Impulsive Noise Suppression of Electrocardiogram Signals with Mediated Morphological Filters

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ABSTRACT
This paper introduces a new and more appropriate ECG signal preprocessing using mediated morphological filters. These filters are based on a particular combination of median operator and classical morphological operators. The proposed method has been applied to adult and fetal ECG signals as an efficient preprocessing task. Accurate numerical descriptions demonstrate better performance quality of the new algorithm compared with that of the classical morphological filters, specially, in ECG noise suppression.

KEY WORDS : Morphological filters - Mediated morphological filters - adult ECG - fetal ECG.

Introduction

Adult and fetal ECG signals include valuable clinical information, but are frequently distorted by noise. The major contaminating noise of ECG recordings is 50-60 Hz noise resulting from mains power [1]. Also another interfering noise is impulsive noise caused by muscles activities [2]. Moreover respiration and motion of patient leads to baseline drift of ECG signal and amplitude variation [3].

Fetal ECG preprocessing is essential before proper analysis of its progressive changes by means of digital filters at the same time as labor. This analysis can help clinicians in making safe and more successful labor. In this regard, hard interpretation of fetal heart rate pattern (FHR) and uterine contraction (also called Cardiotocogram (CTG) for assessment of fetus condition during labor) will be unnecessary [4].

It is therefore important to limit the distortion of the ECG signals caused by preprocessing algorithms, after applying , otherwise it will affect subsequent main processing tasks for identification, recognition, etc., such as the detection of the ECG events comprising QRS complexes, P and T waves. The most common means of noise suppression of ECG signal was by low-pass filtering [5],

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which was ineffective in reducing impulsive noise. On the other hand, high-pass filtering is applied for baseline drift correction of ECG signals [6]. Nonlinear operators, such as median filtering [7,8] or ranked-ordering methods are another effective alternatives to the linear filtering when dealing with impulsive and 50-60 Hz noise rejection[9]. Classical mathematical morphology filters dominate all methods as mentioned above. They have robust performance in preserving the shape of the signal while suppressing the noise [10].

Nowadays , mathematical morphology introduced by Matheron and Serra [11,12], is widely applied in different areas, from entertainment to defense tasks. There are some reports about employing mathematical morphology in ECG wave detection, e.g., in [13]. We have also presented a more efficient morphological ECG baseline drift removal method [14]. Furthermore a generation of filters based on mathematical morphology or its combination with other operators are being developed [10,15-19]. One example of these filters is mediated morphological filters [19]. In this paper, we have applied them in adult and fetal ECG preprocessing as an efficient approach.

The organization of the paper is as follows. An introduction to the mediated morphological filtering is presented in Section 2. The proposed algorithm is described in Section 3. Section 4 discusses the ability and quality of the new algorithm compared with those of the classical one. Finally, Section 5 concludes the paper

Mediated morphology

Mediated morphological filters have their own individual dilation and erosion operators. These operators are based on a particular combination of median operator and classical morphological operators. These filters take the advantages of median and morphological filters, simultaneously.

Mediated morphological operators

Let x and g denote the 1-D gray-scale input signal buried in noise and the structuring element, respectively. D_x and D_g denote their domains. The mediated erosion and dilation, denoted ER and DI , respectively, are defined as follows:

$$ER(x,g,n) = \min\{x(n+v_0) - g(v_0), MED_0\}. \quad (1)$$

$$DI(x,g,n) = \max\{x(n-v_0) + g(v_0), MED_0\}. \quad (2)$$

where n is the index for current sample of x ($n \in D_x$) , v_0 is the location of the center of g , MED_0 is the median of x in a neighborhood defined by the size of g except that, in calculating the erosion, $x(n+v_0)$, ($x(n-v_0)$ in dilation) is replaced with the previous MED_0 (while it assumes a default value in the first calculation.)

Other mediated morphological operators, such as mediated opening) OP ,(closing) CL , (open-closing) OC ,(close-opening) CO , are defined by proper cascades of erosion and dilation:

$$\begin{aligned} OP(x,g) &= DI(ER(x,g),g) \\ CL(x,g) &= ER(DI(x,g),g) \\ OC(x,g) &= CL(OP(x,g),g) \\ CO(x,g) &= OP(CL(x,g),g) \end{aligned} \quad (3)$$

Extended definitions also apply in 2 dimension (2-D), and generally speaking, in N dimension. All the operators have increasing property. Mediated dilation and closing are extensive while mediated erosion and opening are anti-extensive. Similar to classical morphological operators, mediated dilation and erosion are not idempotent and mediated closing and opening are idempotent. These properties are consistent with the established theory of mathematical morphology. These properties are expressed in [14]

The proposed method for preprocessing

Preprocessing of electrocardiogram signal includes some unwanted component, such as 50-60 Hz noise, impulsive noise and baseline drift. Normally, noise suppression is the first step in ECG preprocessing which is followed by baseline drift correction. Here, mediated morphological filters are applied at this stage. Then the classical morphological filters are used in second step. In the first step, the average mean of mediated open-closing as well as mediated close-opening of signal with a short-length structuring element, attenuates high frequency noise components (i.e., noise suppression). In this step, the length of the structuring element should be taken longer than half of the longest period in high frequency noise components, the same as it is done in classical method. Thus all components with shorter periods than twice the length of the structuring element will be removed from signal. Indeed, this step is a low-pass morphological filtering that attenuates the frequencies satisfying the following inequality :

$$f \geq \frac{1}{2 \times \text{length(SE)}}.$$

After the first step of preprocessing (i.e., 50-60 Hz and impulsive noise suppression with mediated morphological filters), we have proved that ,in second step, the classical morphological operators act better than the mediated morphological operators for baseline drift correction. The length of the structuring element governs the reason of this choice. In baseline drift correction, the length of the structuring element is therefore longer than the one applied in noise suppression stage. Classical morphological filters are faster than the mediated morphological filters. Because the mediated morphological filters employ median operator which requires data sorting along the sliding structuring element window and therefore they need more computational time. On the other hand, the classical morphological filters are more suitable and estimate better baseline drift compared with the mediated morphological operators.

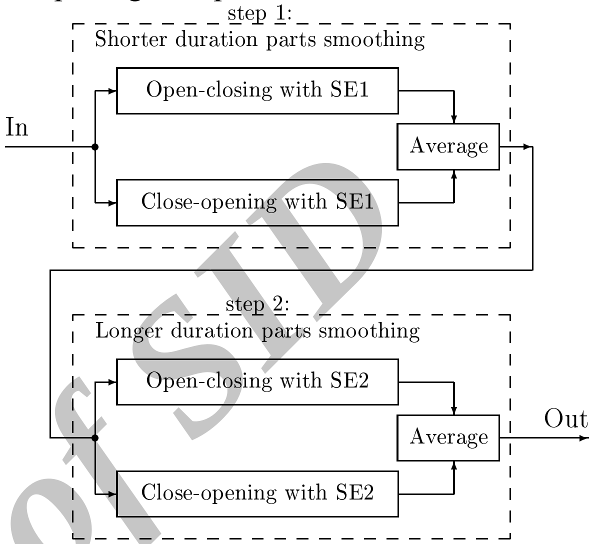

Figure 1: Complete block diagram of ECG Preprocessing.

Figure 1 illustrates a complete block diagram of the proposed morphological ECG signal preprocessing. Figures 2 and 3 show the adult and fetal ECG signals in different steps of preprocessing by the proposed algorithm.

Results and discussion

In this section, we will compare the efficiency of the proposed algorithm with that of the classical one. These comparisons are by valid numerical descriptions over manipulated ECG data of different leads. These ECG signals are without noise and baseline drift and are suitable for comparison as benchmarks. The comparison procedure is as follows. First, the noise is added to the ECG signal, then the distorted signal is filtered by each of the proposed and classical method, separately. In order to investigate the similarity and difference between the filtered signals and

the original ones, we have used three different mathematical descriptions: MAE (maximum absolute error), MSE (maximum squared error) and MCC (maximum cross-covariance).
The noise added to the ECG signals has a Gaussian distribution. Its mean value is equal to zero and its standard deviation is varying from 0.01 up to 0.1 in steps of 0.01. Figure. 4

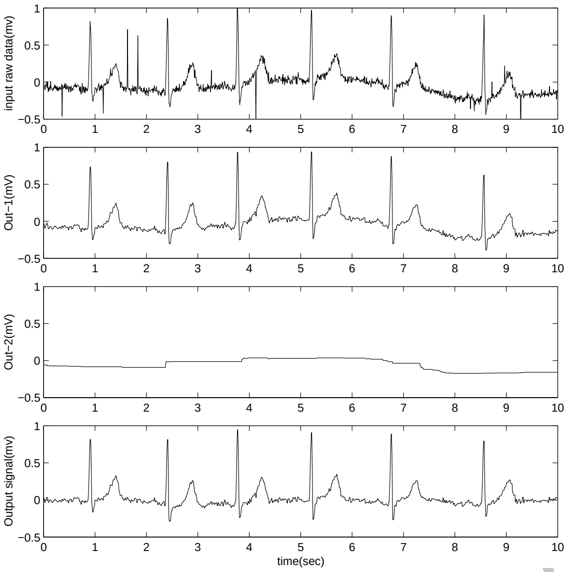

Figure 2: An adult ECG in different steps of preprocessing

demonstrates the result of the comparison in different adult ECG leads. Figure. 5 shows the result in different fetal ECG signals. The comparisons are done with three different numerical descriptions: MAE , MSE and MCC.

It can be inferred from Figures 4 and 5 that the proposed method dominates the classical one. Figure 6 illustrates the effect of the length of the structuring element in adult and fetal ECG noise suppression by the new and classical methods. Also it shows that the new

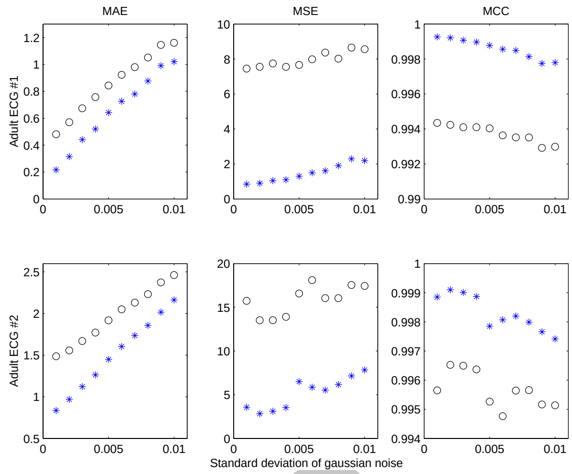

Figure 4: Quality comparison of the proposed and classical methods (* and ○ respectively) in adult ECG noise suppression when the standard deviation of the noise is increasing from .001 to .01 in steps of .001.

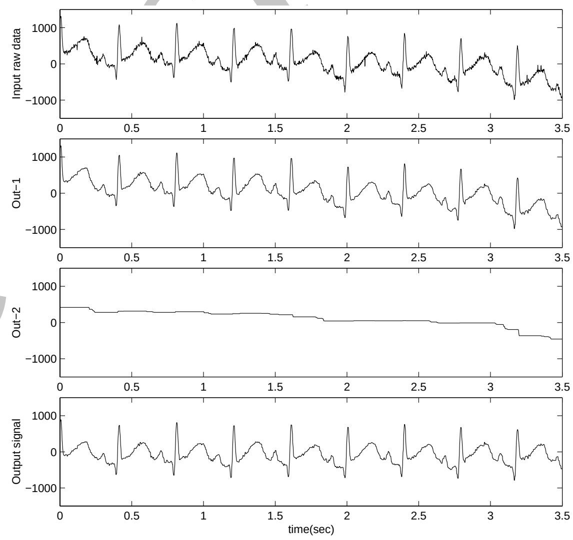

Figure 3: A fetal ECG in different steps of preprocessing.

method is more stable with respect to the changes of the structuring element's length.

Conclusion and future work

We have presented a more effective technique for ECG signals preprocessing and applied it to adult and fetal ECG signals. Numerical evidences prove that applying the mediated morphological filters lead to better performance quality of noise suppression and lower sensitivity to the changes of the structuring element's length when compared with the classical operators. However, as the mediated morphological filters are using median operators, they are time consuming operators. Therefore, one of our future works will be to improve their rate of performance. Another research may concentrate on applying the proposed method to obtain a better performance in determining the fetal ECG ST elevation.

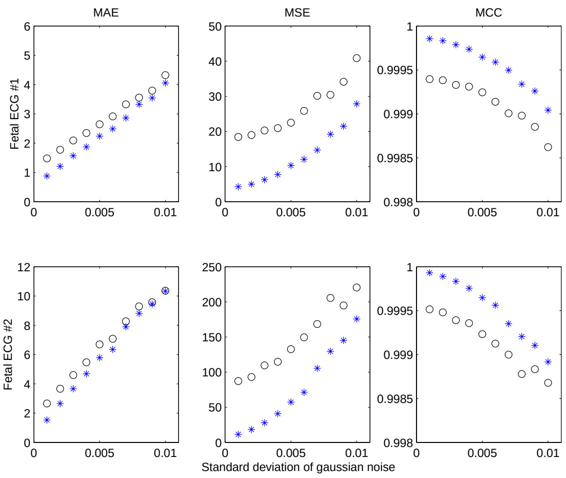

Figure 5: Quality comparison of the proposed and classical methods(* and ∘ respectively) in fetal ECG noise suppression when the standard deviation of noise is increasing from .001 to .01 in steps of .001.

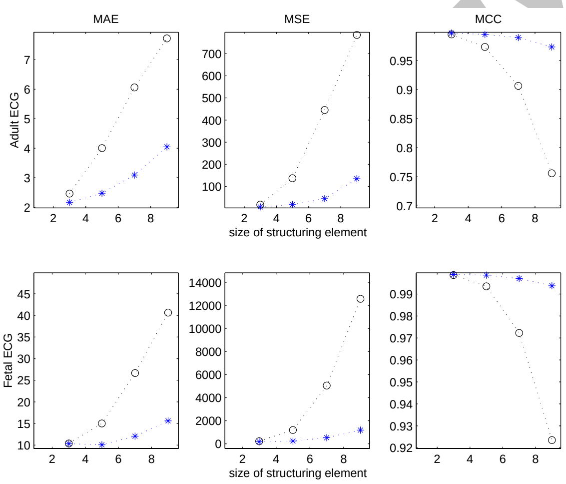

Figure 6: Effect of the structuring element's length in adult and fetal ECG noise suppression by the new and classical method (* and ∘ respectively).

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