

INFANT RESPIRATION AND HEART RATE MONITORING WITH EMFI SENSOR

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Abstract – An EMFi sensor based measurement system for monitoring of respiration and heart rates of an infant is developed in this study. The EMFi sensor is located in the crib between the mattress and sheet and the infant is sleeping on top of the sensor. The EMFi sensor was found to be functional especially in the measurement of respiration rate. The measurement system developed in this study is unobtrusive and comfortable for the infant and no wire attachments are needed.

Keywords: EMFi, sensor, respiration rate, heart rate, unobtrusive monitoring

1. INTRODUCTION

Measurement of vital signals, such as heart and respiration rates, reveals valuable information on the physiological state of a patient. However, there have been relatively few methods to record these variables without a direct contact between an electrode and skin [1] until now. Nowadays, new sensor materials offer a possibility to monitor vital signals unobtrusively. Thin sensors which are made of these materials can be easily integrated into clothing ("wearable") or into daily life objects, e.g. a chair or a bed ("ubiquitous").

During the last few decades the amount of devices using new sensor materials, such as polyvinylidene fluoride (PVDF) and ElectroMechanical Film (EMFi) have been increased remarkably. PVDF is a piezoelectric plastic material having a homogenous and solid structure whereas the structure of EMFi material is cellular. However, both materials generate a charge when they are mechanically deformed and thus operate similarly. With normal measurement arrangement, PVDF and EMFi are not suitable for static measurements and only the change of an external force can be measured. Hence, the sensors made of these materials are useful especially in the measurements of physiological pulsatile signals.

For cardiorespiratory monitoring, several devices based on thin and flexible sensor materials have been developed, and especially PVDF has been used as a sensor material. For instance, Choi and Jiang developed a wearable cardiorespiratory sensor device for long-time monitoring [2]. The device consists of a belt sensor with PVDF film for measuring respiratory cycle and two conductive fabric sheets as heart rate electrodes. Niizeki *et al.* utilized PVDF cable sensors to detect the respiratory activity and ballistic movement due to heartbeat [3]. The cable sensors were

located horizontally along the bed surface, covering the upper half of the subject's body. Siivola examined the use of PVDF to record the body movements caused by the respiration and cardiac action in lying position [1]. The PVDF elements were placed on the bed mattress. Chiu *et al.* used a sensor patch with a structurally curved PVDF for simultaneous heartbeat and respiration detections [4]. The curved structure was used to enhance the detection of the signals. Siivola *et al.* used ETMF (EMFi was previously known as ETMF) in the measurement of respiration [5]. The ETMF detector was placed on a bed at the level of the diaphragm. A more comprehensive review about the use of film-type sensor materials in measurement of cardiorespiratory signals has been previously published [6].

This study concentrates on the development of an EMFi sensor based measurement system for unobtrusive monitoring of the respiration and heart rates of an infant. Cardiorespiratory monitoring has become widely used in the care of infants with a variety of acute and chronic disorders [7]. In addition, diseases such as sleep apnea syndrome and sudden infant death syndrome (SIDS) usually happen during sleep and are thus difficult to detect without continuous monitoring of vital signals [2, 8]. SIDS is defined as the sudden death of an infant under one year of age, which remains unexplained after a thorough case investigation [9]. Also, monitoring of heart rate and respiration plays an important role in neonatal intensive care [10].

Some devices developed for unobtrusive monitoring of the respiration and heart rates of an infant or a child have been reported. For example, Wang *et al.* introduced an unconstrained cardiorespiratory monitor for premature infants [10]. PVDF film was used as sensory material; the sensor was placed on the bed to pick up pressure fluctuation caused by the respiratory movements and heart beats of a premature infant. Higgins and Carr Everbach developed a prototype device measuring the heart and breathing rates of an infant in the crib [11]. The device is based on piezoelectric polymer sheets placed on the floor of a crib. Also other sensor technologies have been utilized in unobtrusive monitoring of vital signals. For instance, Catrysse *et al.* developed a wireless monitoring suit for monitoring of electrocardiogram (ECG) and respiration rate of children in a hospital environment [12]. They developed textile electrodes for the measurement of ECG.

The structure of this paper is as follows. Section 2 gives some theoretical background information on the EMFi sensor material used in this study and also on the

measurement of respiration and heart rates. Section 3 introduces the measurement system. Test measurements are discussed in Section 4. Section 5 presents the results and Section 6 concludes the study.

2. THEORETICAL BACKGROUND

2.1. EMFi material

EMFi is a thin and elastic polypropylene film having a special cellular structure. The internal cellular structure is made by stretching the polypropylene (PP) film preform during manufacturing both in longitudinal and transversal directions [13]. The film is charged by the corona discharge method [14] and metallized on both sides to provide electrodes.

EMFi material consists of three layers: smooth and homogenous surface layers and a dominant, thicker midsection full of flat voids separated by polypropylene layers [15]. Fig. 1 shows a SEM (scanning electron microscope) picture of the structure of the EMFi material.

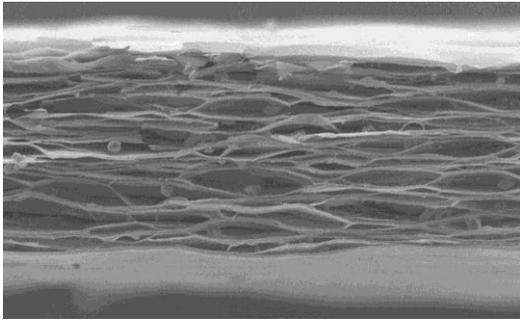


Fig. 1. The structure of EMFi material. Photo: courtesy of VTT.

The sensor operation has a capacitive nature and it is based on thickness variations in the midsection of the film caused by an external force [15]. The electromechanical signal of EMFi arises mainly from the movement of the charged polymer layers with respect to the other layers and is not of piezoelectric origin [16]. Hence EMFi is sometimes called as ‘quasi-piezoelectric’ material.

The EMFi material is sensitive to dynamic forces exerted normal to its surface. The output voltage of the sensor is defined as

$$\Delta V = (1/C) \cdot S_q \cdot \Delta F, \quad (1)$$

where C is the film capacitance, S_q is the sensitivity of the sensor and ΔF is the force impact [16]. The pyroelectric response of EMFi is very weak [17].

EMFi material is commercially available through a Finnish company Emfit Ltd (Vaajakoski, Finland). EMFi material used here was 70 μm thick with aluminium electrodes.

2.2. Respiration and heart rates

Respiration rate is defined as the number of breaths per minute [18]. A typical resting value is 12 for an adult [18]. For an infant, the respiration rate is higher. Hoppenbrouwers

et al. studied spontaneous respiratory rate and variability as a function of age and sleep state in full-term infants [19]. For infants from birth to three months of age respiratory rates and variability decreased. Mean respiratory rates from about 50 breaths per minute to 25 breaths per minute were reported, depending on the age and the sleep and waking states.

Heart rate, the number the heart contracts per minute, normally varies from under 50 beats per minute to over 200 beats per minute in maximal exercise for an adult [18]. Harper *et al.* has been reported the mean heart rate values for infants [20]. For infants from birth to three months age the mean heart rate values from about 165 beats per minute to 115 beats per minute were reported in control infants group, depending on the age and the sleep and waking states.

The heart rate is conventionally determined by measuring electrocardiogram (ECG) with electrodes attached to the chest wall. However, in this study the measurement is based on ballistocardiography (BCG). The origin of the BCG signal is in the mechanical activity of the heart whereas the ECG describes the electrical action. However, BCG and ECG are both measuring the same event, contraction of heart. The BCG signal is generated by the movement of heart and blood [21] and it consists of several segments and has different shape in contrast to the ECG signal. Most relevant components in the BCG signal exist within frequencies from 1 to 20 Hz [21]. If only the contraction of heart is measured, a lower frequency range corresponding to heart rate can be analysed.

The BCG signal can be measured with force or acceleration sensors [22]. Similar sensors can also be used to measure respiration rate by detecting the movement of chest due to respiration.

3. MEASUREMENT SYSTEM

The measurement systems consist of an EMFi sensor, a charge amplifier and a 16-bit AD-converter measuring the charge developed by the sensor.

The EMFi sensor detects the movements provided by respiration and pulsation of the heart and converts them into an electrical signal. The sensor has a shape of rectangle and size 5 cm x 7 cm. The sensor has a two-layer folded structure: the inner surface of the sensor acts as a signal electrode and the outer surface as a grounded electric shield. The connections to the electrodes were done with tin plated copper tape. Finally, to seal the sensor against moisture, the sensor was covered with plastic sheeting. The total thickness of the sensor is 0.25 mm. The connection to the AD-converter from the sensor was made via coaxial wires. The data was collected and analysed with Matlab® software.

4. TEST MEASUREMENTS

Signals arising from body movements are usually massive and they interrupt the recognition of the other signals. Thus the respiration and heart rates are measured here at rest to minimize the effect of movement artifacts.

The cardiorespiratory signals of two infants were measured during sleep with the developed measurement system. The EMFi sensor was located in the crib, between the mattress and sheet. During the test measurements, the infant was sleeping in the crib on top of the sensor in supine position. The sensor was located beneath the thorax of the infant to capture the signal arising from the respiration and pulsation of the heart. Fig. 2 shows the test measurement setup.

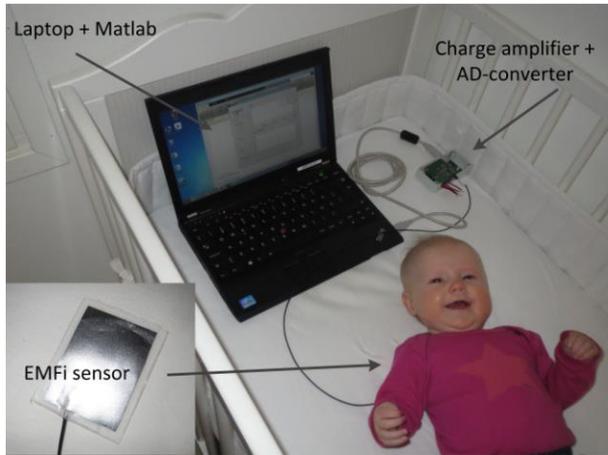


Fig. 2. The test measurement setup. The cardiorespiratory signal is measured with the EMFi sensor located in the crib beneath the thorax of the infant. For clarity, the sensor (shown in details in the lower left corner) is on top of the sheet in the figure.

The first test subject (S1) was a 3-months old female, body mass 5820 g and height 61 cm. The second test subject (S2) was a 2-months old male, body mass 5175 g and height 59 cm. Both infants were full term.

5. RESULTS

Figs. 3 and 4 show examples of the original measured signals. The main component in the signals is respiration on which the smaller amplitude heart pulsation signal is riding. Fig. 3 shows the original EMFi sensor signals measured from infant S1 and Fig. 4 from infant S2.

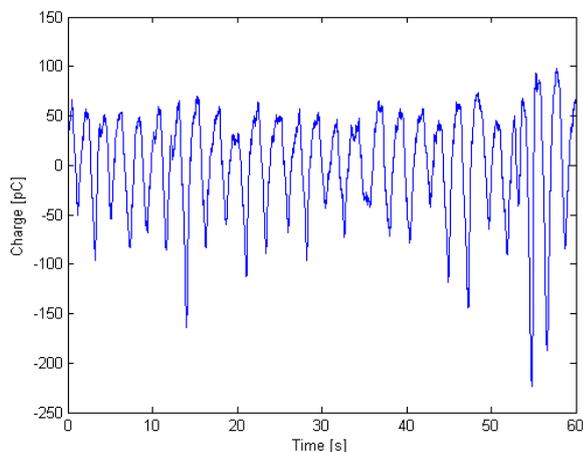


Fig. 3. Original EMFi sensor signals measured from infant S1.

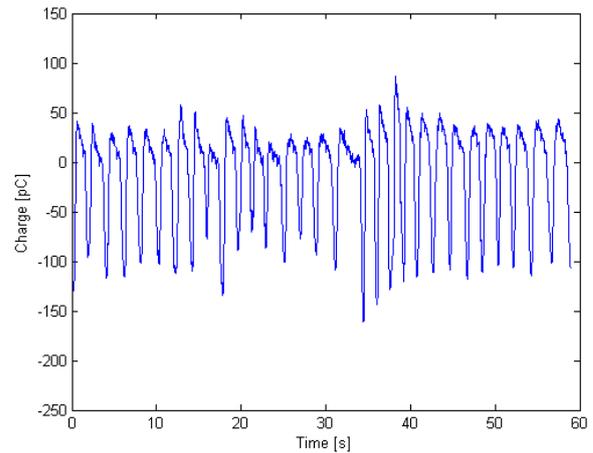


Fig. 4. Original EMFi sensor signals measured from infant S2.

To determine the respiration rate, the signals were filtered with Butterworth second order low pass filter with a cut-off frequency of 1 Hz. Fig. 5 shows an example of filtered respiration rate signal measured from the infant S1. The respiration rate of 28 breaths per minute can be calculated from the figure.

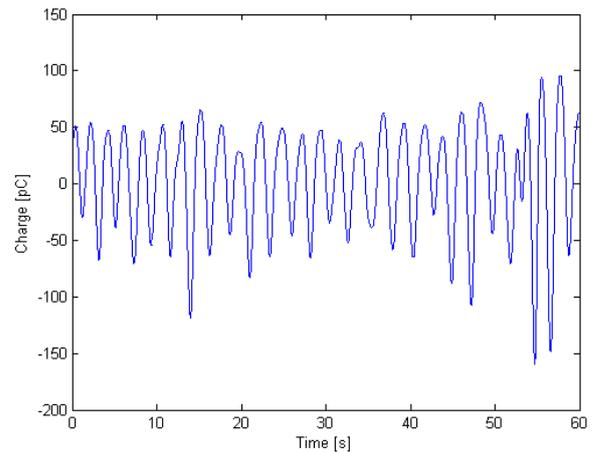


Fig. 5. Filtered signal for respiration rate. The signal is measured from infant S1.

To determine the heart rate, the signals were filtered with Butterworth second order pass band filter. The pass band from 1.5 Hz to 3.5 Hz was used, corresponding to heart rates from 90 beats per minute to 210 beats per minute. Fig. 6 shows an example of the filtered heart rate signal measured from the infant S1. Only a section of 20 seconds is shown to distinguish the separate pulsations. The detected heart pulsations are marked in Fig. 6 with red circles. As can be seen, the amplitude of the heart rate signal varies due to the respiration.

The respiration rate of 28 breaths per minute and the heart rate of 126 were computed from the signal presented in Fig. 3 (infant S1). From the signal presented in Fig. 4 (infant S2) the corresponding values were 33 breaths per minute and 141 beats per minute. These results correspond to the findings reported by Hoppenbrouwers *et al.* [19] and Harper

et al. [20]: the mean respiratory rate was found to vary from 30.3 to 47.6 for 2-months old infants and from 25.1 to 40.6 for 3-months old infants and the heart rate from 129.3 to 165.7 for 2-months old infants and from 117.3 to 150.8 for 3-months old infants, depending on the sleep and waking states.

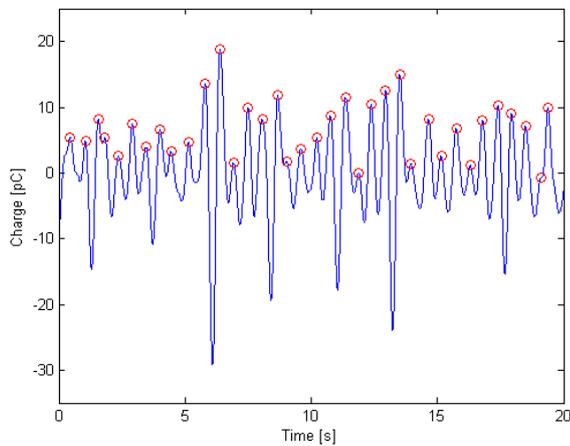


Fig. 6. Filtered signal for heart rate. The signal is measured from infant S1.

6. CONCLUSIONS

The measurement system developed here is designed to be unobtrusive and comfortable for the infant. Traditional monitoring techniques based on electrodes attached on skin may damage the skin of an infant [10]. In addition, with the developed measurement system, no wires are attached to the infant.

Continuous and unobtrusive cardiorespiratory monitoring of an infant in a hospital environment or at home is often required. Some diseases (e.g. sleep apnea syndrome or SIDS) usually happen during sleep [2,8]. It is indicated, that apnea is not a precursor to SIDS, and thus, apnea monitors are not useful for reducing the occurrence of SIDS [7, 9]. However, there are other groups of infants for whom the use of a home cardiorespiratory monitor is justified [7]. For example, home cardiorespiratory monitoring may be used e.g. to allow the rapid recognition of apnea or respiratory failure [7].

We have measured here the respiration and heart rates of two infants. The respiration was clearly seen in the measured signals and the obtained respiration rates were realistic. Also the heart rate values obtained were realistic. However, the pulsation of heart provides a rather small change in the signal and is thus more vulnerable to wrong rate values than the respiration rate. Kärki and Lekkala have been previously evaluated the capability of EMFi and PVDF sensor to measure heart and respiration rates correctly [23]. The heart and respiration rates measured with the EMFi and PVDF materials were compared to reference signals (ECG for the heart rate and a thermistor for the respiration rate).

To further evaluate the sensor, more test measurements are still needed. Also, the effect of movement artifacts should be considered more thoroughly. However, the EMFi sensor developed in this study was found to be functional

especially in the measurement of respiration rate. Also the measured heart rates were realistic, but more easily interrupted by movement artifacts (also respiration). Thus the developed measurement system would be useful in measurements where exact heart rate values are not needed. Application areas can be found e.g. from home care. The measurement system developed in this study is unobtrusive and comfortable for the infant and several advantages can be found when compared to present-day systems (e.g. ECG).

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