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Automatic Auscultation Utilizing Electronic Stethoscope for Early Discovery of Cardiac Diseases

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Abstract
A novel embedded system was designed for early detection of cardiac diseases using electronic stethoscope. Phono cardiogram (PCG) signalwas used to detect cardiac diseases as it contains very useful information about the condition of heart. Phono cardio gram signal was recorded using electronic stethoscope which reacts to the sound waves indistinguishably to the customary acoustic stethoscope, which is then given to hardware circuitry for signal processing such as amplification and filtering of noises and to amicrocontroller. A software was developed to classify the heart sounds as normal and abnormal and extracting some important vital parameters such as total power, Q factor, time duration of first heart sound (t1), time duration between first and second heart sound (t12) and mean 12 from recorded phono cardiogram signal for finding the cardiac condition. The proposed method is cost effective as itneeds minimal equipmentand it utilizes as it were 5 highlights for heart sounds classification comparedto existing technology which are employing a more noteworthy number of highlights.

Keywords
Murmurs, Feature extraction, Phonocardiogram, Microcontroller, Heart sounds

1. Introduction

Early detection of any disease is very important to diagnose and cure in correct time to avoid further complications in later stage which is very difficult to cure and leads to high health care expenditure and also severe damage to life. In this present work,early detection of heart conditions using phonocardiogram recording with digital stethoscope and microcontroller with suitable software was developed. Heart and cerebral problems are the major wellbeing issues all over the world which leads to fatality to life. Electro cardiogram is the commonmethod to identify the various cardiac diseases particularly echo cardiogram is used for heart valve related problems in natural and implanted artificial heart valves. Another very common mechanism used to identify the cardiac diseases efficiently and economically is through analysis of heart sounds. Auscultation of heart is the fundamental tool used in the heart problems diagnosis[1].The recording of heart sounds called phonocardiogram (PCG) contains heart sounds and murmurs in the form of waveform and the machine used to record these sounds called phonocardiograph. This is the devicewhich records heart condition in audible form. Heart sounds are generated due to opening or closing of the heart valves andblood flow through the heart valves or into the ventricular chambers also produces heart sounds. The four parts of a phonocardiogram are S1, S2, S3, and S4, or the first, second, third, and fourth heart sounds. Of these, the two prominent heart sounds, S1 and S2, are brought on by valve closure.Ventricular valve vibrations resulting from first quick filling provide sound S3, while atria contractions during the second stage of ventricular filling produce sound S4.

Due to high cost, limited availability and special skills necessary to record and interpret the results of ECG and echocardiography, heart auscultation methodsremain the primary tool for diagnosis and screening in primary health centers and remote areas. However, diagnosis based on heart auscultation heard though conventional acoustic sounds using ordinary stethoscope or electronic stethoscope needs a special skill and it takes very long time to acquire. Experienced doctors, nurses or technicians only can diagnose and interpret the cardiac diseases correctly using the auscultation method. Many primary health physicians and nurses are documented to have a poor auscultation skill [2].

Early pathological information's of heart valves are available in phonocardiogram signals and it is most useful in early detection [3, 4, 5]. The creation of cardiac soundsisnearly linked to the closing and opening of the atrio-ventricular, pulmonary and aortic valves [6].Many features are available in PCG signal which could be extracted using many feature extraction methods. These features are very useful in finding the cardiac illness that too automatically. Many feature extraction techniques are available for finding the cardiac diseases using PCG. In order to recognize between normal and aortic stenosis patients, wavelet analysis is the best method for feature extraction [7], Short Time Fourier Transform (STFT)is the best method for systolic murmur characterization [8]. Using deep learning it is possible to extract features automatically from the original signal and find connectionsbetween prediction value and data [9].Spectrogram and traditional Phono cardiogram are combined to distinguish pathological murmurs from innocent murmurs [10].To categorize heart valve illness, a diagnosis system utilizing SVM (Support Vector Machine) was presented [11].

Mehmet Ali Kobat et al. used a new method for feature generation and extracted 64 discriminative features to automatically find cardiac valve problems[12]. Many studies uses feature extraction and using these features doctors/ experienced nurses find the cardiac condition. It is a cumbersome method also needs high skill to diagnose from PCG features. Also, many methods need ECG signal to compare with PCG for accurate detection of cardiac problems. So in addition to PCG ECG machine also needed and it makes the system costly. Many PCG studies not directly gives the cardiac conditions but only the features and it needs skilled technicians to interpret. This is the main idea forthis study.This present method is used only for early detection and uses only five vital parameters to identify the cardiac condition. The software used in this study compares the vital feature of recorded PCG and directly display the heart condition as normal or abnormal so that the patient itself can understand his heart condition without going to hospital or consulting any medical professionals. As this method is only early detection and not full-fledged PCG device to know the various cardiac diseases, it needs minimal equipment and cost effective.

2. Materials and methods

2.1. Acquisition of PCG signal and processing

Rather than utilizing a traditional acoustic stethoscope that reacts to sound waves, an electronic stethoscope detects changes in the PCG signal, which substitutes variations in air pressure with variations in the electric field.This digital stethoscope which picks up heart sounds and act as a transducer which converts sound energy in to electrical signal is fed to analog amplifier for amplifying the signal. Using analog to digital converter, the filtered and amplified signal is converted to digital signal. After amplification the signal is given to a 8-bit CMOS Flash-based Microcontroller (ATMEGA 328**)** which can process the signal to identify normal or abnormal based on the five important features such as total power, Q factor, t1, t12 and mean 12.

2.2. Feature Extraction

Generally, many features are used to identify the PCG signal as normal or abnormal. More than 20 features are used in many studies to diagnose the various heart conditions thoroughly. Frequency domain, statistical features,time domain and other classifications are applied to these features. Peak amplitude [13], total power, zero crossing rate [15], Time 1, Time 2, Time 12, Time 21 [16], and other properties are found in the time domain.

The frequency domain features are total hormonic distortion, Q factor, bandwidth, peak frequency[14]etcand statistical feature Mean 12. The following are the detailed features used.The explanations for these qualities are provided below, along with potential information that might be used to distinguish between normal and pathological behavior.

2.2.1 Time domain features.

Peak amplitude: It means, the peak value of the signal. Murmurs have higher peak value compare to normal.

Total Power: The total power of the signal which is related to amplitude. As murmur has higher amplitude compared to normal, murmur has higher total power compare to normal.

Zero crossing rate: This is the speed at which a signal transitions from negative to positive or vice versa.Murmur signal is expected a larger value of zero crossing rate.

Time 1: This parameter is the first heart sound (S1) time duration. Generally, S1 has shorter duration sounds than murmurs having considerably longer S1.

Time 2: This parameter is the time duration of second heart sound S2, larger than S1. For murmur signal a longer S2 could be expected considerably than normal.

Time 12. This is the duration of time between S1and S2. As the region between first and second heart sound is shorter, murmurs is expected to have smaller Time12.

Time 21: This is the duration of time between $S_2$and $S_1$of nextCycle. As the murmur can be appeared just after S2, the area between the end of S2 to start of next cycle's S1 would be smaller.

2.2.2 Frequency domain features

Total Harmonic Distortion (THD): Its definition is the ratio between the fundamental frequency's powers to the total of all the harmonic components' powers. This is the measurement of the signal's harmonic distortion. For murmur signals higher THD is expected

Bandwidth: It is a measurement of the variation between a continuous set of frequencies' lower and upper frequencies.As murmursare having high frequency, higher bandwidth is expected.

Q-Factor: Higher Q-Factor values correspond to slower oscillation decay. So, murmur signal has a higher Q-Factor.

Peak Frequency: Peak frequency isthe frequency where the peak amplitude occurs. Sincemurmurs and normal signals varyin frequency and amplitude, it is also a valuable feature

2.2.3. Statistical feature

Mean 12: In the regions between S1 and S2 or S2 to next cycle's S1, Visible difference was seenin most of the murmur signals. So, the mean value was calculated in these regions and maximum of these two values ismentioned as Mean12 and it is higher for murmur signals.

2.2.4 Selection of Optimal features

All the features are not necessary for early detection of cardiac disease, only some vital features are to be extracted from the recorded PCG. Out of many features explained above, only five optimal features were selected based on Ranker and Info Gain Attribute Evaluation [17]. to segment the signals as murmur and normal signals, these 5 vital features are enough. So, our method requiresonly these 5 features to classify as normal or abnormal.

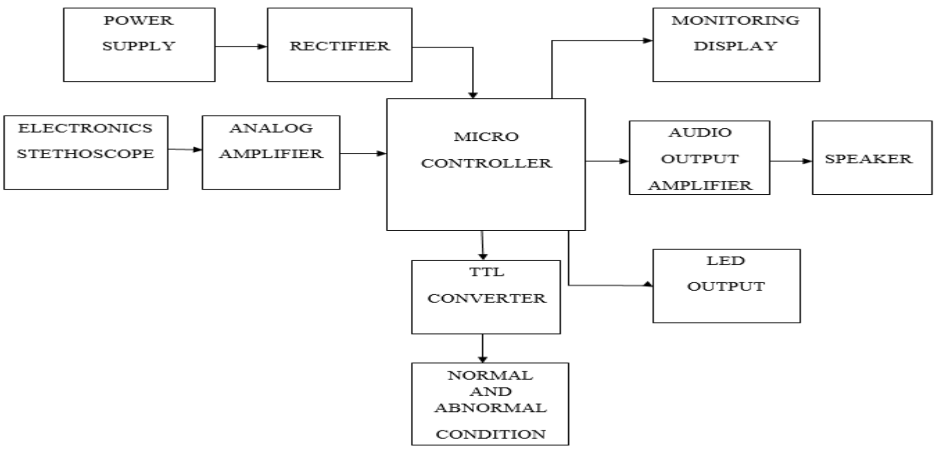

Figure 1 Block diagram of PCG module.

2.3 An Embedded system for heart sound analysis

The proposed system consists of an embedded system contains a hardware part for signal acquisition and software part for feature classification to detect cardiac abnormalities.Because the features of the PCG sound will vary for different valvular heart disorders, the sound signal can be utilized as an early indicator for the diagnosis of cardiac diseases such as aortic stenosis, mitral stenosis, aortic regurgitation, and mitral regurgitation. [18].In our method, as it is used only for early detection, the software part identifies the normal or abnormal PCG exactly and displays the type of cardiac disorder/disease such as normal or murmur. Figure 1 shows the block diagram of PCG heart sound diagnosing system containing different phases such as acquisition of as heart sound using data acquisition techniques, signal processing such as noise filtering, artifact removing and segmentation of PCG signal.Electronic stethoscope is used as sensor for PCG data acquisition as it has the advantage of ease of use, excellent sound quality, high accuracy, real-time waveform display, small volume, good sensitivity and better features compared to conventional stethoscope [19]. PCG is acquired by placing the stethoscope head into the chest piece which converts sound signal into the electrical signal with the help of microphone [20]. The output of the microphone is fed to the signal pre-processing stage which amplifies and filters the signal to improve the signal to noise ratio.In pre-processing phase, vital features will be extracted and in final stage the acquired signal will be classified as normal/abnormal.

The software incorporated in the microprocessor will identify the normal or abnormal sounds based on the normal parameter values compared for each five vital features. The status of the heart will be displayed in the LCD display (**HD44780**) as normal / abnormal with heart beat values also. The TTL converter used here is for serial communication. (The AN-USB-TTL module is a cost-effective method to convert TTL signal to a USB interface. From microcontroller, the signal goes to LED which blinks for every heartbeat. At the same time of displaying in LCD, the PCG signal from microcontroller also connected to speaker through audio output amplifier in which the patient can hear the heart beat sound.

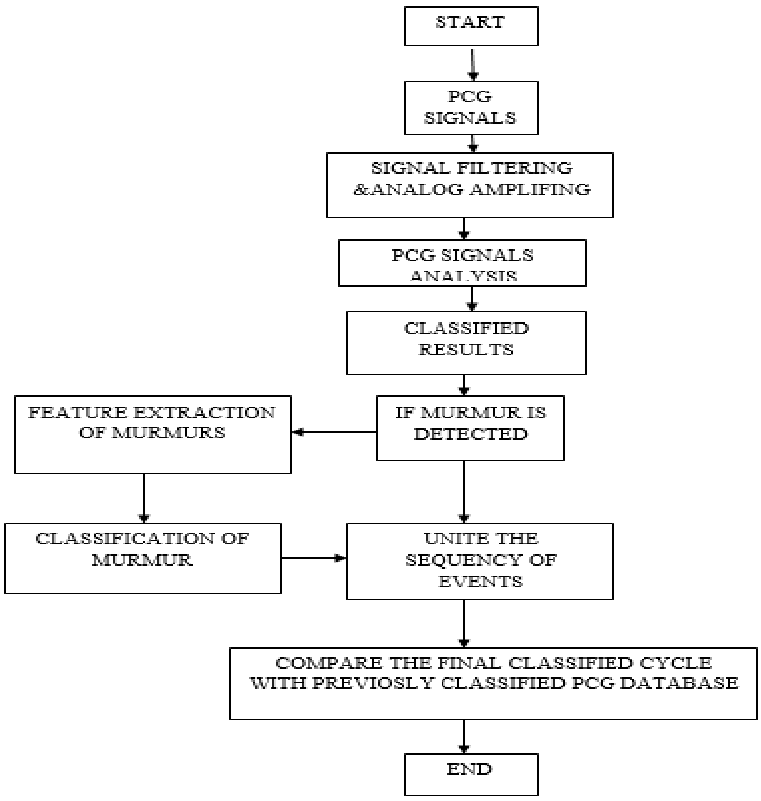

Figure 2 shows the various steps involved in PCG module.

The above flowchart explains the various steps involved like PCG acquisition, signal conditioning, feature extraction and signal classification, to separate the normal and abnormal sounds such as murmurs. The obtained PCG signal is compared with previously classified (Known normal data) PCG database and identify as normal / abnormal and displayed in LCD display.

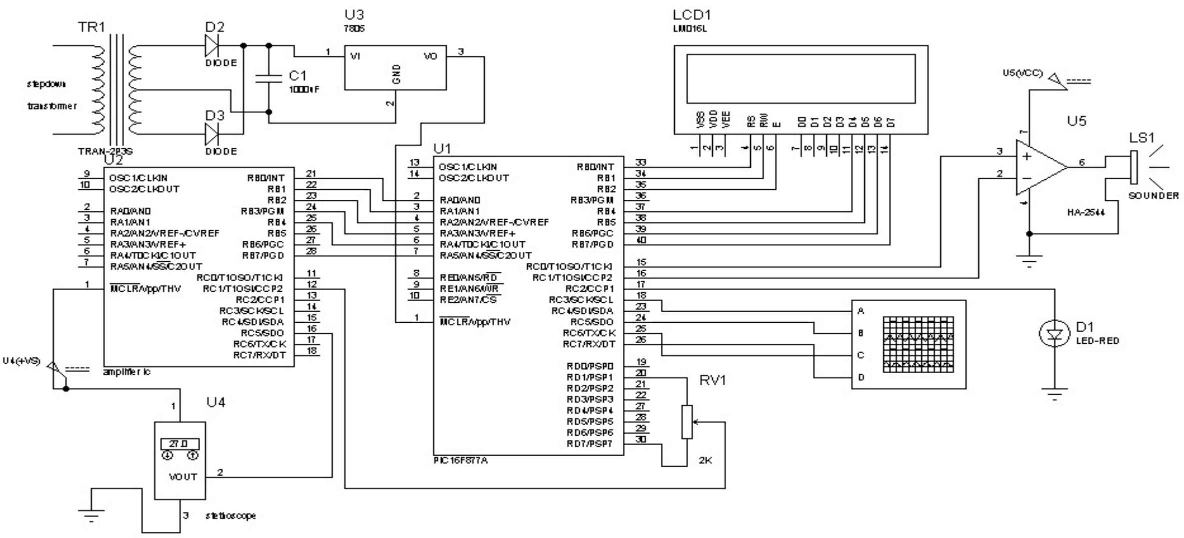

Figure 3. Circuit diagram of PCG module

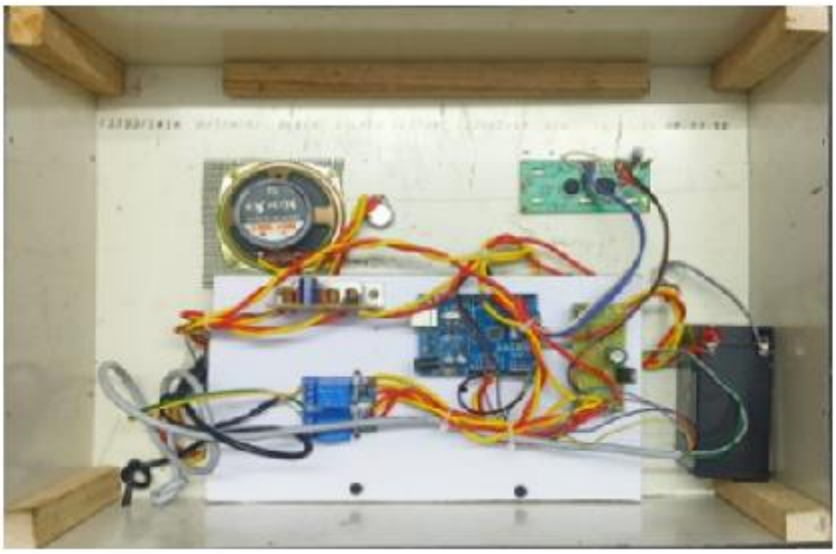

Figure 3, shows the exact circuit diagram of the Phono cardio gram device which includes power supply, microcontroller, LCD display, audio speaker, and LED display.

Figure 4. Proto type model of the PCG module

Figure 4 shows the prototype model of the PCG module which is incorporated with power supply, Battery, Amplifier for audio, speaker, microcontroller board and relays for switching to audio mode and feature extraction mode.

3. Results

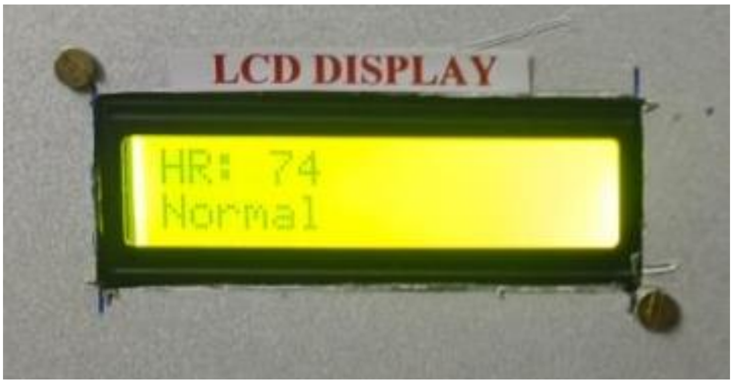

Figure 5 (a) Shows the Normal condition of the heart with Heart beat 74.

Figure 5 (b) Shows the abnormal condition condition of the heart with Heart beat 92 displayed as tachycardia.

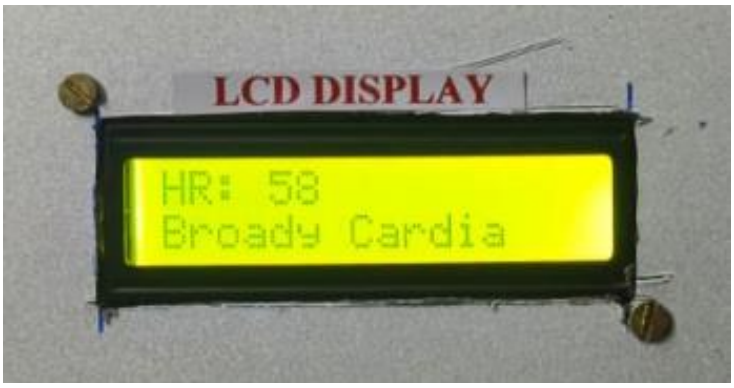

Figure 5 (c) Shows the abnormal condition of the heart with Heart beat 58 displayed as bradycardia.

Figure 5 (d) shows the abnormal condition of the heart displayed as Murmur.

The figures 5(a) to 5(d) shows above are output displays of the heart conditions with different condition as Normal (5 a), Tachycardia 5(b), bradycardia 5(c) and Abnormal conditions for Murmur. As explained above, the conditions of the heart can be known directly by simply placing the electronic stethoscope on the chest. So the patient can take decision himself weather to meet doctor or not by knowing the heart condition.

4. Discussion

Cardiac auscultation is one of the fundamental screening tools for clinical diagnosis of heart valve disorders in primary health care centers [21].Early pathological information about heart valves can be found in the phonocardiogram signal, which has been demonstrated to be highly helpful in the early detection of potential cardiac issues [22, 23]. The generation of heart sounds is linked to the closing and opening of the aortic, atrio-ventricular, and pulmonary valves [24, 25]. Many studies have shown auscultation of cardiac function is very useful in early detection of cardiac diseases. But traditional auscultation method provides an assessment of cardiovascular diseases based on the clinician's knowledge and expertise [26], also this methodology is wasteful and inclined to error [27].Heat valve problems leads to complication if not identified early particularlydegenerative aortic stenosis (DAS) is associated with a high mortality if diagnosed late and if no valve replacement therapy is performed [28]. With advancement of embedded system containing hardware and software, it is now easy to acquire the phono cardiogram data's and extract the features needed to diagnose the cardiac diseases. Lot of studies were developed so far for feature extraction and early diagnosis using phonocardiogram. Out of these methods, many studies need sophisticated techniques and devices to diagnose the cardiac diseases and some method utilizes ECG to correlate with PCG and makes the methods very costly and cumbersome. Particularly for early diagnosis with out the help of medical experts like doctors and nurses, the patient itself can identify the condition of the heart using a simple technique/ system, it needs a system with cost-effective and simple to use by the patient itself.Like glucometer to know the level of blood glucose Level in house itself by diabetic patient and digital blood pressure meter to know the blood pressure by the hyper tension patient, an embedded system was developed to know the condition of the heart whether it is normal or abnormal and the patient can decide whether to meet a doctor or not. The embedded system developed and presented in this study was using only five important features out of many features available as explained in this manuscript for early diagnosis and this is an automatic auscultation system that directly display the heart condition as normal or abnormal. This kind of auto auscultation method/device is not yet presented/published as for as the author is concerned. So, it is a novel and very useful method for cardiac patients.

5. Conclusion

A cost efficient novel embedded system was developed for phonocardiogram using electronic stethoscope for early detection of cardiac diseases. This system requires minimal equipment and does not require ECG recording. Out of many features available for phonocardiogram, only five vital features used to detect the cardiac abnormalities. This system will be more useful for patients in rural/remote areas where other high-end instruments are not available particularly for rural health management. It is especially helpful for newborns, for whom other methods such as ECG recording are challenging to utilize. Cardiac patients who had heart surgery can monitor the status of the heart after the surgery from home itself.Those who are having audible problem can use LED display and who are having visual problem can use audible sound which is incorporated with this system for understanding the heart condition. As this system is very simple to operate and no technical knowledge is needed to understand the heart condition, the patient itself can decide to meet doctor or not based on the result displayed.

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