

**DESIGN AND DEVELOPMENT OF WIRELESS STETHOSCOPE  
WITH DATA LOGGING FUNCTIONS**

**SITI NUR HIDAYAH BINTI AB. MALEK**

A project report submitted in partial fulfilment of the requirement for the award of  
the Degree of Master of Electrical Engineering



Faculty of Electrical and Electronics Engineering  
University Tun Hussein Onn Malaysia

JUNE 2013

## ABSTRACT

Stethoscope is a special device to hear heartbeat sound and monitor pulmonary disease. The most type of stethoscope used these days is the acoustic stethoscope. However, the problem with this acoustic stethoscope is the sound level very low. It is hard to analyze the heart sound and difficult to be diagnosed by a medical doctor. Therefore, this project was developed to monitor and display heartbeat sound using wireless digital stethoscope. The condenser microphone is used as a sensor to capture the low sensitivity of heart sound signal and transmit the signal using Antenna Arduino ZigBee Pro Series 1. Microcontroller Arduino Nano and Arduino Mega were used as a platform to process the signal and sent the result to the computer. Graphical User Interface (GUI) was developed using MATLAB software to monitor real time electrocardiogram (ECG) waveform and for data logging purpose. The result shows that this device able to transmit and receive ECG waveform wirelessly. The ECG signal can be recorded through data logging application for further analysis by the medical personnel.



## ABSTRAK

Stetoskop adalah alat khas untuk mendengar bunyi degupan jantung dan memantau penyakit paru-paru. Stetoskop yang kerap digunakan pada hari ini adalah stetoskop akustik. Walau bagaimanapun, stetoskop akustik ini mempunyai tahap bunyi yang sangat rendah. Ia amat sukar untuk menganalisis bunyi jantung untuk disahkan oleh doktor perubatan. Oleh itu, projek ini telah dibangunkan untuk memantau dan memaparkan bunyi degupan jantung dengan menggunakan stetoskop digital tanpa wayar. Mikrofon kondenser digunakan sebagai sensor untuk menangkap sensitiviti isyarat bunyi jantung yang rendah dan menghantar isyarat menggunakan Antena Arduino ZigBee Pro Siri 1. Mikropengawal Arduino Nano dan Arduino Mega telah digunakan sebagai platform untuk memproses isyarat dan menghantar hasil isyarat kepada komputer. Sistem penggunaan grafik (GUI) telah dibangunkan menggunakan perisian MATLAB untuk memantau masa sebenar gelombang elektrokardiogram (ECG) bertujuan untuk penyimpanan data. Hasil kajian menunjukkan bahawa alat ini mampu untuk menghantar dan menerima gelombang ECG tanpa wayar. Isyarat ECG boleh dirakam melalui aplikasi penyimpanan data untuk dianalisis dengan lebih lanjut oleh kakitangan perubatan.

## TABLE OF CONTENTS

<b>TITLE</b>	<b>I</b>
<b>ACKNOWLEDGEMENT</b>	<b>IV</b>
<b>ABSTRACT</b>	<b>V</b>
<b>ABSTRAK</b>	<b>VI</b>
<b>TABLE OF CONTENTS</b>	<b>VII</b>
<b>LIST OF FIGURE</b>	<b>X</b>
<b>LIST OF TABLES</b>	<b>XII</b>
<b>LIST OF APPENDICES</b>	<b>XIII</b>
<b>LIST OF ABBREVIATIONS</b>	<b>XIV</b>
<b>CHAPTER I INTRODUCTION</b>	
1.1 Introduction	<b>1</b>
1.2 Problem Statement	<b>2</b>
1.3 Objective of Study	<b>2</b>
1.4 Scope of Study	<b>3</b>
1.5 Significant of Study	<b>3</b>
<b>CHAPTER II LITERATURE REVIEW</b>	
2.1 Introduction	<b>4</b>
2.2 Historical of Stethoscope	<b>5</b>
2.3 Previous of Digital Stethoscope	<b>8</b>
2.4 Project Wireless Stethoscope	<b>9</b>
2.5 Human Physiology for Cardiovascular System	<b>10</b>
2.5.1 Heart	<b>10</b>

2.5.2 Heart Beat Cycle	11
2.5.3 Heart Rate	12
2.5.4 Heart Sound	13
2.6 A Technique to Detect Heart Rate Condition	14
2.7 Parameters of Heart Beat Measurement	15
2.8 Electrocardiogram (ECG)	16
2.9 Hardware	18
2.9.1 Electrode Condenser Placement	18
2.9.2 Arduino	19
2.9.3 Antenna Wireless Arduino ZigBee	20
2.10 Software Method	21
2.10.1 Arduino C++ Programming	22
2.10.2 Wireless Setup using X-CTU Program	22
2.10.3 MATLAB ASCII	23
2.10.4 Graphical User Interface (GUI)	24

### **CHAPTER III METHODOLOGY**

3.1 Introduction	26
3.2 Block Diagram of the Wireless Stethoscope	27
3.3 Flow Chart of Transmit Data	28
3.4 Flow Chart for Receive Data	29
3.5 Flow Chart of Graphical User Interface System	30
3.6 Digital Electronics Stethoscope	31
3.6.1 Testing on Digital Electronics Stethoscope for Data Detections	32
3.7 Wireless Stethoscope used ZigBee Pro Series 1	33
3.7.1 Testing on Wireless Communications using ZigBee Pro Series 1	34
3.8 Data Logging Functions	34
3.8.1 Testing on Data Logging Functions Systems	35

**CHAPTER IV RESULT ON THE DIGITAL ELECTRONICS  
STETHOSCOPE**

4.1 Result of Testing on Digital Electronics

Stethoscope **36**

**CHAPTER V RESULT ON THE WIRELESS TRANSMISSION  
SYSTEM**

5.1 Result Testing the Wireless Communications

Using ZigBee Pro S1 **45**

**CHAPTER VI RESULT ON THE DATA LOGGING FUNCTIONS**

6.1 Result of Testing for Data Logging Functions **48**

6.2 Discussion **50**

**CHAPTER VII CONCLUSSION AND RECOMMENDATION**

7.1 Conclusion **51**

7.2 Recommendation **53**

**REFERENCES** **54**

**APPENDICES** **60**



## LIST OF FIGURES

FIGURE		PAGE
2. 1	Early Stethoscope	5
2. 2	Stethoscope History of Laennec's Invention Drawing	6
2. 3	Invention of Stethoscope	7
2. 4	Human's heart	10
2. 5	ECG Waveform	12
2. 6	Auscultogram from Normal and Abnormal heart sounds	14
2. 7	The ECG Connection with Tracing Paper	17
2.8	ECG placement for 10 Electrodes	17
2.9	Types of Omnidirectional Condenser Microphone Sensor	18
2.10	Schematic Diagram of Arduino Nano and Arduino Mega	19
2.11	ZigBee or Xbee Pro 60 mW Wire Antenna – Series 1(802.15.4)	20
2.12	Connection of Break board pins to Arduino with ZigBee and	21
2.13	GUI Templates for Black	24
2.14	Design of GUI System	25
3. 1	Block Diagram of Wireless Stethoscope	27

3.2	Flow Chart Transmit Data of Heartbeats	28
3.3	Flow Chart Receive Data of Heartbeats	29
3.4	Flow Chart of Matlab Graphical User Interface System	30
3.5	Hardware Connection Zigbee 1	31
3.6	The Circuit and Diaphragm of Stethoscope Connections	32
3.7	Wireless Communications for XBee Communications	33
4.2	Sampling Data for 3 Different Subject (a), (b) and (c)	37
4.3	2000's Data for 3 Subjects of Heartbeats (a), (b), and (c)	39
4.4	Three Subject for 400 Data of Heartbeats	40
4.5	Result of PQRST for Subject 1	41
4.6	Heartbeat Signal for Subject 2	42
4.7	Higher Peak of the PQRST Heartbeat for Subject 3	43
4.8	The 450 Data for 5 Heartbeats after Exercise	44
4.9	Heart Beat Subject 4 after Running (Exercise)	44
5.1	Heart Beat Measurement of various Subject	46
5.2	Three Heart Beats from 301's Data Signal	47
5.3	Testing Graph 100 Data for Subject A and B	47
6.1	Design of GUI System	48
6.2	Details Data Logging at Microsoft Excel	49



## LIST OF TABLES

<b>TABLE</b>	<b>PAGE</b>
2.1 List the History of Stethoscope	7
2.2 List Paper of Electronics Stethoscope	8
2.3 List of Paper Wireless Stethoscope	9
2.4 ECG Trace for PQRST	12
2.5 Heart Rate Chart for Babies and Adults	13
2.6 List of Techniques for Heart Beat Measurement	14
2.7 The Parameters of Heart Beat Measurement	15
2.8 Characteristics of Systolic and Diastolic Blood Pressure	16
2.9 Pin Connections between Arduino and ZigBee	20
2.10 ASCII Characters for Decimal Number	23
2.11 Arduino Nano Specifications	61
2.12 Arduino Mega Specifications	62
2.13 ASCII Coding for Input Data	63
2.14 Subject A and Subject B Result for 100 Data.	64
4.1 Data Subject Exercise after 10 minutes Running	68
5.1 Comparison of Heart Rate Measurement	45
5.2 Different Heart Rate per Minute for Man and Woman	46
6.3 Sampling of 30 Subject	66

## LIST OF APPENDICES

APPENDIX		PAGE
1	Specifications on the Arduino Nano	61
2	Specifications of Arduino Mega	62
3	ASCII Code	63
4	Captured 100's Data for Subject A and Subject B	64
5	Data for Exercise after Running 10 Minutes	66
6	Sampling of 30 Subject	67
7	Table Voltage versus Serial Monitor for Data Signal	68
8	TRANSMIT Coding in Arduino	69
9	RECEIVER Coding in Arduino	70
10	Turn On the LED while the Button Press	71
11	MATLAB Data Waveform Coding	72
12	MATLAB for GUI System	73
13	Claim for Final Year Project Mater in Coursework	84
14	Schedule Project Final Wireless Stethoscope	83
15	List of the Tak for This Project	84
16	Submitted Paper BMEiCON 2013, Conference Krabi, Thailand	88

## LIST OF ABBREVIATIONS

ASCII	-	American Standard Co
BPM	-	Beats Per Minutes
DB	-	Decibel
ECG	-	Electrocardiogram
GND	-	Ground
GUI	-	Graphical User Interface
HB	-	Heart Beat
IDE	-	Intergrated Development Environment
LCD	-	Liquid Crystal Display
LED	-	Light Emitting Diode
mm Hg	-	millimeters of Mercury
RX	-	Receive
TX	-	Transmit
WIFI	-	Wireless Local Area Network
XBee	-	ZigBee

## CHAPTER I

### INTRODUCTION

#### 1.1 Introduction

The stethoscope comes from the Greek language for skope means chest and stethos means inspection. It is a very vital transducer for many medical practitioners. and used for end user like doctors, nurses and physicians detect the abnormalities of the heart and lung such as sounds of heart, lung rhythm, and vibration of the intestines and blood flow (Geddes 2005). Diaphragm of head stethoscope is the metal end that is placed on the chest to listen to the lungs and heart sound with the tubing to tapered inner bores. This structure is able to provide a better sound transmission while listening is known as a vacuum tube. The most type of stethoscope used these days is the acoustic stethoscope (Myint & Dillard 2001). However, the problem with this acoustic stethoscope is the sound level is very low make it hard to analyse and diagnose the heart sound by a medical doctor. This is why several forms of digital electronic stethoscope have been developed to replace the conventional acoustic stethoscope. Basically, the purpose of digital stethoscope is to improve the sound resolution, allow variable amplification, minimize interference noise and simplify the output signal.

The digital stethoscope can enhance the auscultation problem of acoustic stethoscope which is easily affected by the movement and noise surrounding. Several techniques with the functions like stethoscope have been widely used such as SPO2,

Sphygmomanometer and Electrocardiogram (ECG) (Francis E H Tay et al. 2009; Jokic et al. 2010).

## **1.2 Problem Statement**

Sound detection of heart beat for the stethoscope is mainly problem that always occurs for medical doctors and physicians at hospital. This problem is in listening to heart sounds through the stethoscope when the signal level of detections is very low and cause very difficult to be analyzed. This is why some form of digital electronic stethoscope needs to be developed to replace the existing acoustic stethoscope. As the diagnosis part can be done by anybody except by an experiences medical doctor or physician for details of analysis, by developing the Digital Stethoscope where it will save the measured heart beat signal from a patient and the data input signal in voltage can easily be read by patient when they used it. This project will monitor the data with wireless transmissions and the result will be saved in real time.

## **1.3 Objective of Study**

The main objective of this project is to Design and Develop a Wireless Stethoscope with Data logging Functions. The detail objective of this study as follow:

1. Develop a Digitalized Stethoscope Using Arduino Nano
2. Develop a Wireless Data Transmission System
3. Verify, Analyze and Compare the Digitalized Stethoscope with the current devices

#### **1.4 Scope of Study**

To design the circuit that will give a result for the heartbeats detection in digitalize stethoscope in number with the sensor circuit is to detect an input analog signal for heartbeats and convert into digital with Arduino Nano as a microprocessor.

Then continued by the development of Wireless Transmission using Antenna ZigBee Pro Series 1 it is to transmit and receive the data of signal from a communications system. The signal is sent directly to a personal computer that contains a data system to record important information about the patient to keep in the software system in real time wave to be analyzed received. Then this wireless stethoscope will be verified and shown the data of heartbeats as a result for the counting of heart rate per minute

Continue by create and design the Data Base of the heartbeat signal using Microsoft Excel for Data Logging information of patients and can be monitored in real time display with record for further analysis also to produce a portable device with a low cost wireless stethoscope

#### **1.5 Significant of Study**

Three categories is describe of Wireless Stethoscope study, first is develop a Digital Electronic Stethoscope, Wireless Transmission system and lastly is a verification on the Digital Stethoscope to detect the heartbeats.

To develop a system that can monitor the health of patients at home without having to commute to the hospital. Also can pleasant a doctor to monitor the health of patients with the information data storage system. Others are wireless device for this system can facilitate the patient to move go anywhere

Propose for this study is serves the others students as their reference or guide in creating new program that is related to the heartbeats. It will also help in computer communications system to identify the best communicate programming language that can be used.

## CHAPTER II

### LITERATURE REVIEW

#### 2.1 Introduction

Initial research was conducted to determine the types of heartbeats that are routinely measured during a visit by a doctor in hospital. This is a respiration rate of breathing that can give a total of heartbeats in heart rate per minute. One of the methods used to measure this heartbeat is by the auscultation method. These methods provide information about a variety of internal body sounds originated from the heart, lungs, bowel and vascular disorders (Khan et al. 2012). The ability to detect heart sounds may be influenced by a number of factors, including the presence of ambient noise or other sensory stimuli. This may result in inaccurate or insufficient information due to the inability of the user to discern certain complex, low-level, short duration or rarely encountered abnormal sounds (Jiang & Choi 2006). Therefore, only the skilled physician who is proficient in the skill of auscultation is likely to make accurate diagnoses upon cardiac auscultation. It is, thus, desirable to enhance the diagnostic ability by processing the auscultation signals electronically and providing a visual display and automatic analysis to the physician for a better comparison study.

## 2.2 Historical of Stethoscope

The expression of stethoscope is an examination that is an acoustic medical device for auscultation, or listening to the internal sounds of an animal body. It is often used to listen to lung and heart sounds as well as the intestines and blood flow in arteries and veins. In combination with a sphygmomanometer, it is commonly used for measurements of blood pressure and to detect small-scale acoustic signal in monitoring tasks. A stethoscope that intensifies auscultatory sounds is called phonendoscope. Acoustics Stethoscope is an evolution of a low cost active artificial ear or also known as ear pieces device to detect a sound frequency of the internal body (Scope n.d.).

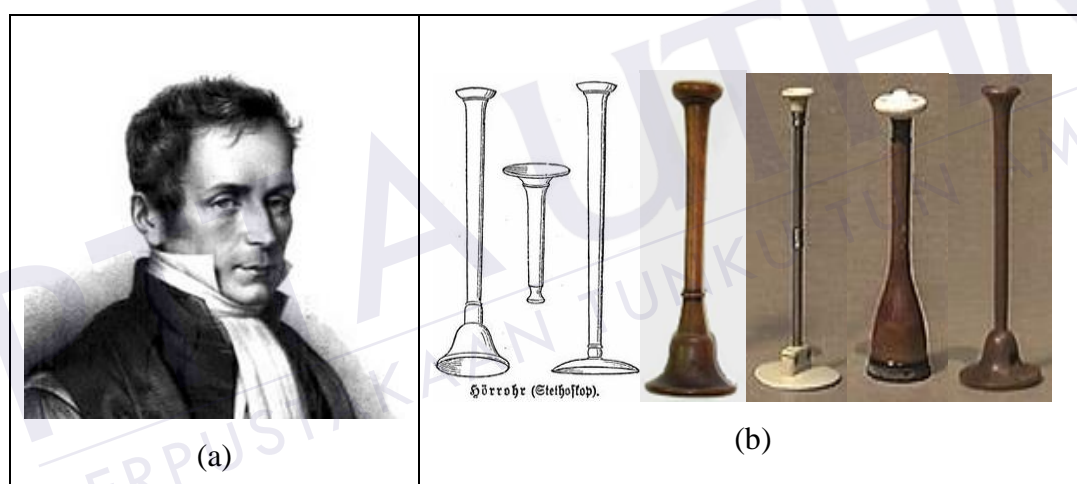


Figure 2.1: Early Stethoscope (a) Dr. Rene Laennec c. 1816

(b) Ear Trumpet Microphone

Stethoscope history began in 1816 with French physician called Doctor Rene Laennec at Necker-Enfants Malades Hospital in Paris. The stethoscope designed by Dr. Rene consisted of a wooden tube and was monaural design as shown in Figure 2.1. With this device which was similar to the common ear trumpet, a historical form of hearing aid; indeed, his invention was almost indistinguishable in structure and function from the trumpet call microphone.

Laennec said to have seen schoolchildren playing with long, hollow sticks in the days leading up to his innovation. The children held their ears to one end of the stick while the opposite end was scratched with a pin, the stick transmitted and



amplified the scratch. His skill as a flautist may also have inspired him. He built his first instrument as a 25 cm by 2.5 cm hollow wooden cylinder as shown in Figure 2.2, which he later refined to comprise three detachable parts (Ramon n.d.).

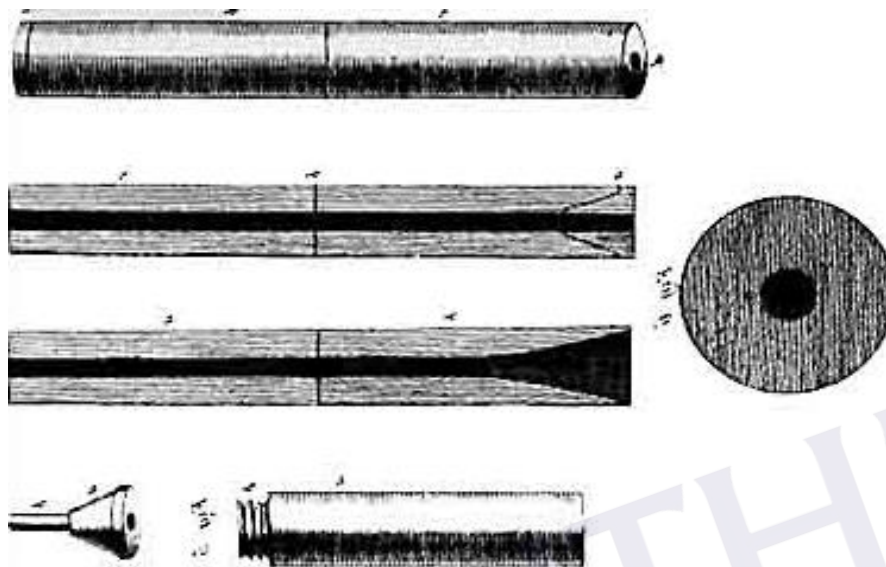


Figure 2.2: Stethoscope: History, Laennec's Invention Drawing

Inspired seen from schoolchildren playing with long, hollow sticks while the children held their ear to one end of the stick while the opposite end was scratched with a pin, the stick transmitted and amplified the scratch. Then he built his first instrument as a 25 cm by 2.5 cm hollow wooden cylinder, which later refined to comprise three detachable parts

Doctor Laennec spent the next three years perfecting his stethoscope's historical design and listening to the chest findings of patients with pneumonia, comparing what he heard to their autopsy lung findings. Then he published the first seminal work on the use of the stethoscope to listen to internal body sounds entitled *De L'auscultation Mediatein* in 1819 at thirty-eight years old. Ironically, Laennec himself died of tuberculosis on August 13th, 1826.

Stethoscope history further evolved to the binaural two ear stethoscope types in 1852 by Doctor George Cammann as a physician at the Northern Dispensary in New York City. He also creates a model of a soft metal and multiple designs for two people to listen at a same time.



Figure 2.3: Invention of Stethoscope (a) Dr. George Cammann c.1855 (b) Cammann Binaural Stethoscope

Figure 2.3 is the Cammann's model stethoscope, made with ivory earpieces connected to metal tube that were held together by a simple hinge joint, and tension was applied by way of an elastic band. Attached the two tubes covered by wound silk and converged into a hollow ball designed to amplify the sound, and then attached to the ball that was a conical or cone shaped, bell chest piece.

Table 2.1 shows the history of the main design of stethoscope from early development until 1900. The features enhance step by step when many inventions are created to make new stethoscope more reliable to be used nowadays.

Table 2.1: History of Stethoscope:

Years:	History Design
1829	Binaural Stethoscopes (two earpiece models) make their debut, but not with much success by a doctor in Dublin.
1860s	The Camman Stethoscope, a binaural model with a bell shaped chest piece is now considered the standard for superior "auscultation" to listen to sounds in the chest by American physicians. It would soon be followed by the Ford model.
1890s	A physician & surgeon supply catalog offers stethoscopes from 40 cents for a simple wooden monaural model up to \$4.00 for a fancier binaural example.
1898	The Bowles Stethoscope with its diaphragm chest piece in a flattering shape appears. These would be joined by the "combination stethoscopes" in 1902 - having both bell & diaphragm chest pieces for better diagnosis.

Table 2.1 Continue

<b>1900</b>	The “Cardiophone” an early electronic instrument to help augment heart sounds arrives on the medical scene.
-------------	-------------------------------------------------------------------------------------------------------------

### 2.3 Previous Study For Digital Stethoscope

Table 2.2 shows the list of papers that focuses on Digital Electronic Stethoscope design. With several types of new features and characters that is being developed to make it more reliable and easy to be used by doctors, physicians and others end user.

Table 2.2: Project Development for others Electronics Stethoscope

<b>Authors:</b>	<b>Title of Paper and Project Development</b>
Jatupaiboon, N Pan-ngum, S Israsena, P Year: 2010	<b>Electronic Stethoscope Prototype with Adaptive Noise Cancellation</b> This electronic stethoscope prototype can filter frequency, reduce external noise and make real time digital signal processing with low cost product (Jatupaiboon et al. 2010).
Myint, W W Dillard, B Year: 2001	<b>An Electronic Stethoscope with Diagnosis Capability</b> This device can extract the heartbeat of sound cycle, also the murmur of data, time frequency analysis, with statistical metrics and diagnosis algorithms (Myint & Dillard 2001).
Rashid, Rb A Ch'ng, H S Alias, M A Fisal, N Year: 2005	<b>Real Time Medical Data Acquisition over Wireless Ad-Hoc Network</b> With real-time digital signal and can plot recording of body acoustic include standard audio data file. Have a multimedia computer with broadband, and a set of multimedia speakers is embedded inside the network with low cost (Rashid et al. 2005).
Reed, Todd R. Reed, Nancy E. Fritzson, Peter Year: 2004	<b>Heart Sound Analysis for Symptom Detection and Computer-Aided Diagnosis</b> This prototype system with heart sound analysis, based on a wavelet decomposition of the sound and a neural network-based on classifier for pathologies (T. R. Reed et al. 2004).

The papers mentioned above have different features in their project prototype development such as the filter on frequency noise and sound, the recording standard for the audio data file also the sound analysis.

## 2.4 Project Wireless Stethoscope

Table 2.3 shows the list of papers that focuses on wireless Stethoscope. There are several wireless communication techniques involved including Bluetooth and wireless local area network (Wifi).

Table 2.3: Project Development for others Wireless Stethoscope

<b>Authors:</b>	<b>Title of the Paper with a Description:</b>
Cho, Kyu Jin Asada, H Harry Years : 2002	<b>Wireless, Battery-Less Stethoscope for Wearable Health Monitoring</b> This system can capture and monitored the respiratory human body sound for asthma and other pulmonary diseases. The sensor and batteries are wireless to make it easy to attach at the skin (Kyu Jin & Asada 2002).
Luo, Yi Years: 2008	<b>Portable Bluetooth Visual Electrical Stethoscope Research</b> This project can separate the sound of cardiovascular sound based on the embedded system, Bluetooth, wireless transmission technology visualized and instrument. It can possess the features in real time display, playback and record the sound functions (Yi 2008).
B. Hok, V. Bythell, M. Bengtsson Years: 1988	<b>Development of a Wireless Stethoscope for Auscultatory Monitoring during Anaesthesia</b> Have microphone and battery operation with range 10 meters at operating theatre. The frequency is lower audible limit to ~20 Hz and the highest expected of the signal to ~ 1 kHz (U. 1988).
Hung, K B Choy, L Luk W H Tso, B Tai S K Years: 2004	<b>Multifunction Stethoscope for Telemedicine</b> This Bluetooth Wireless Communication can be used at home, by providing a video conferencing, remote auscultation, heart and lung sound separation, ECG recording, and automatic pre diagnosis for systems for doctors monitored the patients (Hung et al. 2004).
K. Hung, Y.T. Zhang Years: 2002	<b>Usage of Bluetooth™ in Wireless Sensors for tele- Healthcare</b> Using power consumption of the radio module, with spread spectrum and short range transmission Bluetooth that is an attractive option in medical sensors. Using Powertrain Control Module (PCM) for a feasible solution for transmission of heart and lung sounds.

## 2.5 Human Physiology for Cardiovascular System

The cardiovascular system is a body comprised of the heart, the blood, and the blood vessels also known as the circulatory system and it is for transporting blood. As the cardiovascular system moves blood throughout the body, cells receive oxygen and nutrients while carbon dioxide and other wastes are removed from the body as well (Shin et al. n.d.).

### 2.5.1 Heart

The heart is a powerful muscle, about the size of a clenched fist, located at the left of the centre of the chest with the special type of muscle called the myocardium. Function of heart that has a rhythmic, automatically repeated beating and it is maintained by electrical impulse originating in the sinoatrial central node. It also known as a natural pacemaker that is to supply the blood and oxygen at all parts of the body. The heart is located in the chest cavity just posterior to the breastbone, between the lungs and superior to the diaphragm. Blood is pumped away from the heart through arteries and returns to the heart through veins. The major artery of the body is the aorta and the major veins of the body are the vena cavae (Sepehri et al. 2010). Figure 2.4 shows the heart of human.

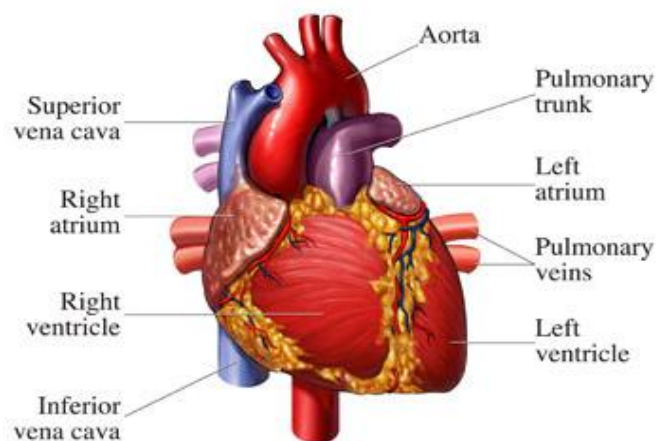


Figure 2.4: Human's Heart

### 2.5.2 Heart Beat Cycle

Heartbeat is a single pulsation of the complete cardiac cycle, when the electrical impulse is conducted and at the same time a mechanical contraction is occurs in muscle contraction and relaxation. This cardiac cycle is related to the flow or blood pressure that occurring from the beginning of one heartbeat to the beginning of the next (Nakajima et al. 1996).

For each beat of the heart involves five major stages. The first two stages, often considered together as the "ventricular filling" stage, involve the movement of blood from the atria into the ventricles. The next three stages involve the movement of blood from the ventricles to the pulmonary artery in the right ventricle and the aorta in the left ventricle (Übeyli 2007).

There are three separate and distinct phases make up the sequential beating of the heart. The relaxing of muscle and refilling of the chamber with blood during the first stage is followed by stages when the atria and then the ventricles contract, sending blood through the heart and out into the arteries. The cycle takes about four-fifths of second; during vigorous exercise, however in times of stress, this speed may increase to double (Maglaveras et al. 1998)(Bauer et al. 2008). The cycle of blood flow is shown in Figure 2.5 and can be simplified as:

1. Diastole – First phase of cycle, deoxygenated blood enters the right atrium and oxygenated blood enters the left atrium. The blood then flows through into the ventricles
2. Atrial Systole – Impulse from the sinoatrial node initiate the next phase of the cycle, during which the atria contract. This squeezes any blood remaining in the atria into the ventricles
3. Ventricular Systole – During this third phase of the heartbeat cycle, the ventricle contract. Valves at the ventricle exits open and blood is forced into the pulmonary artery and the aorta and this phase ends diastole start again. (Book 2001)



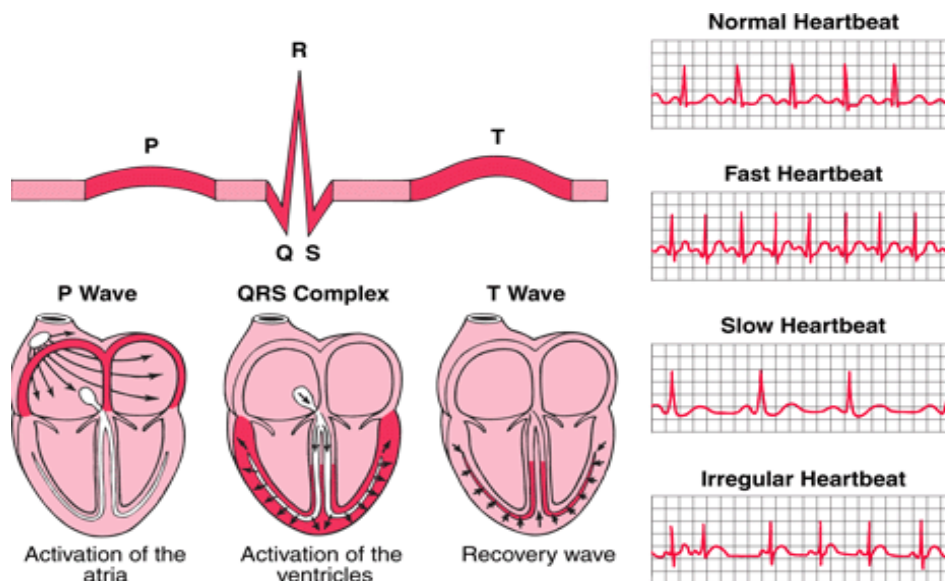


Figure 2.5: ECG Waveform

Table 2.5 shows the ECG Trace for the PQRST Waveform. There have 4 types of heartbeat that is a normal heartbeat, fast heartbeat, slow heartbeat and irregular heartbeat.

Table 2.4: ECG Trace for PQRST Wave

<b>T wave</b>	A ventricular repolarization is a positive deflection, since repolarization is in opposite direction
<b>PR interval</b>	The times is between 120-200ms beginning at P wave and ending of QRS complex
<b>ST segment</b>	The time between QRS complex and start of T wave at a plateau phase of cardiac muscle
<b>QT interval</b>	The time between ~400ms in beginning of QRS complex and end of T wave.
<b>Normal</b>	PT constant, but TP interval changes when HR changes

### 2.5.3 Heart Rate

Heart rate is same with the pulse rate and it is the number of heartbeats per unit of time, typically expressed as beats per minute (bpm). Heart rate can vary as the body's need to absorb oxygen and excrete carbon dioxide changes, such as during physical exercise, sleep, illness, or as a result of ingesting drugs. Due to individuals having a constant blood volume, one of the physiological ways to deliver

more oxygen to an organ is to increase heart rate to permit blood to pass by the organ more often. Normal resting heart rates range from 60-100 bpm. Above is the average of the Heart Rate per Minute for the different ages consider situation of the physical characteristics is the total pumping of heart occurs. Table 2.5 from shows the normal heart rate based on age. As can be seen, the heart rate of baby and adult is quite high. (Bauer et al. 2008).

Table 2.5: Heart Rate Chart for Babies to Adults

AGE (years)	Beats Per Minute (BPM)
New born 0-3 Months Old	100-150
Infants or Babies 3-6 Months	90-120
Infants 6-12 Months	80-120
Children ages 1 - 10	70 – 130
Children age 10 + and Adults	60 – 100
Well-trained Adult Athletes	40 - 60
Adult 20 - 29	99-165
Adult 30 – 39	94-160
Adult 40 – 49	89-151
Adult 50 – 59	84-143
Adult 60 – 69	79-134
Adult 70 and above	75-128

#### 2.5.4 Heart Sound

Heart sounds are the noises generated by the beating heart and the resultant flow of blood through artery (the turbulence created when the heart valves snap shut). In cardiac auscultation, an examiner may use a stethoscope to listen for these unique and distinct sounds that provide important auditory data regarding the condition of the heart (Yan et al. 2010b).

In healthy adults, there are two normal heart sounds often described as a lub and a dub or dup, that occur in sequence with each heartbeat. These are the first heart sound ( $S_1$ ) and second heart sound ( $S_2$ ), produced by the closing of the atrial ventricular valves and semilunar valves respectively (Amit et al. 2009). In addition to



these normal sounds, a variety of other sounds may be present including heart murmurs, adventitious sounds, and gallop rhythms  $S_3$  and  $S_4$  (Yan et al. 2010a). Figure 2.6 shows the phonocardiograms on auscultation from normal and abnormal heart sounds.

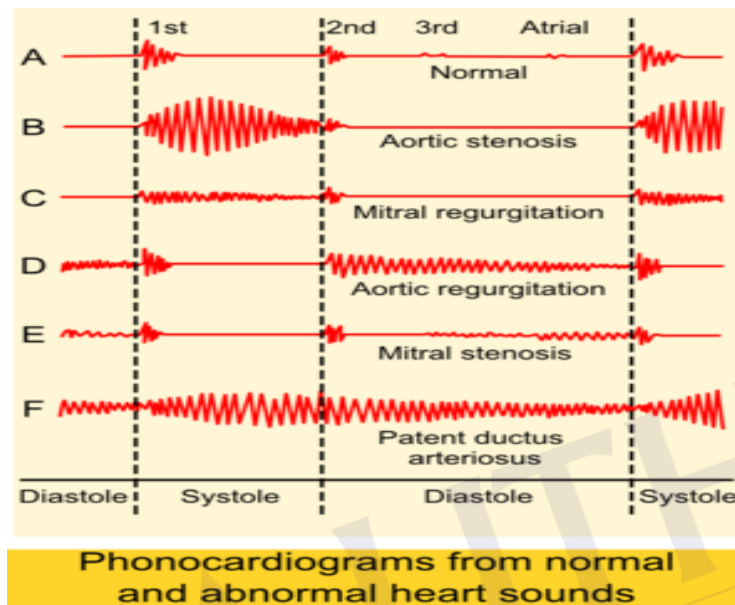


Figure 2.6: Auscultogram from Normal and Abnormal Heart Sounds

### 2.6 A Technique to Detect Heart Rate Condition

Several techniques have been used to detect heart rate. The techniques to detect the abnormalities at heart are based on Korotkoff sound, Blood Flow, Blood pressure, Systolic, Diastolic, Auscultation, Heart Murmurs, Arrhythmia, Tachycardia, and Bradycardia. The summary of the techniques are as shown in Table 2.6 contains 4 measurement. (M. A. Zaltum et al. 2010)

Table 2.6: List of the Techniques for Heart Rate Measurement

<p><b>Korotkoff Sound</b></p>	<p>The technique is implemented by detecting the arterial sound using Blood Pressure Cuff or sphygmomanometer. The sound can be heard through a stethoscope which is put under the cuff at left armhole near heart. The first sound heard after release the cuff is known as systolic and the second sound is known as diastolic blood pressure.</p>
-------------------------------	------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------

Table 2.6 Continue

<b>Auscultation</b>	By listening to the heart beats using stethoscope and sphygmomanometer. Comprises and inflatable cuff place around upper arm.
<b>Heart Murmurs</b>	Generated by turbulent flow of blood sufficient to produce audible noise, which may occur inside or outside the heart. Murmurs may be physiological in benign or pathological at abnormal condition.
<b>Arrhythmia</b>	It is an irregular heartbeat with group of heart conditions which present with abnormal heartbeats like tachycardia and bradycardia.

## 2.7 Parameters of Heart Beat Measurement.

For analysis the heart rate of the human body, several parameters is involves refer to Table 2.7 Among these are the parameters for different types of heart beat measurement that is a Blood Flow, Blood Pressure, Systolic, Diastolic, Tachycardia and Bradycardia.

Table 2.7: The Parameters of Heart Beat Measurement

<b>Blood Flow</b>	The movement of blood through the vessels of the cardiovascular system
<b>Blood Pressure</b>	In a blood vessel, the force exerted by the blood against the vessel wall. This pressure caused by the pumping of the heart that keeps blood circulating. Blood pressure is recorded as 120/80 and read as "120 over 80."
<b>Systolic</b>	Systolic blood pressure refers to the pressure of blood in the artery when the heart contracts. It is the top (and higher) number in a blood pressure reading. Example: systolic pressure is 120 millimeters of mercury (mm Hg)
<b>Diastolic</b>	Diastolic blood pressure refers to the pressure of blood in the artery when the heart relaxes between beats. It is the bottom (and lower) number in a blood pressure reading. Example: diastolic pressure is 80 mm Hg and
<b>Tachycardia</b>	It is a fast or irregular heart rhythm, usually more than 100 beats per minute and as many as 400 beats per minute.
<b>Bradycardia</b>	It is a slow heartbeat means that the heart rate is slower than 60 beats per minute, either occasionally or all the time

Table 2.8: Characteristics of Systolic and Diastolic Blood Pressure

Characteristics	Diastolic	Systolic
<b>Definition</b>	It is the pressure that is exerted on the walls of the various arteries around the body in between heart beats when the heart is relaxed.	It measures the amount of pressure that blood exerts on arteries and vessels while the heart is beating.
<b>Normal Range</b>	60 – 80 mmHg (adults); 65 mmHg (infants); 65 mmHg (6 to 9 years)	90 – 120 mmHg (adults); 95 mmHg (infants); 100 mmHg (6 to 9 years)
<b>Importance with age</b>	Diastolic readings are particularly important in the monitoring blood pressure in younger individuals.	As a person's age increases, so too does the importance of their systolic blood pressure measurement.
<b>Blood Pressure reading:</b>	Diastolic represents the minimum pressure in the arteries with The lower number is diastolic pressure.	Systolic represents the maximum pressure exerted on the arteries with The higher number is the systolic pressure.
<b>Ventricles of the heart for Vessel:</b>	Fill with blood and Relaxed	Left ventricles contract and Contracted of B. Vessel.
<b>Etymology</b>	"Diastolic" comes from the Greek diastole meaning "a drawing apart."	"Systolic" comes from the Greek systole meaning "a drawing together or a contraction."

## 2.8 Electrocardiogram (ECG)

Electrocardiogram monitors are often used in many medical service centers and hospitals to diagnose and monitor a person's health status by measuring their cardiac activity. An ECG is a non-invasive monitor, to evaluate the heart electrical activity, measure the rate and regularity of heartbeats.

On an ECG, P, Q, R, S and T refer to the different spikes on the reading. P represents the depolarisation of the atria of the heart. Q, R and S represent the depolarisation of the ventricles. T represents the repolarisation of the ventricles.

Figure 2.7 shows that the condition when an ECG connection is attached to the patient with the ECG tracing paper to be analysed by the doctors. This is very

important so that the monitoring of the patient continuously to being measured to check the heart beats. This condition is commonly observed at the hospital.

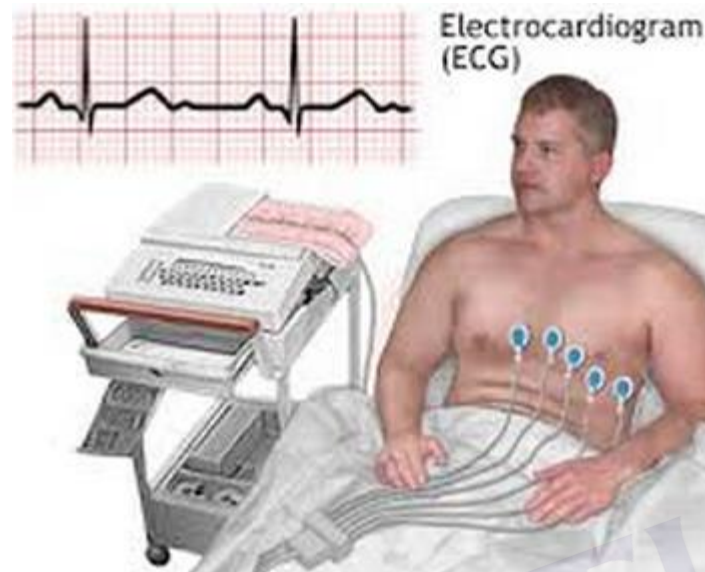


Figure 2.7: Connections with ECG Tracing Paper

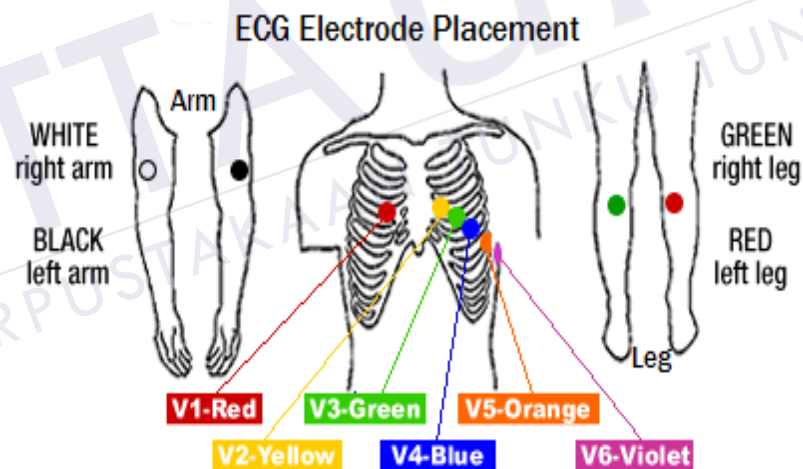


Figure 2.8: ECG placement for 10 electrodes

The standard ECG uses 10 cables to obtain 12 electrical views of the heart as shown in Figure 2.8. These wires break down into 2 groups that is first group for 6 chest leads and second are for 4 limb or peripheral leads with one of it is neutral. A lead is a view of the electrical activity of the heart from a particular angle across the body. The 10 electrodes give 12 pictures that are captured by a group of electrodes.

## 2.9 Hardware

This project has a hardware component to detect the heart beat is measurement which include sensor, microcontroller and the wireless communications system

### 2.9.1 Electrode Condenser Placement

Condenser is a capacitor to convert acoustical energy into electrical energy. It is an electronic component which stores energy in the form of an electrostatic field. They also generally have a louder output, but are much more sensitive to loud sounds, low decibel of sound and vibration (Shin et al. n.d.).

Condenser microphones require power from a battery or external source. This device works at a 1.5V operating supply and has a load resistance of 1 kohm.



Figure 2.9: Omnidirectional Condenser Microphone Sensor (a) C9767 (b) U8052

Figure 2.9 is an omnidirectional electret condenser microphone that is mountable on to a PCB or breadboard. Features of the Condenser Microphone Sensor with small size around 6.0 x 2.2 mm, high sensitivity type around  $\pm 4\text{dB}$  until  $-35$ , impedance less than 2.2 k, maximum operation of voltage is 10 Volt and current consumption Max. 0.5 mA and lastly the sensitivity reduction within  $-3\text{ dB}$  at 1.5V (Anon n.d.). It is come with wavelength of sound at 10 kHz and the connection to the circuit include the term of output and grounding to get the result in voltage.



## 2.9.2 Arduino

Arduino is an open-source electronics prototyping platform based on flexible, simple microcontroller board. The development hardware is easy to use with software writing in the board. For this project by taking an inputs signal from the sensors, it also can control a LED, speaker and wireless communication Zigbee.

Referring to Figure 2.10, this project used Arduino Nano and Arduino Mega as a microcontroller to receive data and then transfer it through Zigbee Pro Series 1 for wireless communications. Arduino Nano is a small, complete, and breadboard-friendly board based on the ATmega328 have 14 digital pins with operate supply power at 5 volts. While for Arduino Mega also a microcontroller board based on the ATmega1280 has 54 digital input and output pins with same operate supply as Arduino Nano. Others for wireless connections is 8 pin used to receive (RX) and transmit (TX) at serial data for Arduino Mega while 2 pins TX and RX for Arduino Nano.

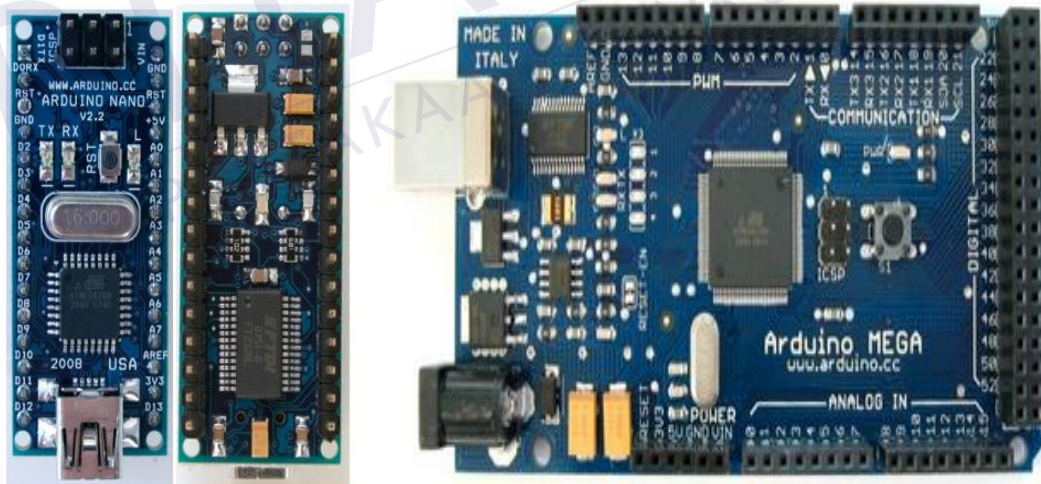


Figure 2.10: Schematic Diagram of Arduino Nano and Arduino Mega

### 2.9.3 Antenna Wireless Arduino ZigBee

Figure 2.11 is a ZigBee/XBee Pro Series 1 used to transfer the data between transmitter and receiver. It is based on an IEEE 802 standard that is IEEE 802.15.4 in networking protocol for fast point-to-multipoint or peer-to-peer networking. It is used in applications that require a low data rate, long battery life, and secure networking. That has a defined rate of 250 kilobits per second, transfer data or a sent the single signal transmission from a sensor or input device.



Figure 2.11: Wire Antenna Xbee Pro 60 mW Series 1(802.15.4)

The wireless communications using ZigBee can be performed by setting up their addressed using X-CTU programming. There are 4 importance pin that is used and according to the Table 2.9, the connections pin between Arduino and connections of the circuit can be referred.

Table 2.9: Pins for Wireless Communication at Antenna ZigBee

ZigBee or XBee	Arduino Pin	
VCC or 3.3V	3.3 Volt	
TX or D Out	RX or 0	
RX or D In	TX or 1	
Ground or GND	GND	

In the setting of wireless communications Figure 2.12 shows the two Antenna of Zigbee, pin NO.1 is for power supply from Arduino Nano 3.3 volt, pin NO.2 is for Transmit (TX) while pin NO.3 is for Receive (RX) and pin NO. 10 is Grounding (GND). After doing this setup, the suitable programming is needed to make 2 XBee communicate between each other as a transmit data input and receiver data output. Then the connections for Antenna on ZigBee Pro Series 1 are change into pin NO.3 for transmitter (TX) and pin NO.2 for receiver (RX). Two personal computer (PC) is needed to make the communications successful according to the address of the wireless that is based on the baud rate 9600.

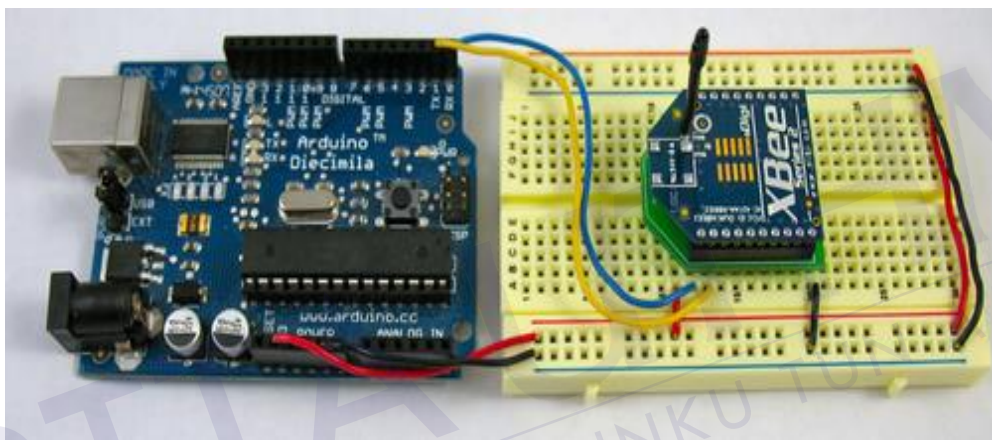


Figure 2. 12: Connection pins between Arduino Duemilanove and Antenna ZigBee

## 2.10 Software Method

Software that is needed to control this wireless stethoscope system can be monitored and analyzed the heartbeats by the doctors or physician. The system that is used for this method is capturing the input signal in voltage that is from condenser microphone sensor and then being read by the software programming system to convert from analog signal into digital signal for final result in the development of wireless stethoscope.



### 2.10.1 Arduino C++ Programming

The Arduino integrated development environment (IDE) is a cross-platform application written in Java. It is capable of compiling and uploading programs to the board with a single click. A language reference in Arduino programs that can be divided in three main parts that is structure, values for variables with constants, and functions. It runs machine code compiled from either C, C++, Java4 or any other language that has a compiler for the Arduino instruction set (Amir Hoshang Kioumars 2011).

### 2.10.2 Wireless Setup using X-CTU Program

X-CTU is a stand-alone tool for configuring ZigBee modules. By download the installation through internet, it will easily install in the personal computer. Then configure the Radio Frequency Modules that is launching the X-CTU software under PC setting by verify the Baud Rate in 9600. The baud rate of a data communications system is the number of symbols per second is transferred. They are simple devices that can use to set up serial communications between the applications. Once installed, it is ready for configuring the ZigBee it will construct a point-to-point network for two devices are going to communicate together. For this project two ZigBee is needed to transmission data and receiving data for wireless communications.

The Heart rate signal was send to the computer through serial communication. MATLAB software will show the result through GUI. Baud rate is set to 9600 to establish the communication between Matlab and serial communication. The 9600 baud means that the serial port is capable of transferring a maximum of 9600 bits per second of data.

$$1 \text{ sec} / 600 = 1.67\text{ms (Data in one Second)}$$

### 2.10.3 Matlab ASCII

MATLAB is a matrix laboratory that is numerical computing environment and fourth-generation programming language. Developed by MathWorks, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, and Fortran..

MATLAB has structure data types. MATLAB supports developing applications with graphical user interface features. MATLAB includes GUIDE (GUI development environment) for graphically designing GUIs. It also has tightly integrated graph-plotting features. It is a high-performance language for technical computing.

Table 2.10: ASCII character in Decimal Number

CHARACTER	BINARY	OCTAGON	DECIMAL	HEXAGON
0	00110000	060	48	30
1	00110001	061	49	31
2	00110010	062	50	32
3	00110011	063	51	33
4	00110100	064	52	34
5	00110101	065	53	35
6	00110110	066	54	36
7	00110111	067	55	37
8	00111000	070	56	38
9	00111001	071	57	39

ASCII stands for American Standard Code for Information Interchange. Computers can only understand numbers, so an ASCII code is the numerical representation of a character, text in computer, and communications equipment. Matlab is the user interface that only understands base on the Table 2.10 as shows is the ASCII code for 10 characters includes description numbers. It is an ASCII character for decimal number that will convert Arduino Data Input signal into ASCII code at MATLAB.

### 2.10.4 Graphical User Interface Design (GUI)

It is a graphical display in one or more windows containing controls, called components that enable a user to perform interactive tasks. It is created using MATLAB tools can also perform any type of computation, read and write data files, communicate with other GUIs, and display data as tables or as plots. . It includes specifying the inputs, outputs, displays, and behaviours of the GUI and the application it controls shows is Figure 2.13. For this project, the pressing a screen button to get the waveform of hearbeats and key in the importance details data of patient (Y. Tang et al. 2010).

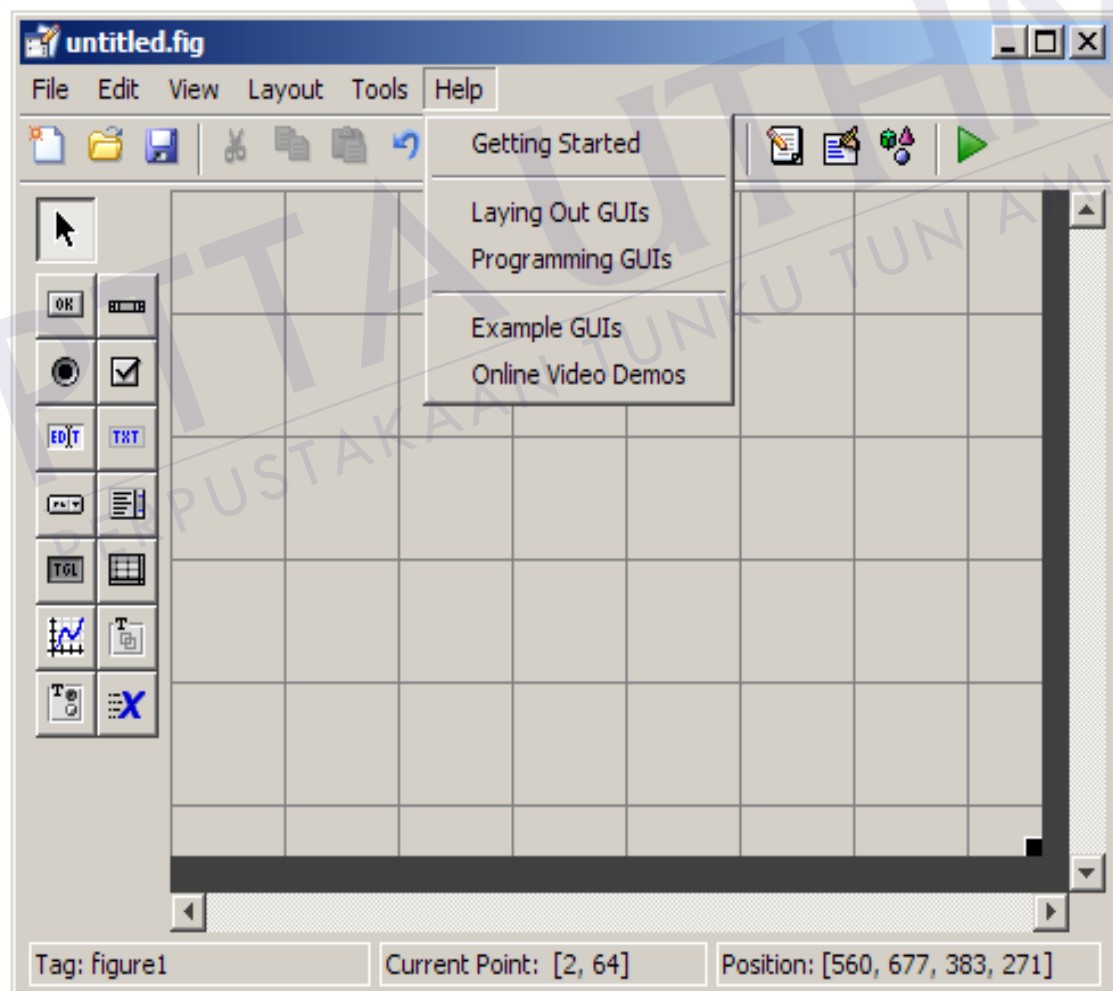


Figure 2.13: GUI Templates for Design System

## REFERENCES

- Al-Jumaily, a M., Lan, H. & Stergiopulos, N., 2013. Brachial artery waveforms for automatic blood pressure measurement. *Journal of biomechanics*, 46(3), pp.506–10. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/23149078> [Accessed April 2, 2013].
- Al-Kuwari, A.M.A.H. et al., 2011. User friendly smart home infrastructure: BeeHouse. In *Digital Ecosystems and Technologies Conference (DEST), 2011 Proceedings of the 5th IEEE International Conference on*. pp. 257–262.
- Amit, G., Gavriely, N. & Intrator, N., 2009. Cluster analysis and classification of heart sounds. *Biomedical Signal Processing and Control*, 4(1), pp.26–36. Available at: <http://linkinghub.elsevier.com/retrieve/pii/S1746809408000530> [Accessed March 2, 2013].
- Anon, Omnidirectional Back Electret WM-61A. , p.61.
- Azahar, N.S., 2012. Centralized Heart Rate Monitoring Telemetry System Using ZigBee Wireless Sensor Network. , 25(Bhi), pp.265–268.
- Bailón, R. et al., 2010. Analysis of heart rate variability during exercise stress testing using respiratory information. *Biomedical Signal Processing and Control*, 5(4), pp.299–310. Available at: <http://linkinghub.elsevier.com/retrieve/pii/S1746809410000418> [Accessed May 14, 2013].
- Bangalore, S., Sawhney, S. & Messerli, F.H., 2008. Relation of beta-blocker-induced heart rate lowering and cardioprotection in hypertension. *Journal of the American College of Cardiology*, 52(18), pp.1482–9. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/19017516> [Accessed April 18, 2013].
- Bauer, A. et al., 2008. Heart rate turbulence: standards of measurement, physiological interpretation, and clinical use: International Society for Holter

- and Noninvasive Electrophysiology Consensus. *Journal of the American College of Cardiology*, 52(17), pp.1353–65. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/18940523> [Accessed March 15, 2013].
- Boyd, S. & Vandenberghe, L., 2010. *Convex Optimization* C. U. Press, ed., Cambridge University Press. Available at: <http://www.informaworld.com/openurl?genre=article&doi=10.1080/10556781003625177&magic=crossref>.
- Chan, M. et al., 2012. Smart wearable systems: Current status and future challenges. *Artificial Intelligence in Medicine*, 56(3), pp.137–156. Available at: <http://www.sciencedirect.com/science/article/pii/S0933365712001182>.
- Christov, I. et al., 2006. Comparative study of morphological and time-frequency ECG descriptors for heartbeat classification. *Medical engineering & physics*, 28(9), pp.876–87. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/16476566> [Accessed May 3, 2013].
- Communicator, M.S., Bwig, T.W. & Bsic, M.A., 2011. Electronic Stethoscope.
- Dennis, A. et al., 2010. Noninvasive diagnosis of pulmonary hypertension using heart sound analysis. *Computers in biology and medicine*, 40(9), pp.758–64. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/20691967> [Accessed May 14, 2013].
- Fox, K. et al., 2007. Resting heart rate in cardiovascular disease. *Journal of the American College of Cardiology*, 50(9), pp.823–30. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/17719466> [Accessed March 15, 2013].
- Fu, B.B. et al., 2013. Research and application of heart sound alignment and descriptor. *Computers in biology and medicine*, 43(3), pp.211–8. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/23332189> [Accessed May 13, 2013].
- Geddes, L. a, 2005. Birth of the stethoscope. *IEEE engineering in medicine and biology magazine : the quarterly magazine of the Engineering in Medicine & Biology Society*, 24(1), pp.84–6. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/15709541>.
- Hung, K. et al., 2004. Multifunction stethoscope for telemedicine. In *Computer Architectures for Machine Perception, 2003 IEEE International Workshop on*. pp. 87–89.

- Jatupaiboon, N., Pan-ngum, S. & Israsena, P., 2010. Electronic stethoscope prototype with adaptive noise cancellation. In *Knowledge Engineering, 2010 8th International Conference on ICT and*. pp. 32–36.
- Jiang, Z. & Choi, S., 2006. A cardiac sound characteristic waveform method for in-home heart disorder monitoring with electric stethoscope. *Expert Systems with Applications*, 31(2), pp.286–298. Available at:  
<http://www.sciencedirect.com/science/article/pii/S0957417405002150>.
- Jokic et al., 2010. An efficient ECG modeling for heartbeat classification. In *Neural Network Applications in Electrical Engineering (NEUREL), 2010 10th Symposium on*. pp. 73–76.
- Kanda, K. et al., 2011. Field Monitoring System Using Agri-Server. , pp.2069–2072.
- Khan, S.I., Jawarkar, N.P. & Ahmed, V., 2012. Cell Phone Based Remote Early Detection of Respiratory Disorders for Rural Children Using Modified Stethoscope. *2012 International Conference on Communication Systems and Network Technologies*, pp.936–940. Available at:  
<http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6200773>  
[Accessed May 14, 2013].
- Kidane, N. et al., 2011. Using EKG signals for virtual pathology stethoscope tracking in standardized patient heart auscultation. *2011 IEEE 37th Annual Northeast Bioengineering Conference (NEBEC)*, pp.1–2. Available at:  
<http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=5778609>.
- Kioumars, A H & Tang, L., 2011. ATmega and XBee-based wireless sensing. *Automation, Robotics and Applications (ICARA), 2011 5th International Conference on*, pp.351–356.
- Kioumars, Amir Hoshang, 2011. Wireless Network for Health Monitoring : Heart Rate and Temperature Sensor. , pp.362–369.
- Kyu Jin, C. & Asada, H.H., 2002. Wireless, battery-less stethoscope for wearable health monitoring. In *Bioengineering Conference, 2002. Proceedings of the IEEE 28th Annual Northeast*. pp. 187–188.
- M. A. Zaltum, M. S. Ahmad, A. Joret, and M. M. Abdul, Design and Development of a Portable Pulse Oximetry System, *International Journal of Integrated Engineering*, vol. 2, no3, pp. 37-44, 2010



- Maglaveras, N. et al., 1998. ECG pattern recognition and classification using non-linear transformations and neural networks: A review. *International Journal of Medical Informatics*, 52(1–3), pp.191–208. Available at: <http://www.sciencedirect.com/science/article/pii/S1386505698001385>.
- Mcmecc, C. et al., 2011. Tele-Auscultation System. , pp.478–481.
- Modules, X.X.R.F., 2009. XBee ® /XBee-PRO ® RF Modules.
- Myint, W.W. & Dillard, B., 2001. An electronic stethoscope with diagnosis capability. In *System Theory, 2001. Proceedings of the 33rd Southeastern Symposium on*. pp. 133–137.
- Nakajima, K., Tamura, T. & Miike, H., 1996. Monitoring of heart and respiratory rates by photoplethysmography using a digital filtering technique. *Medical engineering & physics*, 18(5), pp.365–72. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/8818134>.
- Poulter, N.R. et al., 2009. Baseline heart rate, antihypertensive treatment, and prevention of cardiovascular outcomes in ASCOT (Anglo-Scandinavian Cardiac Outcomes Trial). *Journal of the American College of Cardiology*, 54(13), pp.1154–61. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/19761936> [Accessed May 14, 2013].
- Ramon, D., Stethoscope History. , [http://www\(Doctor Secrets! Medical Information. Clear. Quick. Fun.\)](http://www.DoctorSecrets.com/MedicalInformation/ClearQuickFun/).
- Rashid, R.A. et al., 2005. Real time medical data acquisition over wireless ad-hoc network. In *Applied Electromagnetics, 2005. APACE 2005. Asia-Pacific Conference on*. p. 5 pp.
- Reed, T.R., Reed, N.E. & Fritzson, P., 2004. Heart sound analysis for symptom detection and computer-aided diagnosis. *Simulation Modelling Practice and Theory*, 12(2), pp.129–146. Available at: <http://linkinghub.elsevier.com/retrieve/pii/S1569190X04000206> [Accessed March 14, 2013].
- Sankari, Z. & Adeli, H., 2011. HeartSaver: A mobile cardiac monitoring system for auto-detection of atrial fibrillation, myocardial infarction, and atrio-ventricular block. *Computers in Biology and Medicine*, 41(4), pp.211–220. Available at: <http://www.sciencedirect.com/science/article/pii/S0010482511000205>.
- Sciences, R. et al., 1998. ACOUSTIC PERFORMANCE OF THREE STETHOSCOPE CHEST PIECES . , 20(6), pp.98–101.

- Scope, F., About Stethoscope in History. , [http://www\(Washington Publishers, Tallahassee Florida, USA, and uses Sun Domains and Software\).](http://www(Washington Publishers, Tallahassee Florida, USA, and uses Sun Domains and Software).)
- Sepehri, A. a et al., 2010. A novel method for pediatric heart sound segmentation without using the ECG. *Computer methods and programs in biomedicine*, 99(1), pp.43–8. Available at: <http://www.ncbi.nlm.nih.gov/pubmed/20036439> [Accessed March 6, 2013].
- Shin, J. et al., Design Technology in Portable Digital Esophageal Stethoscope. , pp.94–97.
- Sufi, F. & Khalil, I., 2011. Faster person identification using compressed ECG in time critical wireless telecardiology applications. *Journal of Network and Computer Applications*, 34(1), pp.282–293. Available at: <http://www.sciencedirect.com/science/article/pii/S1084804510001268>.
- Tang, Y. et al., 2010. The Design of Electronic Heart Sound Stethoscope Based on Bluetooth. *2010 4th International Conference on Bioinformatics and Biomedical Engineering*, pp.1–4. Available at: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=5516342>.
- Tay, Francis E H et al., 2009. MEMSWear-biomonitoring system for remote vital signs monitoring. *Journal of the Franklin Institute*, 346(6), pp.531–542. Available at: <http://www.sciencedirect.com/science/article/pii/S0016003209000167>.
- Tay, Francis E.H. et al., 2009. MEMSWear-biomonitoring system for remote vital signs monitoring. *Journal of the Franklin Institute*, 346(6), pp.531–542. Available at: <http://linkinghub.elsevier.com/retrieve/pii/S0016003209000167> [Accessed March 28, 2013].
- U., B.H., 1988. Development of a Wireless Stethoscope for Auscultatory Monitoring During Anaesthesia . *B. Hok U.Uppsala Sweden*.
- Übeyli, E.D., 2007. ECG beats classification using multiclass support vector machines with error correcting output codes. *Digital Signal Processing*, 17(3), pp.675–684. Available at: <http://www.sciencedirect.com/science/article/pii/S1051200406001941>.
- Usanov, D.A. et al., Radiowave monitoring of human respiratory movements and
- Wang, C., Li, Z. & Wei, X., 2013. Monitoring heart and respiratory rates at radial artery based on PPG. *Optik - International Journal for Light and Electron Optics*, pp.2012–2014. Available at:



<http://linkinghub.elsevier.com/retrieve/pii/S0030402613000120> [Accessed May 14, 2013].

Yan, Z. et al., 2010a. The moment segmentation analysis of heart sound pattern.

*Computer Methods and Programs in Biomedicine*, 98(2), pp.140–150.

Available at:

<http://www.sciencedirect.com/science/article/pii/S016926070900279X>.

Yan, Z. et al., 2010b. The moment segmentation analysis of heart sound pattern.

*Computer methods and programs in biomedicine*, 98(2), pp.140–50. Available

at: <http://www.ncbi.nlm.nih.gov/pubmed/19854530> [Accessed March 6, 2013].

Yeh, J.-R. et al., 2010. Investigating fractal property and respiratory modulation of

human heartbeat time series using empirical mode decomposition. *Medical engineering & physics*, 32(5), pp.490–6. Available at:

<http://www.ncbi.nlm.nih.gov/pubmed/20338798> [Accessed March 15, 2013].

Yi, L., 2008. Portable Bluetooth Visual Electrical Stethoscope research. In

*Communication Technology, 2008. ICCT 2008. 11th IEEE International Conference on*. pp. 634–636.

Zulkifli, N.S.A., Harun, F.K.C. & Azahar, N.S., XBee Wireless Sensor Networks for Heart Rate Monitoring in Sport Training. , (in C).

