THE ECG SIMULATOR BY USING ARDUINO

BY

AREERAT MANEERAT

PATTHARASUDA SRIPAKDEE

A PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF ENGINEERING IN BIOMEDICAL ENGINEERING

KING MONGKUT'S INSTITUTE OF TECHNOLOGY LADKRABANG

ACADEMIC YEAR 2020

SCHOOL OF ENGINEERING

KING MONGKUT'S INSTITUTE OF TECHNOLOGY LADKRABANG
PROJECT CERTIFICATE

Project Title	The ECG simulator 3 leads by using Arduino	
Student Name	Miss Areerat Maneerat	Student ID. 60011210
	Miss Pattharasuda Sripakdee	Student ID. 60011250
Degree	Bachelor of Engineering in Biomedical Engineering	

Project Advisor. Signed: ______________________________
(Asst. Prof. Dr. Sarinporn Visitsattapongse)

Committee Signed: ______________________________
(Assoc. Prof. Dr. Chuchart Pintavirooj)

Committee Signed: ______________________________
(Assoc. Prof. Dr. Supan Tungjitkusolmun)

Committee Signed: ______________________________
(Asst. Prof. Dr. Treesukon Treebupachatsakul)

Head of Department Signed: ______________________________
(Asst. Prof. Dr. Sarinporn Visitsattapongse)

Project Title	The ECG simulator 3 leads by using Arduino
Student Name	Miss Areerat Maneerat
	Miss Pattharasuda Sripakdee
Degree	Bachelor of Engineering in Biomedical Engineering
Project Advisor	Assist. Prof. Dr. Sarinporn Visitsattapongse
Academic Years	2020

ABSTRACT

Electrocardiogram or ECG is the one signal in the biomedical term that is a significant role in heart diagnosis. An electrocardiogram records the electrical signal from the heart. It is a quick and non-invasive way to detect signals from the heart. So, the result of the electrocardiogram record will monitor the graph of the heart that has a problem and check the health of a patient and treat a patient in the right diagnosis. Commercial ECG simulators are quite expensive, and some companies do not need to buy a fully functional ECG simulator on the market. It has to be calibrated because some medical devices have ECG graph function as an optional function, such as an ultrasound machine. When buying a commercially available ECG simulator, it is a huge waste of budget. In this project, we want to create the ECG simulator by using Arduino. The user can use it more easily and got the effective ECG signal result as a commercial ECG simulator by using low cost. As a result of the project, we can build an ECG simulator using an Arduino Mega 2560 as a microcontroller. In addition, the ECG simulator can adjust the heart rate of the ECG graph, it can be in the range of 30 - 300 beats per minute. The amplitude can be adjusted at three levels: x1, x2, and x4. Moreover, the measurement error value is not exceeded by the Department of Medical Sciences.

ACKNOWLEDGEMENTS

This project was accomplished with kindness from Assist. Prof. Dr. Sarinporn Visitsattapongse, our appreciated project advisor for her help and support throughout the project. Furthermore, we are grateful for the advice from Assoc. Prof. Dr. Chuchart Pintavirooj for giving us more understanding about the knowledge in this project. In addition, we would like to appreciate CMC biotech company for supporting the funding of our project. Finally, we would like to give thanks to every other people who are not named here for all their helps and supports throughout the period of this project.

Lastly, we would like to thank the School of Engineering at KMITL, especially Biomedical Engineering Department for supporting the area in laboratory and equipment to study and do research until this project is complete.

Areerat Maneerat
Pattharasuda Sripakdee

TABLE OF CONTENT

LIST OF TABLES

Tables page

LIST OF FIGURES

Figures page

LIST OF SYMBOLS/ABBREVIATIONS

Symbols/Abbreviations	Terms
3D	Three-dimensional
ADC	Analog to Digital Converter
ANS	Automatic nervous system
API	Application Programming Interface
AV Node	Atrioventricular Node
aVF	Augmented Vector Foot
aVL	Augmented Vector Left
aVR	Augmented Vector Right
BPM	Beat per Minutes (Heart rate unit)
CAD	Computer-Aided design
CAE	Computer-Aided Engineering
CAM	Computer-Aided Manufacturing
DAC	Digital to Analog Converter
DC	Direct Current
DXF	Drawing Exchange Format
ECG	Electrocardiogram
EEPROM	Electrically Erasable Programmable Read-Only Memory
GND	Ground
GNU	General Public License
GPS	Global Positioning System
HMI	Human Machine Interface
I/O	Input/Output
I^2C	Inter-Integrated Circuit
ICSP	In-Circuit Serial Programming
LA	Left Arm
LCD	Liquid Crystal Display

LED	Light Emitting Diode
LL	Left Leg
MATLAB	MATrix LABoratory
MCU	Microcontroller Unit
MISO	Master input slave output
MOSI	Master output slave input
PWM	Pulse Width Modulation
RA	Right Arm
RAM	Random Access Memory
RX	Receive
SA Node	Sinoatrial Node
SCK	Serial Clock
SCL	Serial Clock
SDA	Serial Data
SDIO	Secure Digital Input Output
SPI	Serial Peripheral Interface
SRAM	Static Random-Access Memory
TFT	Thin Film Transistor
TTL	Transistor-Transistor Logic
TX	Transmit
TXT	Text File (filename extension)
USART	Universal Synchronous Asynchronous Receiver Transmitter
USB	Universal Serial Bus
XLS	Filename Extension (Microsoft Excel spreadsheet file)
XML	eXtensible Markup Language

CHAPTER 1

INTRODUCTION

This chapter provides background and significant of the study, objective of the study, scope of study, period of research and company to practice experience and research.

1.1 Background and significant of the study

Electrocardiogram or ECG is a medical device that uses to record the rhythm of the heart, particularly abnormal rhythm of the heart can occur from damaged conductive tissue that carries the electrical signal or electrolyte imbalance that can cause abnormal rhythm of the heart [1]. An electrocardiograph is a medical diagnostic tool to measure the electrical signal in the heart and record the activity of the heart in deep detail. The interpretation of these detail allows diagnosis of a wide range of heart situations. These situations can vary from monitor to life-threatening [2].

In medical use, they use the ECG signal to obtain information about the electrical function of the heart. This information is numerous and desires to be blended with understanding of the characteristic of the of the heart and physical examination signs to be interpreted. The example of medical diagnosis by using ECG signal, there are chest pain or myocardial infarction (heart attack), a symptom of the heart (murmurs, arrhythmias), electrolyte abnormalities, etc. [4]. In nowadays, there are many companies manufacture the electrocardiogram simulator instrument (ECG simulator) to meet the need of medical terms by the function of commercial ECG simulator will use for an ECG function testing of the medical device. The main function of the ECG simulator, it uses to calibrate ECG function on the medical device to the standard value by following the value of standard of ECG waveform. The modern ECG simulator instrument, its manufacturer with an automatic ECG waveform recognition, measurement, and necessary to be standard testing of ECG function of a medical device. A modern ECG, simulator instrument is carefully about the ECG signal value because it uses to select the set of ECG signal testing to most accurate and correctly on the medical standard to prevent misdiagnosis [1]. Moreover, the accuracy to recognize ECG waveforms on the standard of commercial ECG simulators, the capability to measure ECG in many leads and the other functions in the commercial ECG simulator instrument make the simulator instrument have an expensive cost. The expensive cost of commercial ECG simulator instruments is a limitation of many hospitals that are limited in the management of medical devices and some hospitals unable to buy the standard ECG simulator to calibrate the ECG function of the medical devices on the standard value.

From the above information, it though about the importance of ECG signal that uses to diagnose many symptoms about the heart by looking from the electrical signal value of heart and in medical term, electrocardiograph is a medical diagnosis tool that necessary to measure ECG signal to diagnosis a patient and it has to test the ECG signal value in very carefully to get an accurate ECG waveform as same as a real human. Therefore, an electrocardiograph simulator is a necessary device to generate an electrical signal that can mimic the human heart electrical signals and it uses be a device that uses to calibrate ECG signals on the medical device on the standard. Moreover, the commercial ECG simulators are quite expensive, and a few groups do now no longer have the want to buy a completely useful ECG simulator at the market. In order to have to calibrate the machine because some medical devices have ECG graph function as an optional function, such as an ultrasound machine. When buying a commercially to be had ECG simulator, it's miles a massive waste of budget. For this project, want to create the ECG simulator by the user can use it more easily and got the effective ECG signal result as a commercial ECG simulator by using low cost.

1.2 Objective of the study

1 To create ECG simulator by using Arduino.

2 To create ECG simulator at an affordable price, easy to use and accurate.

1.3 Scope of study

1 Using micro-SD card module to import ECG signal data.

2 Using DAC module to export ECG signal data.

3 Testing the ECG signal by showing ECG graph in oscilloscope and patient monitor.

1.4 Period of research

The research runs from January 2021 to April 2021 for a period of approximately 17 weeks, with a time of 5 days per week.

Table 1 Period of research

Topic	January (week)				February (week)				March (week)					April (week)			
	1	2	3	4	1	2	3	4	1	2	3	4	5	1	2	3	4
1. Defining the Topic and study the working principle of ECG simulator																	
2. Planning the procedures																	
3. Defining the experimental steps and the equipment required.																	
4. Buy the equipment and check the equipment.																	
5. Assemble the equipment and write the code for create ECG simulator.																	
6. Test the result of ECG signal on oscilloscope and patient monitor.																	
7.Improved and stabilize the output																	
8. Design the cover box and assemble																	

1.5 A company to practice experience and research

- CMC BIOTECH CO., LTD.

Address 364 Soi Ladphrao 94 (Panjamitr) Ladphrao Road, Phlabphla, Wang Thong Lang, Bangkok 10310, Thailand

CHAPTER 2

Literature Review, Material Review, and Related Software

2.1 Literature Review

2.1.1 Heart

The heart is an important muscular organ in the human body, consist of cardiac muscles and connective tissue. The main function of the heart is to serve as pumping blood supplied by the circulatory system in the body. The heart is a central part of the circulatory system, which supplied oxygen and the other important nutrient that the body needed to sustain life. In the human, the heart is located between the two lungs and it slightly to the left of the center. It rests on the side of the diaphragm between the chest and abdominal cavity shown in Figure1.[16]

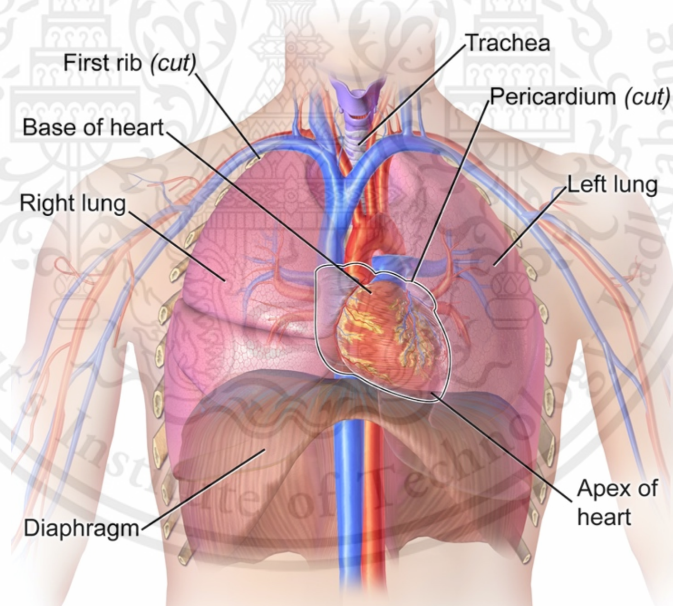


Figure 1 Location of heart in the thoracic cavity [18]

In humans, the heart has a double pump feature that is used to transport blood away from the heart and transport blood back to the heart. The blood circulatory system in the heart will pump the deoxygenated blood away from the heart to the lungs and then exchange the oxygen and carbon dioxide in the blood at lungs then the blood after pass the gas exchange process, it become to oxygenated blood. The oxygenated blood is transported back to the heart, the heart will pump oxygenated blood to supply oxygen to the body by through the blood circulatory system and this process of system is serves to send the oxygen to nourishes the organs of the body and body's tissue. The heart is consisting of three layers of muscle, there are myocardium, pericardium, and endocardium. The myocardium is a thick layer of cardiac muscle; this is a muscle that contracts to pump blood through the body's tissue. The pericardium is a thin layer that covered the heart. The last layer of heart is an endocardium layer. This layer is an inner layer of heart, the characteristics of the endocardium are thin and smooth muscle.[17]

2.1.1.1 Heart layers

Heart walls compose of many types of tissues, there are connective tissue, endocardium, and cardiac muscle. The heart walls are related with the cardiac muscle to enable heart contraction and allow the synchronization of heart to occur a heartbeat. The heart layers are divided into three layers consist of epicardium, myocardium, and endocardium shown in Figure2.[27]

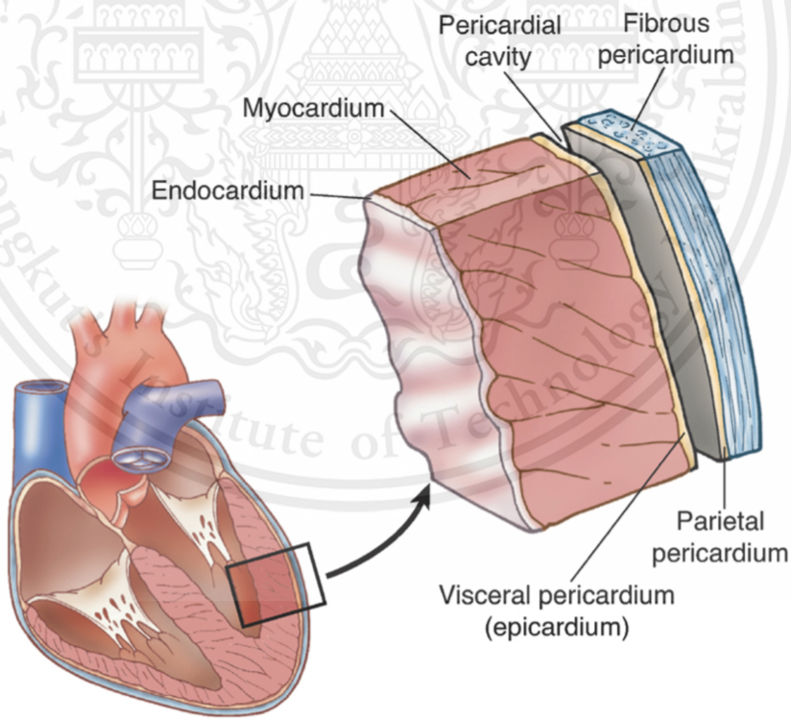


Figure 2 The layers of heart wall [26]

1 Epicardium: The outer layer of the heart and it knows as a visceral pericardium layer. This layer composes of the connective tissues, include the elastic fiber and adipose tissue. The epicardium layer serves as a protection layer that use to protect the inner layer of heart and this layer is produced the pericardial fluid to fill the pericardial cavity by this fluid will reduce the friction of heart. And in the epicardium layer can found the coronary blood vessels that use to supply blood to nourish the heart.

2 Myocardium: The middle layer of the heart. This layer is consisting of a cardiac muscle and the cardiac muscle relate to heart contraction. The myocardium layer is the thickest layer of the heart wall, and the thickness of the heart wall are depending on the use of heart muscle. For Example, the myocardium layer of the left ventricle is thickest layer because this ventricle uses to pump the oxygenated blood to supply the body. And the contraction of cardiac muscle is controlled by the automatic nervous system (ANS) that we cannot order the heart arrest.

3 Endocardium: The inner layer of the heart. This layer is composed of soft tissue and elastic fiber. And it is a layer that assists in forming the heart's valves. The main soft tissue in the endocardium layer is epithelial tissue, this tissue used to overline the thin layer of connective tissue. The main function of the endocardium layer is to provide the protection to heart's valve and heart's chamber.

2.1.1.2 Heart's chamber and circulation through heart.

The heart is divided into four chambers and the heart cavity is divided into the right heart and left heart, which right and left heart are subdivided into two chambers. The subdivide chamber of the right and left heart can divide into upper and lower sections of the heart's chambers. The upper chambers are called an atrium and the lower chambers are called the ventricle. The heart chambers are related to the cardiovascular system, the left heart's chamber relates with receive and transports the deoxygenated blood to the lungs and the right heart's chamber relates to receive and transport the oxygenated blood to supply the body. The receive and transport depend on the role of each heart's chamber. The relationship between the heart's chamber and the direction of blood circulation through the heart's chamber is shown in Figure3.[19] According to the character and role of each heart chamber in human is describes as the following: [19,21]

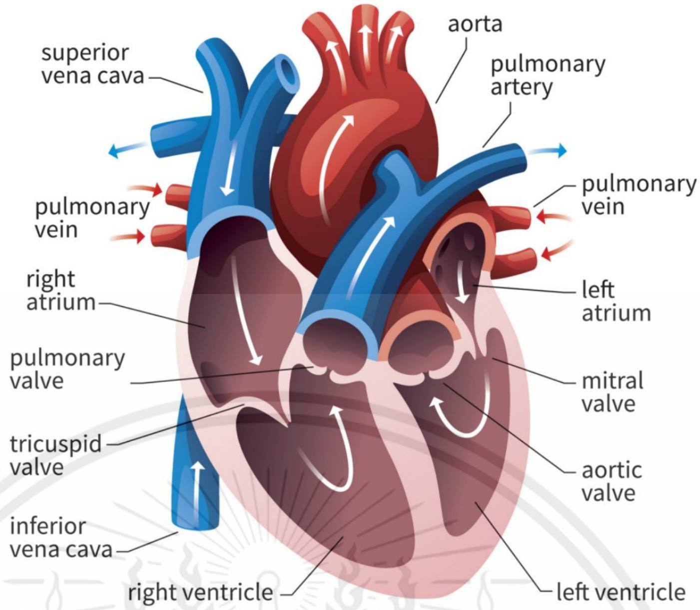


Figure 3 Heart's chamber and circulation direction [20]

1 Right Atrium: The right atrium serves as receiving the blood from the superior vena cava, inferior vena cava, and coronary vein. The blood that transport to the right atrium is a deoxygenated blood. The superior vena cava will bring blood from the upper part of the body starting from diaphragm, there are head, neck, upper limbs, and thoracic region. The inferior vena cava will bring the deoxygenated blood from the lower and middle part of the body, there are the lower limbs and abdominopelvic region. And the coronary vein will transport the deoxygenated blood to the right atrium. This chamber will pump the deoxygenated blood to the right ventricle by blood will flow through the tricuspid valve. The tricuspid valve serves as a guard to prevent blood flow back from right ventricle to right atrium. The right atrium and left atrium are separated by the solid muscular called the interatrial septum.

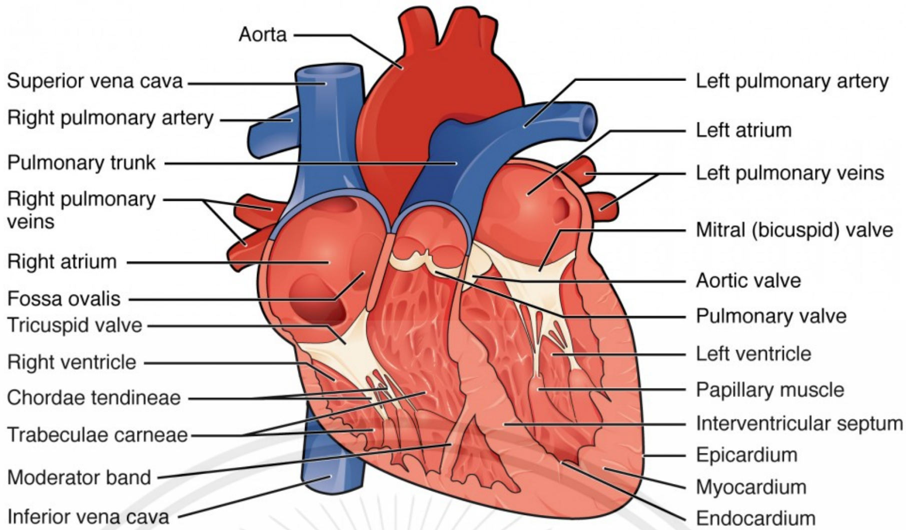


Figure 4 The anatomy of heart in anterior view [19]

2 2 Left Atrium: The left atrium is a chamber that serves as receiving the oxygenated blood from the pulmonary veins and pump blood through the left ventricle. Pumping blood from the left atria to the left ventricle has a mitral valve. The Mitral valve serves as a guard valve to prevent blood flow back from the left ventricle to the left atrium. This chamber will receive the blood after passes the gas exchanging process at the pulmonary capillaries in the lungs. After gases exchange in blood, the blood becomes to be high oxygenated blood and it is transported back to the left atrium through the pulmonary vein.

3 Right Ventricle: The right ventricle will receive the deoxygenated blood from the right atrium through the pulmonary artery. The deoxygenated from right ventricle will flow out from heart to exchanging gas at lung and the deoxygenated blood directly flow to lung through the pulmonary trunk and pulmonary artery. In the pulmonary trunk has a pulmonary valve. The pulmonary valve serves as a guard to allow blood leave to the heart though the pulmonary artery in one way and prevent blood flow back to the heart. the ventricle is divided in right and left ventricle by the interventricular septum. The interventricular septum is a solid muscular and the characteristic of interventricular septum is thicker than the interatrial septum since the ventricle chamber generates high pressure when the heart is contracted. Right ventricle attached to the strong stand of the connective

tissue called the chordae tendineae and this strand is connected to tricuspid valve. And the function of chordae tendineae is forced the heart valve open and close by work with the papillary muscle.

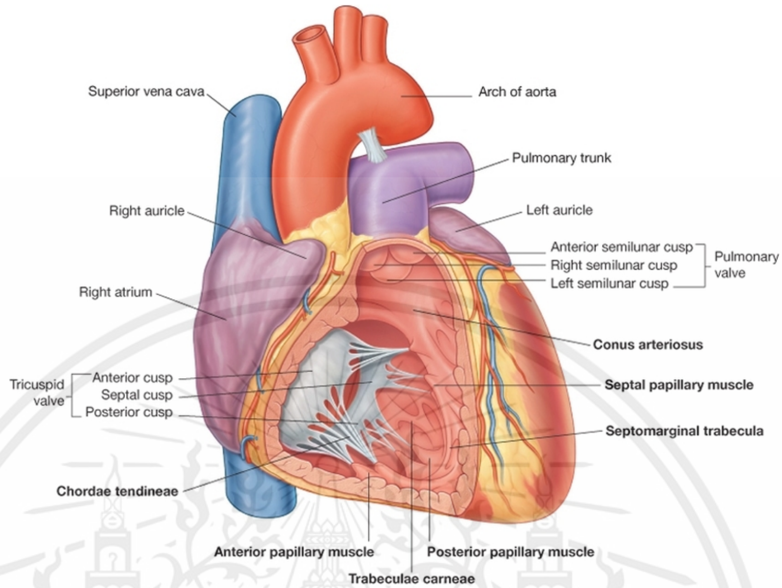


Figure 5 The papillary muscle and chordae tendineae attached to a tricuspid valve [23]

4 Left Ventricle: In left ventricle serves as receiving the oxygenated blood from the left atrium and pump oxygenated blood out of the heart to bringing the oxygenated and nutrient supply to the organs and tissues in the body. When blood flow from the left atrium to the left ventricle will pass the mitral valve and the mitral valve is a guard valve to allow blood flow in one direction and prevent blood flow back. This chamber is the thickest chamber of the heart and has high pressure in this chamber because it's the responsibility to pumping the oxygenated blood through the aorta and to nourish the tissue and organs all over the body through the aorta.

2.1.1.3 Heart's Valves

In the heart's human, there are four main heart valves for each heart chamber. The main function of the heart's valve is to keep blood moving in one direction or allow blood flow in one direction to prevent blood flow back. A heart's valve can open or close are depending on the cardiac cycle and the blood pressure on the heart's chamber. The characteristic of the heart's valve is elastic tissue to provide the flexibility of the heart valve for open and closed properly. The four heart valves in the human are as follows:

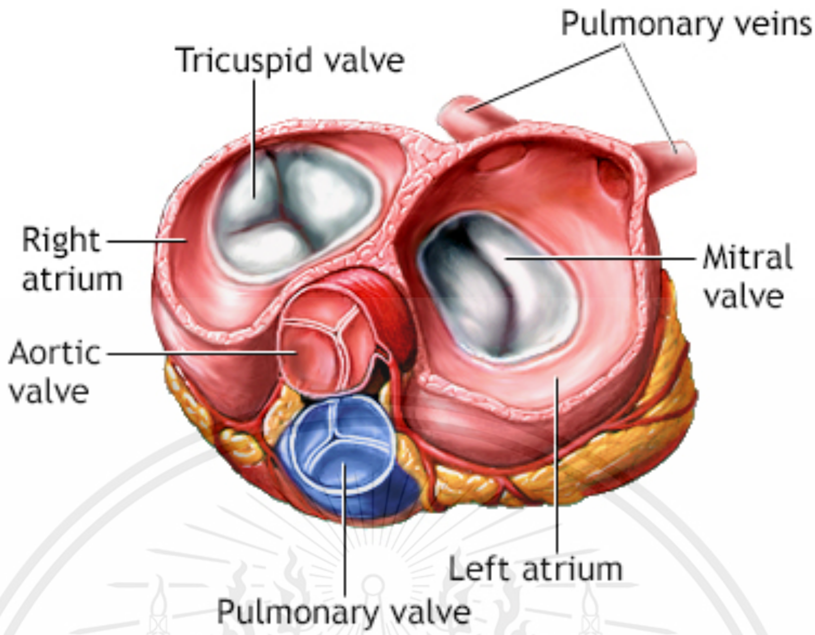


Figure 6 Human heart valves [25]

1 Mitral Valve

This valve knows as a bicuspid valve, and it is located between the left atrium and left ventricle. When the mitral valve opened, mitral valve will allow the blood flow one direction from the left atrium to the left ventricle. And when the mitral valve is closed, this valve will allow the oxygenated blood to fill blood to the left atrium. The function of mitral valve is control blood flow in one direction and prevent blood flow back from left ventricle to left atrium.

2 Tricuspid Valve

This valve is located between the right atrium and right ventricle. When the tricuspid valve opened, a tricuspid valve will allow blood flow from the right atrium to the right ventricle. And after blood flow to the right ventricle, the tricuspid valve will close, it will allow the blood to fill the right atrium. The function of the tricuspid valve is to prevent blood backflow from the right atrium to the right ventricle.

3 Aortic Valve

This valve is located between the left ventricle and aorta. The aortic valve serves as a valve to allow the oxygenated blood to flow out from the heart and prevent oxygenated blood backflow to the left ventricle.

4 Pulmonary Valve

This valve is located between the right ventricle and pulmonary artery. When this valve opened, it will allow the deoxygenated blood flow from the right ventricle out of heart by through the pulmonary artery to bring the deoxygenated blood come to gas exchange process at the lungs. When the pulmonary valve closes, this valve will prevent blood backflow from the pulmonary artery to right ventricle.

2.1.2 The Cardiac Cycle

The cardiac cycle in the human body is a performance of the heart and the cycle starting from the ending of the ECG waveform to the beginning of the new ECG waveform. The cardiac cycle is the pattern of the heart contraction and heart relaxation to complete one ECG waveform or one heartbeat. This cycle consists of two periods: the relaxation of cardiac muscle after contraction and refills blood knows as diastole, the contraction of the heart muscle, and pumping blood know as systole. This was related to heart sound of human that called “lub” and “dub” sounds. This the cardiac cycle related to the changing blood pressure in the heart chamber by causing of contracting and relaxing of the cardiac muscle and it occurred the electrical signal in the heart called an electrocardiogram. The importance of the cardiac cycle is to ensure the efficiency of pumping blood to the body by checking from the heartbeat. The clinical will use the cardiac cycle to analyze medical basic information to check cardiac inpatient and plan patient treatment accuracy. [28,29,3

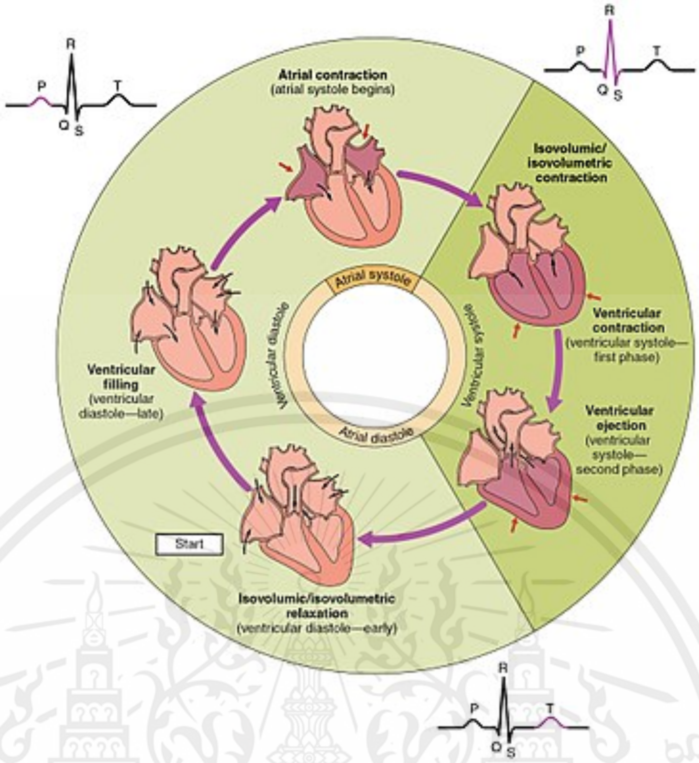


Figure 7 The cardiac cycle corresponding with ECG waveform [28]

The following diagram shows the period of the cardiac cycle when the heart chamber is contracting or relaxing during each cardiac cycle. Each period of the cardiac cycle will record the electrical activity of the heart while the heart muscle is depolarizing or repolarizing in each period. The phase of the cardiac cycle consists of five phases:

2.1.2.1 Atrial Systole

This phase is both atria contracted while both ventricles come to the last stage of relaxation. The atrial systole phase is following the P wave of ECG waveform by ECG recording is produced from wave depolarization that sweeps across the atrium chambers. The atrial muscle is contracted the right atria and left atria at the same time and then the pressure rises in the atrium and then atrium chamber will pump blood to the ventricle chamber.

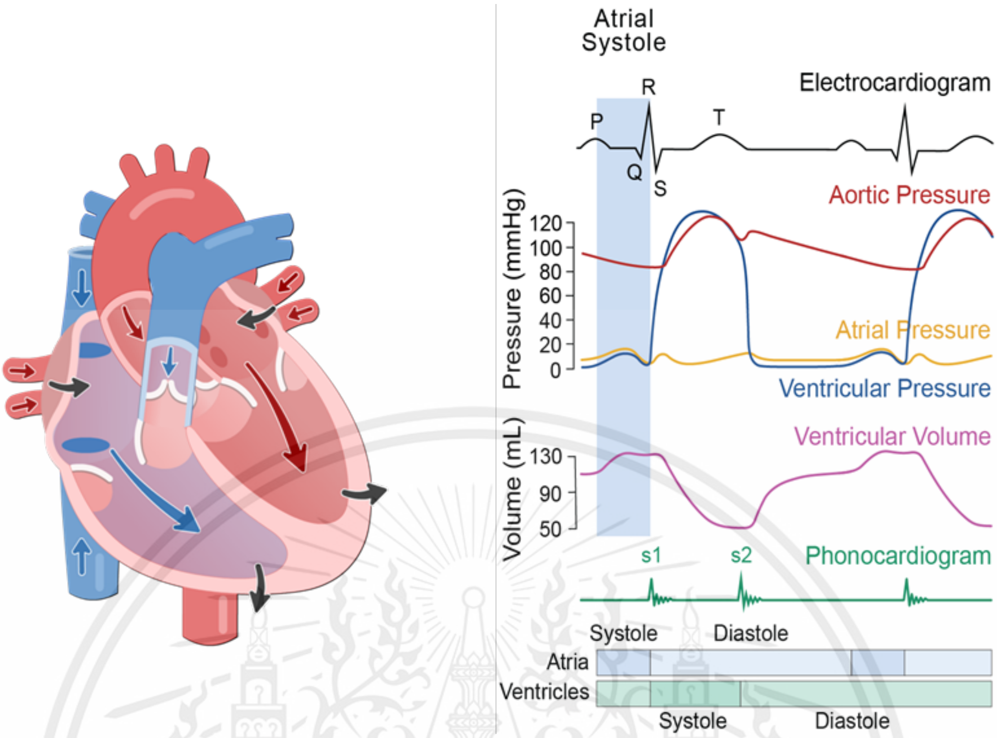


Figure 8 The cardiac cycle corresponding with ECG waveform [33]

2.1.2.2 Ventricular Isovolumetric Contraction

The ventricular isovolumetric contraction occurs when the atrium chamber begins relaxing, and the ventricle chamber begins to contract. This phase is initiate from a depolarization wave the sweeps across both ventricles and it is recording in QRS complex wave on ECG. The end of the atrial systole phase, initially as a ventricle contraction, and the pressure on blood in the ventricle chamber. The blood pressure in the ventricle chambers is a quick rise pressure, while the atria are relaxing. The pressure in the ventricle chamber is raised but the pressure in the ventricle chamber is not high enough pressure to open the pulmonary valve and aortic valve. While the atria are relaxing and blood in ventricle backflow toward the atria chamber and then tricuspid and mitral valves are closed the blood in the ventricle chamber is not ejected from the ventricles in the early stage and it makes the volume of blood in the ventricle chamber constant. So, this phase is an initial phase of an isovolumetric ventricular contraction.

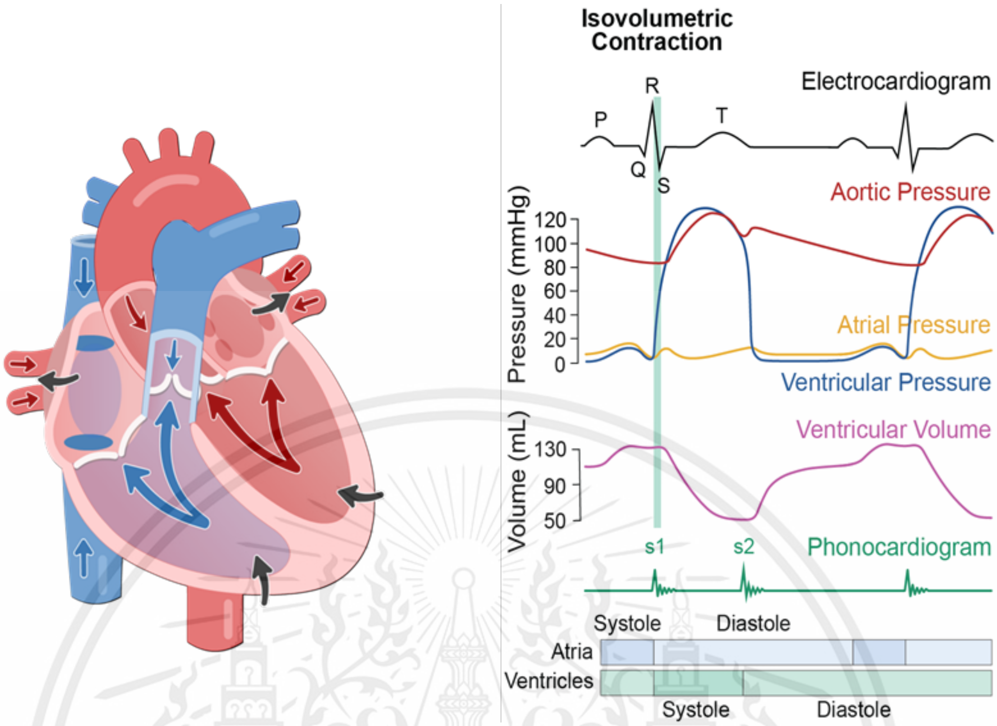


Figure 9 Ventricular isovolumetric contraction phase corresponding with electrocardiogram [33]

2.1.2.3 Ventricular Eject

This phase occurs when the ventricular chamber continues contraction, and the atria chamber remains in the diastole phase. For the electrocardiogram, while the ventricle continues to contract and filling the phase of the beginning near the end of the QRS complex wave and then occur T wave on an ECG. The ventricular contraction is caused by the pressure in the ventricle chamber rise higher than the pressure in the pulmonary trunk and aorta arteries, which push the blood through the semilunar valve. The pressure generated in the ventricular eject phase is generated by the left ventricle by it is referenced from the existing high pressure in the aorta. And both ventricles will pump the same amount of blood and the quantity of blood referred to as the stoke volume.

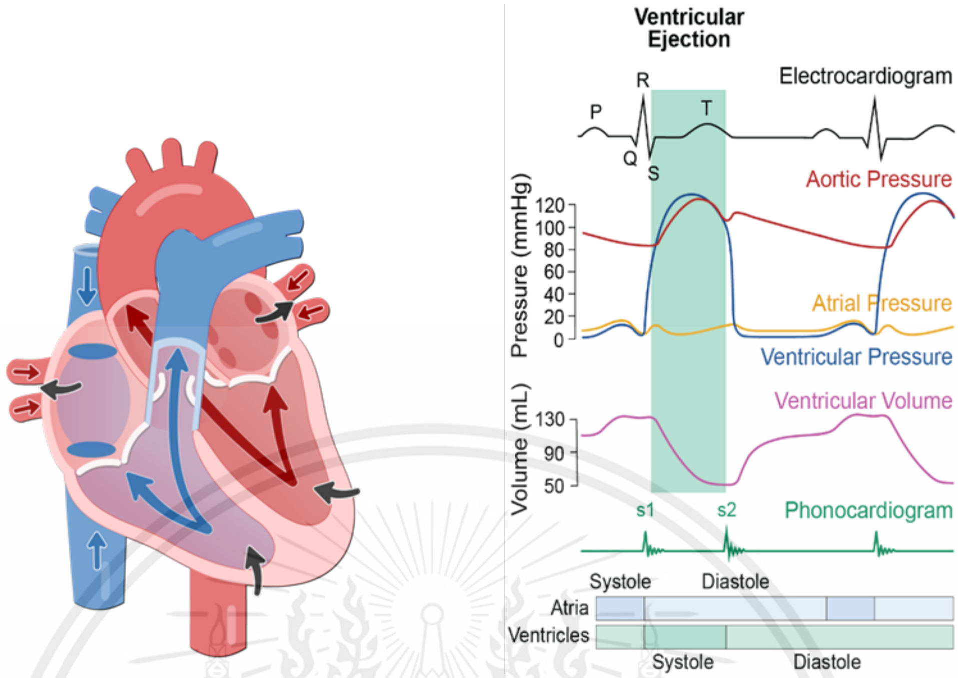


Figure 10 Ventricular ejection phase corresponding with electrocardiogram [33]

2.1.2.4 Ventricular Isovolumetric Relaxation

This phase occurs during ventricular relaxation (the early stage of ventricular diastole) and atria relaxation (the middle stage of atrial diastole). The ventricular muscle started to relax and the pressure of blood in the ventricle begins to fall. The period time of ventricular isovolumetric relaxation phase corresponds to ECG by referred to the end portion of T wave on ECG recording. When the pressure in the ventricle chamber dropped, the pressure in the pulmonary trunk and aorta is dropped. And blood in the ventricle chamber will flow back toward the heart, then the semilunar valves closed to prevent blood backflow into the heart. And since the tricuspid and mitral valve are closed, it gets the volume of blood does not change at the ventricle chamber. So that the early phase of ventricle diastole is called the isovolumetric ventricle relaxation phase.

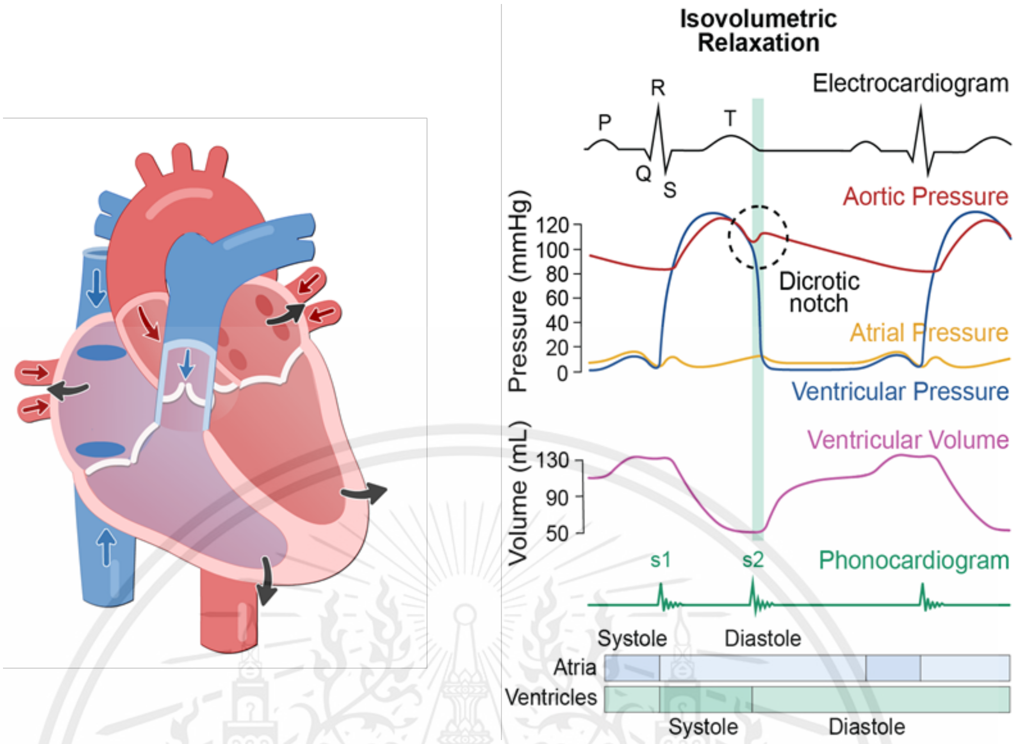


Figure 11 Ventricular isovolumetric relaxation corresponding with electrocardiogram [33]

2.1.2.5 Ventricular Filling

The ventricular filling phase occurred during the middle phase of the ventricular relaxation and the atrial relaxation which corresponding to the period between the end of the one ECG recording and starts a new ECG wave. In this phase, ventricular muscles are relaxing and the pressure in blood at the ventricle chamber continues to decrease. Blood flow from the atria chamber to the ventricle chamber, the atrioventricular valves are opened, and semilunar valves are closed to prevent blood backflow to the ventricle chamber from the pulmonary trunk and aorta arteries. At this stage, it will finish the complete of cardiac cycle of heart in one cycle. [31,32,33]

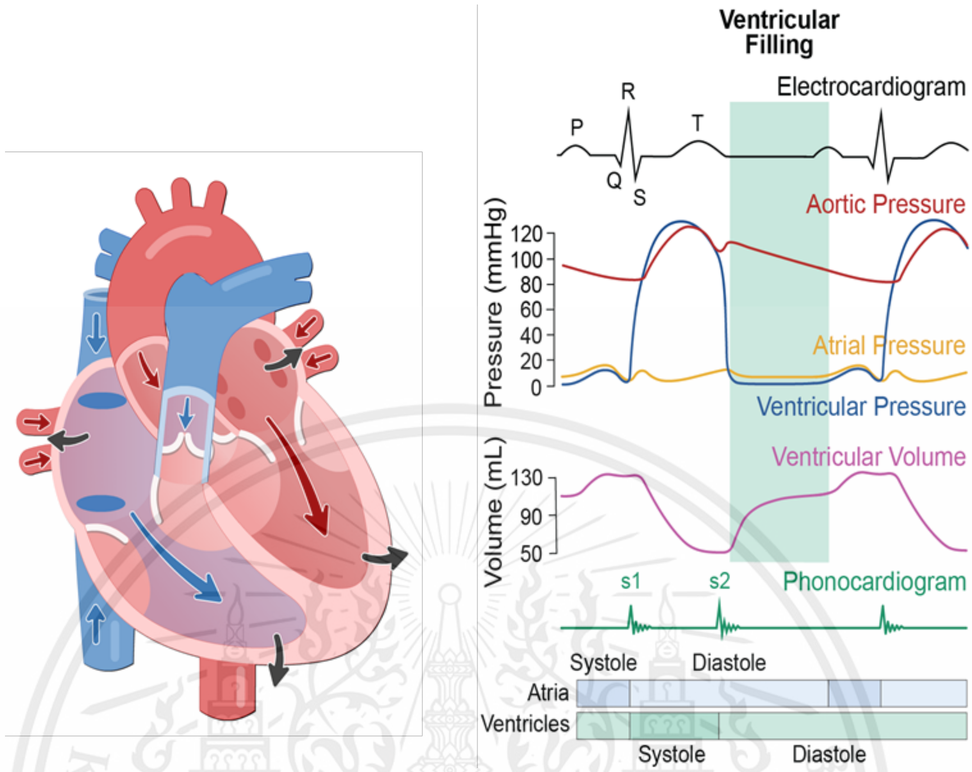


Figure 12 Ventricular filling phase corresponding with electrocardiogram [33]

2.1.3 Electrocardiogram

The electrocardiogram or ECG is the simplest and fastest test that use to evaluate the activity of the heart and it important for heart diagnostics and suitable treatment plans of patients. The electrocardiogram is detected the electrical activity generated by the heart when the heart is contracting. The machine that uses to record the ECG of a patient is called the electrocardiograph. The electrocardiograph will record the electrical activity of heart muscle in form of a graph and display the ECG data as a trace on the ECG paper. The electrical potential in the heart is generated by the conduction system component in heart, there are sinoatrial node (SA node), atrioventricular node (AV node), the bundle of his, and the Purkinje fibers. Detecting the electrical activity or electrical potential of the heart, the ECG signal is too small and difficult to reading. It has to use the electrodes attach to the surface skin as an intermediary to sending a signal through the electrodes then can see the ECG signal on the monitor. [34,35]

2.1.3.1 Sinoatrial Node (SA node)

The SA node is a natural peacemaker of the heart, it consists of a cluster of cells located at the upper part of the right atrium. The cluster cell can produce the electrical impulse and electrical impulses will travel through the heart conduction system that causing heart contraction, blood pumping, and rhythm and rate of the heart. The electrical impulse generated in the SA node will move from cell to cell and through the cardiac muscle into the atrioventricular node (AV node). [36,37]

2.1.3.2 Atrioventricular Node (AV node)

the AV node located at the center of heart between the atria and ventricles. The AV node is a gate of electrical impulse from the SA node by the signal in the AV node will be a slow electrical current before the signal can permit and pass to the ventricle chamber in a short period. The delayed electrical current at the AV node ensures that the atria have a chance to fully contract before the ventricles chamber are stimulated. After the electrical impulse AV node at the ventricle chamber, the electrical impulse will continue to travel down to the conduction pathway.[37]

2.1.3.3 Bundle of His

The bundle of his is an important element in the electrical conduction system. The bundle of his used to transmit the electrical impulse from the AV node to the point of the apex with the bundle of his branches and the electrical impulse travels to the Purkinje fiber and the Purkinje fiber will provide the electrical conduction to the ventricle chamber and it is a causing the cardiac muscle in ventricles to contract. [38]

2.1.3.4 Purkinje Fiber

The Purkinje fibers are located at the surface of ventricle chamber wall. It is a last part of the electrical conduction system of heart. The Purkinje fiber is specialized of the conducting fibers by Purkinje fibers are composed of the electrically excitable cells. The Purkinje fiber can rapidly transmit the electrical impulse from the AV node into the ventricles chamber. And the rapid conduction is allowed the ventricular systole (ventricles contraction).[39]

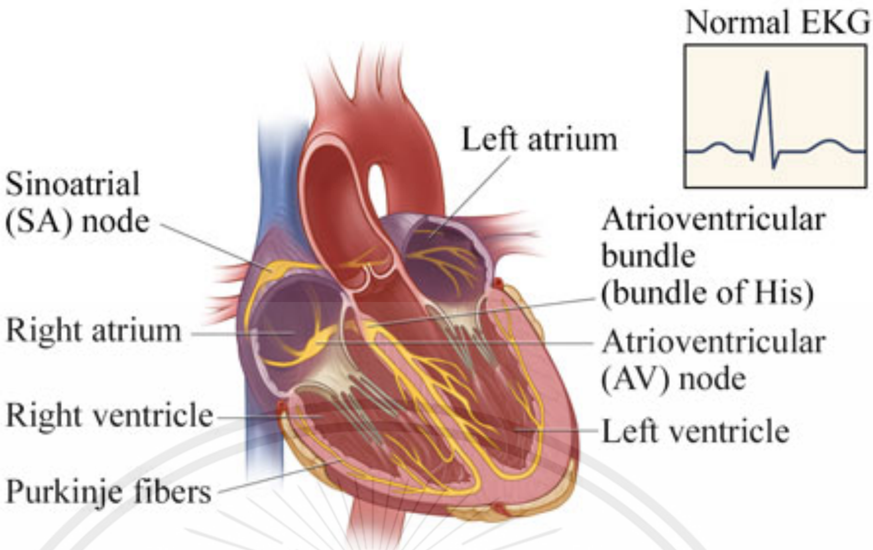


Figure 13 The electrical system of the heart [72]

2.1.4 The characteristic of the normal electrocardiogram (ECG)

The normal electrocardiogram or ECG waveform is characterized from the evaluation of the morphology of the wave and the intervals period on the ECG waveform. The overview of the ECG waveform and interval period of ECG shows in Figure14. The ECG waveform is related to the cardiac cycle in the depolarization and repolarization process when the heart is contracting or relaxing. So, the characteristic of the normal electrocardiogram can divide the waves and intervals as follows:

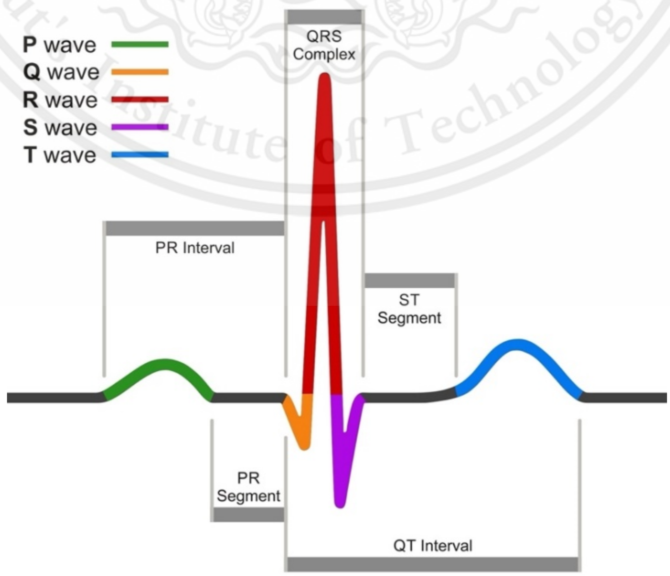


Figure 14 The electrical system of the heart [40]

2.1.4.1 P wave

For P-wave is represent the atrial depolarization by the depolarization wave originated in the SA node, which is a result of the atrial contraction (atria systole). The normal size of the P-wave has a duration of less than 120ms and amplitude less than 2.5mm.

2.1.4.2 PR Interval

The distance line between the starting point of the P wave and the end distance at the beginning of the QRS complex, PR interval used to determine the time when electrical impulse moves from the atrium to ventricles in normal stage.

2.1.4.3 PR Segment

The flat line between the end of the P wave and the start point of the QRS complex. PR Segment used to reflect the slow electrical impulse that move through the AV node. The function of the PR segment is to be a baseline of ECG waveform.

2.1.4.4 QRS complex

The QRS complex is a period of ECG waveform that occurs while ventricle depolarization. And this period appears the related three waves on the ECG waveform. The QRS complex reflects the left ventricular depolarization. A short period of QRS complex means the ventricles are depolarized rapidly, which it turns implied to the conduction system. A wide period of QRS complex means the ventricle slowly depolarization, it may be a dysfunction in the conduction system.

2.1.4.5 ST Segment

The ST segment is a line on ECG waveform that starts from the end of the QRS complex to the beginning of the T wave. This segment is an isoelectric line of ECG waveform. ST segments represent the time between depolarization and repolarization of the ventricles chamber. The ST segment must study in carefully since it has a wide range of conditions.

2.1.4.6 T wave

The T wave occurs when ventricular repolarization by T wave will appear as a small wave after a complete QRS complex. T wave used to reflect the rapid repolarization of contractile cell in the heart. T wave changing can occur in a wide range of conditions. The normal T wave should be a slightly asymmetric and steeper slope downward and has a same direction as QRS complex in the normal ECG waveform.

2.1.4.7 QT interval

The QT interval period starts from the starting point QRS complex and finished at the end of the T wave. The QT interval is used to determine the time of ventricles when ventricles are taken time to depolarization and the repolarization.

2.1.5 The leads of electrocardiogram

The ECG leads are related to the lead system, and we need to explain the difference between ECG leads and ECG electrodes. The electrode of ECG is a part of the conductive pad that is used to attach an ECG pad to the skin of the human body and then we can enable recording the electrical currents from the heart. ECG leads are graphical that use to describe the electrical activity on the heart. The graphical of ECG is created by analyzing the several electrodes. In the other words, each ECG leads can compute the different electrical currents detecting from the heart by using several electrodes. For the standard ECG, there are unipolar leads and bipolar leads. Unipolar leads are divided into two-part consist of augmented leads and chest leads, the unipolar lead has a single positive recording of the electrical current from the ECG electrode, and the other electrodes serve as a composite negative electrode. Bipolar leads are utilizing a single positive electrode and a single negative electrode to measure the electrical potential of ECG on the body. The bipolar leads as known as standard limb leads. Normally, when ECG in humans is recorded, all leads are recorded and called 12 lead ECG. The most of ECG standard is referred in 12 lead that is recommended for diagnosis the abnormal of heart in deep detail and more accuracy for diagnosis abnormal of the heart than unipolar leads and bipolar leads (standard limb leads). For unipolar leads and bipolar leads with heart diagnostic, the doctor will use to check a basic of heart activity, diagnosis the basis abnormal of heart from ECG waveform's patient and a doctor can plan the initial treatment of heart when found the abnormal of the electrical activity of the heart through the ECG graph.[45]

2.1.5.1 Limb Leads (Bipolar)

The bipolar recording is a standard limb lead configuration depicted and shown in Figure.15 by conventional. In bipolar leads, lead I is a positive electrode, and it is attached to the left arm and the negative electrode will attach to the right arm. And the last electrode of lead I will be a reference electrode and it will attach with the left leg to serve as a ground on the body and use this electrode to record the ECG signal from the body. In the configuration of lead II, the positive electrode will attach to the left leg, the negative electrode will attach to the right arm and the reference electrode will attach to the left leg. The lead III has a positive electrode on the left leg and a negative electrode on the left arm show in the picture below. So that, the bipolar lead can measure the electrical potential in each lead from the different electrical potential on two arms.

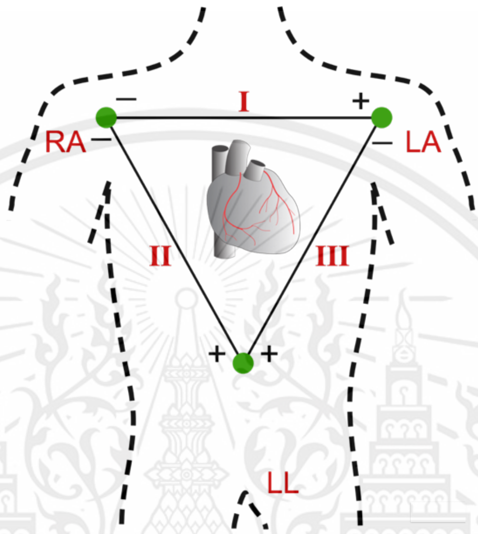


Figure 15 Standard limb lead (bipolar) [46]

The three bipolar limb leads have a shape like a triangle by each lead passes through the heart by heart will be the center of the triangle of a bipolar lead. The triangle of bipolar lead is called the Einthoven's triangle and this triangle name is created to honor Willem Einthoven who the first person to develop the electrocardiogram in the 1900s. Measuring the difference of electrical potential in the heart by using bipolar lead, it based on the ECG rules when a wave is depolarized. The maximal positive of ECG deflection occurs at lead I when a cardiac wave is a depolarization and then the electrical potential traveled in parallel to the axis of the right and left arms. If a wave of depolarization is away from the left arms and the defection of ECG will be negative. The ECG rules, a wave of repolarization will move away from the left arm, and it is recorded as a positive deflection. The limb leads of Einthoven's triangle are collapse and superimpose over the heart, the positive electrode for lead I am a zero degree that relates to the heart can measure voltage in the horizontal axis between LL and RA as shown in Figure below. The positive electrode for lead II is +60 degrees relate to the heart (RA to LL) and the positive electrode for lead

III is +120 degrees relate to the heart (LA to LL). The axis reference system starts from measuring the electrical from heart depolarizing by a wave depolarizing will travel to +60 degree and it produces the greatest positive deflection in lead II. The electrical potential of each lead can calculate follow Einthoven's triangle formula: [46]

$$Lead\ I = LA - RA$$

$$Lead\ II = LL - RA$$

$$Lead\ III = LL - LA$$

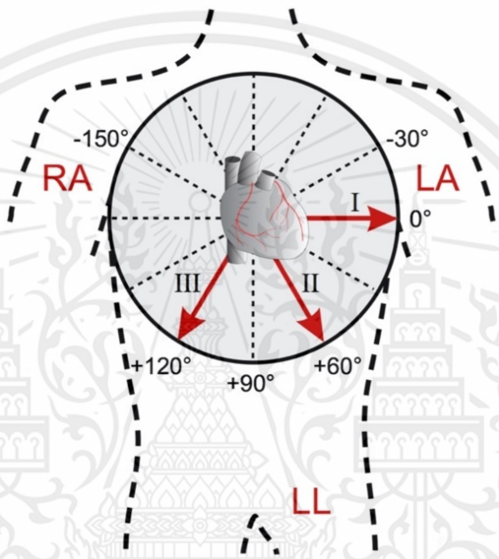


Figure 16 The axis reference system of standard limb lead [46]

2.1.5.2 Augmented Limb Leads (Unipolar)

The three augmented limb leads are unipolar leads because it has a single positive electrode that is a reference node and other electrodes be a negative electrode. The positive electrodes of the augmented limb leads can place on the body in three-position as a standard limb lead position, there is a right arm(aVR), the left arm(aVL), and the last position is the left leg(aVF). All leads are the same electrode that uses in the standard limb leads. The three augmented leads are using the axial reference system by aVL lead is -30 degree relate to the heart at lead I axis; aVR is at -150 degree relate to heart and aVF is at +90 degree relate to the heart. And it is important to learn the learn each lead associate with each axis. The electrical potential of augmented limb lead can calculate from the formula below:

$$aVR = RA - \frac{1}{2}(LA + LL) = \frac{3}{2}(RA - V_w) = -\frac{I+II}{2}$$

$$aVL = LA - \frac{1}{2}(RA + LA) = \frac{3}{2}(LA - V_w) = I - \frac{II}{2}$$

$$aVF = LL - \frac{1}{2}(RA + LA) = \frac{3}{2}(LL - V_W) = II - \frac{I}{2}$$

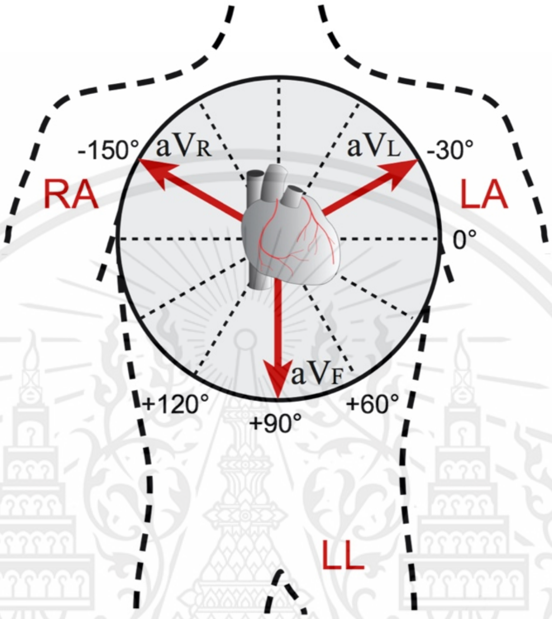


Figure 17 The axis reference system of standard limb lead (Unipolar) [73]

2.1.5.3 Chest Leads (Unipolar)

The configuration of chest leads is placed the six positive electrodes on the chest in different regions of the heart by the electrode that placed on the chest will record the electrical activity of the heart in a perpendicular plane to a frontal plane. The name of the six chest leads is named V1 – V6. The rule of ECG interpretation is the same rules as a standard limb leads. For example, a wave when heart depolarization, will travel to the particular electrode on the chest surface, and then the electrode on the chest surface will occur a positive deflection. The chest leads are used to provide a different view of electrical activity in the heart by chest leads can record the electrical activity in the perpendicular plane that can see the electrical activity in heart in more detail than limb leads, and augmented limb leads. The recording of the ECG waveform is different electrical voltage depends on each electrode on the chest surface and see more electrical activity in the heart than standard limb leads. This chest leads us to understand how the cardiac electrical current is generated in heart and ECG tracing. The importance of chest leads is necessary to understand the volume conductor principle and vectors.

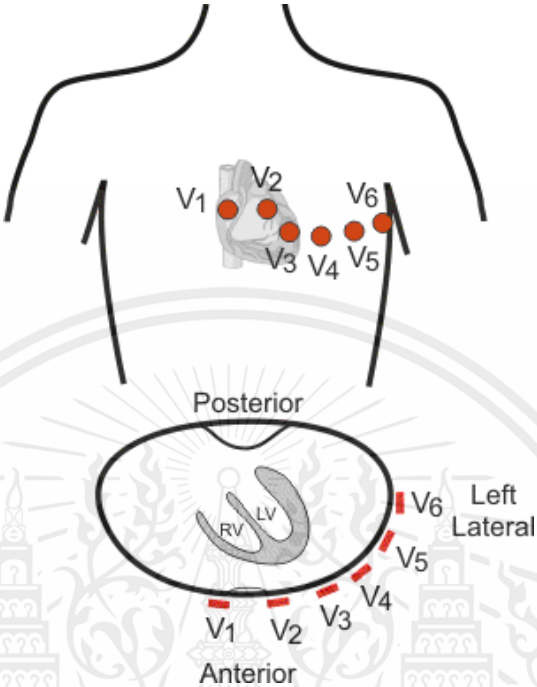


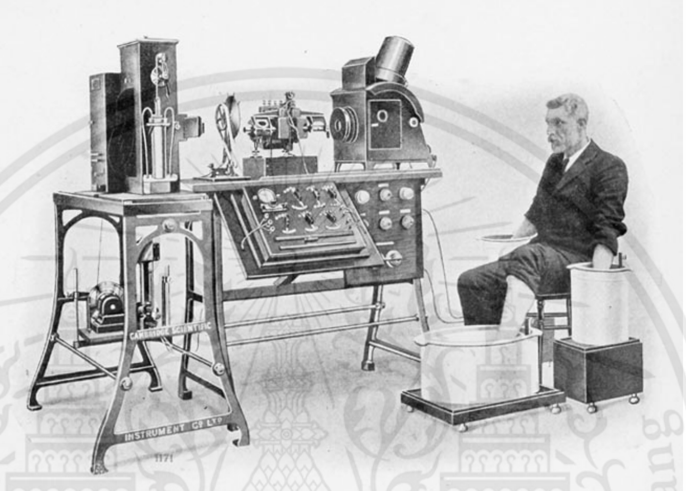
Figure 18 The electrocardiogram chest leads (Unipolar) [74]

2.1.6 Developing of lead system theory

The Discovery of the lead system of the electrocardiogram is occurred from experiments and the establishment of many scientists to discover the lead system of the electrocardiogram to see the ECG signal inside the body and can diagnosis about the electrical activity in the heart. Different scientists have different theorems to discover and improve the lead system. According to developing the lead system of an electrocardiogram are follows:

2.1.6.1 Einthoven's lead system

The Einthoven's triangle is the first theorem of recording the electrocardiogram from the body. This theorem is discovered by Willem Einthoven. He was a Dutch physician, and he invented the first electrocardiogram machine in the 1895s. In the 1903s, Einthoven can record the first electrocardiogram in the world. The methodology to measure electrocardiogram of body, he created a prototype of string galvanometer by the way that he wants to contact his equipment to the body was place the arm and leg in a cold bucket and inside the bucket has a salt solution. Einthoven can produce a sufficient contact resistance to the body and make the first electrocardiogram. The first electrocardiogram is visible from the helping of a string galvanometer. He uses the string galvanometer to measure electrical potential in the heart from the tension of arms and legs, he measured the electrical potential from right arm and left arm, right arm and left leg left arm and left leg.



PHOTOGRAPH OF A COMPLETE ELECTROCARDIOGRAPH, SHOWING THE MANNER IN WHICH THE ELECTRODES ARE ATTACHED TO THE PATIENT, IN THIS CASE THE HANDS AND ONE FOOT BEING IMMERSED IN JARS OF SALT SOLUTION

Figure 19 Einthoven ECG system in 1903s [48]

Einthoven's Triangle referred to the imaginary inverted equilateral triangle that centers on the cheat and a point s being the standard limb leads on arms and leg. The importance of Einthoven's triangle is helpful to identify the incorrect placement leads because incorrect lead placement can lead to error recording the electrocardiogram and make a misdiagnosis. [48,49]

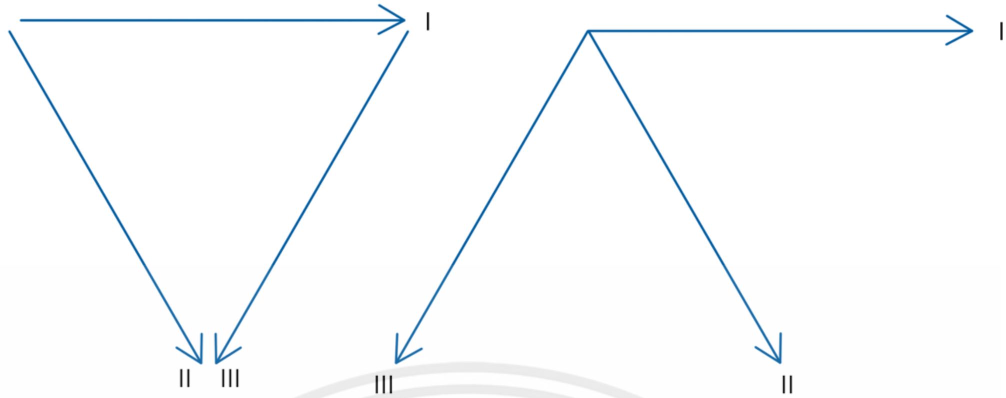


Figure 20 Einthoven's triangle [48]

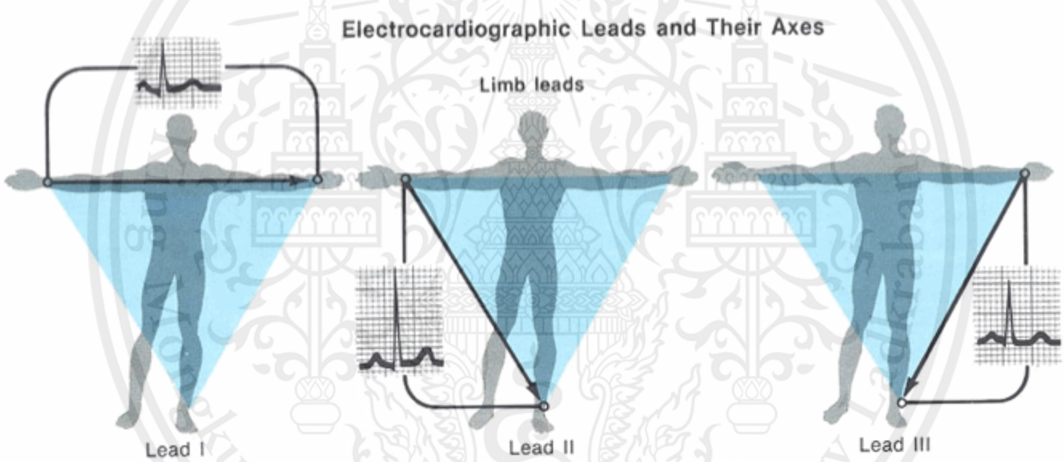


Figure 21 Einthoven's lead system corresponds with ECG on standard limb leads [75]

2.1.6.2 Goldberger's lead system

Developing Einthoven's lead systems by Emanual Goldberger, he had an idea to develop the lead system of Einthoven in 1942. He wants to close the gap and angle between lead I, lead II, lead III, and the reason Goldberger is improving the diagnosis electrical activity of the heart. Goldberger's theorem has occurred the augmented leads, Goldberger thought it make sense to the angle between each lead in half of Einthoven's leads by the accomplish this theorem with the help of resistor network corresponds to analog calculating by following the rules:

$$-aVR = (I + II) / 2 \; aVL = (I - III) / 2 \; aVF = (II + III) / 2$$

The augmented leads have increased the potential of ECG signal in ECG machine amplifies signal reading by 50% by 'a' referred to augmented that increase the size of ECG signal on a machine, 'V' referred to voltage, and 'R, L, F' referred to the position of lead placement on the body, there are right arm, left arm, left leg. For the Augmented lead of Goldberger is place lead position on body same position as Einthoven's leads. This lead system has six vertical (coronal) axes were available.

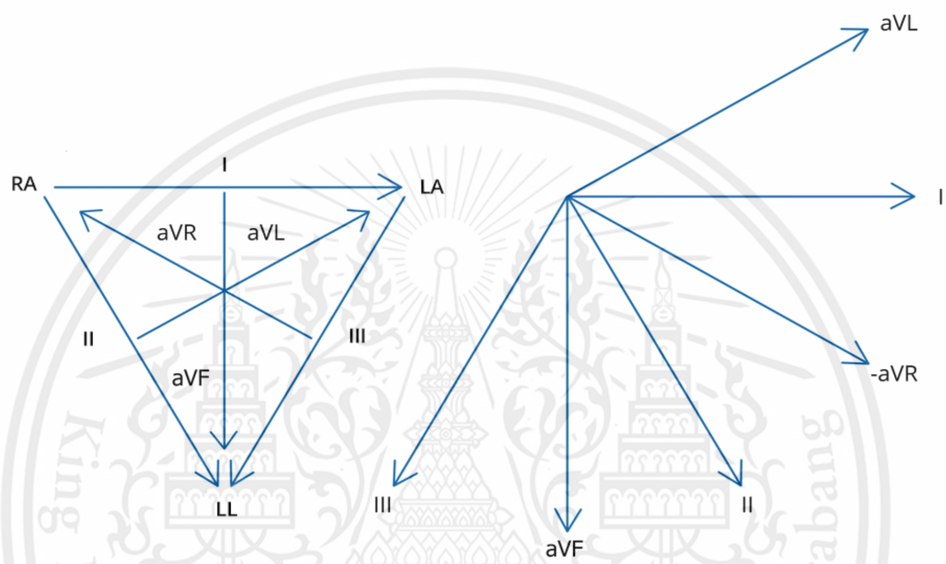


Figure 22 Goldberger's lead system [48]

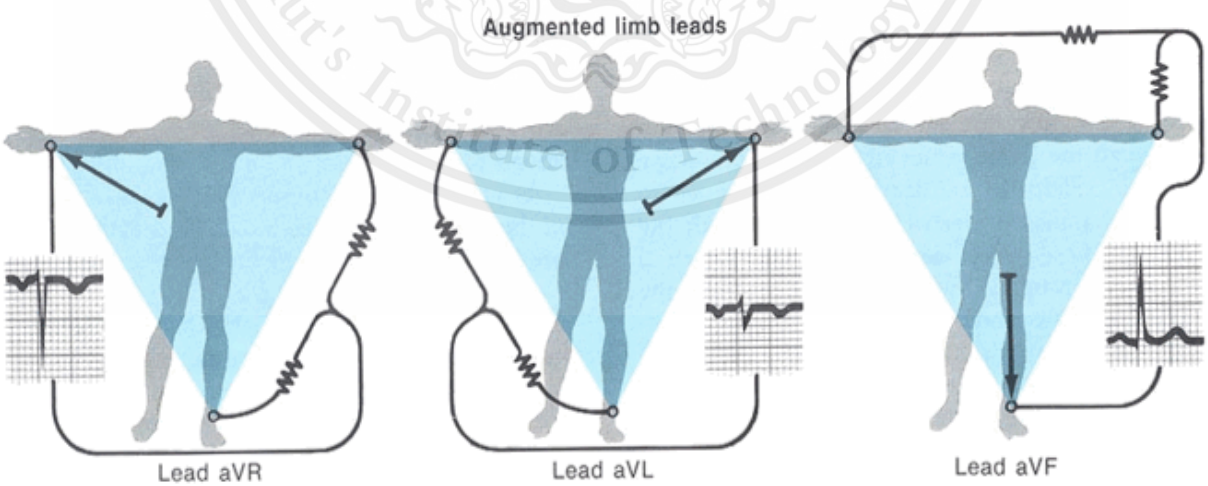


Figure 23 Goldberger's lead system corresponds with ECG on Augment limb lead [76]

2.1.6.3 Wilson's lead system

Following the theory of Goldberger, the lead system of the electrocardiogram is developed in 1934 by a scientist named Wilson. He is developed by adding a horizontal axis through the heart. He added a horizontal axis through the heart by attached the ECG electrodes directly to the chest wall and then measuring the electrical potential in the heart against a vital reference point of the electrode are located at the middle of the heart. The reference point was called Common Terminal (CT) and this point is generated from the resistor network. The lead system of Wilson known as V1-V6 by place electrodes on the chest wall at the left side of the heart. Together with the leads from Einthoven and Goldberger lead system was occurred the standard 12-lead ECG. [48]

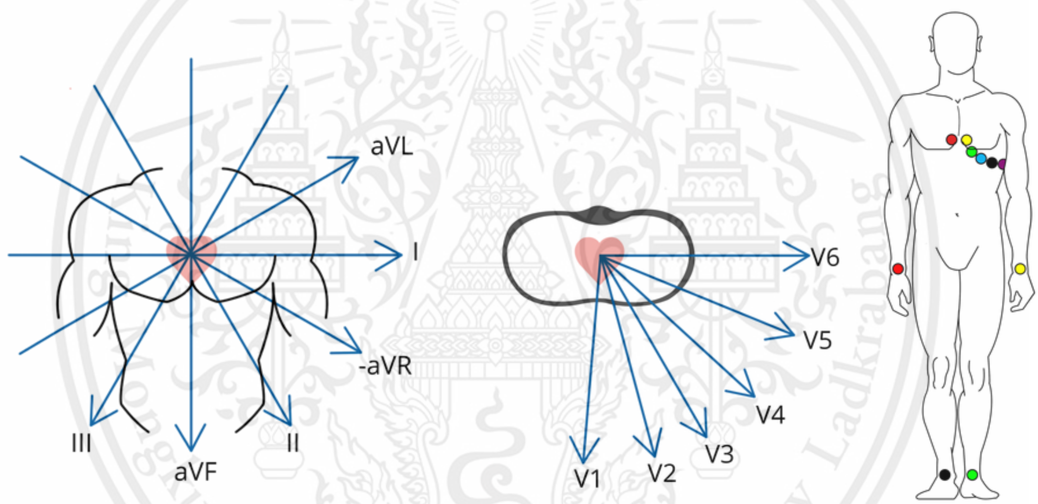


Figure 24 Wilson's lead position of 12-lead ECG

(6 vertical and 6 horizontal visual axes) [48]

2.1.7 ECG interpretation

Interpretation of ECG is an ECG pattern recognition by the ECG interpretation used to understand the pattern of electrical signal that found in the heart and helpful for understanding the theory of ECGs represent. The ECG interpretation starts from looking at the overall electrical signal in the heart and systematically reading the ECG signal follows:

2.1.7.1 Background grid or ECG paper grid

Normally, ECGs are print on a grid of paper. The horizontal axis of the ECG paper grid represents time, and the vertical axis represents voltage. The standard value on the ECG paper grid is 25 mm/secs and shown in the image below. For the background, the grid is used to check the gain of ECG that meets the standard gain of ECG (1mV=10mm, 25mm/sec). The standard of ECG will be related to the ECG paper grid and the wide grid box will follow the figure below.

-A small box is 1 mm x 1mm and represent voltage value 0.1 mV x 0.04 seconds.

-A large box is 5 mm x 5mm and represent voltage value 0.5 mV x 0.20 seconds.

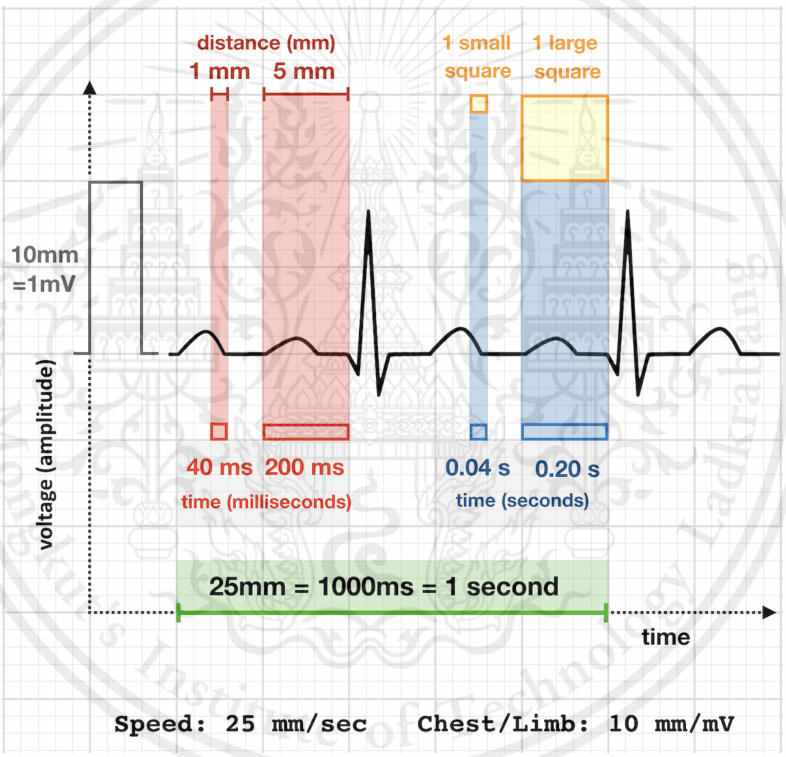


Figure 25 Background grid of ECG [54]

2.1.7.2 Rate and rhythm

The rate and the rhythm of the heart in humans are important things in the ECG interpretation and the rate and the rhythm of the heart are related to the sinoatrial node and depolarization of the heart. The heart rate serves as a vital sign of a body, there are blood pressure, respiratory rate, and changes of age that affect the heart rate of the human body. In adults, a normal rate of the heart is valued between 60 to 100 bpm and in natural, the normal heart rate of adults will higher than children. If heart rate below the normal heart rate is called bradycardia (100 in adults). In the normal resting stage, the physiological rhythm of the heart produces from the sinus rhythm and the sinus rhythm has produced the pattern of P wave, QRS complex, and T wave. In general, the normal sinus rhythm is considered about cardiac arrhythmia. So that, the normal rhythm of the heart occurs from the sinus rhythm from the SA node. Mainly to considering the rhythm of heart, there is check P wave, check widely of QRS complex, check the relation between the P wave and QRS complex, and the last is check the rhythm of the heart that regular rhythm or irregular rhythm. [47,55]

2.1.7.3 Axis

The heart has several axes, and the most common axis of the heart is an axis of the QRS complex. The QRS axis is a general axis that represents the direction of the ventricular depolarization knows as a mean electrical vector in the frontal plane. The axis of ECG interpretation can classify as one of three types, there are normal, left deviated, and right deviated. The normal QRS axis has a value between -30^{o} to $+105^{o}$ from lead I and aVF together with a reciprocal lead. Beyond $+105^{o}$ to $+180^{o}$ is a right axis deviation and beyond -30^{o} to -90^{o}. The QRS axis is normal, it mostly positive waveform in lead I and lead II or lead I and aVF $+90^{o}$ that upper the limit of normal. The normal QRS axis is general direction down to the left by following the anatomy orientation of the heart within the chest. The abnormal of the QRS axis is a change in the physical shape of the QRS complex and orientation of the heart, and the abnormal axis can occur from a defect in the conduction system that is a cause of the depolarization of the ventricle abnormally.

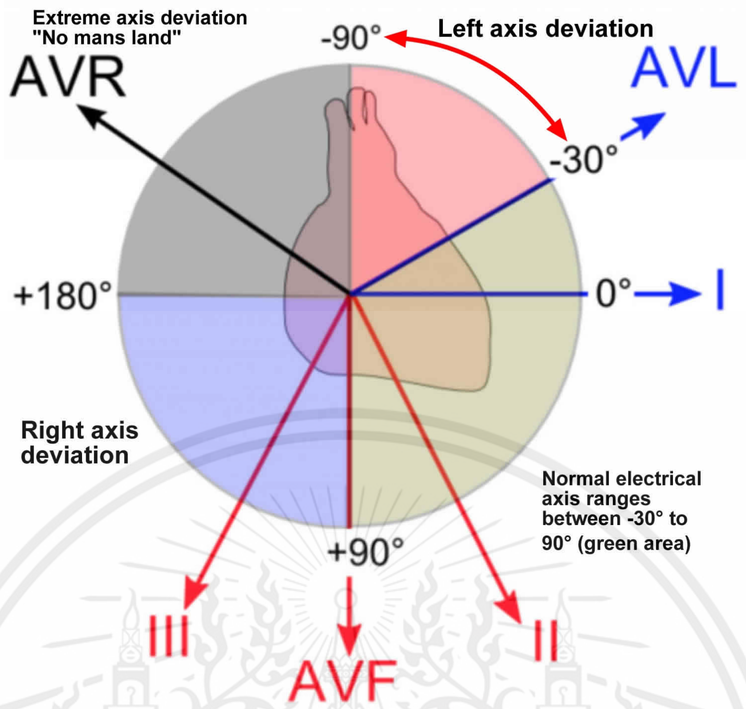


Figure 26 Axis deviation on ECG [56]

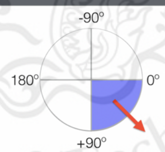
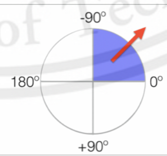
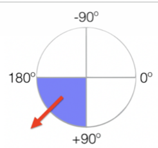
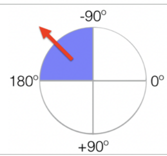
Lead 1	Lead aVF	Quadrant	Axis
POSITIVE	POSITIVE		**Normal Axis** (0 to +90°)
POSITIVE	NEGATIVE		****Possible LAD** (0 to -90°)
NEGATIVE	POSITIVE		**RAD** (+90° to 180°)
NEGATIVE	NEGATIVE		**Extreme Axis** (-90° to 180°)

Figure 27 Summary table of axis deviation on ECG [56]

2.1.7.4 Amplitude and intervals

All of the waves of ECG waveform, the amplitude and interval period between each wave can predict the time duration and range of acceptable amplitude and atypical of time duration range and amplitude. The measuring of the amplitude and intervals of ECG is measured on the ECG paper grid by ECG waveform will print on the grid paper at the standard scale. The value of normal amplitude and intervals of ECG that can accept to be a normal ECG is following the table below:

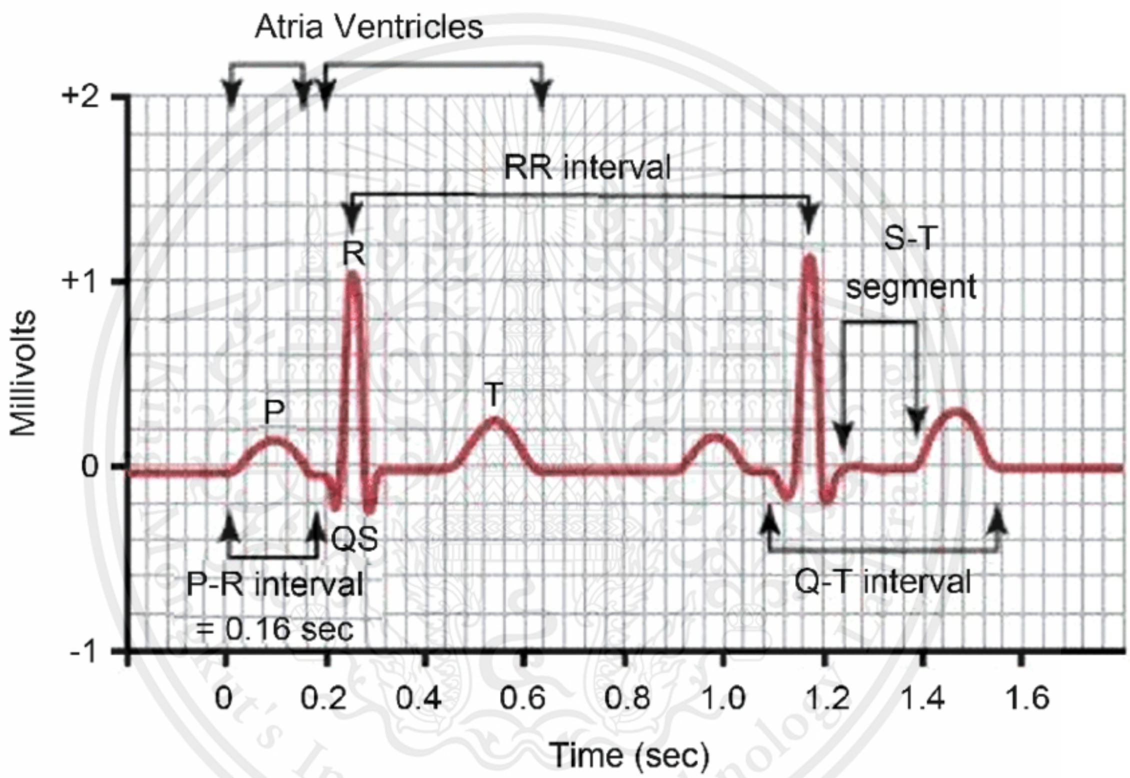


Figure 28 Normal ECG with standard amplitude and intervals [57]

Table 2 Normal amplitude and interval of ECG

Type of wave and interval	Duration (s)	Amplitude (mV/small box (mm))
P wave	≤ 0.12s	- <2.5 mm in limb lead - <1 mm in biphasic V1 (Negative deflection)
PR interval	0.12s – 0.2s	-
QRS complex	- 0.06s – 0.10s (normal) - 0.10s – 0.12s (healthy)	- >0.5 mV in at one standard lead. - >1.0 mV in at one precordial lead.
R wave	-	- < 26 mm in V5 and V6 - < 35 mm in V5 and V6 + S-wave amplitude - ≤ 12 mm in aVL - ≤20 mm in lead I, II, III - < 5 mm if V1 larger than S-wave.
R wave (Peak)	- < 0.035s (right ventricle) - <0.045s (left ventricle)	-
QT duration	- ≤0.45s (Men) - ≤ 0.47s (Women)	-
ST segment	0.08s	-
RR interval	0.6s – 1.0s	-

2.2 Materials Review

2.2.1 Arduino Board

Arduino board is an open-source hardware and software that user can be easy to access both hardware and software to create their project with microcontroller. Arduino is designed and manufactured in form of a single board microcontroller and microcontroller kit for building digital devices. For Arduino board has software license, the software license of Arduino is GNU General Public License (GPL). This software will permit the manufacturer of Arduino board and Arduino software and anyone easily to access this open-source hardware and software. And now the Arduino board is a microcontroller board that was widely to use starting from the beginning user until advance user.

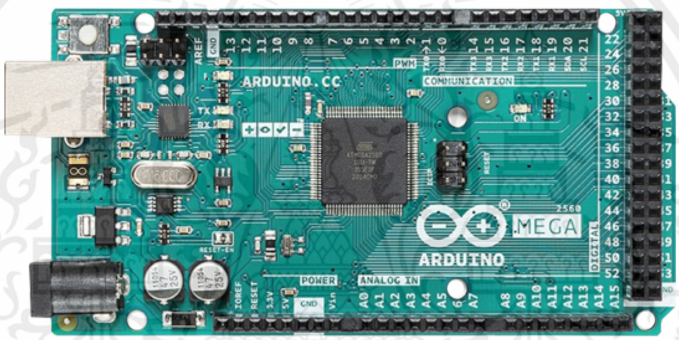


Figure 29 Arduino Board (Arduino Mega 2560) [6]

Arduino boards are designed by used a variety of microprocessors and controllers to manufacturer this board. The Arduino boards are microcontroller boards that have a set of digital and analog input/output (I/O) pins and these pins can interface to the other boards called Shield board and can connect with other circuits. The feature of these microcontroller boards, there is the serial communication interface include Universal Serial Bus (USB). The Universal Serial Bus (USB) is also used for loading programs to the Arduino board. Arduino board is a microcontroller that can program and write code on the board by using C and C++ programming language. The C and C++ programming that uses with the Arduino board, it used with the standard API and it became to Arduino language that is a specific program language of the Arduino board.[5] Arduino also makes simple the working process of the microcontroller and it can give the advantage over other systems for beginners.

2.2.1.1 The function of Arduino board

The function of Arduino board is a flexible function and enormous function depending on users. The main function of the Arduino board is used to control the electronic through reading input and changing it to output. Arduino boards are also used to make different electronics projects in the field of electronics, electrical, robotics, etc. This board is microcontroller board that easily connect to the different modules such as obstacle sensors, presence detectors, GPS modules, etc. In the Arduino board, it consists of different hardware component that has their function and shown in Figure3.[6]

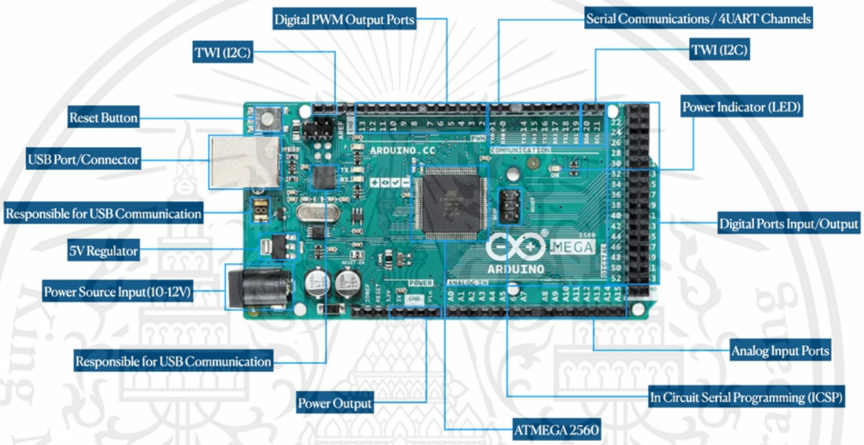


Figure 30 Different part of Arduino Mega 2560

The different hardware components of the Arduino Mega 2560 board that show in Figure3 and the Arduino Mega 2560 board divide into four main components parts consist of power part, pin part, controller part, other parts.

1 Power parts

Every Arduino board needs the power source to drive itself working and an Arduino can be powered their board in three ways:

-DC Jack Power supply: The DC power jack, this port used to input the power to the Arduino board. The DC power jack is usually connected with a DC wall adapter and the voltage of the DC power supply recommend for the Arduino board in most Arduino models is between 7V to 12V. If the voltage above 12V, the regulator of the Arduino board will overheat. If the voltage below 7V, the power that use to drive or supply the Arduino board might not suffice.

-Vin Pin: For Vin pin is used to power the Arduino Mega board by using the external power source. The voltage range of the Vin pin is 7V to 12V.

-USB cable: This port used to connect with the computer and the computer can provide the power to the Arduino board around 5V at 500 mA for the Arduino board to work.

In the Arduino Mega 2560 board, there is the polarity protection diode connecting between the positive of the DC jack power supply to the Vin pin and is rated at 1A. The power source has to consider and determine the suitable power for the circuit. For instance, powering the circuit by using a USB, and the USB port has a limit of 500 mA. If the circuit that uses Arduino uses more than 500 mA, using a USB port might not suffice for the circuit that connects to the Arduino board. For the powering from DC jack power supply port or Vin pin, the maximum capacity available is 3.3V to 5V and it is determined by the regulator on the Arduino Mega 2560 board.

2 Pin parts

The pin on the Arduino Mega board is used to connect the wires to construct a circuit and wire to connect the circuit with another peripheral device or sensor. For this part, there are many pins to support connecting wire or using to interface with other sensor depend on pins function. An Arduino Mega 2560 board has several different kinds of pins, which label name of pins on the board is used to separate the different functions of each type of pins. The diagram pins of the Arduino board will show in Figure4.

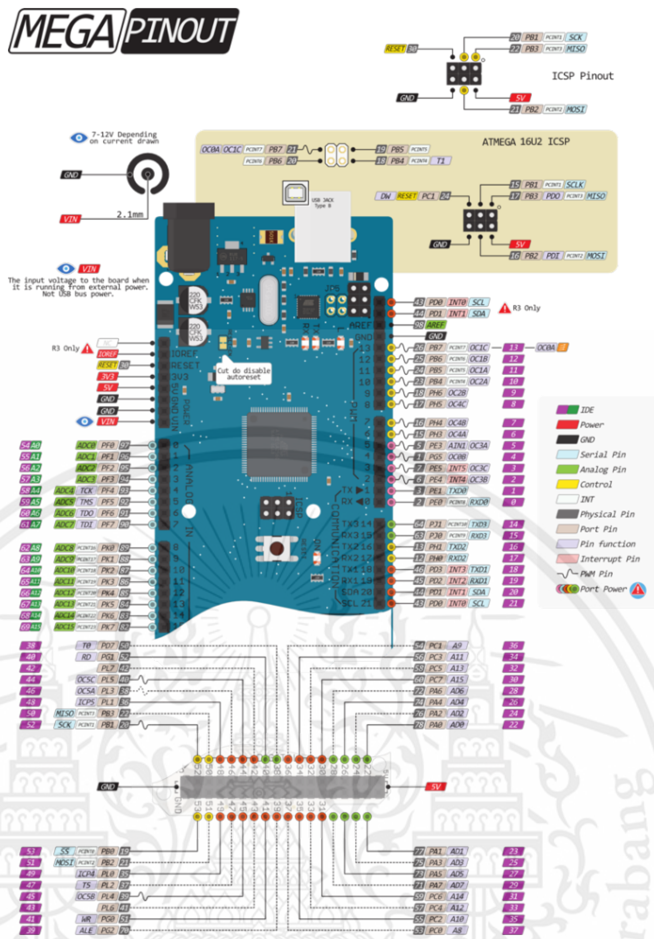


Figure 31 Diagram pins of Arduino board. [12]

Ground or GND: For ground pin or GND pins are used to be a ground of the circuits, used to close the electrical circuit. It used to provide a common reference point throughout the circuit. It important to excess the electrical go to safe place and be a safety pin of the electrical circuit.

-5V and 3.3V: These pins provide regulated 5V and 3.3V to external power components of other circuits according to the specific manufacturer.

-Analog pins: The Arduino Mega 2560 board has 16 analog pins which are the pins that are used to convert analog data to digital data called ADC. These pins served as analog input and they can be a function as digital inputs or digital outputs by reading the analog voltage value from the peripheral devices such as a sensor and then convert the analog value to a digital value. The analog pins of the Arduino Mega 2560 board are labeled from A0-A15 shown in Figure5. In the Arduino Mega 2560 board, there is an ADC 10-bit solution, and it can represent the analog value in the range 1-1024 of digital levels that ADC capability to convert the analog voltage value to digital voltage value into bits which microprocessor can understand.

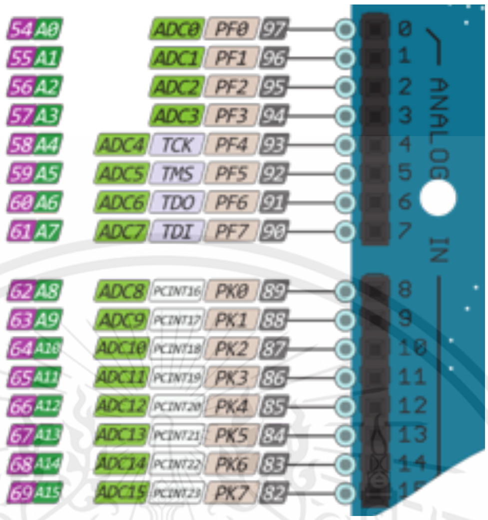


Figure 32 Analog pins of Arduino board.[12]

-Digital pins: These pins are including digital input and digital output. In Arduino boards, the digital pins 54 pins, start from pin0 – pin53 of Arduino board that serves as digital input or digital output pins. Digital pins that serve as digital pins input or output start from pins22 – pins53.

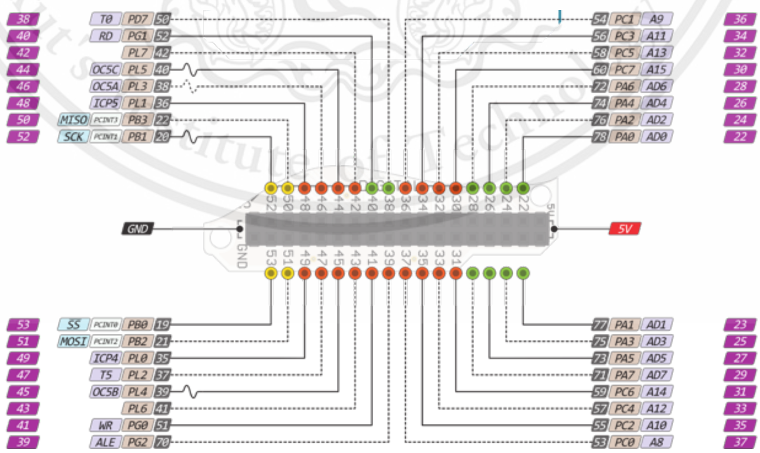


Figure 33 Digital pins of Arduino board [12]

In the Arduino Mega 2560 board, there are digital pins that capability to be a communication pin and PWM pins. For the PWM pins, there are 12 pins consist of pins2 – pins13 and the other digital pin are communication pins (0,1,14,15,16,17,18,19,20,21). [11]

-PWM pins: These pins can notice from PWM word on the board, and this is one kind of digital pin, and it ack like a normal digital pin. In general, Pulse Width Modulation (PWM), is one technique that used to encode the message into a pulsing signal in terms of frequency and duty cycle shown in Figure7. For frequency will use to dictate how long it takes to complete the signal in the single-cycle and the duty cycle will determine how long a signal stays high out of the entire period. Mostly the duty cycle will represent in terms of percentage. [8,9]

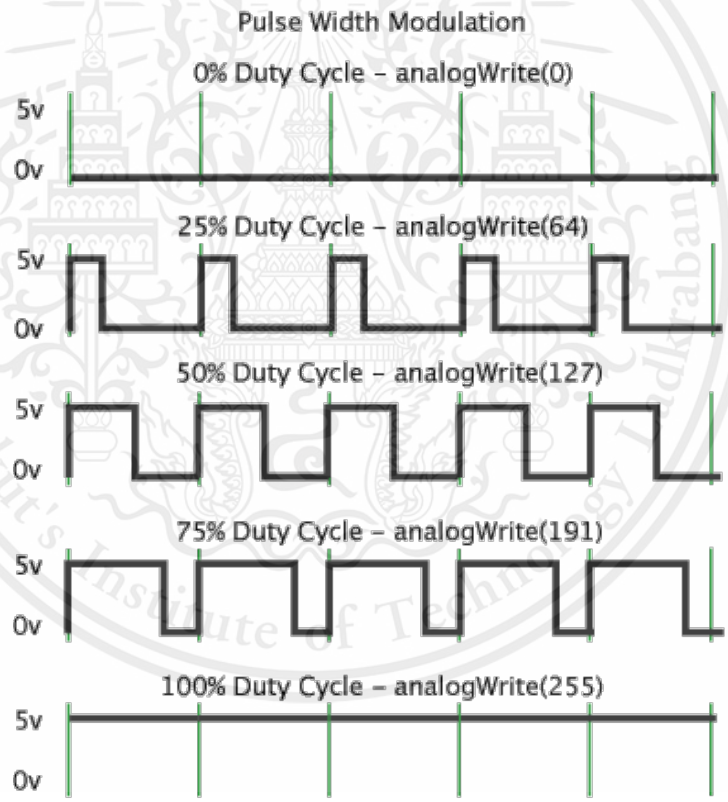


Figure 34 Pulse Width Modulation [10]

Pulse Width Modulation (PWM) is a digital control that is used to create the square wave shown in the figure above and a PWM signal will switch voltage between on and off. The on-off pattern that occurs from PWM simulated the voltages between full

VCC of board (5V) in one pattern. When voltage is switched off, it will switch voltage from 5V to 0V by changing the portion of time the signal.

In the graphic above, the green line represents a control signal period. The period of PWM is an inverse of PWM frequency. The PWM of Arduino has a frequency at about 500 Hz and green lines would measure 2 milliseconds each. And using PWM pins will call to analog Write (), which is code for write the PWM on a scale of 0 – 255. For example, analog Write (255) requests 100% of duty cycle (signal always on at 5v), analog Write (127) request 50% of duty cycle (signal will switch on-off the pattern on half of the time), and analog Write (0) requests no duty cycle (always off at 0v). [10]

-Communication pins: For the communication pins on the Arduino Mega 2560 board, there are 3 communication pins part consist of USART, I^2C, and SPI. The serial communication pins on pin TX/RX and used TTL logic level and input voltage of board is 3.3V or 5V depending on the board. These pins can't directly connect to the RS232 serial port because it operates at ±12V and it can damage to the Arduino board. Serial pins in Arduino board used for serial communication between the Arduino board and other devices. All Arduino boards will have the communication port at least one serial port also known as a UART or USART for data sharing and logging. The Arduino Mega has four serial ports consist of serial0 on pins0(RX) and pins1(TX), serial1 on pins19(RX) and pins18(TX), serial2 on pins17(RX) and pins16(TX), serial3 on pins15(RX) and pins14(TX). For RX pin is serves as a receive pin that ensure the receiving of serial data while TX pin is a transmission pin that uses to transmit serial data. These serial pins are used to communicate with the other external TTL serial device by using RX and TX pins or use to communicate with a personal computer that uses additional. The USB to serial adapter [13]. I^2C pins, digital pins20 for SDA, and pins21 for SCL speed at 400 kHz. These pins are enabled by two wires to communicate with another device. The board carries one I^2C communication by the Arduino Mega board carry two pins of I^2C communication, there are SDA pin and SCL pin. The SCL is a serial data pin that is used to carry data while SCL is a serial clock that use to ensure the synchronization of serial data while transfer the data over the I^2C bus. The last communication pin is SPI pins. The Arduino board contains one SPI communication protocol. These pins are a serial peripheral interface communication protocol. SPI is used to develop the communication between the controller and other connecter device such as sensors. SPI contains two pins, there are MISO (Master input slave output) and MOSI (Master output slave input) for SPI communication.[14]

3 Control parts

The microcontroller that is used to control the Arduino Mega 2560 board is ATmega2560 (8-bit). The operating voltage of the ATmega2560 microcontroller is 5V. Arduino Mega 2560 has a clock speed of around 16 MHz. The ATmega2560 is a single chip microcontroller, and this chip is used in Arduino mega board. This microcontroller board has 8 KB SRAM (Static Random-Access Memory) and 4 KB of EEPROM (Electrically Erasable Programmable Read-Only Memory). [15]

4 Other part

-Voltage regulator: The main function of voltage regulator is used to control the input and output voltage of Arduino Mega board. If the power voltage input more than 12V, the voltage regulator of board will overheat and damage the Arduino board.

-**Reset button**: The reset button of the Arduino board is used to reset the working of the Arduino board and restart running the program from starting. It's useful when the programmer wants to be rerunning the program at a default stage of board by using reset button. After pressed the reset button, it will send some the logical pulse to the reset pin of the microcontroller board and then it will restart the board to the starting point again.

-**ICSP pins**: ICSP or In-Circuit Serial Programming is used to program the AVR microcontrollers. It has a feature of programming by using the serial bus with an AVR programmer using SPI communication. These pins contain six pins consist of MISO (Master input slave output), +Vcc, SCK (Serial Clock), MOSI (Master output slave input), Reset, GND has shown in Figure8. [11,15]

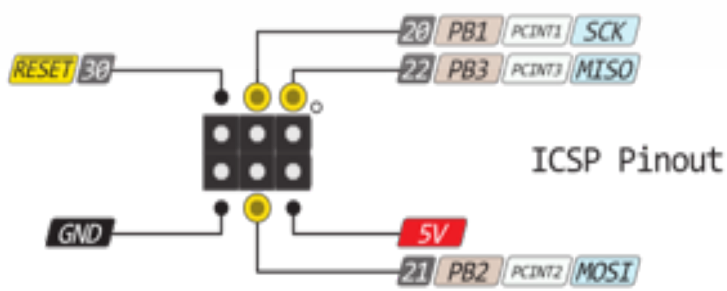


Figure 35 In-Circuit Serial Programming Pinout (ICSP) [12]

2.2.2 MCP4725

The MCP4725 is low power serving equipment and get high accuracy result. This is a digital to analog converter (DAC) with non-volatile memory or called EEPROM. The digital to analog converter (DAC) input and configuration data of DAC can be programmed to control the EEPROM by using an I^2C serial interface. The MCP4725 output has a proportion of the input voltage. MCP4725 is a digital to analog converter 12-bits device with a resolution of MCP4725 is starts from 0 – 4095. The EEPROM features are enabled The DAC device to preserve the DAC enter code at some stage in a power-off time, and the DAC output is available at once after power-up. This characteristic of MCP4725 may be very beneficial whilst the DAC device is used as a helping device for different devices. [44]

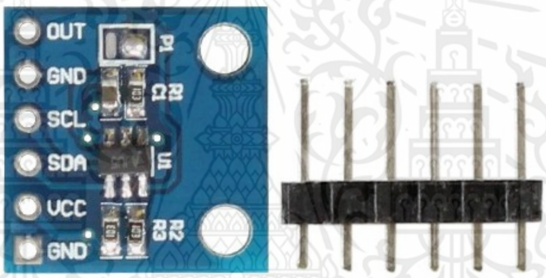


Figure 36 MCP4725 with EEPROM memory.[44]

2.2.2.1 MCP4725 pinout

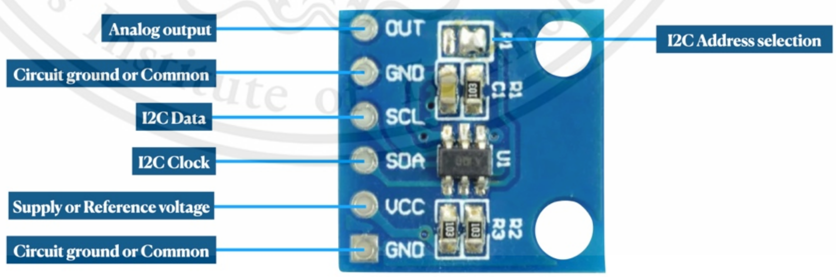


Figure 37 The pinout of MCP4725

2.2.2.2 Block diagram

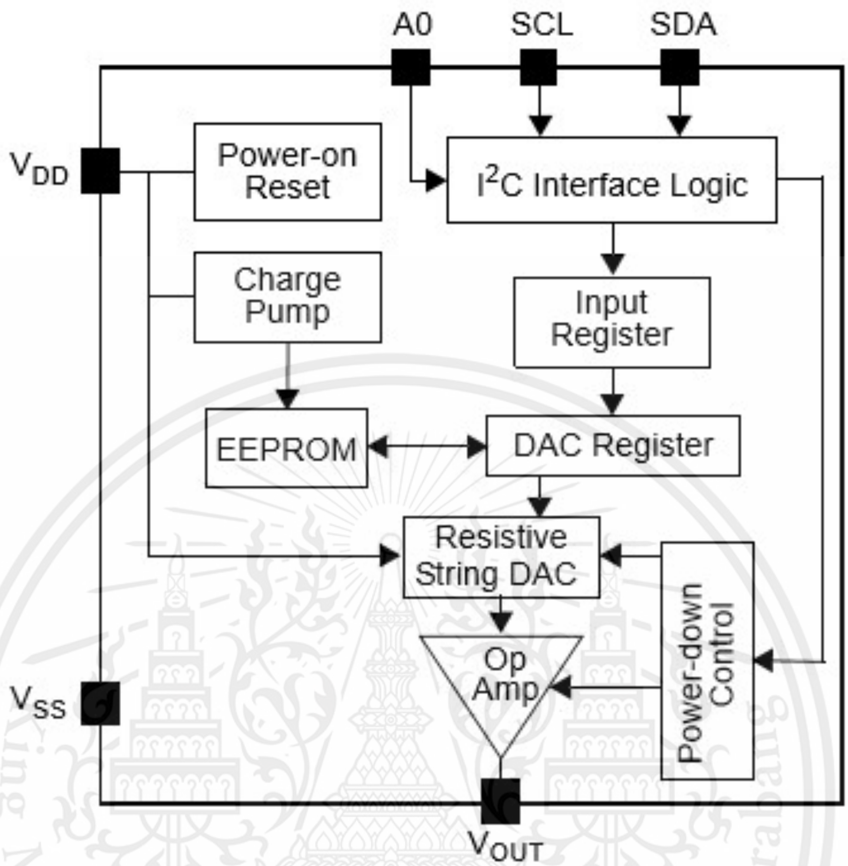


Figure 38 MCP4725 diagram [58]

2.2.2.3 MCP4725 specification

Table 3 MCP4725 specification table. [59]

Parameter	**MCP4725**
Voltage supply (Vs)	2.7V – 5.5V
Abs. Max V_{DD}	-0.3V – 6.5V
Interface	I^2C
I^2C rate	100kHz, 400kHz, 3.4MHz
Resolution	12 Bits
Power down current (I_{DDP})	0.06μA – 2μA
Supply current (I_D)	210μA – 400μA
Short circuit (V_{out} = GND)	15mA – 24mA
Offset error (V_{OS})	0.75% of FSR
Gain error (G_E)	-2% of FSR – 2% of FSR
Capacitive load stability (C_L)	1000pF
Extended temperature range	-40°C – +125°C
Maximum junction temperature (T_J)	+150°C
Input leakage (I_{LI})	±1μA
Input voltage of SDA and SCL pins	$0.3V_{DD}$ – $0.7V_{DD}$
Input voltage of A0 pins	$0.2V_{DD}$
DC output impedance (R_{out})	1Ω
I^2C address (h/w selected = 8 off)	0x60 and 0x61
Storage temperature (T_A)	-65°C – +150°C
ESD protection on all pins	≥6 kV HBM, ≥400V MM

2.2.3 Micro-SD card module

Micro-SD card module for recording or reading data from micro-SD card for increasing the ability to save various data from Arduino board to micro-SD Card with SPI interface. The voltage recommended for a micro-SD card is 3.3 V. So, we cannot directly connect it to a circuit using 5V because it can cause module damaging. There are two ways to use a micro-SD card that composed of SPI mode and SDIO mode. SDIO mode is a faster method of micro-SD card module and SDIO method is used on mobile phones or digital cameras by this method has a complicated mode in micro SD card module is based SPI mode and this is a low-speed mode. SPI mode is easy to use in a microcontroller. A microcontroller system can complete connecting with a micro-SD card module by using a micro-SD card to read and write files. Arduino users can directly use the Arduino IDE with an SD card to complete the library of SD card initialize to read and write the module.

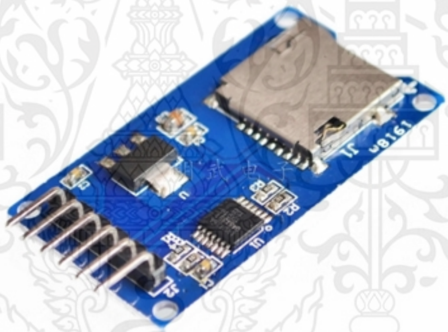


Figure 39 Micro SD Card Module. *[77]*

2.2.3.1 Micro SD card Module pinout

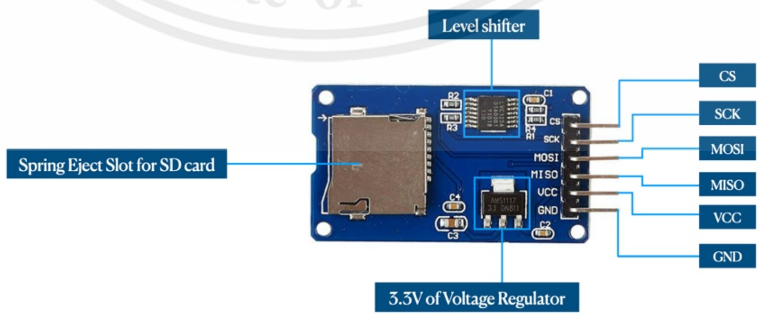


Figure 40 The pinout of Micro SD card module

The control interface of the micro-SD card module has a total of six pins, there are GND connect to the ground of circuit, VCC connects to the power supply to drive the module working, CS is a chip select the signal pin, and MISO, MOSI, SCK, and SPI is an SPI bus that uses to the synchronous serial communication interface of the microcontroller board.

2.2.3.2 Interface parameters

Table 4 Interface parameters of micro-SD card module. [60]

Parameter	**Micro SD card module**
Power voltage (V_{CC})	4.5V – 5.5V
Current (I)	0.2mA – 200mA
Interface electrical potential	3.3V or 5V
Support card type	-Micro SD card: ≤ 2G -Micro SDHC card: ≤ 32G
Size	42mm x 24mm x 12 mm
Weight	5g

2.2.4 Nextion HMI TFT LCD Display Board (NX4827T043)

Nextion is a Human Machine Interface (HMI) equipment that use to control and be a visualization interface between a human and a process of the machine. Nextion is an equipment used to apply with the IoT and the electronics field by users can create their interface on the Nextion display by using Nextion Editor software. Nextion includes two parts, there is the hardware part (TFT board) and the software part (Nextion Editor program). The Nextion HMI board has one serial port to communicate with the TFT board and the microcontroller board. Nextion HMI display can connect to MCU via TTL Serial (5V, TX, RX, GND). For the Arduino board, the user can use the Nextion HMI display with the Arduino board by communicating two boards through the serial communicator (RX, TX) in an easy way. Nextion display is a good choice for a user by reducing time to using and comfortable to use. The caution of the Nextion HMI TFT LCD is this board is working with sufficient power supply condition. If the Nextion board is working under an insufficient power supply, the Nextion model can damage easily. [61,62]

Figure 41 Nextion HMI TFT LCD Display Board (NX4827T043) [61]

2.2.4.1 Nextion display component on board.

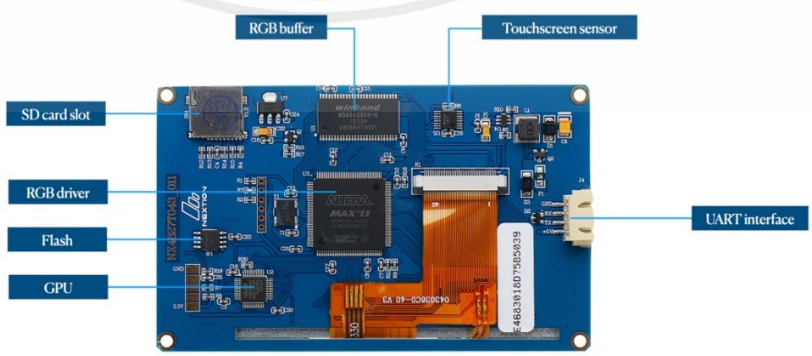


Figure 42 Component on board of Nextion display

2.2.4.2 Nextion display specifications

Table 5 Specifications of Nextion display (NX4827T043)

Parameters	**Nextion HMI TFT LED display (NX4827T043)**
Color	64K (65536 colors), 16 bits
Resolution	480 x 272 pixel
Touches	>1 million
Backlight	LED
Backlight lifetime (Average)	>30,000 Hours
Operating voltage	4.75V- 7V
Operating current (V_{CC} = +5V)	250mA
Power supplies recommend: 5V, 500mA (DC)	
Working temperature (5V, Humidity 60%)	-20℃ – +70℃
Serial Port Baudrate	2400bps – 115200bps (std = 9600bps)
Serial port mode	TTL
USB interface	No
SD card socket	Yes (FAT 32 format), support maximum 32G micro-SD card.
Flash memory	16 Mb
RAM Memory	3584 Byte

2.3 Related Software

2.3.1 Getdata Graph Digitizer

Getdata Graph Digitizer is a program that use to digitize the graph and plot. It is necessary to obtain the original data in terms of the x-axis and y-axis (x, y) from tracking the graph. This program is easily getting the numbers of the x-axis and y-axis by the program will track follow the line of data and then got data in each point. Getdata Graph Digitizer program can support many types of graphic formats such as TIFF, JPEG, BMP, and PCX. The data that got from this program can digitize the graph in an automatic tracking way or manual tracking way depend on the convenience of the user. The range of data in the x-axis and y-axis can adjust the minimum and maximum coordinate system of data. And Getdata Graph Digitizer program can export the data to many formats that suitable for user data with other programs such as TXT (text file), XLS (MS Excel file), XML, DXF (For AutoCAD). This program can be considered the easy program to digitize the data and got accurate data and a beginning person can use this program to digitize the graph and got accurate data easily by digitizing data from the picture.[63]

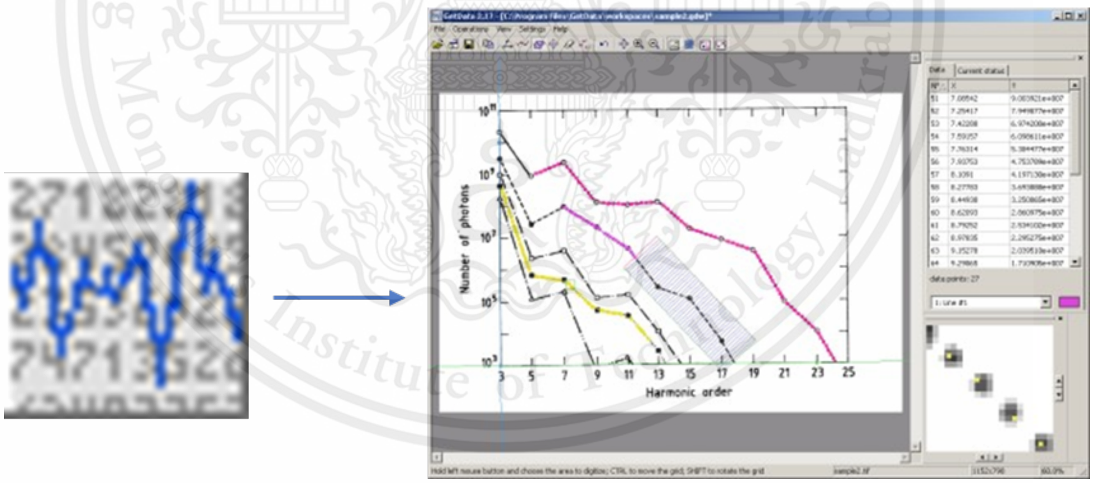


Figure 43 Getdata Graph Digitizer program [63]

This program can digitize data in four step process as follows

1. Open a graph or import the image that you want to digitize data into Getdata Graph Digitizer program.
2. Set the range of coordinate system or scale on the picture
3. Digitize the data on the graph by automatically or manually.
4. Export the data to the clipboard or suitable data file such as TXT, XLS, DXF, XML.

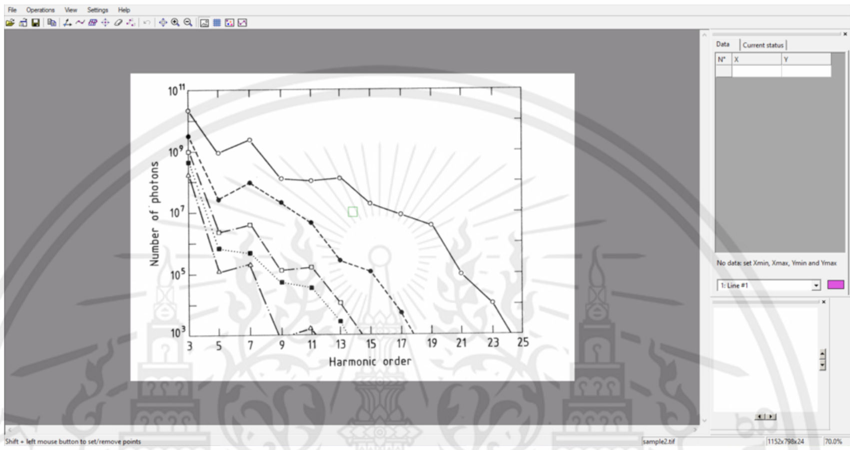


Figure 44 Open a graph or picture to digitize the data

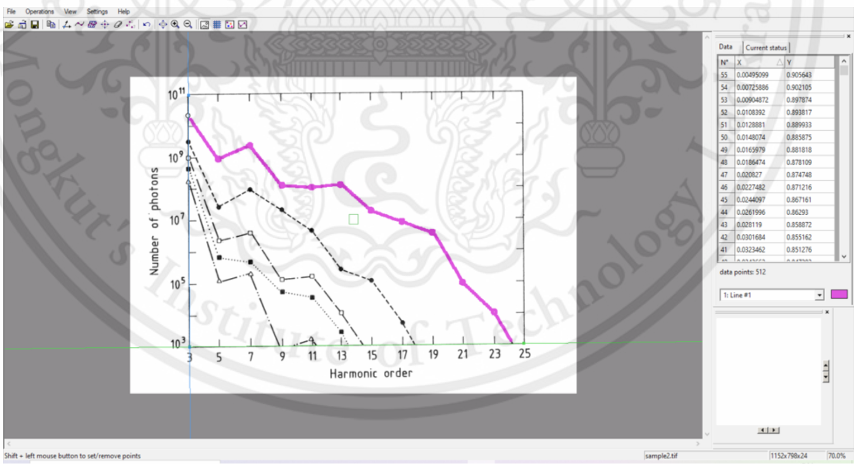


Figure 45 Digitize the graph and the data in coordinate system

2.3.2 MATLAB

MATLAB is a worldwide programming platform for engineer and scientist, this platform design specifically for analyze and design the system and product that can widely use all over the world. The key highlight of the MATLAB program is a MATLAB language and a matrix-based computational language that allowing the program can solve the problem in term of computational mathematics. MATLAB program is allowed the numeric computing function such as matrix function, plotting of function, and the implementation of algorithms. In this program, the user can create the user interface and interface with another program in other languages. MATLAB can call the functions and subroutines written the function in other programming such as C language, Fortran, or Python. The library written in MATLAB program can directly call the function from MATLAB, there are Perl, Java, ActiveX, and many libraries of MATLAB are implemented as extensive in Java library and ActiveX library. Although the MATLAB program is having a unique language and quite hard to learn, this program design for the way you think and the work you do.

So, this program will have a tutorial, guideline, and document support users that want to use this program to more understand about using the MATLAB program and get high efficiency working using from MATLAB program. So, the main target customer of the MATLAB program is worldwide for millions of engineers and scientists that use MATLAB program to learn and study about Scientific principles or various engineering at Complicated to see more pictures from using this program [64,65]

Figure 46 MATLAB program [65]

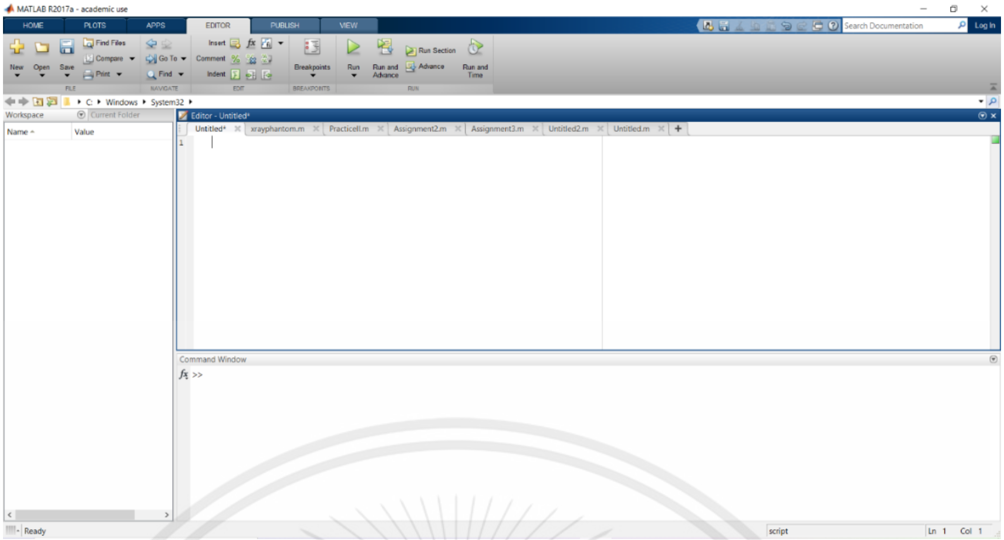


Figure 47 A workspace of MATLAB program

2.3.2.1The advantage of MATLAB programming language.

1. Ease of use: MATLAB program can be used to assess expressions typed at the command line or can execute the prewritten program to check the error of program written easily by using program debug.
2. Support multiple of computer platform: MATLAB program is supported on different computer systems. This program will run on the other entire platform and the example of platform such as Windows, Linux, and MacOS.
3. Predefined function: MATLAB program has an enormous library of predefined functions that use to support the test and prepare the answer to several primary technical tasks. and therefore, the MATLAB language will build your job more leisurely.
4. Independent plotting: In MATLAB program has a basis plotting command and, in this program, the plotting graph or picture can display on the graphical while the computer on MATLAB is running.

2.3.2.2 The disadvantage of MATLAB programming language.

1. Interpreted language: For MATLAB program, it may execute more slowly than compiled language.
2. Cost: MATLAB program has an expensive cost then it decreased necessary for engineer and scientist because MATLAB is cost-effective for the business.[66]

2.3.3 Arduino IDE

The Arduino Integrated Development Environment (IDE) is an open-source program, and it is a program application that can support multiple platforms such as Windows, macOS, and Linux. This platform application provides to use with the microcontroller same category as the Arduino board by Arduino IDE program used to write and upload the program to the Arduino compatible board. The source code of the Arduino IDE is released under the GNU General Public License by this is a free public license that allow user to share and release their work in freedom.

The Arduino IDE is provided many software libraries to support working of user with microcontroller by the software library in this program come from the Wiring project. And users can write the code in Arduino IDE quite easily. Users can share important project information with their stakeholder company. The Arduino IDE program has a comprehensive guide that available to help in the installation process. And this program has a tutorial to support the user who has little experience with a microcontroller or beginning user to understand the working and tool's framework of the Arduino IDE program. So, the Arduino IDE is a highly using rate program by this program ease of use, ease to be writing and understanding the code, and everyone can access this program easily.

Figure 48 Arduino IDE [78]

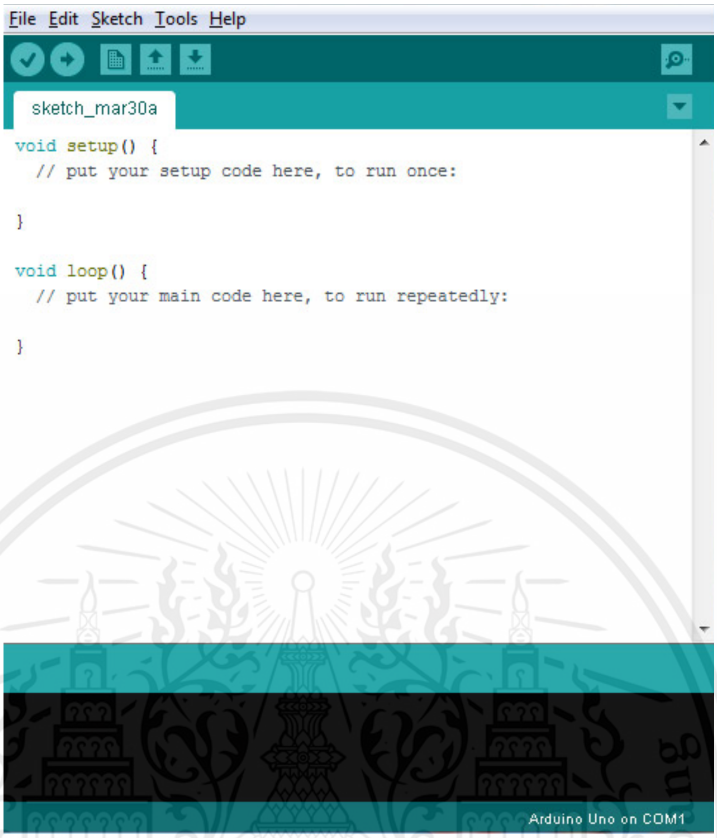


Figure 49 The sketch of Arduino IDE for write and upload the program

2.3.3.1The advantage of Arduino IDE program

1. There are a lot of sketches and shields available and many examples in the sketch.
2. User doesn't use much knowledge to understand and write the code in this program.
3. Low cost for download the Arduino IDE program, everyone easily accesses this program.

2.3.3.2The disadvantage of Arduino IDE program

1. The sketch of the Arduino IDE program is difficult to modify
2. This program doesn't have a debugger to check the scripts.

2.3.4 Nextion Editor

Nextion Editor is a program that uses with Nextion HMI TFT display, it is a development software used for creating a graphical user interface for GUI-intensive devices such as TFT displays, and Nextion Editor program is used to the rapid created the interface display to Nextion HMI devices. Nextion Editor program will help users create the interface of TFT-based devices at faster and easier. The feature in the Nextion Editor has some different features depending on the type of Nextion TFT display.

The ability of this program can simulate the interface before uploading the program to the Nextion TFT display by the user can see the working feature on display after the user designs the interface to the TFT display. And this function in Nextion Editor program will reduce the time to design the interface and see the accuracy result. This program quite easy to design the graphic interface to the GUI intensive device. [69,70]

Figure 50 Nextion Editor program [79]

Figure 51 Nextion IDE to design and program the user interface

2.3.5 Autodesk Fusion 360

The Autodesk Fusion 360 is a 3D designing program that includes CAD, CAM, and CAE in one cloud-based platform. For product development work includes both mechanical and industrial design. Simulation, machining, and collaboration via the Internet in a single package. The tools within Fusion 360 are convenient, fast, and easy to implement from design ideas to prototypes through to production preparation processes. For this program is a cloud-based system, users can easily access to design their work everywhere and every time that user wants to do their design work. The Autodesk Fusion 360 program is suitable for an engineer or who wants to design, simulate, or assembly the 3D of a model to check the suitability and functionality of the design in this program easily. The highlight of this program is the user can share and work as a team to develop and design the product together under the cloud-base system by the user can share a design with anyone or be specific. Which is safe by using the Public sharing link in Autodesk Fusion 360 program.

So, the Autodesk Fusion 360 is a program for design 3D modeling that is convenient for a user to design the work, and the user can work as teamwork to develop design work be better under the cloud base system of the program.

Figure 52 Autodesk Fusion 360 [80]

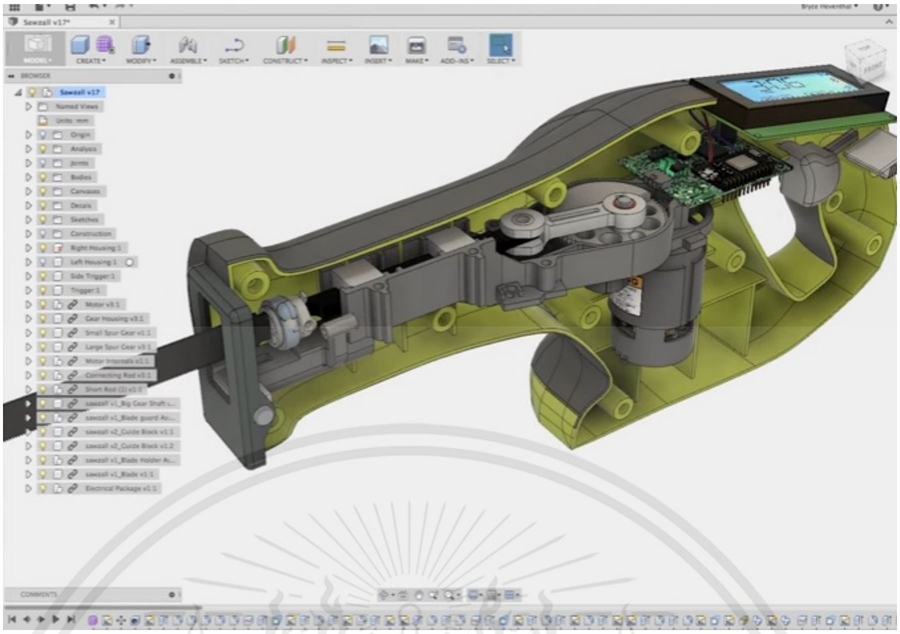


Figure 53 Example design in Autodesk Fusion 360 [81]

2.3.5.1 The advantage of Autodesk Fusion 360

1. The Autodesk Fusion 360 is a program that uses the least experience to be designing the 3D model.
2. Fusion 360 has the functionality to save all of your files online under the cloud base system.
3. Users can access Fusion 360 to create or design their model everywhere and every time and users can access see their work through the application on a tablet or mobile device.

2.3.5.2 The disadvantage of Autodesk Fusion 360

1. The software of Fusion 360 may lag from a low internet connection
2. Fusion 360 uses a lot of the device's memory; it is recommended to select the high value of RAM possible on your device.

CHAPTER 3

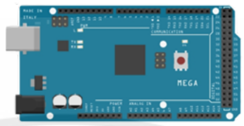
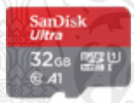
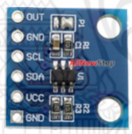
METHODOLOGY

This chapter describes the methodology and related information to do the ECG simulator 3 leads by using Arduino. It consists of the materials and the research process. The material that we use in this project is considering the choice of material and worthiness of using the material in the ECG simulator project because the purpose of this project is to create the ECG simulator at low cost and got the result on standard efficiency. And the material used to make ECG simulator 3 leads by using Arduino is divided into research equipment, research instrument, and research software, and the research process is the process of creating the ECG simulator 3 lead by using Arduino project. This process is divided into four steps, there are define, create, test, and improve and assemble. And each step of the research process has explained the process in detail. The readers can understand the process to do the ECG simulator 3 lead by using Arduino from the contents of this chapter.

3.1 Materials

3.1.1 Research Equipment

Table 6 Research Equipment

No.	Equipment name	Picture	Function
1	Arduino Mega 2560		Microcontroller Board
2	Micro-SD Card Module		To communication between the micro-SD card and Arduino Mega 2560.
3	Micro-SD Card		Storing data
4	Digital to Analog Module		To convert the digital to analog values.
5	Nextion HMI TFT LCD Display Board (NX4827T043)		Interface that allows user to create own display.
6	Wires		Wiring connection
7	Photo board		Connect the electronic components to prototype.

8	Resistors 300 ohm		Voltage divider of ECG signal
9	Resistor 1.4K ohm		Voltage divider of ECG signal
10	Resistor 1K ohm		Voltage divider of ECG signal
11	Resistor 1M ohm		Voltage divider of ECG signal
12	Banana Jack		Use to be an output of ECG signal in 3 leads
13	DC Adapter		To be a power supply of Arduino Mega 2560 board.

3.1.2 Research Instrument

Table 7 Research Instrument

No.	Instrument name	Picture	Function
1	Oscilloscope		Show and measure ECG graph.
2	Digital multimeter		Measure DC voltage.
3	Soldering		Soldering the component with wires.

3.2 Software

3.2.1 Research software

Table 8 Research Software

No.	Software name	Picture	Function
1	Getdata Graph Digitizer program		Auto track the image line then change to x and y coordinate.
2	MATLAB program	MATLAB	Interpolate the ECG data
3	*Arduino Software* (IDE)		Write the code and upload it to Arduino Mega 2560 board.
4	*Nextion Editor*	NEXTION	Create and design display
5	*Autodesk Fusion 360*	360	Create the box for ECG simulator
6	*Pspice* program		Simulate the electrical circuits and simulate the results.

3.3 The research process

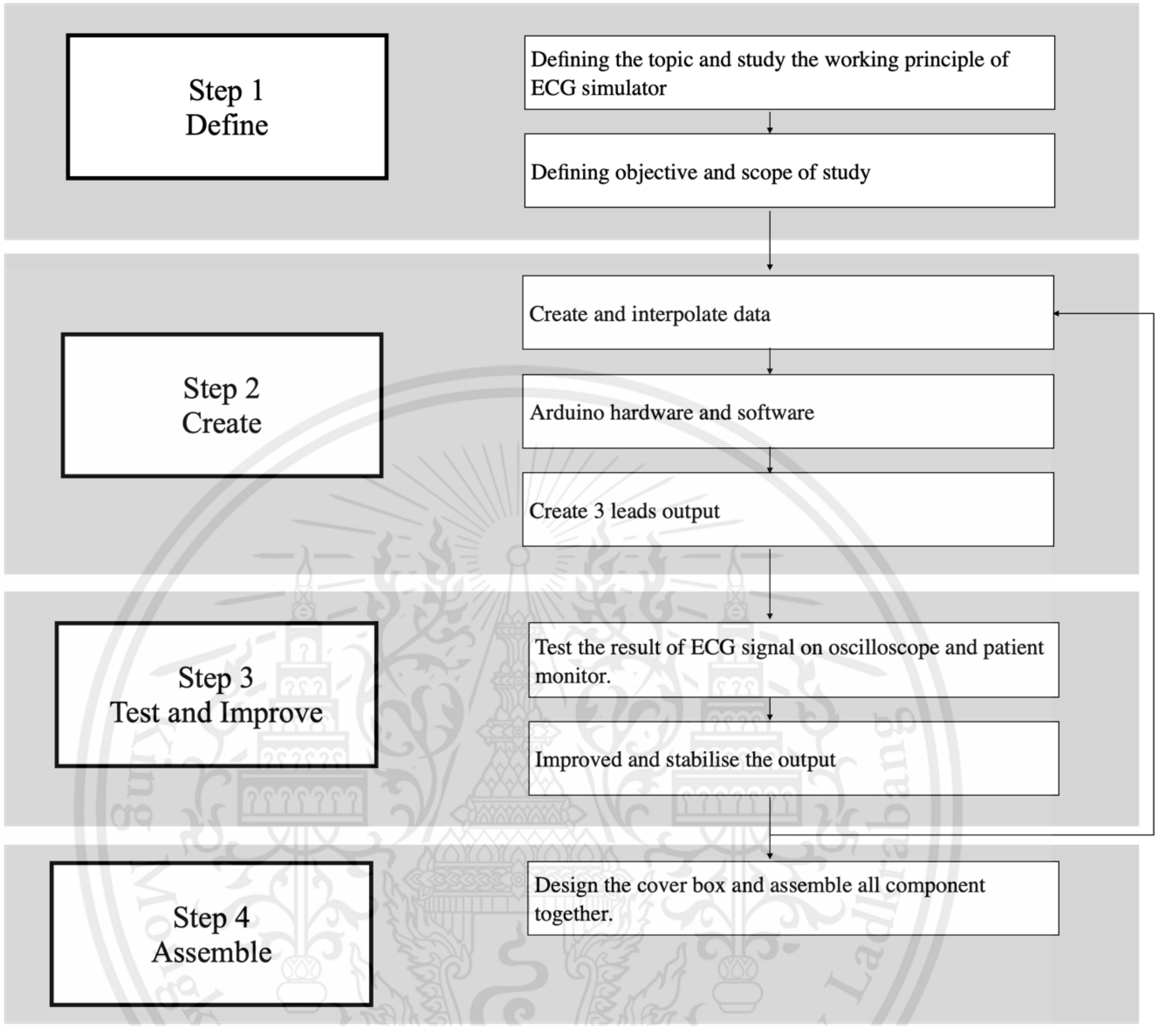


Figure 54 The research processes

3.3.1 Step 1: Define

To determine the topics for research, it is based on surveys of the needs in the company and the interests of the researchers themselves, then gather information, documents and related research to study and find the answers to do the research topics. In addition, it will be designed to develop the characteristics and patterns that are suitable for the company as well as in accordance with the intended objectives. The topic for this research is ECG simulator 3 leads by using Arduino. This project wants to create and develop the function of the ECG simulator and the user can use it more easily to get the effective ECG signal as same as the commercial ECG simulator but with lower cost.

3.3.2 Step 2: Create

3.3.2.1 Create and Interpolate the ECG data

We need the right ECG waveform to digitizer, which finds the standard ECG image and then uses the Get data graph digitizer program for auto track data. The length of the X-axis and the Y-axis must be set, and then the Get data graph digitizer program converts the track points to x-axis coordinates and y-axis. The x-axis is set to range 0 - 0.6 according to the graph paper size and the y-axis is set to range equal to 0-4095 because it uses a DAC 12-bit covert data (Figure38) We will call this information ECG data, after which we export it as a text file.

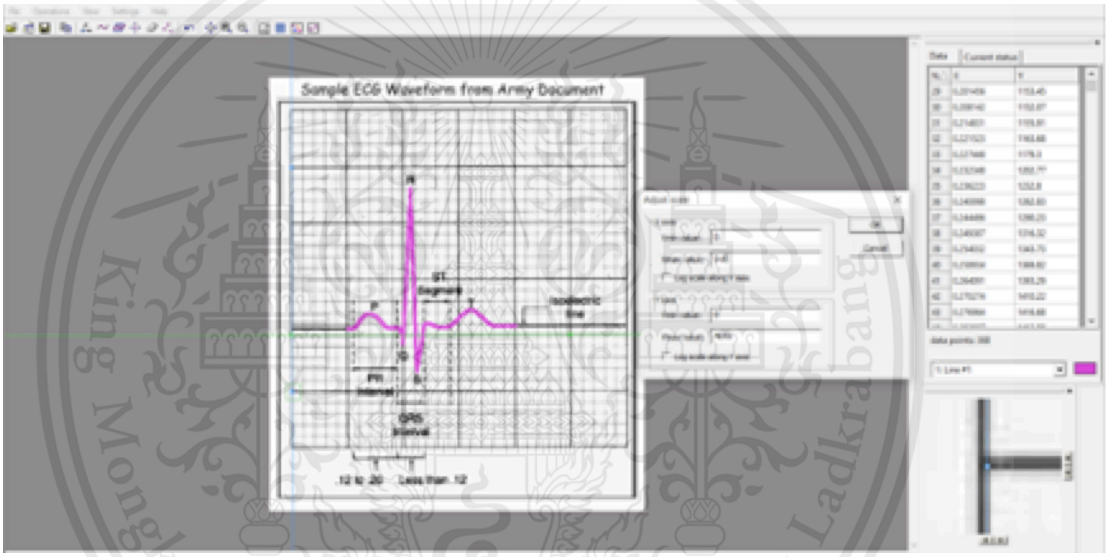


Figure 55 Auto track ECG line on Get data graph digitizer program and set the range

We get ECG data from Get data graph digitizer program as a text file, then import it into MATLAB program to interpolate the data. We use linear interpolation to estimation a values of ECG data by assuming that it is a straight line between known values, which is data from Get data engage digitizer program. We have to interpolate ECG data because the ranges of the x-axis and the y-axis of the obtained data are not equal in each range. In addition, we will be able to adjust the number of ECG data while interpolate. The result after interpolating, the data is shown as in the Figure39. It was found that the resulting ECG graph was more consistent than before interpolate. In addition, the data in the x-axis Each range has the same value.

```
clear
clf

data = load('ECG_data.txt');
x= data(:,1:1);
y =data(:,2:2);
plot(x,y);
figure(1),subplot(121),plot(x,y);
title('Real Data ')


x1= data(:,1:1);
y1 =data(:,2:2);
xin = (0:0.0015:1)';
yin = interp1q(x1,y1,xin);
figure(1),subplot(122),plot(xin,yin);
title('Interpolated Data ')
```

Figure 56 MATLAB code for interpolate ECG data obtained

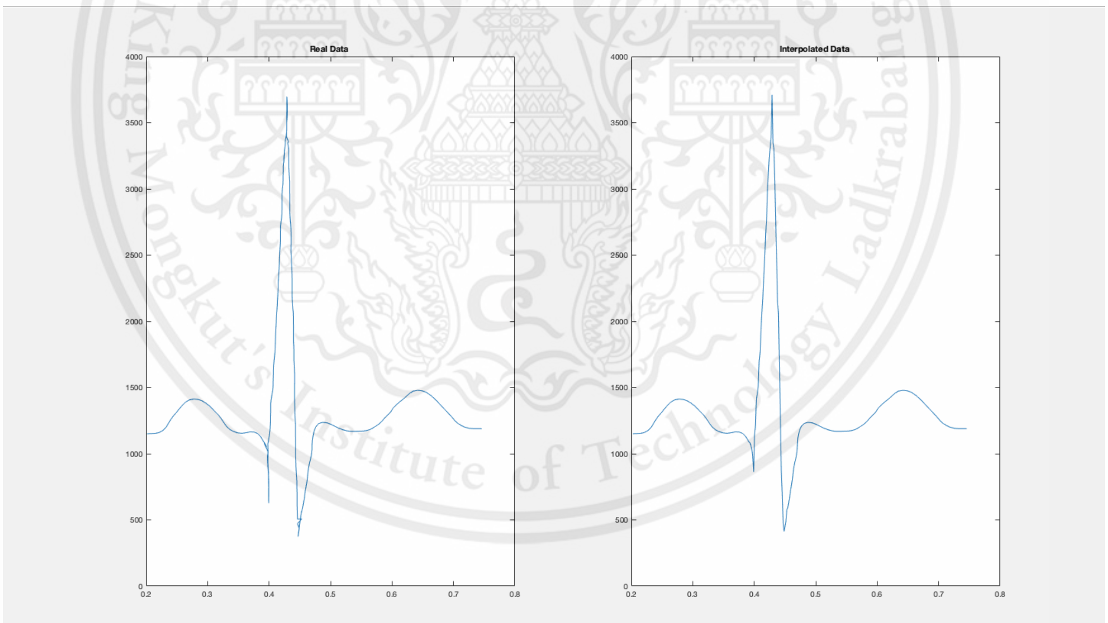


Figure 57 Compare ECG data between before and after interpolating.

Then save the data after interpolating with MATLAB program as a text file and save to micro-SD card.

3.3.2.2 Arduino Part

1 Arduino Mega 2560 board with micro-SD card module

This procedure is for importing ECG data to Arduino Mega 2560 by using the micro-SD card module. We have already interpolated the ECG data, convert it to a text file, and store it in the micro-SD card. Mainly, plug the micro-SD card into the micro-SD card module and connect the micro-SD card to the Arduino Mega 2560 board. And write the Arduino IDE code so that Arduino Mega 2560 can receive ECG data from the micro-SD card module.

The micro-SD Card module is a Serial Peripheral Protocol (SPI) communication device where SPI communication can be used to communicate between the microcontroller board and multiple peripheral devices simultaneously. The micro-SD Card module has 6 pins: MISO (Master in slave out) pin, MOSI (Master out slave in) pin, SCK (Serial clock) pin, SS (Slave select) pin, 5V pin. and GND pin that must be connected to the mega Arduino board 2560 (Figure41).

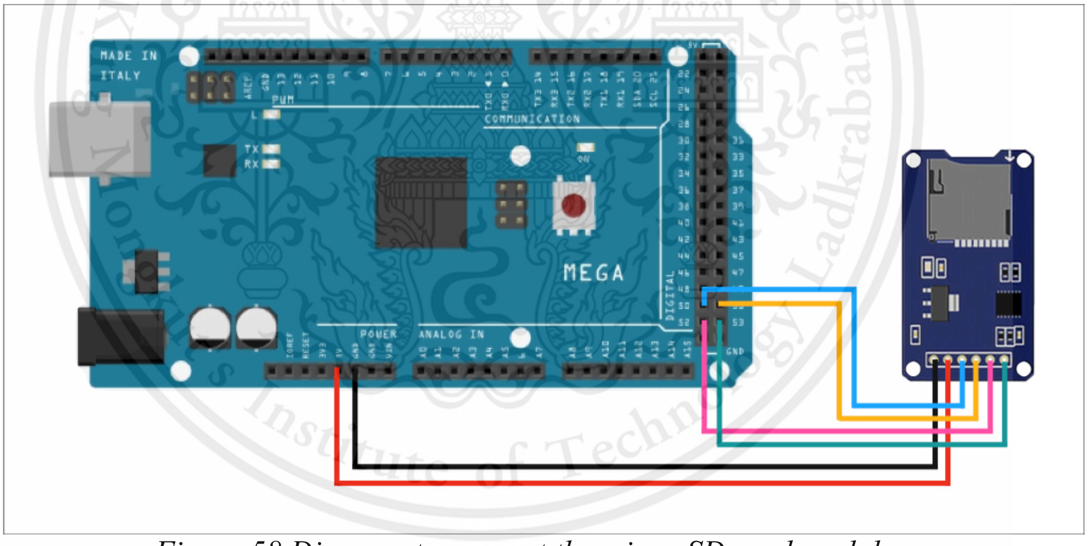


Figure 58 Diagram to connect the micro-SD card module

The code used to receive the values from the micro-SD card with the micro-SD card module will be displayed as in the Figure41, and the resulting value will be shown as in the Figure42.

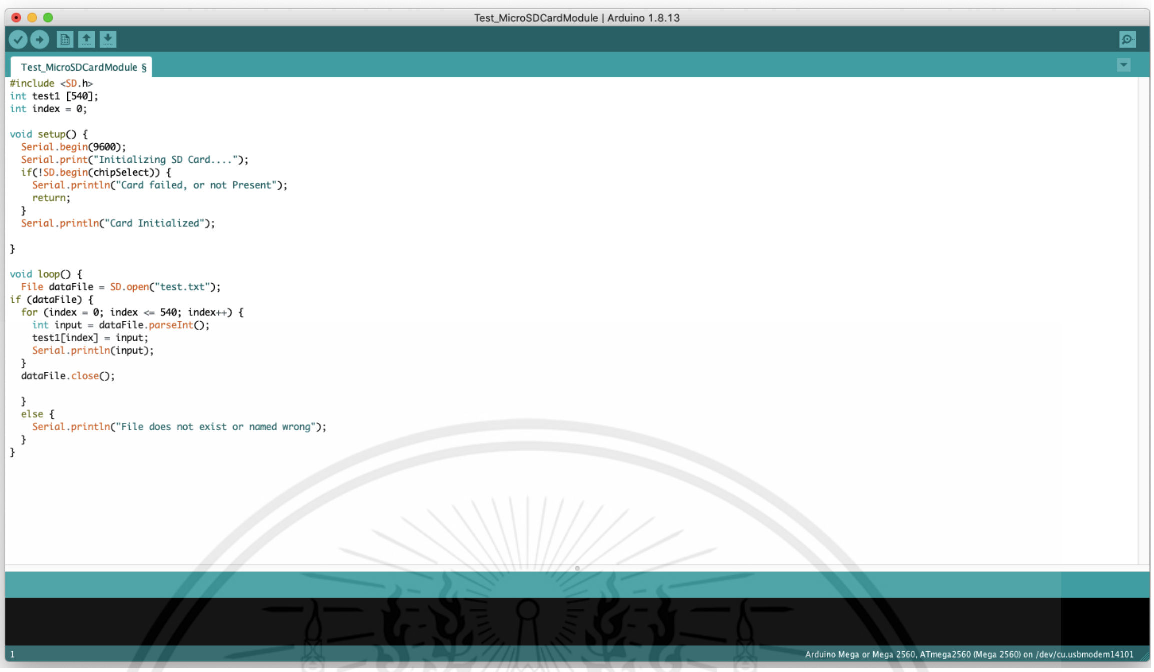


Figure 59 A code to receive values from micro-SD card with micro-SD card module

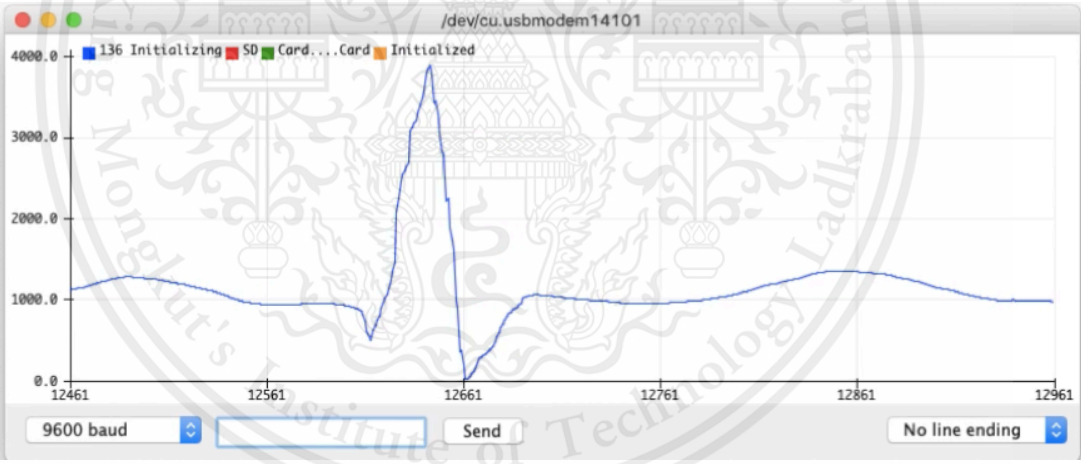


Figure 60 The output obtained from the micro-SD card is displayed

2 Arduino Mega 2560 board with digital to analog module (MCP4725)

This procedure is for exporting the analog data by using digital to analog module (MCP4725). The analog data will show on the oscilloscope. Digital to analog module converts digital signals to analog signals using MCP4725 board, connected as I2C, 12 Bit resolution, digital numeric value between 0-4095. We have used the digital to analog module, where the module we use is MCP4725 board connected to the Arduino Mega 2560 board and write Arduino IDE code to generate a sine or triangle or a square. Then connect the oscilloscope to the digital to analog module (MCP4725) so that the graphs displayed on the oscilloscope screen and check that the graphs we write the code and the graphs displayed on the oscilloscope should have the same look.

Connect the 5V. pin and GND pin of the Arduino Mega 2560 board to the MCP4725 board VCC and GND pin, then connect the A20 (SDA) pin, A21 (SCL) pin to the corresponding I2C pin of the MCP4725 board.

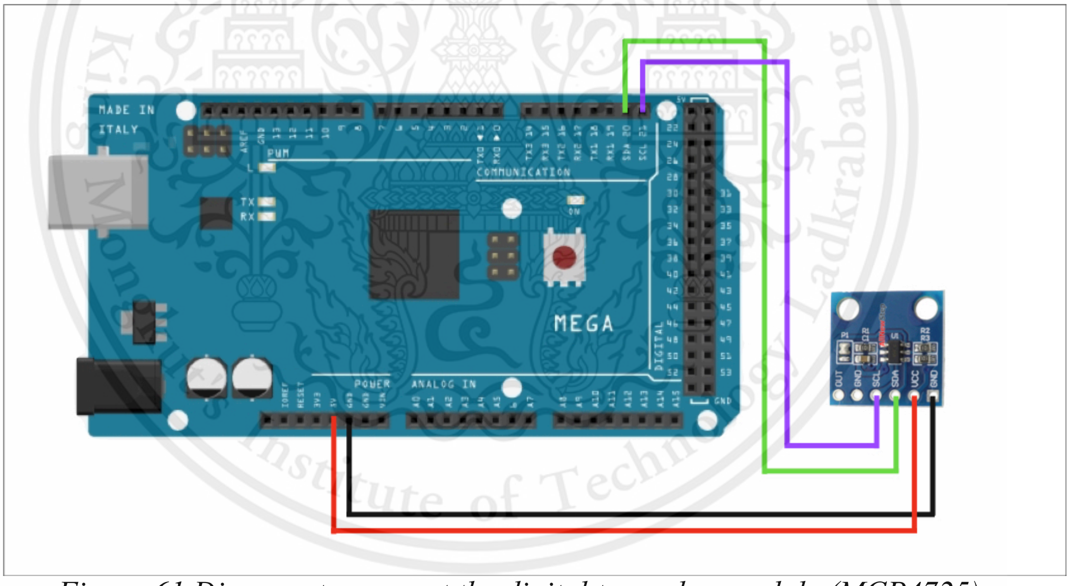


Figure 61 Diagram to connect the digital to analog module (MCP4725)

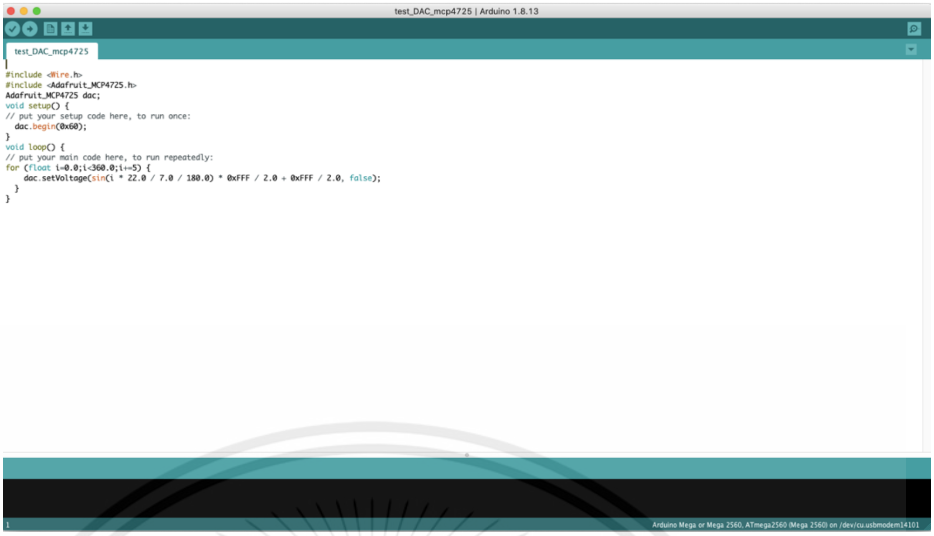


Figure 62 A code to create a sine curve and use the MCP4725 board

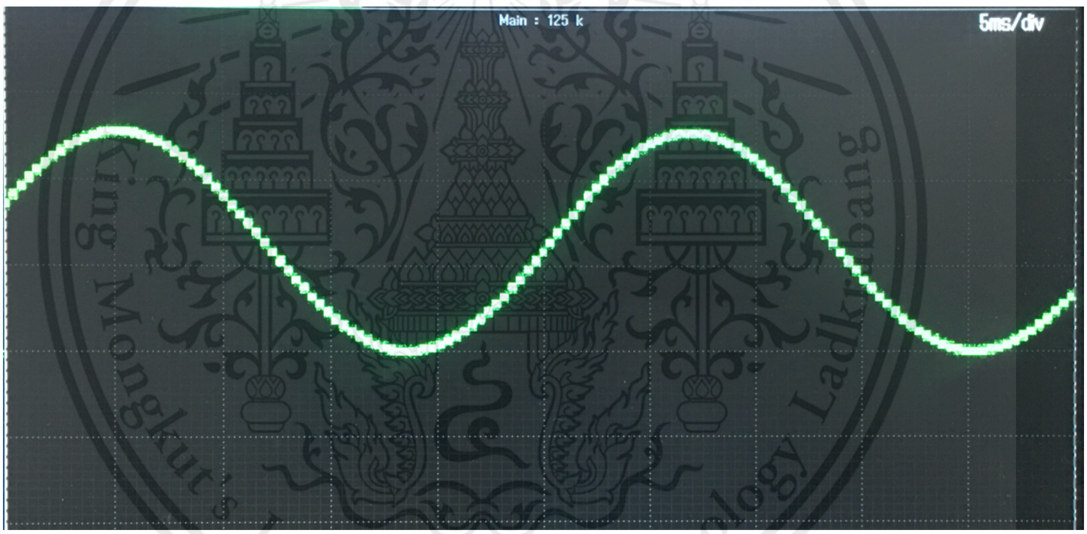


Figure 63 The results show the analog values convert from the MCP4725 board

3 Arduino Mega 2560 board with micro-SD card module and digital to analog module (MCP4725)

This procedure is for importing ECG data to Mega Arduino by using the micro-SD card module and export the ECG data by using digital to analog module (MCP4725). In this step, we connect the micro-SD card module and digital to analog module (MCP4725) together, the Arduino Mega 2560 board is the micro controller that receives data from the micro-SD card module with ECG data and then converts the data to analog by using the digital to analog module (MCP4725). When the oscilloscope is connected to the OUT pin and GND pin of the digital to analog module (MCP4725) on the display of the oscilloscope, the ECG graph is displayed.

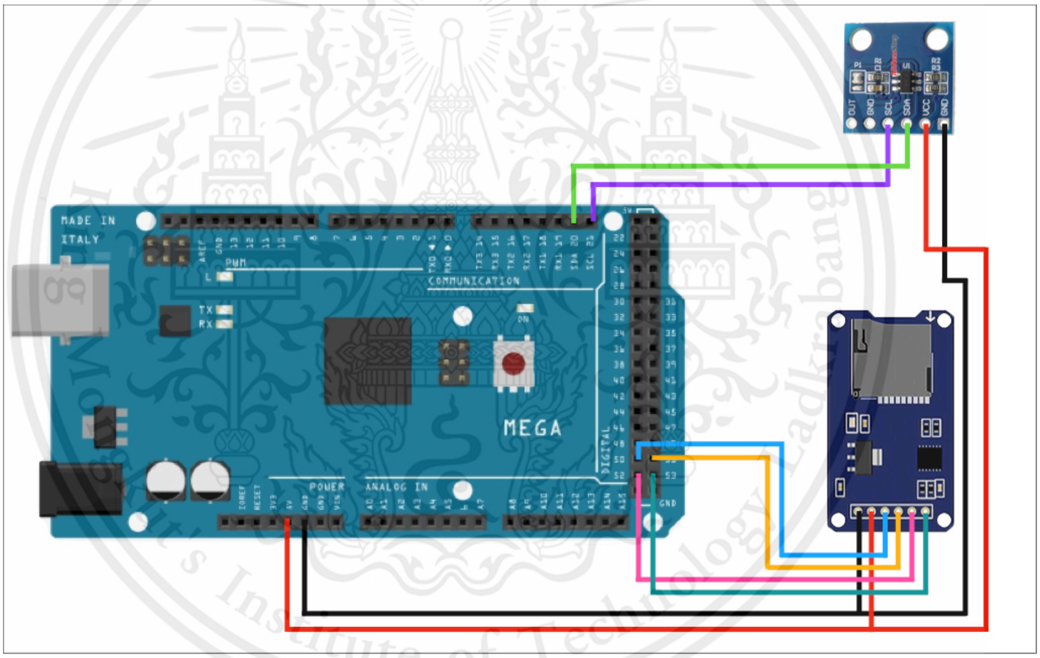


Figure 64 Diagram to connect the micro-SD card module and digital to analog module (MCP4725) with Arduino Mega 2560 board.

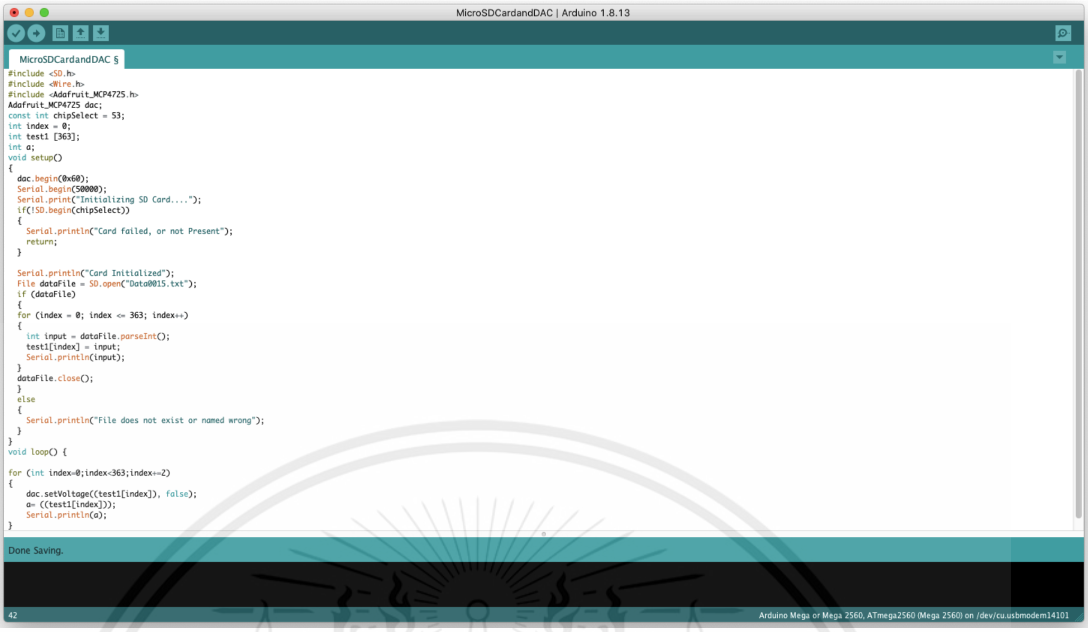


Figure 65 A code to receive values from micro-SD card with micro-SD card module, then digitally convert data via MCP4725 board.

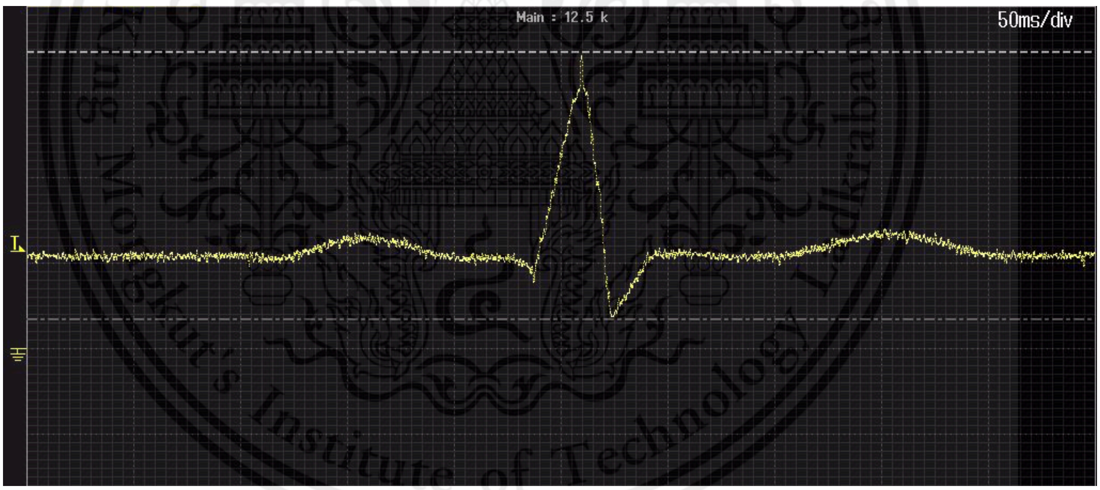


Figure 66 The results show the ECG graph on the oscilloscope.

4 The Nextion HMI TFT LCD Display Board (NX4827T043) for adjusting heart rate and amplitude (gain) of ECG graph.

This procedure is for connect NX482 7T043 to Arduino Mega 2560 which NX4827T043 also known as the Nextion HMI TFT LCD Display Board, it will be a controller and send values to Arduino Mega 2560 for adjusting heart rate and amplitude (gain) of ECG graph. This step is divided into two parts: display creation in the Nextion Editor program and the Arduino program.

-The Nextion Editor programs

Use Nextion Editor to create a display Figure50. It also sends values when buttons are pressed to the Arduino.

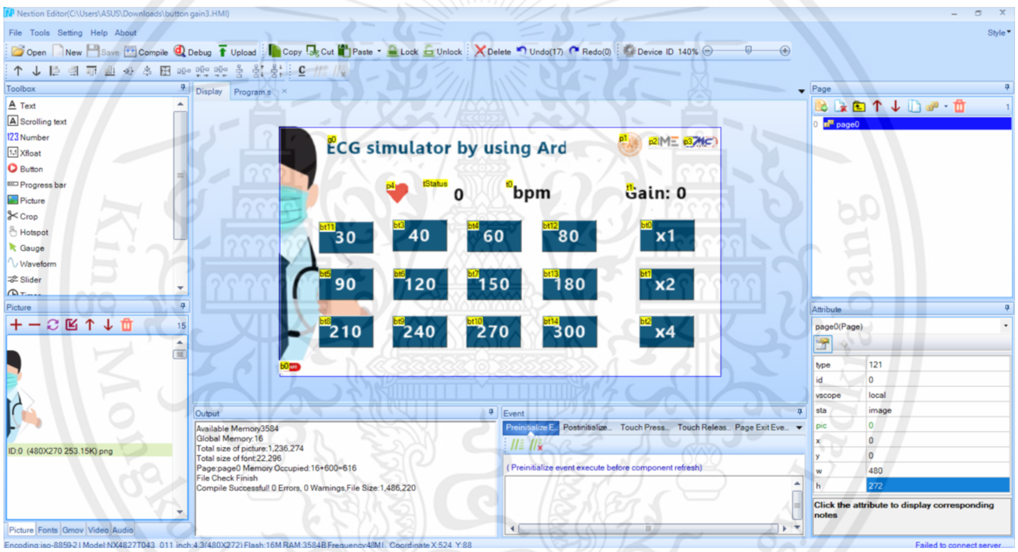


Figure 67 Display design in Nextion editor program

We use the basic function in Nextion Editor program to design the interface to Nextion HMI TFT LCD display (NX4827T043) to send the value to the Arduino board. And the main basic feature from toolbox of Nextion Editor program that we use to control heart rate and amplitude (gain), there are dual state button, button, and text box.

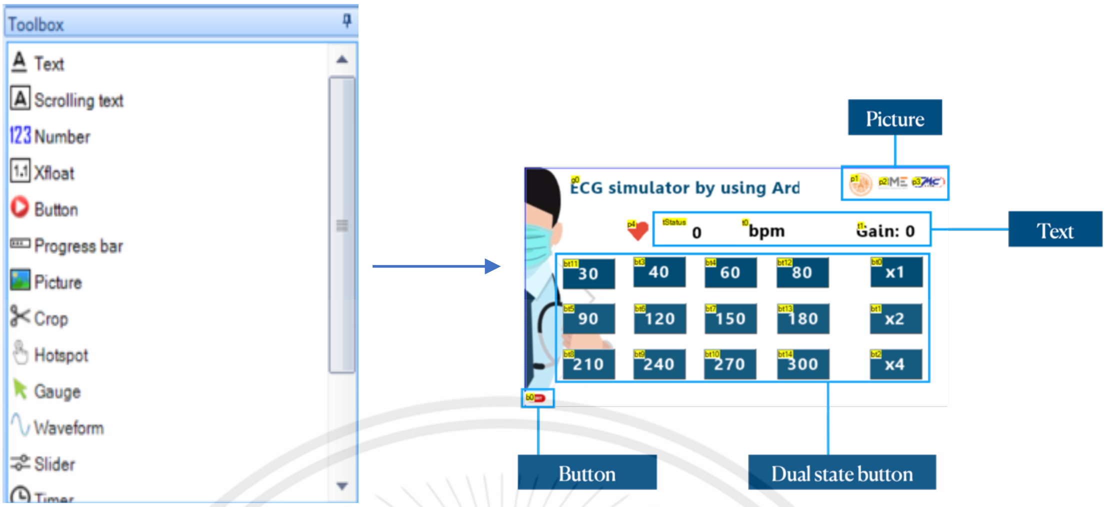


Figure 68 Design interface from toolbox features on the Nextion Editor

1 Button: The button component of Nextion Editor in this project serves as a reset button that use to clear the data to zero by this button can create the command in the touch press event and touch release event. In this project, the command that sent zero to be a clear command data to the Arduino board and the data from Nextion Editor will be sent data in term of hexadecimal data such as “23 03 56 00 00”

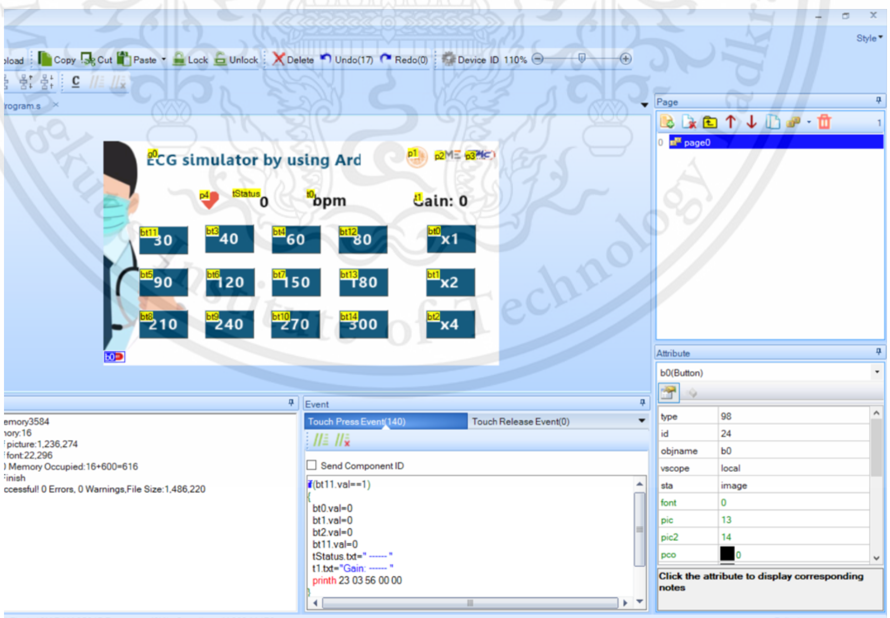


Figure 69 The reset button command in the Nextion Editor

2 Dual state buttons: The dual state button in Nextion Editor program serve as a toggle button and the command of this button can write in the touch press event and touch release event as a button component. And the command from the Nextion Editor will send the data in terms of hexadecimal data.

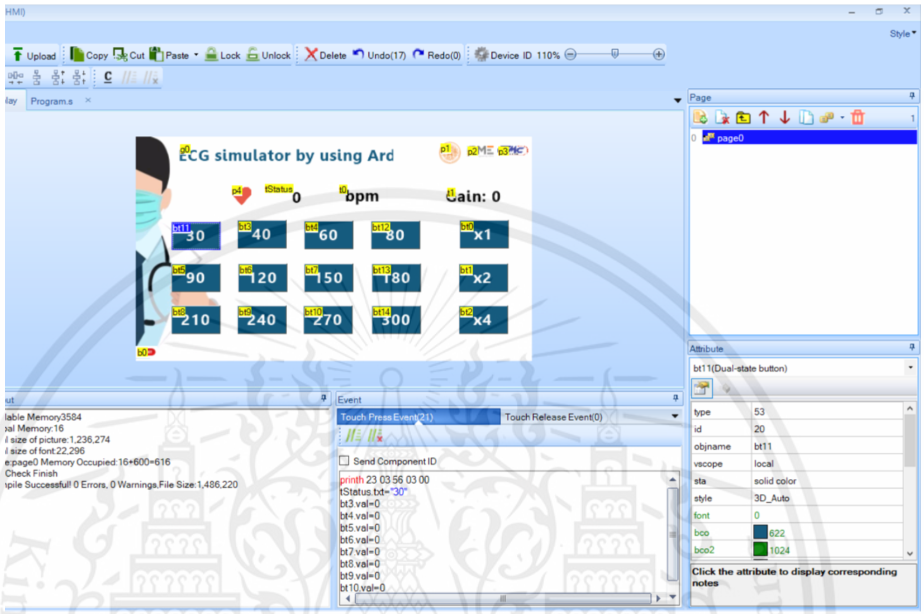


Figure 70 The example command in Dual state button

3 Text: The text in the Nextion Editor program is highly customize that the user can create text in character or password that can change in the attribute of the text component. In this project, we use text to show the value when adjusting heart rate and amplitude (gain). And the notice when using text in the Nextion program should upload or open the fonts before using the text component prevent the command error.

4 Picture: The picture is the tool that use to help users design the interface more easily by the user can upload the picture into the program and can design their interface freely. The kind of pictures can be PNG files and JPG files. And the size of the picture should not bigger than the touch screen device. The picture component is useful in the multi-state and animation sequence.

-Arduino program

In this step, connecting the micro-SD card module and digital to analog module (MCP4725) with Arduino Mega 2560 board is done as before, and then we have connected the Nextion HMI TFT LCD Display Board (NX4827T043) to the Arduino Mega 2560 board after using the Nextion Editor program. The Nextion HMI TFT LCD Display Board (NX4827T043) is attached to the TX pin and RX pin of the Arduino Mega 2560 board. Then the Nextion HMI TFT LCD Display Board will send various values according to the position we press into the Arduino Mega 2560 board. Then the Arduino Mega 2560 board will calculate the resulting value. And use the calculated data combined with the data obtained from the micro-SD card module and send the output via digital to analog module (MCP4725).

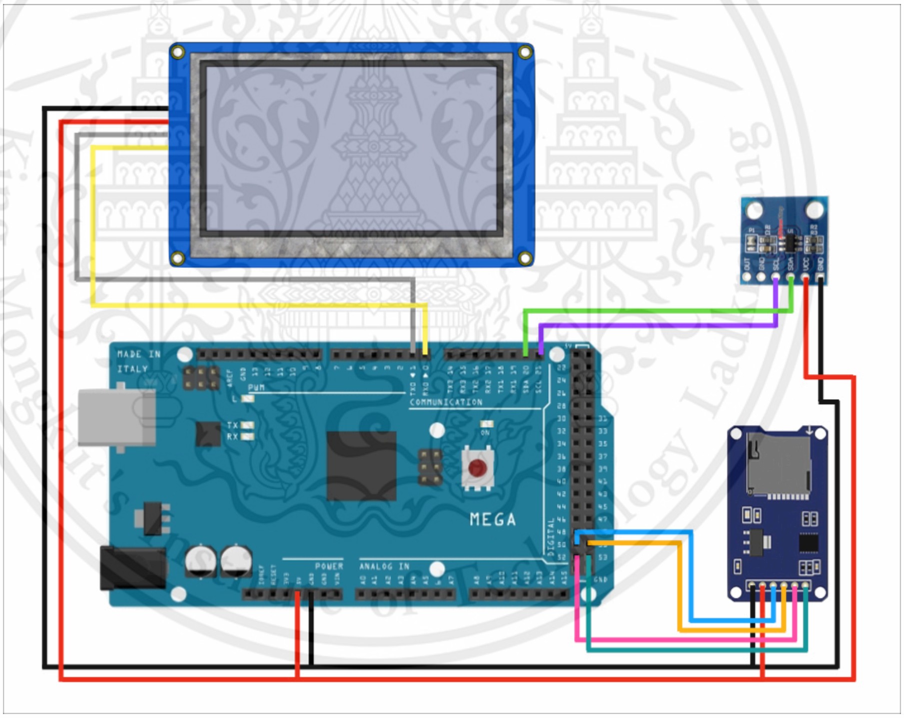


Figure 71 A diagram of ECG simulator 3 leads by using Arduino

The code starts with the Arduino variable setup and import library, then enters the setup function, receives the digital values from the micro-SD card module that reads the data on the micro-SD card, then stores the value and enters the infinite loop that uses the value from the Nextion_serial_listen function and sends the value to the plot function. (Figure55 (a.))

The Setup function starts with the Serial begin setting, which determines the transmission speed. This is called Baud rate, the higher the value, the faster the data will be sent. Then it will receive data from micro-SD card with micro-SD card module. The coding will check for a micro-SD card. If there is no micro-SD card will show "Card failed, or not Present" but if found there will show "Initializing SD Card ...." on serial monitor then read the value from the file which we have entered the name. If read is successful, it will show "Card Initialized", but if reading is not successful it will show "File does not exist or named wrong". Here we use all two values: an ECG 1 cycle comprising P wave, PR interval, QRS complex, ST interval and T wave, and the other is isometric line used to adjust the heart rate. (Figure55 (b.))

The Nextion_serial_listen function works by getting the value from the Nextion HMI Display, which sends the value hexadecimal, and then Arduino receives the value and reads the value, and then changes it to decimal. The values we receive consist of two values: One value is used to adjust the heart rate value (BPM) and the other for adjusting the value of the amplitude (Gain) after receiving the value and then storing it in the BPM and Gain. (Figure55 (c.))

The Plot function works by taking a value from the Nextion_serial_listen function, which accepts two values: BPM and Gain, then calculates the delay time for adjusting the heart rate and the amplitude of the ECG graph for adjusting the gain. When the calculations are complete, it is combined with the stored ECG 1 cycle and isometric line data. Then send the values through the digital to analog module (MCP4725). (Figure55 (d.))

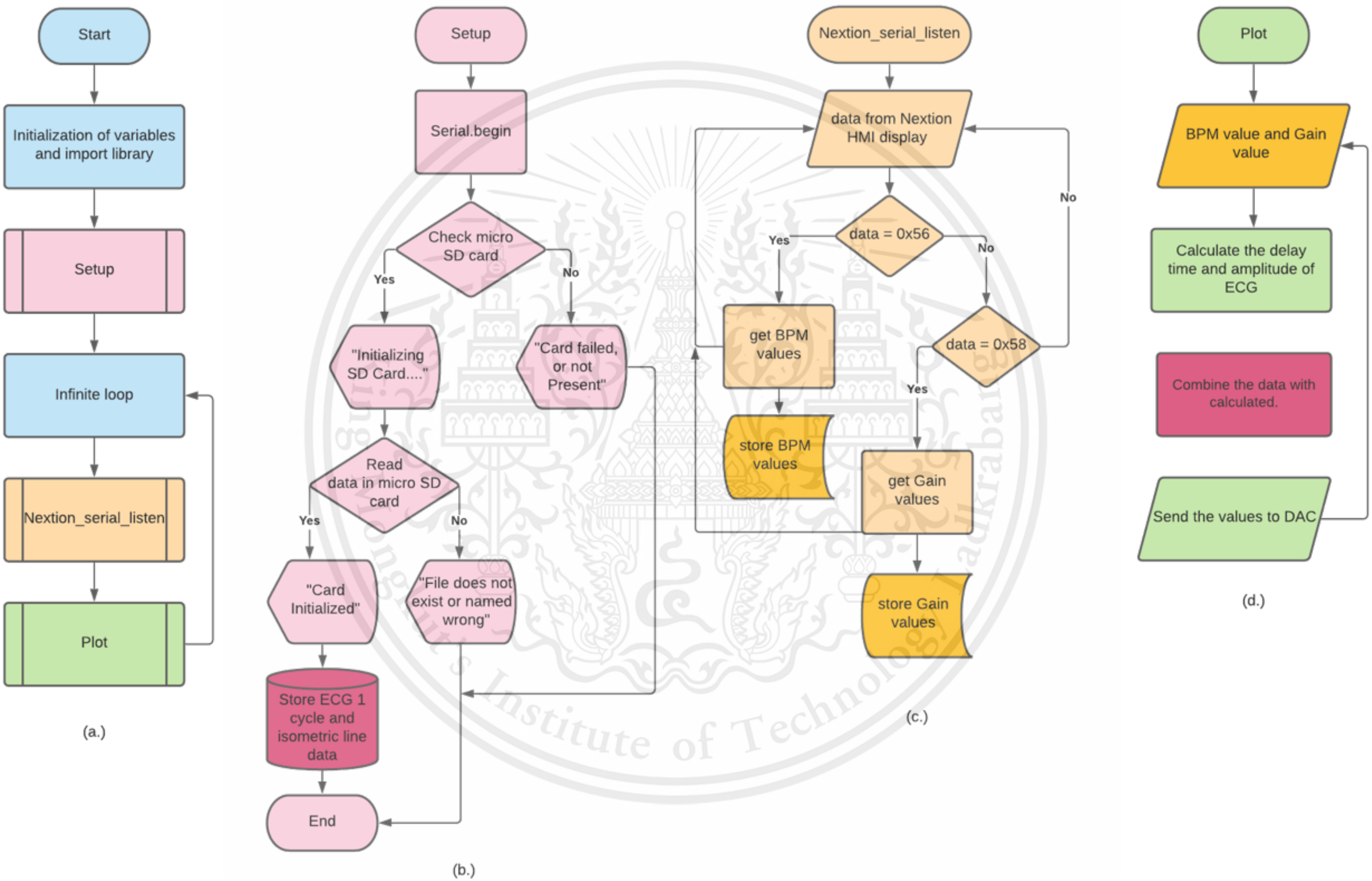


Figure 72 A flowchart of ECG simulator 3 leads by using Arduino

3.3.2.3 Create 3 leads output

1 Simulate the circuit in the PSpice program.

The PSpice program is a program that uses to design the circuit and simulation the output of the circuit and we use this program to simulate the voltage of each lead of the ECG simulator compare with the voltage value from the theoretical principle of the ECG simulator in each lead. For the circuit on the PSpice program, we use Vsin to be a power source of the circuit and the output voltage of the ECG simulator circuit on PSpice will come out in the form of a sine graph. and it allows us to compare the output voltage in each lead easily to compare with the theoretical values. The schematic of the ECG simulator circuit on PSpice follows the figure below.

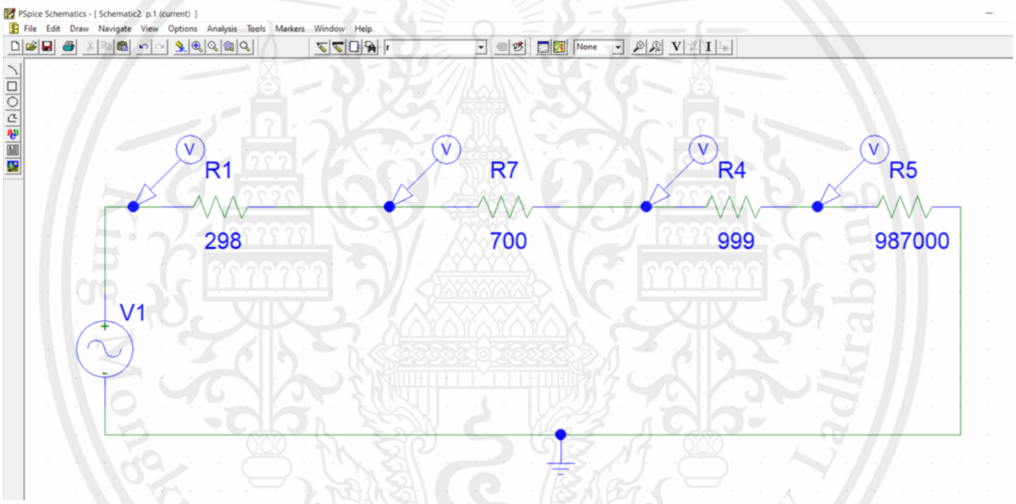


Figure 73 Schematic the ECG simulator 3 leads circuit in PSpice program

2 Measure the voltage in the PSpice program.

The output voltage of PSpice is an output voltage in form of a sine wave because we use the supply source be Vsin and the PSpice program will calculate the voltage in each lead by using the voltage divider calculation by this program will automatically calculate the output voltage in each lead. Calculation of the output voltage depends on the resistor value and input voltage of the circuit. And the output voltage result of each lead in form of a sine wave will show in the Figure below.

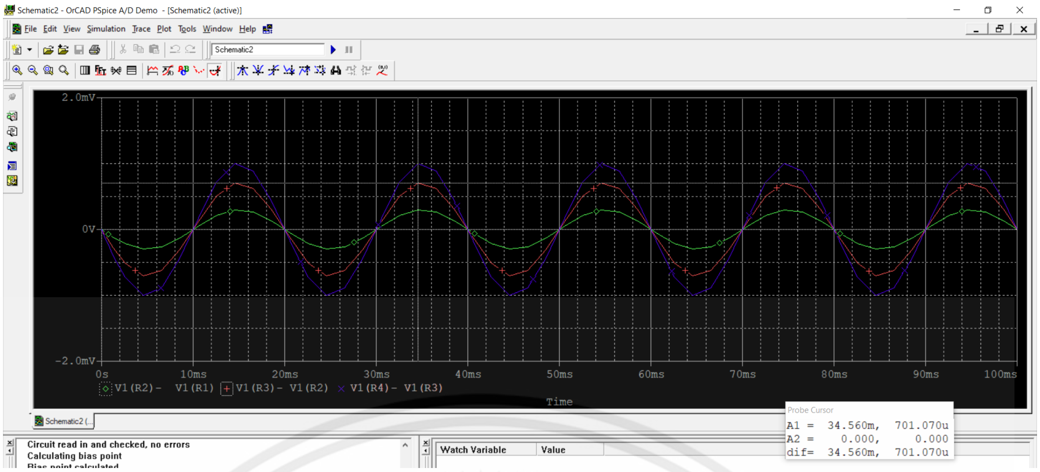


Figure 74 The output voltage of ECG leads I

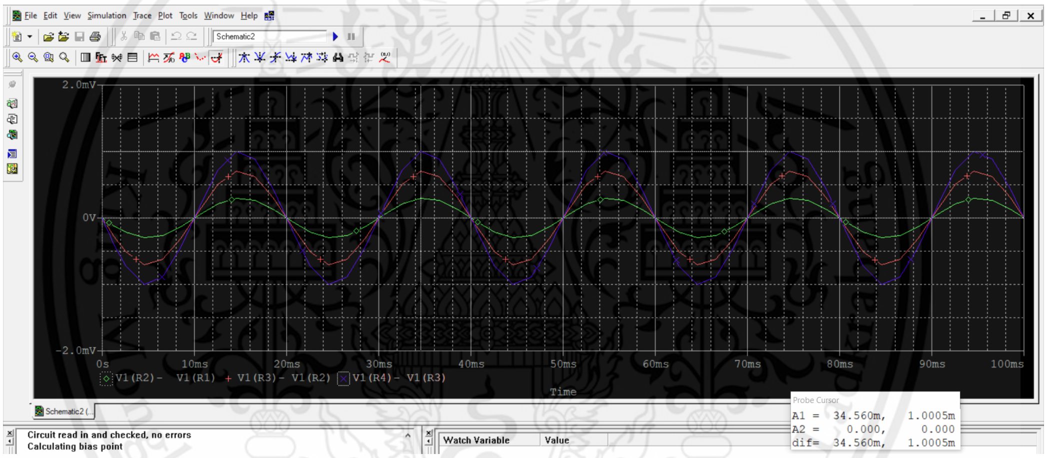


Figure 75 The output voltage of ECG leads II

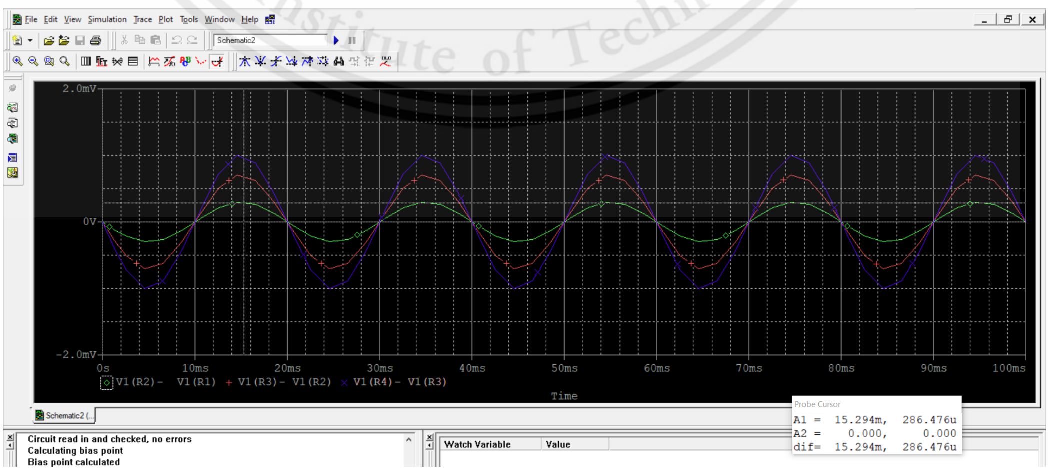


Figure 76 The output voltage of ECG leads III

3.3.3 Step 3: Test and Improve

This step, we connected an output to the oscilloscope to measure the amplitude of ECG in each lead, length of P wave, length of PR interval, length of QRS complex, QT interval and length of ECG 1 cycle. We also measured the BPM in the oscilloscope. We then tested it with a patient monitor and developed it to be in the correct ECG cycle, heart rate and amplitude.

3.3.4 Step 4: Assemble

In this step, we have created a box for ECG simulator, using the Autodesk fusion 360 program to create it to apply the 3D printer pint out. We have created two pieces, the box and the lid, as shown in the figure below.

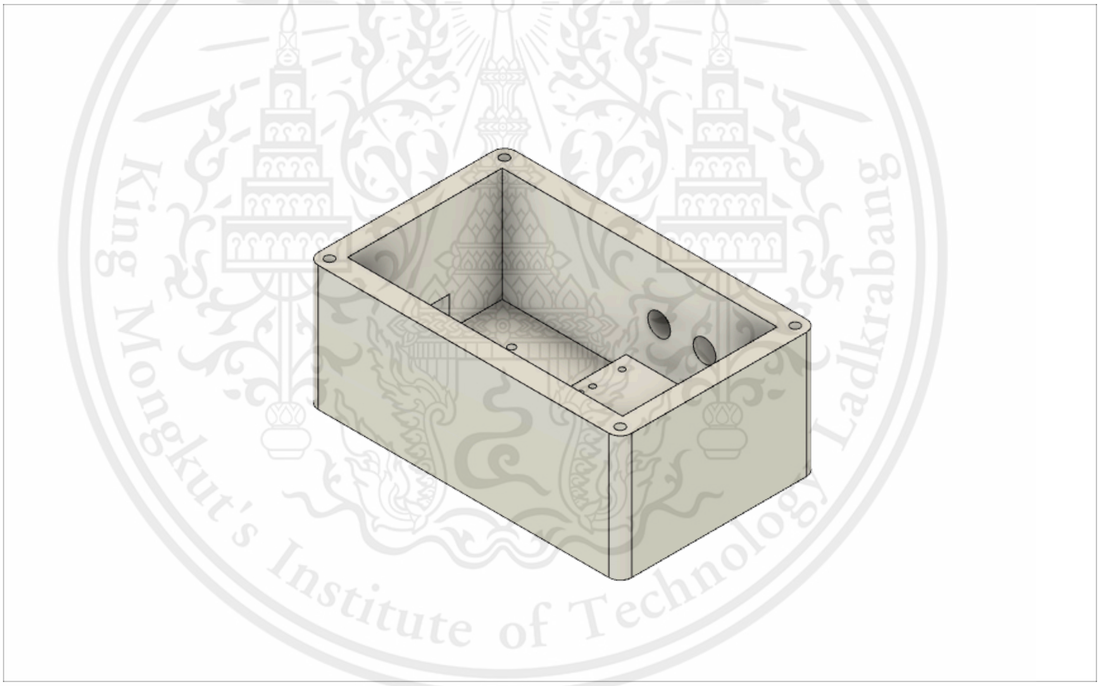


Figure 77 The box to insert the Arduino Mega 2560 board micro-SD card module and digital to analog module (MCP4725).

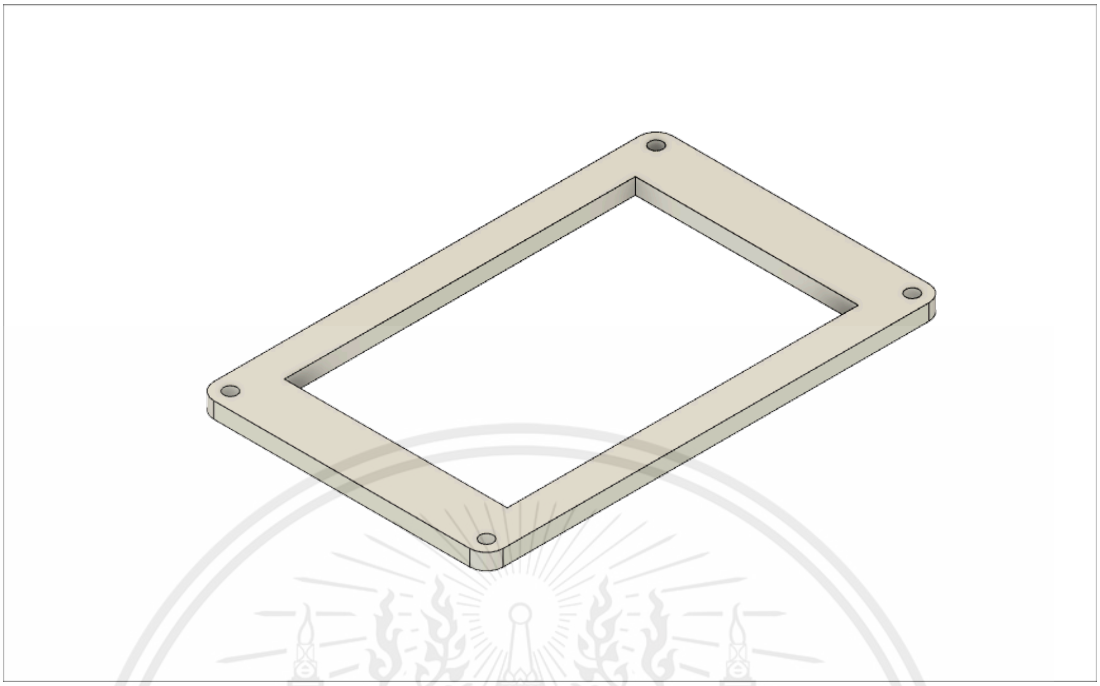


Figure 78 The lid of the box for connection to the Nextion HMI display.

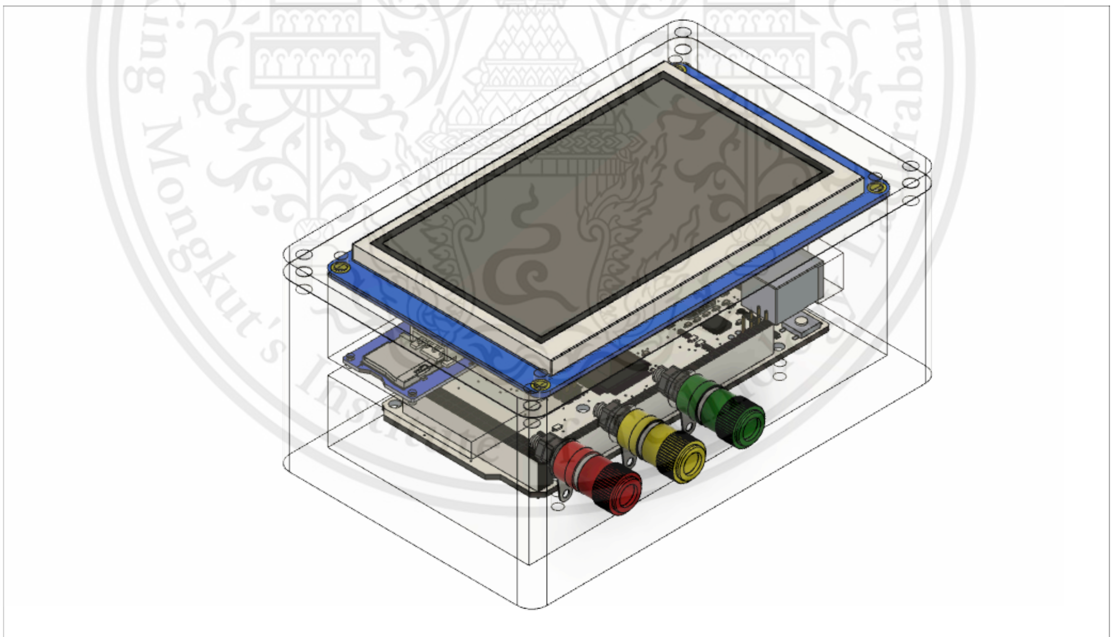


Figure 79 Simulation of ECG simulator 3 leads by using Arduino

CHAPTER 4

EXPERIMENTAL RESULT

In this chapter, we present about the results of the project. Which is divided into two parts, the first is the result measured by the oscilloscope. In this part is divided the result into ECG 1 cycle measurement, each lead measurement, heart rate measurement as well as amplitude measurement. The second part is the result that actually from applied to the real patient monitor.

4.1 The result measured by the oscilloscope.

4.1.1 ECG 1 cycle measurement

For an ECG 1 cycle, it consists of P wave, PR interval, QRS complex and QT interval

-The P wave usually does not exceed 0.120 seconds. The results obtained from three measurements giving the values of 0.084, 0.088 and 0.088 seconds. The mean of these values is 0.087 seconds.

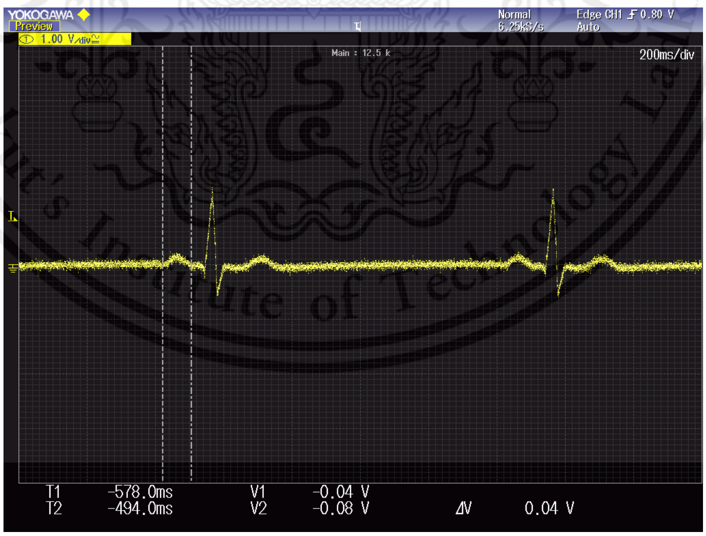


Figure 80 Measure the length of the P wave.

-The PR interval must be equal to 0.120 - 0.200 seconds. The results obtained from three measurements giving values of 0.120, 0.120 and 0.120 seconds. The mean of these values of 0.120 seconds.

Figure 81 Measure the length of the PR interval.

-The QRS complex must be equal to 0.060-0.120 seconds. The results obtained from three measurements giving the values of 0.072, 0.080 and 0.070 seconds. The mean of these values is 0.074 seconds.

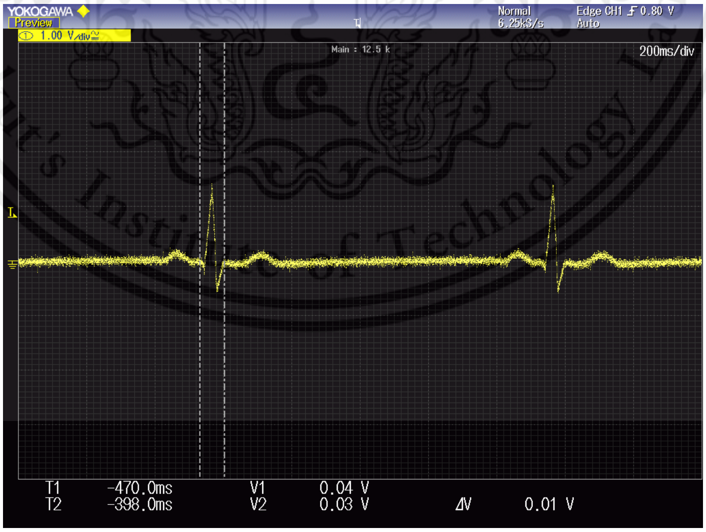


Figure 82 Measure the length of the QRS complex

-The QT interval usually does not exceed 0.470 seconds. The results obtained from three measurements giving values of 0.234, 0.230 and 0.232 seconds. The mean of these values is 0.232 seconds.

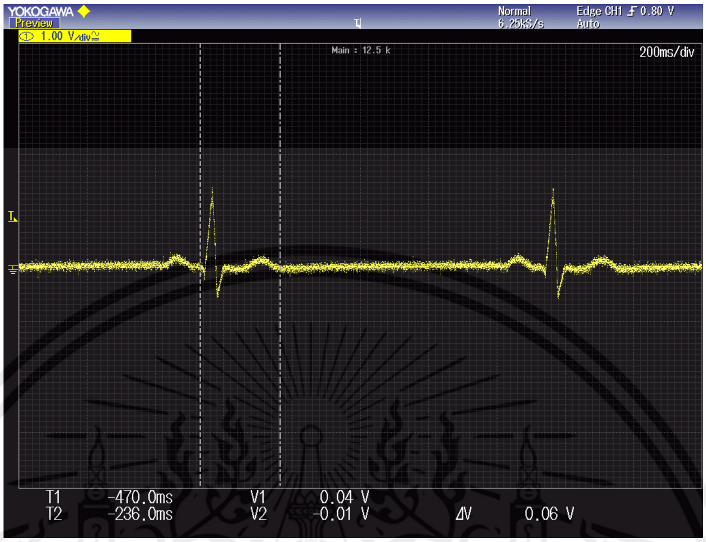


Figure 83 Measure the length of the QT interval

Table 9 The summary value of each type of ECG cycle measurement.

Typical of one ECG cycle	Normal (seconds)	Result 1 (seconds)	Result 2 (seconds)	Result 3 (seconds)	Average (seconds)
P wave	> 0.120	0.084	0.088	0.088	0.087
PR interval	0.120-0.200	0.120	0.120	0.120	0.120
QRS complex	0.060-0.120	0.072	0.080	0.070	0.074
QT interval	> 0.470	0.234	0.230	0.232	0.232

4.1.2 Each lead measurement

Each lead measurement of ECG signal, the principle that we use to calculate the output voltage of ECG signal in each lead by using voltage divider. The process to calculate the voltage divider of each lead follows:

$$V_{\text{in}} = 1.010V.R_1 = 298, R_2 = 700, R_3 = 999, R_1 = 287000ohm$$

$$LeadI = V_{\text{out}} = \frac{R_2}{R_1 + R_2 + R_3 + R_4} \cdot V_{\text{in}} = \frac{700}{298 + 700 + 999 + 987000} \cdot 1.010 = 0.0007Volt$$

$$LeadII = V_{\text{out}} = \frac{R_3}{R_1 + R_2 + R_3 + R_4} \cdot V_{\text{in}} = \frac{999}{298 + 700 + 999 + 987000} \cdot 1.010 = 0.001Volt$$

$$LeadIII = V_{\text{out}} = \frac{R_1}{R_1 + R_2 + R_3 + R_4} \cdot V_{\text{in}} = \frac{298}{298 + 700 + 999 + 987000} \cdot 1.010 = 0.0003Volt$$

-The amplitude of ECG lead I usually does not exceed 2 mV. The result obtained from the calculation and the PSpice program must be equal to 0.0007 mV. We use the amplifier gain 1000 to measure the amplitude of ECG lead I. The results obtained from three measurements giving values of 700, 710, and 710 mV. The mean of these values is 707 mV. Therefore, the amplitude of the ECG lead I is equal to 0.707 mV.

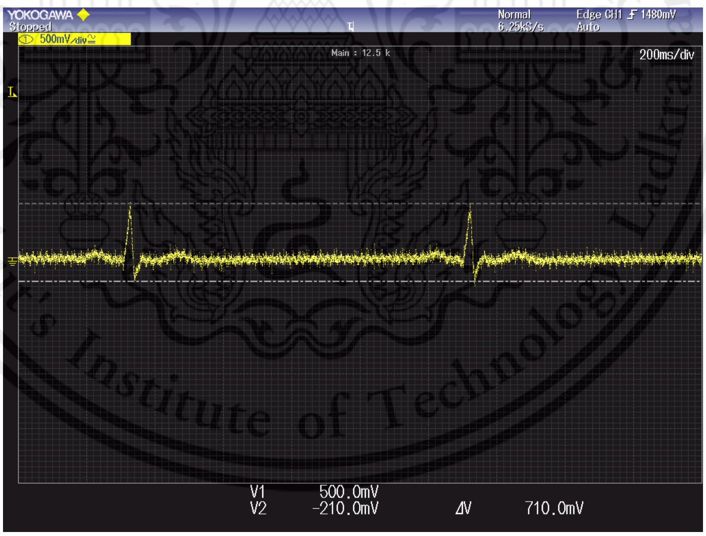


Figure 84 Measure the amplitude of ECG lead I

-The amplitude of ECG lead II usually does not exceed 2 mV. The result obtained from the calculation equal to 1.02 mV. and the PSpice program must be equal to 1 mV. We use the amplifier gain 1000 to measure the amplitude of ECG lead II. The results obtained from three measurements giving values of 1000, 1010, and 1010 mV. The mean of these values is 1007 mV. Therefore, the amplitude of the ECG lead II is equal to 1.007 mV.

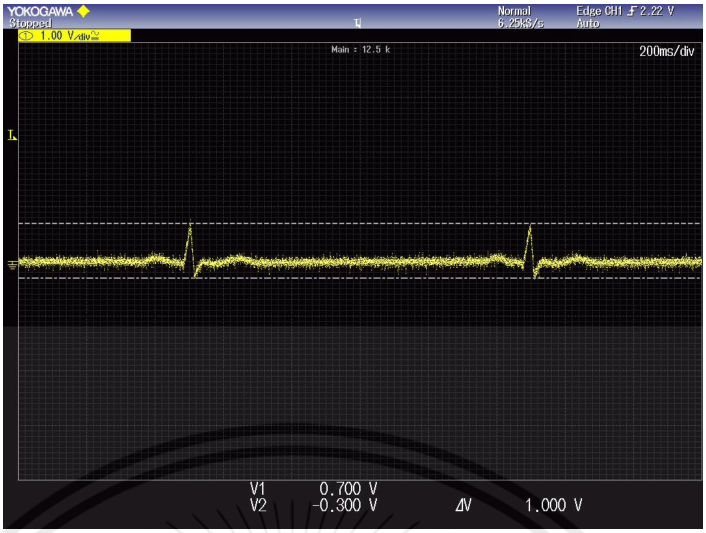


Figure 85 Measure the amplitude of ECG lead II

-The amplitude of ECG lead III usually does not exceed 2 mV. The result obtained from the calculation and the PSpice program must be equal to 0.3 mV. We use the amplifier gain 1000 to measure the amplitude of ECG lead III. The results obtained from three measurements giving values of 300, 300, and 310 mV. The mean of these values is 303 mV. Therefore, the amplitude of the ECG lead III is equal to 0.303 mV

Figure 86 Measure the amplitude of ECG lead III

Table 10 The summary calculating amplitude result of ECG signal.

Calculate(mV.)	Result 1 (mV.)	Result 2 (mV.)	Result 3 (mV.)	Average (mV.)	Error (%)
0.71	0.7	0.71	0.71	0.707	0.422
1.02	1	1.01	1.01	1.007	1.274
0.3	0.3	0.3	0.31	0.303	1.000

Table 11 The summary theoretical amplitude result of ECG signal.

Theoretical(mV.)	Result 1 (mV.)	Result 2 (mV.)	Result 3 (mV.)	Average (mV.)	Error (%)
0.7	0.7	0.71	0.71	0.707	1.0
1	1	1.01	1.01	1.007	0.7
0.3	0.3	0.3	0.31	0.303	1.0

4.1.3 Heart rate measurement

-The set heart rate value is 30 beat per minute and the RR interval that we measured three times are 1.970, 1.970, and 1.970 second. The heart rate results obtained from three calculates giving values of 30.45, 30.45, and 30.45 beat per minute. The mean of these values is 30.45 beat per minute.

Figure 87 Measure the heart rate (30 beat per minute)

-The set heart rate value is 40 beat per minute and the RR interval that we measured three times are 1.515, 1.515, and 1.510 second. The heart rate results obtained from three calculates giving values of 39.60, 39.60, and 39.70 beat per minute. The mean of these values is 39.63 beat per minute.

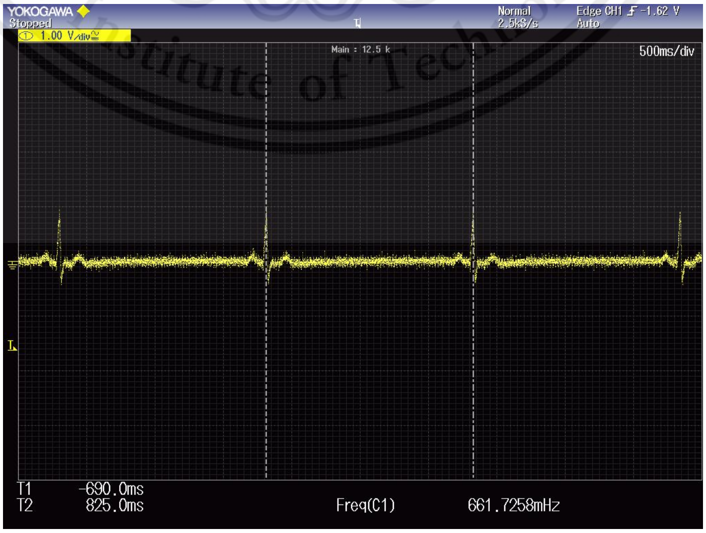


Figure 88 Measure the heart rate (40 beat per minute)

- The set heart rate value is 60 beat per minute and the RR interval that we measured three times are 1.000, 0.995, and 1.000 second. The heart rate results obtained from three calculates giving values of 60.00, 60.30, and 60.00 beat per minute. The mean of these values is 60.10 beat per minute.

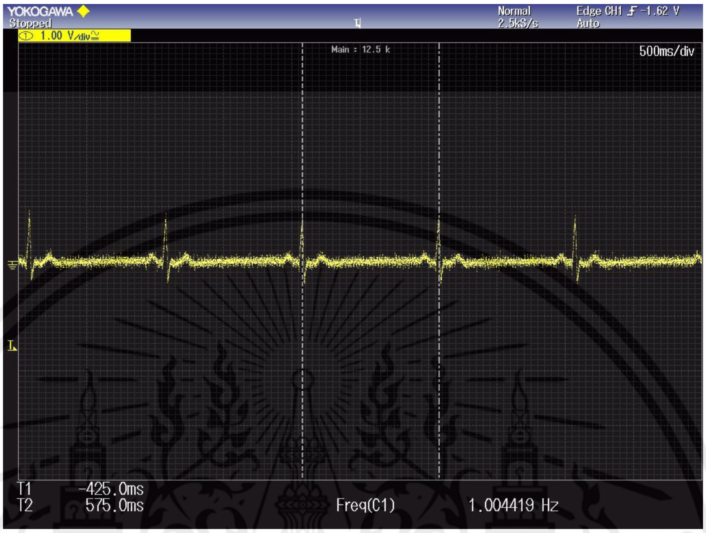


Figure 89 Measure the heart rate (60 beat per minute)

-The set heart rate value is 80 beat per minute and the RR interval that we measured three times are 0.750, 0.750, and 0.750 second. The heart rate results obtained from three calculates giving values of 80.00, 80.00, and 80.00 beat per minute. The mean of these values is 80.00 beat per minute.

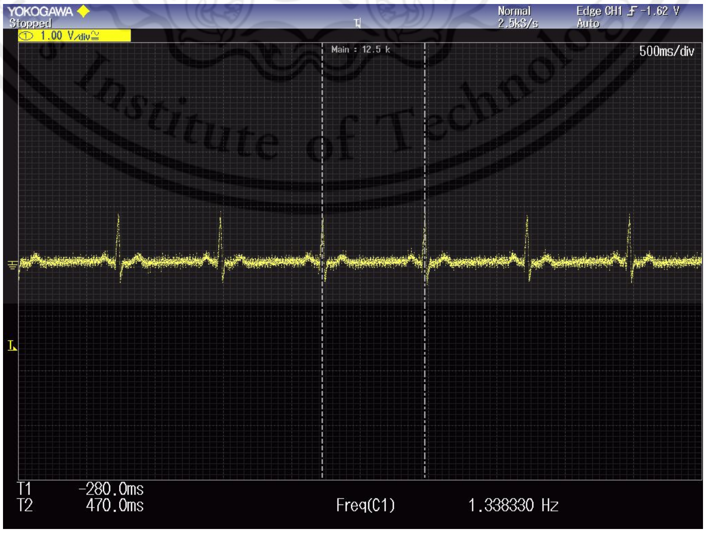


Figure 90 Measure the heart rate (80 beat per minute)

-The set heart rate value is 90 beat per minute and the RR interval that we measured three times are 0.665, 0.665, and 0.665 second. The heart rate results obtained from three calculates giving values of 90.20, 90.20, and 90.20 beat per minute. The mean of these values is 90.20 beat per minute.

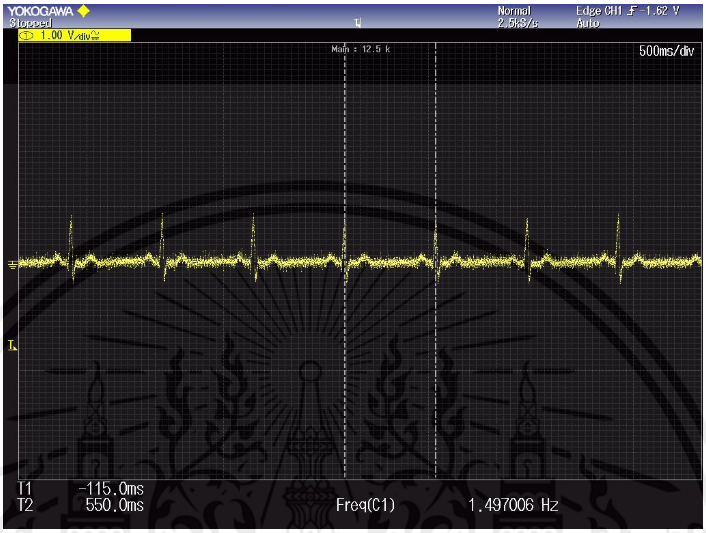


Figure 91 Measure the heart rate (90 beat per minute)

-The set heart rate value is 120 beat per minute and the RR interval that we measured three times are 0.500, 0.500, and 0.500 second. The heart rate results obtained from three calculates giving values of 120.00, 120.00, and 120.00 beat per minute. The mean of these values is 120.00 beat per minute.

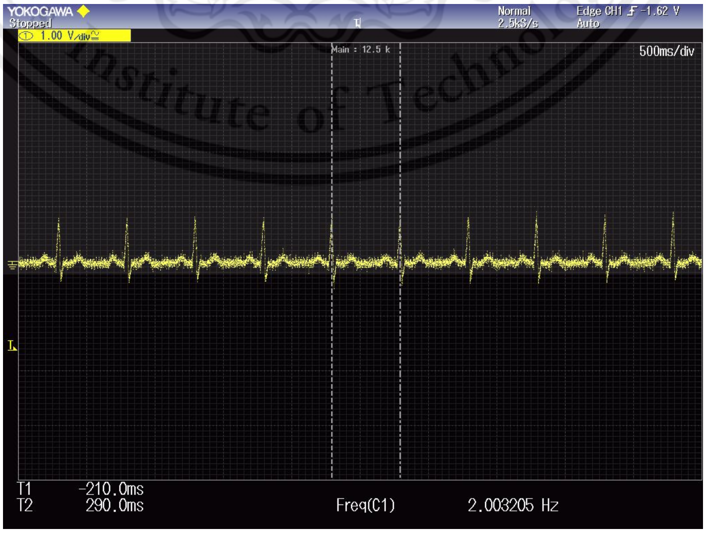


Figure 92 Measure the heart rate (120 beat per minute)

-The set heart rate value is 150 beat per minute and the RR interval that we measured three times are 0.400, 0.400, and 0.400 second. The heart rate results obtained from three calculates giving values of 150.00, 150.00, and 150.00 beat per minute. The mean of these values is 150.00 beat per minute.

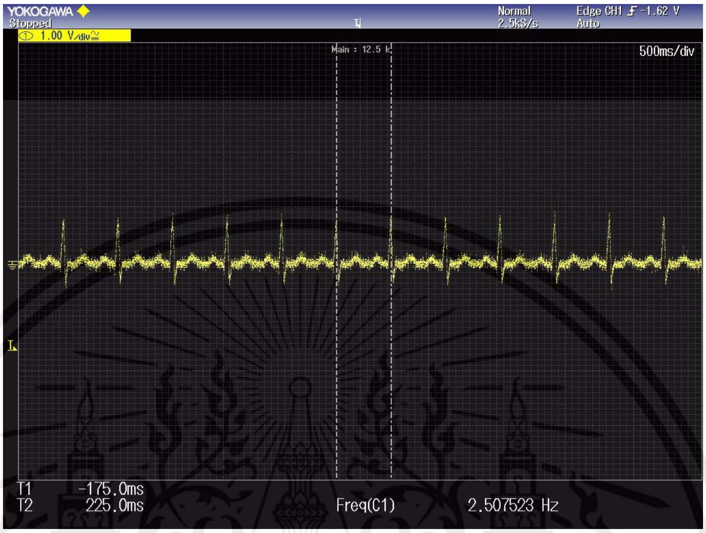


Figure 93 Measure the heart rate (150 beat per minute)

-The set heart rate value is 180 beat per minute and the RR interval that we measured three times are 0.334, 0.335, and 0.335 second. The heart rate results obtained from three calculates giving values of 179.60, 179.10, and 179.10 beat per minute. The mean of these values is 179.27 beat per minute.

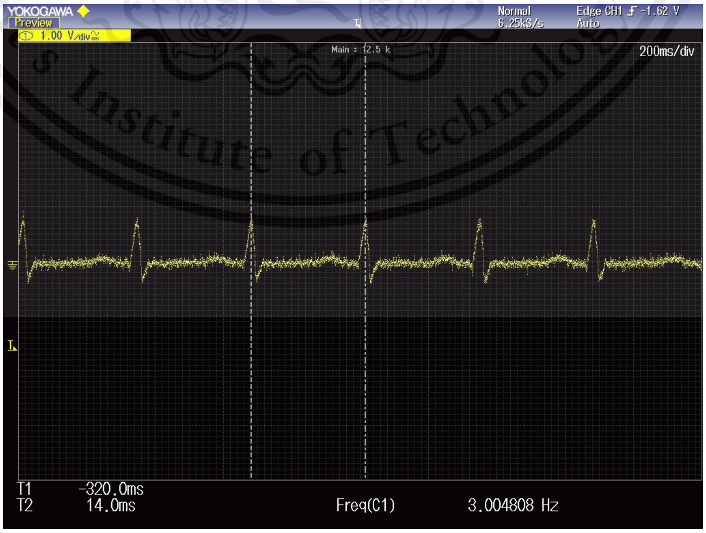


Figure 94 Measure the heart rate (180 beat per minute)

-The set heart rate value is 210 beat per minute and the RR interval that we measured three times are 0.286, 0.286, and 0.286 second. The heart rate results obtained from three calculates giving values of 209.70, 209.70, and 209.70 beat per minute. The mean of these values is 209.70 beat per minute.

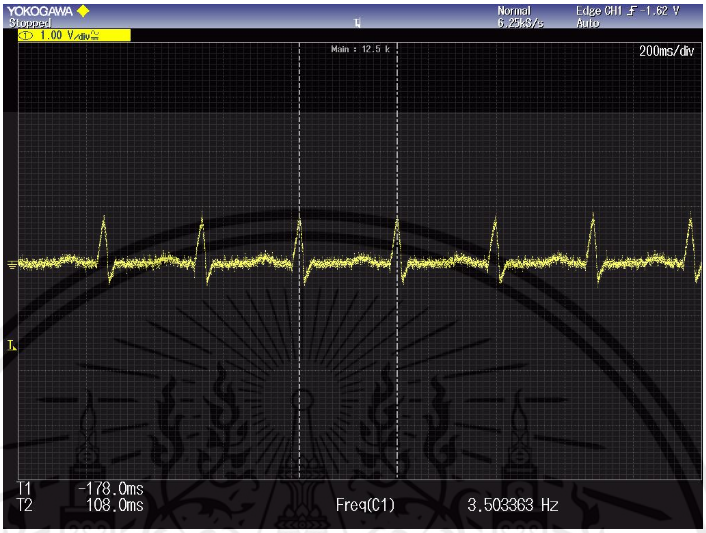


Figure 95 Measure the heart rate (210 beat per minute)

-The set heart rate value is 240 beat per minute and the RR interval that we measured three times are 0.500, 0.500, and 0.500 second. The heart rate results obtained from three calculates giving values of 120.00, 120.00, and 120.00 beat per minute. The mean of these values is 120.00 beat per minute.

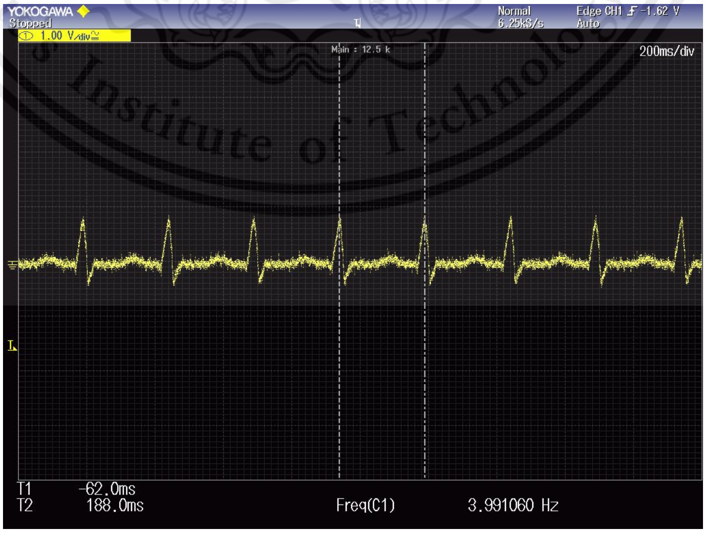


Figure 96 Measure the heart rate (240 beat per minute)

-The set heart rate value is 270 beat per minute and the RR interval that we measured three times are 0.222, 0.222, and 0.224 second. The heart rate results obtained from three calculates giving values of 270.20, 267.80, and 270.20 beat per minute. The mean of these values is 269.40 beat per minute.

Figure 97 Measure the heart rate (270 beat per minute)

-The set heart rate value is 300 beat per minute and the RR interval that we measured three time are 0.200, 0.200, and 0.200 second. The heart rate results obtained from three calculates giving values of 300, 300, and 300 beat per minute. The mean of these values is 300 beat per minute.

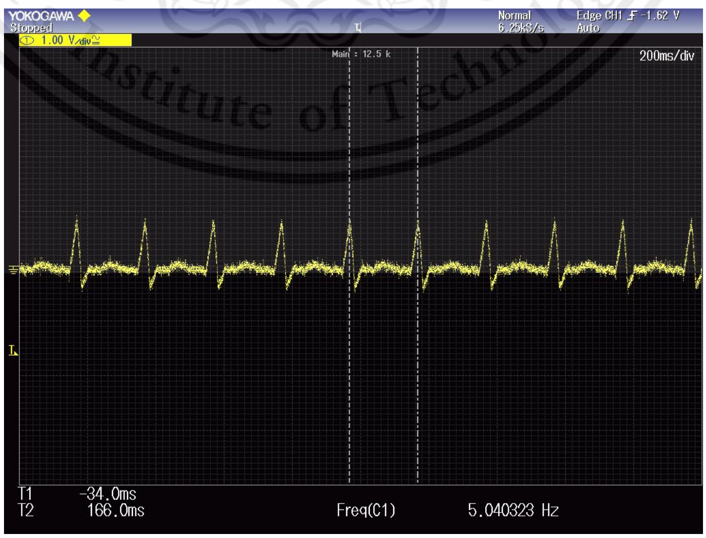


Figure 98 Measure the heart rate (300 beat per minute)

Table 12 The heart rate of ECG on the oscilloscope.

Heart Rate (BPM)	Result1 (BPM)	Result2 (BPM)	Result3 (BPM)	Average (BPM)	Error (%)
30	30.45	30.45	30.45	30.45	1.5
40	39.60	39.60	39.70	39.63	0.92
60	60.00	60.30	60.00	60.10	0.17
80	80.00	80.00	80.00	80.00	0
90	90.20	90.20	90.20	90.20	0.22
120	120.00	120.00	120.00	120.00	0
150	150.00	150.00	150.00	150.00	0
180	179.60	179.10	179.10	179.27	0.41
210	209.70	209.70	209.70	209.70	0.14
240	240.00	240.00	240.00	240.00	0
270	270.20	267.80	270.20	269.40	0.22
300	300.00	300.00	300.00	300.00	0

4.1.4 Amplitude measurement (Gain)

The ECG simulator can adjust the amplitude values, which can be adjusted in all three values: x1, x2, and x4, and the amplitudes on the oscilloscope are 1.010V, 2.020V, and 4.040V. respectively.

Figure 99 Measure the amplitude measurement (x1)

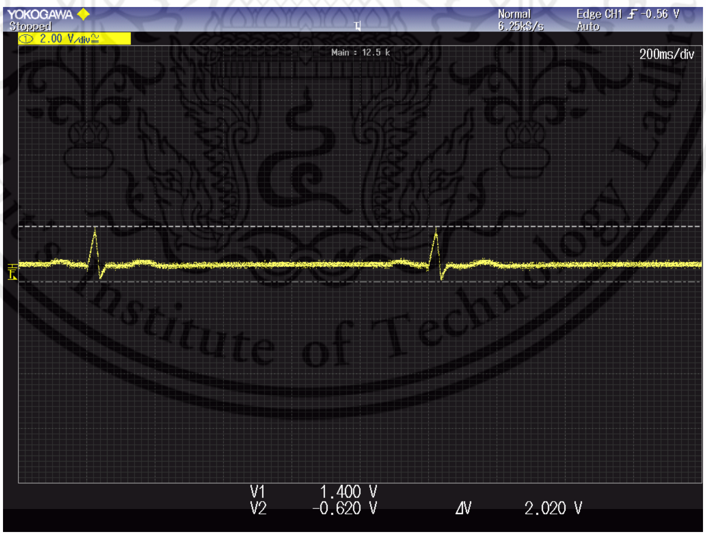


Figure 100 Measure the amplitude measurement (x2)

Figure 101 Measure the amplitude measurement (x4)

Table 13 The theoretical amplitude measurement in each lead of ECG.

Gain	Theoretical (mV)	Result 1 (mV)	Result 2 (mV)	Result 3 (mV)	Average (mV.	Error (%)
x1 Lead 1	0.7	0.700	0.710	0.710	0.707	1.00
x1 Lead 2	1.0	1.000	1.010	1.010	1.007	0.70
x1 Lead 3	0.3	0.300	0.300	0.310	0.303	1.00
x2 Lead 1	1.4	1.420	1.400	1.425	1.415	1.07
x2 Lead 2	2.0	2.010	2.040	2.03	2.027	1.35
x2 Lead 3	0.6	0.605	0.600	0.610	0.605	0.83
x4 Lead 1	2.8	2.800	2.810	2.800	2.803	0.11
x4 Lead 2	4.0	3.980	3.98	3.990	3.983	0.42
x4 Lead 3	1.2	1.180	1.180	1.180	1.180	1.67

Table 14 The calculating amplitude measurement in each lead of ECG.

Gain	Calculate (mV.)	Result 1 (mV.)	Result 2 (mV.)	Result 3 (mV.)	Average (mV.)	Error (%)
x1 Lead 1	0.71	0.700	0.710	0.710	0.707	0.35
x1 Lead 2	1.02	1.000	1.010	1.010	1.007	0.64
x1 Lead 3	0.30	0.300	0.300	0.310	0.303	0.83
x2 Lead 1	1.42	1.420	1.400	1.425	1.415	0.42
x2 Lead 2	2.04	2.010	2.040	2.030	2.027	1.27
x2 Lead 3	0.60	0.605	0.600	0.610	0.605	1.00
x4 Lead 1	2.85	2.800	2.810	2.800	2.803	1.65
x4 Lead 2	4.08	3.980	3.980	3.990	3.983	2.38
x4 Lead 3	1.20	1.180	1.180	1.180	1.180	1.67

4.2 Actually applied to the real patient monitor.

The result after applied the ECG simulator project to the real patient monitor, we measure the different heart rate and different gain of the ECG signal in three time to check the accuracy of heart rate with different gain.

Table 15 The summary of heart rate with gain x1

Heart Rate (BPM)	Result1 (BPM)	Result2 (BPM)	Result3 (BPM)	Average (BPM)	Error (%)
30	30	30	30	30	0
40	40	40	40	40	0
60	60	60	60	60	0
80	80	80	80	80	0
90	90	90	90	90	0
120	120	120	120	120	0
150	150	150	150	150	0
180	180	180	180	180	0
210	210	210	210	210	0
240	240	240	240	240	0
270	270	270	270	270	0
300	300	300	300	300	0

Table 16 The summary of heart rate with gain x2

Heart Rate (BPM)	Result1 (BPM)	Result2 (BPM)	Result3 (BPM)	Average (BPM)	Error (%)
30	30	30	30	30	0
40	40	40	40	40	0
60	60	60	60	60	0
80	80	80	80	80	0
90	90	90	90	90	0
120	120	120	120	120	0
150	150	150	150	150	0
180	180	180	180	180	0
210	210	210	210	210	0
240	240	240	240	240	0
270	270	270	270	270	0
300	300	300	300	300	0

Table 17 The summary of heart rate with gain x4

Heart Rate (BPM)	Result1 (BPM)	Result2 (BPM)	Result3 (BPM)	Average (BPM)	Error (%)
30	30	30	30	30	0
40	40	40	40	40	0
60	60	60	60	60	0
80	80	80	80	80	0
90	90	90	90	90	0
120	120	120	120	120	0
150	150	150	150	150	0
180	180	180	180	180	0
210	210	210	210	210	0
240	240	240	240	240	0
270	269	269	269	269	0.37
300	300	300	300	300	0

CHAPTER 5

CONCLUSION

In this chapter, we will conclude the key parts of working on 3 leads ECG simulator by using Arduino and summarize the results of the project when applied with the real patient monitor in this report. In addition, this chapter will discuss the results of the ECG simulator project and give suggestions for our project to be further developed and improved on the working of 3 leads ECG simulator to be better.

5.1 Conclusion

This project is focused to create the ECG simulator 3 lead by using Arduino that gets the performance at an affordable price, convenient, easy to use and accurate. As commercial ECG simulators are quite expensive, and some companies do not have the need to buy a fully functional ECG simulator on the market. To have to calibrate the machine because some medical devices have ECG graph function as an optional function, such as an ultrasound machine. When buying a commercially available ECG simulator, it is a huge waste of budget, which the ECG simulator we have made can be used to make sure that the ECG graph function can work before use. The cost of this project is around 7000 THB and the cheapest price reach 50% when compared with the commercial ECG simulator product on the market. We can create the ECG simulator 3 lead uses the Arduino Mega 2560 board to be a microcontroller as the Arduino board is a microcontroller that is easy to use and effective enough to be the main controller of this ECG simulator project. The ECG simulator 3 leads by using Arduino has been used with the Nextion HMI TFT LCD, which is a touchscreen LCD and interface display of ECG simulator project. The interface of the Nextion HMI TFT LCD designs the function to adjust the heart rate and amplitude (gain) that allows the users to use easily. We use micro-SD card module to import ECG signal data and the digital to analog module to export ECG signal data.

In terms of accuracy, the measurement of ECG 1 cycle refers to the required value and it is found that the measured value is within the standard range. The theoretical amplitudes of lead I, lead II and lead III must be equal to 0.7,1 and 0.3 mV, respectively.

Amplitude according to the calculations of lead I, lead II and lead III must be equal to 0.71, 1.02 and 0.3 mV respectively. Measurements of lead I, lead II and lead III all three times found that the error value compared to the computation is obtained from the theory, the error values of lead I, lead II and lead III were 1, 0.7 and 1 percent respectively. When compared to the calculations from the voltage divider of lead I, lead II and lead III, they are equal to 0.422, 1.274 and 1 percent respectively. After that, the RR interval is measured to calculate the value of Heart rate. This is set to be equal to 30, 40, 60, 80, 90, 120, 150, 180, 210, 240, 270 and 300 beat per minute. Next, we will calculate the mean and find the percentage of the error, the error values of 1.5, 0.92, 0.17, 0, 0.22, 0, 0, 0.41, 0.14, 0, 0.22 and 0 percent. The last measurement is the amplitude of the ECG, or gain, which has three values, multiplied by 1, 2, and 4 times based on the value of one. It was found that three measurement errors of x1, x2, and x4 are equal to 0 percent. Measurements of lead 1 lead 2 and lead 3 by three times found that the error value compared to the computation is obtained from the theory, the error values of lead I x1, lead II x1, lead III x1, lead I x2, lead II x2, lead III x2, lead I x4, lead II x4 and lead III x4 were 1, 0.7, 1, 1.07, 1.35, 0.83, 0.11, 0.42 and 1.67 percent respectively. When compared to the calculations from the voltage divider of lead I x1, lead II x1, lead III x1, lead I x2, lead II x2, lead III x2, lead I x4, lead II x4 and lead III x4 equals 0.35, 0.64, 0.83, 0.42, 1.27, 1, 1.65, 2.38 and 1.67 percent respectively. From the practical application of the patient monitor, it is found that the value is relatively constant when adjusting the heart rate or amplitude (gain) values as we want as well as it can show the values for both 3 leads, lead I, II and III.

When referring to the Department of Medical Sciences Ministry of Public Health, electrocardiograph simulator heart rate must have range with coverage in the range of 30 to 200 beats per minute and errors are less than or equal to ± 1.5%, our ECG simulator has a heart rate ranging from 30 to 300 beats per minute and errors in each heart rate are not more than 1.5%. Amplitude range values must be simulated to cover 0.5 to 2mV and Error less than or equal to ± 2.5%. Our ECG simulator 3 leads lead I can be simulated averaged 0.707, 1.41 and 2.8 mV. Lead II can be averaged at 1, 2 and 3.9 mV and lead III can be simulated an average at 0.3, 0.6 and 1.18 mV, and all error values are less than 2.5%. In the amplitude range, if measured in all 3 leads, our ECG simulator has rage within the range, but if it measures only one lead, our ECG simulator cannot cover up to 0.5 mV.

5.2 Discussion

Our ECG simulator 3 leads can help test ECG functionality, but not yet a calibration tool. Since we have not done the calibration with the Department of Medical Sciences. In terms of stability and accuracy, we have been using an oscilloscope to measure various values. The signal of the ECG we need is very small in mV unit, so it cannot be measured directly, which requires an amplifier to help. Therefore, the measured value is more inaccurate than using a device that can measure it. As a result, it is found that the values of the ECG 1 cycle are in the standard range. The value of the heart rate has an error not exceeding the limit. There is a value in the specified range of 30-300 beat per minute (standard is 30-200 beat per minute). In the amplitude section, if every lead is measured, it will be in the specified range but if only one lead is measured, it will not fall within the specified range because the digital to analog module (MCP4725) cannot send the value less than this. We can fix by adjusting the resistor values for each lead instead of modifying the transmitted data, in which the value of the measured amplitude has the error less than that. From the practical application of the real patient monitor, it was found that the values were relatively stable and the noise in the patient monitor was less compared to the oscilloscope because the patient monitor's built-in noise was eliminated.

5.3 Suggestions

From the suggestion of engineering who use the ECG simulator to check the ECG function of medical device (Ultrasound machine) and for improving and develop the working of ECG simulator the project be better in the future.

5.3.1 Microcontroller improves ECG data.

Changing the microcontroller board to improve the capability to store more ECG data. The Arduino Mega board has a limited microprocessor to processing much of the ECG data. And it is a cause to limit the number of ECG data to enable the Arduino to process ECG data and to work with other devices that are connected to a microcontroller. So that we should change the microcontroller to increase the efficient working of the ECG simulator and improve the shape of the ECG waveform. The changing new microcontroller must be efficient in receiving large amounts of data to process and sufficient to support other connected devices.

5.3.2 Using the measuring device proper to the type of signal.

The measuring device that uses to measure the ECG signal should be a specific measuring device for a tiny signal to prevent the error and noise that can occur from improper use of measuring instruments. The ECG signal is a very small signal at the microvolt level, and it is a signal that very sensitive and easy to occur noise in the signal. So, that measuring the ECG signal may use the amplify instrument to amplify the signal and then we can measure the signal. The caution of accessory connection such as amplify instrument may have some error and the result that we measure the ECG signal may not accurate as it should be.

5.3.3 Dividing the ECG value by using voltage divider.

The sending the ECG data through each resistor by calculating the voltage divider to divide the ECG value before sending the data to the digital to analog module instead of adjusting the ECG value from writing the code to divide the ECG value before sending ECG value to digital to analog module. As if we adjust the value by writing code, the ECG value that sending to digital to analog module is too small and digital to analog module cannot convert the ECG data and we cannot measure the output of the ECG signal, so that we should use the voltage divider to divide ECG data before sending data to digital to analog module and the output of ECG value after pass the digital to analog module will more accurate.

5.3.4 Using the eliminating noise circuit.

Using the eliminate noise circuit with the ECG simulator circuit may reduce the occurring of noise on the ECG signal when measure the ECG signal on the oscilloscope or applied with the patient monitor. ECG signal is a tiny signal at microvolt level, and it is easy for the noise on the signal to occur. So, connection of the eliminate noise circuit is one way that can reduce the noise occurring on ECG signal, and that makes measuring the ECG signal more accurate.

5.3.5 Take the ECG simulator 3 leads by using Arduino for calibration.

Take the ECG simulator 3 leads by using Arduino to calibrate with the Department of Medical Sciences or an institution that accepts a calibration of the ECG simulator. To truly know the performance of the device as well as can be used to the company or those who want to use it effectively enough. Calibration of device can build the reliability of the device to the user, so that the user can use the device efficiently and safely for the user.

REFERENCES

[1] M. K. Islam, "tudy and Analysis of ECG Signal Using MATLAB & LABVIEW as Effective Tools," *International Journal of Computer and Electrical Engineering,* vol. 4, no. 3, pp. 404-407, 2012.

[2] I. Valais, "Design and Construction of a Prototype ECG Simulator," vol. 8, pp. 11-18, 2014.

[3] B. Editors, "Biology dictionary," 28 April 2017. [Online]. Available: https://biologydictionary.net/diastole/.

[4] ก. ก. ส. กรมสนับสนุนบริการสุขภาพ, August 2016. [Online]. Available: http://medi.moph.go.th/km/tpmd/defib.pdf. [Accessed 29 April 2021].

[5] "AliveCor," [Online]. Available: https://www.alivecor.com/education/ecg.html. [Accessed 3 January 2021].

[6] "Arduino," [Online]. Available: https://www.arduino.cc/en/reference/serial&gt. [Accessed 5 Febuary 2021].

[7] "Wikipedia," 16 April 2021. [Online]. Available: https://en.wikipedia.org/wiki/Arduino. [Accessed 4 February 2021].

[8] R. Bailey, "ThoughCo.," 23 January 2019. [Online]. Available: https://www.thoughtco.com/anatomy-of-the-heart-valves-373203. [Accessed 6 January 2021].

[9] R. Bailey, "ThoughtCo.," 11 May 2019. [Online]. Available: https://www.thoughtco.com/the-heart-wall-4022792. [Accessed 5 January 2021].

[10] "Best-Microcontroller-Project," [Online]. Available: https://www.best-microcontroller-projects.com/mcp4725.html. [Accessed 15 April 2021].

[11] "Better Health," [Online]. Available: https://www.betterhealth.vic.gov.au/health/conditionsandtreatments/ecg-test. [Accessed 10 April 2021].

[12] "Bitesize," [Online]. Available: https://www.bbc.co.uk/bitesize/guides/zrrry9q/revision/4. [Accessed 10 April 2021].

[13] "Botland," [Online]. Available: https://botland.store/ac-and-ca-converters/12805-mcp4725-dac-i2c-converter.html. [Accessed 12 April 2021].

[14] F. R. Breijo-Márquez, "ResearchGate," January 2018. [Online]. Available: https://www.researchgate.net/figure/Normal-electrocardiogram-tracing-Waves-intervals-and-segments_fig1_324061673. [Accessed 15 February 2021].

[15] T. E. o. E. Britannica, "Britannica," 4 May 2021. [Online]. Available: https://www.britannica.com/science/heart. [Accessed 4 May 2021].

[16] M. C. a. R. Buttner, "Life in the fastlane," 4 February 2021. [Online]. Available: https://litfl.com/ecg-rate-interpretation/. [Accessed 6 February 2021].

[17] M. C. a. R. Buttner, "Life in the fastlane," 17 February 2021. [Online]. Available: https://litfl.com/ecg-axis-interpretation/. [Accessed 20 February 2021].

[18] "CardioSecur," [Online]. Available: https://www.cardiosecur.com/magazine/specialist-articles-on-the-heart/lead-systems-how-an-ecg-works. [Accessed 20 January 2021].

[19] "Circuit today," [Online]. Available: https://www.circuitstoday.com/arduino-mega-pinout-schematics. [Accessed 27 February 2021].

[20] "Corpus," 20 August 2017. [Online]. Available: https://corpus.nz/family-history-poems-johanna-emeney/chordae-tenineae/. [Accessed 10 January 2021].

[21] "ECG & ECHO Learning," [Online]. Available: https://ecgwaves.com/topic/introduction-electrocardiography-ecg-book/. [Accessed 18 January 2021].

[22] "ECG & ECHO Learning," [Online]. Available: https://ecgwaves.com/topic/ecg-normal-p-wave-qrs-complex-st-segment-t-wave-j-point/. [Accessed 18 January 2021].

[23] "ECG & ECHO Learning," [Online]. Available: https://ecgwaves.com/topic/ekg-ecg-leads-electrodes-systems-limb-chest-precordial/. [Accessed 18 January 2021].

[24] "ECG Guru," [Online]. Available: https://www.ecgguru.com/heart-illustrations/einthovens-triangle. [Accessed 7 February 2021].

[25] "EKG.MD," [Online]. Available: https://ekg.md/content/t-wave-basics/. [Accessed 5 January 2021].

[26] B. Editors, "Biology dictionary," 28 April 2017. [Online]. Available: https://biologydictionary.net/systole/. [Accessed 12 January 2021].

[27] "Electronics Project Focus," [Online]. Available: https://www.elprocus.com/different-types-of-arduino-boards/. [Accessed 13 February 2021].

[28] "Wikipedia," 25 April 2021. [Online]. Available: https://en.wikipedia.org/wiki/Electrocardiography. [Accessed 25 April 2021].

[29] G. Fitzgerald, "TeachMe Anatomy," 3 April 2020. [Online]. Available: https://teachmeanatomy.info/thorax/organs/heart/atria-ventricles/. [Accessed 16 January 2021].

[30] "GetData Graph Digitizer," [Online]. Available: http://getdata-graph-digitizer.com. [Accessed 4 April 2021].

[31] P. Hignett. [Online]. Available: http://www.csnlc.nhs.uk/uploads/files/cardiac/cardiac_training/Ecg/lead_systems.finalppt.pdf. [Accessed 18 January 2021].

[32] T. Hirzel, "Arduino," 5 February 2018. [Online]. Available: https://www.arduino.cc/en/Tutorial/Foundations/PWM. [Accessed 15 February 2021].

[33] B. M. Horáˇcek, "Springer," [Online]. Available: https://link.springer.com/content/pdf/10.1007%2F978-1-84882-046-3_10.pdf. [Accessed 16 February 2021].

[34] "Human Bio Media," [Online]. Available: https://www.humanbiomedia.org/cardiac-cycle-lesson/. [Accessed 17 January 2021].

[35] M. T. Inc., "Microchip," 2007. [Online]. Available: https://www.best-microcontroller-projects.com/support-files/mcp4725.pdf. [Accessed 5 April 2021].

[36] "Iotguider," 3 July 2017. [Online]. Available: https://iot-guider.com/arduino/basics-of-arduino-mega-2560-board/. [Accessed 3 February 2021].

[37] D. M. Jackson, "Greeky Medics," [Online]. Available: https://geekymedics.com/understanding-an-ecg/. [Accessed 28 January 2021].

[38] "JavaTpoint," [Online]. Available: https://www.javatpoint.com/advantages-and-disadvantages-of-matlab. [Accessed 27 February 2021].

[39] "Kanda.com," [Online]. Available: https://www.kanda.com/what-is-arduino.php. [Accessed 28 January 2021].

[40] "Lumen Anatomy and Physiology," [Online]. Available: https://courses.lumenlearning.com/nemcc-ap/chapter/heart-anatomy/. [Accessed 5 January 2021].

[41] "MathWork," [Online]. Available: https://uk.mathworks.com/discovery/what-is-matlab.html. [Accessed 16 April 2021].

[42] M. Melissa Conrad Stöppler, "MedicineNet," 29 March 2021. [Online]. Available: https://www.medicinenet.com/sa_node/definition.htm. [Accessed 29 March 2021].

[43] "NEXTION," [Online]. Available: https://nextion.tech/datasheets/nx4827t043/. [Accessed 5 March 2021].

[44] "NEXTION," [Online]. Available: https://nextion.tech/editor_guide/. [Accessed 5 March 2021].

[45] "OER services," [Online]. Available: https://courses.lumenlearning.com/suny-ap2/chapter/cardiac-cycle/. [Accessed 18 January 2021].

[46] "OSOYOO," 30 August 2017. [Online]. Available: https://osoyoo.com/2017/08/30/osoyoo-mega2560-board-fully-compatible-with-arduino-mega2560-rev-3/. [Accessed 2 March 2021].

[47] "PB work," [Online]. Available: http://datalogger.pbworks.com/w/file/fetch/89507207/Datalogger%20-%20SD%20Memory%20Reader%20Datasheet.pdf. [Accessed 4 March 2021].

[48] "Pediadiagnosis," 18 October 2020. [Online]. Available: https://www.pediagenosis.com/2020/10/electrocardiography.html. [Accessed 8 January 2021].

[49] S. R., "Socratic," 12 February 2016. [Online]. Available: https://socratic.org/questions/which-is-the-cardiac-muscle-layer-of-the-heart. [Accessed 8 January 2021].

[50] P. Richard E. Klabunde, "Cardiovascular Physiology Concepts," 10 March 2016. [Online]. Available: https://www.cvphysiology.com/Arrhythmias/A013. [Accessed 28 January 2021].

[51] P. Richard E. Klabunde, "Cardiovascular Physiology Concepts," 22 December 2017. [Online]. Available: https://www.cvphysiology.com/Arrhythmias/A013a. [Accessed 28 January 2021].

[52] "SLUCare Physician Group," 15 May 2020. [Online]. Available: http://slu.adam.com/content.aspx?productid=117&pid=2&gid=18093. [Accessed 15 February 2021].

[53] "STEMpedia," [Online]. Available: https://learn.thestempedia.com/courses/introductory-course-on-arduino/lessons/getting-started-5/topic/different-parts-of-arduino-board/. [Accessed 17 March 2021].

[54] "STEMpedia," [Online]. Available: https://learn.thestempedia.com/courses/introductory-course-on-arduino/lessons/getting-started-5/topic/different-parts-of-arduino-board/. [Accessed 17 March 2021].

[55] "SYNERGYSOFT," [Online]. Available: http://synergysoft.co.th/products/8-adsk-mfg/68-fusion360. [Accessed 15 April 2021].

[56] Seliha, "Socratic," 7 December 2017. [Online]. Available: https://socratic.org/questions/is-the-heart-located-posterior-or-medial-to-the-lungs. [Accessed 10 February 2021].

[57] t. H. E. Team, "Heathline," 20 January 2018. [Online]. Available: https://www.healthline.com/human-body-maps/heart#1. [Accessed 5 January 2021].

[58] A. J. Weinhaus, "Springer Link," [Online]. Available: https://link.springer.com/chapter/10.1007/978-3-319-19464-6_5. [Accessed 8 January 2021].

[59] S. White, "TeachMe Anatomy," 24 June 2019. [Online]. Available: https://teachmeanatomy.info/thorax/organs/heart/conducting-system/. [Accessed 13 January 2021].

[60] "Wigipedia," 10 April 2021. [Online]. Available: https://en.wikipedia.org/wiki/Heart_valve. [Accessed 10 January 2021].

[61] "Wigipedia," 18 April 2021. [Online]. Available: https://en.wikipedia.org/wiki/Cardiac_cycle. [Accessed 12 January 2021].

[62] "Wigipedia," 30 April 2021. [Online]. Available: https://en.wikipedia.org/wiki/Sinoatrial_node. [Accessed 1 February 2021].

[63] "Wigipedia," 3 February 2021. [Online]. Available: https://en.wikipedia.org/wiki/Bundle_of_His. [Accessed 1 February 2021].

[64] "Wigipedia," 25 April 2021. [Online]. Available: https://en.wikipedia.org/wiki/Electrocardiography. [Accessed 6 January 2021].

[65] "Wigipedia," 27 March 2021. [Online]. Available: https://en.wikipedia.org/wiki/Einthoven%27s_triangle. [Accessed 25 February 2021].

[66] "Wigipedia," 2 May 2021. [Online]. Available: https://en.wikipedia.org/wiki/MATLAB. [Accessed 25 March 2021].

[67] "Wigipedia," 20 April 2021. [Online]. Available: https://en.wikipedia.org/wiki/Arduino_IDE. [Accessed 3 April 2021].

[68] J. Wilson, "TEP technopreneur," 20 January 2021. [Online]. Available: https://www.theengineeringprojects.com/2021/01/introduction-to-arduino-mega-2560-rev3.html. [Accessed 4 April 2021].

[69] A. ZAIT, "Circuit.io blog," 22 April 2018. [Online]. Available: https://www.circuito.io/blog/arduino-uno-pinout/. [Accessed 6 March 2021].

[70] E. Zhou, "ITEAD.CC," 25 August 2015. [Online]. Available: https://www.itead.cc/blog/nextion-hmi-tft-lcd-display-a-basic-introduction. [Accessed 15 March 2021].

[71] ร. รังสรรค์, "ER Goldbook," 6 January 2016. [Online]. Available: https://ergoldbook.blogspot.com/2016/01/ekg-interpretation.html. [Accessed 2 March 2021].

[72] D. Hiskey, "Today I Found Out," 16 March 2014. [Online]. Available: http://www.todayifoundout.com/index.php/2014/03/can-stun-guns-cause-cardiac-arrest/heart-2/. [Accessed 30 January 2021].

[73] P. Richard E. Klabunde, "Cardiovascular Physiology Concepts," [Online]. Available: https://www.cvphysiology.com/Arrhythmias/A013b. [Accessed 24 February 2021].

[74] P. Richard E. Klabunde, "Cardiovascular Physiology Concepts," [Online]. Available: https://www.cvphysiology.com/Arrhythmias/A013c. [Accessed 24 February 2021].

[75] "Telus," [Online]. Available: http://www3.telus.net/emergency/mi/leads1.htm. [Accessed 6 March 2021].

[76] "Telus," [Online]. Available: http://www3.telus.net/emergency/mi/leads1.htm. [Accessed 5 March 2021].

[77] "Discountsth.com," [Online]. Available: https://discountsth.com/pro/โมดูลบันทึกข้อมูลลง-micro-sd-card-micro-sd-card-module-micro-sd-card-module-s62456213-p4431445886.html. [Accessed 16 March 2021].

[78] "Arduinotronics," [Online]. Available: https://www.arduitronics.com/article/1/เริ่มต้นใช้งาน-arduino-uno-ตอนที่-1-แนะนำตัวกันก่อน. [Accessed 28 March 2021].

[79] "electronic-lab.com," [Online]. Available: https://www.electronics-lab.com/design-hmi-projects-easily-nextion/. [Accessed 3 April 2021].

[80] "Autodesk," [Online]. Available: https://www.autodesk.com.au/products/fusion-360/free-trial. [Accessed 3 April 2021].

[81] "EMMA," [Online]. Available: https://platform.europeanmoocs.eu/course_introduction_to_autodesk_fusio. [Accessed 5 April 2021].