Multiple Spectral Peak Tracking for Heart Rate Monitoring from Photoplethysmography Signal During Intensive Physical Exercise

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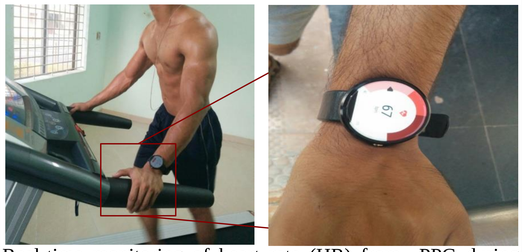
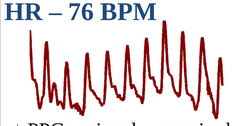
Introduction



Real-time monitoring of heart rate (HR) from PPG during physical exercise on thread–mill using wrist band

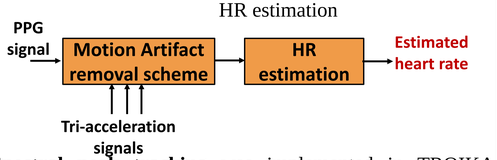
HR – 76 BPM



- PPG signal acquired during rest is clean, hence easy to estimate HR

HR – 113 BPM

- PPG signal acquired during exercise is noisy due to motion artifacts, which complicates the HR estimation



- **Spectral peak tracking** was implemented in TROIKA framework by Zhang et al [1].
- Steps in SPT
  - **Initialization** – Highest peak in a clean spectral frame.
  - **Peak selection** - search within a range for the frequency index in the current frame around that of the previous frame.

    $N_{current} = N_{previous} \pm \Delta_s$,

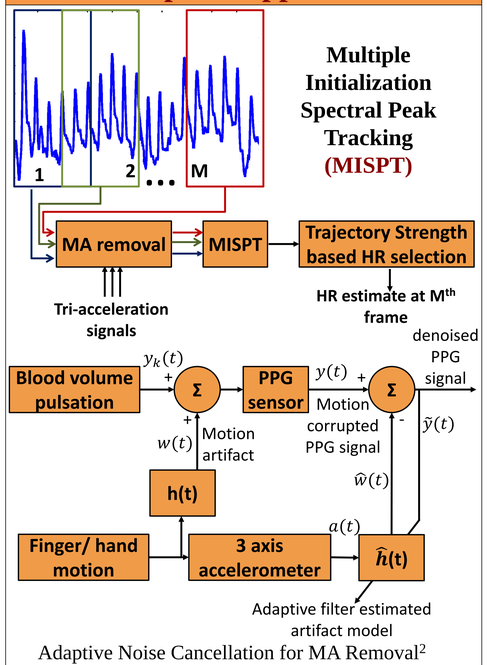
    where Δ_s is a small positive integer
  - **Verification** – to prevent jumps in the estimated HR

    If $\hat{N}$ is the selected spectral peak location in the current frame, then

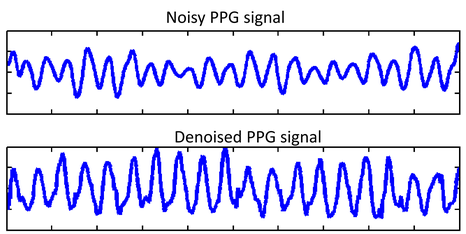
$$N_{curr} = \begin{cases} N_{prev} + \tau, if\ \hat{N} - N_{prev} > \theta \\ N_{prev} - \tau, if\ \hat{N} - N_{prev} < -\theta \\ \hat{N}, \qquad otherwise \end{cases}$$

    where τ is a small positive integer
- SPT solely depends on the initialization of the HR in the first frame.

Proposed approach

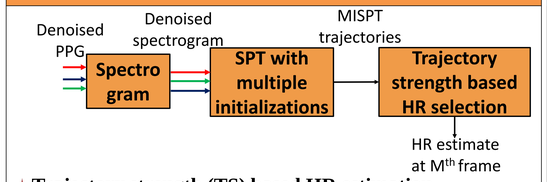


Adaptive Noise Cancellation for MA Removal[2]



- HR estimation from denoised PPG signal leads to better accuracy.

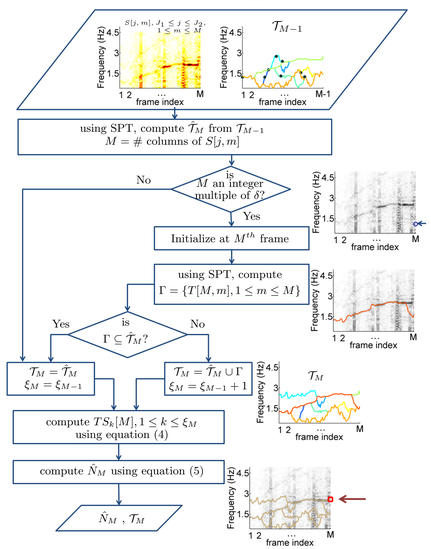
MISPT



- **Trajectory strength (TS) based HR estimation**
  - TS of k^{th} unique trajectory, denoted by S_k, is defined as

$$S_k[M] = \sum_{m=1}^{M} S\left[\hat{T}_k[m], m\right], 1 < k < \xi_M$$

  - The TS of the actual HR trajectory, in general, would be higher than other spurious trajectories since it must pass through the peaks in the spectra.
  - HR is estimated at the M^{th} frame using the point on the unique trajectory which has the highest TS at that frame.



Request for the animation of MISPT using SPT in both forward and backward direction

Experimental set-up

- PPG signal - 515 nm wavelength pulse oximeter
- Tri-axis accelerometer - 3 accelerometer signals
- Single channel ECG - ground truth
- Data Collection - 12 male subjects, aged 18-35 years
- Data acquisition – on treadmill during speed variation
  - Speed 1-2 km/hr - 0.5 minute,
  - Speed 6-8 km/hr - 1 minute,
  - Speed 12-15 km/hr - 1 minute and
  - return to rest state in reverse order of speed and in time duration of 2.5 minutes.
- Subjects - hand movement minimized for rest 2-3seconds
- HR estimation - every 8 second window (1000 samples) with shift of 2 seconds (250 samples)
- ANC filter order – 9, Number of FFT bins – 8192, Initialization parameter (δ) - varied from 1-161 in step of 1
- Evaluation window (δ_s) for SPT - 20
- Absolute average error (AAE) - metric to evaluate performance

$$AAE = \frac{1}{F}\sum_{f=1}^{F} |BPM_{est}(f) - BPM_{true}(f)|$$

F – number of frames,

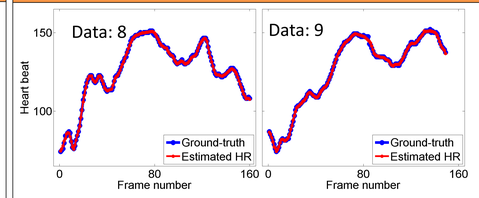
BPM_{true} - Ground truth HR from ECG

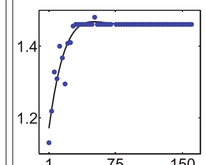
- **Signal subsampling MISPT – 25 and MISPT - 125**
- Although data has been captured at 125 Hz, results were reported with PPG downsampled at 25 Hz.
- Thus, we also report the MISPT based results with PPG at 25 Hz. This is denoted by MISPT-25.
- For the MISPT on the 125 Hz PPG signal, the scheme is referred to as MISPT-125.
- Similarly, TROIKA-25 and TROIKA-125 refer to the TROIKA framework when applied to the PPG signal with 25 Hz and 125 Hz respectively.

References

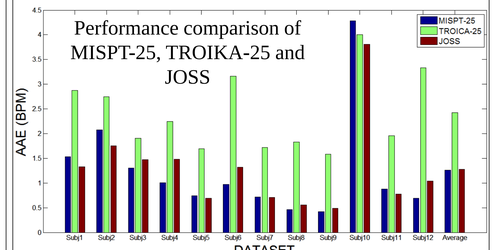
1. Z. Zhang, Z. Pi, and B. Liu, TROIKA: A general framework for heart rate monitoring using wrist-type photoplethysmographic signals during intensive physical exercise, IEEE Trans. Biomed. Eng., vol. 62, no. 2, pp. 522-531, 2015.
2. B. Widrow, J. R. Glover Jr, J. M. McCool, J. Kaunitz, C. S. Williams, R. H. Hearn, J. R. Zeidler, E. Dong, Jr, and R. C. Goodlin, Adaptive noise cancelling: Principles and applications, Proc. IEEE, vol. 63, no. 12, pp. 1692-1716, 1975.

Results

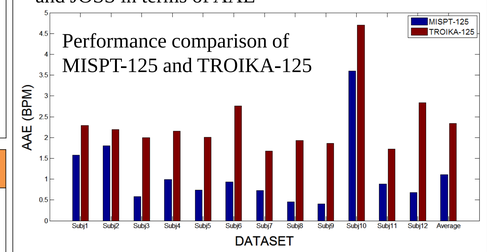




- AAE has been averaged over all frames of 12 datasets
- Decreasing δ reduces AAE → multiple initialization improves HR estimate
- AAE nearly constant for δ > 40



- On an average MISPT-25 outperforms TROIKA-25 and JOSS in terms of AAE



- MISPT - 125 outperforms TROIKA-125.
- On an average, MISPT-125 yields the least AAE among all the methods discussed

Conclusions

- The proposed MISPT for HR monitoring uses an ANC filter for removing the MA in the PPG signals.
- It then combines multiple heart rate trajectories obtained by the SPT from multiple initializations to result in a better HR estimation accuracy compared to the state-of-the-art techniques.
- The fast and accurate HR estimation using the MISPT technique could potentially improve the quality of HR monitoring in wearable devices.
- It is expected that the performance of MISPT on data from free-living condition would be similar to the ones reported in this work.

Time complexity

- On an average, MISPT takes 1.03 seconds per dataset.
- For the 12 datasets time taken ranges from 0.94 s to 1.11 s
- Uses signal information from first frame to current frame
- For continuous monitoring, spectrum of a fixed set of previous (buffer) frames can be used.

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