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QRS triggered averaging for superimposed PPG separation

M. Schubert[1*], F. Samann[2] and T. Schanze[1]

[1] *Institute for Biomedical Engineering (IBMT), Faculty of Life Science Engineering (LSE), Technische Hochschule Mittelhessen (THM) - University of Applied Sciences, Gießen, Germany*
[2] *Department of Biomedical Engineering, University of Duhok, Duhok, Kurdistan Region-Iraq*
[*] *Corresponding author, email: marvin.schubert@lse.thm.de*

Abstract: The current technology of electronic fetal heart rate monitoring shows inaccurate nonreassuring fetus status during intrapartum period. Recently, the fetal pulse oximetry has been introduced as an alternative technique to assess fetal oxygen status. However, the drawback of non-invasively recorded fetal PPG is that the fetal PPG signal is very weak and mixed with maternal PPG signal. In this paper we introduce a method based on QRS triggered averaging to separate the weak fetal PPG signal from the superimposed PPG signal. The approach has been successfully tested on a simple experimental setup with two probands as a substitute for mother and fetus.

I. Introduction

Measuring the fetal photoplethysmogram (PPG) signal using non-invasive pulse oximetry provides more reliable information about the status of fetus than the current electronic fetal heart rate monitoring method. However, the main challenge of the non-invasive transabdominal fetal pulse oximeter method is the extraction of the weak fetal PPG signal from a superimposed PPG that contains information about the mother and fetus together. In literature, two approaches were suggested to recover the weak fetal signal: using adaptive filtering technique [1] or frequency-domain filtering methods [2]. In this paper, a simple approach for QRS triggered averaging of superimposed PPG is proposed. This method is related spike-triggered averaging (STA) which is used in sensory neuroscience to recover neuronal signal components that are phase coupled/correlated to the simultaneously recorded action potentials (spikes) of a neuron [3]. Since the maternal heart rate (60-90 bpm) is quite different from the fetal heart rate (120-160 bpm) [4], and the ECG and PPG signals are correlated to one another, it is possible to consider the event of QRS in the fetal ECG signal to extract the fetal PPG signal from the mixture.

II. Material and methods

The approach of QRS triggered averaging for separating superimposed PPG signals is tested on a simple set-up. To do this, two subjects each place one finger on a specially designed PPG device, see Fig. 1. Person A acts as a substitute for the mother, person B as a substitute for the fetus. The device has two LEDs with a peak wavelength of 700 nm and an array of four low-cost silicon photodiodes connected in parallel by a subsequent current-voltage transformer. The light passes within the fingers from the LED to the photodiodes, so the measurement corresponds to the transmission mode.

In addition to this optically induced superimposed PPG (Fig. 1), the ECGs are recorded for both subjects, as well as a reference PPG (BioPac OXYSSH) for the "mother". The usually higher heart rate of the "fetus" is produced by a short workout before the measurement.

Due to the strong dependence between ECG and PPG, the R peaks of the QRS complexes can be used as triggers to average the superimposed PPG. The R peak has a high prominence and can easily be determined with conventional peak finders e.g. in MatLab or Python. For clarity, the averaging window is set to the length of 3 "maternal" heart beats.

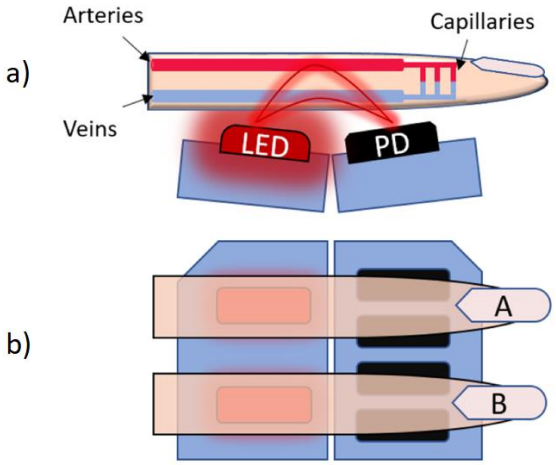

Figure 1: Scheme of the experimental setup. a) side view. The light emitted by the LEDs passes through the finger and reaches the photodiodes (PD). b) top view. The fingers are placed side by side, each is covering one LED and two photodiodes of the PD-array.

III. Results

The recordings have a sample rate of 1000 Hz and a length of 100 seconds. In addition, a high pass filter of 0.05 Hz and a low pass filter of 50 Hz was used for the PPG. The heart rate of the "mother" was 64.5 ± 3.3 bpm and that of the "fetus" was 90.2 ± 3.1 bpm. With these settings and recording length, the “fetal” PPG could be calculated from averaging 103 time windows, see Fig. 2.

IV. Discussion and conclusions

The direct comparison between the determined “maternal” PPG and the reference PPG shows that our method extracts the correct pulse curve. This part is also evident in the superimposed PPG. Slight differences between the PPG reference and our result could be attributed to different filter settings and a small difference in the wavelength (660 nm vs. 700 nm).

The averaged PPGs gradients become softer or blurred towards the end of the averaging window. This is because the subjects' heart rates change slightly over the course of the experiment.

The method of QRS triggered averaging of superimposed PPG signals has worked well under simple laboratory conditions. However, our approach may be a simple but yet powerful method to determine the oxygen saturation of unborn children.

Future work may address the robustness of the method, e.g. in terms of heart rate variability. Likewise, the question of how many averages are necessary to obtain an adequate PPG and, of course, under more realistic conditions.

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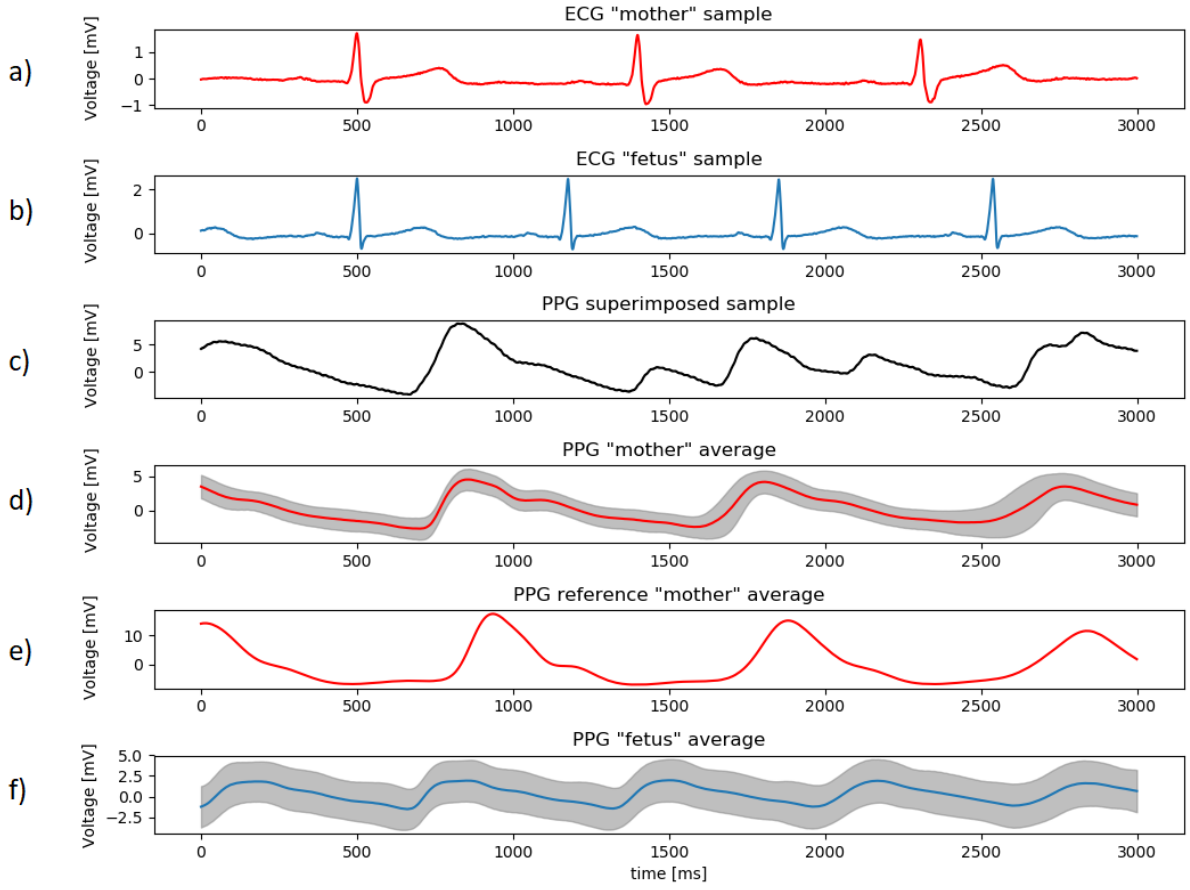

Figure 2: Separation of superimposed PPG by QRS triggered averaging. a) “maternal” ECG, b) “fetal” ECG, c) superimposed PPG from the developed sensor, d) result of the averaging process for the “maternal” PPG with SD of mean, e) reference PPG for the “mother”, f) result of the averaging process for the “fetal” PPG with SD of mean. Averages are calculated from 103 windows.