HEART-RATE DETECTION USING EMFI SENSORS ON A NORMAL LOOKING CHAIR

L.C. Barna, M. Koivuluoma and A. Värri

Institute of Signal Processing, Tampere University of Technology, Tampere, Finland

laurentiu.barna@tut.fi

Abstract: There are many ways to detect the heart-rate of a human subject and the market offers a large range of devices at a cheap price. The drawback of these commercial devices is that they require the subject to wear some kind of sensor (i.e. ECG electrodes, wrist or chest belts, ear lobe sensor) to his/her body and this is sometimes uncomfortable. In this paper we present a method to detect the heart-rate from a subject just sitting on a normal looking chair that has sensitive EMFi sensors attached to it. The amplified sensor signal is band-pass filtered and the peaks of the waveform are detected. The method is able to detect the heart rate correctly for 90-95% of the time when the person sitting on the chair is not moving.

Introduction

Heart-rate calculation has been the subject of many studies but there is still need to investigate new ways to detect the vital signs unobtrusively and at relatively low costs. Young people do not need heart rate measurements very often but the need increases in old ages. The aging population creates more demand for easy heart rate measurement devices.

A continuous monitoring of the heart-rate in the cases of home healthcare is useful to observe the state of a subject and support the independent living of elderly adults in their homes. Sitting on a chair relaxes and doesn't fatigue. Besides, because there are many activities done sitting on a chair, not only at home watching TV or at the table, but also when driving a car or working at the office, monitoring the heart-rate of a subject just sitting on a normal looking chair having no sensors attached to his skin, is an interesting topic to be studied. This allows the continuous real-time real-life monitoring of the subject without creating any discomfort or dislike to the subject. Different approaches to unobtrusive ubiquitous computing of the heart-rate have already been studied, but there is place for improvement [1] [2].

The market offers different devices at relatively cheap prices that can detect the heart-rate. The great majority of these commercially available devices have a common drawback: the subject under measurement has to "wear" some kind of sensor (i.e. ECG electrodes, wrist or chest belts, ear lobe sensor) and this is sometimes uncomfortable for the subject.

New sensors like EMFi (Electromechanical Film) offer fresh perspectives in the studies of signal acquisition. The EMFi material, originally developed and patented by the Technical Research Center of Finland in 1987, is a plastic film which converts mechanical energy to an electrical signal and vice versa. It is flexible, thin and very sensitive. It can be used for monitoring tiny mechanical movements and it has many applications [3].

It is possible to use EMFi for the detection of pressure changes. These changes can vary from the tiny movements of the human body, coming from contractions of the heart muscle in ejecting blood from the ventricles, up to the forces produced by a user interacting with various input devices or the pressure made by the foot steeping on the floor [4].

Ballistocardiography (BCG) is one of the oldest non-invasive methods for cardiac and respiratory evaluation, where it closely reflects the strength of myocardial contraction. 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 [5].

In this study, we show the use of EMFi as an alternative sensor for detecting the heart-rate unobtrusively from a person sitting on a normal looking chair, using the BCG signal.

Figure 1: Placement of EMFi sheets located under the foam and fabrics upholstery. The two EMFi sensors from the wrist supports are missing from this picture. The sensor setup was designed and assembled to the chair by the Technical Research Centre of Finland

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Materials and Methods

The prototype chair used in this study is shown in Figure 1. A total of five EMFi sensor units (made from 8 EMFI rectangular sheets) were taped to a normal looking chair, under the foam and fabrics upholstery in the following setup: two on the seat, one the back support and two on the wrist supports. Under the seat, there was a five channel battery operated charge amplifier and a passband filter from 1 Hz to 220 Hz. The chair was made by the Technical Research Centre of Finland (VTT).

The A/D converter used in our system is DAQP-16 from QUATECH which is a PCMCIA data acquisition card that provides eight differential or 16 single-ended 16-bit analog input channels, with a bipolar input range extending from ±1.25 V to ±10 V.

The sampling rate used was 500 Hz and only the signal from the seat was used in the analysis. Figure 2 shows ten seconds of raw data. The breathing artifact can be clearly seen in the figure as a low frequency baseline drift.

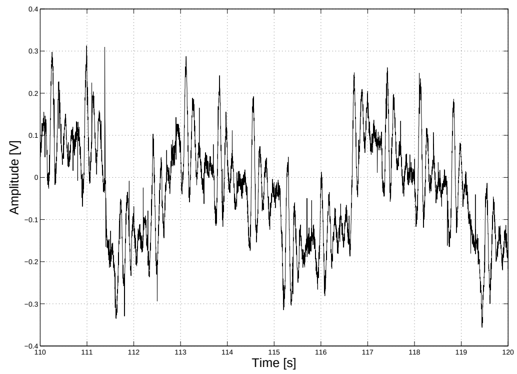

Figure 2: Signal recorded from one of the EMFi sensors located on the seat of the chair. The sampling rate was 500 Hz.

The aim of our algorithm is to detect the J wave of the BCG waveform. The signal is first bandpass filtered (4-8 Hz) and the absolute value of the resulting signal is lowpass filtered with a cutoff frequency of 1.5 Hz. We also calculate the mean signal of the lowpass filtered signal in a moving window of 501 samples. We then find the location of the maximum value in the sections of the bandpass filtered signal corresponding to the sections of the lowpass filtered signal greater than the scaled mean lowpass filtered signal and with a duration greater than a fixed value *N*. Using these locations that represent the locations of the heartbeats we then calculate the heart rate. The bock-diagram of this method is shown in Figure 3.

The algorithm was implemented in C++ for Windows, as a real-time application. Each time a test measurement was made, the data from all the sensors was recorded on disk in a file in the EDF format [6].

In real-time applications, we have to decrease the number of the multiplications per input sample to as low as possible. Therefore, we implemented both the bandpass filter and the lowpass filter in following form:

$$H(z) = F(z^L)G(z) \qquad (1)$$

where $F(z^L)$ is the transfer function of the periodic filter generated from the transfer function of the prototype filter $F(z)$ by replacing z^{-1} by z^{-L}. The overall delay of the filter increase, but the number of the multiplications decrease (38 multiplications needed for the bandpass filter, 19 for the lowpass filter). In Figures 4 and 5 the amplitude response of the bandpass and lowpass filters are shown.

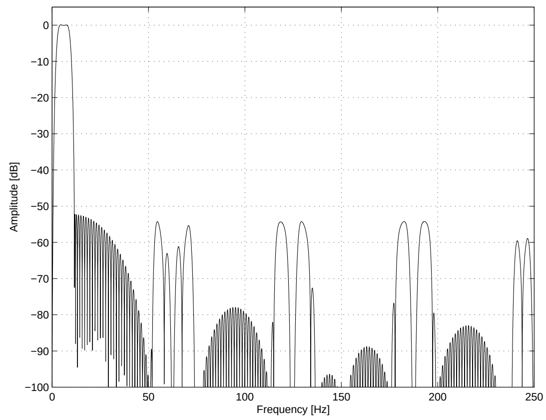

Figure 4: The amplitude response of the bandpass filter implemented as a cascade of the periodic filter and the non-periodic filter.

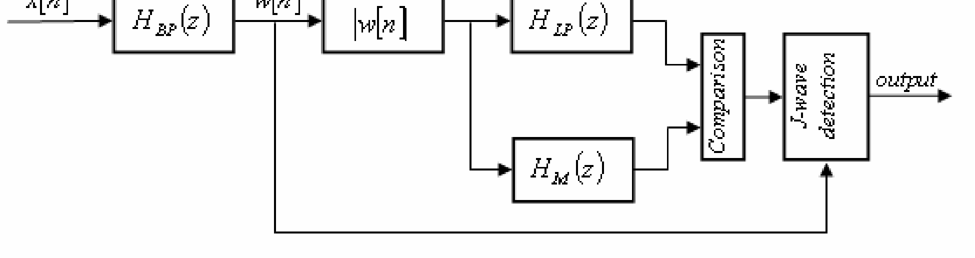

Figure 3: Block-diagram for the detection of J waves from the BCG signal

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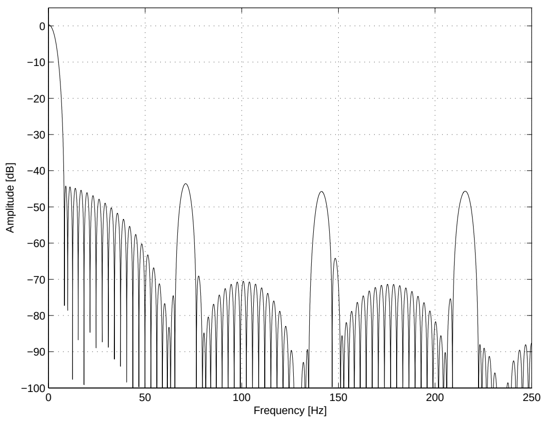

Figure 5: The amplitude response of the lowpass filter implemented as a cascade of the periodic filter and the non-periodic filter.

Results

The chair has been test by the Unit for Computer-Human Interaction (TAUCHI), Department of Computer Sciences, from the University of Tampere, to detect the heart-rate changes during emotionally provocative stimulation for a study of the user's emotions psychophysiology. [7]

In Figure 6, the effect of the bandpass filtering is shown. One can see that the breathing artifact was removed from the original signal and the BCG J waves are clear.

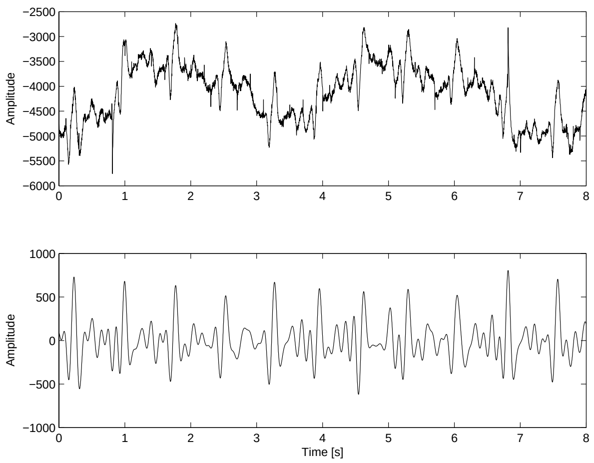

Figure 6: Top: short section of the BCG signal recorded with the chair. Bottom: Same section of the BCG signal after bandpass filtering. The breathing artifact has been removed and the heart beats can be distinguished.

In Figure 7, the output of the lowpass filter and the scaled output of the mean filter are shown. In this study, the scaling factor for the output of the mean filter was set to value 1.3. The minimum duration to detect the J waves was set to N = 40. In Figure 8, the detected J waves are shown. In this short section of the signal, no false or missing detection are found.

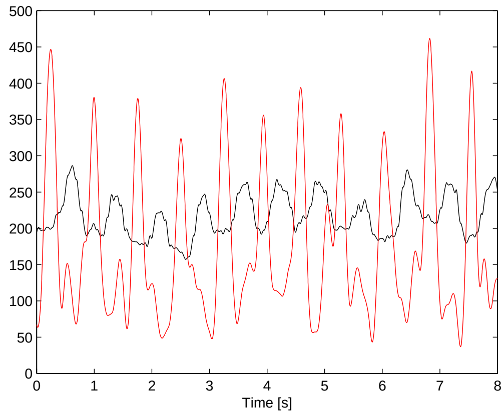

Figure 7: Red signal: the output of the lowpass filter. Black signal: the scaled output of the mean filter. Same section of the signal as shown in Figure 6 has been used.

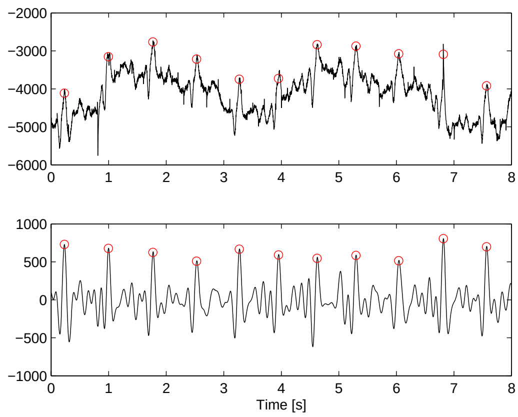

Figure 8: Top: detected J waves in the original signal. Bottom: detected J waves in the bandpass filtered signal.

After the J waves are detected, the heart-rate can be calculated as follows:

$$HR[k] = \frac{60 \cdot FS}{J[k] - J[k-1]}, k = \overline{1, M} \qquad (2)$$

In Equation 2, FS is the sampling rate (500Hz in our study), M is the number of detected J waves and J[k] is the index of the location of the k-th J wave from the beginning of the recording.

In Figure 9, an example of heart-rate calculation is shown. Because some of the J waves have gone undetected (decreased heart-rate) and some false detections occurred (increased heart-rate), some errors in the calculation of the heart rate are seen.

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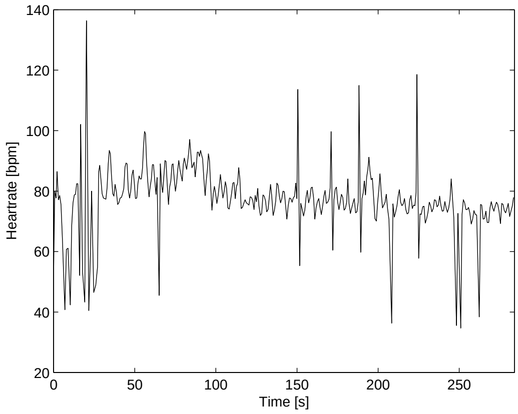

Figure 9: Example of the calculated heart-rate. There are some errors due to the undetected J waves (decreased heart-rate) or false detections (increased heart-rate).

The output of the method was compared to the heart rate calculated from an optical ear lobe sensor recorded in parallel with the BCG. The method shows good results (see Figure 10). To test the reliability of the method, we also compared the result to the heart rate obtained from ECG signal recorded in parallel. The correlation between our the results obtained with our method and the heart rate calculated from the ECG signal, was greater then the correlation between the heart rate calculated with the optical ear lobe sensor and the heart rate calculated from the ECG signal.

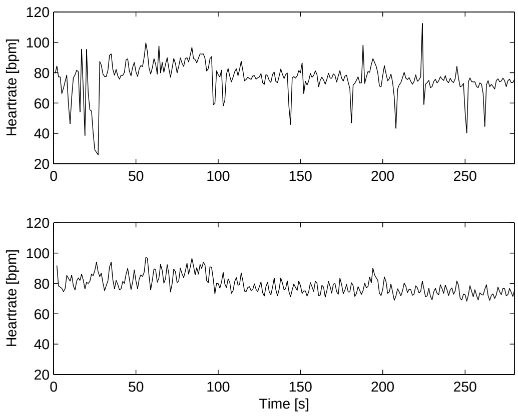

Figure 10: Comparison between the heart-rate (value/s) calculated with our method (top) and one output from an optical sensor (bottom).

Discussion

The test chair described here has many EMFi sensors, but actually only one was needed for the heart rate detection. Using the signal of another sensor may have improved the detection rate slightly, but it would also have complicated the detection algorithm. The present method can be implemented with a relatively inexpensive microcontroller to be placed under the seat as the number of multiplications in the filtering algorithms has been kept small.

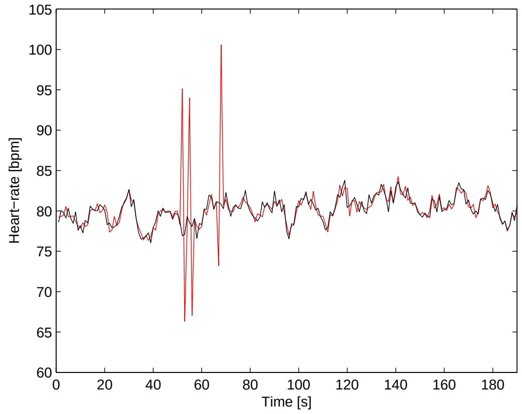

Figure 11: Comparison between the heart-rate (value/s) calculated with our method (red signal) and one calculated from the ECG signal (black signal).

Some improvement can be reached in detection accuracy by developing the detection algorithm further but the EMFi seat sensor based heart rate detection cannot reach as high success rates as ECG electrode based methods. The reason for this is that the visible movements of the person on the chair practically destroy the possibilities of the J wave detection from the BCG but ECG still remains usable for this purpose. If the person sits on the chair calmly, the detection results are good with the EMFi sensor method.

In addition to heart rate the EMFi chair signal can also be used to analyze the breathing rate of the subject by low-pass filtering the signal. The frequency of movements of the person can be detected form the chair signal, too. This could be used as a measure of the anxiety of the sitting person.

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