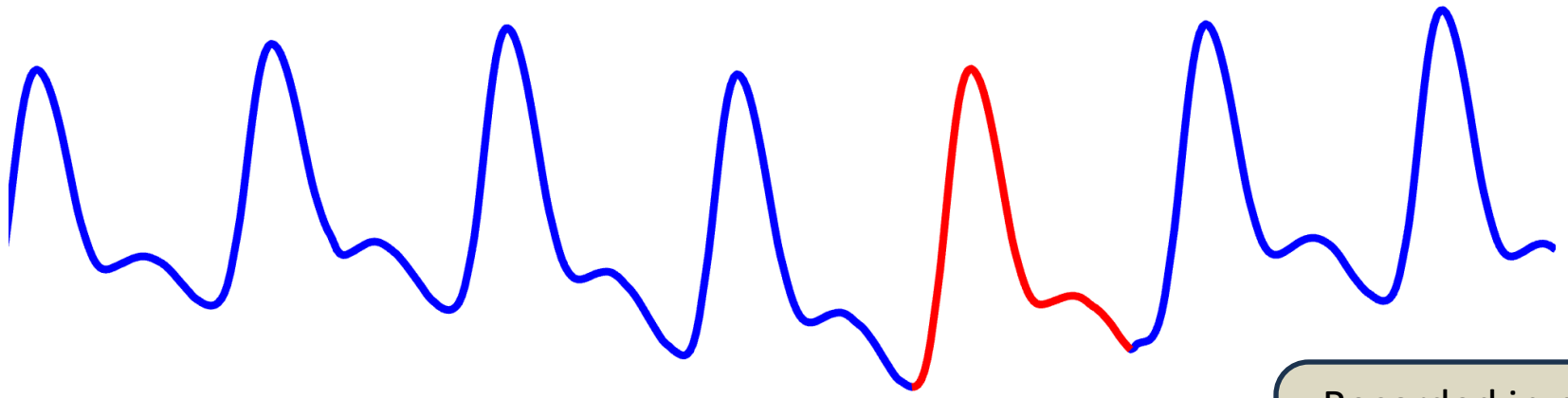


Recorded in preparation for the 2024 Computing in Cardiology Conference.

MSPTDfast: An Efficient Photoplethysmography Beat Detection Algorithm

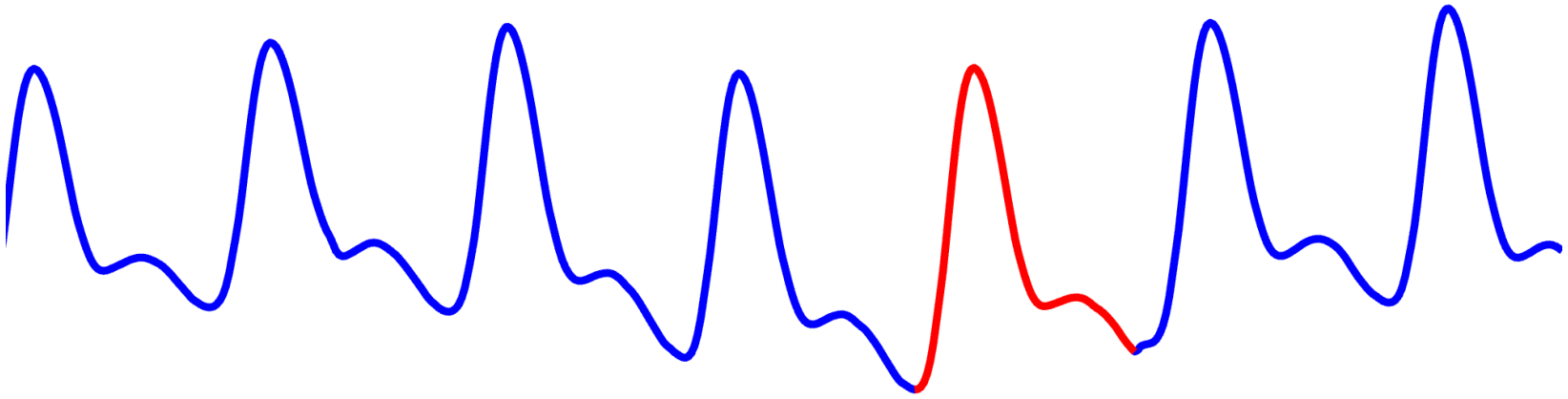
Dr Peter H. Charlton

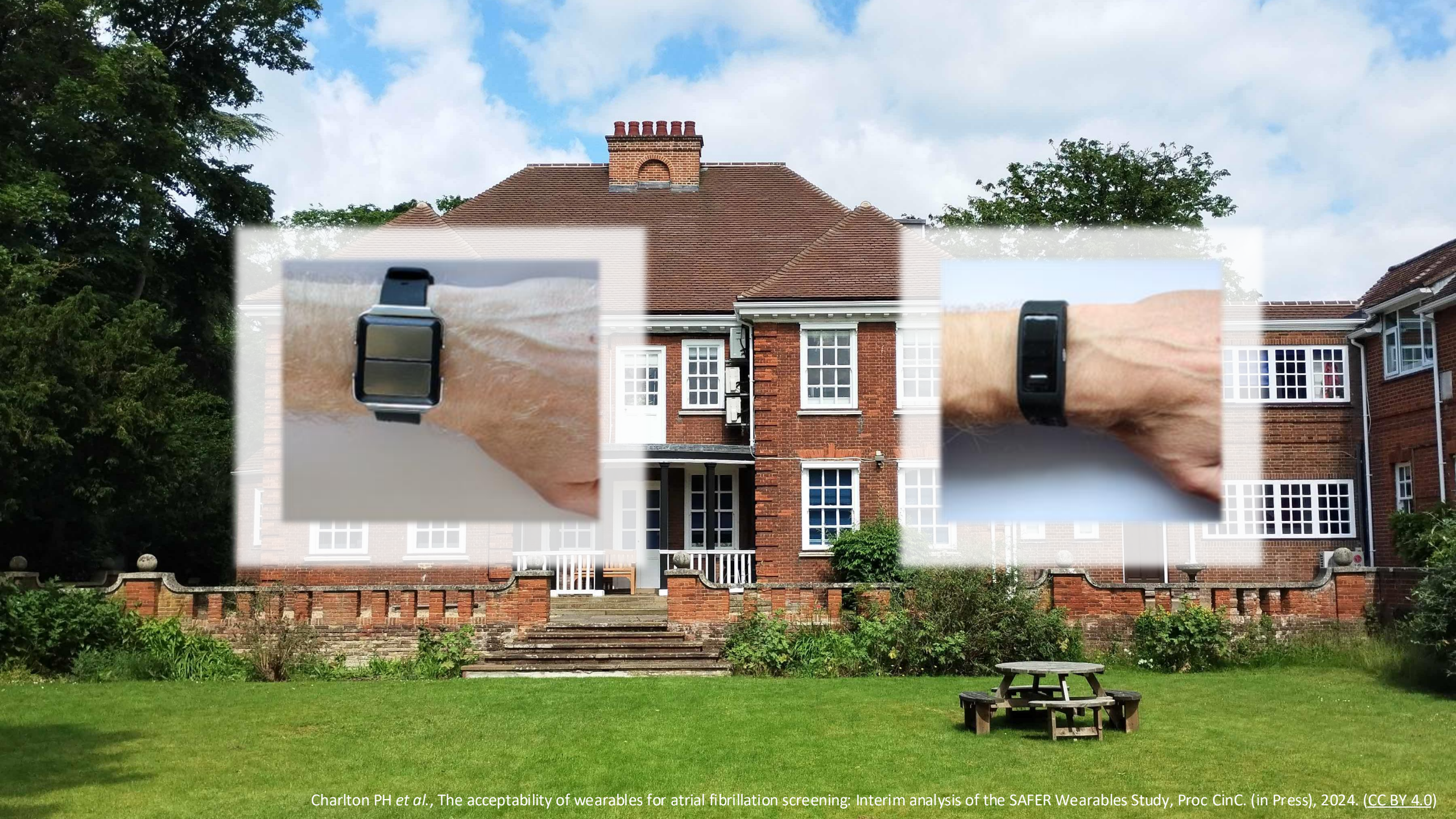
University of Cambridge

City, University of London

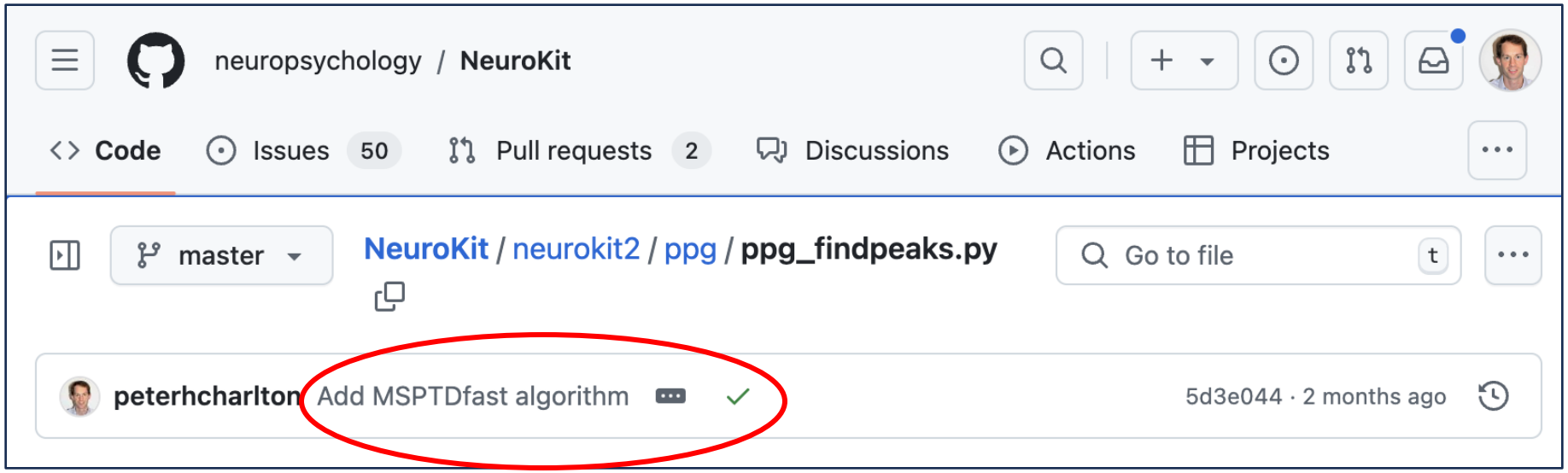
 Data from the MIMIC-III waveform database [1,2,3] (ODbL 1.0). Selected based on [4]. [1] Moody, B. *et al.* (2020). MIMIC-III Waveform Database (version 1.0). PhysioNet. https://doi.org/10.13026/c2607m. [2] Johnson, A. E. W. *et al.* (2016). MIMIC-III, a freely accessible critical care database. Scientific Data, 3, 160035. [3] Goldberger, A. *et al.* (2000). PhysioBank, PhysioToolkit, and PhysioNet: Components of a new research resource for complex physiologic signals. Circulation. 101 (23), pp. e215–e220. [4] Bashar, S.K. *et al.* 2019. Noise Detection in Electrocardiogram Signals for Intensive Care Unit Patients. IEEE Access, 7, pp.88357-88368.

Photo by Luke Chesser on Unsplash





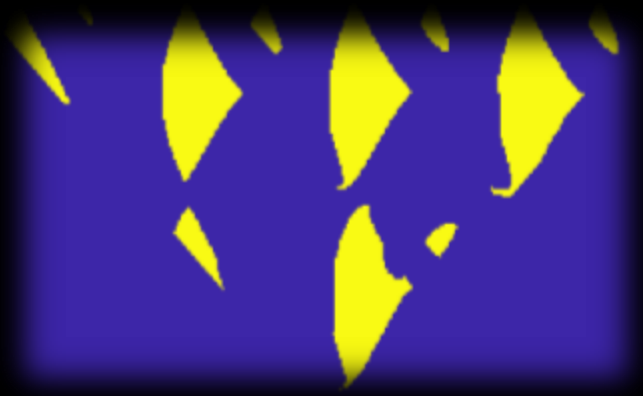
Charlton PH *et al.*, The acceptability of wearables for atrial fibrillation screening: Interim analysis of the SAFER Wearables Study, Proc CinC. (in Press), 2024. (CC BY 4.0)



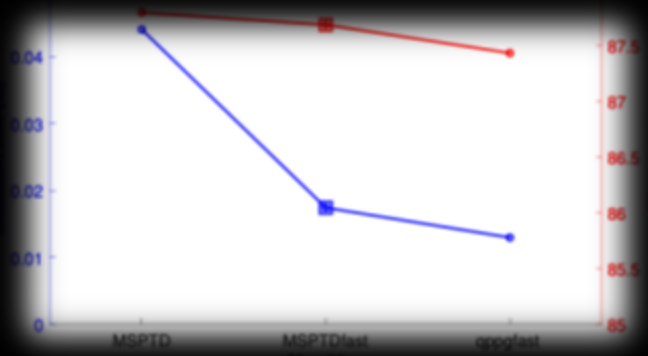
an efficient, open-source PPG beat detector

Towards an efficient, open-source PPG beat detector

1. State-of-the-art

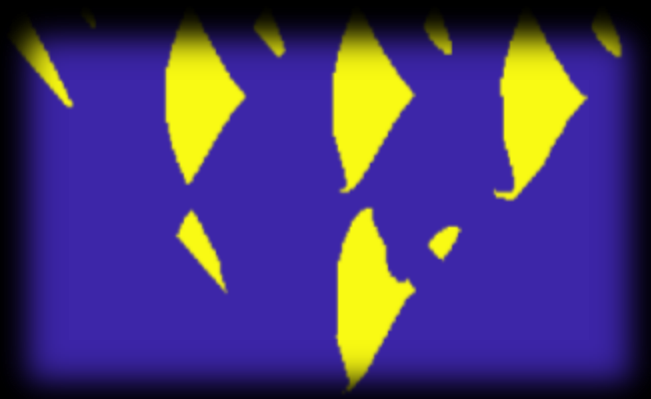


2. Algorithm design and evaluation

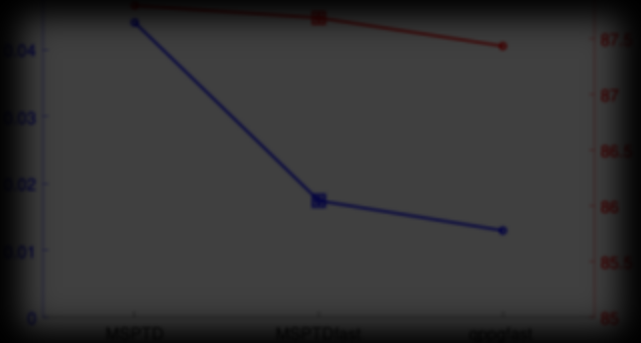


Towards an efficient, open-source PPG beat detector

1. State-of-the-art



2. Algorithm design and evaluation



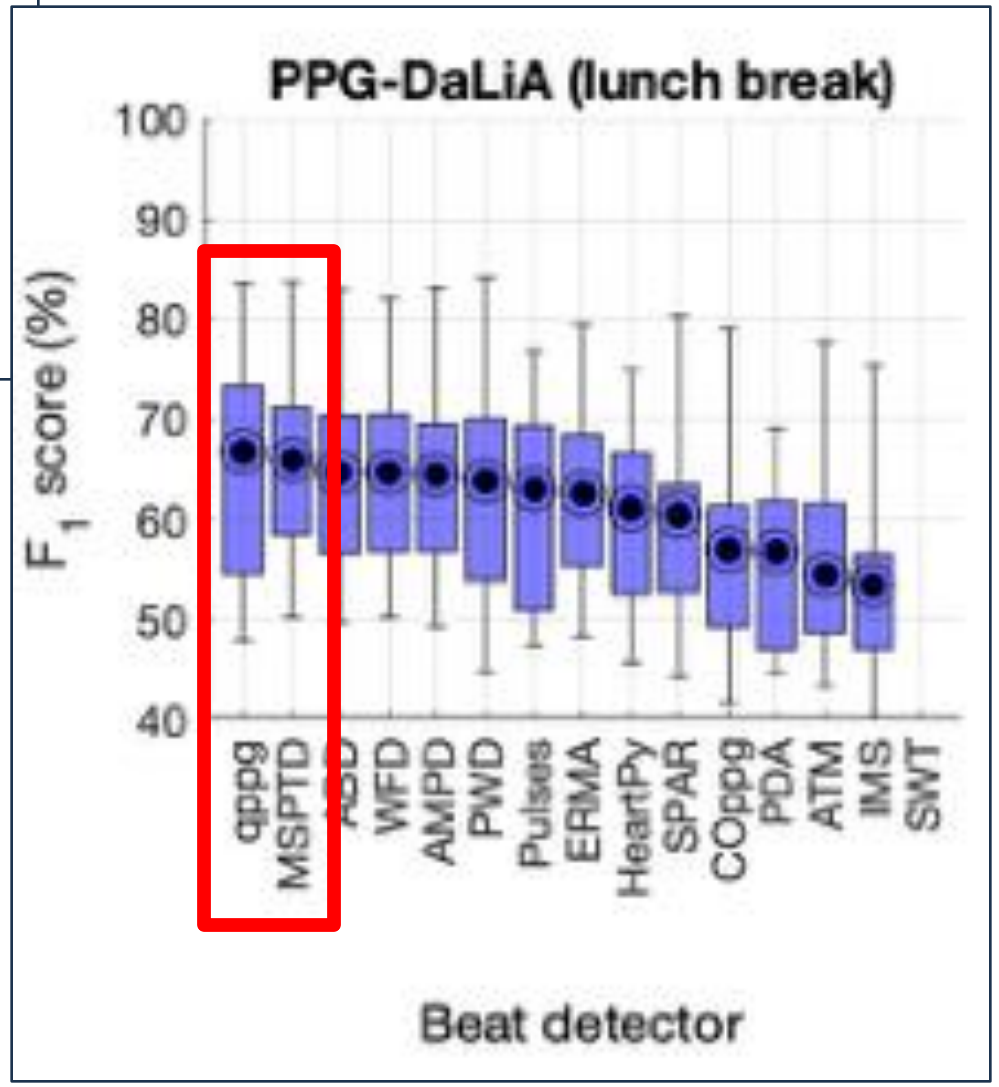
Physiological Measurement

IPEM
Institute of Physics and Engineering in Medicine

PAPER

Detecting beats in the photoplethysmogram: benchmarking open-source algorithms

Peter H Charlton[1,2,*], Kevin Kotzen[3], Elisa Mejía-Mejía[2], Philip J Aston[4], Karthik Budidha[2], Jonathan Mant[1], Callum Pettit[4], Joachim A Behar[3] and Panicos A Kyriacou[2]

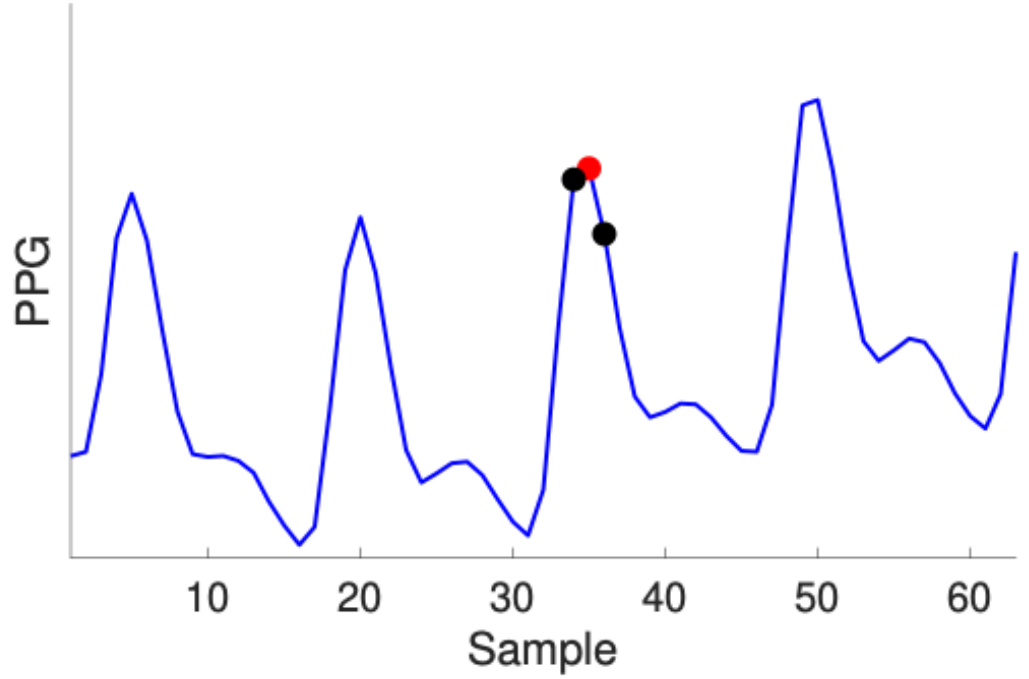


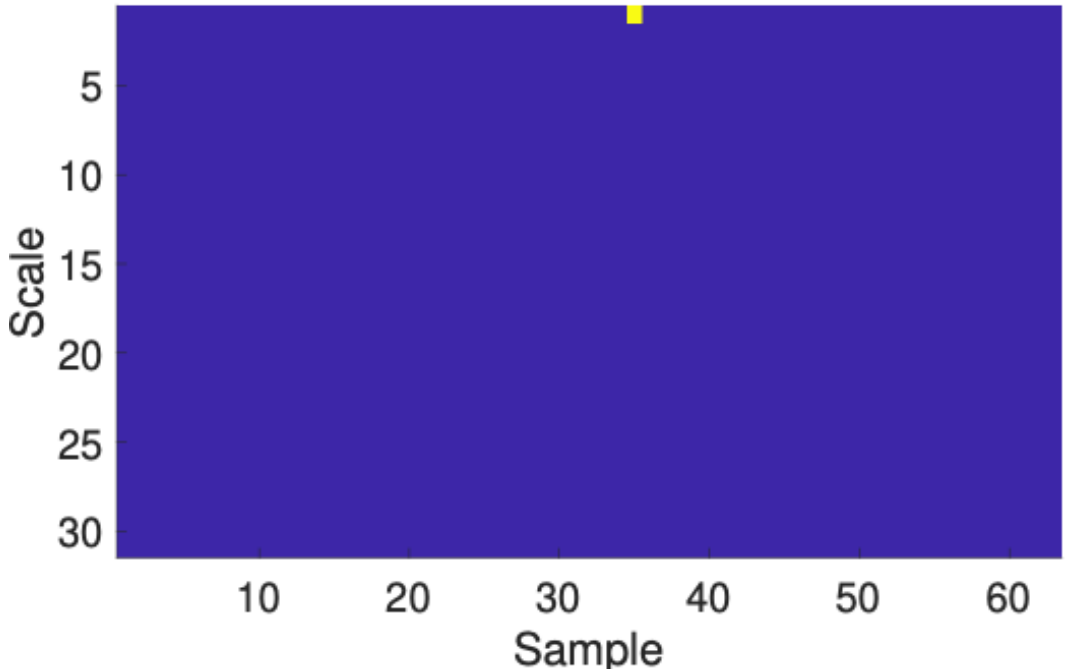
"we suggest that MSPTD and qppg performed best, although we note that this is subjective"

The MSPTD beat detection algorithm

Calculating the local maxima scalogram:

- Point of interest
- Points separated from the point of interest by *n* samples. *n* is the scale.

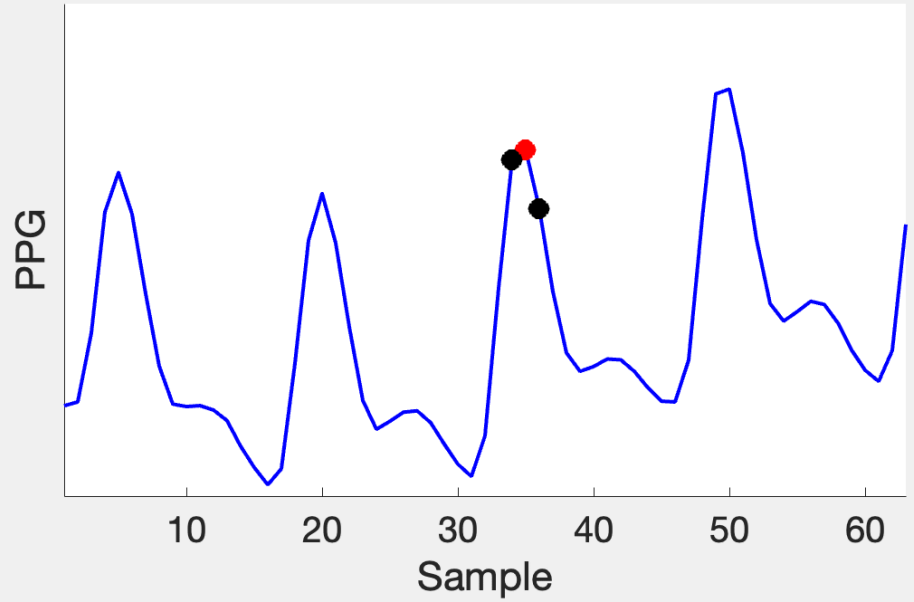


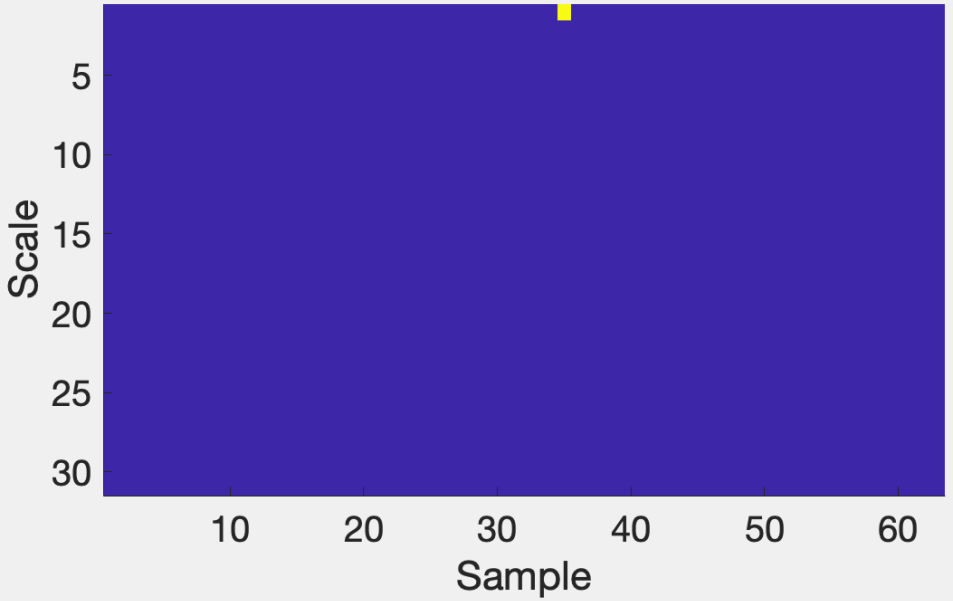


The MSPTD beat detection algorithm

Calculating the local maxima scalogram:

A pulse peak which is higher than most of its surrounding neighbours.

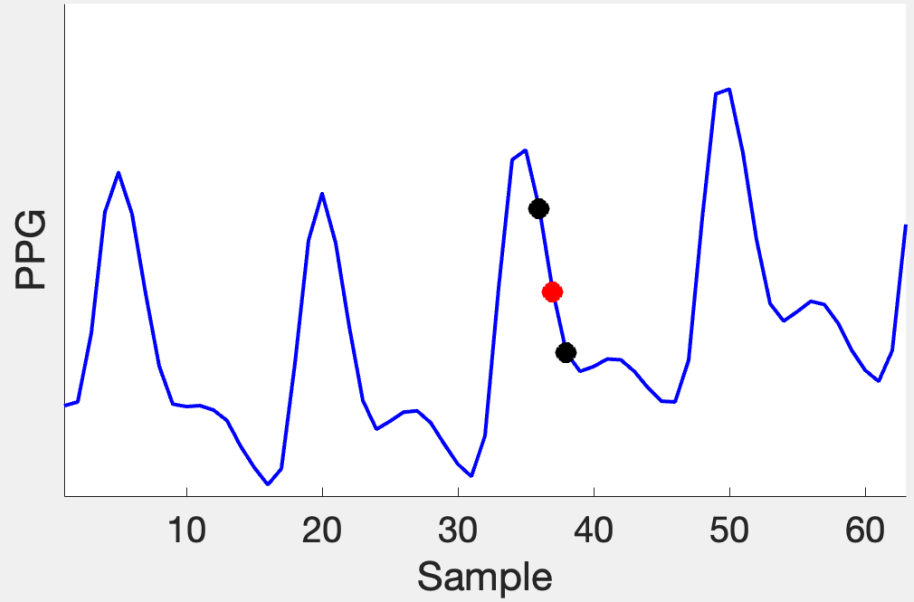


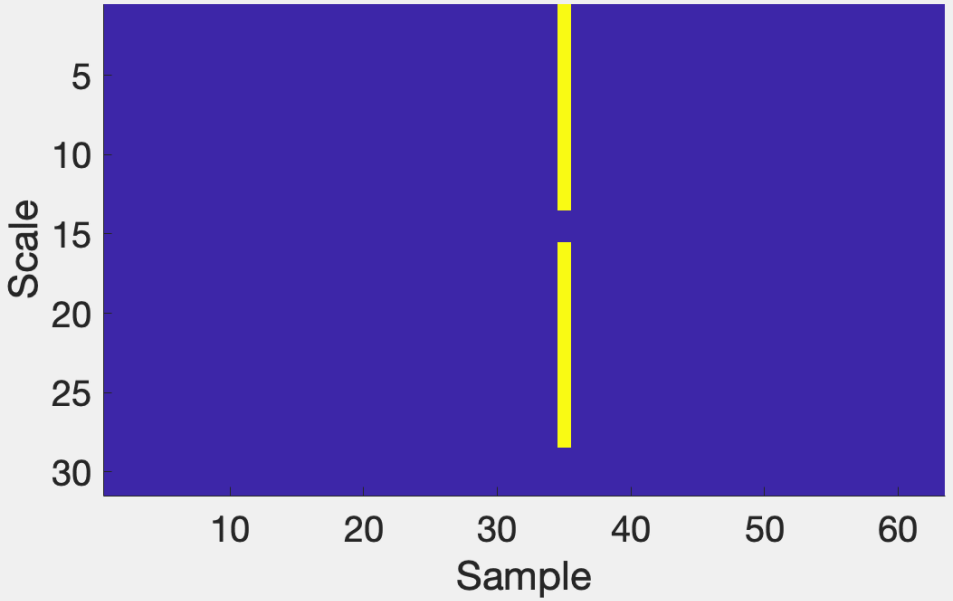


The MSPTD beat detection algorithm

Calculating the local maxima scalogram:

A point on a downslope which is lower than most of its surrounding neighbours.

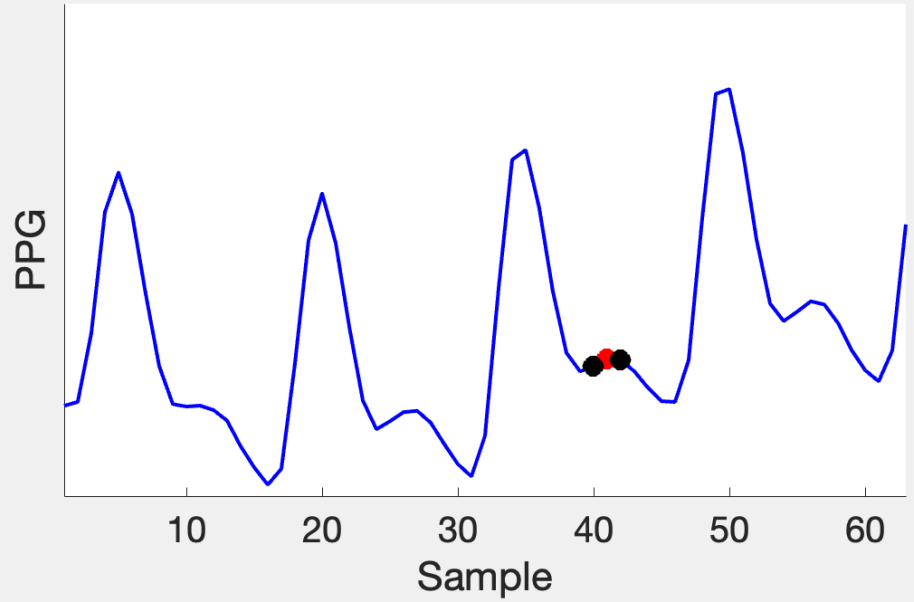


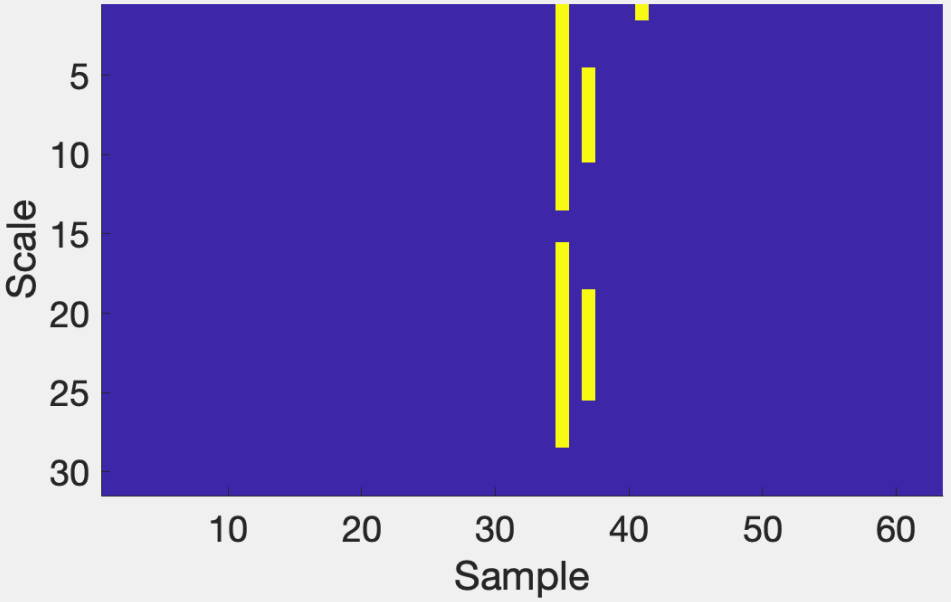


The MSPTD beat detection algorithm

Calculating the local maxima scalogram:

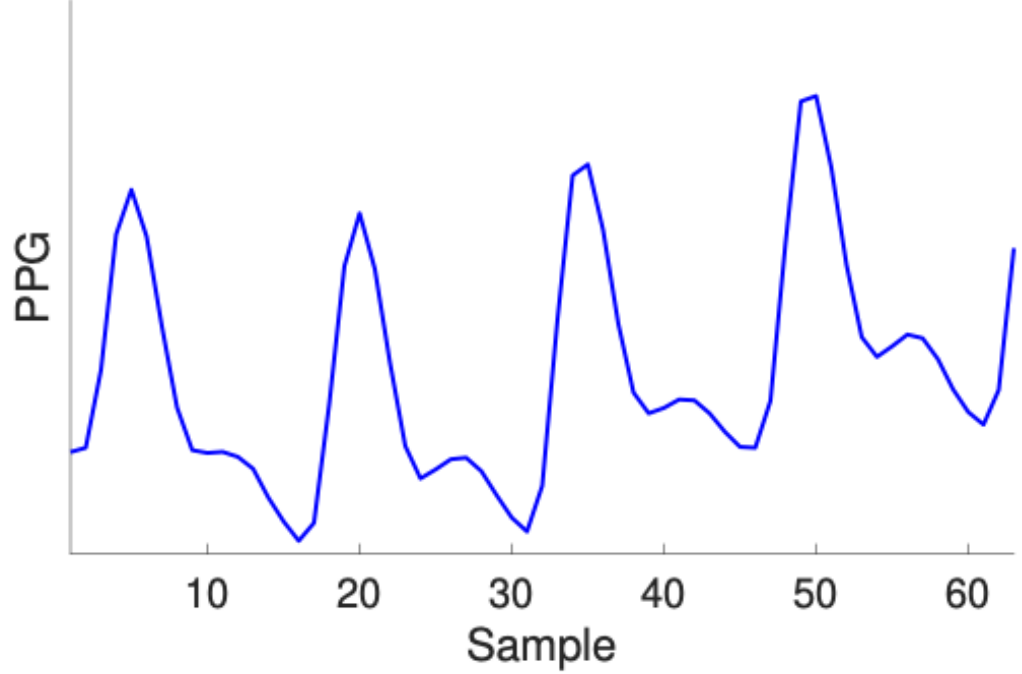
A dicrotic notch which is higher than a few of its surrounding neighbours.



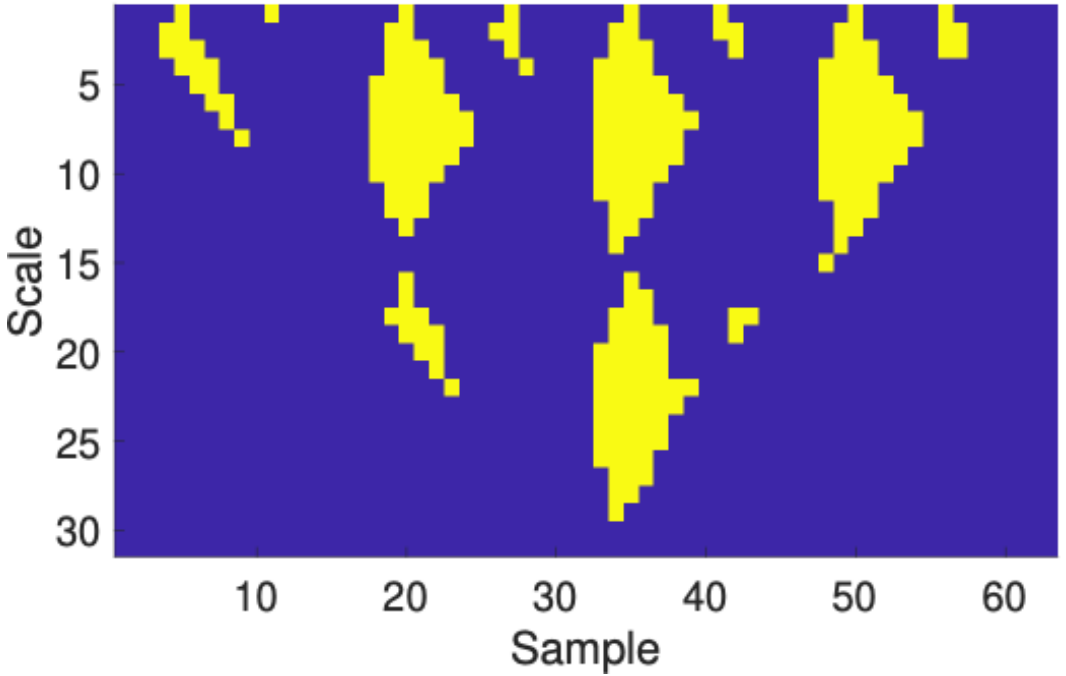


The MSPTD beat detection algorithm

Calculating the local maxima scalogram:

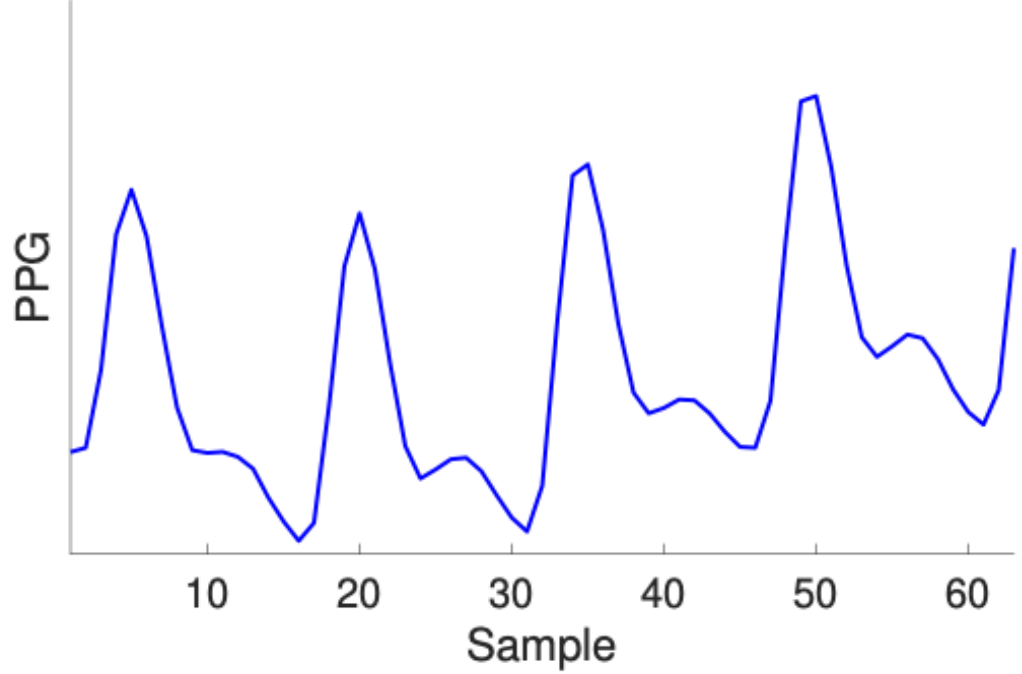


This process is repeated for each point on the PPG signal to produce a ‘local maxima scalogram’.

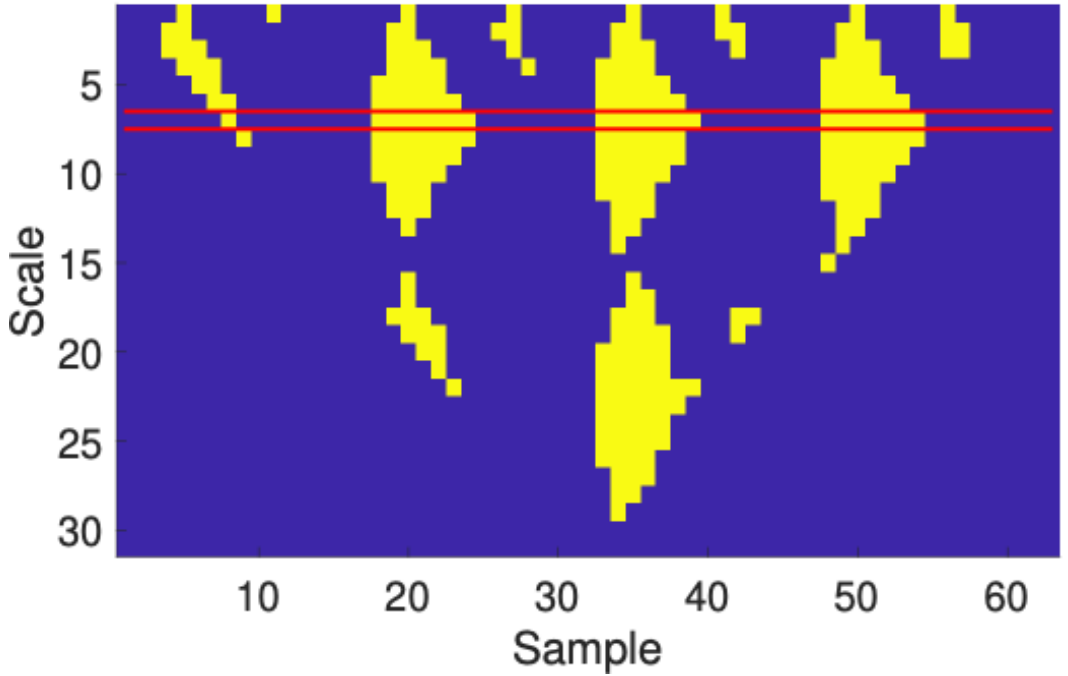


The MSPTD beat detection algorithm

Identifying pulse peaks:

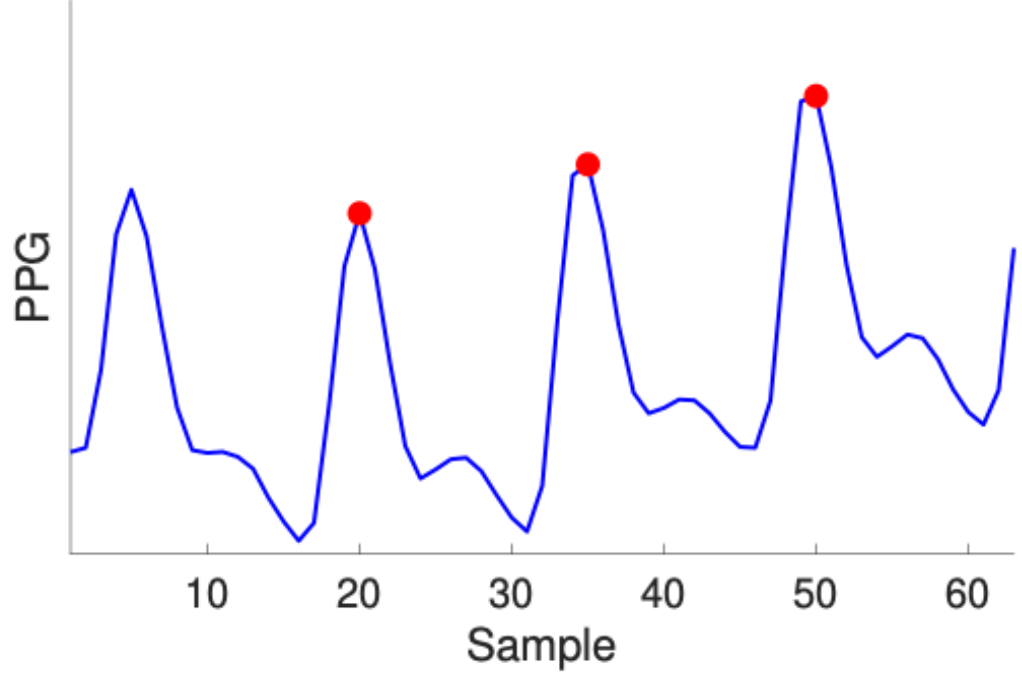


The scale with the most local maxima is identified.

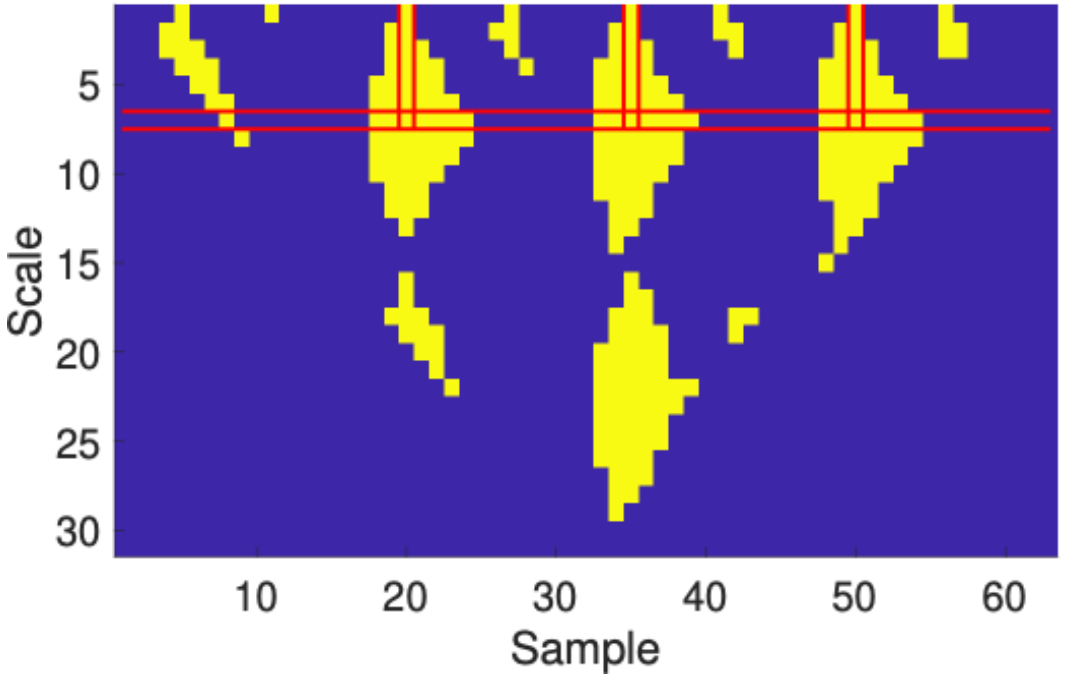


The MSPTD beat detection algorithm

Identifying pulse peaks:

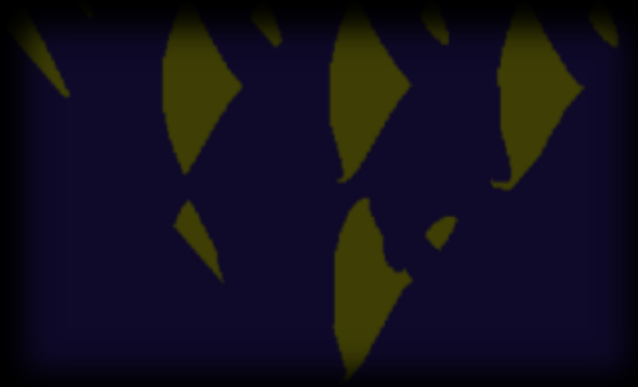


Peaks are any samples which are maxima at all scales up until this identified scale.

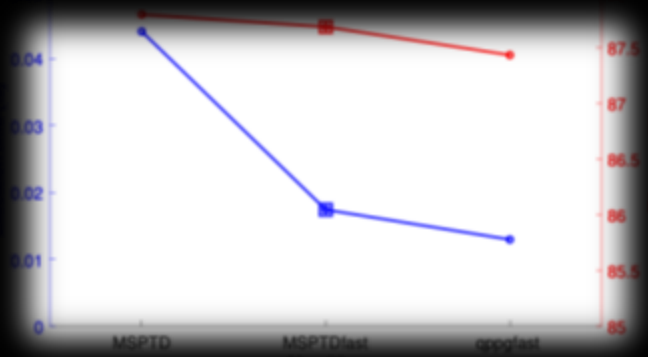


Towards an efficient, open-source PPG beat detector

1. State-of-the-art



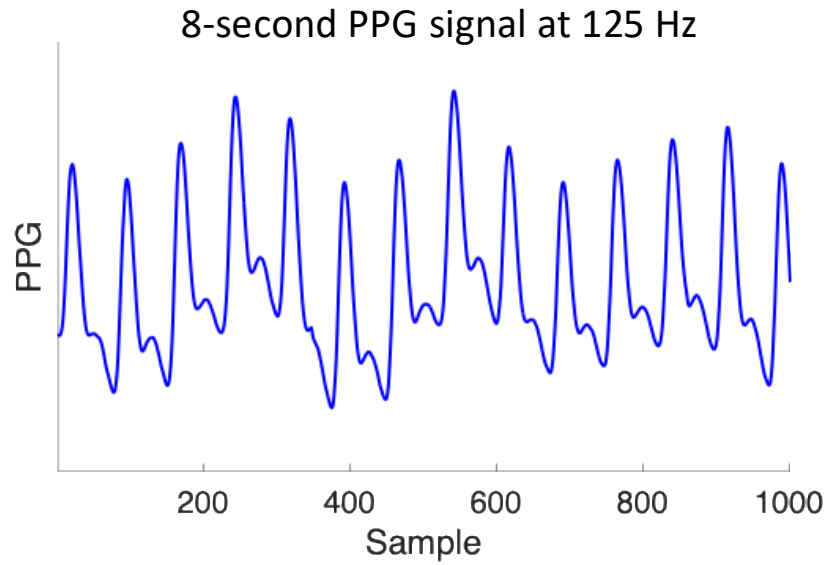
2. Algorithm design and evaluation

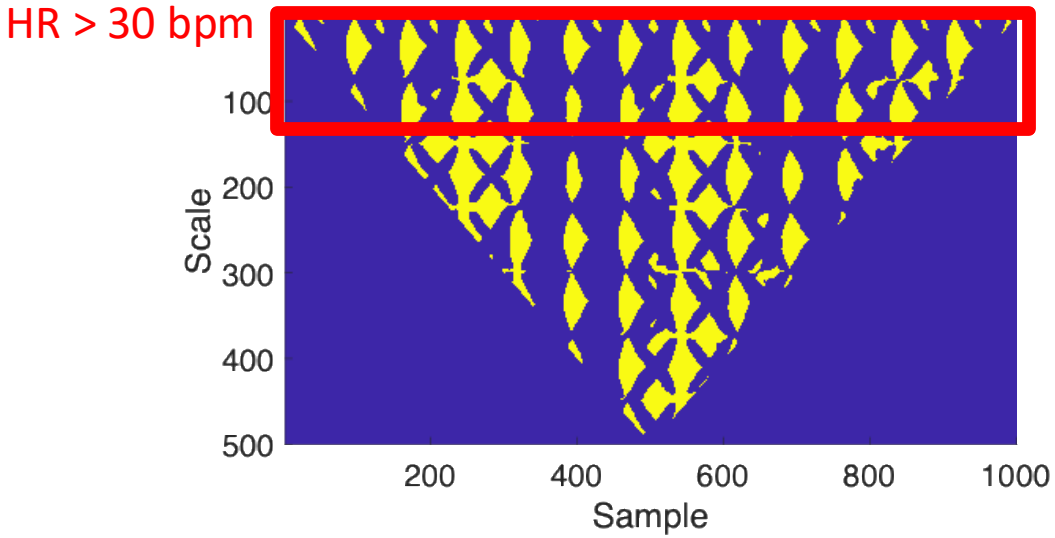


Potential improvements

Potential improvement	Options
LMSs to calculate	peaks and onsets ∗ peaks onsets
LMS calculation method	nested for loops ∗ vectorised approach
LMS scales used	N/2 ∗ only scales >HRmin, with HRmin ∈ {30, 40} bpm.
Sampling frequency (Hz)	original ∗ 10 20 30
Window duration (s)	4 6 8 ∗ 10

* indicates the approach used in MSPTD

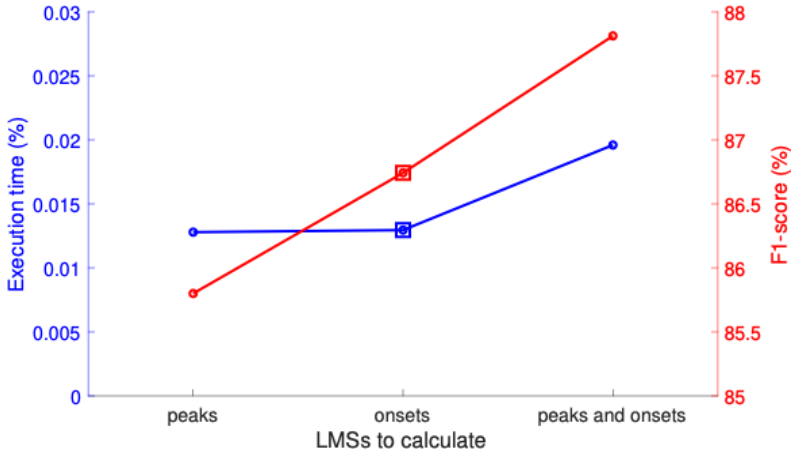




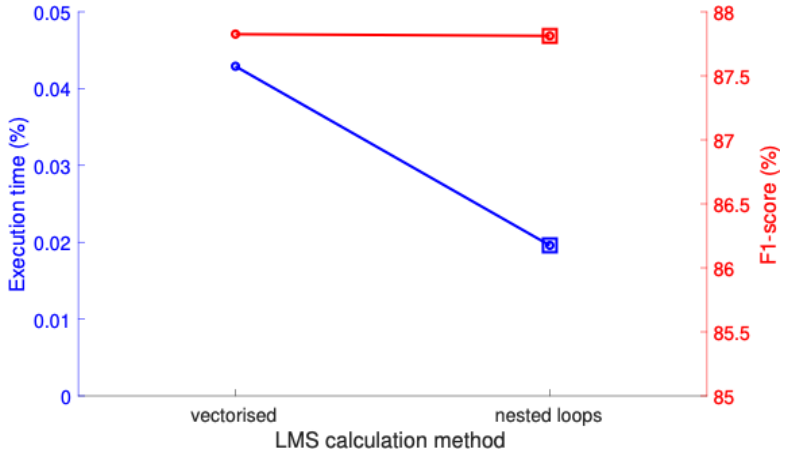
Methods

- Evaluate the impact of each option for each potential improvement on:
  - Execution time (displayed as a percentage of signal duration)
  - F1-score (harmonic mean of sensitivity and PPV of beat detection)
    - In comparison to ECG-derived heartbeats (time-aligned, 150ms tolerance)
- Create 'MSPTDfast' using all potential improvements found to reduce execution time whilst not substantially reducing F1-score.
- Compare 'MSPTDfast' to MSPTD [1] and qppg [2] beat detection algorithms.
- All performed on PPG-DaLiA dataset [3]:
  - Wrist PPG signals acquired using Empatica E4
  - From 15 young subjects
  - During a lunchbreak (duration of 32.4 (28.7-37.2) minutes)

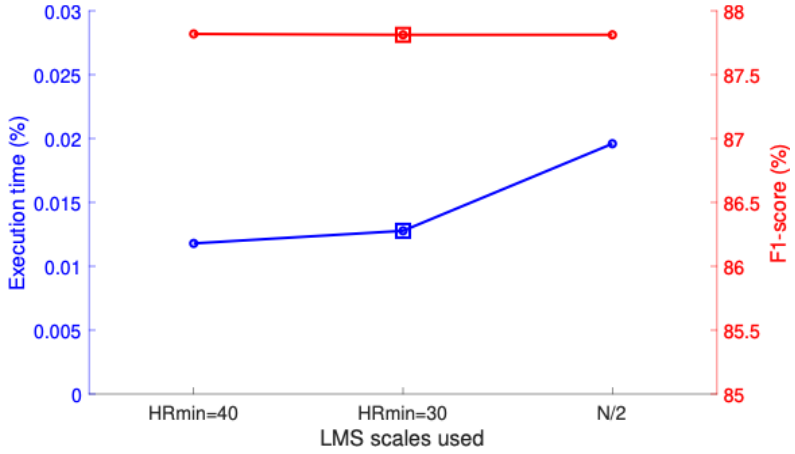
[1] S. M. Bishop and A. Ercole, "Multi-scale peak and trough detection optimised for periodic and quasi-periodic neuroscience data," in Intracranial Pressure and Neuromonitoring XVI. Acta Neurochirurgica Supplement, T. Heldt, Ed. Springer, 2018, vol. 126, pp. 189–195.
[2] A. N. Vest et al., "An open source benchmarked toolbox for cardiovascular waveform and interval analysis," Physiological Measurement, vol. 39, no. 10, 2018.
[3] A. Reiss et al., "Deep PPG: large-scale heart rate estimation with convolutional neural networks," Sensors, vol. 19, no. 14, p. 3079, 2019.



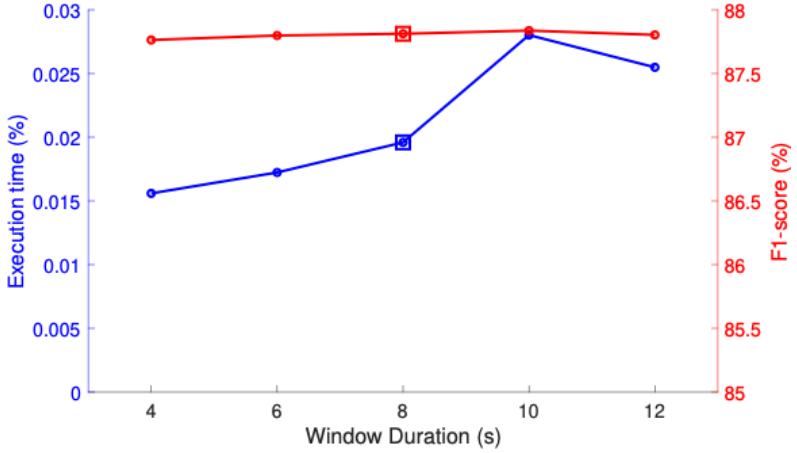
Original ‘peaks and onsets’ approach retained to maintain F1-score



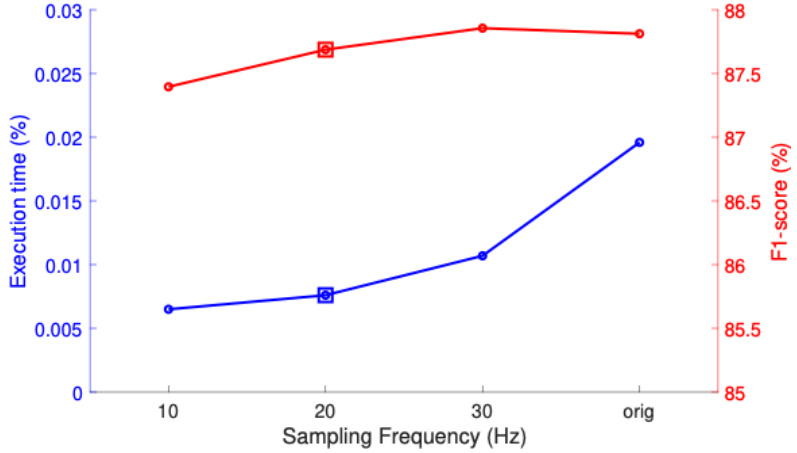
Original ‘nested loops’ approach retained



Only scales corresponding to HRs > 30 bpm used.

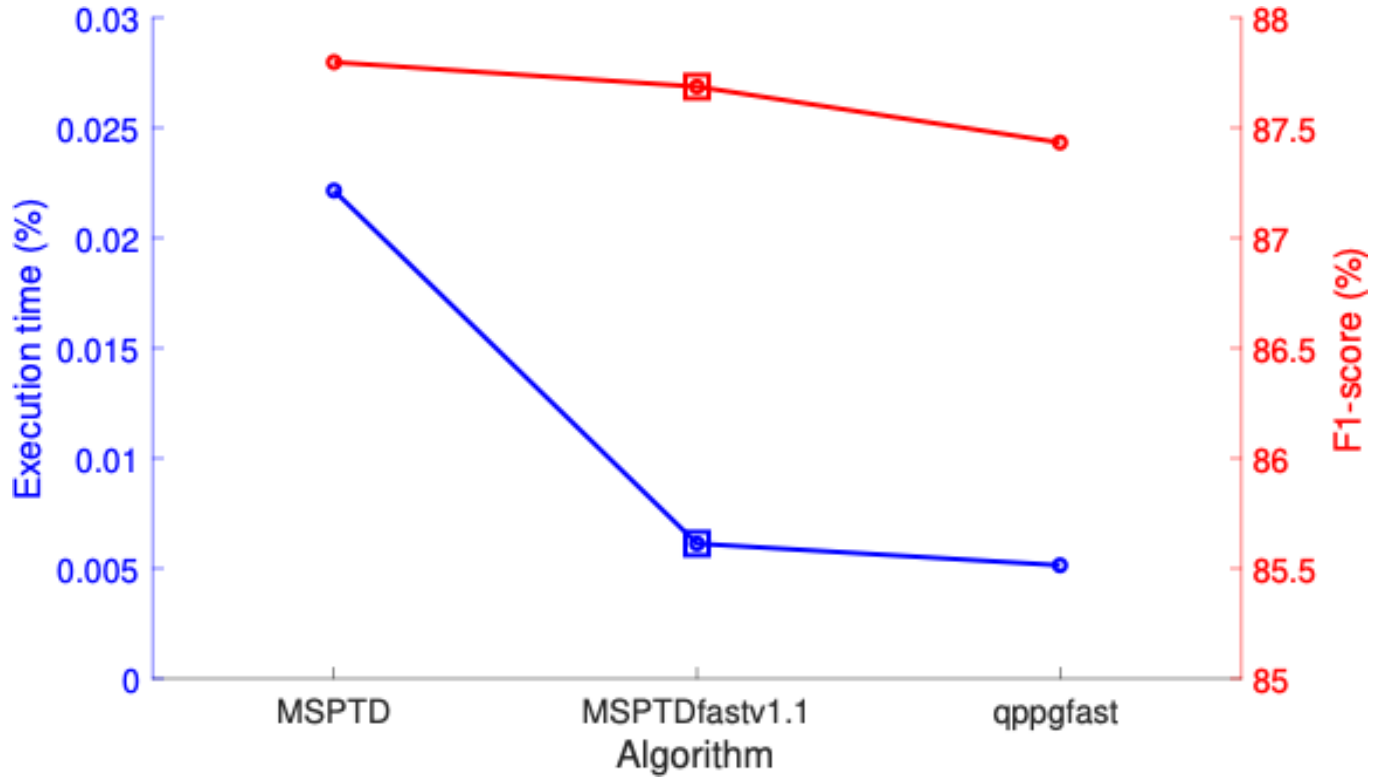


Original window duration of 8 seconds retained.



Signals downsampled to 20 Hz prior to analysis

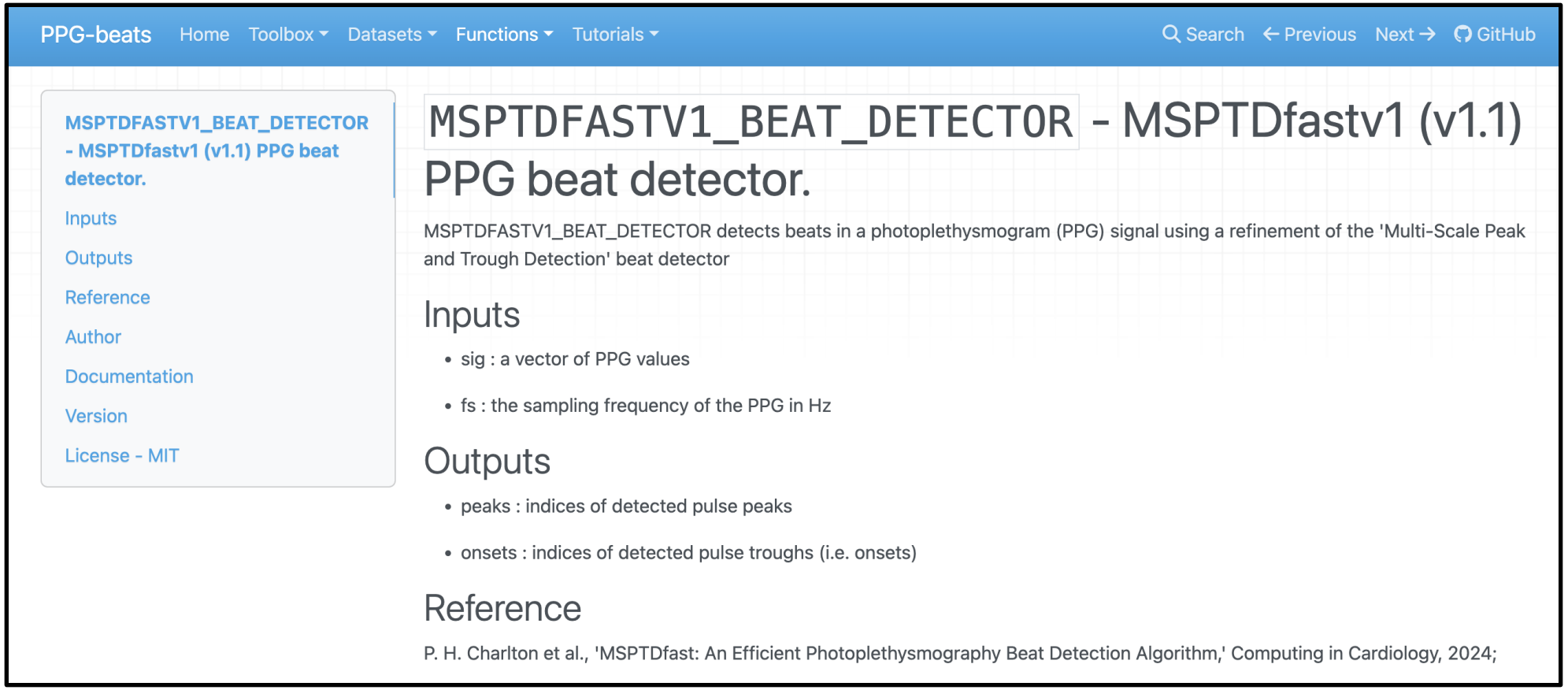
Results



'MSPTDfast' had an execution time of less than one third (27.7%) of the 'MSPTD' algorithm.

This was achieved with only a very small reduction in F1-score of 0.1%.

Results



https://ppg-beats.readthedocs.io/

Results

PPG-beats Home Toolbox Datasets Functions Tutorials Search ← Previous Next → GitHub

Designing a Beat Detector

Designing MSPTDfast (v.1)

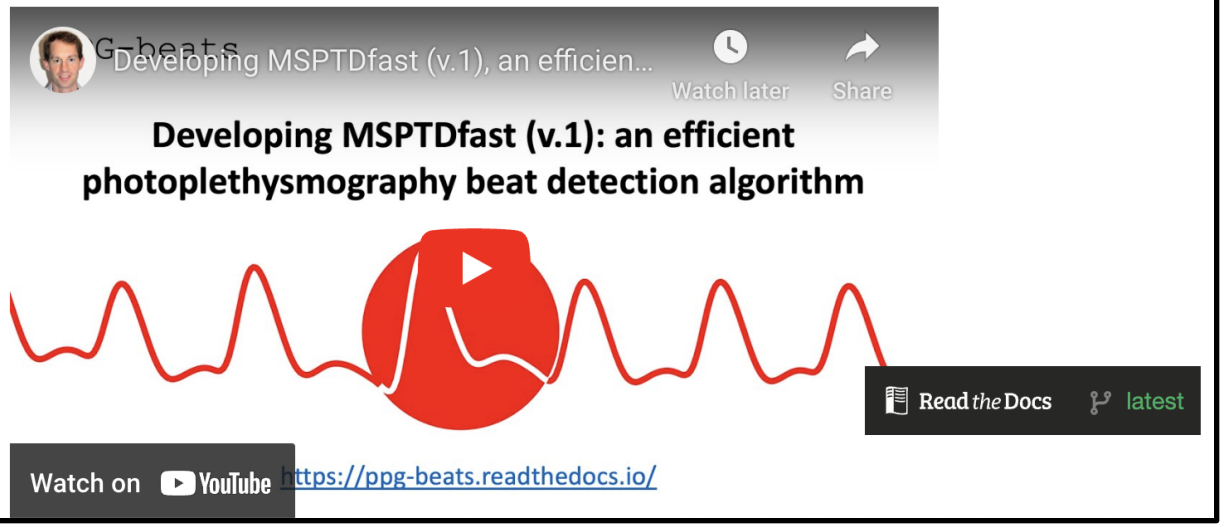
Designing MSPTDfast (v.2)

Designing MSPTDfast (v.1)

This tutorial demonstrates the processes undertaken to design MSPTDfast (v.1), which was designed using a single dataset. The publication describing this work is available here.

- Install the PPG-beats toolbox. *The usual instructions here are for downloading the latest version of the toolbox, whereas you will need the v.2.0 release to replicate the analysis exactly. This can be downloaded from here.*
- Download the PPG-DaLiA dataset in Matlab format from here.
- Use the `assess_multiple_datasets.m` script to run the analysis.
- During this process a new folder will have been created called `proc_data_ppg_dalia_lunch_break`. Within this folder you will find files storing the analysis steps, including the file containing the results: the `ppg_detect_stats.mat` file. Note down the location of this file.
- Finally, analyse the performance of the different algorithm configuration options by running the msptdfast_cinc_analysis.m script.

This tutorial is demonstrated in the following video:



https://ppg-beats.readthedocs.io/

Discussion and Conclusion

- MSPTDfast reduced execution time by 72.3% compared to ‘MSPTD’ whilst retaining beat detection accuracy.

- This was achieved by reducing the size of the LMS matrix by:
  - Downsampling the PPG signal
  - Reducing the number of scales over which beats are detected

With thanks to…

Panicos Kyriacou
Jonathan Mant

University of Cambridge
City, University of London

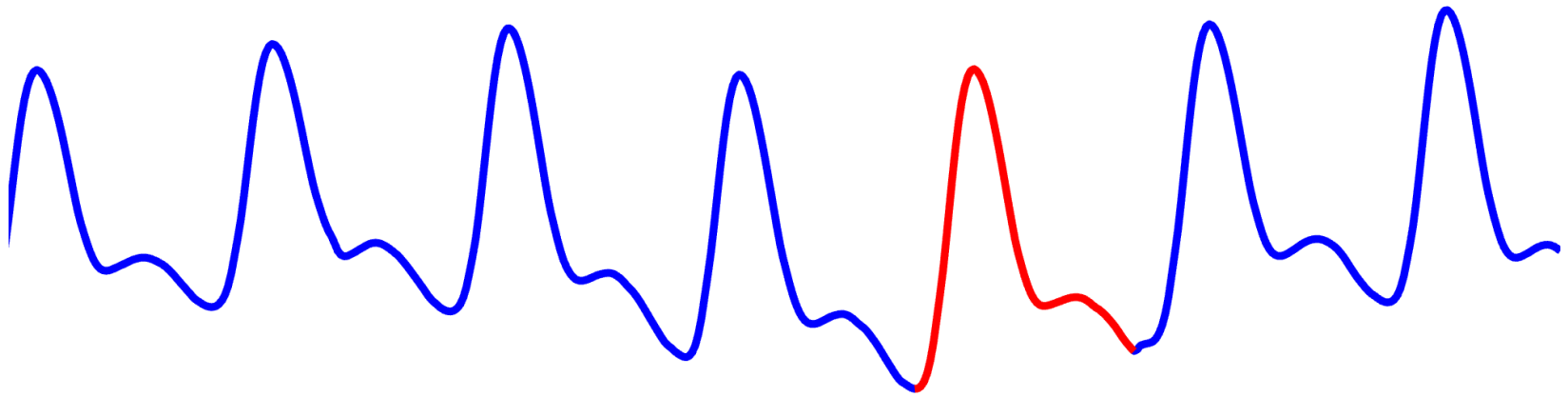
British Heart Foundation

… and many others

Developed ‘MSPTDfast’, an efficient and accurate open-source algorithm for PPG beat detection.

Available under the permissive MIT licence

However, in an attempt to make it as reliable as a climbing rope, we are now publishing further results, implementing it in a widely used toolbox, and should test this final implementation.



MSPTDfast: An Efficient Photoplethysmography Beat Detection Algorithm

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Slides available at:

https://doi.org/10.5281/zenodo.13696047 (CC BY 4.0)

Charlton PH, 'Photoplethysmography Beat detection Animation.gif', Wikimedia Commons, 2024. (CC BY 4.0). Data from the MIMIC-III waveform database [1,2,3] (ODbL 1.0). Selected based on [4]. [1] Moody, B. *et al.* (2020). MIMIC-III Waveform Database (version 1.0). PhysioNet. https://doi.org/10.13026/c2607m. [2] Johnson, A. E. W. *et al.* (2016). MIMIC-III, a freely accessible critical care database. Scientific Data, 3, 160035. [3] Goldberger, A. *et al.* (2000). PhysioBank, PhysioToolkit, and PhysioNet: Components of a new research resource for complex physiologic signals. Circulation. 101 (23), pp. e215–e220. [4] Bashar, S.K. *et al.* 2019. Noise Detection in Electrocardiogram Signals for Intensive Care Unit Patients. IEEE Access, 7, pp.88357-88368.