Magneto-impedance sensor for quasi-noncontact monitoring of breathing, pulse rate and activity status

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Abstract (~250 words):

A novel sensor for quasi-noncontact monitoring of breathing, pulse and activity status of a person in state of rest (during sleep) has been developed using magnetic principles. The sensor is placed transversal on the surface of a flexible mattress and when a person is resting on the mattress the movements, including those associated with breathing and heartbeat, are transmitted to the mattress and, consequently, to the magnetic sensor. This makes the sensor to follow the mattress surface, changing its permeability and modifying the output signal. A special designed electronics select the signals of interest. Being placed on the mattress where the monitored person is resting and with no wire connected on the person's body, the sensor is not creating any discomfort when is used. The sensor has high applicability potential for vital signs (breathing and heart rate) monitoring during sleep for all categories of people (infant, child or adult) in hospitals or at home.

I. Introduction

Assessment of the physiological information during sleep, especially of breathing and heart rate, are of great interest for diagnosing of the sleep disorders and for human body monitoring in the health care situations. The medical devices currently used in hospitals to monitor these parameters use contact methods (wires connected on the subject's body) which imply a high degree of discomfort from the patient point of view and low applicability in children, newborns and uncooperative persons or with low mental status due to the reduced possibility of cooperation with the patients in these category.

To eliminate the discomfort created by the electrodes and wiring the biomedical engineering community has focused to develop simple and non-intrusive methods to monitor the physiological parameters in a noncontact or quasi-noncontact manner.

The true noncontact methods are those methods that do not need a dedicated contact with the device to measure a parameter and include optical [1-2], microwave absorption [3] and radar techniques [4]. The quasi-noncontact methods are those methods that do not involve a dedicated contact with the device to measure a parameter (sensors on the skin, wires etc.), but are not contactless. We refer here to those methods where the contacts with the sensitive elements come from a conjunctural context (i.e. a sensor inserted in an object used often in our day by day life – as example a sensor or a sensor system embedded in a watch, or in bed, or mattress, or even in clothes, and these sensors measure the required parameters without creating any discomfort when the objects are used). From the quasi-noncontact category the most studied monitoring methods are those who ~~determine the cardiac vibrations~~ detect the vibration which arise from cardiac activity, respiratory movements and general body movements in bed using different type of sensors – microbend fiber optic sensors [5], optical sensors [6], piezoelectric sensors [7], and pneumatic sensors [8] – located at the mattress level.

In this work, we present preliminary results on a novel magneto-impedance (MI) sensor for quasi-noncontact monitoring of breathing, heart rate and activity status in bed.

II. Sensor design and operation

The sensor consists of a high permeability $Co_{68.18}Fe_{4.32}Si_{12.5}B_{15}$ amorphous magnetic wire, 1 meter long, 100 µm in diameter, prepared by in rotating water melt spinning [9] at National Institute of Research and Development for Technical Physics – Iasi, Romania, around which is wound a coil with **3000** turns, using enameled 0.07 mm copper wire.

The sensors is placed transversal on the surface of a flexible mattress and when the person is resting (sleeps) on the mattress the movements, including those associated with breathing and heart beats, are transmitted to the mattress and, consequently, to the sensor changing the strains induced in the magnetic amorphous wire. The induced strains modify the wire permeability and consequently the MI response xxx].

The circuit for testing the sensor ability to detect small movement associated with breathing and heart beat is presented in figure 1. ~~The base operation of the magneto-impedance element is similar to the one described in reference [11]~~. The MI element operating principle is described in reference 11.

The magnetic wire is excited by passing through him a square pulse current with constant amplitude. When the wire is subjected to an external longitudinal magnetic field a signal is generated in the surrounding coil. A synchronous detector selects the signal induced during pulse and converts into a DC voltage whose value depends on the external field strength and on the stresses applied to the magnetic wire.

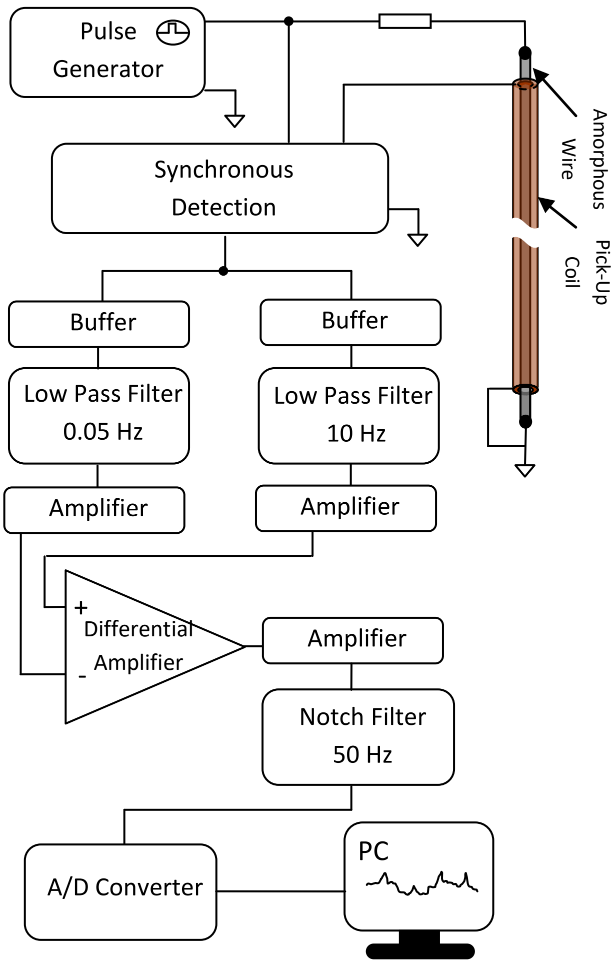

Figure 1. Sensor schematic

When a person is resting on the mattress all movements including those associated with breathing and heartbeat vibrations are transmitted to the mattress and consequently to the magnetic sensor. These make the MI sensor to bend following the mattress curvature, changing his local orientation in the external magnetic field and also changing his permeability due to local stress modification.

The signal obtained from the magnetic sensor (after synchronous detector) contains a predominant DC component and, overlapped, the signal generated due to mattress movement. In order to amplify the signal and to obtain measurable values of the breathing and pulse signal the DC component, who act as an offset, need to be removed. Must be mentioned that the DC component is not constant and changes when the sensor is reoriented in external field (when the mattress is moved, when the resting person change his position on the mattress or when different magnetic sources are added or removed from the mattress – sensor – vicinity). For these reason a static offsets cancelation is not a reliable solution. To obtain a dynamic offset cancelation is necessary to remove the quays-DC components using a high pass filter with a cut off frequency smaller than the one corresponding with breathing frequency which is in the range of 0.1…0.5 Hz [12]. Such a filter is complicated to build and for this reason we used a trick – we divided the sensor signal in two branches to allow independent processing on each one. On the one branch we filter the signal using a low pas filter with a cut off frequency of 0.05 Hz which selects the quasi-DC component of the signal. On the other branch we filter the signal using a low pas filter with a cut off frequency of 10 Hz which remove the high frequency noise and the 50 Hz component from the electrical network. This filter permit to pass the heart bet components which are usually in the range of 1…10 Hz [12]. The signal from each branch is amplified to compensate the signals decreases on the low pass filters. The signal from the first branch (with Fc = 0.05 Hz) is subtracted from the second branch signal (with Fc = 10 Hz) using a differential amplifier. Through this method a band pass filter with the domain between 0.05Hz and 10 Hz is obtained. The signal is further amplified to obtain a measurable signal and the remaining 50 Hz components induced in sensor and electronics from the power network are removed using a notch filter.

The signal, filtered and amplified, is acquired on a PC using an acquisition system with a sample rate of 200 Hz. The breathing and heartbeat signals are separated using digital FFT (Fast Fourier Transform) Filter. The acquisition software was developed in LabVIEW and allows real time tracking, as well as recording and analyzing of the signal variation.

III. System evaluation

To evaluate the system ability to detect the breathing and the heart rate of a person in bed (at rest) we performed the following experiment. A single subject (male, 28 years old, 70 kg) was seated on an inflatable mattress in a similar position with sleep.

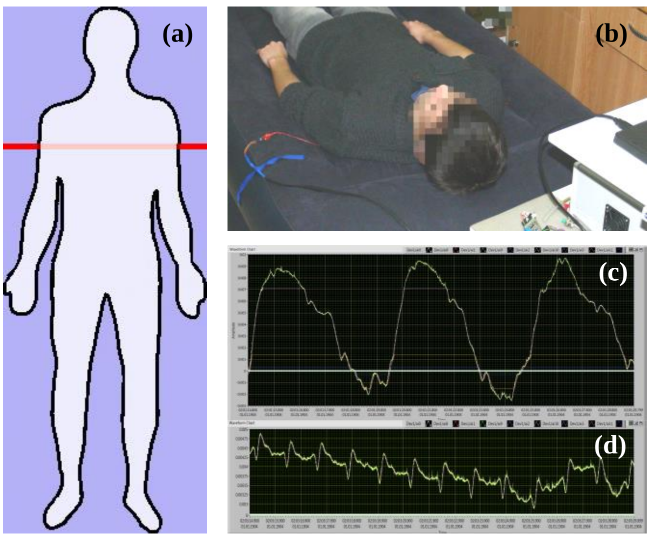

Figure 2. Sensor positioning (a) and images from an experiment (b - subject on the mat; c – breathing signal; d – pulse signal)

The magnetic sensor was placed transversal between mattress and subject thorax (Figure 2). The sensor functionality was tested for different sleep position (on the back, on the abdomen and on one side) and for different hardness of the mattress (different levels of inflation – hard, medium and soft), the sensor being able to detect breathing and heartbeat in all situation.

Figure 3 show the typical signals acquired from sensor. For normal breathing of the subject the acquired signals contain, overlapped, both breathing and heartbeat signal (Fig. 3.a). By digital filtering of the signal using a band pas filter with the range between 0.1 Hz to 0.7 Hz the breathing signal is isolated (Figure 3.b). The heart beat signal is isolated using a secondary band pas filter with the range between 0.8 Hz to 10 Hz (Figure 3.c). The signal acquired when the subject hold his breath (Figure 3.d) show a more clear signal of the heartbeat, compared with the one digitally selected, which means that the breathing signal have small components also in higher frequency. The amplitude of the sensor noise (Figure 3.d) was usually below 0.5 mV.

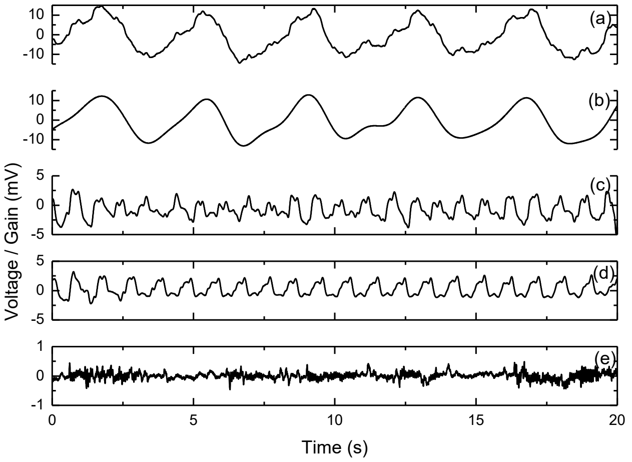

Figure 3. Sensor signals: a) the acquired signal for normal breathing of the subject; b) the breathing signal extracted with digital band pass filter (0.1Hz-0.7 Hz); c) the heartbeat signal extracted with digital band pass filter (0.8Hz-10 Hz); d) the acquired signal when the subject hold his breath (heartbeat signal only); d) the acquired signal when the subject is not present on the mat (sensor noise);

Discussions and Conclusions

sensor noise in normal environment was of the order of

components of the breathing signal are present

Perioada semnal generat de oscillator = 18 us (~ 55 kHz)

Durata puls aplicat pe fir si detectie:= 2 us

Acknowledgements

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