Heart Sound Signal Analysis and Its Implementation in VHDL

Anjali S. Patil, Jayanand P. Gawande and Ajinkya Bankar

Abstract Cardiac auscultation is a primary diagnostic tool in the detection and management of cardiac disease. It is a noninvasive technique of listening to sounds produced by heart. In order to make the system reliable and proceed to make real-time operation, a new method is developed and evaluated. A novel framework for heart sound analysis based on discrete wavelet transform (DWT) decomposition and its implementation in VHDL is presented in this paper. Autocorrelation of the average Shannon energy envelope is extracted as feature from the sub-band coefficients of the heart signal with the DWT. Simulation is done in both MATLAB and Xilinx ISE 12.1 with the help of ModelSim simulator. The proposed method is evaluated on publically available datasets published in the PASCAL Classifying Heart Sounds Challenge.

Keywords Discrete wavelet transform (DWT) · Heart sound · Very high-speed integrated circuit hardware description language (VHDL)

1 Introduction

The heart sounds are mainly classified as first, second, third, fourth, and finally murmurs. The first heart sound also called as lub is produced due to the closing of mitral and tricuspid valves which allow the flow of blood from atria into the

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ventricles for 0.1–0.12 s duration having 30–50 Hz frequency. The second heart sound also called as dub produced when ventricular systole ends due to the closing of semilunar valves. The frequency range of second heart sound is 50–70 Hz, and its duration is 2550 ms. The third heart sounds are produced due to the stoppage of ventricular filling. The frequency range is below 30 Hz and its duration is 0.1–0.2 s. The fourth heart sounds also called atrial heart sounds are produced due to the contraction of the atria. The duration of fourth heart sound is 0.03–0.06 s and its frequency is 10–50 Hz. Murmurs occur in abnormal hearts between normal heart sounds. They are high pitch sounds having range 100–600 Hz and are longer in duration compared to normal heart sounds [1].

The existing monitor heart sound detection method such as electrocardiogram (ECG) requires to wear adhesive gel patches or chest traps which causes skin irradiation and discomfort. Low-cost and noninvasive method photoplethysmography (PPG) is used to detect volumetric changes in blood in peripheral circulation that makes Improper pulse sensing error. Traditional phonocardiogram which records sounds and murmurs made by heart with help of machine called phonocardiography (PCG) has limitations of heart sound storage and processing for lack of quantitative analysis function [1, 3].

This work is divided into two parts. In the first part, wavelet analysis of heart sound signal is obtained in MATLAB. In the second part, wavelet decomposition is implemented in the VHDL by using Xilinx ISE 12.1 and program is simulated in ModelSim simulator.

The paper is organized as follows: Database information and the wavelet analysis of heart sound signal in MATLAB are described in Sect. 2. Section 3 describes VHDL implementation of wavelet analyzed part. Section 4 represents simulation results of both MATLAB and VHDL. Finally, Sect. 5 presents the conclusion.

2 Analysis of Heart Sound Signals

2.1 Database Information

Heart sound datasets collected by the Real Hospital Portugues de Beneficencia, Brazil are used [4]. It consists of two public heart sound datasets. Dataset A contains signals that have a sampling frequency of 4410 Hz. Dataset B contains signals with a sampling frequency of 4000 Hz. Different lengths of audio files are present, i.e., between 1 s and 30 s. Database is present in three categories; Normal, murmur, and extra systole category. 200 normal, healthy heart sounds samples present in Normal category. As the device is removed from the body, these samples contain noise in the final second of the recording. Murmur category contains 66 samples. The noise in form of a whooshing, roaring, rumbling, or turbulent fluid is present (1) between lub and dub and (2) between dub and lub. Extra systole category contains 46 samples and they are occasional and difficult to identify. As heart sounds are out of rhythm having extra or skipped heartbeats such as a lublub dub or a lub dub-dub [4, 5, 6].

2.2 *Estimation of Heart Rate from Heart Sound Signals*

The block diagram of the detailed steps is summarized in Fig. 1.

Heart sound signal block acquires database signal from its location, i.e., read the signals MATLAB. In the preprocessing step of wavelet analysis signals are downsampled by 2 and after downsampling signals are normalized with their maximum absolute value. Next step is the 1-D decomposition using discrete wavelet transform (DWT). DWT is a multiresolution decomposition of a signal. It decomposes a signal into its components in different frequency bands. Convolution method involves decomposition of signals into approximate and detail coefficients. The decimated and normalized heart sound signal is decomposed into four levels by using the Order Six Daubechies (db6) wavelet, due to its morphological similarities to heart sound components. The approximation wavelet coefficients at the fourth level are selected for feature extraction using normalized average Shannon energy envelopes (ASEs) [2]. ASE is calculated using Eq. 1.

$$\mathrm{Es}(n) = -\left(\sum_{i=1}^{N} \Phi a, 4(i)^2 \log \Phi a, 4((i))^2\right) \tag{1}$$

where, Φa, 4(i) is normalized approximate coefficients.

Autocorrelation of ASE provides an automatic and shift invariant accumulation of the periodicity over multiple cardiac cycles. Autocorrelation function can be viewed as the feature representation of the heart sound [2]. It is defined by Eq. 2.

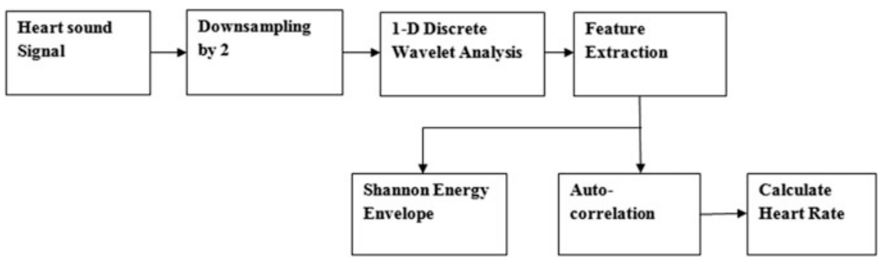

Fig. 1 Block diagram of detailed heart rate calculation

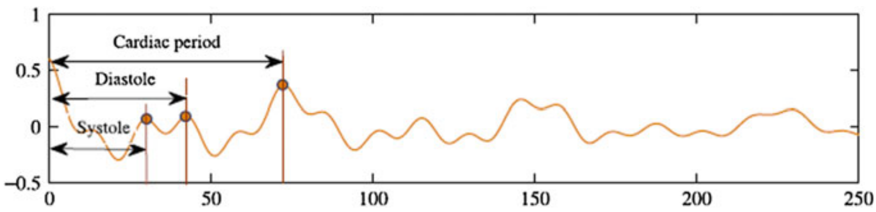

Fig. 2 Heart rate calculation using autocorrelation

$$r(m)\sum_{i=0}^{N-m-1} e(n)e(n+m) \tag{2}$$

where $e(n + m)$ is the time-shifted version of the ASE signal $e(n)$ with a time lag of m for $m = 0, 1, \ldots, M$.

Finally, from autocorrelation function, heart rate is calculated as shown in the Fig. 2.

3 VHDL Implementation of Heart Sound Signals

Field programmable gate array (FPGA) is used to implement the Verilog or VHDL. VHDL stands for very high-speed integrated circuit hardware description language. VHDL is used to describe the structure and behavior of electronic circuits and digital logic circuits [3]. VHDL uses a general purpose parallel programming language. Xilinx ISE 12.1 is used for VHDL coding, i.e., for FPGA implementation. Simulation results are verified in ModelSim 5.7 g simulator. Flowchart for the detailed VHDL implementation is shown in Fig. 3.

4 Experimental Results

In the wavelet analysis of heart sound signals, autocorrelation results are obtained using all three databases, i.e., normal, murmur, and extrasystole. Preprocessing results, DWT decomposition results, and ASE, autocorrelation results are shown in Fig. 4.

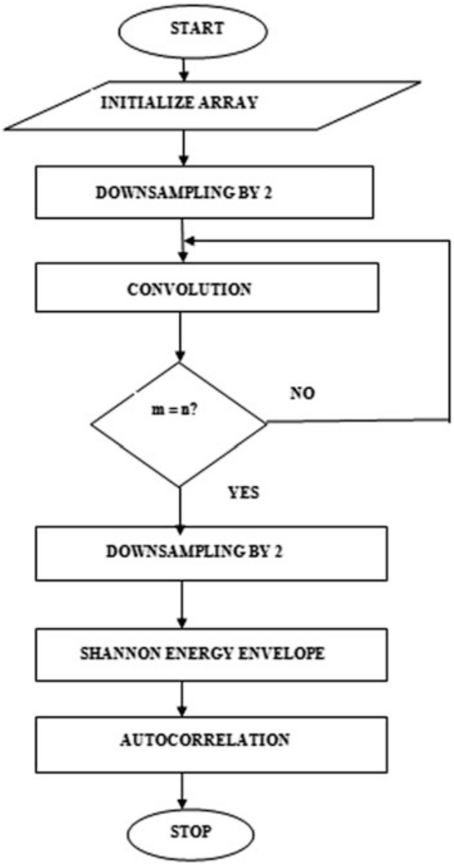

Fig. 3 Flowchart of implementation in VHDL

From these outputs, first highest peak within range 30–120 is considered as suitable peak for the calculation of the heart rate of the heart sound signals. Table 1 shows the heart rates of different category signals.

VHDL implementation results from the simulation in ModelSim are obtained. Dataflow results from the simulation and its corresponding autocorrelation result output plot in MATLAB are shown in Fig. 5.

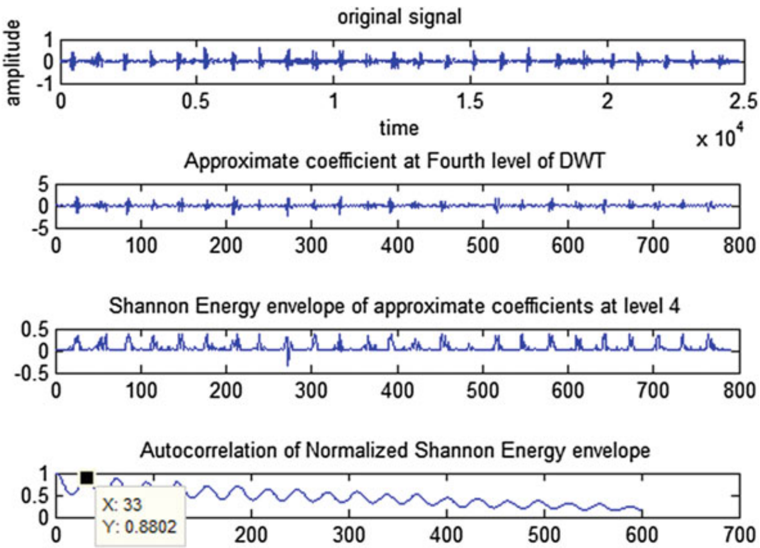

Fig. 4 MATLAB results

Table 1 Heart rate calculation using different samples

Sr No.	Category	Samples	Cardiac period	Heart rate
1	Normal	113_B1	43	83.72
2	Normal	103_D1	32	112.5
3	Normal	103_D2	31	116.12
4	Murmur	112_A	41	87.80
5	Murmur	112_B	42	85.71
6	Murmur	112_D	43	83.72
7	Extrasystole	127_C2	38	94.73
8	Extrasystole	128_A	40	90
9	Extrasystole	130_D	33	109.09

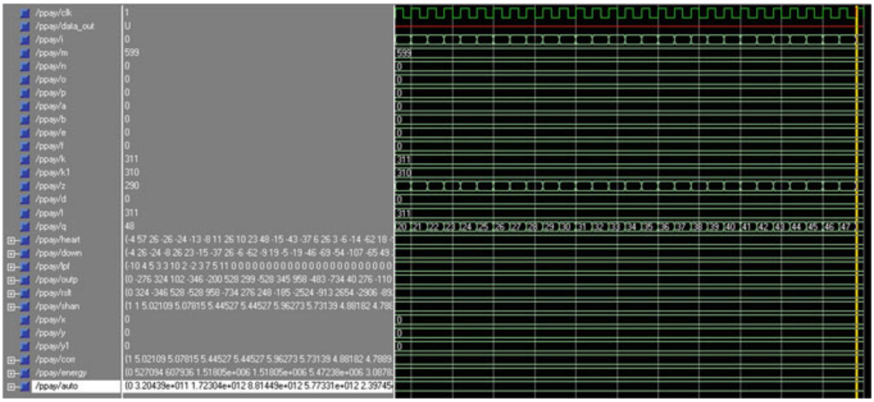

Fig. 5 ModelSim simulation results of VHDL implementation

5 Conclusion

Heart sound signals from the dataset are analyzed using DWT. Feature extraction of the decomposed signal is obtained using average Shannon energy envelope and autocorrelation. According to autocorrelation reference Fig. 2. Cardiac period of each sample from normal, murmur, and extrasystole category is obtained. Heart rate is calculated by using the obtained cardiac period. The exact algorithm is implemented in VHDL for the real-time analysis of heart sound signals. Heart rate shows best varying results for extrasystole category signals of dataset.

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