Health Information Science

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Advances in Electrocardiography Body Surface Potential Mapping (BSPM)

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Executive Summary

This paper presents a study of the possibility to collect heart electric potentials from a rectangular region of the precordial area, using a bioelectrical signal amplifier (BESA) with only 4 input channels and to assemble these signals in order to obtain a more complex result such as Body Surface Potential Mapping (BSPM).

The introductory part contains the rationale of the paper, focusing on the BSPM both from medical diagnosing and technical issues points of view. Further, the technical aspects of the bioelectric signal amplifier (BESA) and of the analog-digital converter (ADC) are discussed and an experiment is described followed by results and conclusions.

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Introduction

- The ECG measurement, though widely used, is a technique insensitive to many cardiac electrical disturbances and pathologies. Body Surface Potential Mapping (BSPM) is a technique for high precision study and analysis of the electrical events in the heart. Its sensitivity for detecting electrocardiac pathologies is far more comprehensive and therefore significantly better than that of standard ECG. However, technical complexity and the high cost of existing custom designed systems have limited the use of BSPM to a small number of laboratories. Efforts to date to simplify the BSPM systems have concentrated on reducing the large number of electrodes used by the systems, but have consequently lowered the level of precision [4].
- "Electrocardiograph body surface mapping can detect an acute myocardial infarction earlier and two to three times more effectively than the traditional 12-lead electrocardiogram (ECG), and it can also pinpoint its precise location reducing treatment delay" [6].

The development of analog to digital conversion and computing will have a very strong impact on the medical laboratory tests based on biosignal processing. The non-invasive character is also of great importance in choosing these tests for diagnosis purposes. Moreover, the availability of biosignal processing devices allows relatively low budget-high quality research.

Technical aspects

Due to the very low voltages (tens or hundreds of microvolts), surface bioelectric signals and heart electric signals in particular, must be amplified thousands of times in order to become readable by a data acquisition device and storable in a computer for further processing.

Unlike classic electrocardiogram (ECG) which uses a limited number of electrodes (often 12), BSPM explores the electric activity by recording bioelectric signals using an electrode array with hundreds of electrodes and consequently a multi-channel bioelectrical signal amplifier (BESA). A multi-channel BESA could be theoretically built using discrete electronics but the resulting devices would be gigantic both in dimensions and cost.

A natural way out of these constraints might be to integrate the BESA entirely on a chip. However there are still many technological challenges (e.g. the integration of capacitors on the chip) which make the efforts to overcome them reflecting in the price of the chip.

The design choices left were:

- to reduce the parallelism of multi-channel BESA and consequently the complexity of the hardware and the costs
- to capture the data in a multi-step fashion which of course, will take a longer time
- to overcome the lack of signal synchronization by a very cheap software solution, providing the bioelectric signals acquired are quasi-periodic during the data acquisition process

The bioelectrical signal amplifier (BESA)

Two basic configurations of amplifiers were considered for the design of the BESA: the classical configuration of the differential amplifier and the configuration of BESA proposed by C. Levkov in Medical Biological Engineering and Computing which uses an operational amplifier (OA) in a non-inverting amplifier configuration and a special body-ground potential equalizing circuit (Figure 1) [2].

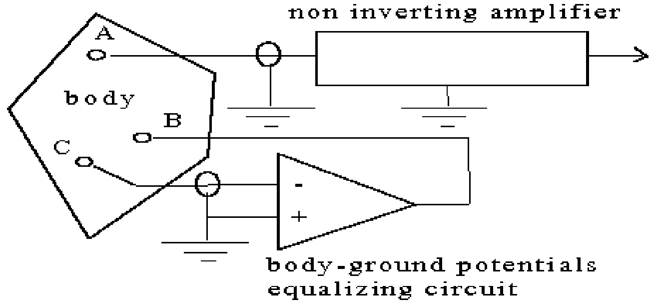

Figure 1. The configuration of BESA proposed by C. Levkov

Although the performances of the two configurations are specified as being quite the same, the latter was preferred due to a very important feature: when building more than one input channel for the BESA, the special body-ground potential equalizing circuit is common to all channels and so, the number of OA used in the first amplifying cell is equal to the number of channels plus one, in contrast with the classic differential amplifier configuration which requires a number of OA equal to twice of input channels number. As a disadvantage, the chosen configuration needs an extra electrode on the patient body (the B electrode which can be placed on any part of the body and whose wire needs not to be shielded).

Because the amplified bioelectric signal at the output of the circuit described above is still too weak to feed the analog-digital converter (ADC), a number of four amplifiers designed as narrow band selective inverting amplifiers was used to pull up the signal. After a few experiments with choosing the right transfer function for the BESA, it turned out that centering the narrow band at 6 Hz (Figure 2) provides a good immunity against both high frequency noise (manifested as signal thickening) and low frequency noise (manifested usually as a wondering, unsteady trace) without attenuating the useful signals too much.

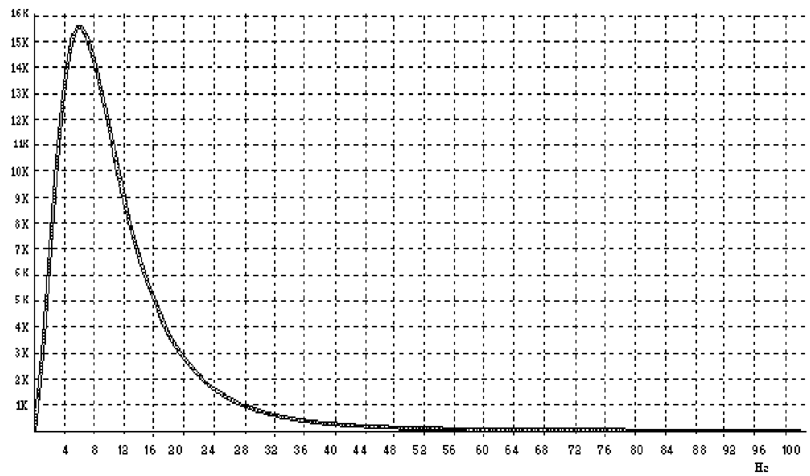

Figure 2. The transfer function of the bioelectrical signal amplifier

The last statement is based on the fact that the signals obtained have a waveform corresponding to all well-known classic ECG waves (P, Q, R, S and T waves). The optimization done using simple optical inspection of the resulting biosignal tracing proved to be a useful and simple method for accepting the transfer function of the device.

In spite of the fact that the waveform has a different shape than the classic ECG wave, it illustrates the same bioelectric events (left and right atria and ventricular myocardial depolarization and repolarization). The difference in waveform shapes is due to the different method of reading the bioelectric signals which are collected as potentials between electrodes A (placed in the precordial area) and C (placed on the right hand), unlike the classic ECG whose V chest unipolar leads signals are collected as potentials between a V electrode (placed in the precordial area) and a virtual indifferent electrode derived from the D1, D2, and D3 leads (the so called *central terminal of Wilson* - CTW).

Figure 3. ECG signals of the same subject, recorded with three different versions of the BESA; the third signal has correspondents for the P, R, S and T waves unlike the first signal, where P and T waves are missing because of an inappropriate transfer function

The data acquisition device

The analog-digital converter (ADC) was designed to use the capabilities of personal computers standard parallel port (SPP), which is not a bi-directional port. For this reason the ADC has two sections: a hardware section and a software section.

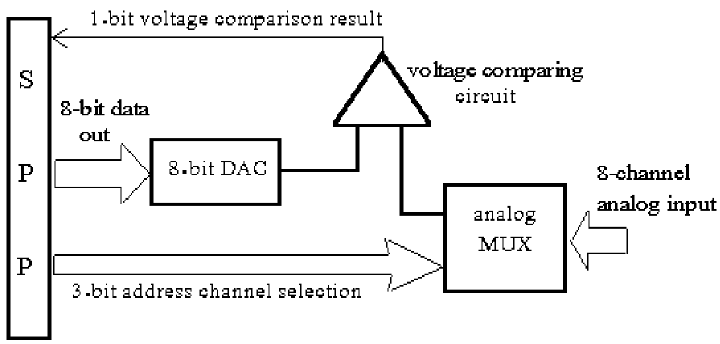

Figure 4. The data acquisition device (ADC)

The hardware section of the ADC contains an 8-bit digital-analog converter (DAC), an analog voltage comparing circuit and an 8-channel analog multiplexer (Figure 4). The software section of the ADC is responsible for implementing the successive approximations algorithm needed for data acquisition and the signal channel selection.

A 4-channel input data acquisition process using the ADC presented above, at a sampling frequency of around 1400 Hz yields the results in Figure 5. Recorded signals are characterized by round shapes since the heart major bioelectric events have much lower frequencies and the BESA does not amplify most of the frequencies higher than 40 Hz.

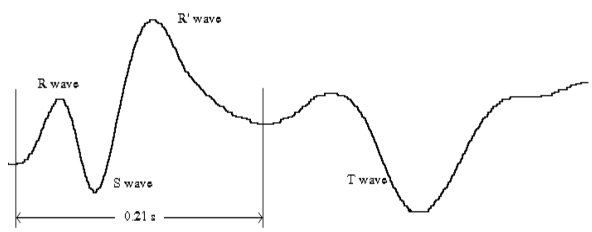

Figure 5. Heart bioelectric signal recorded using a sampling rate of 1400 Hz

Since our low cost implementation relies on sequential recording of successive cardiac cycles, a synchronization step becomes necessary. The method of synchronizing the signals gathered during different data acquisition steps consisted in keeping one of the four electrodes (for example the electrode connected with the first input channel) in the same place (e.g. in the left axilla), so it could get a witness signal, during all steps of the data acquisition process.

After that, a simple software program would synchronize all input signals by matching the witness signals, which are supposed to be identical. In Figure 6 two witness signals before and after performing the synchronization are presented.

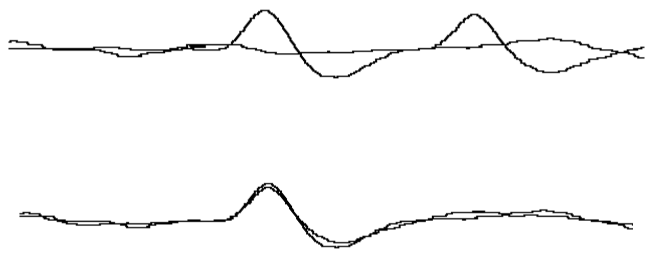

Figure 6. Two witness signals before and after the synchronization

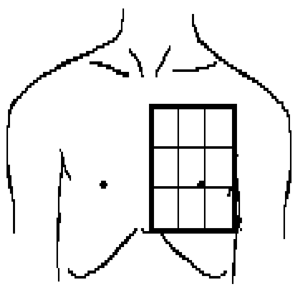

Figure 7. The capture region

Downscaled mapping experiment

For this experiment, a rectangular region of the precordial area was defined (Figure 7). The left-upper corner of this rectangular region corresponds to the second intercostal space, the left bottom corner corresponds to the xiphoid appendix and the right edge of the region is situated on the anterior axillary line.

This rectangular region was divided into 81 zones from which heart bioelectric signals have been recorded using the equipment described above and a number of 108 signals was picked up. From these, 27 signal were witness signals collected with an electrode placed in the left axilla.

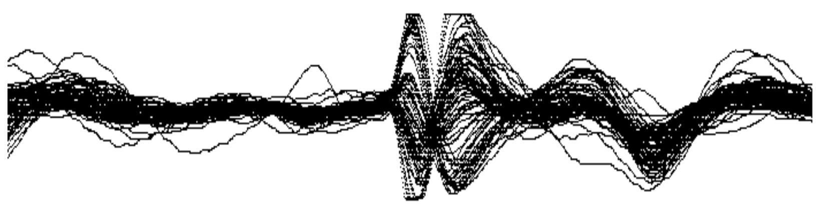

Figure 8. The 81 synchronized signals

The QRS complexes (ventricular depolarization), which are actually the main events of the heart bioelectric cycle, vary in amplitude and shape from the left side to the right side of the explored rectangular area. Therefore, these complexes have an initial positive deflection for left-sided signals and a negative deflection for the right-sided signals (using the patient perspective on left and right).

Further, in the picture above, some of the signals seem to exhibit important variations from the main bundle of signals. They are mostly right-sided signals that suffered recording errors probably because of a bad contact with the skin and presence of chest hair, since no electrode-gel solution was used. These signals were not removed because I thought it is important to see how recording errors can affect the final results.

In Figure 9, are presented 77 body surface potential maps of 9/9 resolution, recorded every 5 milliseconds starting with the first map located in the top-left corner continuing with the next on the same row. Whiter zones correspond to the positive potentials and darker zones to negative potentials.

As expected, the graphic representation of the BSPM during a QRS complex, showed a moving isopotential line which was parallel with the upper-right corner - lower-left corner diagonal of the rectangular region and perpendicular on the heart electric axis as we know it to be in patients with no heart disease. In other words, we obtained a dynamic graphic representation of the bioelectric activity of the heart, as it is perceived on the chest wall with the acquisition devices presented.

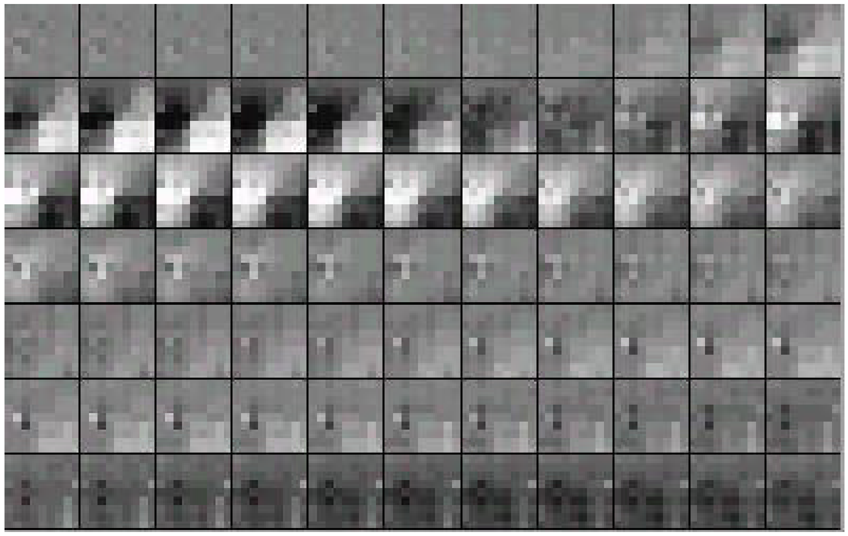

Figure 9. 9/9 resolution body surface potential maps during a QRS complex, recorded every 5 millisecond

Conclusions

The literature shows that there are current efforts in the biomedical engineering community for improving the BSPM method, which today is technologically feasible. The results of the experiment, although down-scaled, indicated that the procedure described is a suitable and cheap method for collecting BSPM data, providing the electric activity of the heart remains largely constant during all the steps of data acquisition process, which may take several tens of minutes depending on the desired resolution of the BSPM.

References

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