

A REAL-TIME INTRAUTERINE CATHETER TECHNIQUE FOR FETAL ELECTROCARDIOGRAM MONITORING

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Abstract—A fetal electrocardiogram (FECG) obtained via an intrauterine catheter (IC) is a compromise between the clinically accepted invasive scalp electrode, and the non-invasive abdominal wall approaches. The catheter is inserted into the uterus during delivery, but is non-invasive to the fetus. The IC can be modified to contain a pressure sensor to monitor contractions. The modified IC would enable fetal heart rate and contractions to be monitored with one sensor. Currently, two sensors that include the invasive scalp electrode and intrauterine pressure catheter are used clinically.

Signal processing is required to obtain a FECG via the IC. Usually the maternal electrocardiogram (ECG) is present in the IC's signal along with electromyographic noise. Obtaining the FECG in real-time further complicates the processing since the FECG can be similar in amplitude to the maternal ECG. Current techniques for maternal ECG cancellation produce a significant residual during the initial processing of the algorithm and/or falsely detect the FECG for the maternal ECG.

A real-time IC technique will be discussed. The results from clinical data from eight patients indicate a FECG with a good signal-to-noise ratio can be obtained even during the first seconds and minutes of operation.

Keywords - Fetal electrocardiogram, intrauterine catheter

I. INTRODUCTION

Various fetal electrocardiogram (FECG) monitoring techniques have been reported in the last 40 years. These methods include non-invasive and invasive techniques. The non-invasive methods can further be divided into non-invasive to the mother and fetus which include the abdominal wall approaches, and non-invasive to the fetus which includes the intrauterine catheter (IC) procedure [1-4]. The clinically accepted scalp electrode is categorized as an invasive method since the electrode is invasive to the mother and fetus [5].

The invasive scalp electrode has proved to be a reliable technique for monitoring fetal status via heart rate (HR) during delivery. However, the scalp electrode is invasive to the fetus. In contrast, the non-invasive abdominal wall approaches would be ideal when compared to the invasive scalp electrode. However, obtaining a FECG from the abdominal wall is non-trivial. The FECG signal strength is very weak, and corrupted with interfering noise from the maternal electrocardiogram (ECG) and muscle activity of the abdominal surface [1-2].

Since the IC technique is non-invasive to the fetus but invasive to the mother, the catheter makes a nice compromise between the non-invasive abdominal wall and scalp electrode techniques. Since the catheter is placed in

close proximity to the fetus and even touches the fetus in some places, the adjacency allows for a greater chance of obtaining a FECG with a favorable signal-to-noise ratio. In addition, the IC used to obtain pressure contraction information can be combined with the IC to obtain the FECG. These combined catheters could then be used to perform the tasks of the scalp and intrauterine pressure catheter with only inserting one device in the uterus [3-4].

The focus of this paper is to present a technique for canceling in real-time the maternal ECG of the signal obtained via the IC. Previously reported techniques produce a noticeable maternal ECG residual during the first seconds and minutes of operation, particularly during the occurrence of a FECG that was larger in amplitude than the maternal ECG [3-4]. The method in this paper introduces signal processing to avoid noticeable residuals during the initial operation of the algorithm in real-time.

II. METHODOLOGY

The system necessary for obtaining a FECG via an IC consists of analog and digital signal processing sub-systems. Analog processing includes an ultra-low noise preamplifier and a bandpass filter. The digital signal processing removes the maternal ECG. Since the focus of this paper is on real-time maternal ECG cancellation, details of the analog processing will not be discussed. However, the ultra-low noise preamplifier had less than 2.0 μ Volts peak to peak noise in a 0.5 to 100.00 Hz bandwidth and the bandpass filter had a passband of 0.05 to 100.00 Hz. The sampling rate for the system is 1KHz.

Digital signal processing for maternal ECG cancellation consists of using a thoracic ECG, lead II, as a trigger to align the maternal ECG of the IC's ECG to determine its average. The maternal ECG average can be used to cancel each maternal ECG complex of the IC's ECG. The following describes the method in more detail.

The first step of this algorithm determines the absolute maximum of the first 8.0 seconds thoracic ECG block of data. Half of the maximum is used as a threshold for a peak detection algorithm. The peak detection algorithm finds the time locations of each peak of the maternal ECG of the thoracic ECG. (The peak detection algorithm of the analysis library of LabVIEW was used.)

The second step uses the peak time locations as triggers to align each maternal ECG complex of the IC's ECG to determine a maternal ECG average. The maternal ECG average of the IC's ECG for the first 8 seconds block of data

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is determined by using the triggers as a reference point for which each maternal ECG complex can be removed from the IC's ECG as a smaller sub-block. Each maternal ECG complex or sub-block is produced by appending 0.2 seconds before and 0.4 seconds of samples after the trigger locations. The 0.2 and 0.4 seconds vary some for a large variation of the maternal HR. To keep the baseline of the maternal ECG average close to the zero crossing, each maternal ECG complex is filtered by taking the first and last five samples of each complex or sub-block and average them. This average value is then subtracted from each sample of the complex.

In step three, each maternal ECG complex is modified to reduce the FECG signal energy. A peak detection algorithm is run on each maternal ECG complex to detect each FECG complex. The FECG's complexes that occur during the maternal ECG QRS wave are ignored. Only the detected FECG complexes outside of the maternal ECG's QRS wave by ± 0.03 seconds will be modified. Next, the detected FECG's QRS complexes are removed and replaced with a linear interpolation that starts from the first and last samples of the detected FECG's QRS complex. With some of the FECG's QRS complexes removed from each maternal ECG complex, maternal ECG averaging can then be performed to produce an average with reduced corruption from the FECG. The reduction in signal corruption will be further discussed in the Results and Discussion sections.

In step four, the modified maternal ECG complexes detected in the first 8 seconds block are summed. (The first and last maternal ECG complexes are thrown out because they may not contain a full maternal ECG complex because the data acquisition may break these maternal ECG complexes.) The maternal ECG average is calculated by dividing the total number of maternal ECG complexes summed.

In step five, the maternal ECG average is subtracted from each maternal ECG complex of the IC's ECG first 8.0 seconds block of data using the trigger locations of the thoracic ECG. The subtraction produces an IC's ECG with the maternal ECG greatly suppressed.

Step six repeats steps one through five for each consecutive 8 seconds block of data where the maternal ECG average is calculated based on the present and previous blocks processed.

III. RESULTS

Two clinical data sets from two of the eight patients studied are presented in Figs. 1 and 2. Figs 1-2(a) contain the thoracic ECG. Figs 1-2(b)(i) contain the IC's ECG, and Figs. 1-2(b)(ii) contain the resulting IC's ECG when a maternal ECG average has not been modified. Figs. 1-2(b)(iii) contain the resulting IC's ECG when a maternal ECG average has been modified. Figs. 1-2(c) contain the maternal ECG complexes without any modification, and Figs. 1-2(d) contain the maternal ECG complexes with

modifications. Finally, Figs. 1-2(e)(i) contain the maternal ECG average found via the maternal ECG complexes of Figs. 1-2(c) and 2(c) respectively. Figs. 1-2(e)(ii) contain the maternal ECG average found via using complexes from Figs. 1(d) and 2(d) respectively.

IV. DISCUSSION

By visually comparing Figs 1-2(b)(ii) and 1-2(b)(iii), an improvement can be seen in the signal-to-noise ratio of the resulting IC's ECG by removing the FECG complexes during averaging. The transient resulting from a large FECG is the most pronounced as a residual particularly during the first few seconds of operation, but can continue even for the first few minutes of operation. However, the residual reduces for both the modified and non-modified methods as time progresses and the maternal ECG average becomes a function of many complexes.

V. CONCLUSION

A significant improvement can be made in the resulting IC's ECG signal-to-noise ratio by removing the FECG complexes before averaging. The modification of the average is particularly noticeable during the initial FECG monitoring in real-time. The reduction in residual produces a FECG that HR and electrophysiological information can be more accurately determined.

A FECG was obtained for most of the eight patients studied. However, positioning of the IC proved challenging in obtaining a significant FECG signal. Additional research is necessary to determine a good technique for IC placement in the uterus.

Finally, the IC could be combined with the pressure catheter. Therefore, the invasive scalp electrode could be eliminated and a catheter could be used to monitor the ECG and contraction information of the mother during delivery.

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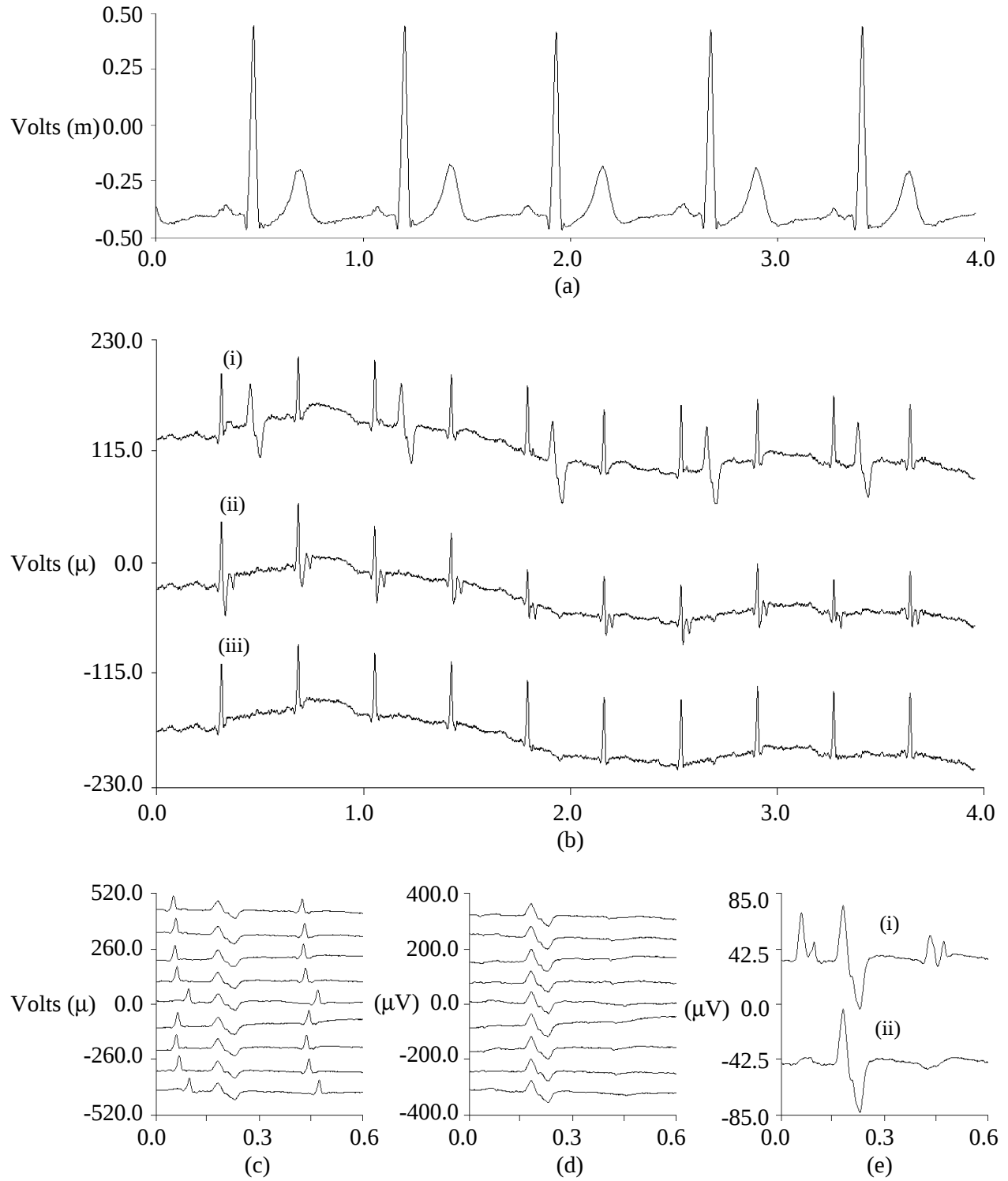


Fig. 1. IC clinical data from patient 1 (all x-axes in seconds). (a) Thoracic ECG. (b)(i) IC's ECG after cancellation without modifying each maternal ECG complex before averaging. (b)(ii) IC's ECG after cancellation with modifying each maternal ECG complex before averaging. (c) Original maternal ECG complexes of the IC's ECG. (d) Modified maternal ECG complexes of the IC's ECG. (e)(i) Average of the maternal ECG complexes of (c). (e)(ii) Average of the maternal ECG complexes of (d).

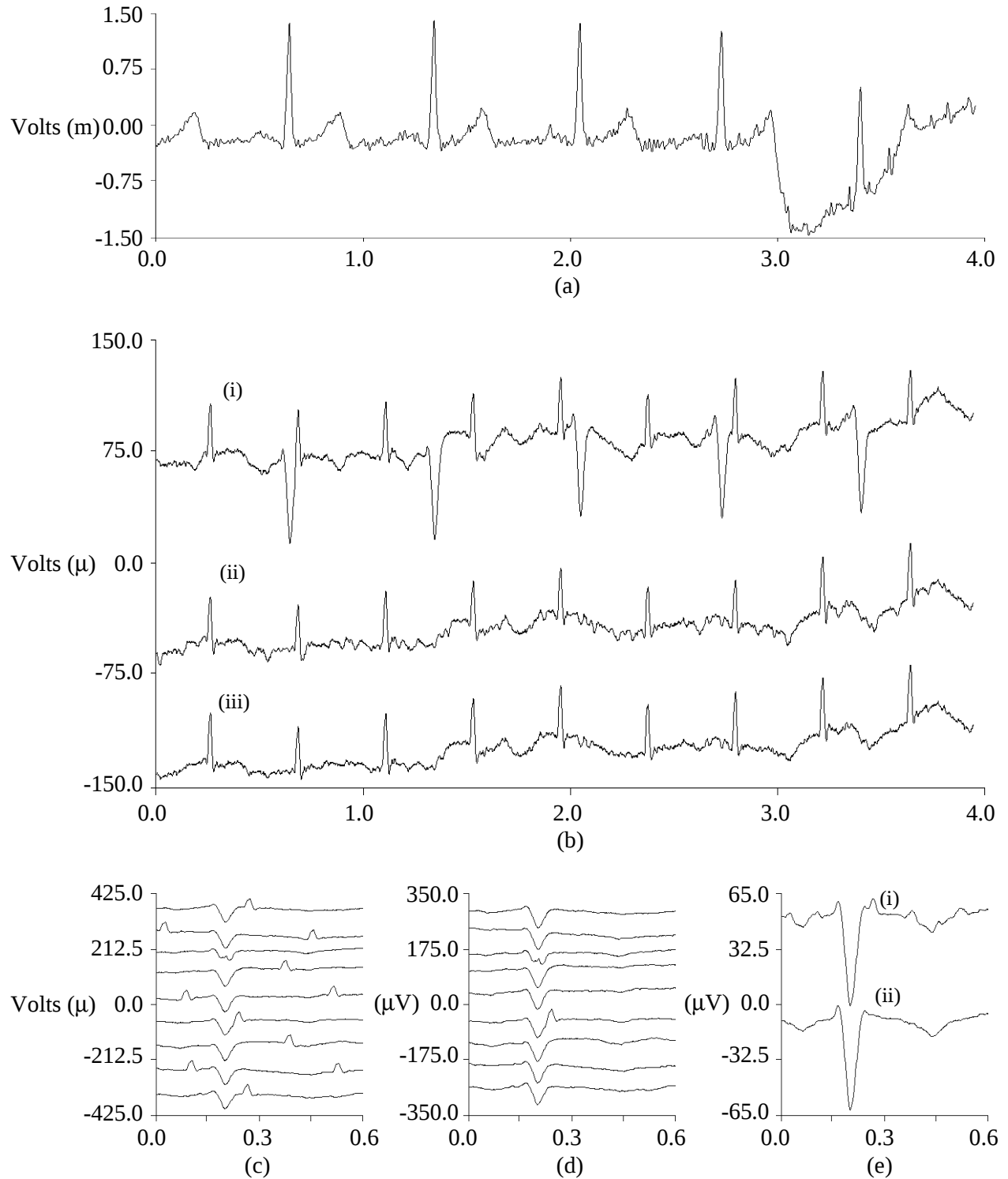


Fig. 2. IC clinical data from patient 3 (all x-axes in seconds). (a) Thoracic ECG (b)(i) IC's ECG. (b)(ii) IC's ECG after cancellation without modifying each maternal ECG complex before averaging. (b)(iii) IC's ECG after cancellation with modifying each maternal ECG complex before averaging. (c) Original maternal ECG complexes of the IC's ECG. (d) Modified maternal ECG complexes of the IC's ECG. (e)(i) Average of the maternal ECG complexes of (c). (e)(ii) Average of the maternal ECG complexes of (d).