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A novel method for pediatric heart sound segmentation without using the ECG☆

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ABSTRACT

In this paper, we propose a novel method for pediatric heart sounds segmentation by paying special attention to the physiological effects of respiration on pediatric heart sounds. The segmentation is accomplished in three steps. First, the envelope of a heart sounds signal is obtained with emphasis on the first heart sound (S_1) and the second heart sound (S_2) by using short time spectral energy and autoregressive (AR) parameters of the signal. Then, the basic heart sounds are extracted taking into account the repetitive and spectral characteristics of S_1 and S_2 sounds by using a Multi-Layer Perceptron (MLP) neural network classifier. In the final step, by considering the diastolic and systolic intervals variations due to the effect of a child's respiration, a complete and precise heart sounds end-pointing and segmentation is achieved.

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1. Introduction

In the past 10 years, some researchers have tried to develop a noninvasive test system for congenital heart diseases detection based on heart sounds analysis techniques [1–4]. There has been a great improvement in developing such a system using manual segmentation along with the electrocardiogram (ECG) signal [5,6]. However, one important obstacle in developing an all-automatic congenital heart diseases detection system has been automatic segmentation of systolic and diastolic periods as well as extraction of S_1 and S_2 sounds. If we could automatically segment the pediatric heart sounds signal and extract S_1 and S_2, then it would be possible to make an all-automatic system to detect and determine congenital heart diseases by noninvasive acoustical method as a stand alone system. Such a system could be used by hospital technicians rather than by a trained physician for disease's detection. In general, we can use a synchronous 12-lead ECG signal for complete segmentation but, in cases of infants or newborn children, such an ECG signal acquisition has its own inconveniencies.

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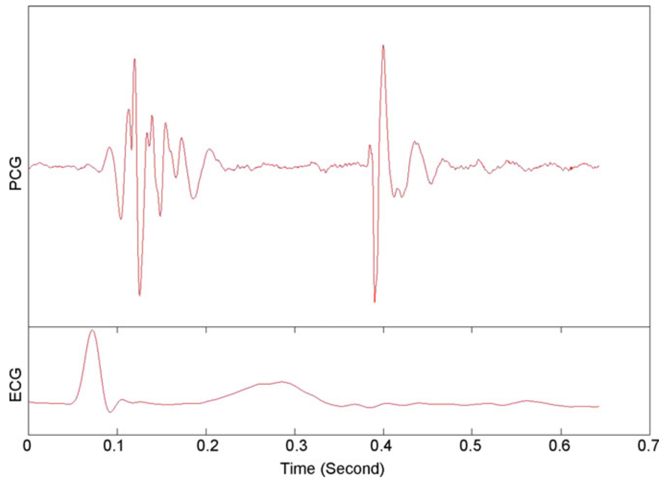

Fig. 1 – A complete heart sound cycle with ECG.

A number of recent works have been done on adult heart sound signal segmentation [7–9]. However, in some cases the end-pointing is done by using the ECG signal.

Based on spectral and timing properties of pediatric heart sound signals, we present an algorithm which extracts cardiac cycles along with S_1 and S_2 sounds from a heart sounds signal. In children, respiration causes a variation of cardiac cycle duration. But, the effect of respiration on diastolic duration is by far more tangible than systolic duration. Based on this effect, we present a novel method for a complete segmentation of children's heart sounds signals. We extract the basic heart sounds by taking into account the repetitive and spectral characteristics of S_1 and S_2 sounds and using a Multi-Layer Perceptron (MLP) neural network classifier.

To evaluate the performance of our work, we trained the method using 60 normal and pathological samples of our data-bank. We then tested the method on 60 other samples separately. We have correctly identified S_1 and S_2 sounds in more than 93% of the cases. The results show that the method opens a way to an all-automatic congenital heart diseases detection through heart sounds analysis in children.

2. Heart sound segmentation difficulties

An electrocardiogram is recording of electrical activities of the heart cells gathered from the surface of the body [10]. Phonocardiogram (PCG) signals are recordings of acoustical waves produced by the mechanical action of heart which are semi-periodic [11]. A normal heart by itself initiates two sounds; the first heart sound (S_1) and the second heart sound (S_2). Mechanical activities of a heart are always originated from its electrical activities [10]. S_1 signal is always after the QRS-complex in ECG signal and S_2 after T-Wave. Fig. 1 shows a synchronous recording of a PCG and its corresponding ECG signal.

Cardiac cycles can be determined by using ECG. However, for congenital heart disease detection, we need to extract S_1, S_2, systolic and diastolic duration in each cardiac cycle. Such segmentation is done manually using the ECG signal for end-pointing of the cardiac cycles. In children with left or right hypertrophic ventricle, axis deviation of heart causes an abnormality on ECG signal which complicates the manual segmentation [10]. Besides, the ECG signal acquisition has its own inconveniencies in children.

Heart sounds analysis is performed on special segments of a cardiac cycle. Depending on circumstances, a PCG signal may be mixed with different environmental noises, artifacts and pathological sounds. Artifacts are random sounds could be initiated from different sources such as movement of the stethoscope. When there is a murmur, the beginning of a heart sound is sometimes completely covered by murmurs. Therefore, automatic segmentation of a child heart cycle without using the ECG is a complicated task.

3. Systolic and diastolic intervals variations

A systolic interval starts at the beginning of S_1 and lasts until the beginning of S_2. A diastolic interval starts at the beginning of S_2 and lasts until the end of the cycle [12]. S_1 sound is a result of closure of mitral and tricuspid valves. A short time after the onset of S_1, aortic and pulmonary valves start opening and the preloaded blood ejects into the arteries [12]. The blood ejection lasts until the closure of the aortic and pulmonary valves [12]. This period of time is called the ejection time (ET) and the part of the systolic duration before the ET is named Pre-Ejection period (PEP). Respiration has significant influences on right ventricular size, diastolic filling time and also heart rate in children [13,14]. The influences of respiration on the left ventricular dimension and filling time are the same as the right ventricular in children [15]. The effect of respiration on diastolic filling time and heart rate is age-dependent [14]. On the other hand, the influence of respiration on the ET is in the opposite direction with respect to the PEP [16]. Therefore, the whole systolic time which is the sum of PEP and ET remains almost constant in contrast with the diastolic period which has tangible variations due to respiration [16]. To verify this assumption experimentally, we compute the variance of systolic period over the variance of diastolic period for each of the 120 subjects of our data-bank, denoted by SOD as follow:

$$SOD = \frac{\text{variance of systolic periods}}{\text{variance of diastolic periods}}$$

Fig. 2 shows the SOD for 120 normal and abnormal cases of the data-bank.

As it is seen in the graph, the SOD is less than one for all the subjects. It is worth noting that the diastolic function is age-dependent [14,17] and the aforementioned results could be valid only for children. The effect of respiration on systolic and diastolic intervals for a child is depicted in Fig. 3.

4. The segmentation method

The method is based on spectral properties of pediatric heart sounds and the influences of respiration on systolic and diastolic timing of cardiac cycles. The segmentation is accomplished in three steps. In the first step (4.1), we obtain an envelope of the heart sounds signal by computing the spectral energy. The spectral energy of the basic heart sounds is limited to a specific narrow frequency band. The envelope shows

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