Noninvasive FECG for estimating the fetal heart rate

Luis Omar Sarmiento Alvarez
Ingeniería de Telecomunicaciones
Universidad Santo Tomás
Bucaramanga, Colombia
luisomar.sarmiento@gmail.com

Yudy Natalia Flórez Ordónez
Ingeniería de Telecomunicaciones
Universidad Santo Tomás
Bucaramanga, Colombia
ynataliaflorez@gmail.com

Alberto González Salvador
Departamento de Comunicaciones
Universidad Politécnica de Valencia
Valencia, España
agonzal@dcom.upv.es

José Millet Roig
Grupo BIO
Universidad Politécnica de Valencia
Valencia, España
jmillet@eln.upv.es

Abstract— **Decelerations of fetal heart rate have been known to be associated with fetal distress. Continuous fetal heart rate monitoring was expected to result in dramatic reduction of undiagnosed fetal hypoxia, but the outputs of FHR monitors were often unreliable and difficult to interpret, resulting in increased rates of caesarean deliveries of healthy infants.**

The most accurate method for measuring FHR is direct fetal electrocardiographic monitoring using a fetal scalp electrode. This is possible only in labor, however, and is not common in current clinical practice because of its associated risks. Noninvasive FECG monitoring makes use of electrodes placed on the mother's abdomen. This method can be used throughout the second half of pregnancy and is of negligible risk. However, it is often difficult to detect the fetal QRS complexes in ECG signals obtained in this way, since the maternal ECG is usually of greater amplitude in them. Other features of the direct fetal ECG, such as FHR variability, may be useful independent indicators of fetal status. There are no accepted techniques for assessing such features from noninvasive FECG, however.

This paper describes a method for locating QRS complex in noninvasive FECG, using techniques based on MECG cancellation, and Principal Component Analysis (PCA). The proposed method locates the fetal QRS complexes with efficiency above 80%.

Keywords—FECG; AECG; MECG cancellation; PCA.

I. INTRODUCTION

Monitoring the fetal cardiac activity can provide important information to obstetricians for the assessment of the fetal well-being. Doppler ultrasound is used for the measurement of the fetal heart rate (FHR) during pregnancy and delivery [1]. However, the FHR is the only parameter obtained by Doppler ultrasound, while research has shown that a global assessment of morphological and temporal parameters of the fetal electrocardiogram (FECG) during gestation can provide additional information about the fetal well-being [2] and can be used for early arrhythmias detection.

The abdominal ECG (AECG) can be obtained by means of surface electrodes placed on the mother's abdomen [3]. In turn, the FECG can be obtained by means of AECG using digital signal processing. The problem is that AECG is formed by a biomedical signals mixture including FECG, maternal electrocardiography (MECG), other electrical signals generated by the mother and external electrical interference. The challenge is to extract the FECG in the resulting composite signal, but it is often difficult to detect the fetal QRS complexes, since the maternal ECG is usually of greater amplitude.

Different variants of linear and adaptive filters have been used for maternal ECG cancellation and FECG extraction [4],[5]. The Blind source separation (BSS) [6],[7],[8], is also used for this purpose. However, the first group presents a scarce performance due to the inaccurate removal of the MECG, and BSS does not take into account the a priori information about the signal of interest, implying an unpredictable and uncontrollable behavior [2].

The fetal heart rate variability (FHRV) in the FECG, may be a useful independent indicators of fetal status, however, there are no accepted techniques for assessing such features from noninvasive FECG. This paper describes a method for locating fetal QRS complex in AECG, using techniques based on MECG cancellation and Principal Component Analysis, in order to obtain the most periodic extracted components with respect to the FECG, ordering from the FECG to MECG, from the first to the last component.

II. METHODS

A. MECG Cancellation

A non-blind method for FECG detection in AECG Is proposed in [2]. The method consists of a three steps sequential analysis approach, in which the a priori information about the MECG is used for the detection of the FECG. First, the AECG data passes through the baseline wander remover, which attenuates the low-frequency components. The output data is processed by a power-line interference canceller, which removes the power-line interference including its harmonics in each channel. Second, the locations of the mother QRS complexes are determined by a QRS detector. This

978-1-4799-1121-9/13/$31.00 ©2013 IEEE

information helps a MECG canceller to remove the MECG from each channel. Thus residuals channels merely contain the FECG combined with EMG interference and measurement noise. Third, the positions of the fetal QRS complexes in residuals are determined by the QRS detector. This information is used by the FECG detector, whose output contains an average FECG complex for each channel over 150 FECG complexes.

B. Principal Component Analysis (PCA)

The problem of the FECG extraction from maternal skin electrode measurements can be modeled from the perspective of blind source separation (BSS)[9]. Given an m-dimensional observation vector $x(n) = [x_1(n), \ldots, x_m(n)]^T$, sources s(n) can be extracted by the linear mixture $s(n) = \boldsymbol{w}^T x(n)$. The challenge is to estimate the mixing matrix $\boldsymbol{w}$ and its (pseudo) inverse which is called the de-mixing matrix $\boldsymbol{w}^T$. Several algorithms have been proposed to find the solution. PCA Algorithm search for a solution, using second order statistics, finding a linear transformation from the correlated observed signals, x(n), to a set of uncorrelated signals, s(n) [10]. Such a linear transformation is possible and easily achieved using single value decompositions (SVD).

C. Fetal Heart Rate Variability (FHRV)

FHRV is analyzed from the fetal heart rate (HR) series that is formed by a sequence of values at time instants τ_m of cardiac beat occurrence, and whose value at time τ_m is a function of the previous R-R interval as measured from the FECG signal. This time series is nonuniformly spaced since the time occurrence of heartbeats does not follow a perfectly regular pattern. Estimation of FHRV can be performed using power spectral density (PSD), but since PSD must be estimated from a set of unevenly spaced samples, it requires resampling to achieve uniform time intervals [10],[11]. This resampling, introduces low-pass filtering and possible artifacts in the estimated spectrum. On the other hand, the Lomb PSD estimation method, does not require evenly spaced samples, and avoids the major problem of classical methods: the low-pass effect of the resampling [12].

III. Experiments and Results

A. Data set

Data consists of a collection of one-minute AECG recordings [13]. Each recording includes four noninvasive abdominal signals. The data were obtained from multiple sources using a variety of instrumentation with differing frequency response, resolution, and configuration; although in all cases they are presented as 1000 samples per signal per second. In each case, reference annotations marking the locations of each fetal QRS complex were produced, usually with reference to a direct FECG signal, acquired from a fetal scalp electrode. Fifteen recording were chosen for this paper. Fig. 1 shows a 10 second segment recording.

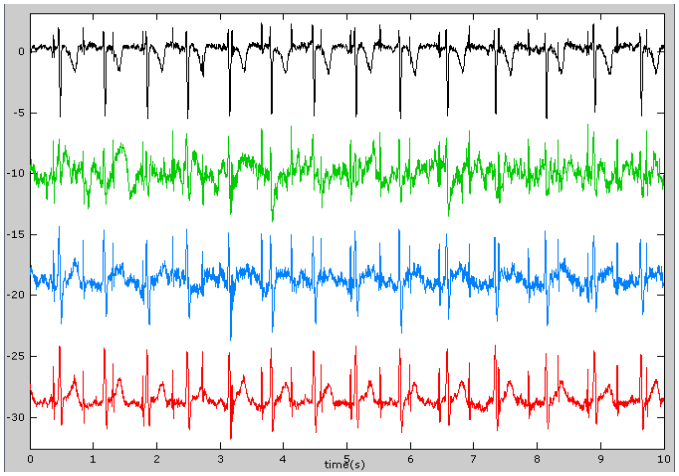

Fig. 1. Ten seconds segment recording AECG.

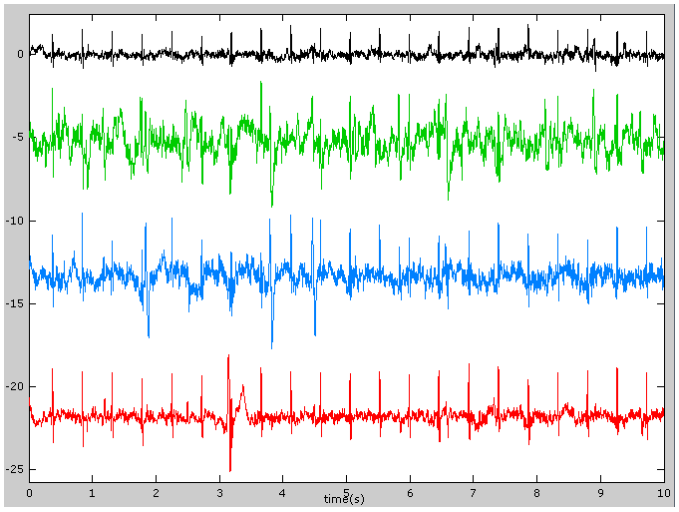

Fig. 2. Ten seconds segment recording estimated FECG after MECG cancellation and PCA.

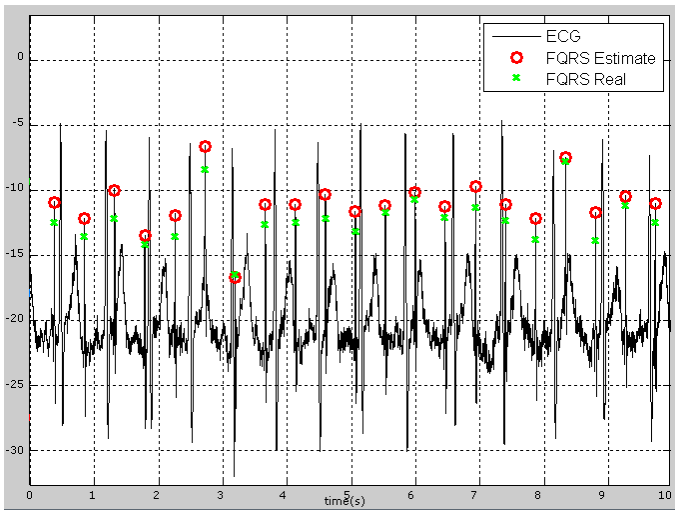

Fig. 3. A channel AECG, FQRS real and FQRS estimate.

B. Data Processing

No pre-processing is applied to the recording. The AECG data passes through the baseline wander remover. Then, the locations of the mother QRS complexes are determined by a QRS detector. With this information a MECG canceller removes the MECG from each channel. To select which of the channel whit more FECG information, PCA algorithm is applied to sort the signals order from the FECG to MECG, from the first to the last component. Thus, the first component is select as FECG. The result can be seen in Fig. 2.

C. Performance measures

The data set contains reference annotations marking the locations of each fetal QRS complex. Then, the position of each estimated QRS complex is compared with the position of each real QRS complex to determine the performances of the proposed method. An estimated QRS complex is considered valid when it is in the same position ± 10 samples as a real QRS complex (± 10 ms at the sampling frequency of 1000 Hz). The FHR detection efficiency is determined as the ratio between the number of valid estimated QRS complex and the total number of real points. Table I shows the efficiency of the proposed method. The mean efficiency is above 80%.

TABLE I. EFFICIENCY PROPOSED METHOD

Recording	Number real QRS complex	Number estimated valid QRS complex	Efficiency (%)
1	128	99	77.3
2	129	118	91.5
3	129	115	89.1
4	128	112	87.5
5	175	134	76.6
6	138	130	94.2
6	123	89	72.4
7	134	113	84.3
8	132	119	90.2
9	127	91	71.7
10	145	115	79.3
11	167	130	77.8
12	163	117	71.8
13	163	134	82.2
14	137	106	77.4
15	128	99	77.3

The position of each estimated QRS complex, R-R series, are not uniformly spaced. Estimation of FHRV can be performed using the Lomb PSD estimation method. Fig 4, shows the Lomb normalized periodogram for statistical significance levels α= .001, .005, .01, .05, .1, .5. With this tool, an analysis FHRV can be initiated from abdominal ECG.

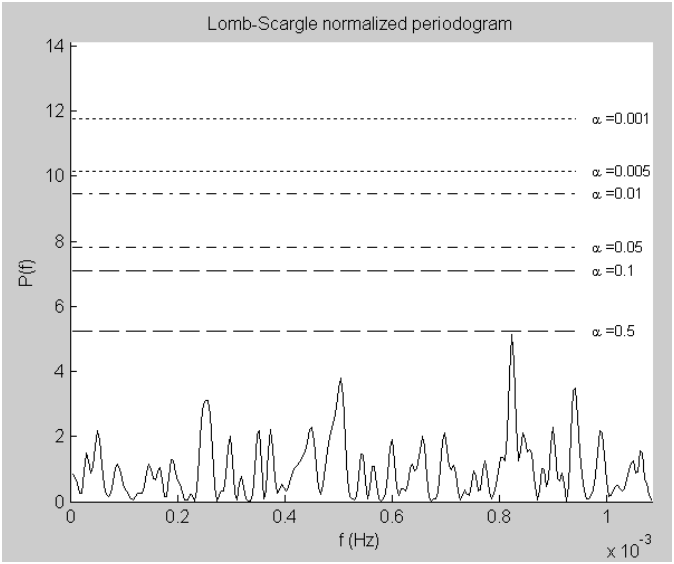

Fig. 4. Lomb normalized periodogram for statistical significance levels α.

IV. CONCLUSIONS

There are no accepted techniques for assessing the features from noninvasive FECG. In this work, a method for locating QRS complex in noninvasive FECG, using techniques based on MECG cancellation and, PCA. The proposed method locates the fetal QRS complexes with efficiency above 80%.

REFERENCES

[1] Lewis M. J. "Review of electromagnetic source investigations of the fetal heart," Med. Eng. Phys. vol. 25, no. 10, p.p. 801-810, december 2003.

[2] Martens S. et al. "A robust fetal ECG detection method for abdominal recordings," Physiol. Meas. Vol. 28, No. 4. p.p. 373-388. 2007.

[3] J. A. Crowe, A. Harrison, B. R. Hayes-Gill. "The feasibility of long-term fetal heart rate monitoring in the home environment using maternal abdominal electrodes," Physiol. Meas. vol. 16, no.3, p.p. 195–202, 1995.

[4] N.J. Outram, E.C. Ifeachor, P.W.J Van Eetvelt, J.S.H Curnow, "Techniques for optimal enhancement and feature extraction of fetal electrocardiogram," Science, Measurement and Technology, IEE Proceedings, vol.142, no.6, pp.482-489, Nov 1995.

[5] Y.C. Park, K.Y. Lee, D.H. Youn, N.H. Kim, W.K. Kim, S.H. Park, "On detecting the presence of fetal R-wave using the moving averaged magnitude difference algorithm," IEEE Transactions on Biomedical Engineering, vol.39, no.8, pp.868-871, Aug. 1992

[6] PP. Kanjilal, S. Palit, G. Saha, "Fetal ECG extraction from single-channel maternal ECG using singular value decomposition," IEEE Trans Biomed Eng, vol.44, no.1, pp.51-59, Jan.1997

[7] V. Zarzoso, AK. Nandi, E. Bacharakis, "Maternal and fetal ECG separation using blind source separation methods," IMA J Math Appl Med Biol., vol.14, no.1, pp.207-225, 1997.

[8] Sarmiento L.O.; Gonzalez, A.; Millet, J., "Synthetic database for testing algorithms of fetal ECG extraction from abdominal ECG," Image, Signal Processing, and Artificial Vision (STSIVA), 2012 XVII Symposium of , vol., no., pp.56,61, 12-14 Sept. 2012.

[9] De Lathauwer, L.; De Moor, B.; Vandewalle, J., "Fetal electrocardiogram extraction by blind source subspace separation," Biomedical Engineering, IEEE Transactions on , vol.47, no.5, pp.567,572, May 2000.

[10] Sarmiento L. O., Et Al., "Estimación no invasiva de la frecuencia cardiaca fetal mediante tecnicas de separación ciega de fuentes". Revista Colombiana de Cardiologia, vol. 17, No..4 p.p. 187 - 190 , 2010.

[11] R. D. Berger, S. Akeselrod, D. Gordon, and R. J. Cohen, “An efficient algorithm for spectral analysis of heart rate variability,” IEEE Trans. Biomed. Eng., vol. BME-33, pp. 900–904, 1986.

[12] Laguna, P.; Moody, G.B.; Mark, R.G., "Power spectral density of unevenly sampled heart rate data," Engineering in Medicine and Biology Society, 1995., IEEE 17th Annual Conference , vol.1, no., pp.157,158 vol.1, 20-25 Sep 1995

[13] Noninvasive Fetal ECG: the PhysioNet/Computing in Cardiology Challenge 2013. http://physionet.org/challenge/2013/