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Remote Monitoring of Heart Sounds in Real-Time

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ABSTRACT

As health care centres have becomes popular, daily monitoring of health-status related parameters is becoming important. An easy, comfortable and patient friendly solution for acquisition, processing and remotely transmitting the information from patient to the centre is therefore an important issue. Phonocardiogram (PCG) is a physiological signal reflecting the cardiovascular status. This paper deals with a Signal Processing Module for the computer-aided analysis of the condition of heart. The module has three main blocks: Data Acquisition, Signal Processing & Remote Monitoring of heart sounds. Data acquired includes the heart sounds. The system integrates embedded internet technology and wireless technology. As the data is being send by internet, it realizes real-time recording and monitoring of physiological parameter of patients at low cost and both at home and in hospital. The analysis can be carried out using computer initially and further by doctor. The tele-monitoring system may provide a low-cost, reliable and convenient solution for data acquisition and real time analysis of the PCG. The heart sounds are acquired using an acoustic stethoscope and then processed using software developed using the simulation tool (Python 2.7) & the recorded PCG transmitted and saved on the server. From where, any time it can be remotely accessed for expert advice and/or for further diagnosis.

Keywords - Cardiac Auscultation, Heart Rate (HR), Heart sounds, Phonocardiogram (PCG), Python, Stethoscope, Wavelet decomposition

I. INTRODUCTION

Heart sounds result from the interplay of the dynamic events associated with the contraction and relaxation of the atria and ventricles, valve movements and blood flow. Heart sound can be heard from the chest through a stethoscope [1], a device commonly used for screening and diagnosis in primary health care. The art of evaluating the acoustic properties of heart sounds and murmurs, including the intensity, frequency, duration, number, and quality of the sounds, are known as cardiac auscultation. Phonocardiography (PCG) is the study of heart sounds, consists of several different components. The first and second heart sounds (S1, S2) are the most significant ones [2]. There are still other events, nevertheless, that may be recorded, including the third and fourth heart sounds (S3, S4) [3], heart murmur and noise. Most of the stethoscopes were acoustic in nature with very less sound amplification. With advent of technology the transition took place into electronic and the more powerful digital-electronic stethoscopes. The Acoustic and the Electronic stethoscopes are widely prevalent in the current market. A fewer number of companies produce stethoscopes each with their unique features.

The PCG-based Heart Rate (HR) measurement is carried out using the detection of cardiac pulse peaks [5]. These algorithms assume a general heart sound model. With a basic normalization, Shannon energy and thresholding on PCG, S1 and S2 are detected, extracted and counted to derive the HR [6]. PCG segmentation techniques that analyze heart sound features are also introduced to make the detection more robust [4]. But by calculating the Shannon energy [6], and also by the segmentation of S1 and S2 [4], it becomes complicated to find HR.

This paper presents an algorithm not only for the direct measurement of heart rate based on PCG but also for the remote monitoring of these signals. Wavelet transform is adopted for PCG time-series processing. Mother wavelet, Daubechies family is used to filter out the added noise from the heart sound signal. Then by taking the square of the filtered heart sound signal peaks are directly detected and then the heart rate. Hence the processing makes easy. However, since heart sounds vary in a great extent, this method effectively deal with unexpected PCG patterns that differ from the presumed model. More importantly the saved data on the server can be accessed anytime from anywhere for the reference or for the expert advice.
This paper is organized as follows. The hardware is revealed in Section II. In Section III, the design algorithm is discussed. The verification of the performance of the proposed method through several experiments is discussed in section VI. Finally, we draw the conclusion in Section VII.

II. HARDWARE ARRANGEMENT

The block diagram for the implementation of the proposed idea is shown in figure 1. In this a microphone is placed inside the hollow tube of stethoscope to convert the mechanical vibrations into the electrical signal and at the other end of the stethoscope an audio jack is placed which can easily be connected to laptop to record the heart sounds. A server is placed to save the information and data of the patient. On which this information can be send through the wireless link. This recorded sound file is saved in *.wav format through python 2.7 and the sound quality is mono. Once the sounds are recorded the further processing is done by the software. At the other end the data can be picked up remotely through internet.

III. DESIGN METHODOLOGY

The detailed steps of the proposed algorithm are illustrated in Fig. 2. It could be generally divided into three parts: PCG Data Acquisition, Processing, and Calculation of heart rate which can be done by finding the peaks of the squared heart sound signal.

3.1. Data Acquisition

The heart sounds are collected from human being. The recordings are made using Microtone Acoustic Stethoscope for about 5 seconds each. The recording is performed in an open space with people walking and talking around. Microphones are the natural choice of sensor when recording sound. These sensors have a high-frequency response that is quite adequate for body sounds. The microphone is an air coupled sensor that measure pressure waves induced by chest-wall movements (by stethoscope). The recordings are done in *.wav format using the software language (Python) provided with the stethoscope. The software also saves the patient's information in text file. The sounds were then digitized with a sampling rate of 22050 Hz, 32 bits/sample. The digitized signal was then processed for finding the heart rate.

3.2. Processing

The whole algorithm was implemented in Python [11]. The steps involved in the heart rate calculation algorithm are shown in figure 2 and its implementation on a real heart sound is shown in figure 3 (of a child) and figure 4 (of an adult). Before wavelet decomposition and reconstruction the original signal was downsampled by a factor of eight so that the details and approximations can result in frequency bands, which contain the maximum power of S1 (first heart sound) and S2 (second heart sound). The Daubechines 6 and 20 is used for wavelet decomposition with 5 levels of decomposition which in this case is d4, d5 [8]. It is proved adequate for heart sound [7]. Then the reconstructed signal is again filtered out with a band pass filter having an order of 11 and the lower and higher cut-off frequencies of 20Hz to 100Hz respectively. Now the 4th and 5th level signals are used for further calculation of heart rate.

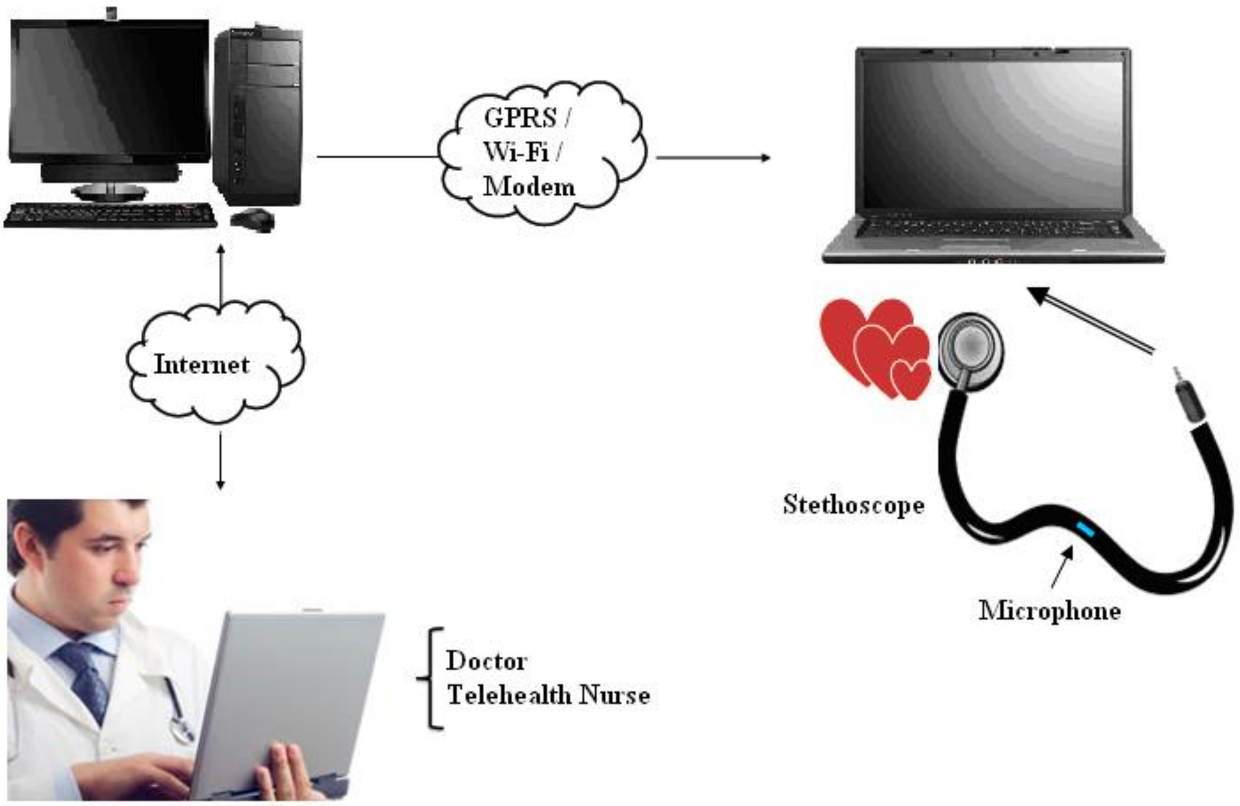

Fig 1: Remote Heart Rate Monitoring

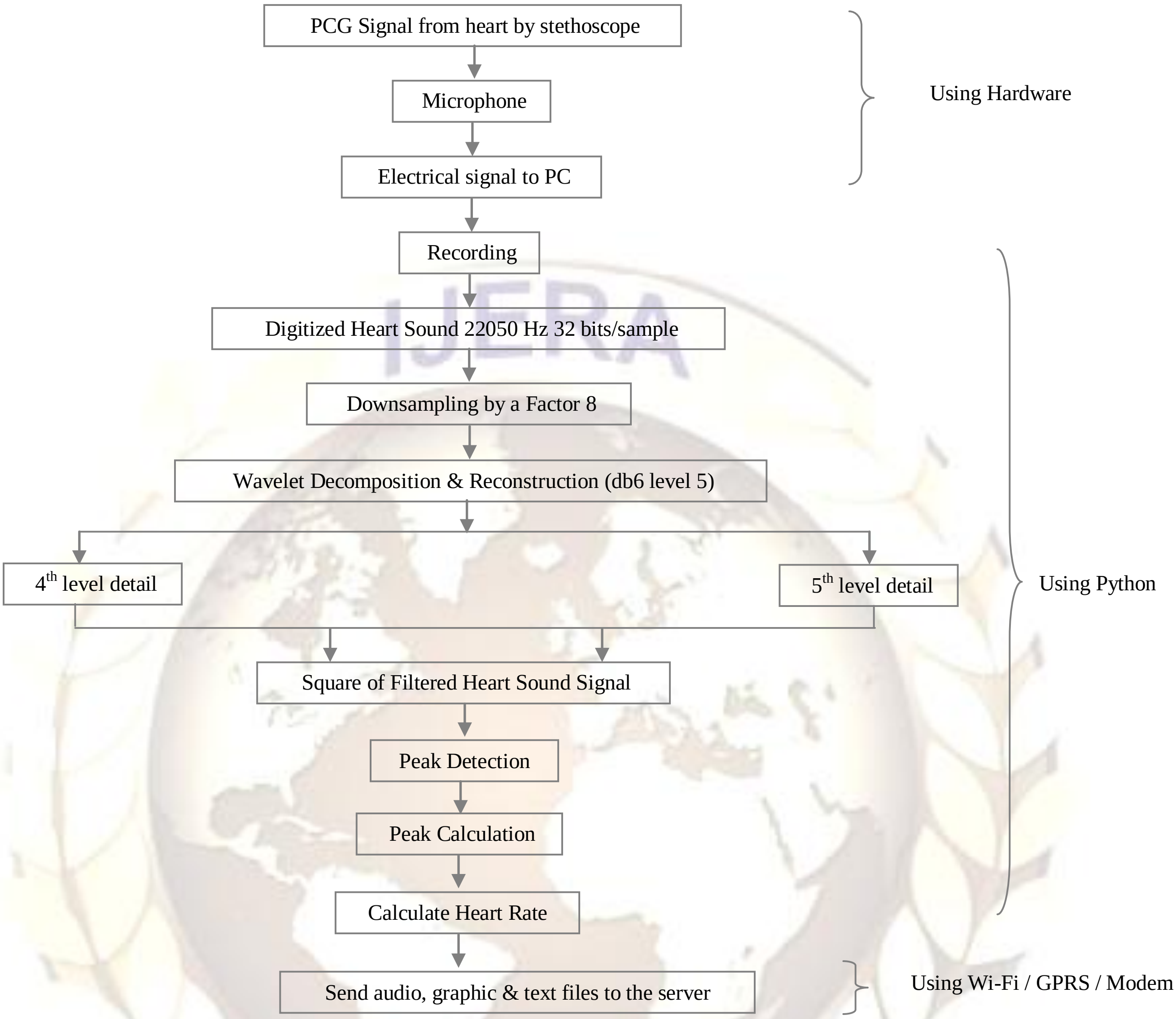

Fig 2: Steps involved in Heart Rate Monitoring

3.3. Peak Detection and Calculation for Heart Rate

Figures 3 & 4 show a filtered PCG signals, and its square signal and a threshold. Based on the envelogram calculated by the square heart sound signal curve, a threshold is set to eliminate the effect of noise and the very low-intensity signal. The peaks of each part whose levels exceed the threshold are picked up and assumed temporarily to be the first and the second heart sound. Here, only one peak for each overshoot is chosen even though there are more than one peaks above the threshold. The choice of the peak for each overshoot is based on the following criteria : (1) one peak is always picked up; (2) more than two peaks means the existence of splitted first or second heart sound, so the first peak is picked up in order to get the onset of each sounds. The actual abnormal heart sound recordings are very complicated and the patterns of heart sounds and murmurs vary largely from recording to recording even for the normal ones. To solve these problems, several additions are made in the procedure [10].

The main problem is that many extra ‘peaks’ are picked up. In order to eliminate the extra peaks, the intervals between each adjacent peaks are calculated. The low-level time limit is set, which is used for deleting extra peaks. When an interval between two adjacent peaks is less than the low-level time limit, there must be one extra peak which should be rejected. When two peaks appear within 50ms, which is the largest splitted normal sound interval [9], the peak having maximum strength is picked up. Then by taking the average separation of the peaks, heart rate is calculated by the formula,

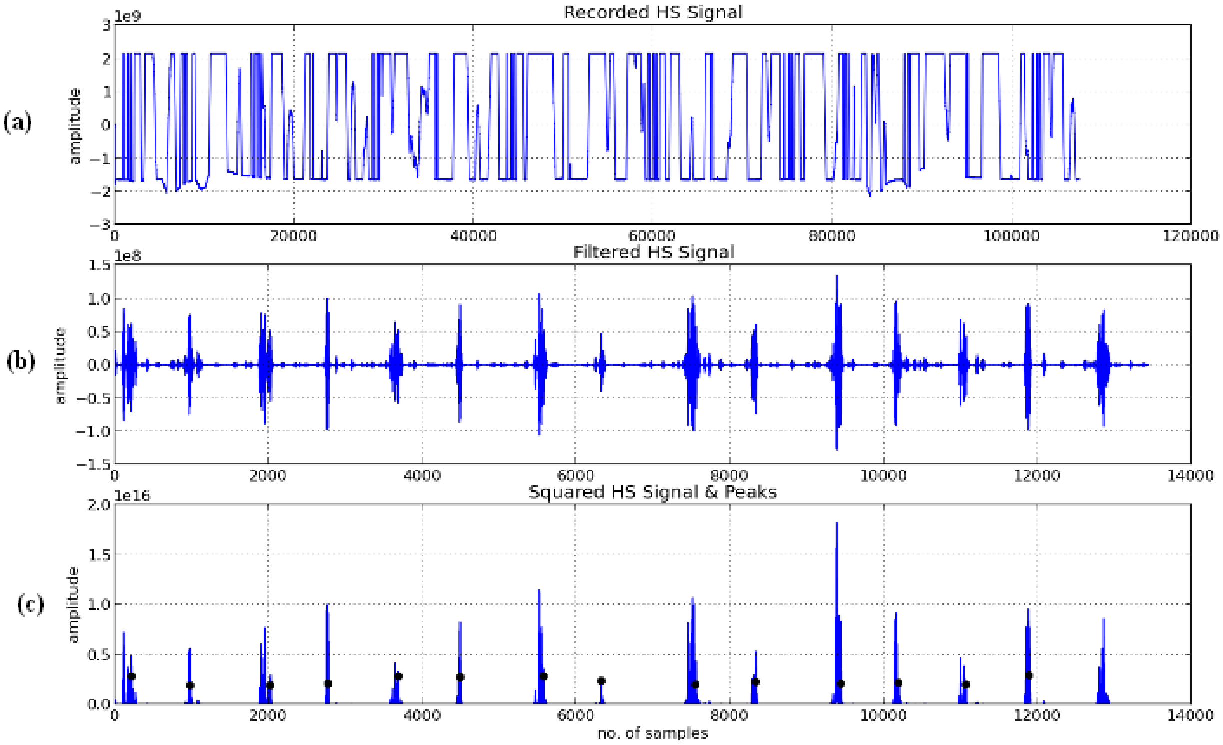

Fig 3: Implementation of Heart Rate Monitoring of a Child (a) Original recorded heart sound signal, (b) 5th level detail of the signal calculated by wavelet decomposition and reconstruction using dB6 (level 5) filter, (c) Square of filtered signal & Peaks detected for S1 & S2 both.

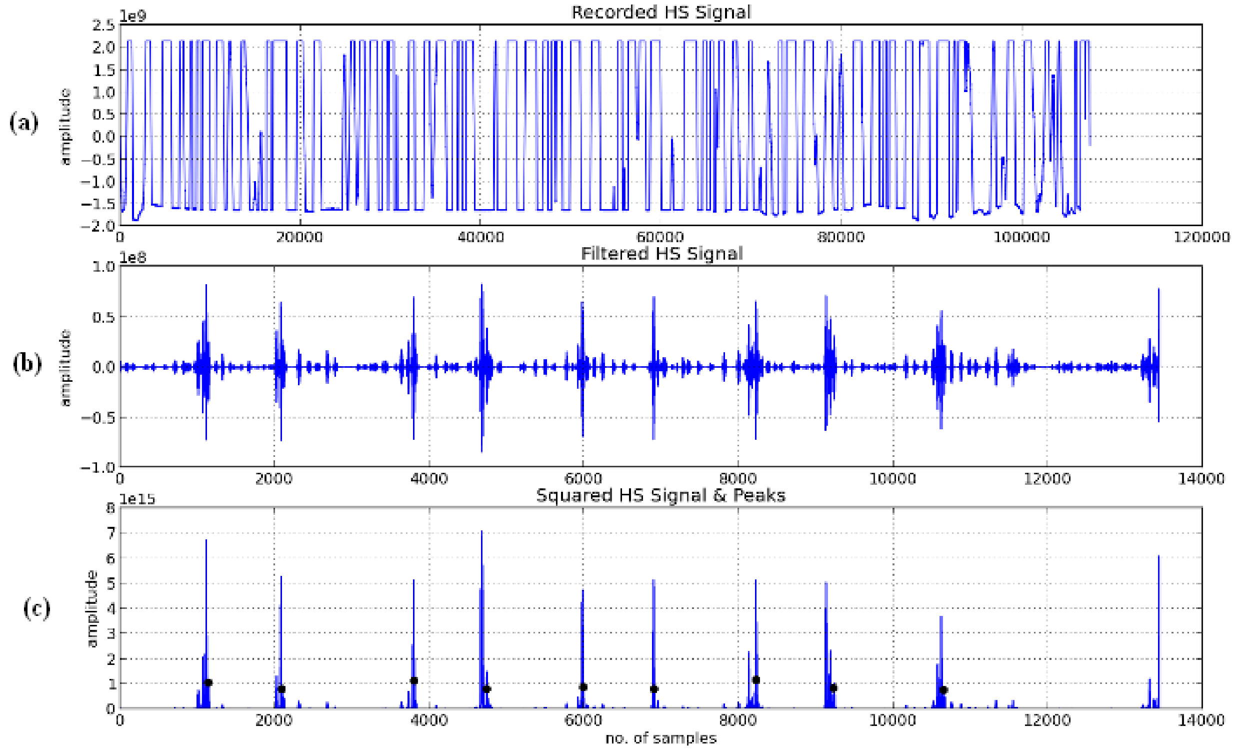

Fig 4: Implementation of Heart Rate Monitoring of an Adult (a) Original recorded heart sound signal, (b) 5th level detail of the signal calculated by wavelet decomposition and reconstruction using dB6 (level 5) filter, (c) Square of filtered signal & Peaks detected for S1 & S2 both.

IV. REMOTE MONITORING

A prototype of a simple and non-invasive system to remotely monitor the real-time heart rate of patients or individuals based on phonocardiography, to study the heart sounds has been developed. Here the detailed data of the patient is sent and saved on to the server. The data contains three main files 1) Audio clip of heart sounds in *.wav format. 2) The graphical representation of heart sounds i.e. phonocardiogram in *.jpeg format and 3) the patient information like name, patient id, doctor's name and patient's heart rate in *.txt format. For sending the information to the server, four wireless network options are there. Those are 2G Modem 1, 2G Modem 2, Wi-Fi and GPRS. By any of these the data is sent. The benefit of using four different wireless networks is that at least if only one network is available at a time the data will be send to the server. If there is no network coverage then the data goes in a queue and as soon as network will be present the data will automatically transferred to server. Once the data reached to server, it can be fetched from anywhere anytime for the expert advice by the internet or remote link.

V. ADVANTAGES OF THE DEVICE

Here the acoustic stethoscope is used instead of electronic stethoscope for acquiring the heart signals results in low cost of the device. Also acoustic stethoscopes are not battery operated. Remaining advance characteristics (Amplification, Noise Rejection and accuracy) of an electronic stethoscope have been achieved through software (Python). Once obtained digitally, sounds may be stored easily. Transmission, analysis, and storage are also possible at any distance. Heart sounds may be recorded in outlying clinics and transmitted to specialized centres for auditory review and analysis by cardiologists. This avoids the expense of patient travel and further consultation. Timely and appropriate intervention reduces the risk of heart damage and death.

VI. RESULTS

The PCG signal has acquired by the acoustic stethoscope shown above in figure 3 and 4. Also the microphone is used inside the hollow tube of stethoscope to record PCG with 32-bit accuracy and 22050 Hz sampling frequency. The experiments are made on several males and females aged from 23 to 40 years old, and on a child of 3 years old without medical history of cardiovascular diseases, and the heart sounds is recorded with the stethoscope placed on the chest near the mitral and tricuspid area. The recording is performed in an open space with people walking and talking around. Normal breathing is allowed during the experiment. Here two results are shown. One is of a 3 years old child and other is of an adult of 27 years old. The parameters of the proposed method are set as follows.

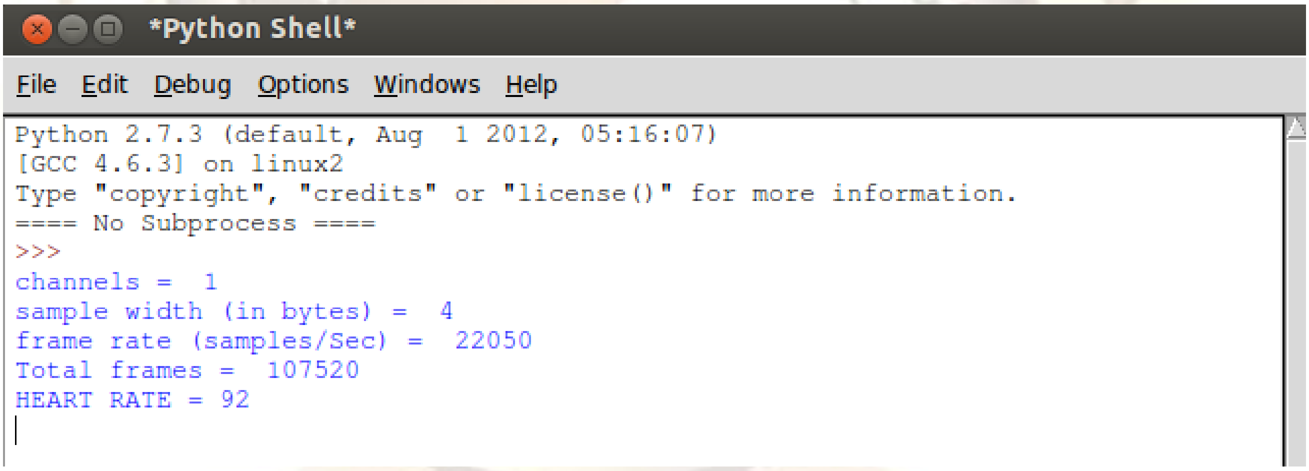

Fig 4: Results of Heart Rate Monitoring (of a child)

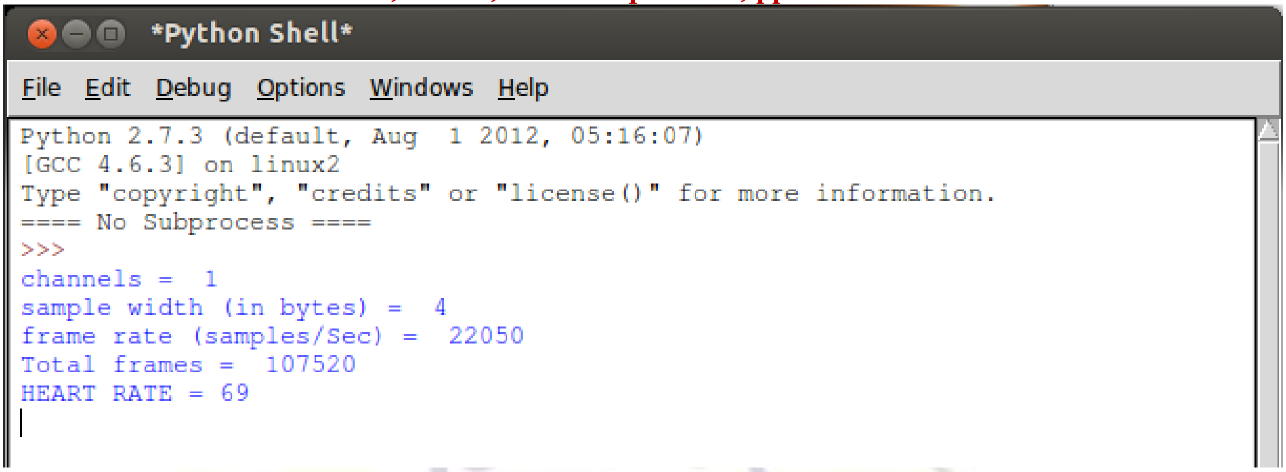

Fig 5: Results of Heart Rate Monitoring (of an adult)

Figures 4 and 5 show the following results for a child and an adult respectively. 1) The channel is mono. 2) Recorded heart sounds have 32-bit accuracy i.e. the sample width is 4. 3) Sampling frequency is 22050 Hz, 4) total frames in 5 sec recorded data sound. 5) The heart rate calculated by peaks detected.

VII. CONCLUSION

A module which acquires the heart sounds and processed them to get the phonocardiogram and heart rate has been developed and this can tele-monitor PCG. A general physician can interact with the module and get quick preliminary diagnosis of heart problems of patients who cannot be easily shifted to advanced hospitals which are at a distance and also who cannot afford high consultation fee and traveling cost. The Module has a provision of extracting information at the end of every step instead of working as a black box to the user. Such module will be a step towards the development of efficient medical care. It will overcome the deficiency of expert cardiologist in both urban and rural areas.

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