JADAVPUR UNIVERSITY

MASTER DEGREE THESIS

A Prototype Design of Cost Efficient Portable Heart Sound Acquisition System: An IoT Sensor Node

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A thesis submitted in partial fulfillment of the requirements for the Degree of Master of Technology in Distributed & Mobile Computing

in the

School of Mobile Computing & Communication

by
ARNAB MAITY
University Roll Number: 001730501015
Examination Roll Number: M4DMC19016
Registration Number: 141112 of 2017-18

Under the Guidance of
DR. ITI SAHA MISRA
Department of Electronics & Telecommunication Engineering
Faculty of Engineering and Technology
Jadavpur University Kolkata-700032

May 29, 2019

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Dr. Iti Saha Misra
Professor, Department of
Electronics and Telecommunication Engineering,
Jadavpur University, Kolkata-700032

Director,
School of Mobile Computing &
Communication
Jadavpur University,
Kolkata-700032

Prof. Pankaj Kumar Roy
Dean, Faculty Council of Interdisciplinary
Studies, Law & Management,
Jadavpur University,
Kolkata - 700032

Certificate of Approval

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____

(Signature of the Examiner)

Date:

Jadavpur University

Abstract

Faculty Council of Interdisciplinary Studies, Law and Management, Jadavpur University
School of Mobile Computing and Communication

Master of Technology in Distributed and Mobile Computing

A prototype design of a cost efficient portable heart sound acquisition system: an IoT sensor node

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Arnab Maity
University Roll Number: 001730501015
Examination Roll Number: M4DMC19016
Registration Number: 141112 of 2017-18

Cardiovascular disease is the leading cause of death in rural as well as urban areas of all developing countries. It resembles more threatening aspects when statistical data for cardiovascular disease has been analyzed. A recent survey shows more than 50 % of death in the rural area is caused only by cardiovascular disease. A deep down study reveals some alarming reasons like financial degradation, high population growth, unavailability of a specialist doctor, unawareness about the current health status, poor infrastructure of the hospital and incompetent early detection care. To prevent this pandemic, numerous engineering approaches have been proposed in the literature but very few of them are sustainable with prevailing rural society. Most of the approaches are either expensive, complex in nature or seeks excellent knowledge and high-grade expertise to handle the system. Computed Tomography (CT) scan, X-ray, Electrocardiogram (ECG) are the most common and effective engineering approaches nowadays but these are still unreachable to the rural society for the absence of infrastructure support. Heart Sound Signal (HSS) that generally originates from the breathing heart, is an important health parameter since ancient time. Practitioner generally listens to the heart sound using the acoustic or digital stethoscope to detect the anomaly in it but it needs expertise and in-depth knowledge. In this work, a heart sound acquisition system has been proposed acknowledging the shortcomings of the current approaches and actual intricacies of the rural health system. Proposed heart sound acquisition system presents superior heart sound listening, on board data storing, simple User Interface to perform the operations, real-time visualization, Wi-Fi connectivity for remote monitoring or IoT implementation and primary level investigation of HSS. Considering the societal perspective, the proposed system is cost-efficient, portable, simple and most importantly the simplest procedure oriented, so that any common person with basic system handling knowledge can go for the data collection and perform the basic operations to aware people about their heart condition. Nearly, 25 real-time data has been collected from real environment of health camps to test the accuracy and effectiveness of the system.

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Regards,

ARNAB MAITY
University Roll Number: 001730501015
Examination Roll Number: M4DMC19016
Registration Number: 141112 of 2017-18
School of Mobile Computing & communication,
Jadavpur University

Signed: ______________________

Date: ______________________

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List of Abbreviations

PCG	**P**honocardiography
HSS	**H**eart **S**ound **S**ignal
CT	**C**omputed **T**omography
ECG	**E**lectrocardiogram
HS	**H**eart **S**ound
DTFT	**D**iscrete **T**ime **F**ourier **T**ransform
DWT	**D**iscrete **W**avelet **T**ransform
CVD	**C**ardiovascular **D**isease
MRI	**M**agnetic **R**esonance **I**maging
DSP	**D**igital **S**ignal **P**rocessing
Wi-Fi	**W**ireless **F**idelity
UI	**U**ser **I**nterface
PC	**P**ersonal **C**omputer
ADC	**A**nalog to **D**igital **C**onverter
LCD	**L**iquid **C**rystal **D**isplay
TFT	**T**hin **F**ilm **T**ransistor
GUI	**G**raphical **U**ser **I**nterface
SD	**S**ecure **D**igital
USB	**U**niversal **S**erial **B**us

List of Symbols

Ψ	|	Wavelet Function

Chapter 1

Introduction

1.1 Overview

Global survey on public health unveils a disquieting fact about cardiovascular disease (CVD) which is one of the major public health problems worldwide. More than 50% of death in rural society causes only because of this cardiovascular disease and nearly two-thirds of people worldwide are at high risk of this burning disease [1]. Statistics show further threatening consequences for the developing country like India, Pakistan and it's sub-continental as the percentage death rate in these regions due to cardiovascular disease increases each year since 1990. In between 1990 and 2016 death rate in India due to cardiovascular disease surged by around 34% from 155.7 to 209.1 deaths/1 lakh population [2]. Fig. 1.1 shows the recent statistical data published in The Lancet [3].

Going deep down to find out the root cause, some obvious reasons come into the picture that needs immediate action to prevent this peril. First of all, poverty that remains integrated into the Indian rural society since its independence is the major problem for our society. As a consequence, poor people are suffering from essential medical treatment and contributed predominately to the mortality rate. Second, patient to doctor ratio, with a high accession in population specialist doctor lacks behind, becomes another major problem. Though, in urban areas of India reaches nearly to its required figure (1:1000), a huge shortfall still remains in rural areas of India. This ratio is extremely critical in its neighbouring countries like Pakistan, Bangladesh, and Afghanistan as the ratio remains below 0.500:1000 [4]. At the same time, the World Bank reported, 70% of the populace in India still living in rural regions that have no or insufficient access to healthcare facilities [5]. This imposes a huge pressure on the specialist doctors in urban areas and increases the risk of error in treatment. Further, due to the lack of infrastructure, some modern diagnosis systems like computed tomography (CT); Cardiac magnetic resonance imaging (MRI) is still unreachable to the rural society. Added to this, complexity in system handling, higher manufacturing cost, and costly screening test makes some medical system unreliable to use. As a matter of fact, people need to travel a long way to urban hospitals to get essential treatment. Sometimes people died without any treatment before reaching to Hospital. Apart from this, self-awareness, socioeconomic burden, improper health system, ignorance about the preliminary health condition and irregular health check-up has also remained a serious issue to Indian society.

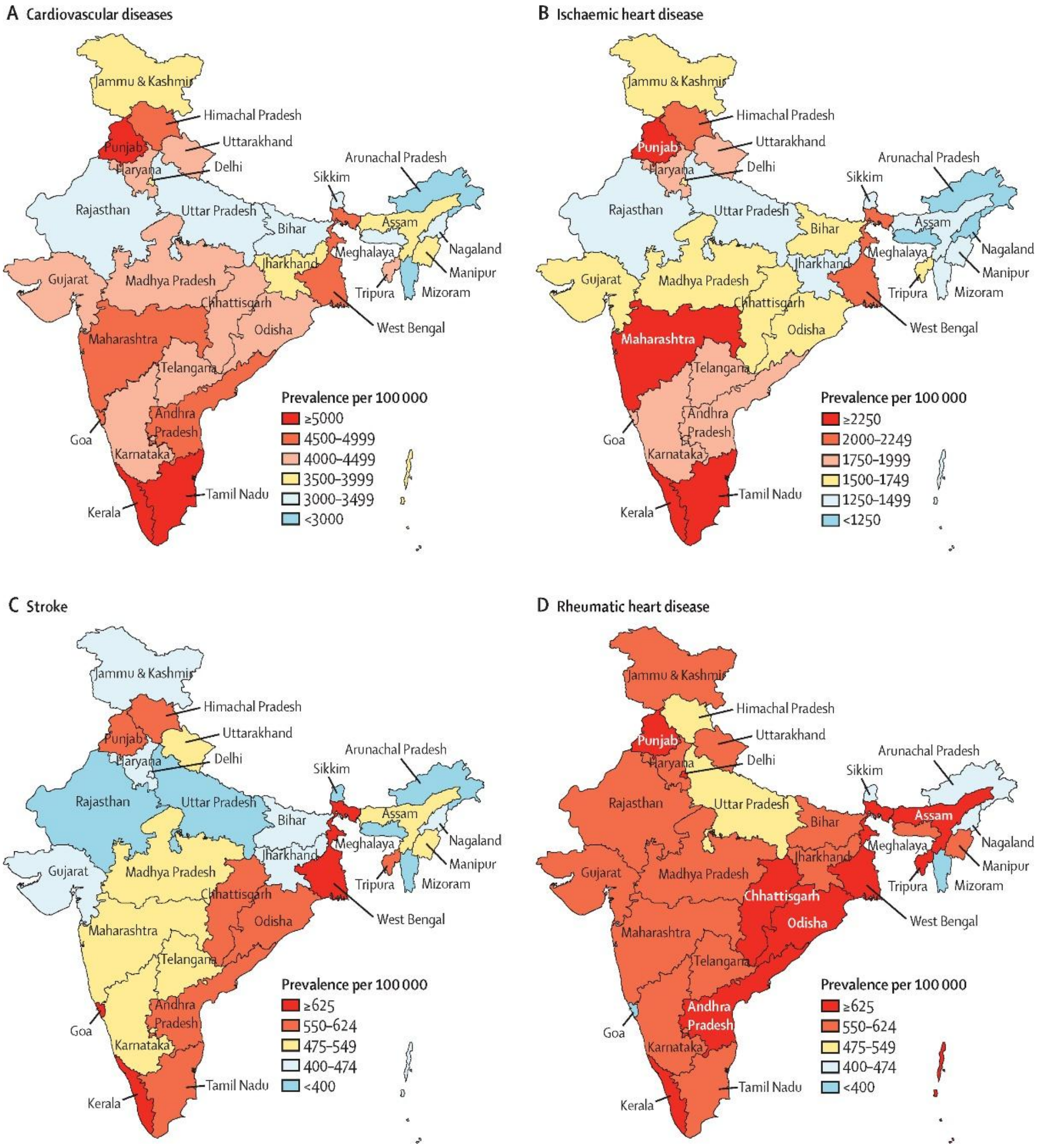


Fig. 1.1State wise statistics for death rate due to different cardiovascular diseases in India [3]

1.2 Motivation

In the last few decades, numerous approaches have been proposed to prevent the increase in mortality rate due to cardiovascular diseases. In the table I some of the popular engineering approaches for the detection of cardiovascular diseases have been outlined that is often used for the diagnosis of cardiovascular diseases.

Table 1.1 Engineering approaches (Biotechnology) for cardiovascular diseases

Technique	Procedure
Digital Stethoscope (Heart Sound)	With this technique practitioner can listen, visualize sound of the heart by putting chest piece near to the heart.
Coronary angiogram	A catheter is inserted into an artery in our body parts to take the x-ray of the coronary artery. The X-ray report shows the abnormality coronary artery.
Coronary computed tomography angiogram (CCTA)	Computed tomography (CT) scan produces a 3-dimensional representation of the heart chambers and coronary arteries supplying blood to the heart.
Blood pressure monitoring	Blood pressure monitor provides accurate information of blood pressure that is very useful in cardiovascular disease detection.
Chest X-ray	Using an X-ray, snapshots are taken of the structure and organs inside the chest (i.e. heart, lung etc.)
Echocardiogram (heart ultrasound)	It gives a picture of heart using ultrasound. It uses a probe either on your chest or sometimes can be done down your oesophagus (throat).
Electrocardiogram (ECG)	An ECG reads heart's electrical impulses. Sticky dots and wire leads are placed on chest, arms and legs. The leads are attached to an ECG machine which records the electrical impulses and prints them out on paper.
Electrophysiology studies	Electrophysiology studies use a computer to find out about an abnormal heartbeat (arrhythmia).
MRI	An MRI works on the principle of strong magnets and radio waves. It constructs detailed images (still or moving pictures of your heart) of the heart on a computer.
Tilt tests	Tilt test is used to see whether different body positions will trigger an abnormal heart beat (arrhythmia).

Among all the approaches, the stethoscope is the most popular, cost-effective and easiest procedure based for the early detection of any cardiovascular disease. From ancient time, the practitioner believes the healthy human body has its own unique sound. So, they listen to the sound of the heart to identify if there is an anomaly present. But this needs eminent knowledge and expertise to understand the nature of the sound, the only specialist doctor can do so. But application of proper de-noising technique, less complex analogical algorithms, efficient acquisition technique can provides us best solution to current situation. Considering all these, our motive is to present a simple but complete system solution of heart sound acquisition, component identification, and analysis with excellent accuracy (> 90%) to be managed by common rural people with only basic hands-on training and knowledge of the system handling. So, literate people with system handling experience can simply organize “healthy heart camps” that will offer a general check-up to help rural people to be conscious of their heart condition. Any selected team can go further for a survey to the rural area and collect the heart sound data. After initial identification, they can send it to the specialist doctor for further analysis. This will focus more on early detection care and prevention with both conventional and innovation techniques.

1.2 Objective

To achieve the goal, we must have to become efficient at every stage of the heart sound signal analysis (i.e. Signal acquisition stage, component identification or signal de-noising stage, feature extraction stage, analysis stage). Heart Sound Signal acquisition system must be cost-efficient, portable, simple method oriented, and reliable to use. Component identification algorithm should be less complex, with a simple mathematical basis and can be done in a procedural way such that one who only knows the basic steps can perform the entire process. Keeping all this, desired system should have the following characteristics:

Portable: Portability must be an essential specification of the desired system so that it can be carried out by anyone to anywhere to diagnose the patient. This will enables common people to get the benefit standing at their own door.

Cost Efficient: Targeting economically backward societies of India and its neighbouring country the designed system must be cost efficient.

Energy Efficient: Energy preservation not only saves the environment but keeps our life more enjoyable. The Place where direct Electricity not available, energy efficient system can be easily implement using renewable energy sources like Solar energy, Wind Energy.

Real-Time: Heart monitoring and cardiac disorder sometime required immediate action to save patient’s life. So, real-time detection and analysis must be another essential feature of the desired system.

Simple: Simplicity in the system will help common literate people to handle the system more easily and efficient. With the help of the system common people will determine the basic abnormality if exist. Then they will forward the findings to the specialist doctors for further clarification.

Easy Procedural based: System handing must be an easy procedural based so that any literate person with basic knowledge of the system can perform the system operations.

Early Detection Capability: Cardiovascular disease is one of lethal disorder that develops day by day. So, early detection of disease can save innocent life with the conventional preventive cares. This can also assist the specialist doctor to determining the abnormality more efficiently.

Reliable to disease detection: The system must be reliable in determining the abnormality of the patient.

So, our objective lies here to implement this entire requirement to a single integrated system to accomplish the aspired goal.

1.3 Contribution

In this work, the study of number of the existing stethoscopes (acoustic and electronic) has been done. As stethoscope is the most reliable medical device to detect an initial indication of cardiovascular disease, starting from the evolution to modern day’s digital stethoscope has been reviewed. We mainly focused on the innovative approaches that directed towards system integration with modern day's low cost, reliable and simple but equally essential technologies. Innovative HSS acquisition system using IOT platform has been proposed and implemented. The complete system has been demonstrated in details for the sake of understanding on system integration. Real-time patient data has been collected using the implemented system by attending medical camps. Collected data has been tested and analysed to evaluate the system performances. Results show a significant improvement in the signal acquisition technique and the real-world implementation of the system. As the system is targeted towards a reliable medical device for cardiovascular disease detection, an enormous research scope has been opened. So, thesis end has been concluded with a details future scope of the work.

1.4 Organization of the Thesis

The rest of the thesis is organized as follows: a detailed related work has been presented in chapter 2 which discusses in detail the existing researches that have been conducted to integrate digital stethoscope to an essential heart diagnosis system followed by background study in chapter 3. In this chapter a detail study on physiology of human heart, physics behind heart sound and characteristics of different heart sound components has been discussed. Chapter 4 entirely dedicated to the design methodology of proposed system. This chapter represents the proposed system with detail description of each module and system component specified in proposed system flow chart. Immediately after that, Real time implementation of designed system and corresponding outcomes are presented in chapter 5. At the end, chapter 5 conclude the work and gives a future direction to take forward this research work for a novel cause.

1.5 Summary of the Chapter

This is an introductory chapter where current scenario of cardiovascular disease in India and its neighbouring country has been surveyed. Then the motivation has been pointed out behind taking the heart sound signal acquisition system design as research area followed by the objective and contribution in this context. Finally the organization of the rest of the thesis has been outlined.

Chapter 2

Literature Survey

2.1 Overview

From very ancient time physician knows that working of the healthy human body has its own unique sound. Clinicians directly put their ear to the patient chest to hear the heart sound. This technique is known as 'Direct Auscultation', was very uncomfortable for the women patient and also had a high risk of infection to the clinician due to great corporal contact. The major revolution came in the auscultation technique in the year 1816 when Rene Laennec invented the stethoscope [7]. Laennec was requested to examine a woman patient with a high degree of obesity with general symptoms of cardiac disorder. It was totally impractical to examine with direct auscultation method. So Laennec used some paper and folded it like pipe and put one end to the patient chest and hears from the other end. It was a very effective approach to listen to HS. Further, he invented the very first auscultation device, acoustic stethoscope. Fig. 2.1 shows the first invented stethoscope by Rene Laennec. From then stethoscope becomes a fundamental medical device for the medical practitioners. In this chapter, a detail literature review on heart sound acquisition device has been reviewed starting from the ancient acoustic stethoscope to modern day intelligent stethoscope.

Fig. 2.1 Ancient stethoscope invented by Rene Laennec [6]

2.2 Acoustic Stethoscope

Acoustic Stethoscope works on the principle of sound wave transmission through the hollow tubes. In general acoustic stethoscope consists of diaphragm (Bell & Chest Piece), flexible rubber tube and an ear tube. Fig. 2.2 shows different components of an acoustic stethoscope.

Fig. 2.2 Basic components of acoustic stethoscope

When a chest piece placed near to the heart, sound wave vibrates the diaphragm creating acoustic pressure wave. This sound wave then propagates through the hollow rubber tube to the aural tube and reaches the listener's ear.
26 years after the invention of the first stethoscope, in 1829 Golding bird describes flexible stethoscope that uses a flexible tube between the ear and the patient chest [8]. In 1851 Iris physician Arthur Leared introduced a binaural acoustic stethoscope. 1 year later, George Philip Cammann commercialized the product with a more perfect and reliable design which has become the standard ever since [9]. In 1858, Somerville Scott Alison represents a new model of the stethoscope which had two separate bells, enabling physician to hear and compare sounds derived from two discrete locations of the body. But this model requires advance knowledge of sound localization and eventually leads to an understanding of binaural fusion [10]. In early 1984, David Littman created a new stethoscope that was lighter in weight and had improved acoustics. Further, he introduced tunable diaphragm which permitted increased excursion of the diaphragm member in z-axis with respect to the plane of sound collecting area [11]. Though acoustic stethoscope reached its supremacy level and considered as utmost reliable medical device till today, it is still stripped of some technically improved feature that can transform the diagnosis pattern undividedly.

The prevalent limitations of the acoustic stethoscope are:

- The sound intensity level of the acoustic stethoscope is very poor as heart sounds are the extremely low-intensity wave. The invention of Stratified continuous (inner) lumen surmounts this problem but not at its aspired level.
- For remote health check-up storing patient data is an essential requirement. The acoustic stethoscope is not competent in storing the heart sound data.
- With the advancement in Computer-aided diagnosis, graphical representation of the heart sound signal is also becomes a crucial characteristic that is not possible with this type of stethoscope.
- Listening to heart sound in a noisy environment using acoustic stethoscope leads to an indefensible prediction of cardiovascular disease.

To overcome these outcomes researcher and medical practitioner looked forward to the solution with an electronic stethoscope.

2.3 Electronic Stethoscope

An electronic stethoscope is an advanced medical device that overcomes the low sound level problem of the acoustic stethoscope by amplifying the body sound electronically. General block diagram of electronic stethoscope has been shown in Fig. 2.3. It first converts the sound energy to electrical energy by placing a transducer attached to the chest piece. Then with the amplifier circuit, it amplifies the low amplitude signal to high amplitude signal for superior listening. A filter is used to remove the unwanted noise frequency from the original pathological heart sound signal.

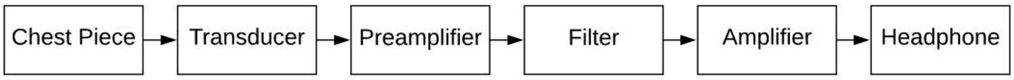


Fig. 2.3 General Model of Electronic stethoscope

The electronic stethoscope was first introduced much before the twenty-first century, but only a minimum level of improvement has been realized in the last few decades. When HSS is recorded and plotted for diagnosis purpose it is called phonocardiography. In1997, Lukkarinen et.al. introduced new phonographic recording system that can record, process and analyze the heart sound signal [12-14]. But the portability was the foremost problem in these devices as PC (Personal Computer) is used to perform the entire process. The cheapest and most effective design was to place a microphone to the chest piece. But the ambient noise interference becomes most concerning to these devices [15]. Currently, piezoelectric crystal has been placed in the diaphragm with an electronically conductive inner surface which forms a capacitive sensor and converts heart sound wave to corresponding electrical pulses more efficiently [16]. Since last decade, implementation of multi-channel signal acquisition [17-19], innovative filter design [20-22], post-acquisition noise cancellation [23-26], ambient recording and mostly advance signal processing techniques [27-29] improved electronic stethoscope a lot but more expensive than good acoustic one. Woywodt et al. believed that electronic stethoscope has the potential to become the most reliable diagnostic tool only if it is configured right away. They formulated a real-time acoustic tool using PC that can collect, analyze and display real-time indicative abnormality in PC Monitor [30]. Over viewing current literature and real-life problems, electronic stethoscope still lags behind in cost-effectiveness, simplicity and most importantly system complexity. Now the researcher explores more reliability, cost-effectiveness, and simplicity in targeted systems using new cutting edge technology platforms. In the next section, we will exploit more details on very recent approaches in digital stethoscope.

2.4 Recent Approaches

With advancement of technology numerous approaches have been proposed to implement electronic stethoscope as a medical diagnosis system. In the Table 2.1 some of the very recent approaches have been summarized.

Table 2.1 Technology Update: Digital Stethoscope

Ref	**Basic Hardware used**	**Proposition**	**Contribution**	**Remarks**
[31]	Arduino UNO, Bluetooth Module	Bluetooth enabled wireless stethoscope	• Low cost • Portable • Real time data storing is possible.	• Long distance monitoring is not feasible • Real time signal analysis is absent. • PC based software is required for diagnosis.
[32]	IOT Platform: Wi-Fi Module, smartphone, Sensors	Preliminary multipurpose-health parameter monitoring chair with E-diagnostic feature.	• low priced diagnosis • non-invasive • Indigenously built medical apparatus • GUI using Meganulink Pro • Wi-Fi module is implemented for remote monitoring.	• Expensive infrastructure required • System handling needs expertise • High manufacturing cost.

Ref	Basic Hardware used	Proposition	Contribution	Remarks
[33]	Wireless Transceiver	Wireless Transceiver is embedded with digital stethoscope that can communicate between PC and chest piece.	• Cost efficient module & Portable • Continuous monitoring is possible	• Requirement of PC added cost to the system • Long distance monitoring is not possible • Separate diagnosis is required • Good expertise and skill required to perform the operations.
[34, 35]	Smartphone	3D printed stethoscope can be connected with smart phone for visualization of signal	• Portable & low cost • Real time HSS can visualize in Smartphone • Dedicated app for signal storing and other functionality	• Real time listening is not implemented • Signal analysis is not possible in the app • Basic characteristic parameters are not computed • No signal processing algorithms present in the system.
[36]	Free scale Kinetis K64 micro controller, Embedded system	The integrated system comprises of Analog and Digital signal acquisition model along with Bluetooth module. It is used to acquire and store the HSS	• Practitioner can listen HS using analog part of the device • HSS can be stored and analyzed using digital part of the system • System is designed to support a wide range of measurement chain configurations	• System handing needs expertise • PC based software is required to characterized the HSS • Infrastructure based system

Ref	Basic Hardware used	Proposition	Contribution	Remarks
[37]	DSP processor	The stethoscope consists of sub band gain adjustment, record functionality, regular and half speed playback functionality, system-level features including battery monitoring, volume Control and a LCD display.	• Focused mostly on low power consumption, portability • Gain adjustment and sub band coding/decoding functionality has been implemented with dedicated algorithms.	• Cost of the system is higher • System Handling needs expertise Characterization of HSS has not been implemented.
[38]	Arduino Mega, Skin resistance Sensor, Temperature Sensor, Heart rate sensor, GPS module, GSM module	Arduino based interactive steering wheel system that detects the signs of an approaching heart attack in individuals with a history of Chronic heart diseases while driving. The developed device continuously monitors the driver's heart rate, body temperature, and skin resistance to detect the disease.	• Real-time monitoring of the heart patient • Innovative sensing and alarming system • Cost effective solution. • If heart-attack detected, driver is guided through a smart algorithm.	• Focus only on the heart-attack detection. Other abnormality detection methods not explained. • Targeted towards the car automation. • Power consumption is higher. • System needs well established infrastructure to become fully functional.

Ref	Basic Hardware used	Proposition	Contribution	Remarks
[39, 40]	Arduino Due, MATLAB Signal Analyzer, Lab view Signal Analyzer	Electronic stethoscope designed to listen to heart and lung sound. Real-time PCG and heart rate calculation have also been implemented. MATLAB is utilized to characterize the signal.	• Heart rate Calculation, Audio processing, Phonocardiograph, DSP has been implemented using MATLAB • Heart sound is collected using innovative signal conditioning circuit.	• Portability is major issue • System integration is difficult • System handling needs expertise
[41]	Arduino Nano, MEGA, Zigbee Transreciever	Wireless stethoscope has been implemented using Arduino nano, Arduino Mega and Zigbee Transceiver module.	• MATLAB GUI has been develop to real time data logging and display in PC screen. Signal can be transmitted over a 100 meters range	• PC is necessary component • Infrastructure based system • Long distance monitoring is not possible
[42 - 44]	SHESOP Smart chair	An intelligent system on Smart chair for monitoring heart rate and Stress levels of car driver.	• System is implemented on car chair and data has been collected for evaluation.	• Not portable system • Manufacturing cost is higher • Used for specific application purpose

Ref	Basic Hardware used	Proposition	Contribution	Remarks
[45]	TMS320F2812 DSP processor, Bluetooth Module	Designed a portable digital esophageal stethoscope system (PDES) that can wirelessly display heart sound waveform, temperature.	• Low cost and Portable • simple to use for anesthesiologists • Can provide heart sound, breathing sound, core Temperature • Wireless data transmission.	• System handling needs expertise. • Signal analysis needs separate system

More details study provides some important observations with the current propositions

- Most of the cases Arduino are used as the controlling unit because of its simplicity and open source IDE [46]. Also Arduino is the basic element that can easily configurable to IOT cloud using wireless connected devices (like: Bluetooth, Wi-Fi module).
- Sound sensor (piezoelectric [47], condenser microphone [48]), body temperature sensor, blood pressure sensor, ECG sensor, heart rate sensor, skin resistance sensor are the most common sensors in literature that are used to detect the cardiovascular disease [38].
- Noise affection due to the sources from internal or external to body is the most important factor in reliable digital stethoscope design. Almost in all designs it is considered as the foremost objective [49-52].
- Different kind of wireless technology like Bluetooth [45], Wi-Fi, and Wireless radio [41] has been implemented throughout the literature for the sake of remote monitoring or wireless connectivity. Wi-Fi has been used as the gateway to the internet or can be used for IOT implementation. Bluetooth is used to communicate with the Smartphone [45]. Wireless radio is implemented for the direct communication between stethoscope and the computer [53].
- DSP processor has been used in many applications to collect, store, and real time visualization of heart sound signal [53, 54].
- Some of the technique used mobile networks to remote monitoring of the patient [55].
- Embedded system based solution are mostly cost effective and easily portable [56, 57].

2.5 Summary

In this chapter, we have discussed the current literature survey on various stethoscopes and the ongoing research techniques. There are numerous individual approaches have been proposed in the literature on a specific stage of heart sound evaluation. But a very few approaches have been found in the literature that focused on the complete system integration. So, the aim is to propose a portable, cost-effective, and reliable system that will facilitate the evaluation of heart sound in a single box.

Chapter 3

Background Study

3.1 Overview

Before going deep into the proposed methodology a brief background study is included to be familiar with the technical terms used in the proposition. The entire theoretical background of 'Heart Sound Signal' mainly focused on three basic words (i.e. Heart, Sound, and the Signal). In this chapter, the physics of sound explained the term Sound. Physiology of heart has been elaborated with the introduction of the basic human heart anatomy, cardiac cycle, and different heart valves. Heart sound section describes each sound component generated by the breathing heart, whereas mathematical methods include the two essential mathematical tools of signal processing i.e. Fourier Transform and the Wavelet Transform.

3.2 Physics of Sound

A study on heart sounds is by no means complete without an introduction to the physics of sound. Sound is a vibration that propagates as a wave of pressure through a transmission medium. A vibrating source creates vibration to its surrounding medium and set its own particle in motion. In each movement, each particle generates high and low pressure to its nearby particle, therefore, creating a chain effect, propagates through the medium at the speed of sound. The behaviour of sound can be characterized by the frequency and intensity of the vibration. Where frequency is the number of occurrences of particle oscillation per unit of time and period is the duration of time of one cycle [58]. Apart from these, the speed of sound and medium of transmission plays a key role in the sound wave. When this wave propagates and reaches to our ear, it vibrates the tympanic membrane and specific perception from the brain recognizes the sound. The human brain can recognize the sound of a frequency range between 20 Hz -20 kHz.

3.3 Physiology of heart

The pumping of blood through the blood vessels of our body tissue has been performed by the muscular organ called heart. It consists of 4 chambers, 2 atria and 2 ventricles. Fig. 3.1 shows the basic structure of a human heart.

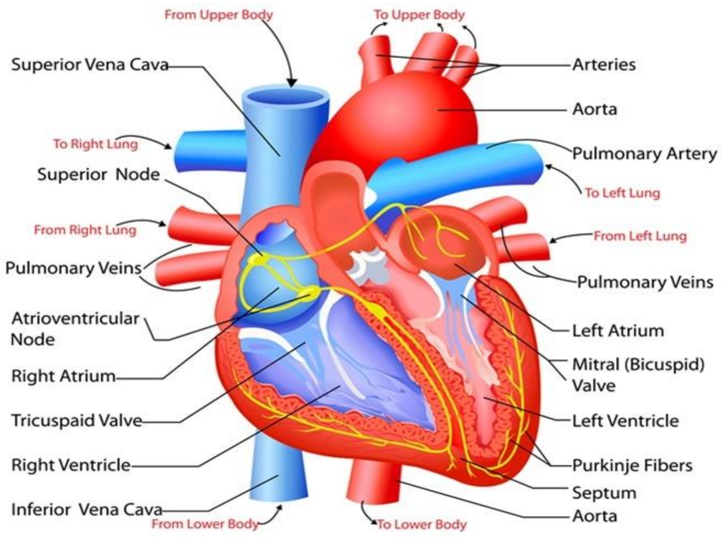


Fig. 3.1 Typical structure of a human heart [59]

Continuous contraction and relaxation of the heart with every heartbeat is generally called a cardiac cycle. In a complete cardiac cycle, heart purifies the venous blood and delivers exogenous blood to the body. Venous blood enters the right atrium and pumps to the lung for purification. After purification in lung oxygen-rich blood reach to the left atrium and pumps back to the body blood vessels via the left ventricle. The filling of blood to the ventricles is known as diastole while pumping of blood from ventricles to aortas is known as systole. Fig. 3.2 shows the complete systole and diastole process of the heart. The blood flow in human heart is controlled by a number of valves that are repeatedly close and open to ensure one directional flow. The blood flow in the human heart is controlled by a number of valves that are repeatedly close and open to ensure one directional flow.

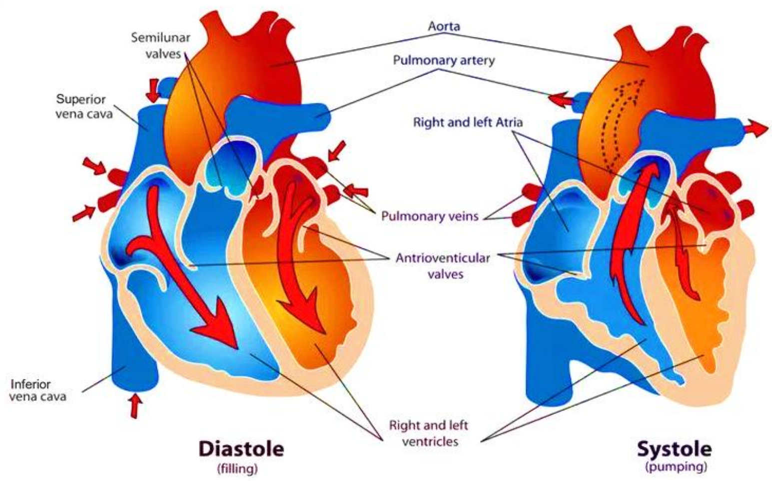


Fig. 3.2 the Cardiac Cycle [60]

3.4 Heart Sound

Heart sounds (HS) are the noise generated by the breathing heart that provides important auditory information about the condition of the heart. Depending on the closing and opening of different heart valves, heart sounds are four types S1, S2, S3, and S4. Apart from these murmurs, clicks, and rubs that generally depends on abnormal behaviour of blood flow, are also great indications of heart abnormality. In a normal healthy adult, only S1 and S2 can be observed. Other sounds are produced only due to the different abnormality in the heart.

3.4.1 Characteristics of heart sound

A detailed characterization of each heart sound component has been outlined in Table 3.1.

Table 3.1 Different Heart sound Components and their characteristics

Type	Sound Component	Subcomponent	Reason of occurrences	Sound	Characteristics of the Component			
					Intensity	Frequency (Hz)	Duration (mSec)	Location
Primary Heart Sound	S1	M1	Mitral valve Closure	"lub" of "lub-dub"	loudest	0-100	20-30	beginning of ventricular contraction, or systole
		T1	Tricuspid valve closure					
	S2	A2	Aortic Valve closure	"dub" of "lub-dub"	Lower than S1	10-200	30-80	beginning of ventricular diastole
		P2	Pulmonary Valve Closure					
Extra Heart Sound	S3		Blood back and forth between the walls of the ventricles.	"lub-dub-ta" or "slosh-ing-in"	Lower than S2	100-200	5-10	Beginning of diastole after S2
	S4		Blood flow into a stiff or hypertrophic ventricle.	"ta-lub-dub" or "a-stiff-wall"	Lower Than S2	150-250	5-15	end of diastole and immediately before S1

Heart Sound Type	Sound Component	Reason of occurrences	Sound	Characteristics of the Component			
				Intensity	Frequency (Hz)	Duration (mSec)	Location
Other ab-normal Sound	Murmur	turbulent flow of blood through or near the heart	whooshing sound	Lower than S2	10-500	Variable duration	In between S1 & S2
	Click	adventitial sounds	Clicking sound	high-pitched	10-500	Short duration	Loudest in beginning of diastole
	Rub	Inflammat-ion of pericardium	Rubbing Sound	high-pitched	10-500	Short Duration	loudest in systole

3.4.2 Graphical representation of Heart sound

Graphical representation of the heart sound signal is known as phonocardiography. Sound is first recorded in digital form. Then the signal is sampled and plotted against the amplitude and the duration of the signal. Amplitude is directly proportional to the intensity of the sound while duration is the duration of the recording. The human ear can only interpret a certain range of sound frequency. But graphical representation allows the detection of audible/sub audible heart sounds and murmurs and makes a permanent record of each distinct event. The graphical representation of normal heart sound signal with each component specified is shown in Fig. 3.3. It is clearly observable that S1 component are generally high pitched sound and the S2 components are low pitched sound.

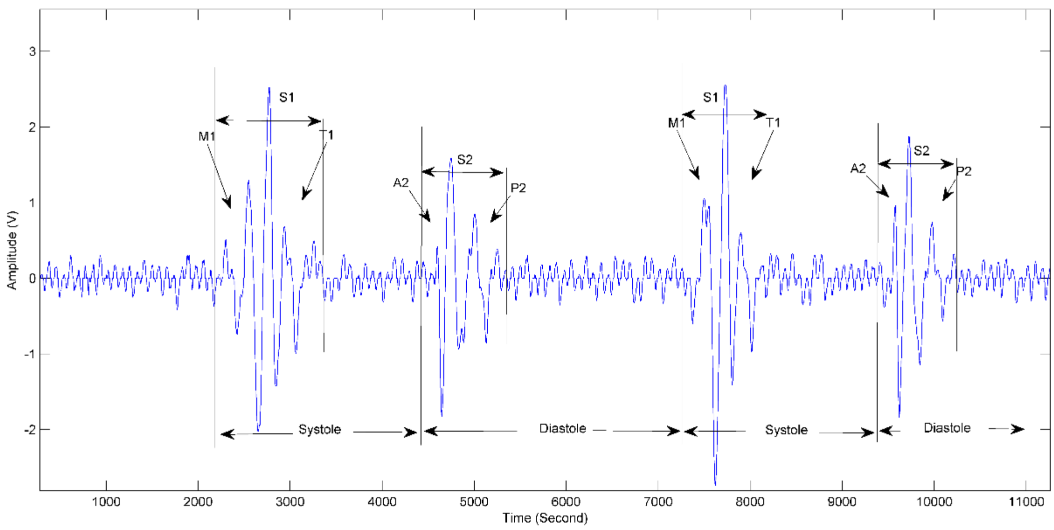


Fig. 3.3 Normal heart Sound signal and its sound component

3.5 Common Cardiovascular diseases and their characteristics

For the early prediction of heart disease, the researcher must have some knowledge of common cardiovascular diseases with their characteristics. In Table 3.2, a list of very common cardiovascular diseases is outlined. This information will certainly help researchers to predict the abnormality in heart by comparing different results set of their research.

Table 3.2 Cardiovascular diseases and their characteristics

Disease	**Cause**	**Symptoms**
Heart Stroke	Blocking of the artery (ischemic stroke) or the leaking or bursting of a blood vessel causes interruption of blood flow in the brain.	• HBR<50 or HBR>100 • Body Temperature 89°F to 93°F • cold sweat, Nausea, Fatigue, Dizziness, Chest pain, Numbness in the Left Hand, Very High/Low Blood Pressure
Aortic Stenosis	Narrow aortic valve opening that restricts the blood flow from the left ventricle to the aorta.	• High pitch S1 • Duration of S1is longer • Presence of murmurs • Breathlessness, Chest Pain, Fainting, Weakness
Mitral Regurgitation	Leakage of blood backward to atrium through the mitral valve.	• Fatigue • Out of breath • Low pitch S1 • Presence of murmur can be observed • Duration of S1 is longer • High blood pressure, Headache, Enlarge heart
Aortic Regurgitation	Leakage of the aortic valve causes blood to flow in reverse direction from the aorta into the left ventricle.	• Duration of S2 is longer • a systolic ejection murmur can be observed • Orthopnea, Paroxysmal nocturnal dyspnea, Palpitations, Angina pectoris, Cyanosis (in acute cases)
Mitral Stenosis	Narrowing of the mitral valve opening that prevents blood flow from the left atrium to the left ventricle.	• Presence of S3 and S4 can be clearly observable. • Shortness of breath • Enlarged heart • increased systolic pressure
Heart arrhythmia	irregular or abnormal heartbeat, too fast or too slow.	HBR<50 or HBR>100

3.6 Mathematical Methods

Mathematics is the branch science which deals with the study of shape, quantity, structure space and change. We can't complete our research work without any touch of mathematics. In this section, a brief introduction of Fourier Transform and Wavelet Transform has been explained.

3.6.1 Fourier Transform

Digital signal processing is worthless without an introduction to the Fourier transform. Fourier Transform is a mathematical operation that converts time domain signal to the corresponding frequency domain signal. Depending on the type of signal Fourier Transform is of two types: Continuous time FT (CTFT) and Discrete Time FT (DTFT). In this work DTFT is utilized to perform the frequency domain analysis of the heart sound signal.

Discrete Time Fourier Transform:

DTFT relates an aperiodic, discrete time sequence with a periodic continuous frequency spectrum. DFT decomposed the signal into sine and cosine waves, with frequencies equally spaced between zero and one half of the sampling frequency. The DTFT of an input sequence x (n) can be given as,

$$X\left(e^{-jn\omega}\right) = \sum_{n=-\infty}^{+\infty} x\,(n) e^{-jn\omega} \quad (1)$$

And the Inverse DTFT can be represented as,

$$x(n) = \frac{1}{2\pi}\int_{-\pi}^{\pi} X(e^{-j\omega})\, e^{jn\omega} \quad (2)$$

3.6.2 Wavelet Transform

Wavelet Transform nowadays becomes the most powerful tool in the DSP domain for the sake of non-stationary signal processing. Heart Sound signal processing is difficult with many powerful mathematical tool as it is non-stationary in nature [61]. Fourier Transform can provide the information about the frequency component present in the signal but it fails to provide the information of time localization of frequency [62]. In this work, we will utilize Discrete Wavelet Transform to de-noise the noisy heart sound signal and perform the component level analysis.

Discrete Wavelet Transform:

The very first step in the wavelet transform is the decomposition of the signal. Decomposition of the signal can be done using the predefined mother wavelet coefficient. In this work, DB10 mother wavelet is chosen for the decomposition purpose as this is very similar in shape to the heart sound component [63]. Fig. 3.4 shows the different type of wavelet function. At the very initial step, wavelet function shift and scale itself to get the maximum similarity with the signal. Repetition of this operation finds all the frequency present in the signal. Mathematical expression of scaled and shifted wavelet function is given as,

$$\Psi_{a,b}(x) = \frac{1}{\sqrt{a}} * \Psi_{a,b}\left(\frac{x-b}{a}\right) \quad (3)$$

Where the wavelet function is Ψ(x) and it is scaled with the scaled factor "a" and shifted by "b".

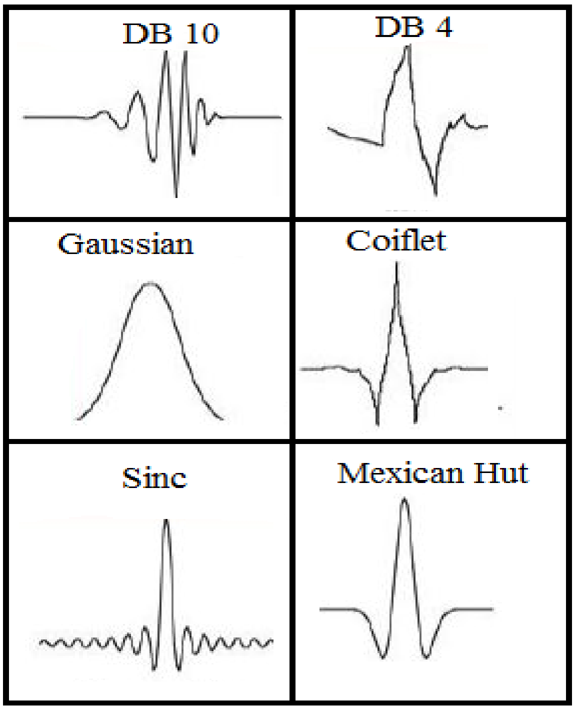


Fig. 3.4 Different types of Wavelet Function

Now decomposition system consists of a low pass filter and a high pass filter that forms a filter bank tree [64]. Low pass filter allows the detail coefficient of the signal while high pass filter provides approximation coefficient. Complementary filter can be represented as,

$$Y_{low}[n] = \sum_{k=-\infty}^{\infty} x[k]g[2n-k] \quad (4)$$

$$Y_{high}[n] = \sum_{k=-\infty}^{\infty} x[k]h[2n-k] \quad (5)$$

Where, Y_{low} [n] and Y_{high} [n] are output of HPF and LPF after sub sampling by 2 and x (k) is the heart sound sequence. Fig. 3.5 shows the wavelet decomposition up to level 6. At end of the operation, decomposed signal is reconstructed with suppression of noise using best fitted thresholding method. The reconstructed signal can be represented as,

$$X[n] = \sum_{k=-\infty}^{\infty} x[k]g[2n-k] + \sum_{k=-\infty}^{\infty} x[k]h[2n-k] \quad (6)$$

In soft thresholding method the wavelet coefficients whose absolute values are lower than threshold are set to zero and remaining components are modified as per the thresholding function. The soft thresholding function can be written as,

$$D_s(d_{jk}|t) = \begin{cases} 0, \ \text{for} \ |d_{jk}| \leq t \\ d_{jk} - t, \ \text{for} \ |d_{jk}| > t \\ d_{jk} + \ t, \ \text{for} \ |d_{jk}| < -t \end{cases} \quad (7)$$

Where d_{jk} represents the k^{th} wavelet coefficient at j^{th} decomposition level with‘t’ as the threshold level.

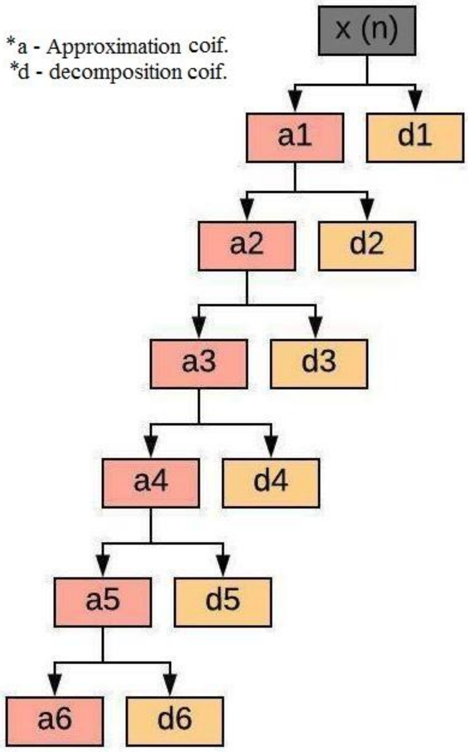


Fig. 3.5 Decomposition up to level 6

3.7 Summary

So in this chapter, a concise introduction to the theoretical background has been impersonated. This information will help to understand the basic operation and logic presented in the proceeding chapters.

Chapter 4

Design Methodology of the Proposed System

4.1 Overview

The acoustic signal conveys countless health information of different body parts; especially heart sound signal that accomplishes crucial information of the heart. Understanding of acoustic sound based on listening needs not only professional practice but also the wealth of experiences. The primary aim of this work is focused on the implementation of a heart sound signal acquisition system targeting IoT implementation. But the proposed system is customized in such a way that this can be easily upgraded to a complete heart sound analyzer system. While designing, system parameters that are pondered with significant importance are:

- Reliability
- Cost effectiveness
- Portability
- Easy system handling
- Energy saving capability
- Wireless connectivity for remote healthcare
- Real-time visualization of the heart sound signal
- Reliable listening to the heart sound
- Easily upgradable for future work
- Directed towards the complete system integration for cardiovascular disease detection
- Infrastructure Independence

The proposed system consists of four sub-modules. Each module is designed focusing on the direct implementation of the current drawbacks exist in the very recent literature.

4.2 Proposed System

Proposed system consists of four sub unit:

Sensor Module: Sensor Module deals with the direct listening of the heart sound signal and generates the heart sound analog signal for the controller.

Controller Module: Controller module works as the brain of system that controls system UI in TFT LCD module, stores acquired signal in SD card, sends the data over Wi-Fi, process the heart sound data for basic analysis and most importantly controls the PC interfacing related communications.

Power Unit: Power unit uses both renewable and non-renewable energy source to power up the entire system.

PC Interface: PC Interfacing is introduced to perform the in-depth analysis of the acquired heart sound signal. A details study on each module has been outlined in the subsequent sections.

4.2.1Block Diagram

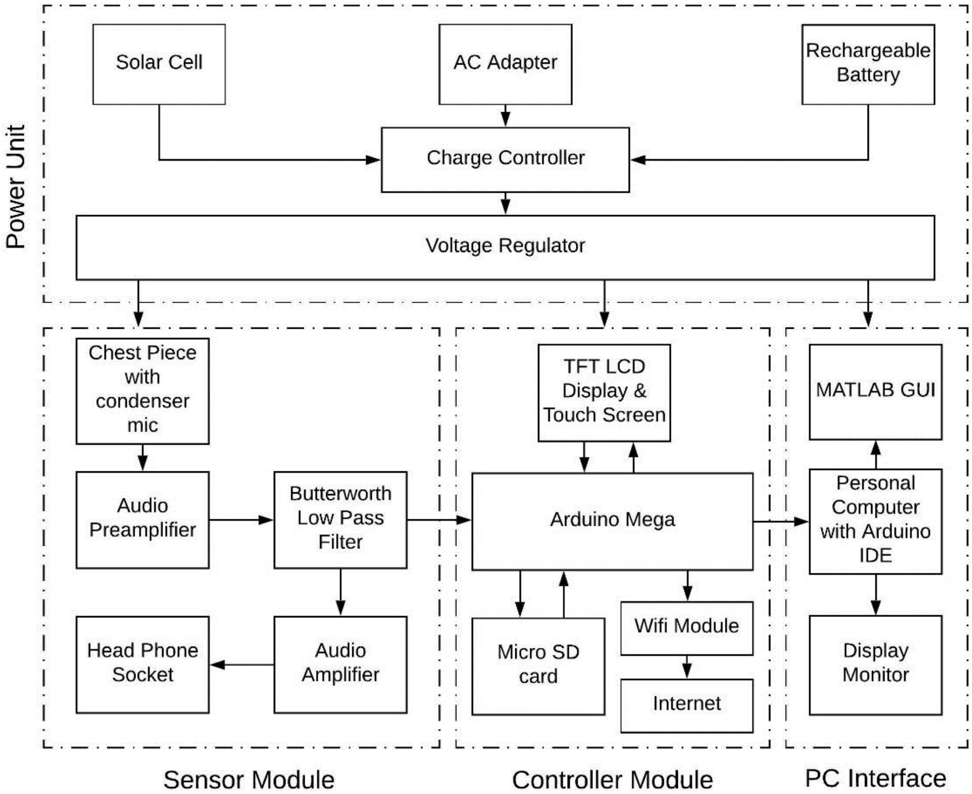


Fig. 4.1 Block diagram: Proposed Heart Sound Acquisition System

4.2.2 Sensor Module

A sensor is a device that senses physical quantity and converts into electrical signals. In this work, sensor module is proposed to detect the heart sound from human body. At the very first stage, heart sound wave is detected using chest piece placed near to the heart and converted to the electrical signal using transducer microphone attached to it. Then, analog electrical signal is amplified using opamp based preamplifier and fed to the low pass filter for the removal of high frequency noise components. Filtered signal is now pass to the controller module for processing. With addition of another Audio amplifier, filtered output has been fed to the head phone socket for direct listening of the heart sound. This module can be easily used as an electronic stethoscope with superior sound quality and adjustable sound level. Deliverables of this module are:

- Superior listening compared to acoustic stethoscope

- Minimized noise effect
- Adjustable sound level
- Very low cost
- Can be attached to any controller for sensing the heart sound

Chest Piece

Chest piece is an acoustic device that senses the vibration of sound wave generating from different parts of our body. In this work, chest piece is used for the detection of mechanical sound wave. Fig. 4.2 shows the different components of a chest piece.

Fig. 4.2 Chest Piece and its different components

Diaphragm is a firm flexible membrane that vibrates with the oscillation generated by the heart. Depending on the model of the stethoscope chest piece can have tunable diaphragm to facilitate binaural acquisition using both diaphragm and the bell. Once diaphragm or bell detects the sound, it is transferred to the drum. Drum is a hollow tube sound absorber that enhances the acoustical performances. Passing through the drum the heart sound signal reaches to the acoustic value stem. In general case acoustic valve stem leads to the stethoscope tubing. But in this work we have placed a transducer microphone in front of acoustic valve stem to convert the mechanical sound wave to corresponding electrical pulse (Fig. 4.2).

Transducer

Transducer is an electronic device that converts physical quantity such as pressure, temperature etc. into an electrical signals. Condenser microphone can converts the acoustic pressure into the corresponding electrical signals with addition of energy source.

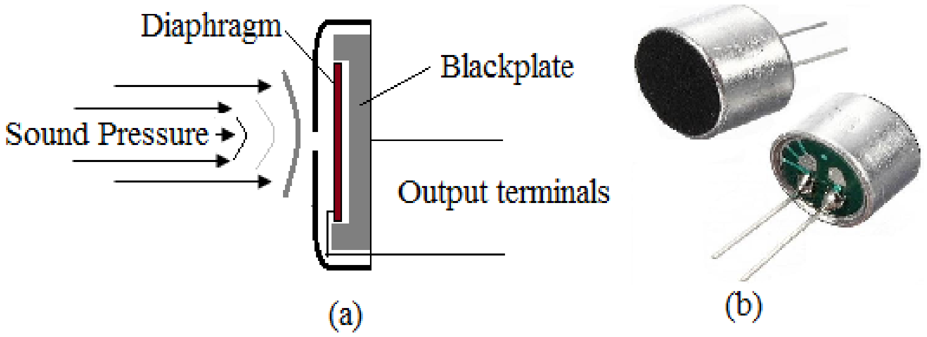


Fig. 4.3 Condenser microphone & working principle

Condenser microphone works on the principle of parallel plate capacitor. As shown in Fig. 4.3 (a), two parallel plates are placed inside the Condenser microphone. The forward plate or the diaphragm vibrates according to the incoming pressure of the sound wave. This causes the change in distance between two parallel plates and further change in the capacitance. Capacitance (C) of parallel plate capacitor can be expressed as,

$$C = \frac{\epsilon A}{d} \tag{8}$$

Where, A is the cross sectional area of plate, ∈ is the permittivity of the medium and d is the distance between two parallel plates. Fig. 4.4 represents the transducer circuit that is responsible for the conversion of sound wave to the corresponding electrical part. This part of the sensor module produces the low amplitude heart sound analog signal. To enhance the low amplitude level, a preamplifier circuit has been introduced. In the next section, a details discussion has been presented for the preamplifier circuit.

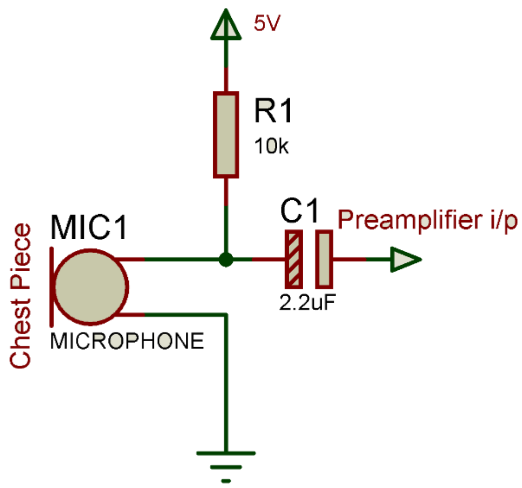


Fig. 4.4 Transducer Circuit

Preamplifier

A preamplifier is an electronic amplifier that enhances the power level of weak electrical signal into an output signal strong enough for further processing. Preamplifier circuit is used here to get the signal ready for the filtration using low pass filter designed in next stage. In this work, a passive pre-amplifier has been designed using LM358 IC. LM358 is a low power, dual operational amplifier. Brief specification of LM358 collected from the datasheet outlined as below [65].

Table 4.1 Specification of LM358

Specification	**Value**	**Specification**	**Value**
Supply Voltage	3-32V	O/P Current	2-20mA
Unity Gain BW	1 MHz	No. of opamp	2
DC gain	100 dB	Operating Temperature	-65 to 150 ^{0}C

Analog signal generated from the transducer is nearly in range of 1 mV to 10 mV and can be reached maximum up to 50mV. So an average of 20mV has been taken as an input voltage level. To increase the voltage level we have to design and choose the component values wisely. The maximum possible output voltage of preamplifier is 200 mV. So a voltage gain of 20dB is required to enhance the power. The typical application circuit as given in the datasheet of LM358 with some basic required modification is used for designing this pre-amplifier [65]. Details pin diagram of LM358 and the preamplifier circuit has been shown in Fig. 4.5.

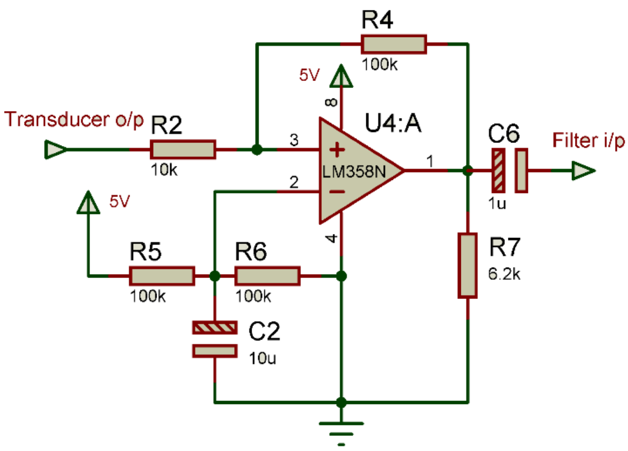


Fig. 4.5 Preamplifier Circuit

Low Pass Filter

Heart sound signal is very prone to affect by the various internal and external noise sources to the body. So, a filtration technique must be integrated with the system to eliminate the unwanted noise from the actual signal. Generally, Heart sound signal components including murmurs have the frequency spectrum within a range of 10 to 500 Hz [66]. Beyond this range, the signal is considered as noise or unwanted signal. A low pass filter having cut off frequency of 500Hz will be the excellent pick for this purpose. With the incorporation of LPF, spectrum component possessing a higher frequency than the cut off (i.e. noise) will be attenuated and the remaining part will pass through to the subsequent stages. This will certainly improve significant sound quality for a reliable diagnosis. Generally, the range of frequency that a filter rejects or pass can be characterized by its magnitude response. Fig. 4.6 shows the magnitude response of the ideal and a practical 3rd order Butterworth low pass filter having cut off frequency of 500 Hz. As indicated in the response curve, practical filter lags with a transition period because of its non-ideal characteristics. To get a sharp transition similar to the ideal curve, we need to increase the order of the filter. With this determination, first order and the second order filters are cascaded to form the 3rd order low pass filter, so that individual frequency response results into the optimized frequency response of the overall filter.

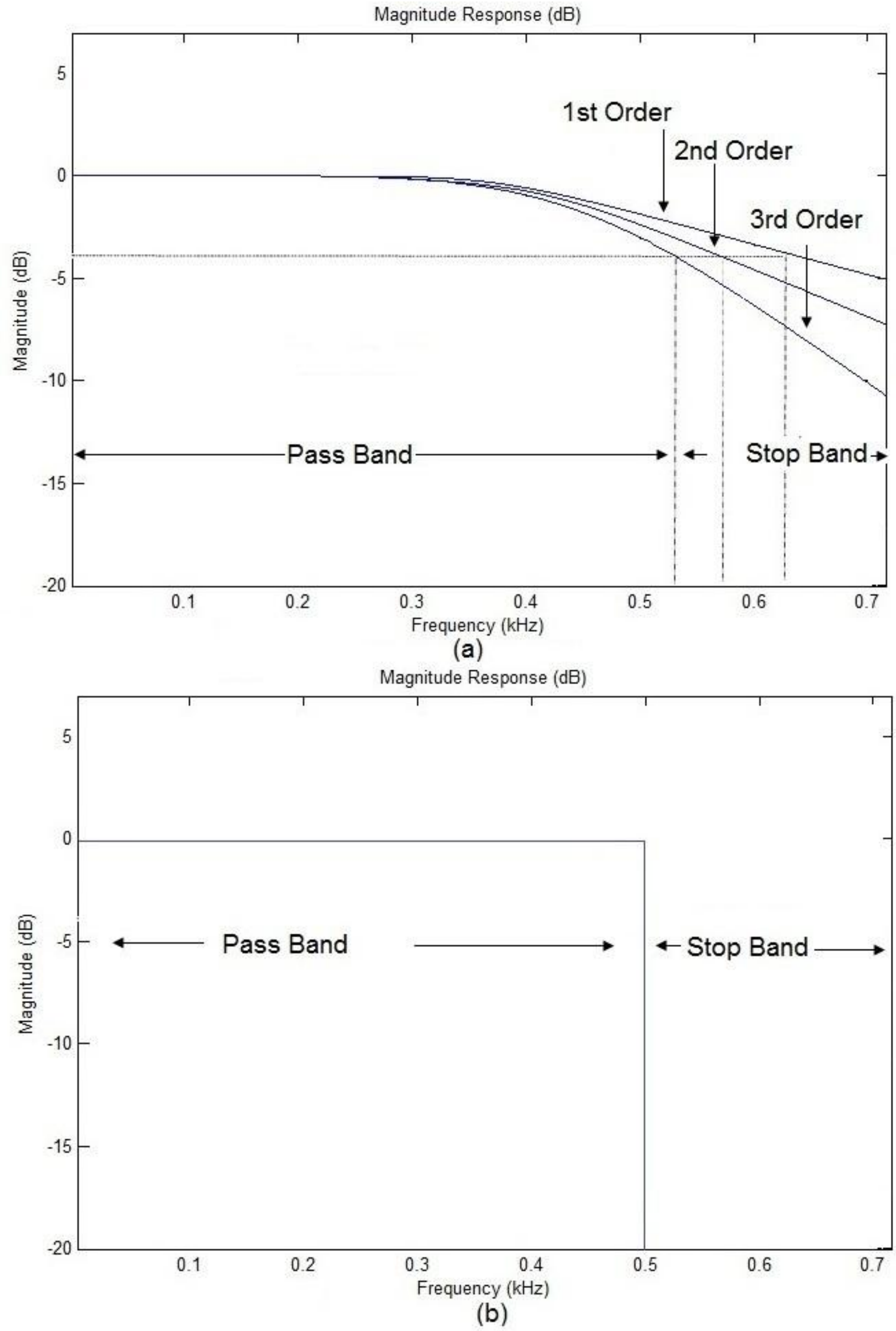


Fig. 4.6 Magnitude response of (a) 3rd order filter & (b) Ideal filter

Design Procedure: In this work, Butterworth low pass filter with Sallen-key topology is used because of its maximally flat response within its pass-band. The designed circuit has been shown in Fig. 4.7 and brief design steps are as follows,

- **Cut of frequency: (f_c)** = 500 Hz.
- **Filter coefficient:** Generalized transfer function of LPF is

$$A_i(s) = \frac{A_0}{\prod_i (1+a_i s + b_i s^2)} \tag{9}$$

Where a_i and b_i are the filter coefficient and A_0 is the pass band gain of the filter. Filter coefficient for 3rd order Butterworth LPF with the maximum pass band flatness optimization collected from [67] are,

Table 4.2 Filter coefficient of LPF

Order	**Filter**	**a_i**	**b_i**	**K_i**	**Q_i**
3	1st order filter	a_1=1.000	b_1=0	1.000	-
	2nd order filter	a_2=1.000	b_2=1.0000	1.272	1

*K_i is the ratio of the corner frequency of a partial filter, f_{ci}, to the corner frequency of the overall filter, f_c and Qi is the quality factor of the partial filter.

Now transfer function of 1st order LPF is,

$$A\ (s) = \frac{A_0}{1+\omega_c RCs} \tag{10}$$

Whereas, transfer function of 2nd order Sallen-key topology based LPF is,

$$A\ (s) = \frac{A_0}{1+\ \omega_c[C_7(R_8+R_9)+(1-A_0)R_8C_8]s+\omega_C^2 S^2 R_8 R_9 C_7 C_8} \tag{11}$$

These two equations will be compared with the general equation to find out the required component values of the circuit.

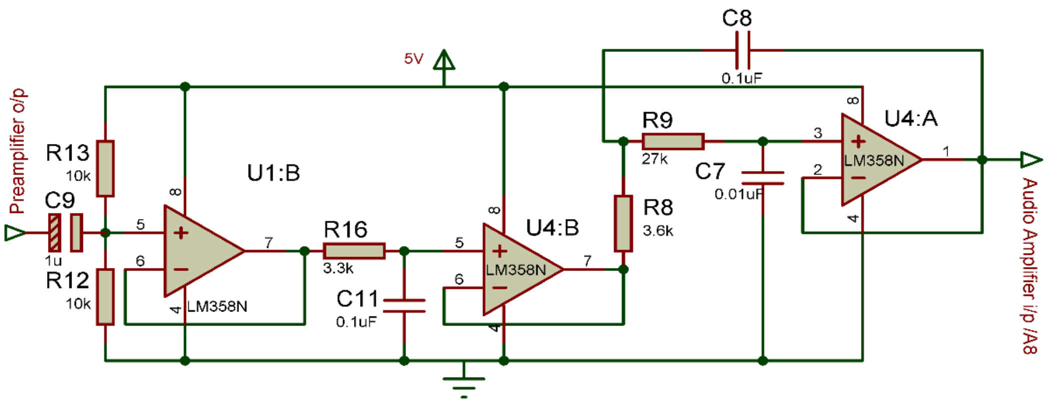


Fig. 4.7 3rd order low pass Butterworth filter circuit

- **First order filter's circuit parameters:**
  - Taking, C11=0.1uF and by comparing Eq.9 and Eq.10, R16 can be calculated as,

$$R16 = \frac{a_1}{2\pi f_c C_{11}} = \frac{1}{2\pi * 500 * 10^{-7}} = 3.2\ K\Omega \sim 3.3\ \mathrm{K}\Omega \qquad (12)$$

- For superior gain accuracy, the non-inverting amplifier reduces to a voltage follower by imposing unity gain.

- **Second Order filter' parameter:**
  - Unity gain is considered for high gain accuracy and low Q factor (<2).
  - Taking C7=0.1uF and C8=0.01uF then R8 and R9 can be calculated from the equations,

$$a_2 = \omega_c[C_1(R_8 + R_9)] \qquad (13)$$

$$b_2 = \omega_C^2 S^2 R_8 R_9 C_7 C_8 \qquad (14)$$

Calculated values are, R8=3.62≈ 3.6 $K\Omega$; R9=28.32 ≈ 27$K\Omega$;

Note: C_8, C_9 must follow $C_8 \geq C_7 * \frac{4b_2}{a_2^2}$

Audio amplifier

An audio amplifier is an electronic circuit that increases the power of low level audio signal to a high level for performing specific task. Here, the audio amplifier is used to enhance the voltage level of the audio signal coming from the low pass filter to the level that is high enough for driving a headphone. Fig. 4.8 represents the incorporated audio amplifier circuit to the acquisition system.

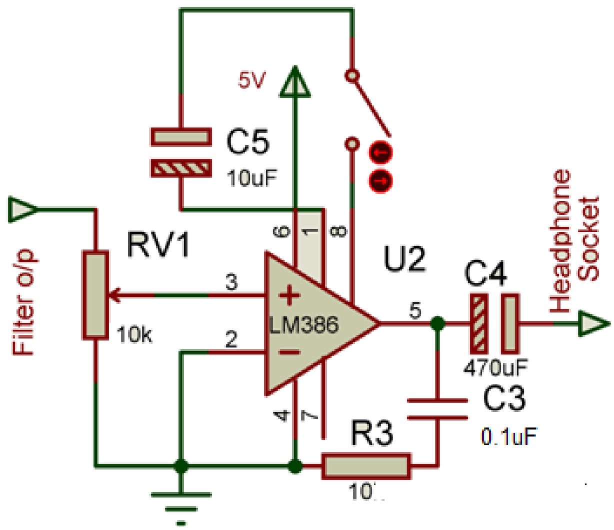


Fig. 4.8 Audio Amplifier Circuit

Audio amplifier has been designed with low cost, low voltage power amplifier IC, LM386 from Texas Instrument. The gain of this IC is internally set to 20. But the addition of an external capacitor of 10uF between pins 1 and 8 will increase the gain to any value from 20 to 200. So a high level enhancement of the signal power can be possible with this. The typical application circuit given in the datasheet of the LM386 is integrated here [68]. Using the 10 kΩ potentiometer user can increase or decrease the volume of the incoming heart sound signal. As shown in the circuit, an external switch is connected with 10uF capacitor in series to enable the high level gain of the amplifier when required. For the patient having very low intensity heart sound, this switch can be pressed to reach the required level of amplification.

4.2.3 Controller Module

Controller Module is the brain of this heart acquisition system. It controls and performs all the basic operations designed for the heart sound acquisition system. An Arduino Mega 2560 R3 board is used as the controller. On board UI of the acquisition system has been implemented using a2.4 inch TFT touch screen LCD. TFT LCD module comes with a built-in SD card slots. So, it also served purpose of data storage in 8GB memory card. ESP8266 Wi-Fi module adds the flavor of IOT implementation of the system and enhances the remote monitoring capability. For better visualization of the signal, PCG is displayed in the LCD Monitor using a USB cable and a PC with pre-installed Arduino IDE. Considering all of these aspects, deliverables of this module are:

- Storing of heart sound data in SD card
- Sending the heart sound data over Wi-Fi
- Touch screen based user interface to perform the operations
- Basic level analysis of heart sound
- Interfacing with Personal Computer
- Display the signal to the PC monitor

Arduino Mega

Arduino Mega 2560 R3 is an open-source hardware platform that is controlled by ATmega2560 microcontroller. Arduino boards are such a hardware system that can be programmed and run by everyone with a little or no technical background. The complete structure of an Arduino Mega 2560 is shown in Fig. 4.9.

The influencing parameters that are considered for the inclusion of this device in this work are:

- Two voltage regulator i.e. 5V and 3.3V which provides the flexibility to regulate the voltage for other hardware module attached to it.
- Arduino Mega comes with more memory space, bigger size and more I/O pins.
- Arduino programming software called Arduino IDE which is open source and can be used with any Arduino boards.
- Arduino Mega is specially designed for the complex project that requires more memory or the complex operation such as signal processing, 3D printing.

- There are three ways to power the board: USB cable to power the board, transfer code to the board or you can power it up using Vin of the board or through Power jack or battery.
- This board comes with resettable poly-fuse that prevents the USB port of your computer from overheating in the presence of high current flowing through the board.

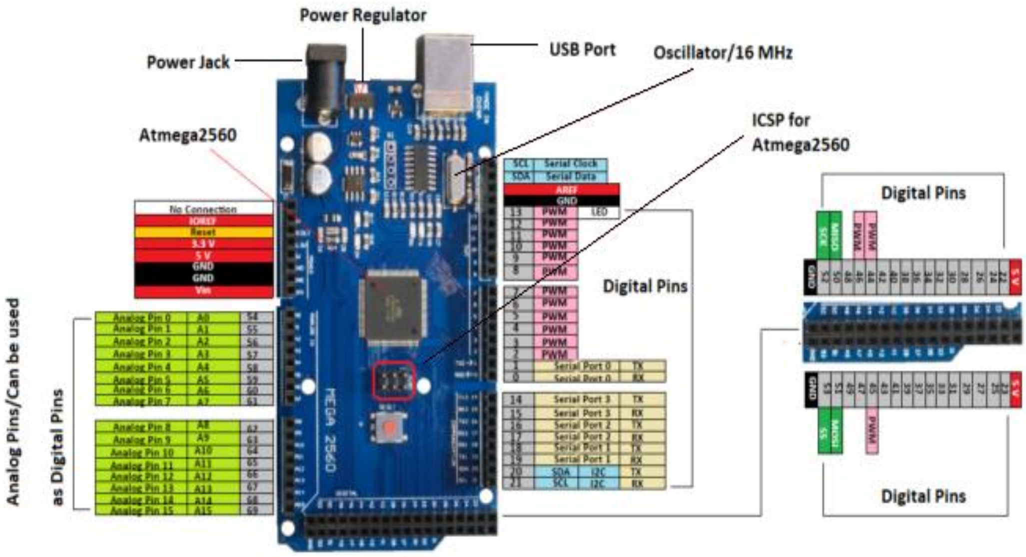


Fig. 4.9 Pin out of Arduino Mega 2560 R3 [69]

A brief technical specification of Arduino Mega 2560 R3 has been outlined in the Table 4.3.

Table 4.3 Technical Specification of Arduino Mega

Specification	**Value**	**Specification**	**Value**
Microcontroller	ATmega2560	Flash Memory	256 KB of which 8 KB used by boot loader
Operating Voltage	5V	SRAM	8 KB
Input Voltage (recommended)	7-12V	EEPROM	4KB
Input Voltage (limits)	6-20V	Clock Speed	16 MHz
Digital I/O Pins	54 (of which 14 provide PWM output)	DC Current per I/O Pin	40 mA
Analog Input Pins	16	DC Current for 3.3V Pin	50 mA

ESP8266 Wi-Fi Module

ESP8266 Wi-Fi module is included in this work to make the acquisition system an IoT platform. Though the module is integrated with the acquisition system, it is currently not performing any defined task. This module is embedded entirely for the future work targeting towards IoT implementation. Here, a brief introduction on ESP8266 and the details hardware connection has been explained.

ESP8266 Wi-Fi module is low cost, standalone wireless transceiver that can be used for end-point IoT developments [70]. It enables internet connectivity to heart sound acquisition system using TCP/UDP communication protocol. To communicate with the ESP8266 Wi-Fi module, Arduino Mega needs to use set of AT commands via UART having specified Baud rate (Default 115200). ESP8266 comes with capabilities of

- 2.4 GHz Wi-Fi (802.11 b/g/n, supporting WPA/WPA2),
- general-purpose input/output (16 GPIO),
- Inter-Integrated Circuit (I^2C) serial communication protocol,
- Analog-to-Digital conversion (10-bit ADC)
- Serial Peripheral Interface (SPI) serial communication protocol,
- I^2S (Inter-IC Sound) interfaces with DMA(Direct Memory Access) (sharing pins with GPIO),
- UART (on dedicated pins, plus a transmit-only UART can be enabled on GPIO2), and
- Pulse-width modulation (PWM).

ESP8266-01 Module Pin Description:

- **3V3**: - 3.3 V Power Pin.
- **GND**: - Ground Pin.
- **RST**: - Active Low Reset Pin.
- **EN**: - Active High Enable Pin.
- **TX**: - Serial Transmit Pin of UART.
- **RX**: - Serial Receive Pin of UART.
- **GPIO0 & GPIO2**: General Purpose I/O Pins. These pins decide what mode (boot or normal) the module starts up in. It also decides whether the TX/RX pins are used for Programming the module or for serial I/O purpose.

Hardware Connection: Hardware connection that has already implemented to the acquisition system is shown in Fig. 4.10.

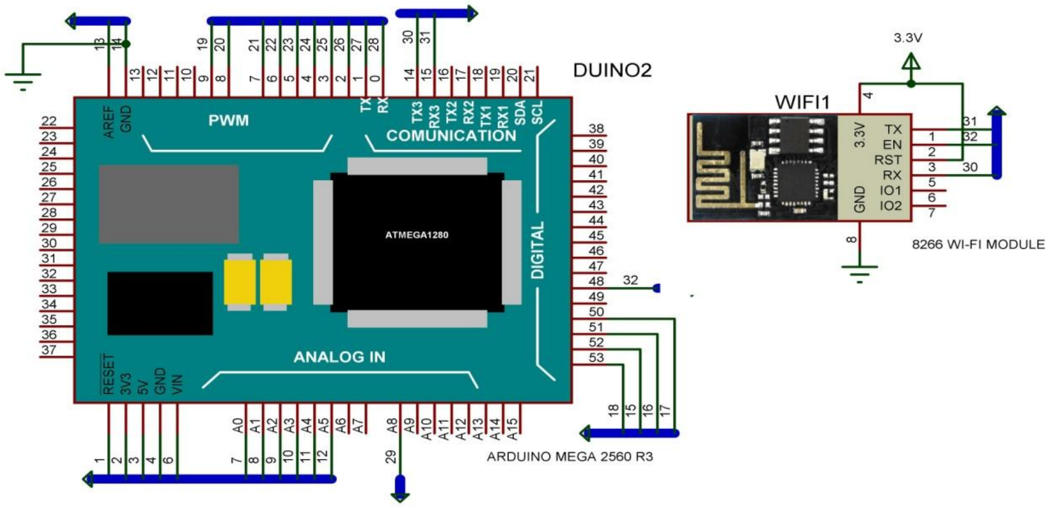


Fig. 4.10 ESP8266 Wi-Fi Module interfacing with Arduino Mega Board

SD card Module

Arduino boards don’t have sufficient storage space to store heart sound data files. So an external storage device is required to store the data. Secure Digital or SD card is a non-volatile memory card format developed by the SD Card Association (SDA) for use in portable devices. SD card is used here to store the heart sound signal data as bulk data storage. The data is stored in the format of .txt file. As TFT LCD module comes with inbuilt SD card slot, no separate module is used in this work. The corresponding pins for SD cards in TFT LCD are connected directly with the Arduino Mega. The Corresponding pins connections are,

TFT LCD Pin	**Arduino Pin**	**TFT LCD Pin**	**Arduino Pin**
SD_CS	Pin 53	MOSI/SD_D0	Pin 51
SD_SCK	Pin 52	VCC	3.3 V
MISO/SD_DI	Pin 50	GND	GND

An 8 GB memory card is used in our work. Each 4 sec heart sound data requires a maximum of 200 KB memory. So, approximately 35000 of data samples can be stored in the memory card. The interfacing circuit of memory card and the Arduino mega has been shown in the Fig. 21.

TFT LCD Module & UI

To control the entire heart sound acquisition system, a direct user interface is required. A 2.4 inch TFT touch screen LCD is used in this work for the designing of the User Interface. After displaying the welcome note, designed UI takes the patient name, age, weight from the user. After that it redirected the sensor choice page and as per the user input comes to the functionality page. Here user can store, analyze, send or view the signal by touching to the corresponding functions displayed in the UI. Fig 4.11 represents the typical image of 2.4 inch TFT touch LCD module.

Fig. 4.11 2.4 inch TFT Touch LCD screen

The brief specification of the used TFT module are,

- 2.4” TFT LCD with Touch screen
- Pixels: 240X320
- Operating Voltage: 3.3V
- Operating Mode: SPI and 8-bit mode
- Interface IC: ILI9341 Interface
- SD card option available for storing data.
- Can be easily interfaced with Arduino (Free Library available).

LCD module is a plug and play ready shield that can directly push the LCD screen on top of the Arduino UNO boards. But the SD card pins are different for the Arduino Mega boards (i.e. 50, 51, 52 and 53), so external wire has been connected to make the module functional. The details connection has been shown in Fig. 4.12.

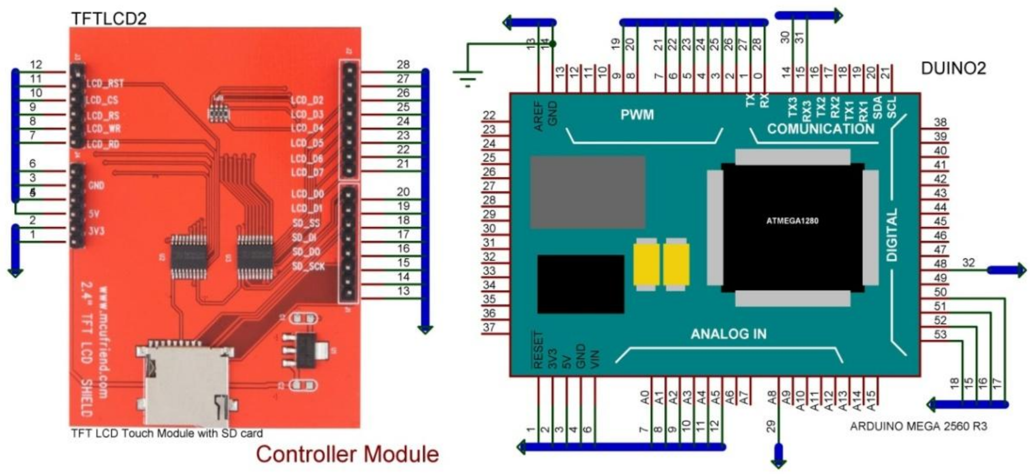


Fig. 4.12LCD & SD card interfacing with Arduino Mega Board

4.2.4 PC interfacing

TFT LCD Screen shown in the previous section is insufficient to display the real time signal because of its limited pixels and size. There will be a huge chance of erroneous prediction of disease by the visualization technique. Also, very deep level signal process needs high level memory and computational power are not available in the Arduino boards itself. To overcome these basic limitations, we can add large display for visualization and highly computational processor. But for now, PC has been interfaced with the acquisition system to prevent these limitations. With the indirect interfacing (i.e. via Arduino IDE installed PC) with display monitor, heart sound signal can be easily visualize to interpret the cardiovascular disease. For deep level signal processing preinstalled MATLAB can enhance the system capability to a great extent. The Arduino USB cable is directly connected to the PC or portable LAPTOPs or in any Android Mobile to perform the deep level functionality. So deliverable of this module can be outlined as.

- Acquisition system can be connected with PC with just a USB cable
- Heart sound signal can be visualize from the Laptop screen or Desktop Monitors using Arduino 'serial monitor' application.
- Deep level signal processing can be possible with MATLAB platform.
- SD card data can be forwarded to the PC storage.

Display

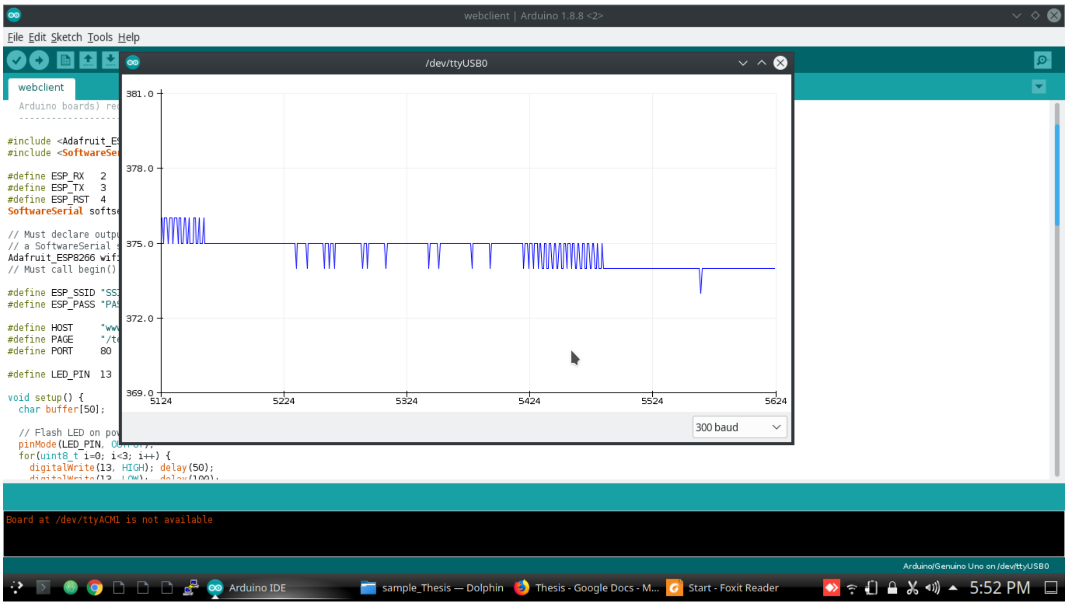


Fig. 4.13Arduino serial plotter displaying the incoming signal

For clear and reliable visualization of heart sound signal, large and high resolution screen is required. LCD monitor or the Laptop screen can serve this purpose efficiently and reliably. So, Arduino IDE based serial plotter is utilized to display the real-time signal is computer screen. Arduino serial plotter is a tool that comes with preinstalled Arduino IDE that takes incoming serial data from Arduino USB port and displays them in a plot (Fig. 4.13). The vertical Y axis increases or decreases as the value of the incomes data changes and the X axis values shifts towards left with each execution of the *Serial.println()* command.

Signal Process using MATLAB GUI

For in depth digital signal processing a specialized microprocessor with optimized architecture is required. Arduino Mega doesn't have sufficient resource to execute complex algorithms that can analyze the heart sound signal in depth but the basic information. In this case, a very simple algorithm can be designed or directly use existing signal processing tools. MATLAB is well established computing environment developed by Mathworks [71]. MATLAB allows multi diverse signal processing tools that can analyze the heart sound signal very efficiently. In this respect, A MATLAB GUI is designed that is only for sole purpose of the heart sound signal analysis using Wavelet transform. As this thesis work only focus on the heart sound signal acquisition system. Development of the signal processing considered as the future work. Fig. 4.14 shows the developed very basic MATLAB GUI for the signal visualization. In this GUI, a bulk of signal can be imported to visualize it simultaneously. A lot of development can be done on this platform to make a MATLAB GUI based complete heart sound analysis tool.

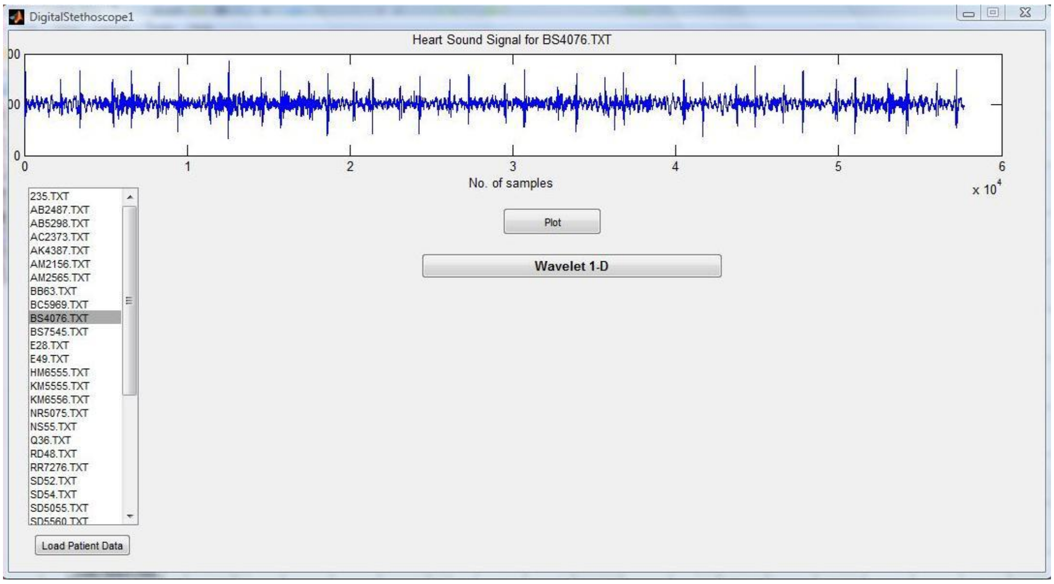


Fig. 4.14 GUI in MATLAB platform for multiple signal visualization

Arduino IDE

Arduino Integrated Development Environment (Fig. 4.15) is an open source, cross platform application used to write and upload the programs to the Arduino boards. This is a very user friendly IDE for the development of the Arduino codes that is generally based on C or C++. After writing code in the sketch, user compiles and upload the code to the Arduino board connect via dedicated USB port. The basic technical specifications of Arduino IDE are,

- **IDE version:** 1.9.0-beta
- **Written in:** Java
- **Operating System:** Windows, macOS, Linux
- **Platform:** IA-32, x86-64, ARM
- **License:** LGPL or GPL license

Apart from the coding interface Arduino IDE has great features of serial monitor and serial plotter for debugging the code uploaded to the Arduino board. Serial monitor directly displays the serial data sent via USB cable from the Arduino boards. Whereas Serial plotter plots the serial data (only numerical values) sent from the Arduino boards. The serial plotter is utilized in this work to display the real-time heart sound signal to the computer monitor.

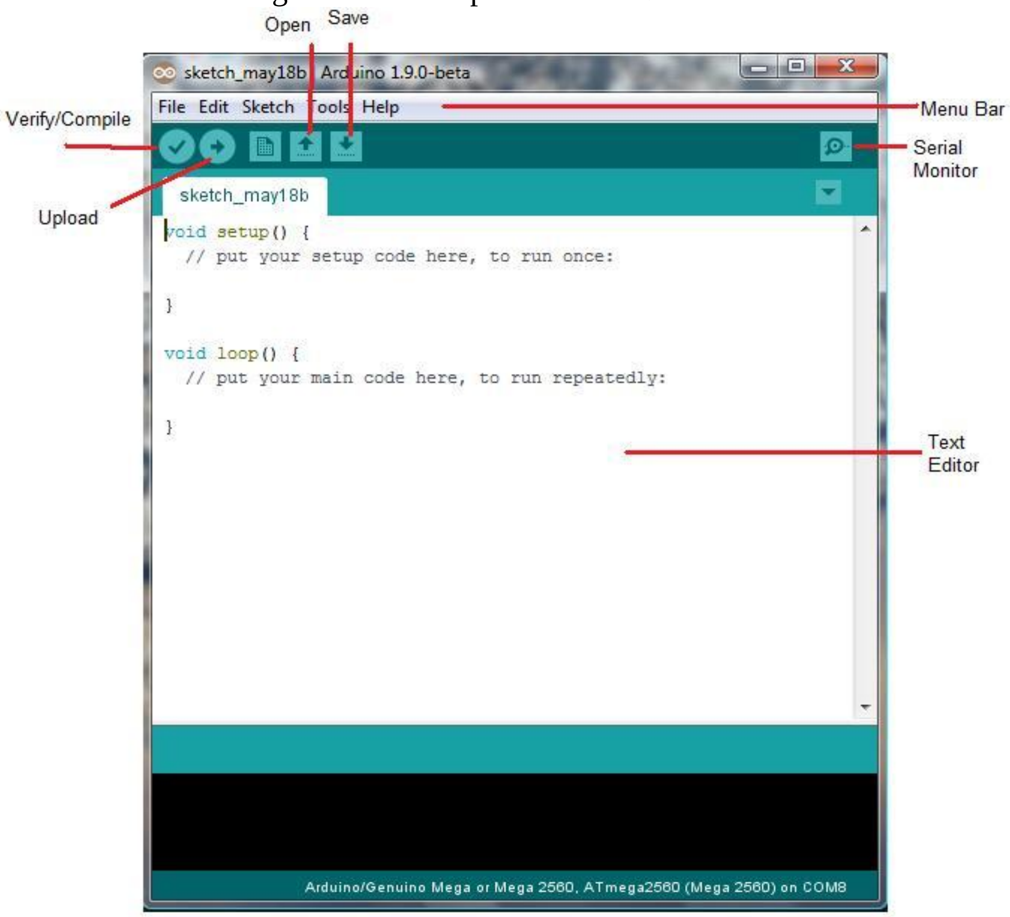


Fig. 4.15 Different icons of Arduino IDE

4.2.5 Power Unit

Power unit delivers energy to the entire system. Availability of direct electricity is still a difficult task in rural areas of India. Following the aforementioned fact, a multi-source power unit has been designed in this work. This module applies both renewable and non-renewable energy source to control the module. The power unit is a separate module of the entire system. This module can be simply isolated from the original system with just replacement of a normal 9V battery. The complete circuit of the power module has been shown in Fig. 4.16. The deliverables of this unit can be listed as:

- Separate power unit.
- Entire unit can be replaced by just a 9V battery.
- Renewable energy source.
- Separate module to ensure portability.
- Multi-source energy.
- Regulated power supply for the entire system.

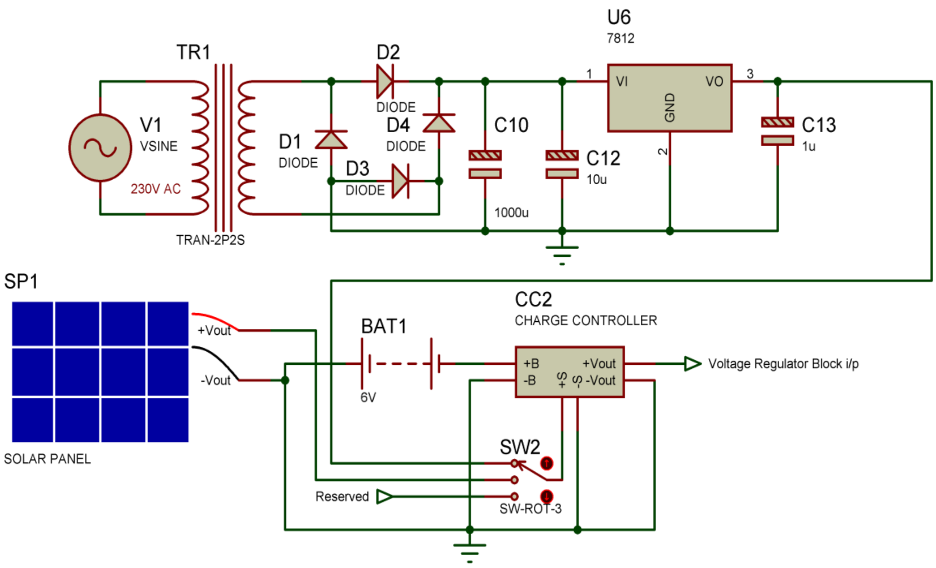


Fig. 4.16 Complete circuit diagram of the power unit

Solar Cell

A solar cell is a renewable energy harvesting device that converts the energy of light directly into electricity. The details specifications of the used solar cell are:

Table 4.4 Specification of solar cell

Specification	**Value**
Max Rated Power (Pmax)	10 Watts
Voltage at Max Power (Vmp)	17.3 Volts
Current at Max Power (Imp)	0.59 Amps
Open Circuit Voltage (Voc)	21.8 Volts

Rectifier

A rectifier circuit is required to convert the alternating current to direct current. Proposed system operates on the DC source. So a conversion circuitry is required to work with the system. Typical bridge rectifier circuit has been used in this work with IN4007 diode, 230V to 12 V, 1A step down transformer and LM 7812 voltage regulators. A brief specifications (Table 4.5) of these components are outlined below:

Table 4.5 Specification of circuit components

Component Name	**Specification**
1N4007 Diode	PIV=1000V,Average Rectified Forward current=1A, Forward Voltage=1.1V
Transformer	12-0-12, 1A step down
LM7812	Maximum Input Voltage=35V, Output = 11.75 to 12.25, Quiescent Current=6 mA

Battery Unit

A rechargeable battery is used for system while no direct energy source will be available. A 6 V 4.5Ah battery is integrated to the power unit. The typical image of the battery used is:

Fig. 4.17 6V, 4.5 Ah rechargeable battery [72]

Charge Controller

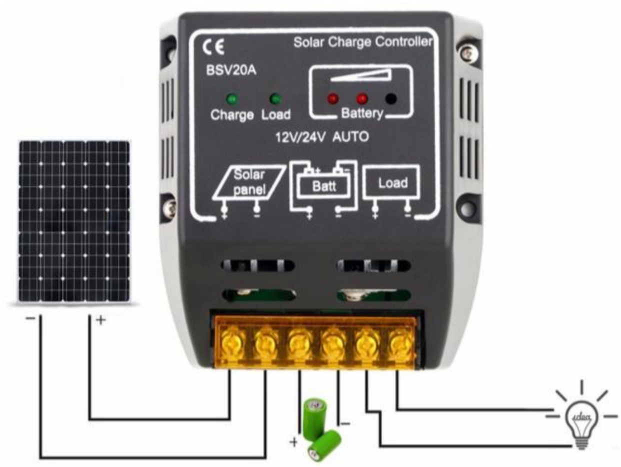


Fig. 4.18 Typical structure of charge controller [73]

Charge controller is an electronic device that controls the overcharge or over-drain of a rechargeable battery. Charge controller not only preserves the battery life but also saves the valuable energy. This circuit mainly used for the solar panel applications. In this work it is used for both Rectifier output and solar panel output using a 3 rotor switch. Fig.4.18 shows a typical charge controller.

Voltage regulator

Voltage regulator block contains a voltage regulator circuit that is integrated to main acquisition system. Both sensor module and controller module need power supply of 5V. So, a LM7805 based voltage regulator is used for the regulated power supply. Fig. 4.19 represents the voltage regulator circuit.

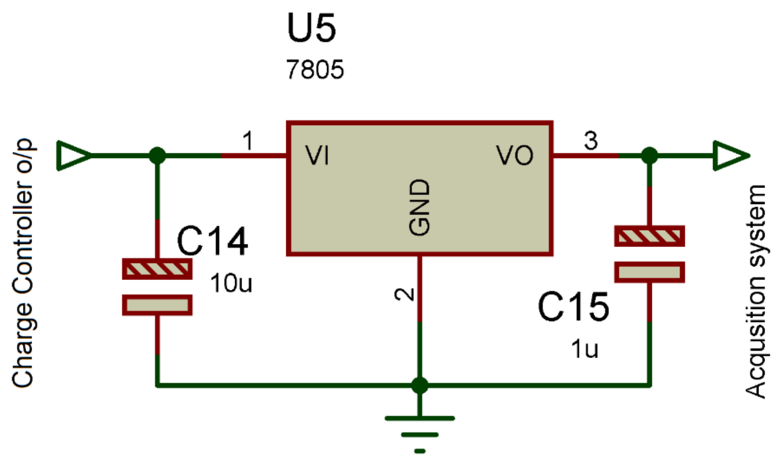
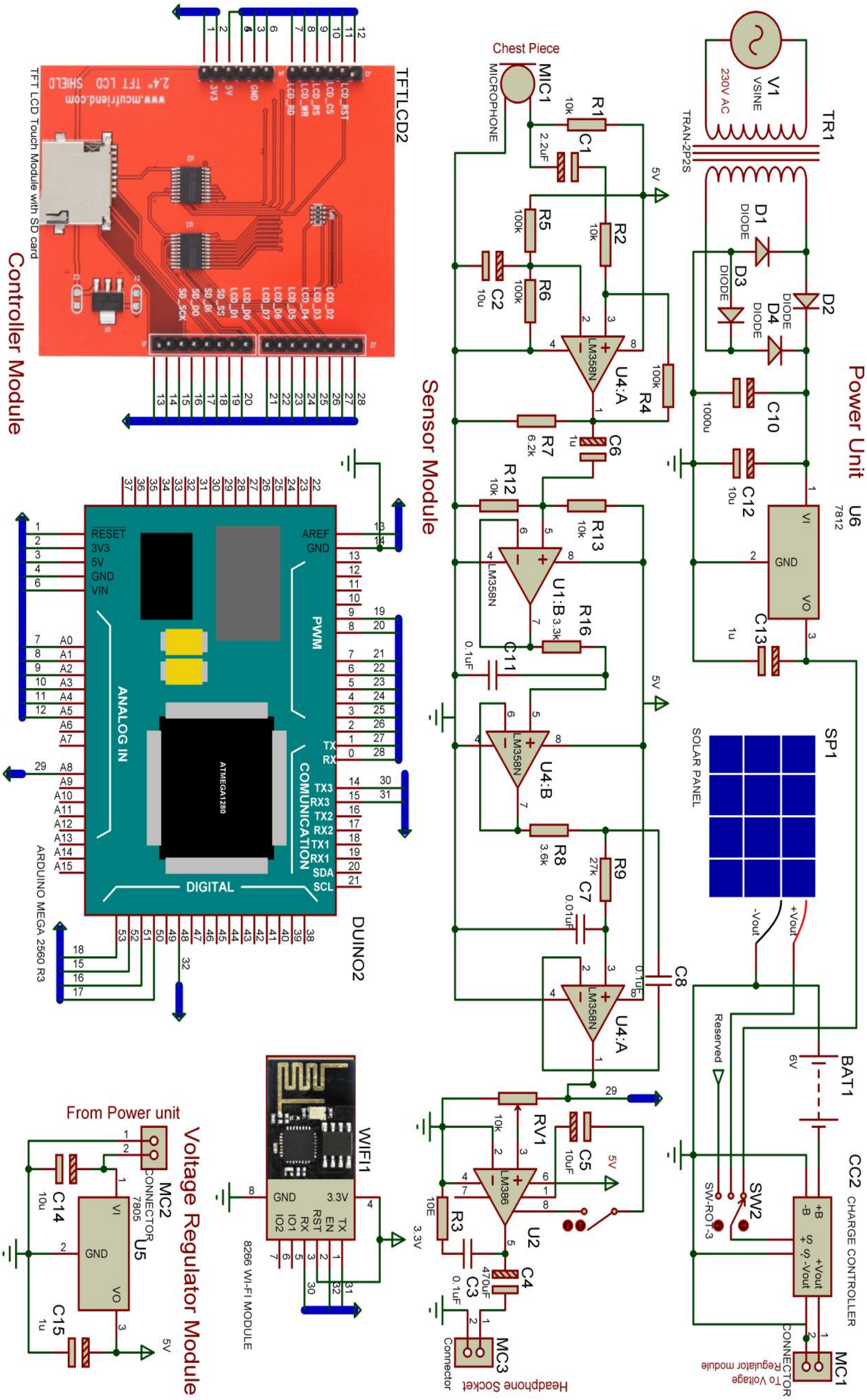


Fig. 4.19 Voltage regulator circuit.

4.3 Complete Circuit Diagram



4.4 Summary

Proposed Heart Sound Acquisition system has been presented in this chapter. Starting from the block diagram to component level description each and every part has been outlined in depth. Starting with the power unit, each module of the power unit has been explained thoroughly. Inclusion of non-renewable energy source to the system makes it undoubtedly eco-friendly solution. Innovative, cost effective heart sound sensor module can be attached to any kind of controller or the microprocessor for the data collection and heart sound listening reliably and effectively. PC interfacing sometime adds portability issue for desktop PC but it helps in an efficient interpretation of heart sound signal. MATLAB GUI implementation dreamed for a user-friendly cardiovascular disease diagnosing tool. The controller module provides wide varieties of system functionality like: data storage, Heart sound analysis, Visualization of signal, easily understandable touch screen based UI for controlling the system operation. If the entire system can be implemented with efficiency and expertise accuracy this will surely became a greatly useful tool for the rural society. In the next chapter, real time implementation of the entire acquisition system has been presented.

Chapter 5

Real Time Implementation and Evaluation

5.1 Overview

In this chapter our aim is to represent the implementation procedures and the corresponding outcomes of it. The entire sensor module first tested in breadboard module wise and then finally implemented in a Vero board. Power Unit has been tested using variable load. Coming to the controller module each part of the external module has been tested separately using Arduino serial monitor applications. SD card testing has been done using built in 'SD' library of the Arduino IDE. TFT LCD module testing and the calibration has been done using 'MCUFRIEND_kbv' library. Wi-Fi module testing has been done based on the AT command sending from the serial monitor of Arduino IDE. For the real time data collection from heart patient, we have attended medical camp. Collected data has been verified and analyzed in MATLAB platform. Details implementation and the results are presented in the subsequent sections outlined below.

5.2 Module testing

Implementation of hardware platform required rigorous testing of each module to perform effectively when they will be integrated. Module testing explains the test results of each module and the difficulties raised during the testing.

5.2.1 Power Unit testing

Power unit testing includes the testing of Solar cell, transformer, LM7812 voltage regulator IC and the charge controller. All of them performed accurately as given in the datasheet of the corresponding circuit components. Fig shows the primary circuit of the power unit implemented in bread board. A 5 watt LED lamp is used to test the backup time of the fully recharged battery. It takes nearly 5 hours to discharge completely. Fig. 5.1 shows the used components of power unit.

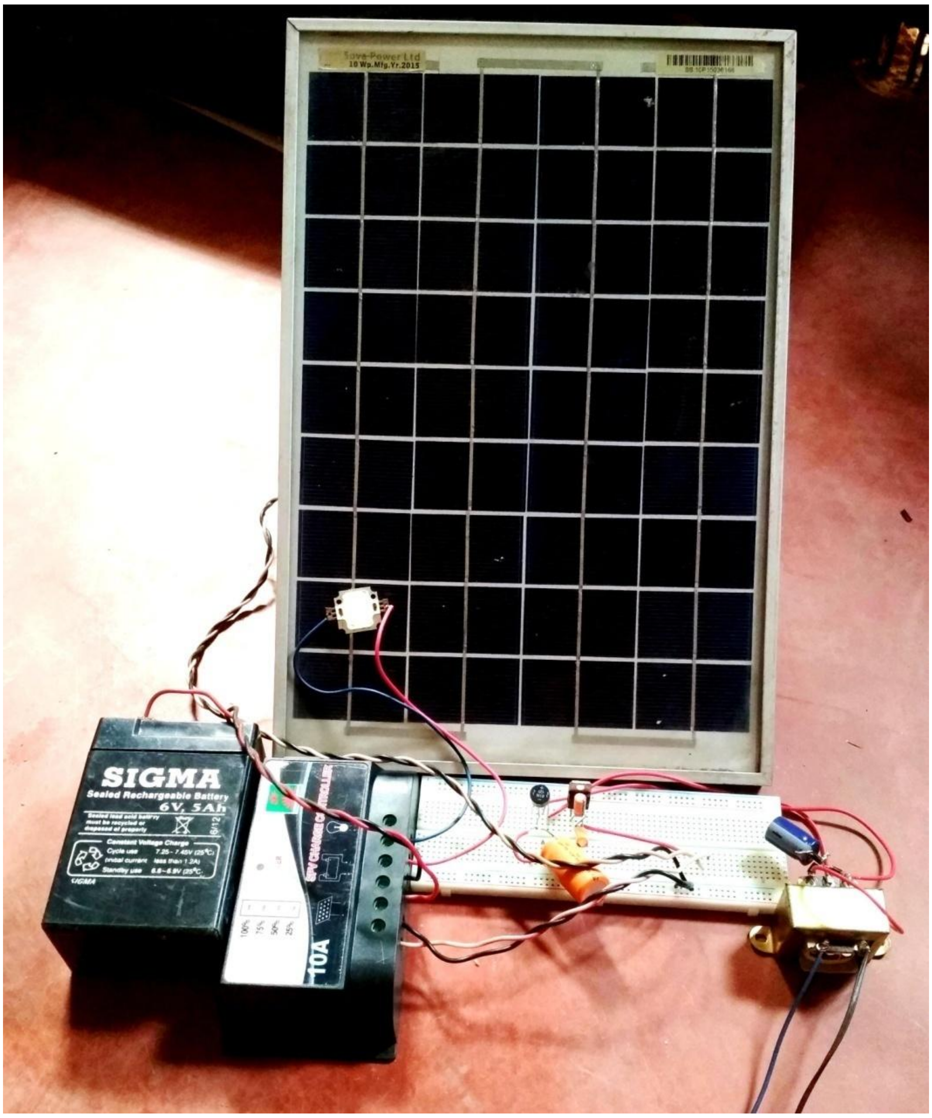


Fig.5.1 Power unit components

5.2.2 Sensor Module testing

Sensor module testing mainly focused on the preamplifier testing and Low pass filter implementation. It also considers the signal acquisition environment to test the noise immunity. Using sinusoidal signal from function generator and oscilloscope low pass filter has been tested. Low pass filter has been tested using sinusoidal signal from function generator and provides desired result. Though the module works perfectly in less noisy environment but the sensor module fails to get the accurate signal in extreme noisy environment.

5.2.3 Controller Module testing

Controller module testing comprises of the SD card interfacing, TFT LCD module interfacing, Wi-Fi module interfacing and the PC interfacing. For each test case Arduino IDE and the Arduino Mega is used.

PC Interfacing:

PC interfacing is required at very first step because Arduino needs specific instruction to operate. Arduino IDE is PC based application that uploads the instruction written in C language compiling in machine language to the Arduino boards. Arduino IDE software has been downloaded from its official website and installed in the windows PC. Now Arduino boards can be directly connected to PC using built in USB port and USB cable. With the right selection of port and Arduino boards under “Tools” in Arduino IDE, interfacing has been started. Fig. 5.2 shows the interfacing of Arduino and the PC with preinstalled Arduino IDE.

Fig. 5.2 Interfacing of Arduino board and PC

SD card Interfacing:

At very first step, SD card is connected to the Arduino module as per the connection shown in Fig.4.12. After that the SD card library example ‘ReadWrite’ has been uploaded to the Arduino boards using USB connection between PC and the Arduino boards. As the name suggest, this example performs the direct read and write operation to the memory card. In very first try, SD card detection failed due to incorrect file format of the memory card. Generally, Arduino SD library is compatible with only FAT16 or FAT 32 file system. So, before inserting it the SD card slot, SD card must be formatted as FAT16 or FAT 32 file system. After that, the read and write operation executed perfectly.

TFT LCD touches screen interfacing and UI testing:

LCD shield is well designed for the Arduino UNO. It also suits perfectly with Arduino Mega as well but due to difference in the SD card pins, external wired connection is required. User just needs to plug the shield above the Arduino mega and configure it for the LCD and the touch screen. But the touch screen needs calibration due to variation in manufacturing. Calibration and graphic testing has been done with the MCUFRIEND_kvb library examples. Only then, designed UI has been tested for all possible warning messages. Fig. 5.3 shows different windows of the designed UI. Window 5.3(a) in the figure accepts the patient information from the user. Required validation in each input field also works correctly. Window (b) ask user to choose the sensor type for the data acquisition. This window currently accepts the data only for heart sound acquisition sensor. Remaining fields are designed for future works. As in future multiple sensors will be added to the acquisition system for simultaneous data collection. Window 5.3(c) is main window; here user can perform various operations in the heart sound signal. 'SEND' and 'analyze' operation currently not functional and kept as a future scope. 'SAVE' button will save the heart sound signal directly to the memory card with the patient information entered at the beginning. A strict validation for unusual user input (i.e. entering no. in place of name, non-numeric value in age etc.) or system fault (i.e. absence of memory card, fault in memory card) has been implemented and tested. Fig. 5.3(d) shows the memory card missing error.

Fig. 5.3Different Window of the designed UI (a) Patient information window (b) Sensor choice (c) Functional Window (d) Validation error for missing memory card

Sensor Module interfacing:

Arduino Mega boards have 16 dedicated analog pins that are usually takes analog signal as input and process the same using onboard ADC. TFT LCD touch screen module uses 4 analog pin to perform different tasks. The remaining ports can be interfaced with any sensor module for data collection or processing. Heart sound signal sensor has been tagged to the analog pin 8 to perform its defined task. Other analog pins can be used for any other type of signal acquisition. That is the reason why sensor choice window has been implemented in the UI design part and left for the future work. In built ADC of Arduino Mega, converts the analog signal to digital form before storing to the memory card. As per the specification given, Arduino ADC has10 bit resolution and can achieve up to 77 kHz of sampling rate. But considering SD card write delay, execution delay the achieved sampling rate of the heart sound signal is nearly 5 kHz. It is much greater than Nyquist Rate defined for the heart sound signal as the heart sound signal spectrum generally lies between 10 to 500 Hz.

Wi-Fi Module Interfacing:

Though Wi-Fi module has been included in this work for the IoT implementation, currently it is not performing any wireless data transmission. This module is successfully interfaced with the acquisition system using AT commands. All hardware connection and the basic communication between Arduino and Wi-Fi module have been successfully tested. For data transmission just a block of code needs to be added in the main Arduino program to enable the data transmission and reception over internet.

5.3 Real time signal Acquisition

After integration of entire module, desired heart sound acquisition device has been achieved. Fig. 5.4 represents the complete heart sound acquisition system.

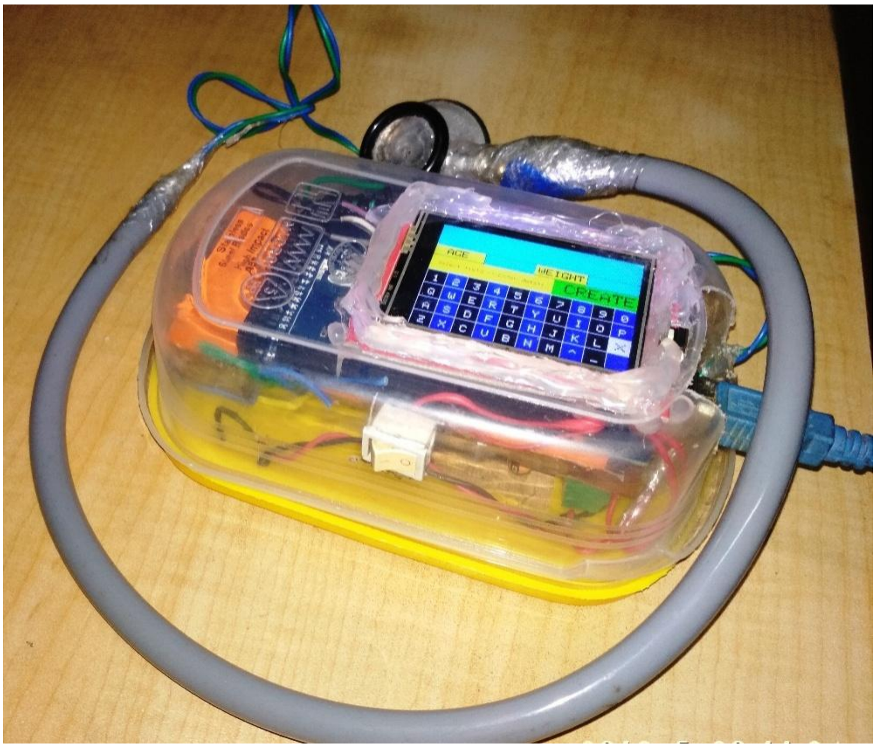
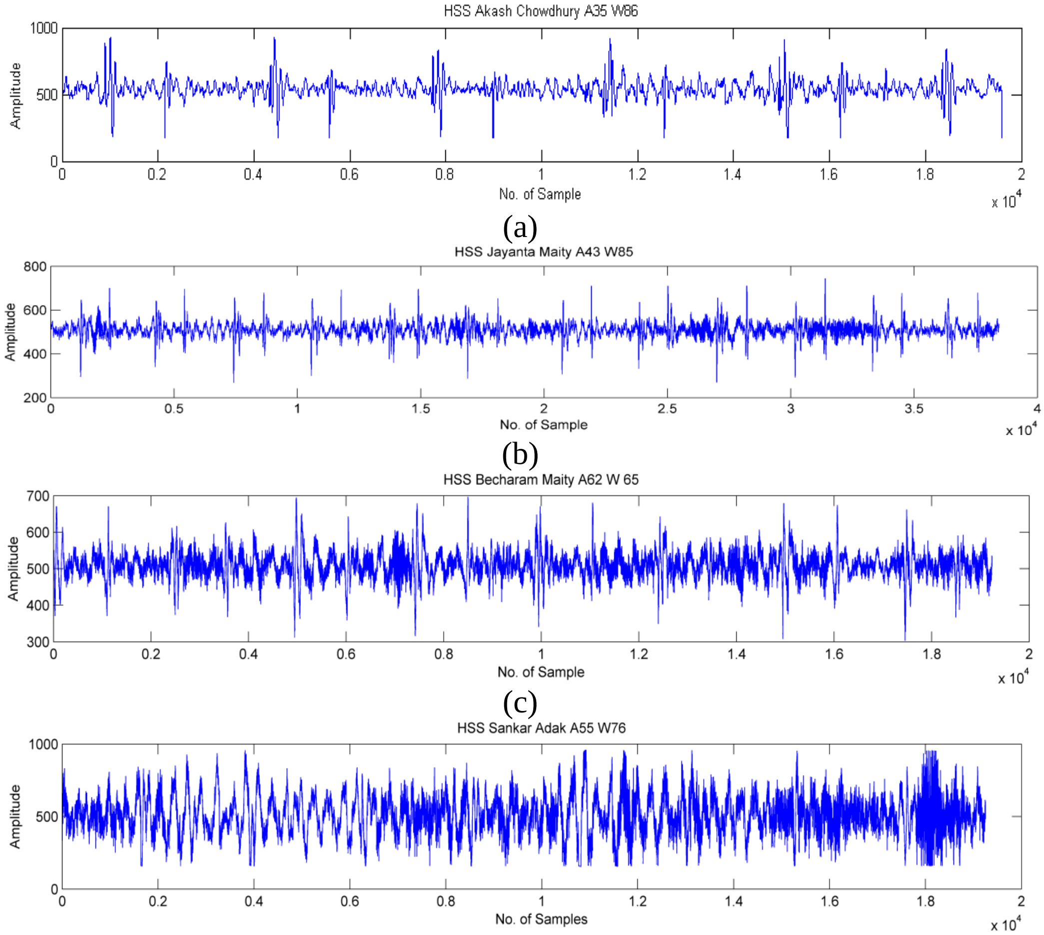


Fig. 5.4 Designed heart sound acquisition system

Heart sound data has been collected from some of student in the department within the age group of 19-20. As all of them have nearly same kind of heart sound without any abnormality, some patient data was required to full proof the system. So we have attended a rural health camp for the real-time data collection in real environment to collect both normal and abnormal heart sounds from mixed aged patient in a noisy and less noisy environment. Nearly 25 heart sounds data set have been collected successfully from the patients suffering from different cardiovascular diseases. The most difficulty arise during the data collection in the health camp is the noisy environment, unavailability of direct electricity. Very few of the data found totally damaged due to the noise from the loud speaker and the uproar of the patient. But remaining data defines the great success of the heart sound acquisition system. Fig. 5.5 represents some of the patient data collected from the health camp.



(d)

Fig. 5.5 Heart Sound signals of patients collected from the health camps under the environment of (a) Indoor (b) Health camp in normal hours (c) Health camp with presence of loud speaker (d) Extremely noisy environment

5.4 Signal Processing in MATLAB platform

For the characteristics parameter extraction and analysis of the heart sound signal, MATLAB platform may be utilized further. The objective of my thesis is to design low cost, portable easy to use heart sound acquisition method. The future scope of work based on the collected data need to be de-noised first, segmented and then feature exaction will be performed. As an example work taking one sample of the collected heart sound, de-noising is performed using wavelet transform based hard thresholding method [74] and then analyzed for detection method proposed following [75].

De-noising using wavelet hard-thresholding: De-noising of the noisy heart sound signal has been done using wavelet hard thresholding method available in the MATLAB wave menu. Fig. 5.6 shows noisy and de-noised signals using hard thresholding method.

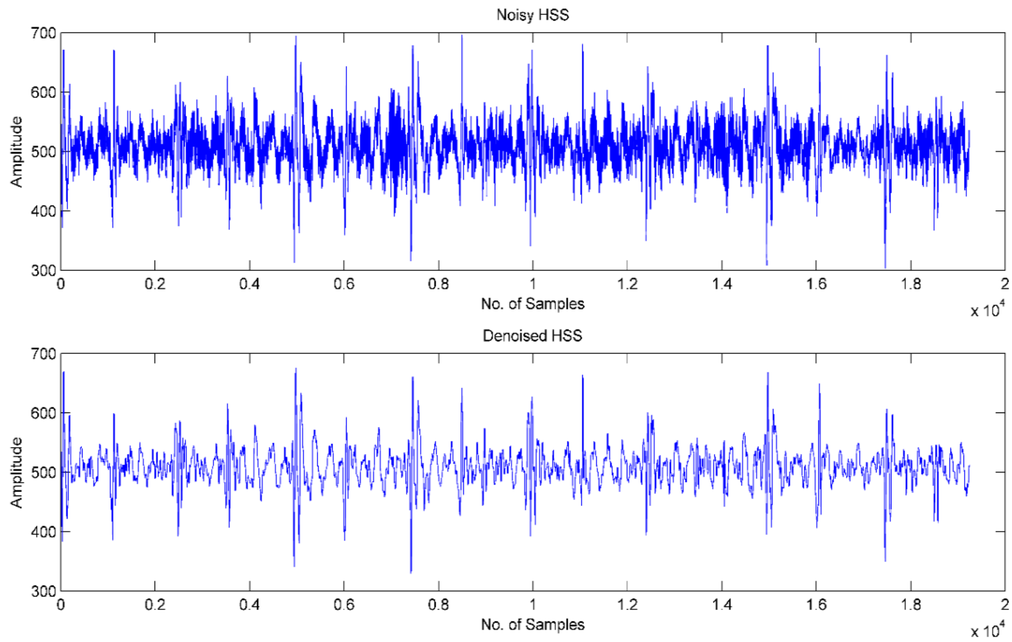


Fig. 5.6 Signal de-noising using Wavelet hard thresholding method

Segmentation: Heart sound segmentation separates the each heart sound component individually and provided more detail visualization of each sound component. Fig. 5.7 shows the each heart sound components segmented separately, which proves that our designed system is accurate enough for heart sound signal acquisition.

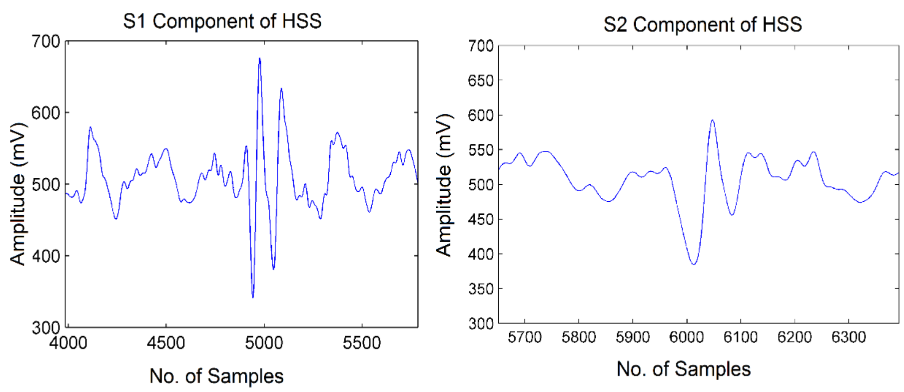


Fig. 5.7 Segmented Heart Sound (S1, S2) of HSS

Feature extraction and anomaly detection: Feature extraction process determine the characteristics parameter value of each heart sound component such as the duration of S1, duration of S2, duration from S1 to S2, PSD etc. Fig. 5.8 shows the Power spectral Density of S1 and S2 component respectively. Table 5.1 represents the parametric values of the heart sound signal as an example following [74].

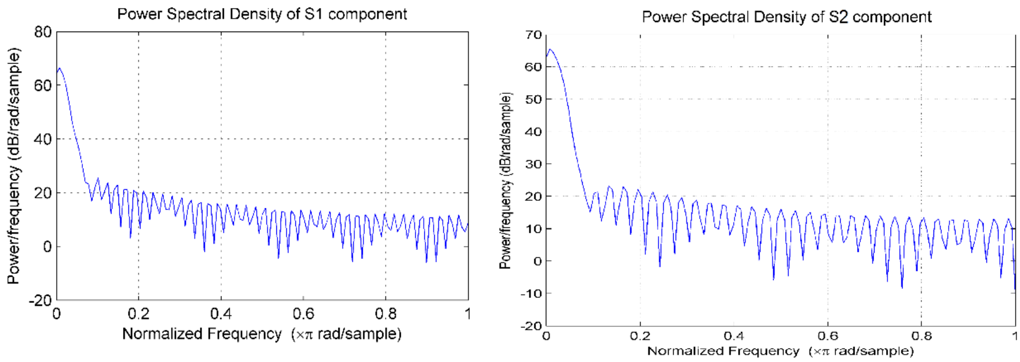


Fig. 5.8 PSD curve for S1 and S2 component of HSS

Table 5.1 Characteristic parameter values of HSS components

Parameter	**Value**	**Parameter**	**Value**
Duration of S1	70mSec	Duration of S1-S2	270mSec
Duration of S2	43mSec	Duration of S2-S1	221mSec
Heart Beat Rate	95 bpm		

If we compare Table 5.1 and Table 3.1 it seems that parametric value differ from normal heart values. So, the patient has been advised to visit specialist doctors for further clarification.

5.5 Summary

In this chapter we have implemented the desired heart sound acquisition system and evaluated the applicability in real-world scenario. Nearly, 25 heart sounds data have been collected from the patients in a health camp. Some of the analyzed data found abnormal in nature and some are from normal heart. For testing purpose, volunteers in the health camp have asked to collect the heart sound data from a patient. With some basic instruction, they could manage to collect the data efficiently. It proved that the designed device is easy to use and user friendly. It was one of our main goals of the thesis work. All aspects of the acquisition system have been verified with real-world implementation. Further improvement and research direction can make the system more accurate and reliable for the exact disease detection. Inclusion of Wi-Fi module in the acquisition system makes it a perfect IoT sensor node.

Chapter 6

Concluding Remarks and Future Direction

6.1 Conclusion

The main aspiration of this work is to deliver a cost-effective and simple instruction based heart sound acquisition system. So, the current epidemic on cardiovascular disease has been painted to bring out the motivation towards this field of study. Literature survey chapter surely provides a greater overview of the current systems and techniques to the new researchers on this field. Following the challenged specification, each module of the acquisition system is customized to keep the design process as simple as possible. It is evident from the real-time implementation and evaluation that heart sound acquisition system can provide early prediction and real time evaluation on heart sound data. Because of its cost efficiency and simplicity, any ordinary people can collect the heart sound data from patient without any basic infrastructure. After visualization and basic analysis, heart sound data can be sent to the specialist doctor for further clarification. The acquisition system is defined as the cost efficient because of its open source hardware and software platform, extremely low cost circuit components. Lightweight hardware components and the user-friendly UI design make the system simple and portable. Inclusion of Wi-Fi module in the acquisition system makes it a perfect IoT sensor node. For remote monitoring, the system can be customized easily by just changing the uploaded code in the Arduino module. Power unit with a renewable energy source will bring a great impact where direct electricity is not available. Over viewing all these it can be concluded that designed acquisition system will assure a great impact on rural society if used properly. Inside great light of successful implementation, extremely noisy hours in the health camp and the requirement of simpler algorithms for de-noising and signal analysis directing the researchers toward extensive future work.

6.2 Future Directions

Heart Sound Signal analysis has different 4 different steps: signal acquisition, de-noising, segmentation & feature extraction, and anomaly detection. So a wide range of future works is waiting based on this platform.

- Improvement in the chest piece design to reduce the external noise affection.
- Improvement in the filter design for noise reduction.
- Simpler de-noising algorithm compared to wavelet transform that can be run in Arduino like low resource platform.
- Implementation of IoT platform for heart sound signal analysis.
- Simple algorithm design for the segmentation, feature extraction and anomaly detection.

- Deduction of ECG signal from Heart Sound Signal (or PCG)
- Implementation of smartphone interfacing with the acquisition system.
- Large and High resolution LCD interfacing to visualize the signal directly from the device.
- Multiple sensor addition to the system for different kind of signal acquisition.

References

[1] https://www.cdc.gov/heartdisease/facts.htm

[2] Prabhakaran, Dorairaj, Panniyammakal Jeemon, and Ambuj Roy. "Cardiovascular diseases in India: current epidemiology and future directions." Circulation 133.16 (2016): 1605-1620.

[3] Prabhakaran, Dorairaj, et al. "The changing patterns of cardiovascular diseases and their risk factors in the states of India: the Global Burden of Disease Study 1990–2016." The Lancet Global Health 6.12 (2018): e1339-e1351.

[4] Kumar, Raman, and Ranabir Pal. "India achieves WHO recommended doctor population ratio: A call for paradigm shift in public health discourse!" Journal of Family Medicine and Primary Care 7.5 (2018): 841.

[5] https://en.wikipedia.org/wiki/Cardiovascular_disease

[6] http://www.antiquescientifica.com/web.stethoscope.monaural.laennec.htm

[7] Scherer, John R. "Before cardiac MRI: Rene Laennec (1781-1826) and the invention of the stethoscope." Cardiology journal14.5 (2007): 518-519.

[8] Wilks, Samuel. "The Evolution of the Stethoscope." British Medical Journal 2.2428 (1907): 115.

[9] Montinari, Maria Rosa, and Sergio Minelli. "The first 200 years of cardiac auscultation and future perspectives." Journal of Multidisciplinary Healthcare 12 (2019): 183.

[10] Wade, Nicholas J., and Diana Deutsch. "Binaural hearing–Before and after the stethophone." Acoustics Today 4.3 (2008): 16-27.

[11] Packard, Thomas J. "Tunable stethoscope." U.S. Patent No. 4,440,258. 3 Apr. 1984.

[12] Lukkarinen, S., et al. "A new phonocardiographic recording system." Computers in Cardiology 1997. IEEE, 1997.

[13] Lukkarinen, Sakari, et al. "Multimedia personal computer based phonocardiography". Proceedings of 18th Annual International Conference of the IEEE Engineering in Medicine and Biology Society. Vol. 5. IEEE, 1996.

[14] A. S. Brown et. al., “PhiSAS: A Low-Cost Medical System for the Observation of Respiratory Dysfunction”, IEE Seminar on Appropriate Medical Technology for Developing Countries, pp. 10/1-10/5, 2002.

[15] Tavel ME. Cardiac auscultation. A glorious past- and it does have a future! Circulation 2006; 113:1255-59

[16] Yashaswini, B. S., and B. S. Satyanarayana. "The design of an electronic stethoscope-review." International conference on computer science and informatics (ICCSI)–Hyderabad–on 9th march. 2012.

[17] Nunes, Diogo, et al. "A low-complex multi-channel methodology for noise detection in phonocardiogram signals."2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC). IEEE, 2015.

[18] Wang, Hong, and Le Yi Wang. "Multi-sensor adaptive heart and lung sound extraction." SENSORS, 2003 IEEE. Vol. 2. IEEE, 2003.

[19] Samanta, Pranab, et al. "Classification of coronary artery disease and normal subjects using multi-channel phonocardiogram signal." Bio cybernetics and Biomedical Engineering (2019).

[20] Hossain, Irina, and Zahra Moussavi. "An overview of heart-noise reduction of lung sound using wavelet transform based filter." Proceedings of the 25th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (IEEE Cat. No. 03CH37439). Vol. 1. IEEE, 2003.

[21] Tan, Boon Hock, and M. Moghavvemi. Real time analysis of fetal phonocardiography. Vol. 2. IEEE, 2000.

[22] Roy, Joyanta Kumar, et al. "A Simple technique for heart sound detection and identification using kalman filter in real time analysis." 2018 International Symposium in Sensing and Instrumentation in IoT Era (ISSI). IEEE, 2018.

[23] Jain, P. K., & Tiwari, A. K.: An adaptive thresholding method for the wavelet based denoising of phonocardiogram signal. Biomedical Signal Processing and Control, 38, 388-399 (2017).

[24] Deb, A., Kar, A., & Chandra, M.: Advanced linear adaptive filtering methods for active noise control: A technical survey. In 2015 International Conference on Advanced Computing and Communication Systems (pp. 1-5). IEEE (2015).

[25] Basak, K., Mandal, S., Manjunatha, M., Chatterjee, J., & Ray, A. K.: Phonocardiogram signal analysis using adaptive line enhancer methods on mixed signal processor. In Signal Processing and Communications (SPCOM), 2010 International Conference on (pp. 1-5). IEEE (2010).

[26] Koutsiana, E., Hadjileontiadis, L., Khandoker, A. H., & Chouvarda, I.: A Comparative Phonocardiography Study: Two Wavelet Based Methods for Fetal Heart Sound Detection. Computing, 45, 1 (2018).

[27] Valencia, D., Orejuela, D., Salazar, J., & Valencia, J.: Comparison analysis between rigrsure, sqtwolog, heursure and minimaxi techniques using hard and soft thresholding methods. In 2016 XXI Symposium on Signal Processing, Images and Artificial Vision (STSIVA) (pp. 1-5). IEEE (2016).

[28] Jia, H., Ren, Y., & Zhang, X.: An improved wavelet packet threshold function for speech enhancement method. JOURNAL OF INFORMATION &COMPUTATIONAL SCIENCE, 10(3), 941-948 (2013).

[29] Strazza, A., Sbrollini, A., di Battista, V., Ricci, R., Trillini, L., Marcantoni, I., & Ancona, I.: PCGDelineator: An Efficient Algorithm for Automatic Heart Sounds Detection in Fetal Phonocardiography. Computing, 45, 1 (2018).

[30] Woywodt A, Herrmann A, Kielstein JT, Haller H, Haubitz M, Purnhagen H.A novel multimedia tool to improve bedside teaching of cardiac auscultation. Postgrad Med J 2004; 80: 355-7

[31] Frank, P-W. Lo, and Max Q-H. Meng. "A low cost Bluetooth powered wearable digital stethoscope for cardiac murmur."2016 IEEE International Conference on Information and Automation (ICIA). IEEE, 2016.

[32] Sarkar, Sayan, and Renata Saha. "A futuristic IOT based approach for providing healthcare support through E-diagnostic system in India." 2017 Second International Conference on Electrical, Computer and Communication Technologies (ICECCT). IEEE, 2017.

[33] Shi, W. Y., Jeffrey Mays, and J-C. Chiao. "Wireless stethoscope for recording heart and lung sound." 2016 IEEE Topical Conference on Biomedical Wireless Technologies, Networks, and Sensing Systems (BioWireleSS). IEEE, 2016.

[34] Aguilera-Astudillo, Carlos, et al. "A low-cost 3-D printed stethoscope connected to a smartphone." 2016 38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC). IEEE, 2016.

[35] Sarmiento, Tatiana Ortegon, et al. "Non-Immersive Virtual Cardiac Auscultation Interactions Employing a 3D Printed Stethoscope." 2018 9th International Conference on Information, Intelligence, Systems and Applications (IISA). IEEE, 2018.

[36] Kajor, Marcin, et al. "A prototype of the mobile stethoscope for telemedical application." 2018 XIV-th International Conference on Perspective Technologies and Methods in MEMS Design (MEMSTECH). IEEE, 2018.

[37] Johnson, Julie, et al. "An ultra-low power subband-based electronic stethoscope." 2006 IEEE International Conference on Acoustics Speech and Signal Processing Proceedings. Vol. 3. IEEE, 2006.

[38] Abu-Faraj, Ziad O., et al. "Design and Development of a Heart-Attack Detection Steering Wheel." 2018 11th International Congress on Image and Signal Processing, BioMedical Engineering and Informatics (CISP-BMEI). IEEE, 2018.

[39] Malik, B., et al. "Design and development of an electronic stethoscope." 2017 Internet Technologies and Applications (ITA). IEEE, 2017

[40] Tiwari, Hemant Kumar, and Ashish Harsola. "Development of embedded stethoscope for Heart Sound." 2016 International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET). IEEE, 2016.

[41] Malek, S. Nur Hidayah, et al. "Design and development of wireless stethoscope with data logging function." 2013 IEEE International Conference on

Control System, Computing and Engineering. IEEE, 2013.

[42] Iskandar, Ade Surya, Ary Setijadi Prihatmanto, and Yoga Priyana. "Design and implementation electronic stethoscope on smart chair for monitoring heart rate and stress levels driver." 2015 4th International Conference on Interactive Digital Media (ICIDM). IEEE, 2015.

[43] Sinharay, Arijit, et al. "Smartphone Based Digital Stethoscope for Connected Health--A Direct Acoustic Coupling Technique."2016 IEEE First International Conference on Connected Health: Applications, Systems and Engineering Technologies (CHASE). IEEE, 2016.

[44] Fattah, Shaikh Anowarul, et al. "Stetho-phone: Low-cost digital stethoscope for remote personalized healthcare." 2017 IEEE Global Humanitarian Technology Conference (GHTC). IEEE, 2017.

[45] Shin, Ji-Yun, et al. "Design technology in portable digital esophageal stethoscope." 7th International Conference on Networked Computing. IEEE, 2011.

[46] Karar, Mohamed Esmail. "Practical microcontroller-based simulator of graphical heart sounds with disorders." 2017 Intl Conf on Advanced Control Circuits Systems (ACCS) Systems & 2017 Intl Conf on New Paradigms in Electronics & Information Technology (PEIT). IEEE, 2017.

[47] Setyowati, Veni, Jodelin Muninggar, and Made RS Shanti NA. "Design of heart rate monitor based on piezoelectric sensor using an Arduino." Journal of Physics: Conference Series. Vol. 795. No. 1. IOP Publishing, 2017.

[48] Kirchner, Jens, Sara Souilem, and Georg Fischer. "Wearable system for measurement of thoracic sounds with a microphone array." 2017 IEEE SENSORS. IEEE, 2017.

[49] Bai, Ying-Wen, and Chao-Lin Lu. "The embedded digital stethoscope uses the adaptive noise cancellation filter and the type I Chebyshev IIR band pass filter to reduce the noise of the heart sound." Proceedings of 7th International Workshop on Enterprise networking and computing in Healthcare Industry, 2005. HEALTHCOM 2005.IEEE, 2005.

[50] Jatupaiboon, N., S. Pan-Ngum, and P. Israsena. "Electronic stethoscope prototype with adaptive noise cancellation." 2010 Eighth International Conference on ICT and Knowledge Engineering. IEEE, 2010.

[51] Suseno, Jatmiko Endro, and Muhammad Burhanudin. "The signal processing of heart sound from digital stethoscope for identification of heart condition using wavelet transform and neural network." 2017 1st International Conference on Informatics and Computational Sciences (ICICoS). IEEE, 2017.

[52] Hall, Donald L., Matthew I. McTaggart, and William K. Jenkins. "Use of adaptive filtering for improved performance in digital stethoscopes." 2017 51st Asilomar Conference on Signals, Systems, and Computers. IEEE, 2017.

[53] Pawar, Chetan K., and Uttam M. Chaskar. "FM based eletronic digital stethoscope using DSP." 2014 International Conference on Control, Instrumentation, Communication and Computational Technologies (ICCICCT). IEEE, 2014.

[54] Bai, Ying-Wen, and Cheng-Hsiang Yeh. "Design and implementation of a remote embedded DSP stethoscope with a method for judging heart murmur." 2009 IEEE Instrumentation and Measurement Technology Conference. IEEE, 2009.

[55] Prasad, V. R., and G. M. Phade. "Design of Electronic Stethoscope and Heart Rate Monitor for Remote Area Application." International Journal of Computer Applications137.10 (2016).

[56] Monika, V., et al. "Embedded Stethoscope for Real Time Diagnosis of Cardiovascular Diseases." 2017 IEEE International Conference on Computational Intelligence and Computing Research (ICCIC). IEEE, 2017.

[57] Fernandes, Joao T., et al. "Using Low Cost Embedded Systems for Respiratory Sounds Auscultation." 2018 15th International Symposium on Wireless Communication Systems (ISWCS). IEEE, 2018.

[58] https://courses.lumenlearning.com/physics/chapter/16-2-period-and-frequency-in-oscillations/

[59] https://questionans.com/frequently-ask-questions-about-human-heart/

[60] https://www.thoughtco.com/phases-of-the-cardiac-cycle-anatomy-373240

[61] Salman, Amy H., et al. "Performance comparison of denoising methods for heart sound signal." 2015 international symposium on intelligent signal processing and communication systems (ISPACS). IEEE, 2015.

[62] Varady, P. "Wavelet-based adaptive denoising of phonocardiographic records." 2001 Conference Proceedings of the 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society. Vol. 2. IEEE, 2001.

[63] Vonesch, C., Blu, T., & Unser, M. (2007). Generalized Daubechies wavelet families. *IEEE Transactions on Signal Processing*, *55*(9), 4415–4429.

[64] Starck, Jean-Luc, Emmanuel J. Candès, and David L. Donoho. "The curvelet transform for image denoising." IEEE Transactions on image processing 11.6 (2002): 670-684.

[65] http://www.ti.com/lit/ds/symlink/lm2904-n.pdf

[66] Shin, Ji Yun, et al. "Development of smartphone-based stethoscope system." 2013 13th International Conference on Control, Automation and Systems (ICCAS 2013). IEEE, 2013.

[67] https://web.mit.edu/6.101/www/reference/op_amps_everyone.pdf

[68] http://www.ti.com/lit/ds/symlink/lm386.pdf

[69]https://www.theengineeringprojects.com/2018/06/introduction-to-arduino-mega-2560.html

[70] Doukas, Charalampos, and Ilias Maglogiannis. "Bringing IoT and cloud computing towards pervasive healthcare." 2012 Sixth International Conference on Innovative Mobile and Internet Services in Ubiquitous Computing. IEEE, 2012.

[71] https://in.mathworks.com/products/matlab.html?requestedDomain=

[72] https://robotskull.in/product/sunca-6v-4-5ah/

[73] https://www.dhgate.com/product/20a-12v-24v-solar-panel-charge-controller/387545867.html

[74] Kumar, Mr Arun, and Anup Mishra. "Performance Evaluation of Different Thresholding Method for De-Noising of Vibration Signal Using Discrete Wavelet Transform."

[75] Mandal, Dulal, Arnab Maity, and Iti Saha Misra. "Low Cost Portable Solution for Real-Time Complete Detection and Analysis of Heart Sound Components." Wireless Personal Communications (2019): 1-25.