Employing TESPAR Method in Biomedical Signal Processing for Pathological Acoustic Analysis

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Abstract. Acoustic analysis is a useful tool to diagnose diseases, such as heart, lung, or voice diseases. Compared to other existing tools, it presents two main advantages: it is a non-invasive tool, and provides an objective diagnosis, therefore being a complementary tool to the invasive methods. This paper is focused on using Biomedical Signal Processing techniques with the aid of the TESPAR method to assess the pathological state of the subject by means of the acoustic analysis.

1 Introduction

Acoustic analysis is a useful disease diagnostic tool, very effective for heart, lung, or voice diseases. Compared to other existing tools, it presents two main advantages: it is a non-invasive tool, and provides an objective diagnosis, therefore being a complementary tool to the invasive methods [4]. This paper is focused on using Biomedical Signal Processing techniques with the aid of the TESPAR method to assess the pathological state of the subject by means of the acoustic analysis.

2 Methods

The well known and employed stethoscope is one of the most primitive devices designed to help doctors in listening to sounds. It is, though, simply a tool used for transmitting the sound energy from the patient's chest wall to the physician's ear via a column of air. The key disadvantages of this widely used but very basic method are the amplification, inaccuracy, requirement of medicine professionals and possible loss of information.

The electrocardiography technique (ECG) does not take into consideration the acoustic heart signals with all their frequency components. It also shows only the chronological sequence of mechanical events that occur, in a waveform representation [6]. That is why a good solution is to apply ECG along with the so-called phonocardiography (PCG), and the two methods together are able to give more accurate diagnoses of the heart's status. PCG also requires highly educated professionals to master it. However, their efficiency can be highly increased when they are provided with such devices.

Our proposed solution is based on capturing the signals from a patient that is able to move freely. The capturing device is performing amplification, preprocessing, local storage and remote data transmission. The Electrocardiograph (ECG) signal is used as the reference wave in the analysis of heart sounds. The reference wave helps the observer in distinguishing the various parts of the cycle.

The biomedical system can be equipped either with active sensors and an associated electronic part (e.g. the MSP430 microcontroller or DSP hardware [5]) or with similar techniques able to capture low-noised samples of data (in this case, the audio signal). A DSP can easily embed compression algorithms in it, transferring the signal into a compressed digital form to a PC. Figure 1 shows the interconnections of the amplified preconditioned signal from both PCG and ECG samples with the microcontroller and the transceiver used for the PC interaction.

The signal preconditioning interface uses a multiplexed 6 channel input module. The heart sounds are converted into electrical signals by 6 flat bandwidth response, high sensitivity Sennhaiser microphones. The microphones are firmly attached to the chest wall by an adhesive strip. Each input amplifier uses a set of ultra low noise SSM2134 operational amplifiers. The SSM2134 circuit has an input noise voltage of 3.5nV/√Hz and a 13V/μs slew rate.

A good solution for the microcontroller is to use the MSP430 chip, and for the transceiver is to use the new CC 1000 from TI, which provides interconnection capabilities with a wide-range of DSP chips and microcontrollers. The PCG signal along with its reference ECG signal is captured by the amplifier which communicates with the microcontroller. All the chips are powered by a 3V DC power supply.

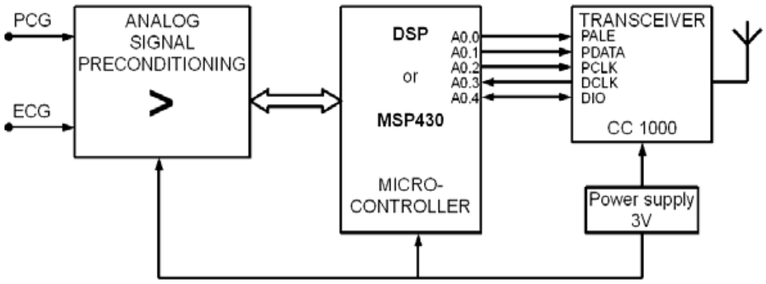


Figure 1. Hardware block diagram

The CC1000 [7] can be easily interfaced with any microcontroller now on the market. To configure the CC1000, three I/O pins are required (one bi-directional and two output pins). The pins connected to PDATA and PLCK can be shared with other circuitry, if these circuits are not active when the configuration interface is active. The ALE signal must be driven by pin dedicated only to interfacing the CC1000. For the data interface, two I/O pins are required, one for DIO (bi-directional for the CC1000, output for the CC1050) and one for DCLK (input). The pin used to interface with DCLK should be able to generate an interrupt on signal edges.

TESPAR Compression Algorithm

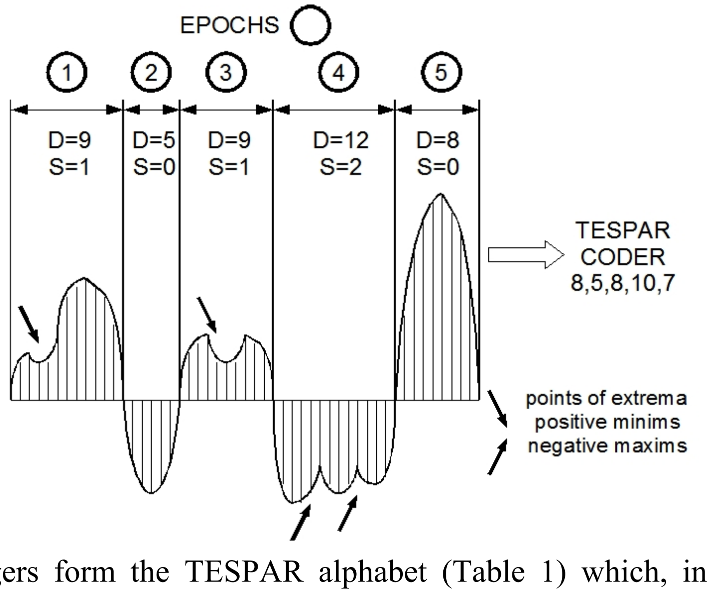
The TESPAR (Time Encoded Signal Processing and Recognition) method is a powerful, flexible and economic technology that is recommended for applications in a wide range of signal processing [1]. TESPAR architectures can easily be embedded into DSP units or microcontrollers.

The system works at very high sampling frequencies which imply the storage of large amounts of data blocks. Data needs to be sent through cables or networks to a computer interface, to enable specialists to perform an analysis on it. Therefore the compression is highly recommended since it reduces not only the amount of data to be stored but also the overhead in the transfer to the processing unit interface (the PC in our case).

TESPAR is a simplified digital language, first proposed by King and Gosling [3] for encoding speech. The process may be extended to any information carrier that can be represented using a bandwidth-limited signal. TESPAR is based on a precise mathematical description of waveforms, involving polynomial theory, which shows how a signal of finite bandwidth can be completely described in terms of the **locations** of its real and complex zeros. TESPAR encodes the data using a standardized alphabet and provides compression ratios of up to 98%, while the information or signal loss is low and the reconstructed waveform respects the initial one with only negligible differences [2].

The key of the TESPAR concept is to consider two descriptors which define the epochs of the TESPAR alphabet, the duration (D) and the shape (S). The duration D is computed as the number of samplings between two consecutive zero-crossings, while S is counted as the number of opposite-sense extrema points (positive minimums and negative maximums) which exist between two such consecutive real zeros. The longest epoch has a duration equal to half the period of the lowest frequency, and the shortest epoch has equal to half the period of the highest one (Fig. 2). The encoding procedure is based on a predefined alphabet (dictionary) and uses the two elements (D, S) as input to encode, outputting the encoded value as an integer between 1 and 28 (the TESPAR alphabet). This procedure is mostly based on the observation that even though several waveforms characterized by different values of D and S are encoded to the same integer, the two forms are not significantly different between them, and the reconstruction of the waveform could comprise any of these shapes. Also, shapes with same (D, S) pair's effects can be considered identical even though their representation may be different because of amplitude (see epochs 1 and 3 in figure). Some TESPAR variations also include this parameter in the encoding procedure, for a better precision.

Figure 2. Wave TESPAR analysis



The following integers form the TESPAR alphabet (Table 1) which, in reduced form, contains only 28 symbols:

	S=0	S=1	S=2	S=3	S=4	S=5		S=0	S=1	S=2	S=3	S=4	S=5
D=1	**1**	**-**	**-**	**-**	**-**	**-**	**D=8**	**7**	**8**	**8**	**8**	**-**	**-**
D=2	**2**	**-**	**-**	**-**	**-**	**-**	**D=9**	**7**	**8**	**8**	**8**	**-**	**-**
D=3	**3**	**-**	**-**	**-**	**-**	**-**	**D=10**	**7**	**8**	**8**	**8**	**8**	**-**

	S=0	S=1	S=2	S=3	S=4	S=5		S=0	S=1	S=2	S=3	S=4	S=5
D=4	4	4	-	-	-	-	D=11	9	10	10	10	10	-
D=5	5	5	-	-	-	-	D=12	9	10	10	10	10	10
D=6	6	6	6	-	-	-	...	...	...	...	...	...	...
D=7	6	6	6	-	-	-	D=37	23	24	25	26	27	28

Table 1. Coding process. Standard 28 symbol of the TESPAR alphabet

Due to the spectral composition of the signals in our case, we don't require the amplitude to be a parameter in the TESPAR algorithm, hence further reducing the amount of data. Figure 3 shows three of the most significant signal shapes in case of a normal heart and a couple of pathological cardiac conditions.

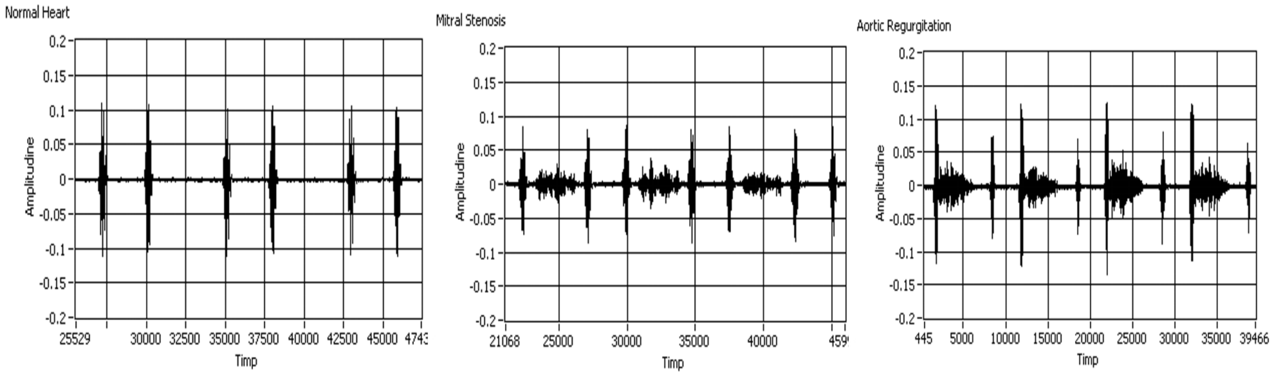


Figure 3. Filtered acquired signals

By analyzing the zoomed signals it turns out that when a pathological condition is present, it always becomes visible as an addition to the already powerful spectral *S* signals. The generated noise is a clear sign that a pathological condition is to be reported to the computer.

Figure 4 presents the spectral analysis of the above signals.

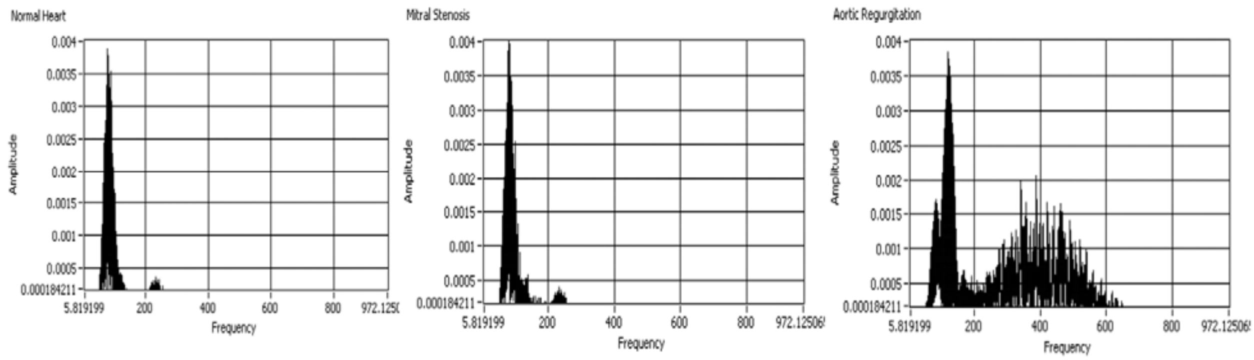


Figure 4. Spectral analysis

After significant testing in a simulation setup using LabView with a PCI 6052 acquisition board, we are able to say that the useful signal can be well fitted in the 60Hz - 600Hz bandwidth. The sampling frequency used was 11 KHz. The murmurs caused by the turbulence in the blood vessels can be identified as large spectral density noises, with a large duration. The spectral density of the noise is important because it allows shaping the *D*-parameter in the TESPAR alphabet. The microcontroller computes the consecutive zero crossings distance by selecting the 180÷200Hz and 300÷600Hz intervals.

All types of pathologies may be identified by creating a histogram in the RAM memory of the microcontroller. A pattern histogram is filled with the normalized values for the given frequency intervals and the number of detected minims and extremes for each epoch. Finally this is the S parameter. The TESPAR symbols are stored in the TESPAR matrix in a cumulative way for each *D* parameter. The signals which are present outside the mentioned intervals are ignored since the spectrums of the signal in case of a healthy heart are always present. Figure 5 shows the histogram with the TESPAR encoding. During the reference signal training session, all the desired histogram envelopes are computed and stored in the microcontroller's program memory by using a bootable hardware. All the previously acquired histograms serve as reference for the investigations of signals of unknown pathology.

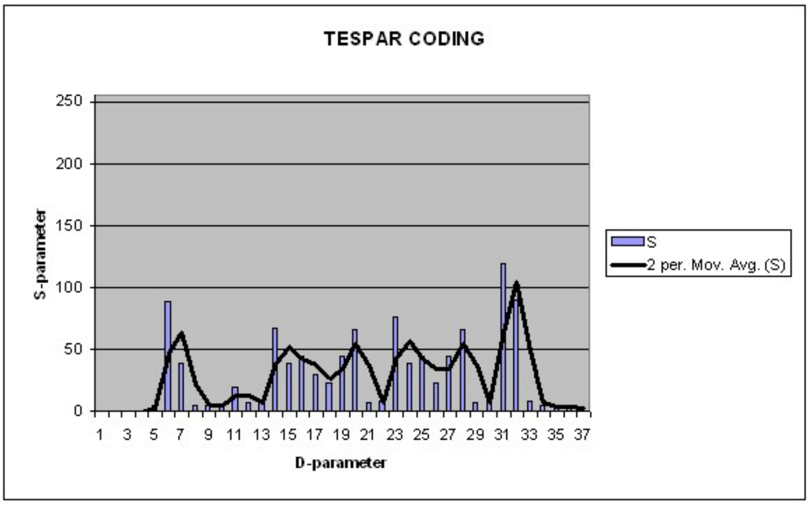


Figure 5. TESPAR coding histogram

The communication channel to a computer or device used for assessment of the captured signal can be made over serial ports, USB, Bluetooth or Ethernet. The PCG information is transmitted in its TESPAR compressed form and may be reconstructed on the guest computer, by performing the inverse procedure (decoding) of the TESPAR-encoded information. If the requirement is just a simple comparison of PCG waveforms, TESPAR encodings may well serve this comparison themselves, therefore eliminating the need for decompression. The ECG signal is also transmitted through a different channel to the computer; it is not compressed because there is enough bandwidth to send it in its raw form. In practice, the professionals will compare any pathological warning with the hints from the well known ECG displayed signal.

3 Results and Discussion

The electronic device used for acquiring, amplifying and digital conversion (using TESPAR alphabet) of the acoustic signal is relatively easy to build, and allows having a larger storage capacity into a reduced dedicated hardware memory.

Due to the integrative behaviour of the coding, the system has greater noise immunity than a classical one by using an Analog-to-Digital converter. The mathematical processing of the raw ECG data can be made on the computer using software.

Having the ability to observe in almost realtime the waveforms of the acoustic analysis is a great advantage, but since data can also be stored, this analysis can also be done „offline“, which enables specialists to work remotely and thus opens the possibility for *non-invasive distance health state assessment*, if appropriate devices and the internet are used. The resulted amount of data after the TESPAR ecoding is significantly lower than its raw form. It is also important that the entire signal assesment program is embeded in the microcontroler which is able to make decisions in a autonomus way. This opens great oportunities for similar audible signal processing without affecting portability and power consumption.

4 Conclusions

The use of such a combination between mathematical methods, biomedical engineering processes and the evaluation of audio signals emitted by the subject of the investigation provides a modern, non-invasive, non-computationally-intensive yet powerful solution in the analysis, discovery and assessment of diseases. We make use of the properties of organs sending acoustic signals that are correlated to the health state of the organ, employ biomedical signal acquisition and processing techniques to record these acoustic signals, and use the TESPAR method to encode the large quantity of data with high compression and very low loss levels, which allows it to be transferred to a computer to be interpreted by professionals.

At this moment we are able to succesfully discriminate between a normal heart signal and the aortic regurgitation signal, which has the highest spectral noise density of all the pathological signals we have measured.

As a future work we plan to write a software routine for histogram reading for all the well-known pathological conditions of the heart. The recognized condition was confirmed by the irregular shape of the ECG.

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