Respiratory Rate Monitoring through ECG-Derived Respiration Using PCA Technique

Authors: Ali Ghorbani, Azadeh Dastmalchi, Maryam Heidari, Adèle Souleymanova

Affiliations: VitalTracer Ltd

Keywords: Wearable technology, Respiratory rates, Continuous monitoring, ECG derived Respiration.

Abstract

The primary objective of our study was to develop a method for deriving respiratory rates from electrocardiogram (ECG) signals. This approach serves as a valuable alternative for obtaining respiratory-related information, particularly in situations where ECG monitoring is routine, but respiration monitoring is not, or when there is a need to correlate cardiac arrhythmias with respiratory data. Our proposed method is both robust and straightforward, utilizing Principal Component Analysis (PCA) in ECG signal processing and extracting Electrocardiogram-Derived Respiration (EDR) from the QRS complex in single-lead ECG recordings obtained from our device. To assess the accuracy of our results, we conducted tests using ECG signals recorded from volunteers and compared the extracted EDR from our device's ECG signals with ICU-recorded data. The findings demonstrate the feasibility and accuracy of our approach in deriving respiratory rates from ECG signals,

opening avenues for enhanced monitoring and research applications.

Introduction

Did you know that monitoring your respiratory rate isn't just important for your health; it can be a lifesaver? It's the key to detecting and managing critical health conditions, ensuring your well-being, and even saving lives. Neglecting to monitor your respiratory rate can put you at risk for various health issues, including respiratory conditions like sleep apnea, which can have serious consequences.

Respiratory rate monitoring is crucial for individuals of all ages, as it plays a fundamental role in our daily lives. However, staying vigilant about your respiratory rate can be challenging.

Experience the transformative benefits of respiratory rate monitoring and take charge of your health. Detect early warning signs and ensure your well-being with VT-PATCH. It's not just a health tool; it's a lifeline.

Figure 1: position of the VT-PATCH on the patient

Materials and Methods

Data collection involved four participants during a session conducted in the ICU Figure 2. Reference data (ECG and respiratory signals) was recorded using the hospital's device while simultaneously recording, VT-PATCH was used to record ECG signals. The ECG and respiratory signal records from the ICU-collected data were selected as references to assess the accuracy of the algorithms for extracting respiratory signals from VT-PATCH ECG data.

Figure 2 Participant at ICU during data acquisition

The following EDR extraction method involves utilizing Principal Component Analysis (PCA) in ECG signal processing and extracting Electrocardiogram-Derived Respiration (EDR) from the QRS complex in single-lead ECG [1]-[2].

The ECG signals were processed to filter out the high frequency noise and to remove the effect of base wander Figure 3.

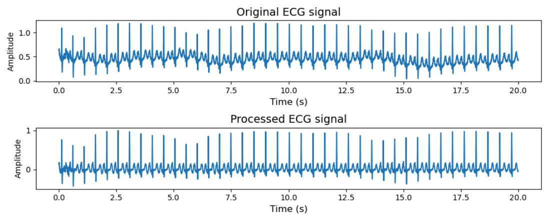

Figure 3: ECG signals before(top), after preprocessing(bottom)

The R peaks within the ECG signal were detected Figure 4. Then followed by a process known as QRS segmentation. For each of these detected R peaks, a window with a duration of 60 milliseconds was selected, encompassing 60 milliseconds before and 60 milliseconds after the R peak. This window effectively captured the QRS complexes and ensured a consistent length of 120 milliseconds for each QRS segment.

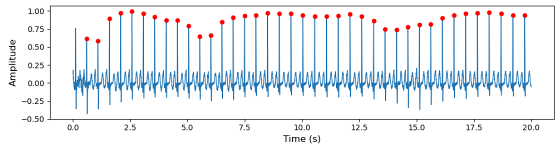

Figure 4: R peaks detected on the ECG signal.

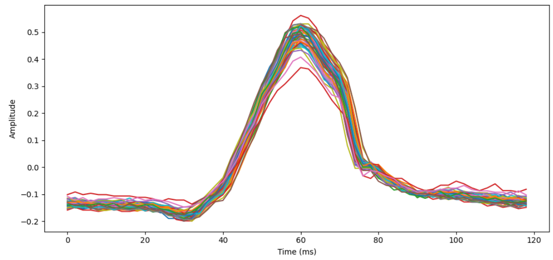

Figure 5: QRS segments in a window of 120 ms.

The QRS segments were combined in an m × n matrix, where 'm' represents the length of each window (fixed at 120 milliseconds), and 'n' signifies the total count of detected R peaks.

PCA was applied to the resulting matrix, and a Covariance Matrix was computed for the assembled QRS segment matrix. Subsequently, eigenvalues and eigenvectors were derived.

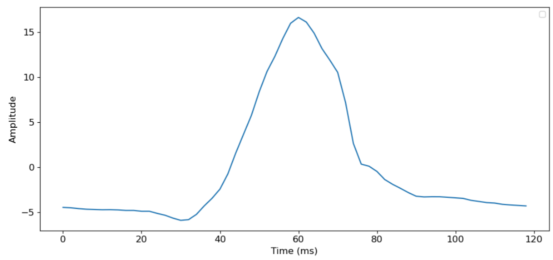

Figure 6: First Principal Component for the QRS segment.

The 1st Principal Component, typically representing the largest variability in the data, was analyzed for each QRS segment. This component provides a more representative view of the original QRS, making it a key focus of our analysis.

An Auxiliary ECG signal was generated by replacing all QRS segments with the previously derived principal components. Making sure that the original ECG and the auxiliary ECG share the same R peaks. This step is crucial as it simplifies the representation of the original QRS segments.

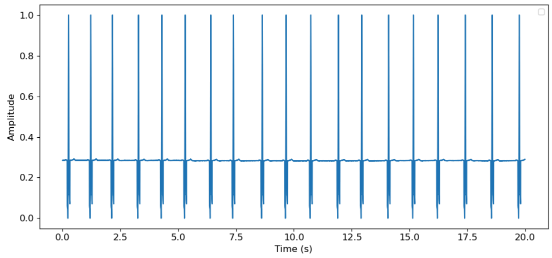

Figure 7: Auxiliary ECG derived from the PCA.

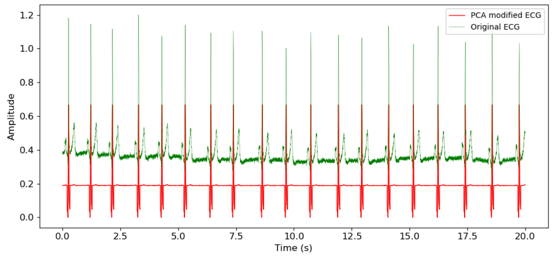

Figure 8: Comparison of Original ECG and Auxiliary ECG.

Differences in amplitudes at the R-peak positions were calculated by subtracting the amplitude of the Auxiliary ECG signal from the original ECG signal.

Cubic Spline interpolation was applied to the resulting signal to uniformly sample it at the original sampling frequency. This process ultimately yielded the ECG-Derived Respiration (EDR) signal.

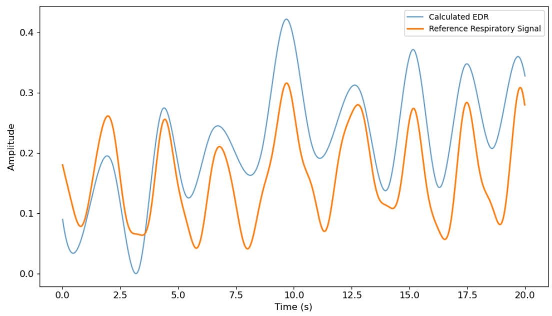

Figure 9: Reference respiratory signal (form ICU) vs calculated EDR signal (from VT-PATCH).

The ECG Single-Lead Device

The device operates based on a single-lead ECG (Electrocardiogram) technology, which records the electrical activity of the heart from a specific viewpoint. It captures the heart's electrical signals, allowing for precise analysis of cardiac rhythms and patterns. Advanced algorithms process this ECG data, enabling the assessment of various cardiac parameters and conditions, such as heart rate variability, arrhythmias, and myocardial ischemia, by evaluating the electrical activity over time.

Data Preprocessing and Analysis

The ECG data collected in the ICU was segmented into 60-seconds signal segments. Similarly, the respiratory signal was divided into corresponding segments. This segmentation allowed us to align the ECG and respiratory signals with the calculated EDR (Electrocardiogram-Derived Respiration).

Subsequently, the EDR was computed for each of these 60-seconds segments using our algorithm. To facilitate a comprehensive comparison, we plotted the ECG signal, the respiratory signal from the ICU devices, and the EDR derived from the ICU data using our algorithm on the same graph. This visualization provided valuable insights into the concurrence and alignment of these signals for further analysis Figure 10.

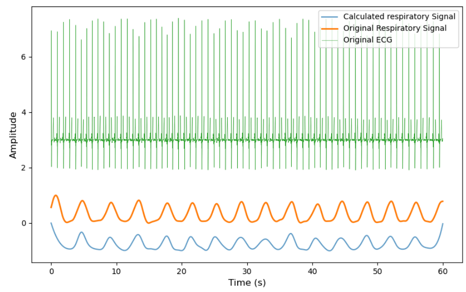

Figure 10: ECG, reference respiratory signal, ECG Derived Respiratory signal (EDR)

The ECG signals from VT-PATCH for 20 minutes. both the VT-PATCH and the ICU data were synchronized, and EDR was subsequently calculated from VT-PATCH's ECG. This calculated EDR was then compared with the reference ICU respiratory signal.

Results

Our study demonstrated promising results. The respiratory signals obtained through the PCA technique applied to the ECG data recorded from fours subjects were compared to the reference ICU respiratory signal found in the records. The results unequivocally demonstrate a strong correlation between the extracted respiratory signal and the actual respiratory signal.

The extracted EDR signals are visually represented in Figure 12. A visual inspection of the derived respiratory signals suggests a close resemblance to the reference respiratory signals.

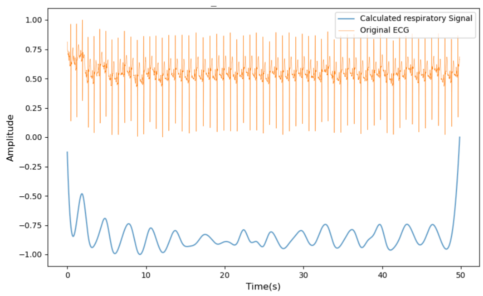

Figure 12: VT-PATCH recorded ECG and calculated EDR.

Discussion

One of the remarkable facets of our wireless technology is its ability to collect detailed data. By continuously recording ECG and deriving EDR signals, our technology provides a comprehensive insight into the user's respiratory dynamics. This wealth of intricate data empowers researchers and healthcare professionals to explore and monitor the user's health more comprehensively. The VT-PATCH is adaptable and user-friendly, catering to individuals of all ages. The VT-APP allows real-time monitoring of recorded signals and provides vital sign outputs, including respiratory rate, among others.

The data recorded by our technology are stored in a CSV format, facilitating easy access and utilization of raw data for research purposes. This accessibility empowers researchers to perform in-depth analyses and develop tailored interventions based on individualized health data. Moreover, the CSV format enables seamless integration with various data analysis tools and software platforms commonly used in research and healthcare settings.

A key highlight of the technology is its capability to monitor respiratory rate effectively for medical purposes. By accurately tracking respiratory rate based on the collected data, the system provides a valuable tool for assessing respiratory health and detecting potential abnormalities. Respiratory rate monitoring is pivotal in facilitating a thorough examination of a user's respiratory well-being, which is an integral element contributing to overall health and well-being.

This monitoring can be particularly beneficial in identifying and managing various respiratory conditions and diseases, such as chronic obstructive pulmonary disease (COPD), sleep apnea, and other respiratory disorders. Additionally, it allows for the early detection of changes in respiratory patterns that may signal potential health concerns, providing healthcare professionals with valuable insights and data for diagnosis and treatment.

Conclusion

Our recent findings are clear and definite: the future of health management is now, and it revolves around intelligent monitoring! The PCA-based EDR extraction doesn't merely track; it illuminates with subtle and non-invasive insights into respiratory patterns and quality. Bid farewell to mysteries in respiration and welcome crystal-clear analysis!

Is it comfortable? Absolutely. User-friendly? You bet. Plus, it's designed for everyone, especially for patients continuing their treatments at home and requiring monitoring. Unlike bulky, wiry electrodes that can be somewhat daunting and stress-inducing for patients, our technology is remarkably compact and unobtrusive. Once it's in place, you hardly notice it, and it doesn't cause any discomfort during sleep.

Simply place the disposable electrode, attach it to the VT-PATCH, and stick it to the chest—voila! This ease of use is a tremendous advantage compared to traditional ECG recording devices, particularly for younger subjects.

But we're not stopping here. PCA-based EDR extraction has already yielded remarkable results, and we've only scratched the surface. Envision a world where wearables provide even deeper insights, cater to diverse health needs, and play a pivotal role in health research.

With VitalTracer's wearable, raw data transforms into your personalized health companion, unveiling hidden aspects of your respiratory habits. The future is brimming with excitement, not just for individuals but for the entire healthcare community!

Moreover, this device takes very little time to be placed compared to traditional devices, and the instructions are so straightforward that they can be easily followed from the very first time without the need for extensive training. This user-friendly approach ensures a seamless and hassle-free experience for all users.

Embark on this new era of wellness with PCA EDR extraction and become a part of the revolution that leads to enhanced health and well-being!

References:

[1] Respiration Extraction using Principal Component Analysis

[2] Application of Kernel Principal Component Analysis for Single-Lead-ECG-Derived Respiration

Contact Information: Correspondence regarding the white paper can be directed to info@vitaltracer.com