REWARD algorithm [5] for R peaks detection in the ECG

X and O points detection

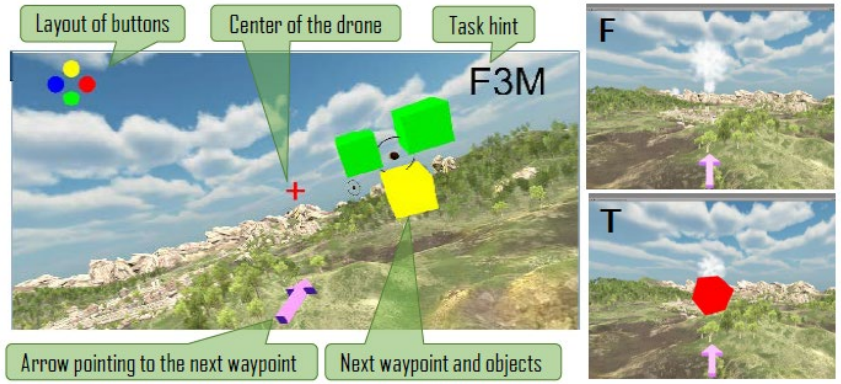
4

- Searching for possible X and O points based on derivative analysis
- Selecting optimal X-O pairs based on condition checking following the signal morphology

[4] D. Acharya et al., “Application of adaptive Savitzky–Golay filter for EEG signal processing,” Perspectives in Science, 2016.
[5] L. Orlandic et al., “REWARD: Design, Optimization, and Evaluation of a Real-Time Relative-Energy Wearable R-Peak Detection Algorithm,” EMBS, 2019

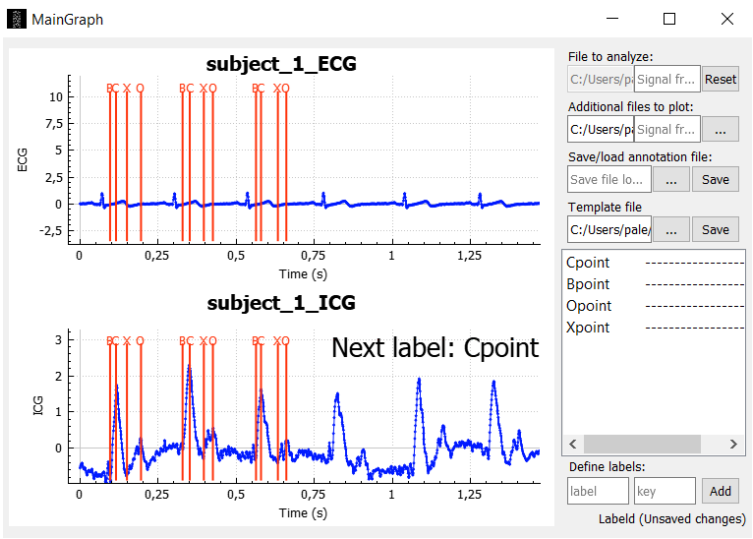
Experimental setup: Dataset

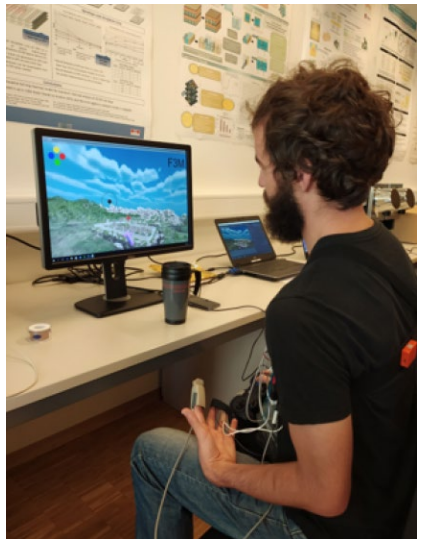
- Original database
  - During an experimental session of a virtual search and rescue mission with drones [6]
  - ICG and ECG signals from 24 healthy subjects
  - Baseline state and higher level of cognitive workload



https://link.springer.com/chapter/10.1007/978-3-030-49695-1_26

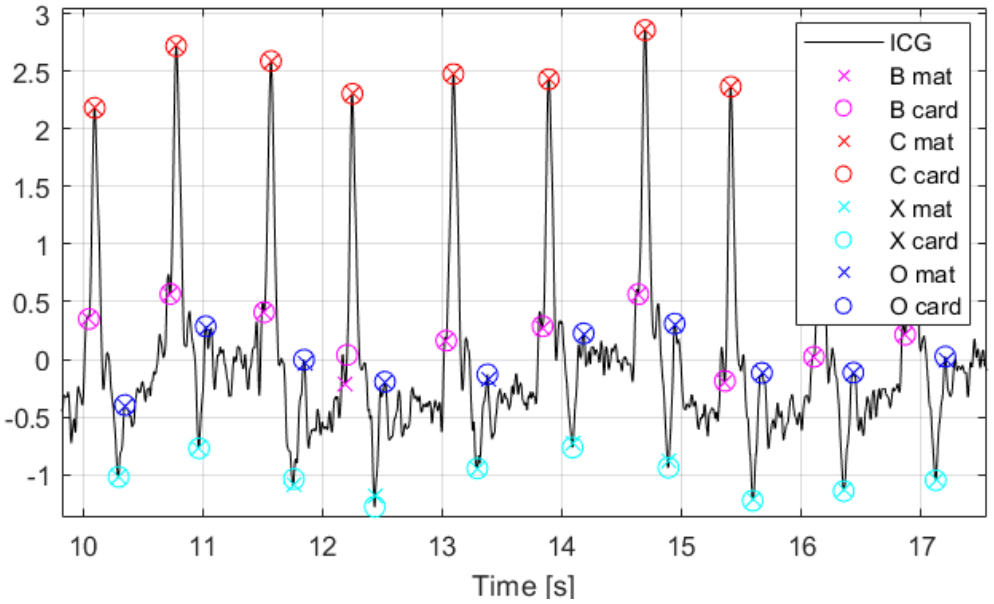
- ICG database
  - Database annotation by the cardiologists from the Lausanne University Hospital
  - Open access physiological signal labeler software [7]
  - 4 blocks of randomly chosen signal segments containing 10 beats from BL and CW tasks of each subject

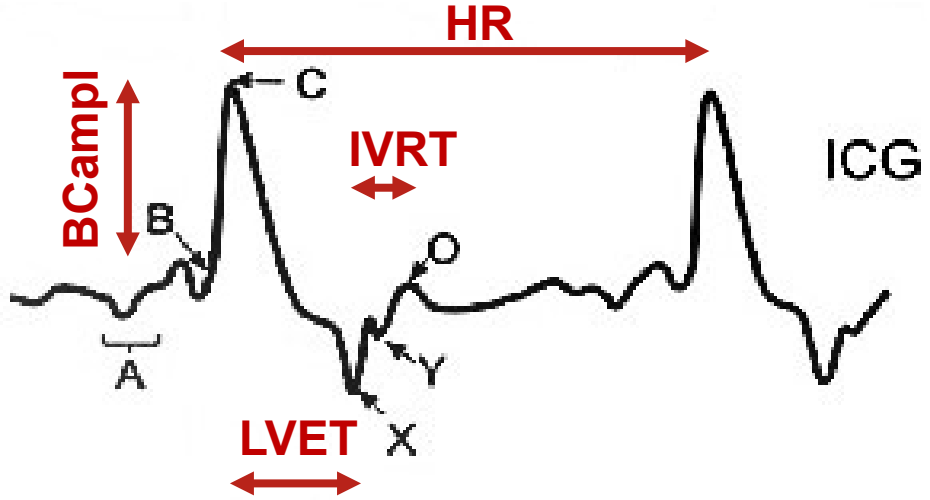




[6] F. Dell'Agnola et al., "Cognitive workload monitoring in virtual reality based rescue missions with drones", 2020
[7] S. Zanoli et al., "Physiological signal labeler," 2021

Experimental setup: Evaluation





- Detecting true positives (TPs), false positives (FPs), and false negatives (FNs)
  - Tolerance of ±30ms from annotated point is used
- Perfomance metrics
  - sensitivity (SE), positive prediction value (PPV), detection error rate (DER), geometric mean (gmean), mean error (*me*), and its standard deviation (σ)
- Hemodynamic parameters
  - Heart rate (HR)
  - Left ventricular ejection time (LVET)
  - Amplitude of the C peak
  - Isovolumetric relaxation time (IVRT)
  - Relative error of parameter value when compared to annotated parameter

Results

- Characteristic points delineation
  - C points almost perfect detection (gmean 98.6%)
  - B, X, and O points bit worse with 94.9%, 90.3% and 84.3% gmean
- Hemodynamic parameters
  - HR is the most precise
  - LVET and IVRT are less precise, but still well within the 30 ms resolution
- Challenging comparison with SoA
  - Different approaches, don't mention resolution
  - Comparison with ±150ms and mean error
  - Our perfomance better or equally good

PERFORMANCE OF REBEATICG PER ANNOTATED POINTS

Annot. Points	Performance measures			
	SE [%]	PPV [%]	Gmean [%]	$me \pm \sigma$ [ms]
B	95.30 ± 5.65	94.48 ± 6.96	94.88 ± 6.28	1.75 ± 0.90
C	99.09 ± 1.86	98.13 ± 3.44	98.60 ± 2.50	0.12 ± 0.08
X	90.55 ± 9.51	90.06 ± 9.82	90.30 ± 9.58	1.09 ± 0.35
O	84.58 ± 15.45	84.08 ± 15.45	84.32 ± 15.39	1.31 ± 0.22

The tolerance in respect to the reference values is ± 30ms

QUALITY OF AUTOMATIC CALCULATION OF HEMODYNAMIC PARAMETERS

Parameter	HR	LVET	IVRT	BCampl
Mean absolute error [ms]	0.11±0.54	9.7±4.7	8.3±9.4	
Mean relative error [%]	0.01±0.04	3.6±1.7	10.2±11.0	3.9±6.5

Conclusions

No lightweight algorithm portable to wearable devices for ICG monitoring

ReBeatICG

- New real-time low-complexity beat-to-beat delineation methodology
- Relying only on the ICG signal for hemodynamic parameters
- High precision delineation of ICG characteristic points and monitoring of hemodynamic parameters

No standard evaluation metrics or database for ICG delineation assesment

ReBeatICG database

- A new open-access database of annotated ICG signals
- Includes 1920 beats, fully (B, C, X and O points) annotated by a cardiologist

EPFL

EMBEDDED SYSTEMS LABORATORY

Questions?

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