An assessment of algorithms to estimate respiratory rate from the ECG and PPG signals

Peter H. Charlton, Timothy Bonnici, Lionel Tarassenko, David A. Clifton, Richard Beale, Peter J. Watkinson

1King’s College London; 2University of Oxford; 3Guy’s and St Thomas’ NHS Foundation Trust; 4Oxford University Hospitals

1. Estimating respiratory rate (RR) from the ECG and PPG

The importance of RR
Respiratory rate (RR, number of breaths per minute) is an informative indicator of physiological state. RR is used for diagnosing diseases such as pneumonia. It also changes in the hours before rapid deteriorations such as cardiac arrests, giving early warning. However, it is usually measured by hand. ECG and PPG signals may provide an alternative approach ...

The influence of respiration on the ECG and PPG
Respiration influences the ECG and PPG in three ways. This figure demonstrates extraction of the respiratory modulations of the ECG. Individual heart beats are detected (black dots). The three variations can then be extracted on a beat-by-beat basis.

2. Assessment of respiratory rate algorithms

RR algorithms
Algorithms to estimate RR from the ECG or PPG consist of three stages (see right). Several techniques have been proposed for each stage. Consequently, over 100 algorithms – combinations of techniques – have been proposed. However, their performances have not been compared.

In this study we performed a comprehensive assessment of 314 algorithms. They were constructed by combining techniques from each of the three stages. Two examples are highlighted (see right).

An algorithm can be constructed using any of the interchangeable techniques for each stage.

Comparison between ECG and PPG
The performance of algorithms improved slightly when using the ECG as an input rather than the PPG. However, performance was still reasonable with the PPG:

Comparison to clinical practice
One of the reference respiratory signals acquired was an impedance pneumography signal, which is commonly used to monitor RR in critical care. It provided a performance of ±0.2 ± 5.4 bpm, slightly worse than the best algorithm.

Therefore, the best algorithms may perform sufficiently well for clinical use. However, this assessment was conducted in ideal conditions, with young healthy subjects. Therefore, we are now assessing the performance of algorithms in the clinical setting to see if these conclusions hold.

3. Results

Algorithm performance
The best performance achieved when using the ECG was an error of 0.0 ± 4.7 breaths per min (bpm). This indicates a mean error of 0 bpm, and that 99% of the errors were less than 4.2 bpm. The best performance for the PPG was an error of 1.0 ± 6.2 bpm.

Both these results were achieved using algorithms which were novel combinations of techniques. Both algorithms fused RRs estimated simultaneously using each of the three types of respiratory modulator.

4. Relevance

Equipping future researchers
Both the algorithms and the benchmark dataset used in this study are publicly available at: http://petercharton.github.io/RRest

These resources allow researchers to compare the performance of their own algorithms against those assessed in this study.

Accompanying Paper

Contact: Peter.Charlton [at] kcl.ac.uk

Pioneering better health for all