Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnLine 52-27 (2019) 421–426

Influence of System Configuration on the Quality of Non-Invasive Fetal Electrocardiography Measurement

Jindrich Brablik, Radana Kahankova, and Radek Martinek

Department of Cybernetics and Biomedical Engineering,
Faculty of Electrical Engineering and Computer Science, VSB - Technical University of Ostrava, 17. listopadu 2172/15, 708 00 Ostrava-Poruba, Czech Republic
jindrich.brablik@vsb.cz, radana.kahankova@vsb.cz, radek.martinek@vsb.cz

Abstract: This paper introduces a pilot study investigating the influence of various parameters on the quality of electronic fetal monitoring based on non-invasive fetal electrocardiography. The investigation was carried out as a necessary step in development of an embedded system for fetal monitoring designed as a wearable device. The experiments included measurements of four different configurations on a subject at 34th week of pregnancy by means of 2.0 generation g.USBamp biosignal amplifier from g.tec medical engineering company. The study results in the recommendation of the most suitable system configuration and the electrode placement in terms of the signal quality and the clinical feasibility.

© 2019, IFAC (International Federation of Automatic Control) Hosting by Elsevier Ltd. All rights reserved.

Keywords**:** fetal electrocardiography, NI-fECG, electronic fetal monitoring, system configuration

1. INTRODUCTION

The fetal heart rate monitoring (fHR) in its early form was based on the intermittent observations of fetal heart sounds. Growing development of the science and technology enabled introduction of the first fetal monitors based on phonocardiography in the mid-20th century (Smyth *et al.*, 1958). However, these devices were not able to differentiate between the maternal and fetal heart sounds, so the automated fHR determination was not possible at that time (Carrera *et al.*, 2003).

Along with that, in 1953, among the first attempts to monitor fHR continuously by means of fetal electrocardiography took place (Smyth *et al.*, 1953). In the coming decade, several research groups focused on this topic consequently introduced improvements that are being used for internal monitoring in current obstetrics, such as the modern type of intrauterine catheter (Williams *et al.*, 1952), fetal scalp electrode (Hunter *et al.*, 1964), or cancellation system (Hon *et al.*, 1957). These findings led to better understanding of correlations be-tween the measured biological signals (fHR, uterine contractions, etc.) and the fetal health state (Hon *et al.*, 1996). Based on that in 1969, Huntingford and Pendleton published the first classification system of fetal heart rate (Huntingford & Pendleton, 1969).

Finally in late 1960s, the ultrasonic fetal Cardiotocography (CTG), a non-invasive method for simultaneous fHR and uterine contractions monitoring, was introduced. Subsequently, this method was accepted by the medical community, entered the delivery rooms in 1968 with the first commercially available fetal monitor, Hewlett-Packard 8020A, and remains there until today.

Although CTG is the most commonly used method of electronic fetal monitoring (EFM), there is number of evidence that decreases its credibility (Euliano *et al.*, 2013 and Sartwelle, 2012). According to Sartwelle (2012), CTG is unreliable especially for the courtroom use due to its false-positive profile, which results in a significant economic loss. Despite all mentioned, Doppler-based EFM continues as the standard of care throughout the World.

Fetal Electrocardiography (fECG) is one of the most promising methods in terms of replacing conventional monitoring methods using CTG (Reinhard *et al.*, 2010). The fetal well-being is assessed based on the electric potentials sensed by means of electrodes placed on the maternal body (non-invasive method, NI-fECG) or directly on the fetal scalp (invasive fECG monitoring). The fetal heart rate is calculated from the detected RR intervals and thus this method is able to monitor fHR variability more accurately (Jezewski *et al.*, 2017). Moreover, both mother and fetus are not exposed to any kind of radiation. Uterine contractions can be also monitored by sensing the electrical activity on the maternal abdomen. This method is known as electrohysterography and it is potentially more accurate for uterine activity monitoring than intra-uterine pressure catheter (Jacod *et al.*, 2010). Therefore, NI-fECG is capable to fully replace the conventional monitoring by means of CTG (Graatsma *et al.*, 2010).

Since for NI-fECG monitoring the ECG electrode is not directly attached to the fetus, it suffers from high amount of interference and artifacts that are being sensed with the signal of interest. Specifically, maternal electrocardiogram (mECG) contains almost the same frequencies and temporally is recorded concurrent with fECG, and it is not a trivial task to separate them (Christov *et al.*, 2013). Thus, advanced signal processing methods can be helpful in increasing the applicability of NI-fECG

Nevertheless, contrary to adults ECG research, the research community focused on fetal ECG signal processing suffers from lack of open access databases for the evaluation of the algorithms. Moreover, this method has not been standardized in terms of electrode placement, which varies according to the fetal position (Rooijakkers *et al.*, 2014). Therefore, each of the available databases includes different

2405-8963 © 2019, IFAC (International Federation of Automatic Control) Hosting by Elsevier Ltd. All rights reserved.
Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2019.12.700

data and it makes an objective evaluation nearly impossible. Some authors (Behar *et al*., 2014, or Martinek *et al*., 2016) introduced synthetic signal generators to produce data for their experiments, however, the results obtained using artificial test signals often differ from those performed on signals from clinical practice. Therefore, the real measurements need to be carried out in order to provide the evaluation of the system performance.

In this paper, we introduce the practical issues associated with the real measurements of the NI-fECG. We also propose the optimal system configuration to acquire high quality NI-fECG recordings. This is a vital condition for the fECG extraction algorithms to perform well. We also provide the evaluation of various measurement deployments. Based on that, we suggest the optimal electrode placement in accordance with the system configuration in terms of its clinical feasibility and the quality of the output signals.

2. PRACTICAL ISSUES

This chapter introduces the main practical issues associated with the fECG measurement, namely electrode placement and system configuration.

2.1 Electrode Types and Placement

Different types of NI-fECG devices use diverse types electrodes and their deployment. Various elelectrodes and the approaches are associated with improving Common-Mode Rejection. There are following types of electrodes used for NI-fECG monitoring:

1. *Sensing electrodes (SE)*. These electrodes measure the abdominal or thoracic signals, which are used as the inputs to the extraction system. The number of these electrodes differs among different commercial devices or research papers starting from 1 electrode (used for single channel techniques). The maximum of the electrodes used is associated with the clinical feasibility and both financial and computational costs.

2. *Common (or reference) electrode (CE)*. In (Hayes-Gill *et al.*, 2003), the authors recommend the CE to be placed opposing the location of at least 3 sensing electrodes such that the line taken between the CE and each of the SE passes through the womb of the pregnant subject.

3. *Active Ground/Ground reference (GND).* Some authors (Taylor *et al.*, 2003) recommend to place the GND adjacent to the navel, while others prefer to locate it on the sides of the abdomen (Behar *et al.*, 2019), on the back (Vullings, 2010) or even on the left thigh (Jezewski *et al.*, 2012).

There are significant differences in electrode deployment among the databases, different researchers and also the commercially available devices, as illustrated in Fig. 1. While the positioning of the measurement electrodes does only influence the magnitude or polarity of the signal, the placement of common reference electrode (blue) and the active ground (black) causes significant changes in the recorded signals since it may help in minimizing both the polarization potential and the maternal component. Therefore, it may significantly influence the performance of the extraction algorithms. The optimal number of electrodes may also differ for each extraction algorithm since blind source separation methods (such as independent Component analysis or principle component analysis) performs better with high number of abdominal inputs whereas a multi-lead system using an adaptive algorithm requires low number of abdominal electrodes but at least one thoracic reference electrode (Kahankova *et al*., 2019)..

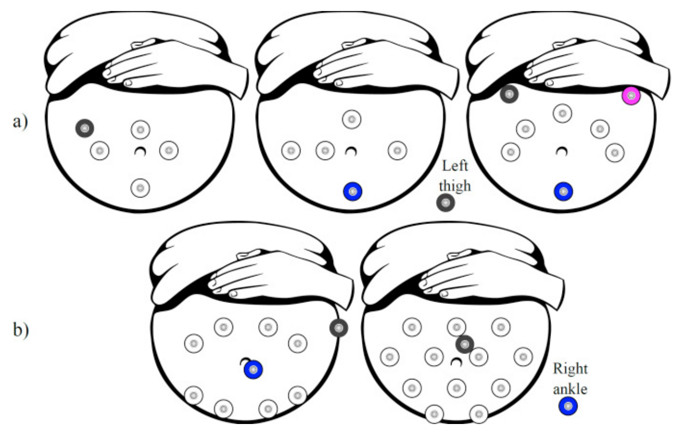

Fig. 1. Examples of the deployment of the measurement electrodes (abdominal – white, and chest– purple), common reference (blue), and the active ground (black): a) from left: commercially available device MONICA AN24, positioning used in publically available databases ADFECGDB and NIFEADB; b) from left: Vullings (2010) and Taylor et al.*, 2003.*

2.2 System Configuration

The measurement system configuration is an important factor influencing the quality of the fetal monitoring. Among the most important parameters one has to keep in mind are:

1. *Ground electrode placement.* This electrode is used to provide common potential for the measurement system. It is needed for getting differential voltage and significantly increases common mode rejection by subtracting the same voltages (power line, RF and other superposed signals) showing at active (sensing) and reference electrodes. Ground electrode can be place anywhere on the body. Its position is generally not relevant, because it does not contribute to the measured waveform.

2. *Reference electrode placement.* This electrode is connected as a second input (V_{in-}) to differential amplifier. Its function is suppression of the unwanted signals (muscle and movement artefacts) in order to further improve the Common-Mode Rejection. For fetal monitoring the electrode is usually placed close to other sensing electrodes,

which may result in lower signal amplitude, but it dramatically suppresses the motion and muscle artefacts.

2.3 Signal Pre-processing

The preprocessing of the recorded signal and the extraction of the fetal component are vital for the electronic fetal monitoring system functioning. The main aim of these steps are to prepare the signal and extract the desired information about the fetal well being, usually assessed by the fetal heart rate.

The preprocessing stage includes the basic filtration of the signal according to the desired signal time-frequency properties. The most common preprocessing procedures, also utilized in this paper, are:

1. *Bandpass filtering* (cut-off frequencies 0.5 and 100 Hz);
2. *Notch filtering* (according to the location Notch filter set to 60 Hz or 50 Hz);
3. *Bipolar signal derivation* (subtraction of two signal measured by sensing electrodes).

The fetal ECG extraction can be performed using a great variety of methods, which can be divided based on the inputs needed for their functioning:

1. Combined Source (CS) methods. These methods are effective in reducing the noise that can be identified and recorded and thus used as the reference input of the adaptive system. In case of the fECG signal, the signal considered as the noise is the maternal ECG, which can be recorded by means of electrode placed on the maternal thorax. This signal is assumed to contain only maternal component. An adaptive algorithm is able to estimate the maternal component contained in the abdominal electrocardiogram based on the given reference signal. By subtracting this estimated mECG signal, the estimated fECG signal can be obtained.
2. Abdominal Electrodes Sourced (AES) methods. These methods use the inputs measured by the abdominal electrodes only and thus do not require the additional chest channels. The maternal component to be suppressed is estimated from those inputs, usually multiple of them.

Recently published review reveals that clinical tests should be performed in order to create a recommendation for electrode placement according to the stage of pregnancy, fetal position, number of fetuses, and the algorithm used for the extraction. This article will provide an initial investigation in this matter.

3. MATERIAL AND METHODS

In this section, we describe the measurement system and the deployment used for the experiments.

3.1 Measurement System

As a measurement system we used 2.0 generation g.USBamp biosignal amplifier (Fig. 2) from g.tec medical engineering company, designed mainly for investigation of brain, heart and muscle activity. System features 16 DC-coupled simultaneously sampled analog input channels with 24-bit resolution, sampling frequency up to 38.4 kHz, ± 250 mV and biosignal pre-amplifier. Channels are clustered into four groups per four channels with separate ground and reference inputs, which allows measurement of up to four subjects at the same time. As a preprocessing, internal digital bandpass and notch filters as well as bipolar derivation can be applied to each measured channel. For advanced timing synchronization with external events, digital triggering inputs and outputs can be used. Input channels are designed to be compatible with both passive and active electrodes. System offers easy configuration, setup and high-speed online data processing for SIMULINK and LabVIEW as well as driver package/API for other programming languages.

Fig. 2.Measurement system: generation 2.0 g.USBamp (The MathWorks, 2019).

For our research we developed a custom application in LabVIEW development environment (using the provided LabVIEW API) that allows complex configuration of g.USBamp system, data logging to .tdms (Technical Data Management Streaming) files and basic signal processing (peak detection and heart rate calculation). Based on brief experimentation we employed following configuration when conducting measurements described in next section. Measurement with this configuration provided the highest quality signals where noise and movement artefacts were significantly suppressed.

- Sample rate 600 Sa/s
- Ground and reference inputs for all groups interconnected to single potential.
- Bandpass 8th order Butterworth approximation filter with low cutoff frequency f_L = 0,5 Hz and high cutoff frequency f_H = 60 Hz.
- Notch 4th order Butterworth approximation filter with f_L = 48 Hz and f_H = 52 Hz
- Bipolar derivation between sensing electrodes (Fig. 1 white) and selected reference sensing electrode (Fig. 1 blue).

3.2 Measurement Deployment

To ensure feasibility and reproducibility of the experiments and to cover most of the available electrode placements, as depicted in Fig. 1, we designed the universal measurement deployment, see Fig. 3. The design included total of 16 electrodes that were positioned on the body of the pregnant woman – 14 on the abdomen, one on the right ankle, and one on the left thigh. The switch between the individual configurations was performed by changing the inputs of the system.

It is important to note that we omitted some of the electrodes that were redundant (i.e. the recordings included almost identical signals). This lowered the number of electrodes in some of the configurations, such as the one used in Taylor *et al.*, 2003.

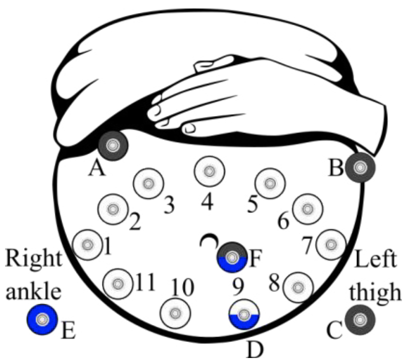

Fig. 3. Measurement deployment. Sensing electrodes (white 1 – 11), ground reference (black A, C, F), and common reference electrode (blue D, E, F).

Four different configurations of the measurement system were tested:

1. *Jezewski.* This configuration was used in the ADFECGDB database (Jezewski *et al.*, 2012). It includes 4 SEs (1, 2, 4, and 7), the GND (C) placed on the left tight and the reference (D) on the bottom of the abdomen.
2. *Behar.* This configuration was used in the NIFEADB database (Behar *et al.*, 2019). It includes 4 SEs (1, 3, 4, 5, and 7), the GND (A) placed on the left tight and the reference (D) on the bottom of the abdomen.
3. *Vullings.* The configuration introduced in the investigation of Vullings (2010) includes 8 SEs (2, 3, 5, 6, 8, 9, 10, and 11), the GND (B) placed on the left waist, and the reference (F) is placed adjacent to the navel.
4. *Taylor.* This configuration of Taylor *et al.* (2003) includes 12 sensing electrodes (1 – 11); the GND (F) is placed adjacent to the navel and the common reference (E) on the right ankle.

Table 1 summarizes the above mentioned configurations and links them to the design of the general measurement deployment introduced in Fig. 3.

Table 1: Configurations tested

Configuration Name	Sensing electrodes	Ground reference	Reference
Jezewski	1, 2, 4, 7	C	D
Behar	1, 3, 4, 5, 7	A	D
Vullings	2, 3, 5, 6, 8 – 11	B	F
Taylor	1 – 11	F	E

RESULTS

The experiments included measurements on a real subject in 34[th] week of pregnancy. The total of 14 electrodes were positioned on the abdomen in the way to cover most of the commonly used electrode deployment as shown in Fig. 4.

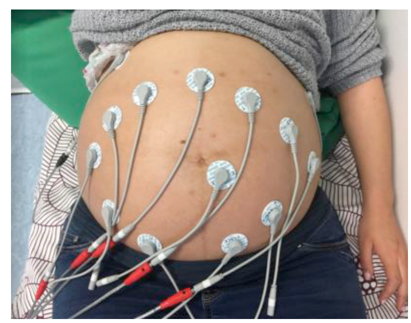

Fig. 4. Measurement deployment in real subject at 34[th] week of pregnancy.

Figures 5 – 8 show the resulting records of each configuration as listed in the Table 1. In each record, the fetal R peaks are marked. In the cases of the *Vullings* and *Taylor* configurations, only 5 signals of the best quality were plotted in figures 4 and 5, respectively. The recordings were shifted by 50 uV in order to enhance the clarity of the readings.

Besides the ratio between fetal and maternal component, the shape and orientation of the QRS complexes are among the most important factors for the quality of the maternal ECG suppression. For extraction algorithms, the QRS complexes should be either negative or positive. Contrary, if the QRS complex is biphasic, the algorithms show lower performance.

In the most of the signals in the *Jezewski* configuration, the magnitude of the fetal component is low in comparison with the maternal one (see Fig. 5). However, in the signal recorded by means of SE 4 and 7, the ratio between the fetal and maternal magnitude is low. Additionally, their orientation is the same (positive), and thus, the mECG suppression is feasible.

In the *Behar* configuration (see Fig. 6), the magnitude of the fetal component is comparable with the maternal one, especially in the abdominal signal recorded by means of sensing electrode 4, 5, and 7. Moreover, the placement of the sensing electrodes is convenient for the implementation of the configuration into the clinical practice since it offers a space for the placement of the conventional CTG probes if needed. It is also feasible to be incorporated into a wearable device (e.g. using belts or patch system).

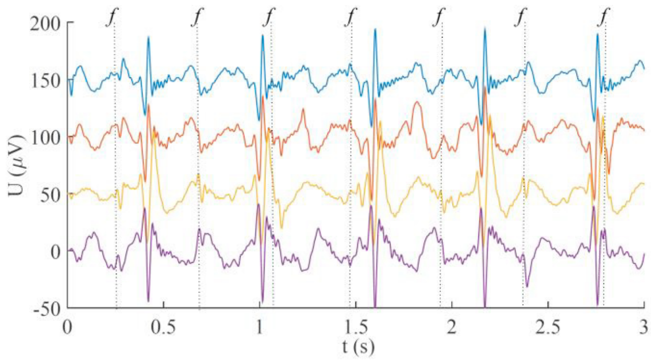

Fig. 5. The output signals of the sensing electrodes 1, 2, 4, and 7 (as listed in the Table 1) for the Jezewski configuration.

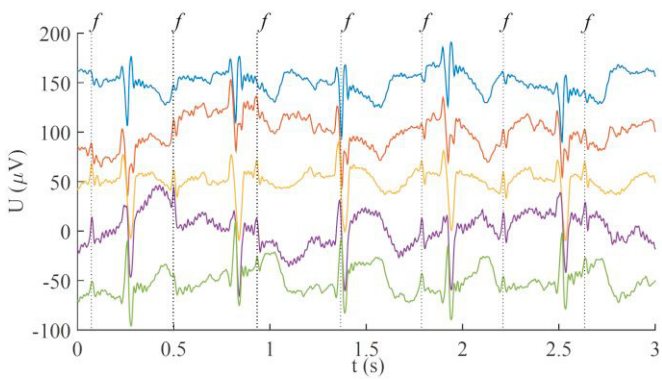

Fig. 6. The output signals of the sensing electrodes 1 – 5 (as listed in the Table 1) for the Behar configuration.

The quality of the recordings in the *Vullings* configuration can be considered as the lowest (see Fig. 7). Only 2 out of the 8 SE, i.e. the SE electrodes 5 and 6, are sufficient in terms of the fetal component magnitude. In the others, the fetal component is nearly not notable by the naked eye. The orientation of the maternal QRS complex is positive in the upper SEs (5 – 8), for the rest of them, the orientation is biphasic or mostly negative.

The magnitude of the maternal QRS complex in the *Taylor* configuration is highest among all of the tested configurations (see Fig. 8). The magnitude of the fetal component is significantly lower and the maternal QRS complexes are biphasic. Thus, the fetal ECG extraction would be challenging.

The above analysis of each record is summarized by Table 2. The results imply that *Behar* configuration is the most suitable in terms of the number of SE with a high quality signal, maternal:fetal magnitude ratio (m:f ratio). The only slight negative of this configuration is the morphology of the maternal QRS (mQRS) complex, which is biphasic in some of the signals, which could influence the fetal ECG extraction.

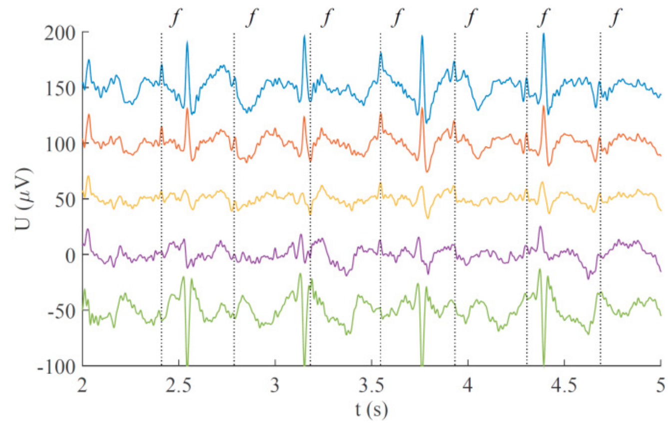

Fig. 7. The output signals of the sensing electrodes 5, 6, 7, 8, and 4 (as listed in the Table 1) for the Vullings configuration.

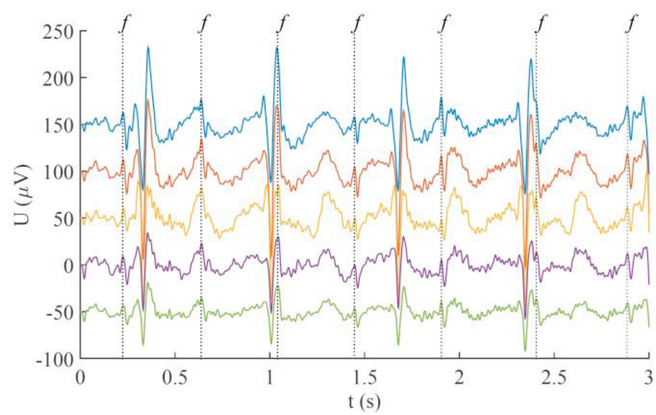

Fig. 8. The output signals of the sensing electrodes 2, 3, 5, 9, and 7(as listed in the Table 1) for the Taylor configuration.

Table 2: Tested configurations

Configuration Name	Best quality signal SE	m:f ratio	mQRS
Jezewski	3, 4	Low	Positive
Behar	2, 3, 4	Low	Negative/ biphasic
Vullings	5, 6	High	Positive
Taylor	2, 3, 9, 7	High	biphasic

CONCLUSION

This article investigated the influence of system configuration on the quality of NI-fECG monitoring. The main factors that were considered and tested were the electrode placement and the hardware system configuration. The results showed that the electrode placement herein denoted as *Behar* is the most suitable in terms of the signal quality and the clinical feasibility. Moreover, the paper introduced the optimal system configuration to ensure high quality input signals. This was necessary step in order to develop an embedded system for fetal monitoring designed as a wearable device for pregnant subjects. In the future research, it is necessary to test the configurations as well as the performance of the extraction algorithms for the different subject, in different stage of pregnancy and different fetal positions.

ACKNOWLEDGMENT

This article was supported by the Ministry of Education of the Czech Republic (Project No. SP2019/85). This work was supported by the European Regional Development Fund in the Research Centre of Advanced Mechatronic Systems project, project number CZ.02.1.01/0.0/0.0/16 019/0000867 within the Operational Programme Research, Development and Education. This work was supported by the European. Regional Development Fund in A Research Platform focused on Industry 4.0 and Robotics in Ostrava project, CZ.02.1.01/0.0/0.0/17 049/0008425 within the Operational Programme Research, Development and Education. This paper has been elaborated in the framework of the grant programme "Support for Science and Research in the MoraviaSilesia Region 2018" (RRC/10/2018), financed from the budget of the Moravian-Silesian Region.

REFERENCES

Behar, J. A., Bonnemains, L., Shulgin, V., Oster, J., Ostras, O., & Lakhno, I. (2019). Noninvasive fetal electrocardiography for the detection of fetal arrhythmias. *Prenatal diagnosis*, 39(3), 178-187.

Behar, J., Andreotti, F., Zaunseder, S., Li, Q., Oster, J., & Clifford, G. D. (2014). An ECG simulator for generating maternal-foetal activity mixtures on abdominal ECG recordings. *Physiological measurement*, 35(8), 1537.

Carrera, J. M. (2003). The technological development of fetal surveillance: a long history. In *Controversies in Perinatal Medicine* (pp. 22-39). CRC Press.

Carrera, J. M. (2003). The technological development of fetal surveillance: a long history. In *Controversies in Perinatal Medicine* (pp. 22-39). CRC Press.

Euliano, T. Y., Nguyen, M. T., Darmanjian, S., McGorray, S. P., Euliano, N., Onkala, A., & Gregg, A. R. (2013). Monitoring uterine activity during labor: a comparison of 3 methods. *American journal of obstetrics and gynecology*, 208(1), 66-e1.

Graatsma, E. M. (2010*). Monitoring of fetal heart rate and uterine activity* (Doctoral dissertation, Utrecht University).

Hayes-Gill, B. R., Barratt, C. W., & Pieri, J. F. (2014). *U.S. Patent No. 8,880,140*. Washington, DC: U.S. Patent and Trademark Office.

Hon, E. H., & Hess, O. W. (1957). Instrumentation of fetal electrocardiography. *Science*, 125(3247), 553-554.

Hon, E. H., & Quilligan, E. J. (1996). The classification of fetal heart rate. Childbirth: *The medicalization of obstetrics*, 2, 339.

Hunter, J. C. A., Braunlin, R. J., Lansford, K. G., & Knoebel, S. B. (1964). *U.S. Patent No*. 3,120,227. Washington, DC: U.S. Patent and Trademark Office.

Huntingford, P. J., & Pendleton, H. J. (1969). The clinical application of cardiotocography. BJOG: *An International Journal of Obstetrics & Gynaecology*, 76(7), 586-595.

Christov, I., Simova, I., & Abacherli, R. (2013, September). Cancellation of the ma-ternal and extraction of the fetal ECG in noninvasive recordings. In *Computing in Cardiology Conference* (CinC), 2013 (pp. 153-156). IEEE.

Jacod, B. C., Graatsma, E. M., Van Hagen, E., & Visser, G. H. (2010). A validation of electrohysterography for uterine activity monitoring during labour. *The Journal of Maternal-Fetal & Neonatal Medicine*, 23(1), 17-22.

Jezewski, J., Wrobel, J., Matonia, A., Horoba, K., Martinek, R., Kupka, T., & Jezewski, M. (2017). Is abdominal fetal electrocardiography an alternative to doppler ultrasound for FHR variability evaluation?. *Frontiers in physiology*, 8, 305.

Jezewski, J., Matonia, A., Kupka, T., Roj, D., and Czabanski, R. "Determination of fetal heart rate from abdominal signals: evaluation of beat-to-beat accuracy in relation to the direct fetal electrocardiogram," *Biomedizinische Technik/Biomed. Eng*., vol. 57, no. 5, pp. 383- 394, 2012.

Kahankova, R., Martinek, R., Jaros, R., Behbehani, K., Matonia, A., Jezewski, M., & Behar, J. A. (2019). A Review of Signal Processing Techniques for Non-Invasive Fetal Electrocardiography. *IEEE Reviews in Biomedical Engineering.*

Martinek, R., Kelnar, M., Koudelka, P., Vanus, J., Bilik, P., Janku, P., ... & Zidek, J. (2016). A novel LabVIEW-based multi-channel non-invasive abdominal maternal-fetal electrocardiogram signal generator. *Physiological measurement*, *37*(2), 238.

Reinhard, J., Hayes-Gill, B. R., Yi, Q., Hatzmann, H., & Schiermeier, S. (2010). Comparison of non-invasive fetal electrocardiogram to Doppler cardiotocogram dur-ing the 1st stage of labor. *Journal of perinatal medicine*, 38(2), 179-185.

Rooijakkers, M. J., Song, S., Rabotti, C., Oei, S. G., Bergmans, J. W., Cantatore, E., & Mischi, M. (2014). Influence of electrode placement on signal quality for ambulatory pregnancy monitoring. *Computational and mathematical methods in medicine*, 2014.

Sartwelle, T. P. (2012). Electronic fetal monitoring: a bridge too far. *Journal of Legal Medicine*, 33(3), 313-379.

Smyth, C. N., & Farrow, J. L. (1958). Present place in obstetrics for foetal phonocardiography and electrocardiography. *British Medical Journal*, 2(5103), 1005.

Smyth, C. N. (1953). Experimental electrocardiography of the foetus. *The Lancet*, 261(6771), 1124-1126.

Taylor, M. J., Smith, M. J., Thomas, M., Green, A. R., Cheng, F., Oseku-Afful, S., ... & Gardiner, H. M. (2003). Non-invasive fetal electrocardiography in singleton and multiple pregnancies. BJOG: *An International Journal of Obstetrics & Gynaecology*, 110(7), 668-678.

The MathWorks, Inc. G.tec Support from Data Acquisition Toolbox. *MathWorks* [online]. 2019. Available at: https://www.mathworks.com/hardware-support/gtec.html

Vullings, R. (2010). Non-invasive fetal electrocardiogram: analysis and interpretation. Eindhoven: Technische Universteit Eindhoven.—2010.—225 p.

Williams, E. A., & Stallworthy, J. A. (1952). A simple method of internal tocography. *The Lancet*, 259(6703), 330-332.