A Morphology Algorithm Based on 2-Dimensional Flat Structure Element on ECG Baseline Wander Elimination

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Abstract

Baseline wander always exists along with ECG signal. It is a kind of noise and may interference the diagnosis of cardio diseases, especially for the automatic diagnosis. Most methods could eliminate baseline wander already, however be difficult to meet the requisition of low distortion. To solve this problem, a morphology algorithm based on 2-D flat structure element is proposed, where flat structure element is often employed in previous work. The structure element is designed according to the shape, amplitude, period of the ECG signal itself, for a more accurate approximating to the ECG waveforms. Moreover, such structure element is variable by the feedback of filtered waveforms, which could elevate its robust. This algorithm is tested with the data from 8 files of MIT/BIH arrhythmia database, which contains 8 different shapes in ST segment, covering most of the cardiac conditions. The results are estimated in the baseline elimination as well as the distortion induced by filtering on the P waveform, QRS wave group, and the ST segments of ECG signal. Compared with those arguments of several classical strategies, the signal to noise ratio after processed by morphology based on non-flat structure element reaches the highest among all methods, and the ratio of deformation lowest, which means that this algorithm could both reduce the baseline wander, and control the distortion effectively.

1. Introduction

The baseline wandering of ECG signals is often induced by patients' respiration. It will bring interference to ECG diagnosis, especially in Computer-Aided Diagnosis.

The main methods towards baseline wander can be classified as High-pass filter, cubic spline and morphology. Some low frequency waveforms such as ST segment of ECG, it has an overlap with that wander, and it's difficult to be removed totally only by high-pass filter. At the same time, the energy of the ECG signal may meet a loss. The cubic spline is a non-linear technique, and the effectiveness of wander elimination by cubic spline depends on the exactness of the detection of the waveforms [1]. For normal (including shapes and location) P-R segments, it can make a wonderful denosing, inducing no distortions to the signal [2]. However when this part presents pathological process or sub clinical, cubic spline turns unfit [3]. For signals with heavy wander, the spline cannot reach the standard either [4].

Morphology, which is employed widely on image processing, is to characterize the primary feature. It works with so-called structure element which is extracted analogical as the main part of the image for recognition and analysis. In the field of ECG signal procession, morphology could deal with each segment of the waveforms and restrain the noise especially baseline wander [5]. In 1989 Chu [6] first put morphology to baseline wander elimination, which changes the shape of ST segment too, as in figure 1.

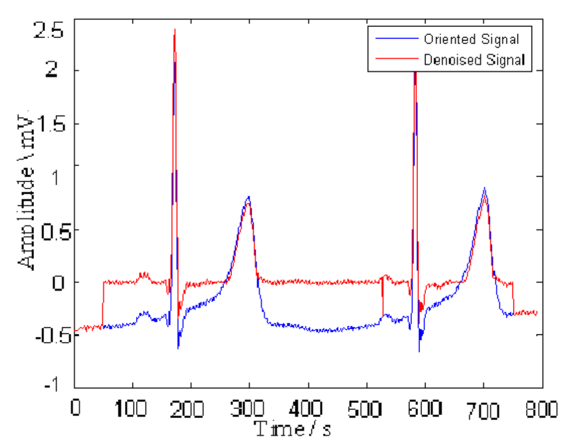

Figure 1. Baseline wander elimination by morphology.

From figure 1, the shape and amplitude of QRS waveforms changes quite little after morphology procession, and the ST segment does not share the same felicity. The slope of ST has been depressed and distorted, which may induce interference to clinical diagnosis.

In 2003, Sun [7] proposed a modification, including an open-close/close-open operation for QRS detection and removal, a close-open/open-close operator for P and T removal, and then the baseline can be acquired without ST distortion. Its disadvantage is, that the time complexity will be very high with 8 open or close operators; besides, it presents not so good when the frequency of wander turns a little higher. Four years later till 2008, Mao [8] modified Chu's method with a QRS depression first, following 3 open-close operators. That could reduce the morphology computing by 25%, still the complexity is high.

2. Two-Dimensional structure element

The low frequency of ST and TP segment causes an overlap with the baseline wander on the frequency spectrum. Compared with the high frequency and high amplitude QRS waveforms, these ST and TP segments are more similar to the wander, so as in figure 2, they are prone to be removed as noise [6].

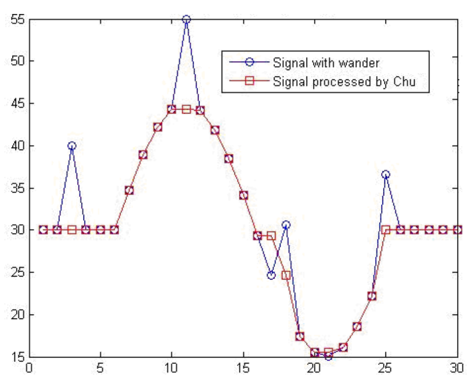

Figure 2. Signal processed by morphology in which some segments are mistaken as wander.

The signal is figure 2, named as P(x), is a pulse signal shown as equation 1. These pulses are the simulation of the R waveform. And we design a sinusoidal signal S(x) as baseline wander, as in equation 2.

$$P(x) = \begin{cases} 10, & x = 3, 11, 18, 25 \\ 0, & others \end{cases} \qquad (1)$$

$$S(x) = \begin{cases} 15\sin(2(x-6)/\pi) + 30 & 7 \le x \le 25 \\ 30 & others \end{cases} \qquad (2)$$

From figure 2, at the first two pulses (the 3rd and the 11th point respectively), there hasn't appears wander inside pulse, and so the baseline can be acquired without influence on "signal", except for the 'top' of the sinusoidal at point 11, when after procession it spears as a line instead of an arc. Unfortunately at the third pulse (the 18th point), there is a wander inside it; and after operated some points of the baseline are classified as "signal" and left, which simulates the distortion on QRS. Same happens at the last pulse, where the 25th point should be plotted between its previous and next points. In a word, a 1-D structure element may lead to distortions both on ST segment (as the 10th to 12th point in figure 2) and on the QRS waveforms (the 17th and 18th points).

Structure element should be designed according to the modality of signal to be remained. Traditional methods on signal procession often hold a 1 dimensional structure element with all elements 0 or 1, to ignore or retain the specific points of the signal. However, QRS keeps a wide range of amplitude, merely "0" and "1" could not fully express its potentials, which will make the baseline consist with the real one.

This can be solved with 2 dimensional structure elements. We settle a rule as follows for any signal: Set a 2 dimensional array, whose number columns is comported with the signal period and the number of rows should be large enough for the signal amplitude. The "0" and "1" of the elements is defined according to the pulse we want to ignore or retain. The structure element for the signal of figure 2 is shown below in figure 3, where "●" stands for 1 and "○" for 0.

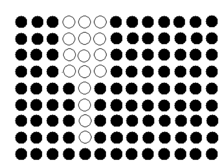
Figure 3. 2-D Structure element for signal in Figure 2.

Baseline can be acquired after close operation with 2-D structure element, as in figure 4.

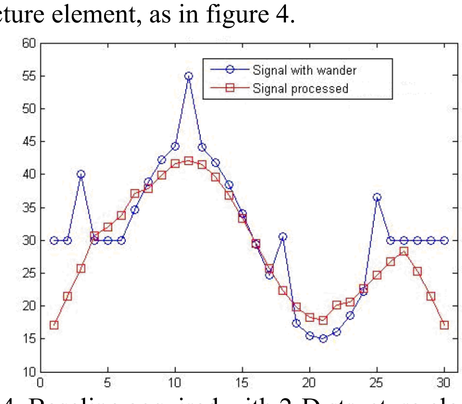

Figure 4. Baseline acquired with 2-D structure element.

From figure 4, the baseline we get with 2-D structure element goes the same trend, only with lower amplitude. That avoids the distortion on both ST and QRS waveforms. Still, there are 2 problems: the attenuation on amplitude, and the distortion on the first and last period. The attenuation can be resolved by compensation, and the later problem could be prevented by extend.

Obviously, with a 2-D structure element we can control distortion more effectively, and the more rows exist in the structure element, the result approaches real baseline better.

3. Experiments

3.1. Data

8 Samples of MIH/BIH arrhythmia database are selected, whose ST segments represent normal(Nor), concave elevation(CCE), straight elevation(STE), convex elevation(CVE), down-sloping depression(DD), horizontal depression(HD), up-sloping depression(UD), and sagging depression(SD), for testing the performance of 2-D structure element. Wanders are added into these signals to make different SNR (signal to noise ratio) as 2dB, 1dB and -0.5 dB.

3.2. Methods

Morphology is employed, with 1-D and 2-D SE respectively, to compare their “denoising” and “distortion control”:

1) Correlation Coefficient (AC)[9]: AC is a value between -1 to 1. The nearer it is to 1, the denoising presents better. Generally AC should be larger than 0.8.

2) Average energy attenuation of QRS waveforms (AE): Attenuation is also a kind of distortion and plays a vital role in evaluation of signal procession. In a whole period of ECG, the energy of QRS is the most convenient to compute for its higher amplitude and wider interval. Besides, the potential value of QRS implies some pathologic information [10], so the control of QRS attenuation is very important.

AE is evaluated by dB, with no attenuation it should be 0. When it’s positive there must be attenuation, and when negative it means the QRS energy has increased.

3) Potential Change (StV) of ST Segment: StV is to evaluate the distortion on ST segment. Baseline wander comes from environment, leads condition and patients’ respiration [3], and cannot be prevented. Slight wander is permitted in clinical standards, no more than 0.1 to 0.3 mV when elevate, or 0.1 mV when depression [11].

4. Experimental result

2-D SE is designed follow the rules in Part 2, and the experimental result is listed below in table 1 to 4， taking the results where SNR = 2 and 0.5 dB as example:

Table 1. Experimental result for ECG signal by 1-D structure element (SNR=2).

ST shape	AC	AE/dB	StV/mV
Nor	0.9950	-0.6487	0.0413
CCE	0.9917	-0.0658	0.2018
CVE	0.9000	3.0368	0.0658
HD	0.9821	-0.0834	0.0345
UD	0.9859	-2.0397	0.2382
DD	0.994	0.6496	0.1613
STE	0.992	-0.8063	0.0215
SD	0.9145	4.5304	0.1885

Table 2. Experimental result for ECG signal by 2-D structure element (SNR=2).

ST shape	AC	AE/dB	StV/mV
Nor	0.9967	-0.1180	0.0186
CCE	0.9956	-0.1249	0.1286
CVE	0.9152	2.3312	0.0378
HD	0.9878	-0.1340	0.0188
UD	0.9919	-0.1817	0.1257
DD	0.9976	0.0662	0.0446
STE	0.9963	0.1359	0.0103
SD	0.9437	1.3851	0.1019

Table 3. Experimental result for ECG signal by 1-D structure element (SNR=0.5).

ST shape	AC	AE/dB	StV/mV
Nor	0.9947	-0.5737	0.0444
CCE	0.9864	-0.0591	0.2007
CVE	0.8984	2.8670	0.0769
HD	0.9823	-0.1395	0.0388
UD	0.9858	-2.0223	0.2398
DD	0.9935	0.6364	0.1831
STE	0.9917	-0.9935	0.0289
SD	0.9115	4.5534	0.1894

Table 4. Experimental result for ECG signal by 2-D structure element (SNR=0.5).

ST shape	AC	AE/dB	StV/mV
Nor	0.9524	-0.2180	0.0356
CCE	0.9874	-0.0248	0.1297
CVE	0.8346	1.6338	0.0437
HD	0.9588	-0.2019	0.0564
UD	0.9451	0.4422	0.1463
DD	0.8644	0.4558	0.1771
STE	0.8410	4.4694	0.0634
SD	0.8405	1.1702	0.1831

As can be seen in those tables, the baseline removal is not obviously if the signal SNR and AC is already high enough, but when it is low, for example in table 1 and 2, where the SNR equals -0.5dB, the AC of signal after morphology can reach 0.99 by 1-D structure element, the AC by 2-D structure element is about 4.08% lower, still it is larger than 0.95.

On distortion control, the 2-D structure element presents excellent. Under any SNR listed, the attenuation is limited less than 0.2dB, as 1/10 to 1/5 as that of 1-D.

Potential changes of ST segment are also restrained. With the 1-D structure element, the potential change can reach 0.24 mV, already at the edge of the threshold of [11]. To the contrary, the 2-D structure element makes it 1/2 of it, no more than 0.15 mV.

The signal after processed with 2-D structure element is shown in figure 5.

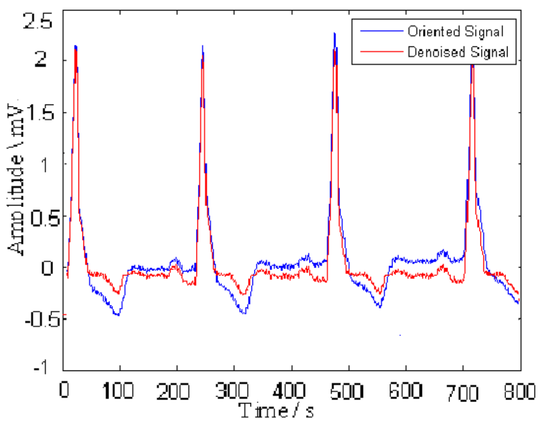

Figure 5. Signal processed with 2-D structure element.

5. Conclusions

The most advantage of 2-D structure element is the efficiently control of ST distortion, reducing it by 50%. This could ensure the diagnosis more accurate and credible.

The 2-D structure holds correlation coefficient larger than 0.9, which means the denoising availability. On condition of higher SNR, the AC of 2-D structure element is a little lower than that of 1-D, however on expense of it, the distortion is restrained strictly, where this exchange is worthy.

But it can still be improved, for example in figure 3, the slope of QS segment is brought down. This should be reformed. And this time we only include 8 samples, in the future more files of ECG will be added in, such as PVC, to make sure this method more generally.

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