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Heart Sounds Parameter Extraction for Automatic Diagnosis

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Abstract. For efficient heart inspection with an automatic and non-invasive system it is imperative to collect different signals from human body. In the sequence of the development of a standalone Portable Decision Support System for Heart Failure Detection and Medical Diagnosis it was decided to record heart sounds to help in diagnosis process. However, automatic identification and parameter extraction of heart sounds deals with several challenges, such as, noise sources and low level signal pressures at microphone, as well as, abnormal sounds that overlaps normal signals. This paper discusses phonocardiography and its signals, as well as, signal processing techniques able to extract important parameters and indicators from heart sounds.

Keywords: ECG, e-Health, Heart Sounds, PCG

1 Introduction

Heart diseases keep leading the mortality indicators related with human health, thus the first assistance and rapid diagnosis is the key for saving lives. The most used tools for first assistance are Electrocardiogram (ECG) and Phonocardiogram (PCG). While ECG signal is assumed to be a more efficient diagnosis tool than PCG, there are heart defects that cannot be detected with ECG and can be detected with PCG, mainly the problems associated to heart valves and heart murmurs. Therefore, in the sequence of the development of a standalone Portable Decision Support System for Heart Failure Detection and Medical Diagnosis (PDSSH) project [7], it was also needed to include the ability to collect and treat heart sounds.

This paper focuses in the PCG signal characteristics and the importance of its components in heart diagnosis. The paper starts with a brief exposition about heart sounds fundamentals and their correspondence in heart cycle. Further it is presented an explanation of the murmurs associated to valvular diseases, followed by the most important results obtained by other authors in the area of parameter extraction and classification, and finally a conclusion.

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2 Heart Sounds

The normal heart sounds usually listened with a stethoscope refers to the atrioventricular (A-V) valves at the beginning of systole, and the closure of the semilunar (aortic and pulmonary) valves at the end of systole. Because the normal heart cycle is considered to begin in the A-V valves, the sound produced at the beginning of the systole is considered the first sound (S1). Therefore, the second sound (S2) is associated to the end of the systole.

In addition to the signals S1 and S2, there are a third heart sound called S3 and a fourth heart sound called S4 or more commonly Atrial Heart Sound. The S3 sound is very difficult to hear and it is not clear the source of it. It is stated by [4] that this sound may be heard in youth, some athletes, and pregnant women, and if it is heard in holder ages, could indicate congestive heart failure. Relative to S4 sound, it occurs prior to S1 and it is associated to the movement of blood from the atrium to the left ventricle and usually indicates ventricular hypertrophy. Finally, if the S3 and S4 are present, its combination is referred to be the S7 sound. Figure 1 is a standard representation of the various events of a cardiac cycle created by Dr. Carl J. Wiggers. The cardiac cycle consists of two periods, systole and diastole and this representation shows the time correspondence of the heart events as: Blood pressure; Ventricular volume; Electrocardiogram and Heart sounds.

Since the vibrations produced by the heart are mechanical, they can travel trough the surrounding organs and tissues to the outside of the body. At this point, they can be captured by a stethoscope or a phonocardiograph.

Depending of the source and the characteristics of the tissues involved, the frequencies will be different. Therefore, the frequencies of the hart sounds are related with the type and size of the structures involved. Imagine a small and a big drum in an orchestra; the vibrations produced by the smallest have higher frequencies than the vibrations produced by the bigger drum. It is almost the same with heart sounds. In practice, the frequencies involved into heart sounds are in the range of 3 Hz to 500 Hz, with peak at about 20 Hz[4]. These means that, to get all the information from heart sounds we need an electronic device since human hears are not capable to detect frequencies lower than 20 Hz and also are not sensible to sound pressures as lower as the ones produced by some of the heart sounds frequencies.

2.1 Murmurs

Abnormal heart sounds are known as murmurs, where certain murmurs are directly associated to specific cardiac problems. The more commons are valvular insufficiency and valvular stenosis. Valvular insufficiency is when heart valve cannot close efficiently and the blood flows in reverse direction, producing turbulence after valve closure. Valvular insufficiency associated to tricuspid valve or bicuspid valve exhibits a swish sound immediately after the first heart sound which can mute S1. On other hand, valvular insufficiency associated to aortic or

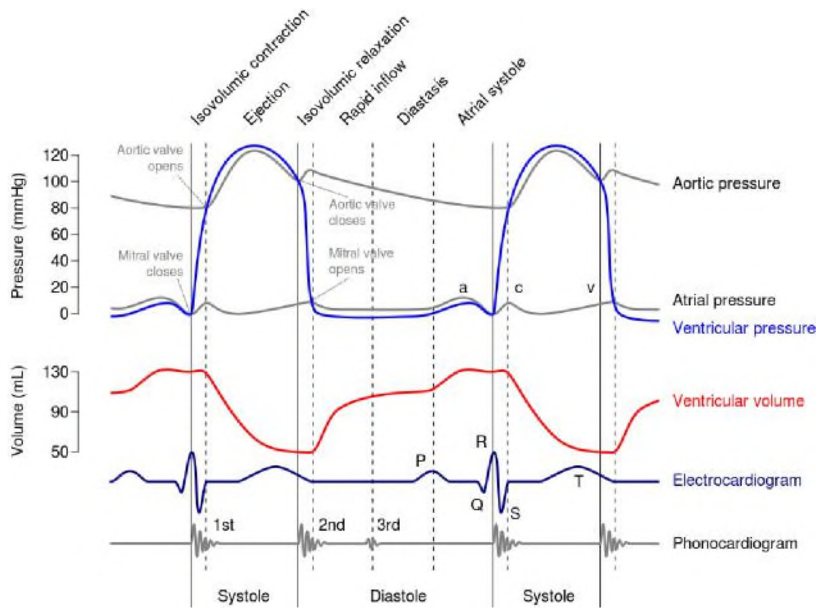

Fig. 1: Wiggers Diagram, showing various events of a cardiac cycle [13].

pulmonary semilunar valve results in a swish sound immediately after the second heart sound. Valvular stenosis is a valve narrowing that prevents the valve from opening fully. A stenosed atrioventricular valve results in a rushing sound immediately before the S1, and a stenosed semilunar valve results in a rushing sound immediately before the S2[3].

The murmurs can be classified as systolic murmurs or diastolic murmurs, depending if they appears in the systolic or diastolic zone of cardiac cycle (Figure 1). The duration of the murmur is usually classified with relation to where it occurs in the systole or diastole as shown in Figure 2. If the murmurs occur in the beginning, extend into mid or end of systole or diastole respectively, it is used the terms "proto", "meso" and "tele", and for murmurs that are present from the S1 to S2 or S2 to S1 it is used the term "holo". Finaly, if S1 and S2 are not present, the term used is "pan" [10].

3 PCG Parameter Extraction

The heart sounds are classified as normal or abnormal (murmurs). For the case of normal heart sounds we have the S1 and S2, and with respect to murmurs we have the cases mentioned in section 2.1. To detect these signals electronically we need to use signal processing algorithms for signal detection and classification.

Fig. 2: Murmur duration and names[10].

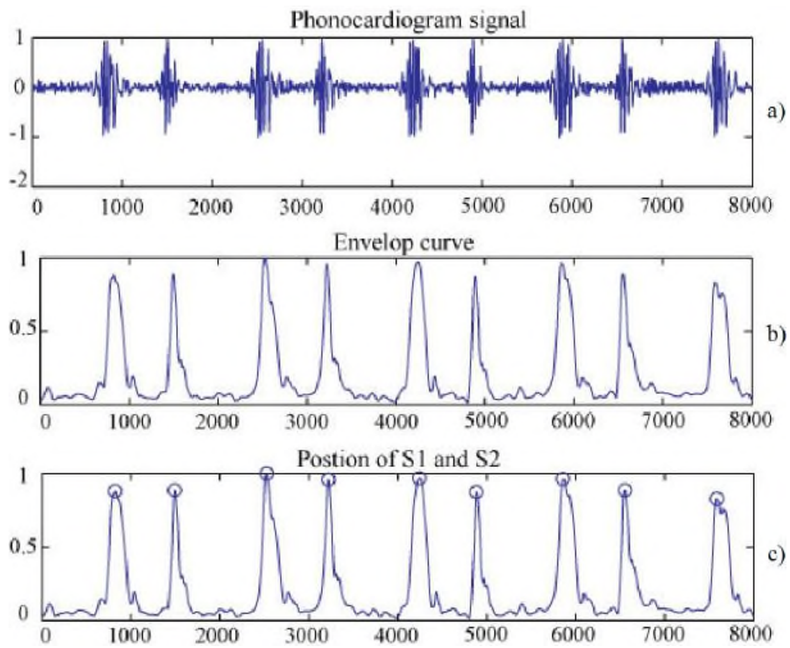

Fig. 3: S1 and S2 peak detection. a) original phonocardiogram signal ; b) envelope curve; c) peak detection of S1 and S2 heart sounds[1].

One of the most used technique in signal detection is the envelop extraction. The technique is mainly used to identify the shape of the area produced by the signal and can also be used to get the time-domain information. In the case of phonocardiogram, since we have S1 and S2 as separated pulsed rings with different duration, we can use the envelope to detect the length of the pulse. An effective method for envelope extraction is the use of wavelets [8] [9] [11] [12], where the use of this technique can produce smooth signal envelops with an accurate S1 and S2 peak detection as denoted by[1] in Figure 3, where Figure 3a) shows the original phonocardiogram signal, Figure 3b) is the envelope curve and Figure 3c) depicts the peak detection of S1 and S2 heart sounds.

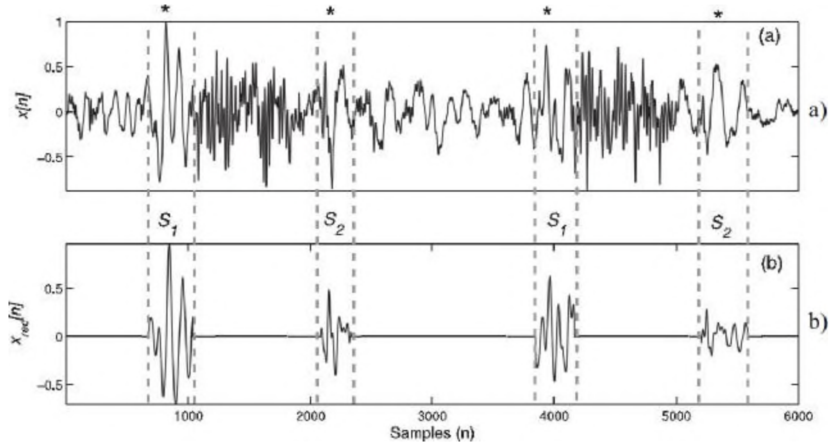

Fig. 4: ensemble EMD and kurtosis technique applied to a severe mitral regurgitation case. a) original signal, b) reconstructed signal[1].

The envelop extraction can also be performed with other techniques, as Shannon envelop or Hilbert transform. These two techniques was compared by Samjin Choi and Zhongwei Jiang [2], where Shannon envelope shown high segmentation efficiency for abnormal cases rather than normal cases, while Hilbert envelope shown low segmentation rates for both cases.

Another method involves the use of Empirical Mode Decomposition (EMD) as proposed in [11]. The authors employed ensemble EMD and kurtosis features to detect and extract S1 and S2, their durations and heart cycle segmentation into four components: diastole; S1; systole; S2. Figure 4 shows the results of the algorithm (Figure 4b) applied to a severe mitral regurgitation case Figure 4a.

It is important to refer that for efficient signal segmentation the heart sounds needs to be clean from external noise sources. For this it can be used adaptive algorithms for denoising as the ones already used in previous works [5] [6].

4 Conclusion

With this work we can conclude that heart sounds plays a significant role in heart inspection and heart problems diagnosis. Must of the signal processing techniques used are based on wavelets. Nevertheless, EMD also proved to be a promising technique.

Despite the clear success of some techniques for S1 and S2 detection and extraction, many heart sounds associated to heart problems remain slight approached and difficult to detect and classify. Here we clearly have a long way to travel, and it is here that we can find a challenge for PDSSH system.

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