# The Potential of EMFi Sensors in Heart Activity Monitoring

Jarmo Alametsä, Alpo Värri, Mikko Koivuluoma, Laurentiu Barna
Digital Media Institute, Tampere University of Technology, Tampere, Finland

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## 1. Introduction

The unobtrusive monitoring of patients and people's general physiological state using wearable sensors has attracted a lot of attention in recent years. Our research group has studied the possibilities of using EMFi (Electromechanical film) sensors for monitoring tiny mechanical movements caused by the activity of the heart.

The EMFi material, originally developed and patented by the Technical Research Centre of Finland in 1987 [1], is a plastic film which converts mechanical energy to an electrical signal and vice versa. It is basically flexible and thin biaxially oriented polypropylene film coated with electrically conductive layers, which are permanently polarized. EMFi has a static charge corresponding to hundreds of Volts. Changes in the pressure acting on the film generate a charge on its electrically conductive surfaces and this charge can be measured as a current or voltage signal, often with a charge amplifier. Thus the EMFi acts as a sensitive movement sensor. The sensitivity is an order of magnitude better than the one obtained with usual piezo materials.

As a result of high intrinsic resistance and bubble structure the charge persists for a long time. A disadvantage is that storing or using the sensors in temperatures above 50 $^{\circ}C$ ages the material. A study indicates that the sensitivity of the EMFi sensor decreases in the first eight months, but remains relatively constant after that when the temperature is held at constant 50 $^{\circ}C$ all the time [2].

Ballistocardiography (BCG) [3] is one of the oldest non-invasive methods for cardiac and respiration evaluation, where it closely reflects the strength of myocardial contraction. When the heart pumps blood first from the atrium via ventricles to the pulmonary arteries and ascending aorta, through aortic arch to the peripheral circulation, recoil of opposite direction is applied to the body and its force and direction is changing according to the cardiac cycle. The contracting heart forms ballistic recoil via blood flow to the aorta and pulmonary arteries and this pulse wave travels through the vascular system and diminishes gradually. The pulse wave travels at 4 – 5 m/s and the propagation speed is dependent of the elasticity of the veins and the level of blood pressure.

BCG as an unobtrusive method can be used to get information about the activity of the heart, the condition of the heart and breathing patterns. By studying the speed of propagation of the pulse in peripheral circulation, it could perhaps be possible to evaluate the state of atherosclerosis of a person.

We have applied EMFi sensors as mattresses, in a chair and in smaller pieces in a few positions on the body (Figures 1, 2 and 3). The resulting EMFi signals resemble the ballistocardiogram from which the heart rate is relatively easy to determine. Especially in the chair form, the sensor can be so well hidden that the subject does not even know that he/she is being monitored.

In this paper we present some traces and preliminary results from the EMFi signals acquired from the surface of the skin with EMFi strips. Our aim was to study what kind of signal is possible to get from certain places of the body and to study temporal differences between the signals.

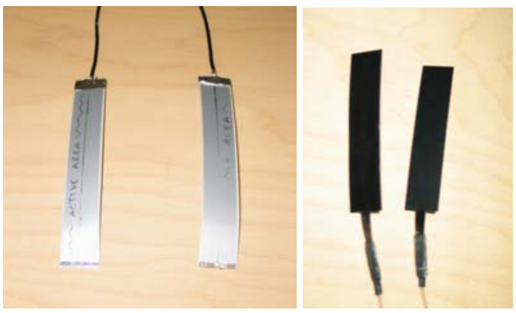

Figure 1. EMFi strips used in the study. The strips are 15 x 2 cm (left side) and 11,4 x 2,1 cm (right side).

Figure 2. A 27,6 x 30 cm EMFi sensor sheet applied on a chair

## 2. Measurement system

The signals from EMFi sensors were recorded with the self-made Mobile Physiological Measurement Station [4] and stored to the hard disk of the measurement computer (Figure 3; left side). An off-the-shelf general amplifier is not suitable for EMFi sensors due to their electrical characteristics. We have also made software which can record the signals directly to the EDF format [5]. The measured signals were obtained by taping the sensors directly to the surface of the skin in the shown positions (Figure 3; right side).

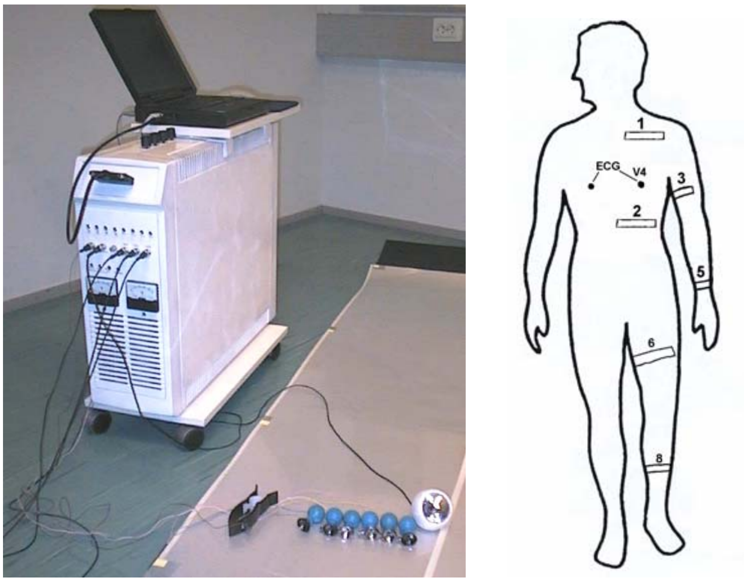


Figure 3: On the left side the recording computer, the main unit of the physiological signal measurement station, EMFi sheets, the PCG electret microphone and the ECG electrodes are shown. The numbered measurement sites on the body are shown on the right.

## 3. Measurements

In order to measure the movement of the chest and the recoil of the heart the EMFi strips were attached as shown in Figure 3. The first ECG electrode was attached to the chest (position V4) and the second one to the corresponding place on the right side of the chest.

The subject was sitting, on a 27,6 x 30 cm EMFi [6] sheet taped to a chair (Figure 2). In the first measurement, the ECG, the signal from the chair EMFi and the signals from the EMFi strips in positions 1 and 2 were measured (Figure 3; right). The strips were changed to positions 3 and 5 for the second and to positions 6 and 8 for the third measurement. In our measurements we have used both 500 Hz and 1000 Hz sampling frequencies, but theoretically 100 Hz is sufficient for BCG.

## 4. Signal analysis methods

All the signals were first filtered with a FIR 30 Hz lowpass filter in order to remove the 50 Hz mains interference and to preserve the frequency range of interest. The main components of the ballistocardiographic signal are in the frequency range of 3 – 10 Hz [7], but other frequencies may also have a diagnostic value.

Different analysis methods can be used to detect BCG complexes. One such method is presented in [8]. With this method, the BCG complexes can be detected with very good accuracy. The second version of the analysis method is presented in [9]. The further development of the method is under study.

The classification of the BCG signal is important for the deeper analysis of the BCG signal. Two different methods are presented in [10], using either a principal component analysis (PCA) method or the discrete wavelet transform.

## 5. Results

A reasonably good BCG-like signal was obtained from all EMFi sheets. The test subjects sat intentionally quietly and there were relatively few movement artefacts. The amplitude of the signal was largest in the chair sheet. The characteristic shapes of the BCG curves can be seen in it. From the arm measurement a characteristic shape of wave compared to the chair EMFi was seen. Examples of the recorded waveforms are shown in figures 4 to 6. Note that the vertical scale of the figures are arbitrary as the signals are not calibrated in any way.

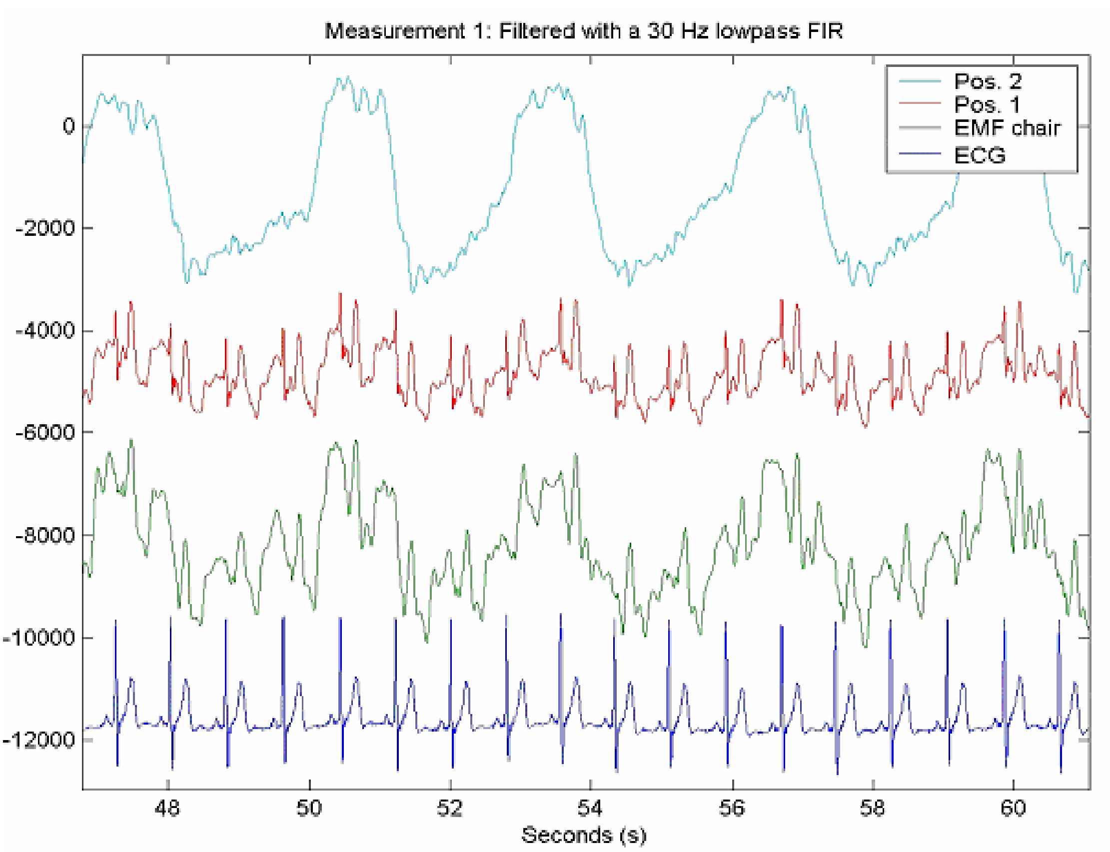


Figure 4: Measurement 1 from the chest during normal respiration. Signals shown (bottom-up): ECG, signal from the chair EMFi sheet, signal from the strip in position 1 and signal from the strip in position 2. The movements caused by respiration can be seen in all EMFi channels. The sharp spikes in the EMFi signal of the strip in position 1 are caused by cross-talk from the ECG channel of the PCMCIA analogue-to-digital conversion card.

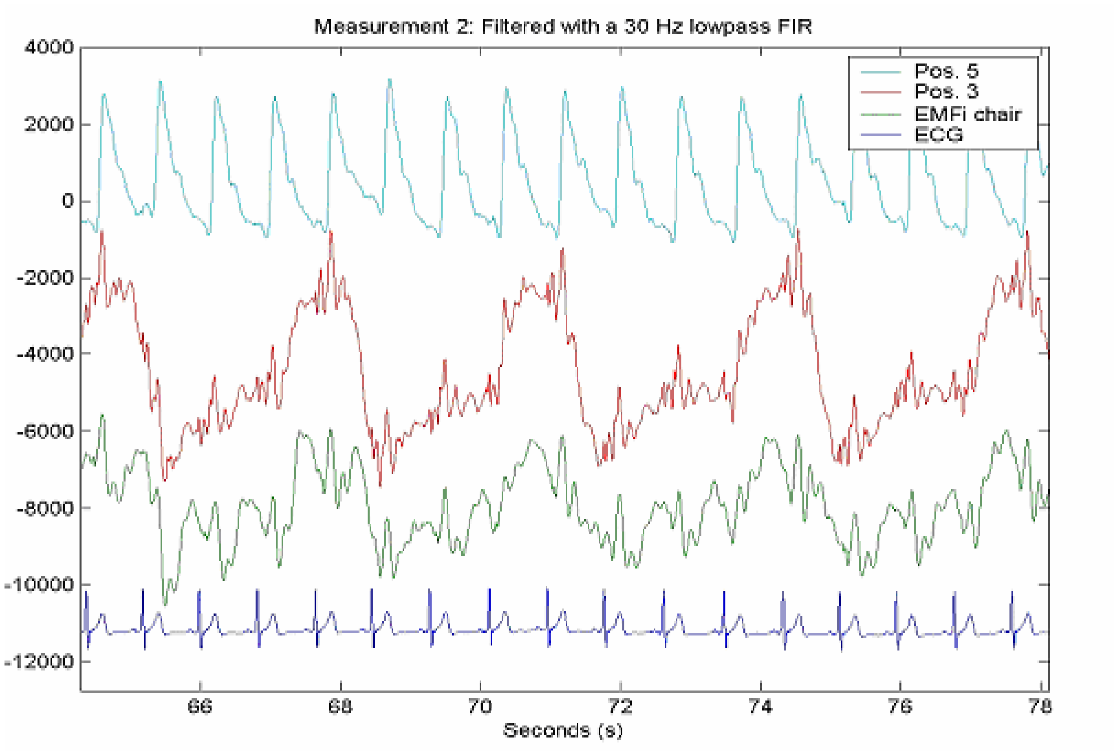


Figure 5: Measurement 2 (hand during normal respiration). Signals shown (bottom-up) ECG, signal from the chair EMFi sheet, signal from the strip in position 3 and signal from the strip in position 5. The influence of respiration on the measured signals is attenuated in the position 5 signal and looks stronger in the position 3 signal. The pulse can be calculated easily from the EMFi signal from position 5. In the position 5 EMFi signal from the wrist a fast transition up between the systoles of the heart can be seen and it is followed by a slow decline to the next ventricle contraction.

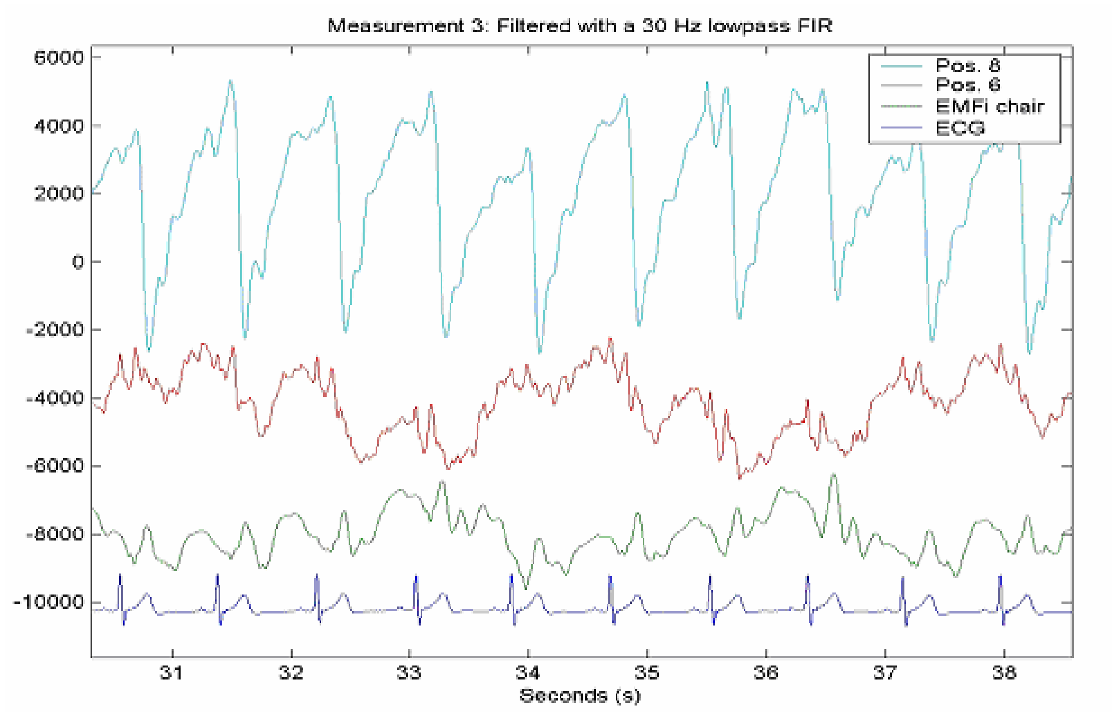


Figure 6: Measurement 3 (leg during normal respiration). Signals shown (bottom-up): ECG, signal from the chair EMFi sheet, signal from strip in position 6 and signal from the strip in position 8. The effect of respiration on the EMFi signal obtained from position 8 is smaller than in the chair EMFi signal. A fast transition down (from the middle and to the end of ECG T –wave) can be seen between the heart cycles.

## 6. Discussion

This study analyzed signals from only a few persons and the duration of the recordings was relatively short. Therefore the conclusions drawn can be considered only preliminary at the moment. However, EMFi sheet has shown its potential in ballistocardiographic studies in monitoring the changes in cardiac function. It might give further information about the elasticity of the veins uninvasively and conveniently. Being totally non-invasive, the EMFi sheet can also be used in long-term monitoring of people.

Using EMFi as a sensor gives possibilities for measuring large subject groups in clinical and home care for example in screening risk groups of heart failure. Studying the acquired BCG signal from the heart might give possibilities to detect heart related problems in early stages. Also the phase of respiration can be seen in the signal and respiration related phenomena can be studied. Automatic signal processing methods are crucial in using the sensors in mass screening.

Before these studies can be performed with sufficient reliability, a few technical details need to be sorted out. First the frequency response of the sensor-amplifier system should be obtained by applying calibrated mechanical vibrations on the sensor and measuring the voltage in the output of the amplifier. This measurement would also establish a quantitative relationship between the obtained voltages and force changes. Secondly a simple mechanism in calibrating the sensor in the field is required so that quantitative measures can be used in patient follow-up.

## Acknowledgements

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**Address for correspondence**

Jarmo Alametsä
Institute of Signal Processing, Tampere University of Technology
P.O. Box 553, FIN-33101 Tampere, Finland
jalam@cc.tut.fi