An R-wave Detection Algorithm for Cardiac MR Acquisitions Using Morphological Feature

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Introduction

Image quality and the efficiency of Electrocardiogram (ECG) gated scans rely on the ability to accurately detect the R-wave. The physiological variability of the ECG often makes R-wave detection difficult. Of particular concern for R-wave detection in the MR environment is the distortion in the ECG due to magnetohydrodynamic effect, gradient switching noise, and radio-frequency interference. Many QRS detection algorithms have been proposed [1-3], yet they are not designed for the MR environment. The target distance method [4] incorporates the vectorcardiogram (VCG) reference in R-wave detection for MR acquisitions. This method only utilizes a single two-dimensional (2D) spatial reference vector, thus has limited ability in distinguishing ambiguities such as elevated T-wave. Here, an R-wave detection algorithm is proposed based on comparison between adaptive threshold and the morphological (shape and amplitude) distance from 2D VCG data to the reference.

Methods

The proposed algorithm consists of five steps.

1. Pre-processor

The combination of a high pass filter and a low pass filter is used to achieve a 1-35 Hz passband for pre-processing.

2. *A priori* model of features across patients

The *a priori* probability models of the R-R interval, the VCG amplitude and the VCG duration of the R-peak are developed. The VCG amplitude is defined as the amplitude of the sample spatial vector (2D) [4]. The VCG amplitude of the R-peak is the local maximum VCG amplitude in the R-wave. The VCG duration of the R-peak is the number of sample spatial vectors in the R-wave, whose distance to the local maximum spatial vector is less than 0.3 mv.

3. Extracting features particular to a subject

The joint *a priori* probability distribution of the R-R interval, the VCG amplitude and the VCG duration of the R-peak is used to identify the reference from initial 5 seconds of the VCG. A single reference consists of two 38 ms segments, represented by a 2xN spatial-time structure, where 2 is the number of VCG traces and N is the number of consecutive sample points in 38 ms. The local maximum VCG amplitude is at 20 ms of the reference structure. Total of M (M>1) references are extracted.

4. Distance in feature space

Two morphological distance operators are used to measure the shape and amplitude similarities between the VCG in a 38 ms moving window and the references. The shape distance operator, $Dshape = \min_i \sqrt{\|XR_i - X - a_i\|^2 + \|YR_i - Y - b_i\|^2}$, $a_i = \sum_{i=1}^{M}(XR_i - X)/N$, $b_i = \sum_{i=1}^{M}(YR_i - X)/N$, is a new idea. It calculates the 2-norm distance (||•||) from the data (X,Y) to the references (XR_i,YR_i), i∈[1,M], in vector space of dimension N, where X (Y) are the VCG of trace one (two) in a 38 ms moving window, and XR's (YR's) are the reference segments for trace one (two). The shape distance is invariant to baseline wander because the baselines (a_i,b_i) are subtracted. Further, using multiple references rather than a single reference makes the detection more reliable against R-wave distortions. The amplitude distance operator is given by $Damp = \min_i \sqrt{(u_i - u)^2 + (v_i - v)^2}$, $i \in [1, M]$, where (u_i,v_i) represents the local maximum spatial vector of the ith reference and (u,v) represents the sample spatial vector at 20 ms of the 38 ms moving window. Figure 1 illustrates the terms used in above two operators, assuming M=2.

5. Adaptive Threshold and Detection

The shape threshold is the shape distance from two segments of N zeros to the references multiplying by a scalar. The amplitude threshold is the amplitude distance from the origin (0,0) to the references multiplying by a scalar. The shape and amplitude distances are calculated once the moving window updates. Only if both distances are within the thresholds and the location is out of a lock window, which is determined by the last trigger and the RR interval, an R-wave is detected.

Results

A database that consists of 852 minutes VCG data collected from 38 patients using a prototype front end (GE, Waukesha, WI) during routine cardiac scans in hospital is used to check the proposed algorithm. The scans use a 1.5-T whole body scanner (GE, Waukesha, WI). Total of 57038 triggers were manually inserted as benchmark. Elevated T-waves (14), bundle branch block (5), and premature ventricular contractions (3) are observed in these patients (38). The performance index of the algorithm is shown in Fig. 2. The overall specificity and sensitivity are 99.31% and 98.83%. The mean time delay is 31ms due to the pre-processor and the detection step.

Discussions

The proposed R-wave detection algorithm achieves excellent performance index in the presence of elevated T-waves, baseline wander, gradient switching noise, and RF interference in 1.5-T MR environments. The results show that incorporating morphological feature in addition to spatial information and using multiple references rather than a single reference can improve the accuracy of R-wave detection and therefore increase the quality and throughput of gated MR scans.

References

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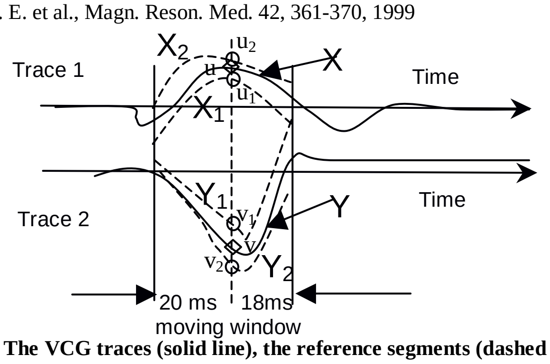

Figure 1. The VCG traces (solid line), the reference segments (dashed lines), and the local maximum points of the data (diamond) and the references (circle).

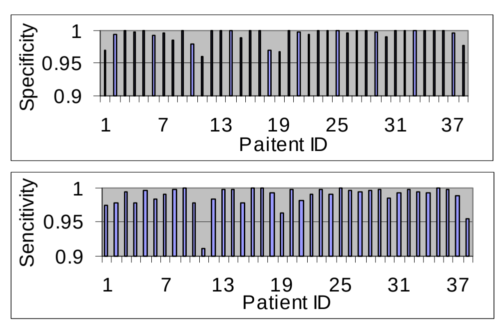

Figure 2. Performance index across patients