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Monitoring of respiration, seismocardiogram and heart sounds by a PVDF piezo film sensor

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***Abstract* – In-vivo monitoring of patient's cardiac mechanics via seismocardiogram was recently introduced (demonstrated).**
Usually, seismocardiogram is recorded using accelerometers placed on patient's sternum. This study present the ability of a PVDF piezo film transducer to record the mechanical activity of the heart (seismocardiogram and heart sounds) and also of the respiration-related, thorax motion. The transducer was positioned on patient's sternum and held in position by a chest strap. Patient's ECG signal was simultaneously recorded to provide a time-reference of the cardiac activity. The piezoelectric sensor was able to record respiratory movements, seismocardiogram and heart sounds: these signals can be obtained from the recorded signal by applying simple filters. The seismocardiogram waveform appears to be dependent on the various phases of the respiratory cycle. The recorded signal from the sole piezoelectric sensor can provide relevant information such heart rate, respiratory rate, timing of mechanical event within the cardiac cycle, etc.

I. INTRODUCTION

Seismocardiography (SCG) is a non-invasive method based on recording the vibration generated by the mechanical contraction of the heart [1] [2]. The compression waves generated by the pumping action of the heart propagated through the thorax and can be detected, noninvasively, at patient's outer chest wall. Traditionally, vibration is recorded by placing an accelerometer on the sternum while the patient lie supine, but vibrations can be actually measured all over the thorax (especially on the precordial area) and for any body position. Even if SCG is relatively recent, the recording of body movements associated with cardiac activity was proposed much earlier, as for the ballistocardiogram [3]. A renewed interest in these techniques is due to the large availability of low-cost sensor (e.g. MEMS accelerometers) [4] and the possibility to pervasively monitor patients [5].

SCG signal contains features that corresponds to specific events within the cardiac cycle as mitral closure, aortic opening, etc., in particular simultaneous recording of SCG and echocardiogram allowed to recognize specific events timing and a SCG wave nomenclature was proposed [6]. Furthermore, SCG timing can be related to the primary heart sounds (S1 and S2) measured on phonocardiogram (PCG).

The SCG spectrum cover the infrasonic range (i.e. frequencies below 25 Hz) because SCG is primarily generated by the motion of the heart wall, while the audible PCG signal is mainly generated by the blood flow.

As an alternative to the use of accelerometers, the ability to record the movements of the chest through different sensors has been explored.

This study focuses on the ability to measure precordial accelerations on patient's chest by means of a piezoelectric sensor. In particular, the research aimed to assess the ability of a unique, wideband sensor to simultaneously measure the slow respiratory movements, the seismocardiogram and the heart sounds.

II. MATERIAL AND METHODS

Polyvinylidene fluoride (PVDF) polymeric film exhibits strong piezo-electricity (but also pyro- and ferroelectric) properties and it has therefore been used as a sensor and transducer material [7] and found application in biomedicine [8] [9] [10].

In particular, a PVDF piezoelectric sensor produced by Measurement Specialties™ (CM-01B Contact Microphone) was selected, which is based on sensitive but robust PVDF piezo film combined with a low-noise electronic preamplifier. The PVDF piezo film is coupled with a round, rubber pad (7 mm in diameter) that allows an easy contact with patient's body; it offers high sensitivity to vibration and minimizes external acoustic noise. The mechanical coupling with the actual PVDF piezoelectric sensor has a spring constant of 20 N/m. The sensitivity of the sensor is 40 V/mm. the frequency response of the sensor is broad and appears flat until 1 kHz (showing a resonance at about 5 kHz).

Patient was comfortably seated on a chair with a

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backrest support. The sensor was kept in position onto the sternum by a belt worn around the patient's chest. The patient was asked to relax and to breathe normally.

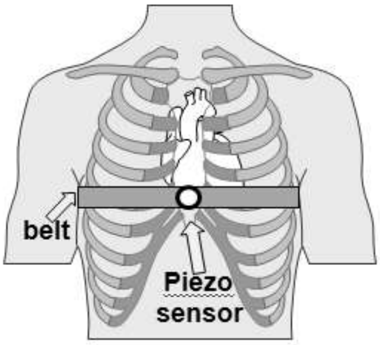

Figure 1: piezoelectric sensor placement

The output voltage signal from the sensor was amplified by 15 V/V by means of a high input impedance, wideband, voltage amplifier. Simultaneously, the ECG lead I was recorded from the patient. Both signals were acquired by means of an acquisition board (@ 10 kHz, 16-bit). Afterwards, microcontrollers were used to sample the signals (@ 1 kHz, 12-bit) to verify the feasibility to propose a portable (or even wearable) measurement system [11] [12].

The raw signal provided by the sensor was filtered to extract the different information contained in it. In particular, the following frequency bands were considered: 0.05 - 1 Hz for the respiratory signal; 1-50 Hz for the SCG signal and 50-150 Hz for heart sounds.

III. RESULTS

Fig.2 shows a short section of the recorded signals.

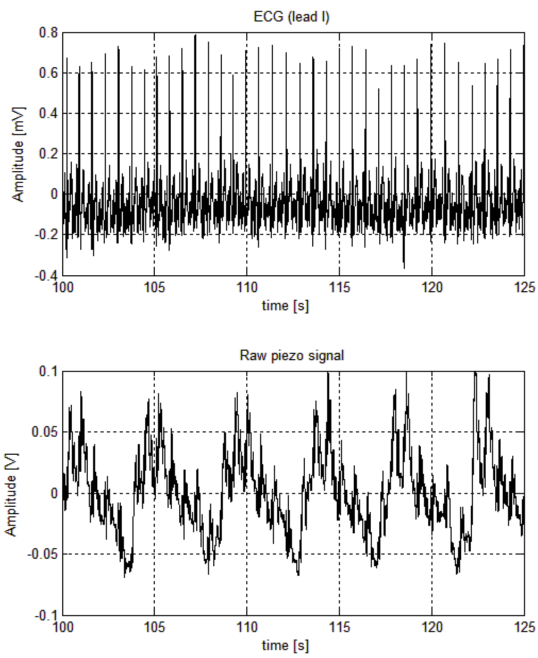

Figure2: Raw, recorded signals:
ECG (top trace); output of PVDF piezo sensor (lower trace)

The top trace shows the electrocardiographic signal, while the lower trace shows the raw signal coming from the sensor. Within the sensor signal are clearly recognizable six breathing movements of the patient (the most slow and wide fluctuations). The SCG signal is constituted by the smaller oscillations that temporally match up at the ECG QRS-waves. The heart sounds contained in the signal are extremely lower in amplitude than the previous signals and they cannot be noticed by eye.

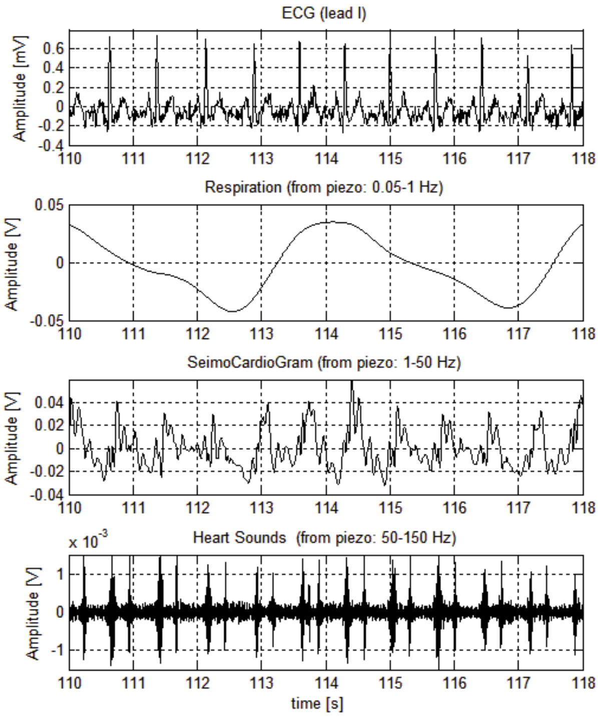

Figure3: Piezo signal decomposed in frequency bands:
ECG (top trace- reference); Respiration (trace 2);
SCG (trace 3); Heart Sounds (trace 4)

Fig. 3 shows the piezoelectric signal decomposed into the three frequency component plotted along with the ECG signal (trace 1). It can therefore be noted the respiratory signal (trace 2 - frequency band 0.05-1Hz); the SCG signal (trace 3 - frequency band 1-50Hz; the heart sounds (trace 4 - frequency band 50-150Hz).

The respiratory rate matchs with that obtained by using QRS area [13]. It may be noticed a change in the SCG signal according to the various phases of the respiratory cycle. This phenomenon has already been highlighted by previous studies [14] [15] [16] and probably depends on the different ways of propagation of heart-related vibration within the chest, whose volume changes during the respiratory cycle. However, it is worth mention that the variation of thoracic volume generates a different pressure on the sensor because of the belt wrapped around the chest.

A synchronised average of SCG waveforms relating to individual cardiac cycles by taking the R-peak of the ECG as time reference was performed to appreciate the temporal correlation of the ECG signal with the SCG signal.

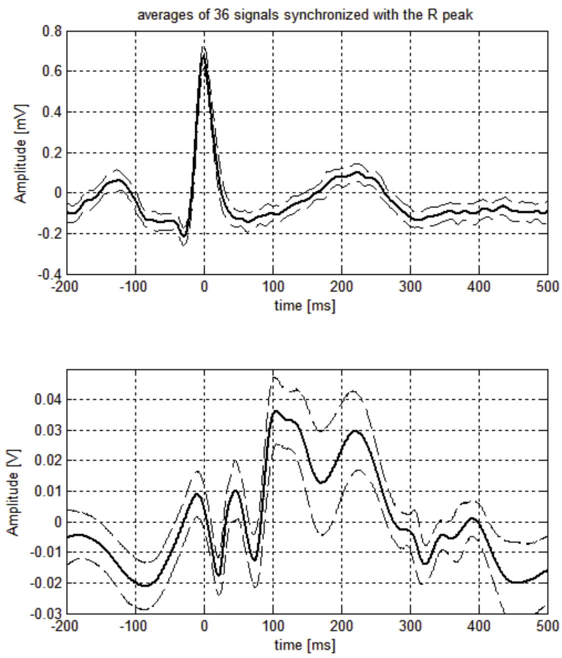

Figure4: Synchronized average of the ECG (top trace) and the SCG (lower trace) signals on a total of 36 heart beats. The R-peak of the ECG signal was taken as time reference. Averages are plotted as bold lines, while dashed lines show +/- a standard deviation.

Fig. 4 shows the results obtained from the operation of synchronized average made of 36, consecutive heartbeats. In bold is shown the SCG average signal while, with a dashed line, is shown + / - one standard deviation.

The large standard deviation of the SCG signal highlights the significant variability of this signal, which appears to be strongly influenced by the movement of the chest caused by breathing.

IV. COMMENTS AND CONCLUSIONS

This study shows the possibility to monitor simultaneously patient's respiration, seismocardiogram and heart sounds by using a single a PVDF piezo film sensor placed onto the sternum.

This sensor can be easily embedded into portable devices for patients' continuous monitoring [5] [17] [18] [19] [20] [21].

Furthermore, very preliminary observations proved that similar signals (modifications of the waveforms were observed) can be recorded on a large area of the patient's thorax, even when there is not a direct contact with the ribs or other bones. However, the amplitude of the piezoelectric signal depends on the contact pressure of the sensor on patient's skin. It is worth mentioning that, because of the large bandwidth of the piezo sensor, also the patient's speech (superimposed on the other signals) is recorded.

Piezoelectric sensors can be valid substitutes of accelerometers (1-axis) to monitor the SCG signal. In particular, piezo sensors offer better performance than common accelerometers for frequencies higher than 100 Hz, useful to detect cardiac sounds. Moreover, piezo sensors, at least when applied via a belt wrapped around the chest, are able to measure much more efficiently breathing movements.

Information provided by this sensor can be used (either alone or in combination with other signals) to compute the heart rate and its variability [22]. Moreover, this sensor can possibly find application in fetal monitoring [23] [24] [25].

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