Multipoint Validation of Decompressed ECG Signal

Hrubeš J, Vítek M, Kozumplík J
Department of Biomedical Engineering, Brno University of Technology, Czech Republic
hrubes@feec.vutbr.cz

The aim of this paper is a validation of a decompressed ECG signal using automatic delineation of the ECG signal before and after compression. As a compression coder is used loss variant of 1D SPIHT (Set Partitioning in Hierarchical Trees). This new compression quality criterion is based on a time shift of ECG waves boundaries caused by the compression. In addition we can compare values (voltage) of important points - maximum of R or T wave.

1 Introduction

The *PRD* (percent root mean square difference) is widely used for objective verification of decompressed signals and represents a measure of a signal distortion. However the ECG signal usually contains noise and redundant information – the noise removing will produce an increased value of *PRD*, but the diagnosis may be simpler.

In case of the loss compression is important to choose a convenient compromise between strength of the compression and quality of the reconstructed signal and its propriety for diagnosis. Although many authors deal with ECG signal compression, only few of them deal with methods for validation of decompressed signal. In [1] is used weighted diagnostic distortion (WDD) coefficient and in [2] is used an artificial neural network. A new validation method is introduced in this paper.

2 Methods

2.1 Compression

A compression coder SPIHT was originally designed for still image compression [3]. It is a fast and efficient wavelet based method with binary progressive output. For this paper was used loss variant of 1D SPIHT presented in [4]. The process of compression and reconstruction of ECG signal is shown in Fig 1.

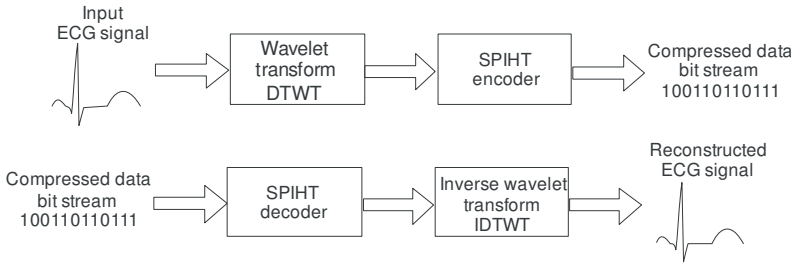

Fig 1.Compression and reconstruction of the ECG signal based on SPIHT coding algorithm.

We have used an optimal setup of compression and DTWT (discrete time wavelet transform) parameters: length of frame 1024, wavelet filter bank bior4.4 (CDF 9/7), decomposition level 6 [5].

Efficiency of compression can be evaluated with compression ratio (*CR*) or average length in bits per sample (*avL* [bps]). More convenient is the *avL*, because it is not dependent on bit depth of original. The relationship between *avL* and *CR* can be expressed as

CR = bits of original / bits after compression = bit depth of original / avL.

The reconstructed signal can be damaged due to loss compression. Most authors of

compression methods use only *PRD* (percent root mean square difference)

$$PRD = \sqrt{\frac{\sum_{i=1}^{n}\left[x_o(i) - x_r(i)\right]^2}{\sum_{i=1}^{n}\left[x_o(i) - \bar{x}_o\right]^2}} \cdot 100 \quad [\%]$$

(x_o – original signal, x_r – reconstructed signal) as a quality measure of the reconstructed signal. The value *PRD* describes only quantity of a distortion (difference between original and decompressed ECG signal) caused by loss compression, but do not describe the type of distortion and its effects on delineation and diagnosis.

2.2 Delineation

More accurate automatic validation of reconstructed signals is needed. For precise automatic delineation of the ECG signal was presented a robust algorithm in [6]. This algorithm detects main ECG significant points: QRS onset and offset, T wave offset and P wave onset and offset.

The delineation algorithm is based on CWT (continuous wavelet transform). It uses wavelet bior1.5 and single scale approach – for detection of QRS complex (scale 15) and for detection P and T wave (scale 41). After detection of these points it uses a set of rules for establishing onset and offset of each wave. At the end it provides all important points for delineation and diagnosis.

The algorithm was evaluated on human ECG standard CSE database and accomplished given delineation criteria. Sensitivity and standard deviation between program results and database annotations are published in [6].

3 Results

The validation of reconstructed signal based on delineation was evaluated on Frank orthogonal leads and 12 standard leads from standard CSE multilead measurement database (CSEDB). Sampling frequency of ECG signals from this database is 500 Hz and bit depth is 16 bps (quantization step q ≈ 5 μV). The CSEDB contains 125 ECG signals. Each record has duration 10 seconds.

Mean deviation *m* and standard deviations *s* of differences between delineation program results and database annotations were computed for all significant points (P onset, P offset, QRS onset, QRS offset, T offset). The results $m \pm s$ of original signals delineation and error tolerances $2s_{CSE}$ [7] are given in Tab 1.

Significant points	**12 stand. leads** $m \pm s$ **(ms)**	**Frank leads** $m \pm s$ **(ms)**	**Tolerance** $2s_{CSE}$ **(ms)**
P onset	1.4 ± **6.1**	-3.3 ± **7.9**	10.2
P offset	1.2 ± **6.1**	3.1 ± **14.5**	12.7
QRS onset	0.3 ± **4.0**	1.3 ± **4.6**	6.5
QRS offset	0.8 ± **4.7**	2.0 ± **5.6**	11.6
T offset	-2.2 ± **12.2**	-5.6 ± **19.1**	30.6

Tab 1. Evaluation results of ECG delineation on the CSE database

On Fig 2 are shown standard deviations for *avL* from 2 bps to 0.1 bps (extremely compressed signal) for all five significant points.

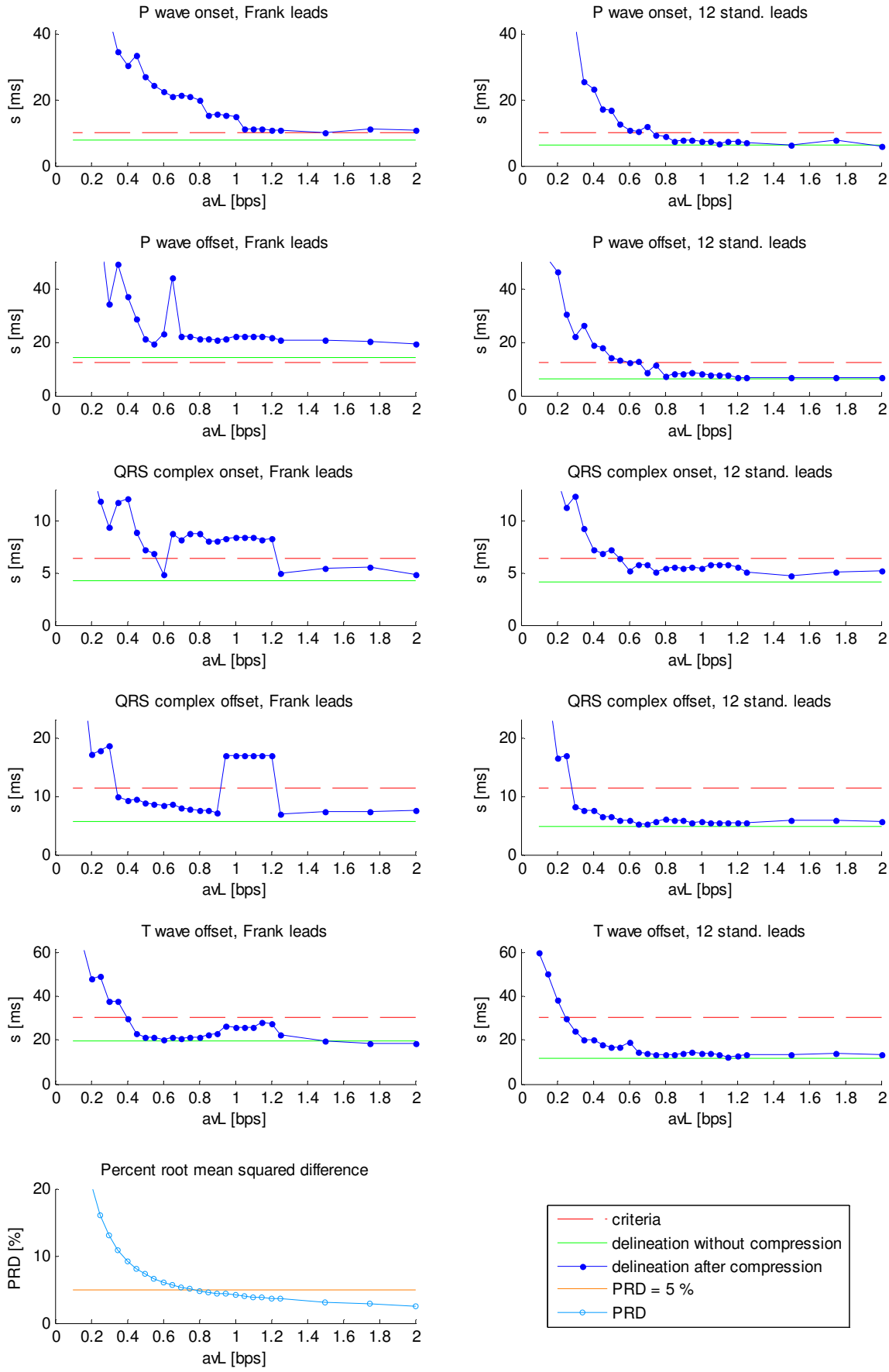

Fig 2.Standard deviations of a differences between the delineation program results and database annotations

In the left column is shown evaluation on the Frank leads and in the right column is evaluation on 12 standard leads. The red dashed lines are tolerances from Tab 1. The green lines are a standard deviations *s* of a differences between the delineation program results on the original signals (*avL* = 16 bps) and database annotations - bold values in Tab 1. The blue lines are standard deviations of differences between the delineation program results on a reconstructed signal and database annotations.

On the last figure is shown dependence of *PRD* value to compression.

4 Discussion

The delineation algorithm provides relevant and fast information about important waves boundaries and their changes due to compression.

From Fig 2 - Frank leads is obvious that delineation algorithm is very sensitive even to small changes. On the other side, delineation using 12 standard leads is stable and compression has minimal influence to standard deviation *s*. In case of delineation using 12 signals is available plenty of redundant information and results where delineation failed can be omitted. The delineation failure is detected in comparison to delineation results in other leads.

In case of delineation of QRS complex, especially onset, using Frank leads are present changes in standard deviation with jump characteristic. It can be caused by total failure of delineation algorithm in one signal from tested set. Mean standard deviation is still few samples, because sampling frequency of the ECG signals is 500 Hz, therefore time interval between two samples is 2 ms. Interesting point is that using higher level of the compression results in correct delineation again.

Delineation of the 12 standard leads is stable and compression has minimal influence. It is safe to compress using the SPIHT algorithm with *avL* down to 0.8 bps. Higher level of the compression caused rising values of standard deviation s of the P wave onset and offset.

The shape of *PRD* function is hyperbolic. Compression with *avL* = 0.8 bps matches with *PRD* about 5 %.

Next step should be definition of rules to decide whether the ECG signal was damaged by the compression and is inconvenient for diagnosis.

5 Conclusions

The new compression quality criterion was presented in this extended abstract. It is based on a time shift of ECG waves boundaries caused by the compression. The delineation algorithm provides good information about influence of the compression artefacts on a diagnosis. The correct delineation is a first step in a determination of the diagnosis.

From results is obvious, that compression using SPIHT algorithm with *avL* down to 0.8 bps has minimal influence on delineation of 12 standard leads. These results confirm supposition that the reconstructed signal with *PRD* about 5 % is still acceptable for further diagnosis.

Next step should be establishing of important intervals (QRS, QT, ST …) and amplitudes and shapes of individual waves. For more precise evaluation of compression artefacts is convenient to monitor changes of amplitudes.

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