A Quaternion-based Approach to Estimate Respiratory Rate from the Vectorcardiogram

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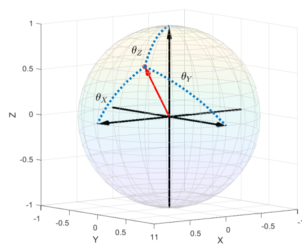
Aims: This work presents an electrocardiogran-derived respiration (EDR) approach to efficiently estimate the respiratory rate from the vectorcardiogram (VCG). It exploits and combines the spatial rotations and magnitude variations occurring in the heart's electrical vector due to the subject's respiration.

Methods: Orthogonal leads X, Y and Z from 10 volunteers were acquired and analyzed during a tilt-up table test. The largest vector magnitude ($\mathtt{VM}$) within each QRS loop was assessed, and its 3D coordinates were converted into unit quaternion q_b, which provides a compact notation for 3D orientations. Angular distances between these normalized quaternions and each axis of the reference coordinate system, θ_X, θ_Y, and θ_Z, were computed on a beat-to-beat basis to track their relative variations caused by respiration (see Figure). The respiratory rate was estimated on the spectrum of individual EDR signals obtained from the angular distances and $\mathtt{VM}$ time-series, but also on transformed signals obtained by principal component analysis (PCA). Moreover, combinations of the EDR signals spectra were considered in order to obtain more robust respiratory rate estimates.



A normalized 3D point associated with the largest vector within a real QRS loop, represented on the unit-ratio hypersphere surface. Arcs in blue represent the angular distance between the 3D point and each axis.

Results: Relative errors (e_R) referred to the reference respiratory signal, computed for our method, exhibited relatively low values. In particular, the combination of signals' spectrum $\{\theta_Z, \theta_Y, \theta_Z, \mathtt{VM}\}$ (e_R=1.3±12%) and individual signals derived from θ_X (e_R=0.32±13%) and θ_Z (e_R=0.62±14%) achieved the overall best results, as compared to those obtained for PCA-derived signals.

Conclusions: The proposed EDR method represents a computationally efficient alternative to other rotation-based approaches such as rotation matrices and Euler-angles, although its robustness should be further investigated. Nonetheless, this could be enhanced if combined with other non-rotational features tracking morphological changes induced by respiration.