Elektronik Stetoskop Tasarımı
Electronic Stethoscope Design

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Özetçe— **Günümüzde gelişen teknolojiye rağmen, hala insanlar yanlış veya geç teşhis yüzünden hayatlarını kaybetmektedir. Erken teşhis ile birçok hastalık ve hasta için oluşan olumsuz etkiler önlenebilir bu şekilde kardiyolojik hastalıkların önüne geçmek mümkündür. Kalp seslerinin stetoskop ile dinlemek basit ve etkili bir yöntemdir. Ancak stetoskop bazı kalp rahatsızlıklarını belirlemek için yeterli değildir. Bu hastalıklardan bazıları da kalp kapakçıklarıyla ilgili rahatsızlıklardır. Kalp kapaklarının doğru çalışmamasından dolayı meydana gelen üfürümler de bu rahatsızlıklardan biridir.**

Bu projenin temel amacı elektronik bir stetoskop geliştirerek ses sinyallerini grafik olarak gözlemlemektir. Stetoskop ile dinleme yaparken hekimlerin karşılaştığı en büyük zorluk, bu uygulamanın tecrübe gereksinimdir. Dahası hekim yeterli tecrübeye sahip olsa dahi, 1. ve 2. derece kalp üfürümlerini duymak zordur. Bir diğer etken ise taşikardi hastalarında hekimlerin birinci kalp sesi (S1) ve ikinci kalp sesi (S2) zamanlamasına karar verememeleridir. Bu projede kalp seslerini elektronik sinyallere dönüştürerek, sinyallerin grafik halinde izlenmesi amaçlanmıştır. Bu projede hekimlerin stetoskop ile dinleme yaparken fark edemedikleri veya insan kulağının duyamayacağı sesleri görüp tanı koymalarını sağlamak amaçlanmıştır. Bu projenin sağladığı bir diğer avantaj ise kalp sesleri dijital veri halinde alındığı için, dijital ortamda paylaşılması rahatlıkla sağlanacaktır. Bu sayede hekimler şüphelendikleri bir bulguyu farklı bir görüş almak için başka hekimlerle paylaşması koyulan tanıyı daha güvenilir bir hale getirecektir.

Anahtar Kelimeler—elektronik stetoskop; kalp; kalp sesleri; kalp üfürümleri; kalp kapakçıkları.

Abstract— **Nowadays, despite the developing technology lots of patients lost their lives because of wrong and late diagnosis. With early diagnosis, most diseases and negative effects of the diseases for the patient can be prevented. Early diagnosis can also prevent cardiological diseases. Although auscultation of the chest with a stethoscope is an effective and basic method, a stethoscope isn't enough for the diagnosis of some diseases. One example of these diseases is heart valve malfunctions when the valves do not work as desired heart murmurs occur.**

The main goal of this project is to develop an electronic stethoscope and observing obtained signals as a graphic. The main difficulty while auscultation of chest with a stethoscope is, this procedure needs lots of experience and also even tough physician have enough experience, it's very hard to diagnose grade 1 and 2 heart murmurs. Furthermore, while auscultation tachycardia patients, generally it's very hard to decide where the first heart (S1) sound and second heart sound (S2) begins. In this project, it is planned to demonstrate heart sounds as a graphic. This method provides physicians to diagnose all kinds of chest sounds easily even the sounds which they cannot diagnose or recognize with their ears by stethoscope. Moreover, as the chest sounds are obtained as digital data, these data can be sent as desired. When a physician needs to get someone else's idea, these recordings can be sent to another professional.

***Keywords—electronic stethoscope; heart; heart sounds; heart murmurs; heart valves*.**

I. INTRODUCTION

Nowadays, despite the developing technology lots of patients lost their lives because of wrong and late diagnosis. With early diagnosis, most diseases and negative effects of the diseases for the patient can be prevented. Early diagnosis can also prevent cardiological diseases. Although auscultation of the chest with a stethoscope is an effective and basic method, a stethoscope isn't enough for the diagnosis of some diseases. One example of these diseases is heart valve malfunctions when the valves do not work as desired heart murmurs occur.

Healthcare applications mainly depend on the diagnosis of disease before treating it, to do so from past to now humanity always developed new technologies for both diagnostic and therapeutic purposes. By developing technology now we can use better and advanced processors and sensors, also these developments provide us easier controls over digital signals. Basically, most electricity depended medical devices working principle is to convert mechanical, electrochemical, or very low electrical energy to workable electrical signals. These signals are processed and modified to information that presents medical records of a human body.

Although advanced technologies are involved in medical applications there are still examples that are related to late and wrong diagnosis. With early diagnosis many diseases are preventable; also side effects of illnesses that influence patients can be avoided. Moreover, understanding the problem at an early stage makes treating the disease much easier. However, a mostly diagnosis of heart diseases are very hard and consumes lots of time. Listening to heart sounds with a stethoscope is a very basic and effective way of diagnosis. However, a stethoscope is not enough for specific purposes. One example of heart disease that is very hard to diagnose is heart valve malfunctions. To ensure that patient has the disease or not doctors request some tests which are mostly expensive, time-consuming, or device that is doing the test is expensive so the institution doesn't have that device[1]. So, however, the stethoscope is not an effective way for diagnostics of heart diseases economically it offers the best solution for now.

A. Heart and Murmurs

The heart is an internal organ that pumps blood to all body from beginning of life to death, this one is one of the indispensable organs in the body. The heart has four chambers; these are right atrium (RA), left atrium (LA), right ventricle (RV) and left ventricle (LV) [2]. Heart valves connect ventricles and atriums also ventricles to arteries. If we consider valve connections; tricuspid valve connects right atrium to the right ventricle, mitral valve connects left atrium to the left ventricle, aortic valve connects the aorta to the left ventricle, finally pulmonic valve connects pulmonary vessel to right ventricle[3]. When any of these valves malfunctions and cannot close completely blood leakage occurs and turbulent blood flow causes the sound, this sound is called a heart murmur.

According to an article first person who describes heart murmurs is Laennec in 1819 [4]. By late 19th century physicians divided into two, some of them believed that systolic murmurs are organic which is photogenic, the others stated that murmurs are functional which is heart sounds that physicians are expected to hear at specific times of human life. These murmurs are graded in 6 groups, grade 1 systolic murmur is barely audible and grade 6 systolic murmur is very loud which can be heard without a stethoscope. A study made in 1933 by Freeman and Levine's determined the frequency and significance of systolic murmurs. Almost 20% of patients had grade 1 or 2 systolic murmurs. These patients had some common diseases and these murmurs are considered as functional because when common diseases are controlled, murmurs frequently disappeared. 19% of patients had grade 3 or 4 murmurs and they realized that these patients have organic heart disease or anemia. In conclusion, they stated that the grade of systolic murmurs is useful for diagnosis.

Murmurs are divided into two; these are systolic murmurs and diastolic murmurs. They are both organic murmurs. Both of these murmurs are related to 3 main factors; too much blood flow from normal vessels, forward blood flow where blood needs to go backward, backward blood flow where blood needs to go forward [5]. Murmurs are named according to their timing; systolic murmurs take place between systole and diastole and diastolic murmurs take place between diastole and systole.

B. Heart Sounds

The first step in diagnosing heart diseases is auscultation. It is a term that is referred to listening to internal body sounds by stethoscope. The main purpose of auscultation is to examine circulatory and respiratory systems, generally the heart and lungs. While listening to heart sounds physicians generally expect to hear only functional heart sounds first heart sound (S1) and second heart sound (S2). First heart sound (S1) is a sound that indicates the starting of ventricular systole, it is a sound of closing atrioventricular valves and second heart (S2) sound indicates the starting of diastole, it is a sound of closing aortic and pulmonic valves. Apart from these sounds, there are also other noises that the heart creates. These are third heart sound (S3), fourth heart sound (S4) and murmurs [6].

Third heart sound (S3) and fourth heart (S4) sound can be both functional and pathological. In normal conditions heart only produces S1 and S2. However, third heart sound (S3) and fourth heart sound (S4) can be heart according to the patient's age or disease. Third heart sound (S3) occurs at the end of S2 and fourth heart sound occurs before S1 [8]. The third heart sound (S3) occurs because of a sudden stop of the left ventricle's longitudinal expansion. This stopping action provides vibration of blood inside the ventricle; this vibration is heard as third heart sound (S3). S3 can be both philological and functional, physicians expect to hear S3 at children, patients bellow 40 years old, and pregnant women; these are functional reasons for hearing S3 sound. Also, there are lots of pathological reasons such as left ventricle failure, aorta, and pulmonary tightness, aorta, and pulmonary failure. S4 is a sound that is created by blood entering the ventricle by atrial contraction. This sound is generally soft and has a short duration. Although S4 caused by atrial contraction, its source is ventricle, because blood moves from atrium to ventricle. Also, forth heart sound can be heard at every person after they passed 40 years old.

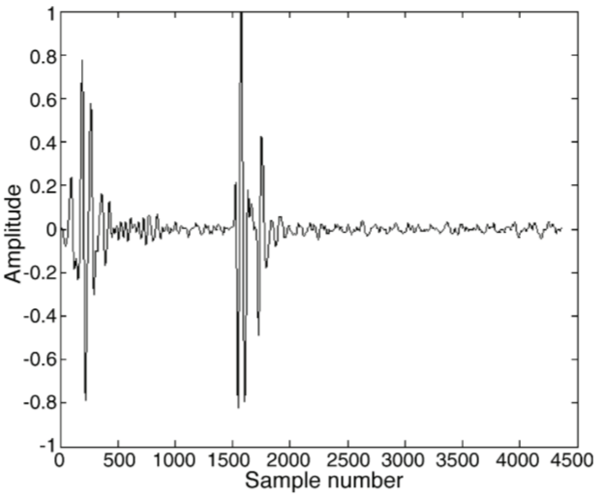

Fig 1. Sound signal which is expected at normal heart [7].

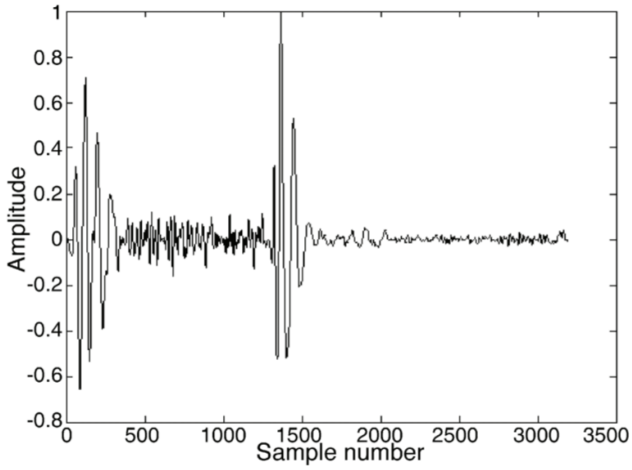

Fig 2. Sound signal which is expected at systolic murmur [7].

First heart sound is a sound of closing atrioventricular valves but in normal conditions mitral valve closes before tricuspid valve so the first heart sound has 2 parts; these are called mitral (M1) and tricuspid (T1). However, the time between the closing mitral valve and the tricuspid valve is very short that the human ear can't realize this sound as separate sounds. The first heart sound (S1)'s frequency range is between 25-45 Hz and it has 50-100 Ms duration. The second heart sound (S2)'s frequency range is between 50-70 Hz and it has 25-50 Ms duration [9]. Another research about heart murmurs states that heart sounds and murmurs frequency range is up to 1500 Hz [10].

Murmurs are caused by heart valve malfunctions and every heart valve can be heart by specific locations. These are aortic valve area, pulmonic valve area, Erb's point, tricuspid valve area, mitral valve area. These areas are defined according to the direction in which valves are facing. Heart sounds spread all over the chest wall but these areas are used to listen to specific valves more carefully.

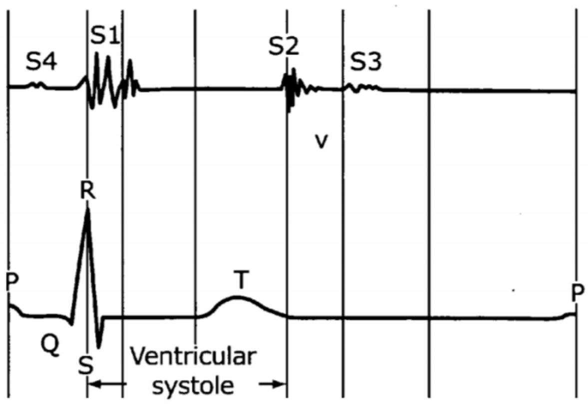

Fig 3. Heart sounds timing according to an ECG signal [11].

C. *Production of lung sounds*

Heart sounds aren't the only sound that can be heard while auscultating the chest. Also examining the respiratory system can be done via listening chest. This diagnostic method is safe, easy, and noninvasive. According to an article lung sounds have 3 main characteristics such as quality, intensity, and frequency. These characteristics are used to differentiate similar sounds [15]. Lung sounds are classified into 2 categories; these are breath sounds and adventitious, also called abnormal, sounds. In normal conditions breath sounds are heard over the trachea and chest. Abnormal sounds are heard as background sound to breath sounds.

Breath sounds are divided into 3 groups; these are normal tracheal sound, normal lung sounds also called vesicular breath sound and bronchial breath sound. Firstly, normal tracheal breath sounds are harsh, very loud, and high pitched sounds that can be heard over trachea. Their frequency range is between 100 to 1500 Hz. The second breath sound is normal lung sounds. These sounds are also called vesicular breath sounds. Expiratory sound is audible on at the early phase because of the nature of expiration which causes the generation of less turbulent airflow. Origin of inspiration and expiration is also different. While inspiration originates in lobar and segmental airways, expiration's origin is more central airways. Generally, normal lung sounds frequencies are less than 100 Hz. Lastly, bronchial breath sounds can be heard over manubrium and between C7 and T3 vertebra. This sound contains higher frequencies than normal breath sounds because of the low pass filtering of the alveoli. Bronchial breath sounds subdivide to 3 groups such as tubular, cavernous, amphoric sounds [15].

D. Stethoscope

The stethoscope was invented in 1816 by French doctor Rene Laennec; he invented a stethoscope because direct auscultation of chest was insufficient and embarrassing especially for female patients. Firstly, he used a rolled paper and he realized that sounds were amplified. He didn't stop with the paper stethoscope, he also improved his invention, after 3 years, he used wood in order to rolled paper [16]. These stethoscopes were called as monaural stethoscope because listening to chest sounds was achieved by one ear. After stethoscope become popular over the world, lots of people tried to develop this technology. However, the most significant one was done in 1856 by George Cammann, this stethoscope was cost-effective and similar to 20th-century models. He used ivory knobs to transmit sound directly to ears.

The first diaphragm, nowadays called a chest piece, was invented by Rober Bowles and Sprague combined bell with the diaphragm in 1926. In 1961 Littmann redesign the stethoscope developed by Sprague, this design was easier to use, lighter, added open chest piece for recognition of low-pitched sounds, and closed-chest piece to filter low pitched sounds [17].

There are 3 parts of nowadays stethoscopes; these are cheats piece (diaphragm and bell), air-filled hollow tube, and earpieces. Also, the chest piece is divided into 2 parts diaphragm and bell. When the diaphragm is placed on the patient's chest, body sounds which are vibrations vibrate the diaphragm and diaphragm produces acoustic pressure waves, these waves are traveled to earpieces by an air-filled hollow tube. The diaphragm is used to listen to high-frequency sounds. The second part of the chest piece is a bell, although both bell and diaphragm work in the same way, the bell is used to listen to low-frequency sounds. The frequency difference is caused by their different shapes. According to an article, physicians still cannot decide whether using diaphragm or bell for auscultation. Half of the doctors prefer diaphragm for auscultation, the other half prefers bell for auscultation [18].

The other type of stethoscope is an electronic stethoscope; these devices are used to amplify low-level body sounds. While acoustic stethoscopes transmit sound to ears via air-filled hollow tubes, electronic stethoscopes convert sound signals into electrical signals which can be amplified later. Researches showed that electronic stethoscope is better for listening to heart sounds according to an acoustic stethoscope. However, there is no difference while listening to breathing sounds [19].

E. Problems About Stethoscope

By developing technology physicians have more reliable options for diagnostic purposes, lots of devices are invited for this purpose such as electrocardiogram (ECG), ultrasound, and Doppler techniques [7]. However, most of them cost a great deal of money furthermore institutions that don't have these devices become insufficient [20]. So although, listening to heart sound by stethoscope is not an easy way of diagnosis it is still effective in order to use these devices. However, listening to heart sounds with a stethoscope is not an easy task and requires lots of experience also newly graduated or still studying physicians have a hard time to diagnose heard diseases with a stethoscope so this application is going to be much easier and reliable by supported by technology.

II. MATERIAL AND METHODS

In this study, the main goal is to design an electronic stethoscope which outputs heart sounds as a graphic. This allows physicians to visualize sounds signals. Visualization provides physicians to detect diseases even they are not able to detect with a conventional stethoscope and with their ears. By supporting conventional stethoscope with technology, this project is going to make diagnosing the heart valve diseases and more other diseases much easier. The main case about conventional stethoscope is the necessary experience requirement for auscultation. Because this project visualizes sounds as a graphic, that experience requirement is meaningless.

As this project is related with signals, firstly these signals have to be in specific amplitude in order to be detected by electronic components. Amplification isn't the only case also signals have to be filtered before going into the processor.

A. Microphone and Chest Piece

In order to get the body sounds from the chest, the chest piece is required. After chest piece collected body sounds from the chest, these sounds have to be converted into electrical signals. A microphone that is inserted into an air-filled hollow tube converts sound to electrical signals.

B. Amplification Circuit

Sound signals which are converted to voltage difference via microphone haven't got enough amplitude to visualize at oscilloscope or processed at microcontroller. So the amplification process is needed in order to work with these signals. This amplification process can be done with MAX 9814 microphone amplificator or any other amplification module. At the end of amplification process signals can be applied on filtering circuits and it can be processed by microcontroller.

C. Low Pass Filter Circuit

A simple filter circuit is designed to pass specific frequency range and attenuate frequencies out of this frequency range. And filtering circuits divide into 2 groups; these are active and passive circuits. Passive filter circuits include coil and capacitor components. On the other hand, active filters include additionally transistor and OP-amp (operational amplifier), and coil don't used in these circuits. Active filters have various advantages according to passive filters. For example; frequencies that filter is going to pass don't attenuate and also active filter's input impedance is high and output impedance is low. Because of OP-amps bandwidth is limited filtering of some frequencies is impossible.

Low pass filter circuits pass signals which are lower than the specific frequency and attenuates which is higher than specific frequency. That specific frequency is called a cut off frequency (Fc).

$$Fc = \frac{1}{2\pi\sqrt{R1R2C1C2}}$$

Cut of frequency is calculated by this formula.

D. High Pass Filter Ciruit

High pass filter passes only frequencies which are higher than the frequency cut off value and frequencies which are higher than cut off value are attenuated.

$$Fc = \frac{1}{2\pi\sqrt{R1R2C1C2}}$$

Cut of frequency is calculated by this formula.

E. Notch Filter Circuit

Notch filters also called band-stop filters are used to eliminate specific frequency from frequency domain. In this case notch filter is going to be used to eliminate power lane frequency which is 50 Hz.

Frequency which is going to eliminate from frequency range is calculated by fallowing formula;

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{C_2C_3R_3(R_1+R_2)}}$$

F. Microcontroller

As a microcontroller, Arduino Mega is used in this project. Arduino Mega based on Atmega2560 microprocessor. It has 54 digital input and output pins, 16 analog pins, and 16 Mhz crystal oscillator which means its clock speed is 16Mhz.

G. Arduino IDE

Arduino boards are programmed with Arduino IDE computer software. Atmega2560 on the Arduino comes with a bootloader which provides to upload new codes without using an external hardware programmer. Arduino IDE communicates with the STK500 protocol.

H. Data Set

According to research about classifying heart sounds, they have recorded 176 different patients' heart sounds and give them to the public domain [22]. This research contains both organic and pathological heart sounds so while testing the project these records are going to be used to verify the functionality of the device.

İ. Amplification

Firstly, using chest piece sounds signals are going to get from the patient's chest. A microphone that is inserted into an air-filled hollow tube (a part of the stethoscope) is going to give electrical signals. The microphone converts sound signals into electrical signals via diaphragm and magneto inside it. However, these electrical signals can be processed neither with filters or microprocessors so they have to be amplified. After that amplification and filtration processes are going to be done.

Because signals that are obtained from the microphone's amplitude are very low, amplification is necessary. This amplification is made by MAX 9814 microphone amplificator. After the amplification signals can be filtered to eliminate unwanted frequencies from the system.

J. Filtration

According to a research normal heart sound's frequency range is between 20 to 150 Hz [23]. Another research worked on murmurs states that heart murmurs frequency can be up to 1500 Hz [10]. According to these articles, all heart sounds are fitted in 20 to 1500 Hz frequency range so filtering frequencies except 20 – 1500 Hz range provides only heart sounds to be processed via a microcontroller. Also, lung sound's frequency can go up to a maximum 1200 Hz so this filtration will not attenuate any respiratory sounds [15].

K. Processing Signals via Microcontroller

After filtration process signals are obtained as amplified and purified from unnecessary frequencies. These signals are transferred into the microcontroller's analog input. With the help of analog to digital converter (ADC) in the microcontroller, these signals are converted into digital data which microprocessor can work on.

III. RESULTS

Heart sounds records from data set are applied on the micro controller. Output signals are obtained as following graphics. See Fig 4-5-6.

Fig 4. First heart sound (S1) and second heart sound (S2) signal (Systole and diastole) obtained from microcontroller

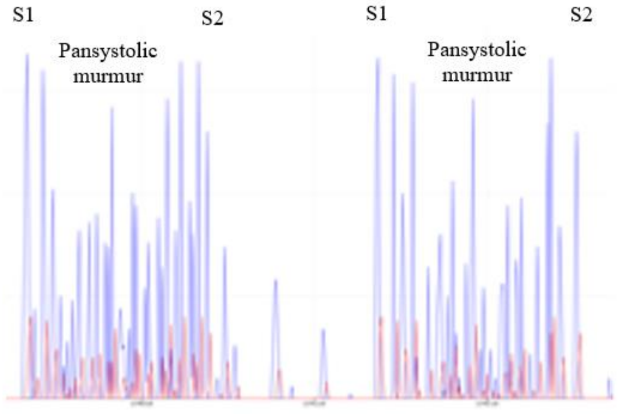

Fig 5. Pansystolic murmur sound signal obtained from microcontroller

According to Fig 4 health heart's systole (first heart sound (S1)) and diastole (second heart sounds (S2)) phases can be distinguished easily.

Fig 5 shows the output signal of a microcontroller when sound recording of a patient who has pansystolic heart murmur given to microcontroller as an input. First heart sound (S1) and second heart sound (S2) also murmurs, pansystolic heart murmur in this case, can be distinguished easily.

Normally, S2 is a sound that is heard when aortic and pulmonary valves are closed. In normal conditions aortic valve is closed before the pulmonary valve. However, these events are so close to each other so the difference is unnoticeable. On the other hand, when the patient at the inspiration period, second heart sounds (S2) can be heart as 2 sounds. There are respectively closing of the aortic valve and closing of the pulmonary valve. This event is called a split S2 and can be seen at Fig 6.

According to these figures, the microcontroller is able to give outputs understandable for physicians. When the graphs are shown to intern physicians, they are able to diagnose the diseases by reading the graphs.

Fig 6. Sound signal of split S2 obtained from microcontroller

IV. DISCUSSION

Globally, the diagnosis of any diseases is prior to the treatment of a disease. To treat a disease, firstly physicians have to know what they are dealing with. Also while diagnosing a disease, there are some problems such as wrong diagnosis or time consumed while waiting for test results. This project is aimed to reduce time while diagnosing heart disease and also as mentioned earlier, reducing experience that is needed auscultation of the chest.

In this project, Arduino Mega is used as a microcontroller, although it has a fairly sufficient processor, in the future faster-clocked processor can be used as a microcontroller. Also, Arduino IDE is used in order to show digital heart sound signals. When the sampling frequency or basically communication frequency of the Arduino is increased graphs become more detailed but they started to move much faster. In order to slow the graph down additional software can be used but it wasn't necessary at the experimental phase of the project.

The other important point is getting body sounds from the chest; in this project due to insufficient funds, the first part of the project could not be completed. Because of the missing stethoscope, all the experiments achieved by giving data set recordings directly to filters and microcontroller. So we can say that in theory systems works but these experiments also have to be done with stethoscope with a real patient.

V. CONCLUSION

Lots of patients lose their lives because of heart diseases, heart valve malfunctions are one of the most dangerous diseases. This project is aimed to provide a reliable and less time-consuming option for diagnosis. Diagnosis of most of the diseases via auscultation is very hard, especially for physicians who have less experience and physicians who are newly graduated. This system provides a diagnosis of the diseases with less experience and also prevents unnecessary usage of expensive and time-consuming diagnosis methods. Furthermore, with this system prevention of false-negative diagnoses is aimed. Another advantage of this project is; as the heart sounds are obtained as digital data, these data can be sent to other physicians for their opinion about the case. This method provides a diagnosis to become more reliable.

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