New Algorithm for Fetal QRS Detection in Surface Abdominal Records

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Abstract

The proposed method detects fetal R waves on abdominal non-invasive records. An exponentially averaged pattern of the mother PQRST segment is obtained and subtracted. Subsequently the fetal R detector based on a Smoothed Nonlinear Energy Operator (SNEO) is applied to the residual signal. Finally, criteria about amplitude, heart rate and backward search are settled to correct false detections.

To evaluate the fetal R detector, 10 multichannel records were used, acquired between gestation week 22 and 40. The position of the fetal R waves were manually marked (N=1490), and these reference marks were compared with the ones from the detector. It was obtained a 88.83% of sensitivity and a 91.32% of positive prediction value. The application of the detector to all the abdominal channels will probably allow improving the obtained results.

1. Introduction

The acquisition and analysis of electrical activity of the heart has been a theme of study since the beginning of the electrocardiography. Non invasive techniques of fetal monitoring are Doppler ultrasound, ultrasound M-mode analysis, fetal electrocardiography, and fetal magnetocardiography. Among these methods the most commonly used is Doppler Ultrasound because is both simple to use and cheap. However, this method inherently produces an averaged heart rate and therefore cannot give the beat-to-beat variability [1]. Fetal electrocardiography has similar advantages, but in addition offers the potential for monitoring beat-to-beat variability and performing electrocardiogram morphological analysis. Its disadvantage is that its reliability is only 60%, although it is the only technique that offers truly long-term ambulatory monitoring, because no energy is supply to the fetus [2].

The main drawbacks of this technique are related to the low amplitude of the signals, the different types of noise, the overlapping spectrum amongst mother and fetal ECG and the variation of the morphology of the signal depending of the stage of gestation.

The fetal heart rate variations observed over 20 minutes during pregnancy and labour have commonly been used as indirect indicators of fetal condition. The possibility of monitoring ECG during longer periods will allow to obtain more information about the status of the fetus [3].

There are plenty of works about comparing of the fetal heart rate variability obtained from measures taken from electrocardiogram and using an echo cardiographer. One of the conclusions yielded is that although in most of the times the measurements are the same, variability in time series obtained form electrocardiogram is greater. The apparent "better quality" of the series form echocardiograph is really a smoothing, thus losing precision in variability. It is a cosmetic improvement, but unreal [1, 4, 5].

The detection of fetal QRS complex on surface records is not an easy task, mainly due to the overlapping of the mother signal; nevertheless, there are several works about detection algorithms applied to this type of records [3, 6, 7].

2. Methods

2.1. Material

For the evaluation and testing of the new foetal QRS (FQRS) complex detector, 10 multichannel records (2 thoracic and 4 abdominals) were acquired, but for verification only one abdominal channel was used. Gestational period varies between 22 and 40 weeks. Signals were acquired using disposable Ag/AgCl electrodes, amplified with a g.BSamp (Guger Technologies) amplifier, and sampled with a 16 bit acquisition board (ICPDAS 1602) at a sampling frequency of 1 kHz. In order to reduce skin impedance the areas of electrode placing were gentle abraded with Parker Redux Paste.

2.2. Description of detector

The proposed method detects fetal R waves on the signal resulting from the previous cancellation of

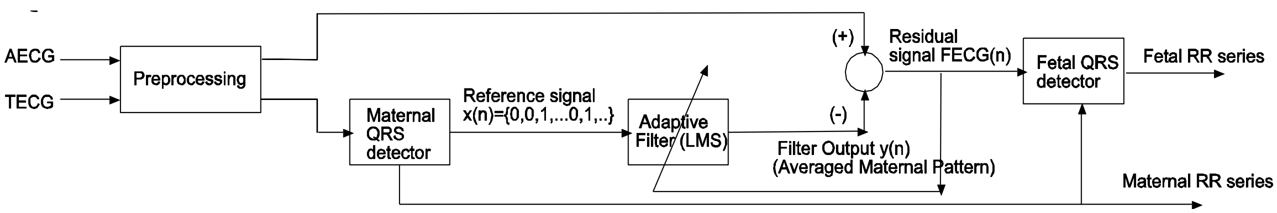

Figure 1. Block Diagram of the proposed algorithm.

maternal ECG contribution in an abdominal lead. An exponentially averaged pattern of the maternal P-T segment (MPTS) is obtained applying an Adaptive Impulse Correlated Filter (AICF), and subtracted when this pattern occurs (see Fig.1). Subsequently the developed fetal R detector is applied to the residual signal. Finally, criteria about amplitude, heart rate and backward search are settled to correct false detections.

2.2.1. Preprocessing

An interpolated finite impulse response (FIR) filter with lineal phase has been used to cancel baseline wander and power line interference [8].

2.2.2. Maternal QRS detection

The detector of maternal R waves utilized is the developed by Pan and Tompkins [9]. It is a conventional detector of R waves because the signal-to-noise ratio (SNR) of the maternal QRS is enough in the thoracic derivation, and it is based on the analysis of the amplitude and derivative of the QRS complex. It applies backward-search with reduced threshold to improve possible false detections. The marks of the maternal R detector are used for the canceller of the MPTS to locate the pulses to average, and by the fetal QRS detector to cancel the maternal QRS residues.

2.2.3. MPTS cancellation

For the cancellation of the MPTS, an AICF has been utilized [10]. The AICF uses an adaptive structure based on the LMS (Fig. 1), where the reference signal, x(n), contains the called regeneration time; the instants of occurrence of the maternal R waves obtained from the detector of QRS. An adaptive filter of these characteristics behaves as an exponential averager, storing in the coefficients of the filter an averaged alias of the signal [11]. The output, y(n), of the adaptive filter is subtracted from the original signal to cancel the contribution of the MPTS present in the same (Fig. 2). The resultant residue after the cancellation of the MPTS depends on the correct alignment of the pulses, and of the chosen value for the constant of adaptation. In the utilized structure the constant of adaptation controls the depth of the average.

2.2.4. Fetal QRS detection

To improve the SNR of the fetal QRS complex (FQRS) to the other components of the signal residue, a non-linear operator was used, the Nonlinear Energy Operator proposed by Teager and Kaiser (NEO). NEO has been utilized for detection of spike-like signals because it is sensitive to instant changes in the energy depending of the frequency [12]. In this way the residues of maternal P and T waves are reduced. Due to that NEO is noise sensitive, especially if contains components of high frequencies, it was used the Smoothed Nonlinear Energy Operator (SNEO), that applies a smoothing window of. For a discrete signal, x(n), this operator is defined as:

$$\psi\,[x(n)] = x(n)^2 - x(n+1)\cdot x(n-1)$$
$$\psi_S\,[x(n)] = \psi\,[x(n)] \otimes w(n)$$

where ψ is the NEO operator, ψ_S the SNEO operator, $\otimes$ the convolution operator and w(n) the smoothing window function (in this work, a 6 points Barlett window has been used).

In order to determine the threshold on SNEO, in each segment of signal a linear approach was used where the constant term is related to an absolute threshold to avoid residual noise, and the second term depends on the value of SNEO in the segment. A priori it cannot know if on a MPTS residue there is an overlapped FQRS. To avoid the extreme values that this residue can produce in SNEO, the median value of SNEO excluding the sections around the maternal R annotations (cSNEO) has been chosen. The expression of the used threshold of SNEO is:

$$umb\_SNEO = k_0 + k_1 \cdot median(cSNEO)$$

In order to determine the positions of the FQRS, it is obtained in the first place the values of SNEO greater than umb_SNEO. Next those values that fulfill a criterion of separation greater than a certain minimum value, related with the minimum period between waves FQRS are selected (t_min). Finally, the maximum of the FQRS detected by local search is marked (fig 2).

In order to correct the possible presence of false positives (FP: erroneous detection of FQRS) or false

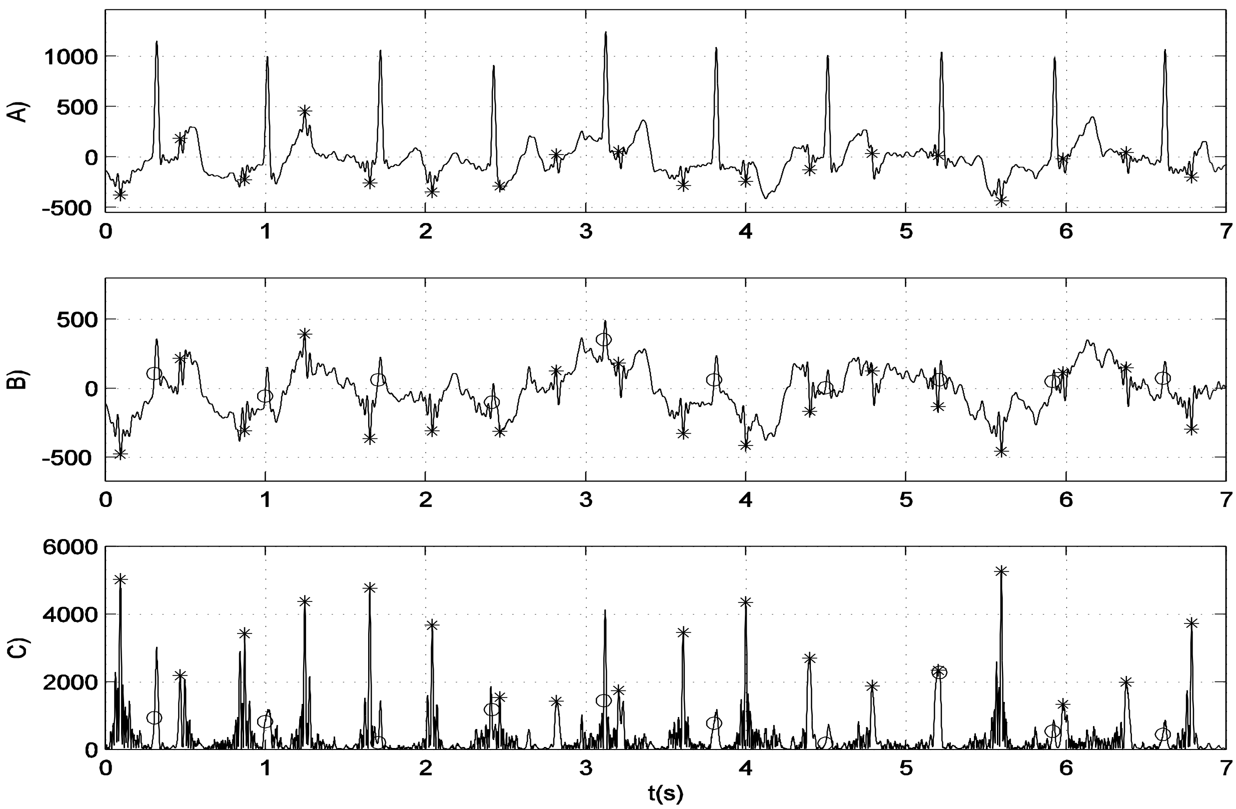

Figure 2. A) Original ECG. B) Error signal (r(n)) before AICF cancellation. C) Transformation SNEO on r(n). Fetal R waves are marked with asterisks, and maternal R waves marked with circles.

negatives (FN: lack of true detection of FQRS), a criterion based on the normal rate between FQRS waves has been applied. For it, each annotation within a valid interval is verified respect to the last detected annotation (vci). If the period is shorter than the expected one, it is a FP that must be eliminated. If it is longer, a FQRS has not been detected (FN), and must be made a backwards search with reduced threshold to locate it.

The parameters of the detector were optimized making a sweeping of values and selecting those for which the detection is better on the set of records. The final values were: k_0=2, k_1=1, t_min=0.3s, vci=15%.

3. Results

The position of the fetal R waves were manually marked in the first 60 seconds for each record (N=1490), and these reference marks were compared with the ones from the detector. The obtained results are summarized in Table 1. For the analyzed records, average values of sensitivity (S) and positive prediction (+P) near 89% and to 91%, respectively, were obtained.

Both the mean and the standard deviation of the position error (PEM, PES) between the mark of the expert and the detector show values around 10 ms. These results are related to the cases of overlapping between maternal and fetal QRS [13]. The results of the detector could be improved using multiple derivations to validate the obtained detections.

N	S (%)	+P (%)	PEM (ms)	PES (ms)
1446	88.83	91.32	11.96	9.56

Table 1. Results of the detection of FQRS. N: number of analyzed fetal waves R. S: sensitivity (%).+P: value of positive prediction (%). PEM, PES: average and standard deviation of the precision error (in ms).

4. Discussion and conclusions

A detector of fetal waves R in noninvasive records of fetal ECG obtained during the pregnancy has been described. The detector will enable to obtain not only fetal RR series, but also an averaged pattern of the fetus ECG, allowing therefore the analysis of the morphology of the signal. The proposed method detects fetal R waves on the signal resulting from the previous cancellation of maternal ECG contribution in an abdominal lead. An exponentially averaged pattern of the mother PQRST segment is obtained applying an Adaptive Impulse Correlated Filter (AICF), and subtracted when this pattern occurs. Subsequently the developed fetal R detector is applied to the residual signal. The R detector is based on a Smoothed Nonlinear Energy Operator (SNEO). Finally, criteria about amplitude, heart rate and backward search are settled to correct false detections.

The results obtained in this work present high values of sensitivity and positive prediction. However, the precision error requires later adjustments of the detector, also using a wider set of records. The application of the detector to all the abdominal channels will probably improve the results.

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