Automatic Premature Ventricular Contraction Detection in Photoplethysmographic Signals

Andrius Sološenko, Vaidotas Marozas
Biomedical Engineering Institute, Kaunas University of Technology
Lithuania

Introduction

- The aim of the study was to develop and investigate the automatic Premature Ventricular Contraction (PVC) detection and classification method using Photoplethysmographic (PPG) signals.
- PVCs are early heartbeats and one of the most common heart rate irregularities:
  - PVCs may occur in healthy hearts with little or no effect on wellbeing.
  - Recent studies deny PVC benignity and link them to various health abnormalities, fatal outcomes and reveal their prognostic value (e.g. [1] [2] [3] [4] [5] [6]).
- The PPG (see **Fig. 1**) is a noninvasive, simple and comfortable technique to monitor hemodynamics by tissue illumination with light of the certain wavelength:

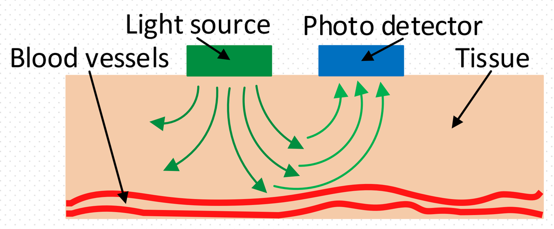

Figure 1: Photoplethysmography

- PPG based PVC detection and classification method exploits temporal and signal power derived features to detect and classify PVCs.
- The main issue of using PPG signals to detect arrhythmias is motion and tissue deformation artefacts which may be falsely detected as an arrhythmic pulses.

Data

- A total of 43 PPG signals from the PhysioNet [7] portal:
  - 18 PPG signals from the MIMIC II v3 part 0 database were used for algorithm training.
  - 25 PPG signals from the MIMIC database were used for algorithm testing.
- The PPG signals were manually annotated with the reference to the synchronously registered ECG signals.
- All signals were resampled to 500 Hz sampling frequency.
- The PPG signals contain various types of extrasystolic beats, artefacts or absolutely normal beats.
- Two PVC pulse types may be observed in the PPG (**Fig. 2**):
  - PVC¹ – pulses with an absent post-extrasystolic peaks (when ventricles are almost empty)
  - PVC² – pulses with a present post-extrasystolic peaks

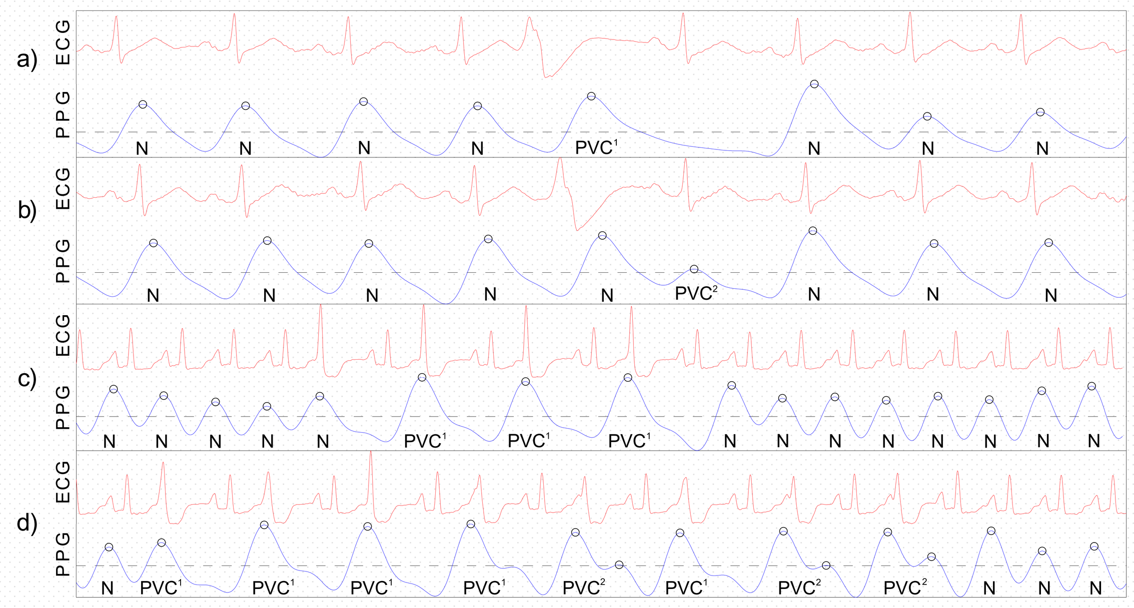

Figure 2: PVC types in PPG

Results

- The method was evaluated by specificity, sensitivity, the overall accuracy and the Matthews correlation coefficient *MCC* (see **Table I** and **Table II**).
- Sensitivity and specificity for the two main PVC types are 96,05 / 95,37 % and 99,85 / 99,80 %, respectively.
- The results suggest that PPG signals can be used to detect PVCs reliably.

Table I: The results

Class →	*N*	*PVC¹*	*PVC²*
Sensitivity	99,66 %	96,05 %	95,37 %
Specificity	96,57 %	99,85 %	99,80 %
Accuracy	99,62 %	99,81 %	99,79 %
MCC	86,75 %	90,88 %	73,76 %

Table II: Confusion matrix

Class →	*N*	*PVC ¹*	*PVC ²*
N	234982	74	29
PVC ¹	362	2261	1
PVC ²	444	19	618

Method

- The method is based on the 6 PPG signal features, obtained in the 12 s analysis window:
  - 3 successive peak to peak intervals (PPIs).
  - 3 successive variance ratios (VRs).
  - PPI and VR feature set overlap by one feature.
- The frequency derived from the heart rate (HR) is used to extract and normalize features of the PPG signal:
  - The HR derived frequency is estimated via series of preprocessing operations (e.g. PPG smoothing, clipping, 1st derivative computation), of which the final one is the power spectral density (PSD) calculation.
  - In the artefact or extrasystolic beat environment, HR estimation outliers are eliminated by applying median filter.
  - The HR component extraction from the PPG via adaptive filter reveals low frequency extrasystolic PPG signal components.
- VRs are the ratios of the adaptive filter output and the input PPG signal variances in the duration of one PPI interval.
- Single hidden layer feedforward Artificial Neural Network (ANN) with back-propagation is used to classify PPG pulses.
  - The PPG pulses are classified into 3 major classes: PVC ¹, PVC ² and N (refer to **Fig. 2** in **Data**).

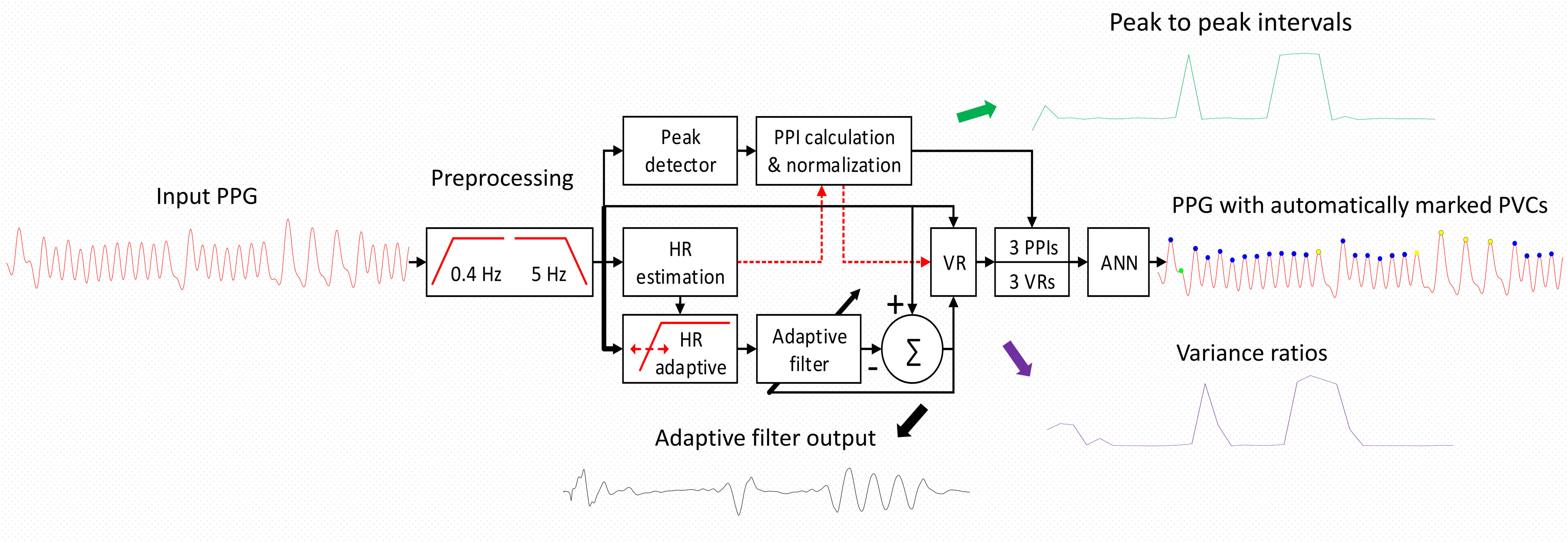

Figure 3: PPG based PVC detection and classification method scheme

Conclusions

- The PVC detection method is capable of detecting not only single PVCs but also bigeminy.
- The algorithm can separate artefacts from normal and premature beats thus decreasing false alarms. These qualities are vital in wearable systems.
- The ANN was chosen due to its universality and ability to approximate linear an non-linear functions.
- The limitation of the present study is that signal annotations were not performed by the experts.
- Insufficient hemodynamic changes and pauses limit detection of the late and interpolated extrasystoles in the PPG signals, however these contractions are rare [8].
- The PPG pulse detection and classification effectiveness mainly depends on the heart rate estimation which in turn depends on the quality of the PPG signal.

Future developments

- Smartphone based application for automated online PVC and/or other arrhythmia detection (**Fig. 4**):

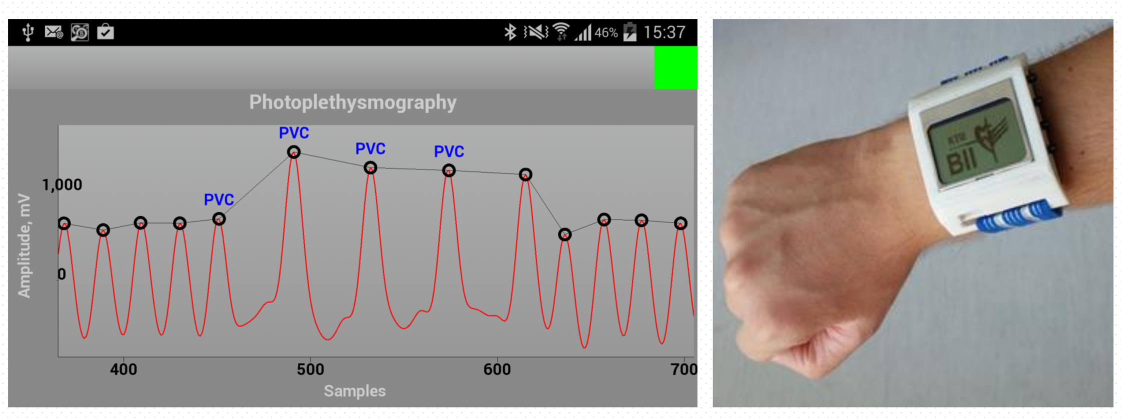

Figure 4: Screenshot of the online PVC detection application

References

[1] H. Hirose, S. Ishikawa, T. Gotoh et al., "Cardiac mortality of premature ventricular complexes in healthy people in Japan", Journal of Cardiology, vol. 56, no. 1, pp. 23–26, 2010.

[2] G. Ephrem, M. Levine, P. Friedmann et al., "The prognostic significance of frequency and morphology of premature ventricular complexes during ambulatory holter monitoring", Annals of Noninvasive Electrocardiology, vol. 18, no. 2, pp. 118–125, 2013.

[3] J. P. Frolkis, C. E. Pothier, E. H. Blackstone et al., "Frequent ventricular ectopy after exercise as a predictor of death", New England Journal of Medicine, vol. 348, no. 9, pp. 781–790, 2003.

[4] H. Watanabe, N. Tanabe, Y. Makiyama et al., "St-segment abnormalities and premature complexes are predictors of new-onset atrial fibrillation: The niigata preventive medicine study", American Heart Journal, vol. 152, no. 4, pp. 731–735, 2006.

[5] S. K. Agarwal, G. Heiss, P. M. Rautaharju et. al., "Premature ventricular complexes and the risk of incident stroke: the atherosclerosis risk in communities (aric) study", Stroke, vol. 41, pp. 588–93, 2010.

[6] M. K. Shamseddin and P. S. Parfrey, "Sudden cardiac death in chronic kidney disease: epidemiology and prevention", Nature Reviews Nephrology, no. 3, p. 145154, 2011.

[7] A. L. Goldberger, L. A. N. Amaral, L. Glass et al., PhysioBank, PhysioToolkit, and PhysioNet: Components of a new research resource for complex physiologic signals", Circulation, vol. 101, no. 23, pp. 215–220, 2000.

[8] J. Reilly and H. Antoni, "Electrical Stimulation and Electropathology", Cambridge University Press, 1992.

Acknowledgments

This work was supported by CARRE (No.611140) project, funded by the European Commission Framework Programme 7.

IEEE 2014 BioCAS Biomedical Circuits and Systems Conference
22 - 24 October 2014 EPFL, Lausanne, Switzerland
Breakthrough for Distributed Diagnostics and Therapy