

Embedded System Based Portable Device Design for Measuring ECG/Pulse

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Abstract

In patients with cardiovascular disease, ECG (Electrocardiography) recording and pulse data must be monitored. ECG devices frequently used in hospitals provide output on paper but cannot transfer data to a computer environment. In this case, it is not possible to store, compare and analyze patient data. Portable holter devices used today are generally heavy and are of a size that will cause discomfort to the patient. The long cables used both increase noise and disturb the patient. In some of the new generation devices designed, the control unit and sensors are on separate cards and are combined with cables. This causes noise to be added. In this study; a lightweight, ergonomic, integrated on a single card, ECG/Pulse test device using short electrode cables was designed. An ergonomic case was produced to place the device in the middle of the rib cage. Patient data can be transferred to the specialist doctor thanks to the mobile software created for instant patient monitoring. The design will be very useful for patient monitoring, especially in intensive care units.

Keywords: Portable electrocardiography, pulse measurement, ESP32-Wroom, biomedical signal processing

EKG/Nabız Ölçmek için Gömülü Sistem Tabanlı Taşınabilir Cihaz Tasarımı

Öz

Kardiyovasküler rahatsızlığı olan hastalarda, EKG (Elektrokardiyografi) kaydının ve nabız verisinin takip edilmesi gerekmektedir. Hastanelerde sıkça kullanılan EKG cihazları kağıt üzerinde çıktı vermekte fakat bilgisayar ortamına veri aktarımı yapamamaktadır. Bu durumda hastaya ait verilerin saklanması, karşılaştırılması ve analizi mümkün olmamaktadır. Günümüzde kullanılan taşınabilir holter cihazları genellikle ağır ve hastaya rahatsızlık verecek boyutlardadır. Kullanılan uzun kablolar hem gürültüyü artırmakta hem de hastayı rahatsız etmektedir. Tasarlanan yeni nesil cihazların bir kısmında da kontrol ünitesi ve sensörler ayrı kartlarda olup kablolarla bir araya getirilmektedir. Bu durum gürültü eklenmelerine neden olmaktadır. Bu çalışmada; hafif, ergonomik, tek kart üzerinde bütünleştirilmiş, kısa elektrot kabloları kullanan EKG/Nabız test cihazı tasarlanmıştır. Hastaya ait veriler, anlık hasta takibi için oluşturulan mobil yazılım sayesinde, uzman doktora aktarılabilir. Yapılan tasarım, özellikle yoğun bakım ünitelerinde hasta takibi için oldukça faydalı olacaktır.

Anahtar Kelimeler: Taşınabilir elektrokardiyografi, nabız ölçme, ESP32-Wroom, biyomedikal işaret işleme.

1. Introduction

In recent years, patient monitoring systems that deal with vital signs such as electrocardiography (ECG), heart rate (HRV), respiratory rate, oxygen saturation (SPO₂), and body temperature have been developed [1-3]. By real-time analysis of biological signals received from the patient, the patient, doctor, caregiver, and a healthcare institution are provided with information about the patient's health status. The general condition of the patient is revealed through analyzes made from records over a certain period of time [4]. Especially in chronic patients requiring long-term follow-up and home care services; Telemedicine applications that include dynamic web software that reports, displays and graphs patient data to doctors in real time give good results [1,5]. Recent advances in the internet of things (IoT) have enabled the partial processing and transmission of patient data [6]. Systems are being developed that detect the patient's heart signal, detect arrhythmia in the heartbeat using intelligent signal processing methods, and provide information to the doctor, the patient, or a relative via the internet [3, 7]. Such devices, which can measure signals without limiting daily life, are being rapidly developed to be smaller, smarter, cheaper and with lower power consumption [8, 9]. With such wearable systems, it is possible to monitor patients remotely. Biomedical data can be transferred to databases via mobile devices and computers and monitored in real time by patients and doctors through created applications [2]. For example, it is possible to monitor and record the heart rate in real time with a belt worn by an athlete [10]. Patient monitoring systems that instantly record data from biomedical sensors (ECG, pulse rate, SPO₂, temperature, movement, etc.) are becoming widespread [2,3,11]. Read data is usually recorded instantly with microcontrollers. Wi-Fi, Bluetooth etc. It is transferred to the main server using communication systems [2].

It is not easy for people living in remote areas to access health facilities due to reasons such as traffic and insufficient transportation services [1,12]. For this reason, remote patient monitoring systems should be used effectively. For example, regular remote monitoring of the ECG signal in heart patients in daily life; It is effective in determining the type of rhythm disorders that are unknown when they will occur and in investigating the cause of pain that occurs while working, walking or sports [5,13,14]. It uses multiple electrodes to collect ECG data and the signal is plotted on a piece of paper (electrocardiogram). This prevents the device from being portable and the patients' activities. Since it requires the patient to go to the hospital frequently and stay in the hospital for a long time, it also increases the hospital burden and cost. Therefore, low-cost, portable, small, wireless ECG devices are designed for long-term ECG signal monitoring [2,6,7,15]. Portable ECG devices are now widely used for long-term recording of signals, transferring them to the hospital and remote monitoring [6,15]. If an unusual situation occurs in systems designed using on-body sensors; to the ambulance, doctor, hospital, caregiver, etc. will send messages and can also diagnose with software [16-18].

To understand the ECG, it is necessary to know the functioning of the heart. In Fig. 1, ECG is associated with the functioning of the heart. In the figure, the P wave shows the depolarization of the atria. Immediately after the P wave, the atria contract and a slight increase in the atrial pressure curve is observed. QRS waves appear approximately 0.16 seconds after the onset of the P wave, and these waves indicate depolarization of the ventricle. With depolarization,

contraction begins and ventricular pressure begins to rise. The last visible T wave indicates the repolarization of the ventricles and the time when they begin to relax. Pressure changes in the atria: A wave occurs as a result of the contraction of the atria. C wave occurs when the AV valves stretch backwards as a result of contraction of the ventricles. V wave is due to the slow flow of blood from the veins to the atria when the AV valves are closed [20].

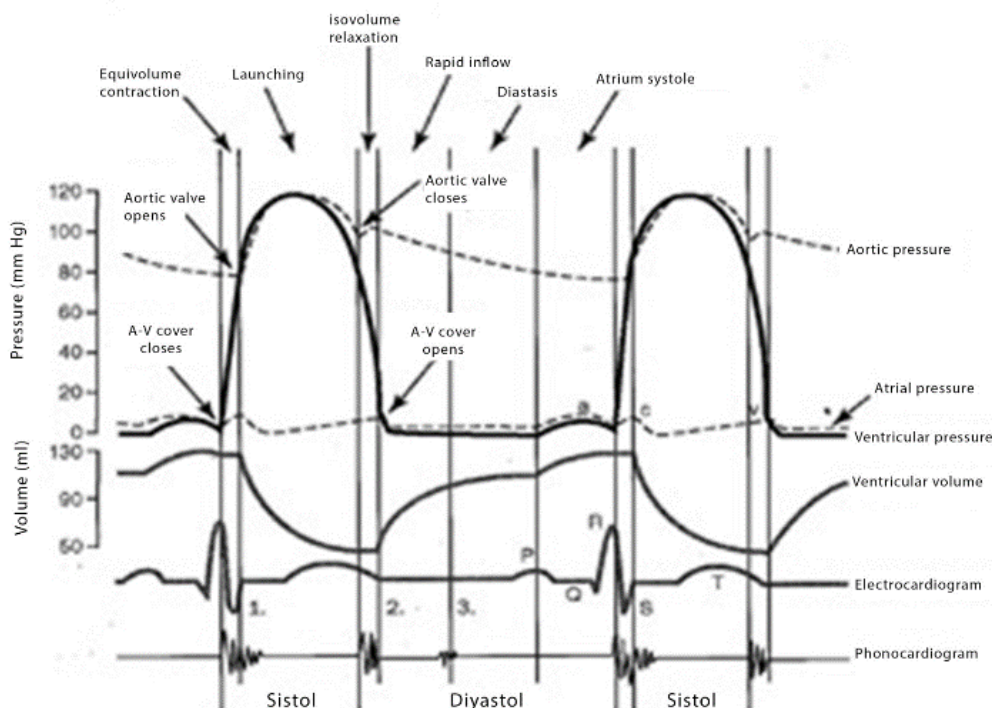


Figure 1. The relationship between the electrocardiogram and the cardiac cycle [20].

Cardiovascular system; Thanks to the blood circulating in a closed system, it delivers the substances needed to the tissues, especially oxygen, and removes the waste substances, especially carbon dioxide, from the tissues [21,22]. During physical activity; The heart, circulatory and respiratory systems must work in harmony to meet the increasing energy needs of the muscles. For this, there must be complete harmony in the functioning of the lungs, pulmonary circulation, heart and peripheral circulation [23].

Heart attacks, heart failure and arrhythmias from cardiovascular diseases (CVD) are the main causes of sudden deaths worldwide [2,5,13,24,25]. With population growth and aging of society, the incidence of CVDs has also increased [25,26]. CVDs are affected by age, fitness activity, cholesterol level, diabetes, body size, body position, etc. Many factors can affect an individual's heart rate [2]. Arrhythmia is an irregularity of the heart rate and causes abnormalities in the heart rhythm. Normal sinus rhythm (NSR) is usually between 60 and 100 beats per minute. When the heart rate exceeds 100 beats per minute, it is called tachycardia, and when it falls below 60 beats per minute, it is called bradycardia [20,27-29].

The cause of short-term, spontaneous heart rate variability (HRV) in humans remains unclear [30]. KHD; It is thought to arise from the chaotic structure of the respiratory and circulatory system, imbalances in the autonomic nervous system, and the complex interaction between the

brain and cardiovascular system [31-33]. Determining HRV is important for identifying various heart disorders. Heart rate change is perceived by the change in time difference between consecutive QRS complexes on ECG signals [34]. ECG, Photoplethysmography (PPG) and Oscillometric methods are used to measure HRV. The standard deviation value occurring between the peak-to-peak intervals (between two R waves) in the ECG signal is defined as HRV [35]. The average number of heart beats in a healthy person is determined as 72 beats/min, the mean beat interval is 833 ms, and the standard deviation is 40 ms [35]. Systems that use more pulse sensors are recommended to obtain BPM (Beats per Minute) [13]. Photoplethysmogram (PPG) signals used for this purpose; These are the signals obtained as a result of optical measurement of volumetric changes occurring in capillaries [36].

Biomedical signals are mainly used to diagnose or detect certain pathological or physiological conditions [2,22]. ECG; It is a non-stationary biomedical signal that provides information about the internal electrical impulses produced by heart cells that enable the heart to work. In fact, ECG is the recording of this electrical activity (biosignal) that occurs as a result of the heart performing its functions on paper (in memory as data) [5,6,13,15,37,38]. The ECG signal reflects the rhythmic electrical depolarization or repolarization of the heart muscle that occurs before or after contractions [39]. With this electrical activity occurring in the heart, the functioning of the heart muscle and neural conduction system is examined [5,36]. ECG; It is used to detect changes in heart rate and rhythm or the shape of the QRS complex [2,15,40]. Abnormalities in the electrical activity of the heart can cause abnormal conduction or rhythms that can cause the heart to beat too fast, too slow, or irregularly [38]. Fast and easy evaluation of the ECG signal offers an effective treatment method in the diagnosis of these diseases [27]. Tachycardia, bradycardia and arrhythmia disorders are detected through ECG data transferred to the computer and recorded [20,28,29,40].

As seen in Fig. 2; There are six major waves in a normal ECG. These; They are P, Q, R, S, T and U waves. The P on the ECG shows atrial depolarization, the QRS complex shows ventricular depolarization, and therefore these waves are depolarization waves. The T wave indicates ventricular repolarization and therefore these waves are repolarization waves [20,41]. The U wave represents the terminal period of ventricular repolarization. Although atrial repolarization exists theoretically, it cannot be observed in practice because it remains within the QRS complex. The horizontal line between two cardiac cycles when there is no electrical activity is called the isoelectric line [41].

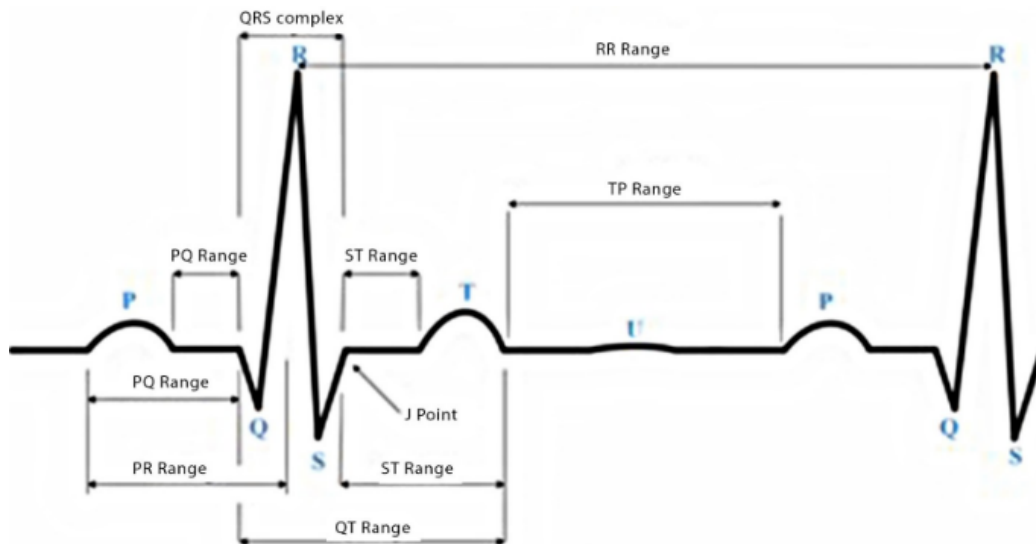


Figure 2. Normal ECG wave example [37].

In portable systems, the ECG signal is usually recorded with the help of three ECG electrodes [17,18,20,42]. In addition to the right arm (RA) and left arm (LA), an additional electrode called right arm driven (RLD) is used to increase the common mode rejection ratio (CMRR) [14]. These analog signals formed during the functioning of the heart are weak and contain noise. For this reason, the signal must be strengthened and cleared of noise [20,42]. The analog biosignals coming from the electrodes separately are combined by the heartbeat sensor AD8232 to create an ECG signal. The weak signal with a magnitude of (mV) is amplified thanks to the amplifier in the AD8232 integrated [3,7,13,15,17,18,28,43]. ECG signals can be amplified approximately (250-1000) times with bioinstrumentation amplifier circuits [17,18,26,42]. Then the signal is digitized and noise is filtered [3,17,18].

In studies in this field, wireless ECG device design and computer interface designs, which generally include microcontrollers, are carried out [17,18]. Analog signals can be converted into digital signals with the help of analog digital converter (ADC) integrated circuits or microcontrollers [17,18]. In such studies, ECG signal processing algorithms are used such as Raspberry Pi, Odroid, Beaglebone black, ESP-32, Arduino Nano etc. It is run in embedded system structures [3,26]. Embedded system preference is related to operating speed, content and physical structure [24]. The use of ESP32 is common in biomedical applications due to its small structure [3].

Noise signals are added to biomedical signal recordings for various reasons [28]. It is divided into two: physiological noises that interfere with the recorded signal from other sources in the body and non-physiological noises that interfere with sources outside the human anatomy [5]. Since the ECG signal has additional noise, it cannot be analyzed directly. In order to reveal a sign that may be meaningful for another disease, the signal must be separated from the noise [5,22]. Filters are used to suppress the negative effects of all factors affecting biological signals and network noise [26]. Filtering removes signal components of unwanted frequency and keeps signal components in a desired frequency region. Generally, four types of filters are used: “low pass, high pass, band pass and band stop filter” [19]. For example, when a band-pass filter

consisting of a low-pass filter (LPF) and a high-pass filter (HPF) is used, this ensures that noise outside the frequency band in which the QRS operates is removed from the signal [27]. IIR (Infinite Impulse Response) based filters are generally used to filter the ECG signal [15]. Digital filtering methods in the MATLAB program are also used to filter ECG signals transferred to the computer [20].

The filtered signal can be Bluetooth, Wi-Fi, GSM Module, etc. depending on the content of the cable or embedded system used. It is transmitted to the computer or mobile phone environment through methods [3]. It is quite common to record ECG data by transferring it to a mobile phone or computer via Bluetooth [17,18,44]. Additionally, digitized biosignals can be transferred to a server using Wi-Fi technology [2,3]. Data can be transferred to the cloud server system via Wi-Fi [2,13]. Likewise, it is possible to transfer it to Icloud for IOS and MAC [3,11]. In environments where communication is difficult, the GSM module (SIM800L) can be used to communicate via SMS and the data is sent to the base station [11]. With an android application, data can be viewed in real time, recorded and transferred to another source via GSM technology [7,43,44]. At the end of the data recording process, the data can be forwarded to the physician's e-mail address along with the patient information [13,17,18].

The evaluation of ECG in clinical applications is carried out with the interpretation of the evaluator, based on the naked eye scanning of the morphological features specified in various guidelines. Computer-assisted ECG analysis is seen as a faster, objective and consistent method [37]. For this purpose, various signal processing, artificial intelligence, deep learning and machine learning methods are used [7,29,45]. For this, abnormal situations in ECG signals must be detected and a warning system must be created [2]. Languages such as Python and C++ are frequently used for the interface software created [26]. With such software used, the performance of the heartbeat is evaluated through an intelligent process [7,43]. For PQRST detection by ECG signal analysis; Digital Signal Processing (DSP) methods such as Wavelet Transform (WF), Fast Fourier Transform (FFT) and Artificial Neural Networks (ANN) are used [2,26,27,40]. Using continuous wavelet transform; QRS, P and T waves can be distinguished from noise, baseline drift or irregular heartbeats. For these analyses, signals are often; It is taken from various databases such as MIT-BIH arrhythmia, MIT-BIH Normal Sinus, MIT-BIH Noise Stress Test [15,24,46,47]. Tachycardia, bradycardia and rhythm disorders can be diagnosed automatically through ECG data transferred to the computer [20,28]. Analysis of the QRS complex plays an important role in detecting cardiac arrhythmias. Similarly, PR interval and QT intervals are also used to classify various heart-related disorders [39].

In our study, a system that is portable, ergonomic, consumes low energy, can record ECG and pulse signals, transfers data to a computer or mobile phone, and holds all components together with a microcontroller on a single board was designed. In such test devices, electrodes, sensors, and embedded system cards are used as discrete devices. In this case, the connection points, connection cables and the distance between them increase the noise level that interferes with very sensitive signals. Additionally, since it is very messy, it is difficult to carry on the patient. For these reasons; In this study, we designed all circuit components, including the embedded system, on a single PCB. With this design, the noise rate was reduced and a more ergonomic,

portable and sterile design was created. After data transfer, signal noise was removed using a digital filter. The data transferred from the computer to the computer was transferred to an Android software on the mobile phone. ECG and pulse data are instantly transferred to the mobile environment and the results are transmitted to the user and healthcare professionals via the application.

2. Material and methods

Working Principle of the Designed Test Device

In this study, an electronic circuit board was designed to read ECG and pulse data obtained via surface electrodes. The data processed by the system microcontroller, along with the developed system software, will be transferred to the mobile application. The user's real-time ECG and pulse data can be displayed numerically and graphically. Figure 3 shows the general operation of the system. JAVA, one of the suitable programming languages, was chosen for the development of the Android application.

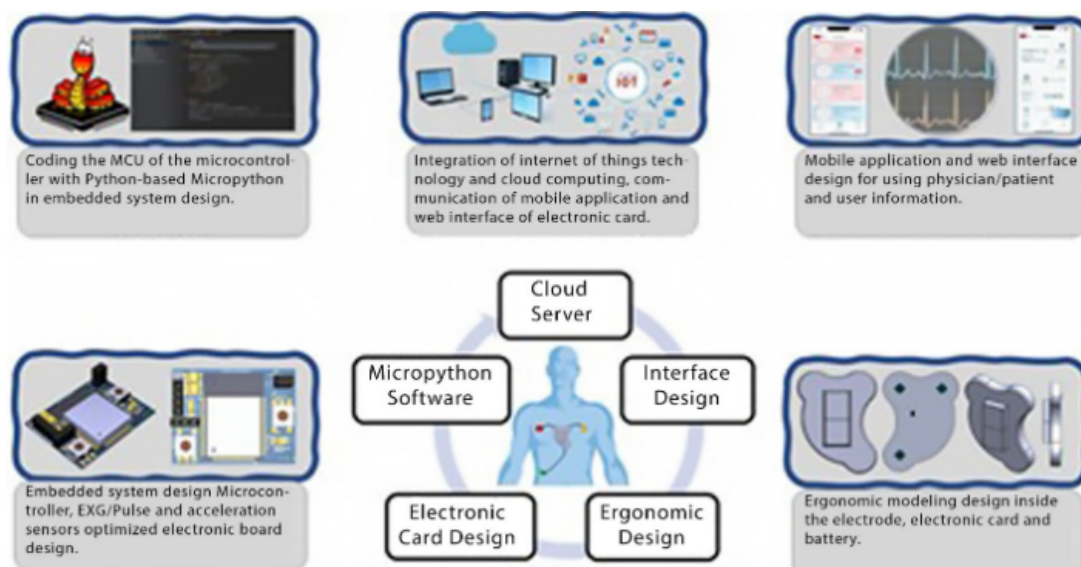


Figure 3. Creation of the system algorithm of the designed test device.

For wearable exercise devices, the AD8232 is placed near the heart. When the distance from the heart to AD8232 is small; the heart signal is stronger, there is less muscle noise (high frequency, amplitude muscle signal) interference, and the noise effect is less. The circuit in Fig. 4 is designed for these purposes. After the electrodes are placed at appropriate points on the body, their ends are connected to the AD8232 integrated circuit. The signal is at (mV) level and is amplified by the internal opamp in the IC. During amplification, the resulting signal must be filtered because noise and interference are also amplified [49].

System Model of the Designed Test Device

As seen in Fig. 6, in the design content of the test device; It includes ESP32-Wroom microcontroller, ADXL345 acceleration sensor, power circuit, CP2102 circuit, battery charging circuit, AD8232 sensor circuit. A lithium battery charging circuit with battery protection was designed to meet the energy requirements of the circuit. For serial communication from the circuit, the Tx, Rx pins in the CP2102 USB-UART converter circuit were connected to the Tx, Rx pins in the ESP32. In this way, data was transferred to the computer via USB.

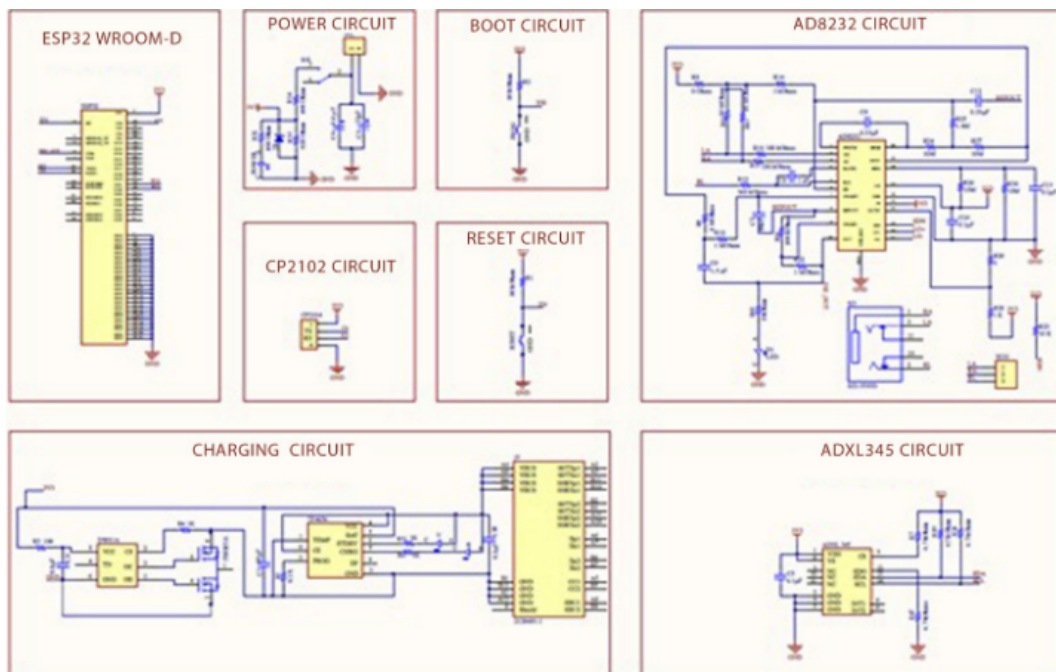


Figure 6. Detailed representation of the test device in the Altium design environment.

AD8232; It can also be supplied on ready-made cards as an ECG/Pulse sensor. However, as seen in Fig. 7, in our study, the test device was added directly to our circuit layer. In the drawn circuit, a connection socket (header) has been created to connect the electrodes to the connection terminals named RA, LA and RL. The electrode data connected here is transferred to the IN+, IN- and RLD inputs of the AD8232 ECG/Pulse sensor. ADC in the embedded system was used to digitize the analog ECG signal received from the output end of the AD8232 integrated circuit. ESP-Wroom-32, ADXL345 accelerometer connection can be seen in the circuit. ADXL345 sensor is added for respiratory information.

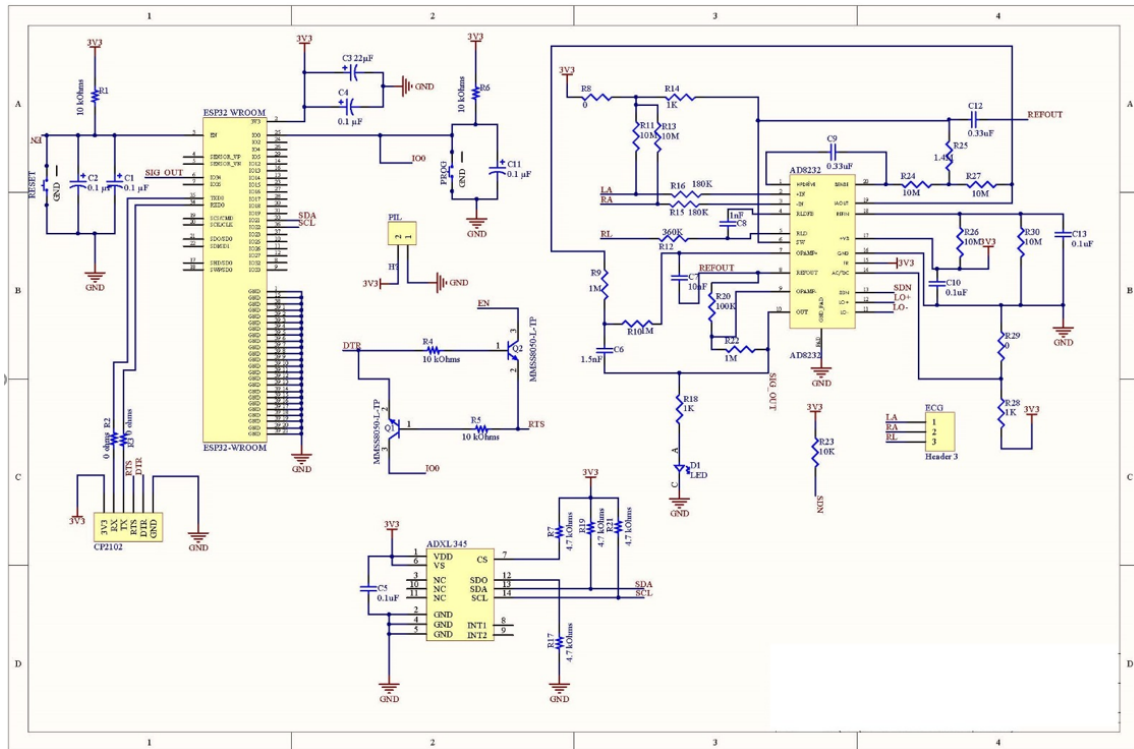


Figure 7. Hardware drawing of the electronic board of the tester.

Fig.8 shows the assembled PCB and circuit elements of the test device. The size of the tester is designed as 2.5cm*3.5cm.

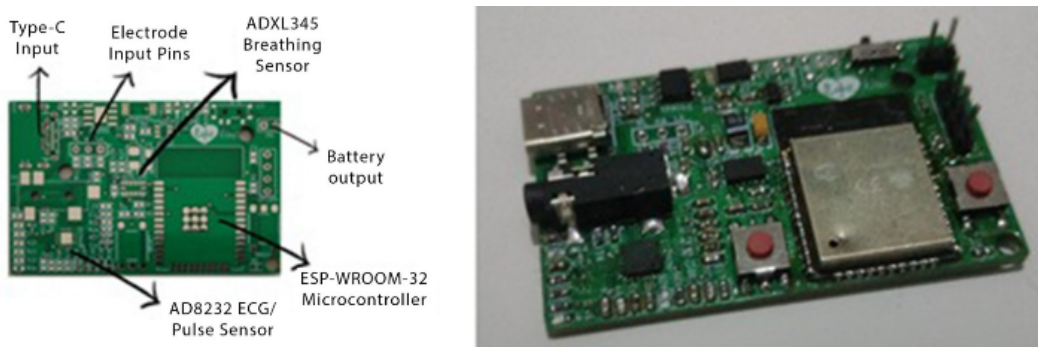


Figure 8. PCB and Assembled Representation of Test Device

Operation of the Tester

The analog signal transferred from the electrodes (ECG/Pulse) to the sensor and processed in the integrated circuit was received by the ADC pin on the ESP32 card and converted into a digital signal and made ready for processing. While digitizing the analog signal, the sampling frequency was set to 200Hz. Data collection from the port is done every 5ms with the Timer function. The filtering process of the received data, whose amplitude was increased by reading it as analog and digitized in ESP, was started. Noise below 0.5Hz frequency is caused by the patient's movement and breathing. A high-pass filter was used to remove this noise. In addition, muscle signals, which are another source of noise, cause high-frequency interference. A low-pass filter was used to filter out frequencies higher than 35Hz, where the ECG signal is

significant. Thus, components other than the meaningful data range (0.5Hz–35Hz) of the ECG signals were filtered out. The most important feature of the IIR filters used is that they enable adaptive filtering depending on past signal values and their filter size is small. The R-R peaks of the ECG signal were detected in the ESP software and the time value (ms) was calculated. The data obtained was converted into beats per minute. The processed ECG and pulse data were transferred to an Excel file on the system computer via USB cable connection. Visualization was provided by using the Serial Analyzer program for graphic drawing on the computer.

3. Results and discussions

When ECG signals are read from multiple electronic components, the noise generated by cables and connections is reduced thanks to the integrated electronic card. Furthermore, the ECG data is digitally filtered by the microcontroller software. The card allows the patient's pulse signal to be read.

The ECG/pulse data transferred to the computer will be transferred to the mobile software created on the mobile phone. The data will be transferred to a personalized SQL Server database. First, this software records personal data, and the selected individual's measurements are transferred directly to the database. The developed mobile application allows for instant data viewing by patients, physicians, and other users. A profile system containing user demographic information has been created for all system users. Within the mobile application, patients are registered with the system, and a physician-patient user interface is created to display the data. Figure 9 shows an example of the program interface.

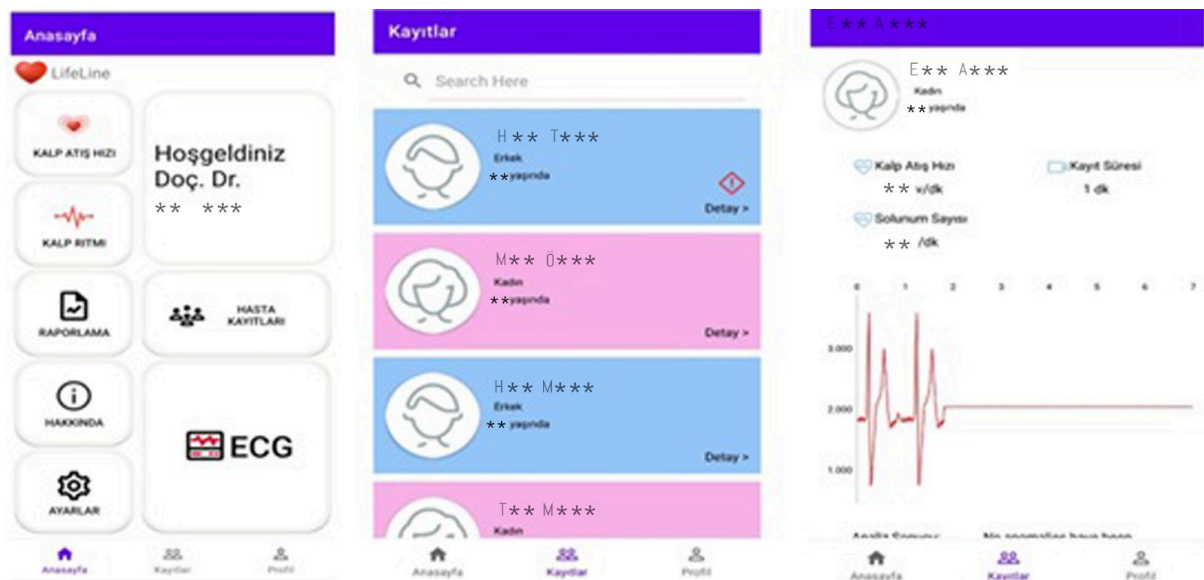


Figure 9. Example of the appearance of the home page, registered users and their data in the mobile application.

The external prototype designed for the test device is manufactured from biocompatible, anti-allergenic, and antibacterial polypropylene-polyethylene alloy plastic materials. The designs were created in Solidworks. The physical structure of the device was designed in two separate ways, considering infant-child and adult sensitivities. The test device designed for adults is

shown in Figure 10-a, and the test device designed for infants and children is shown in Figure 10-b. More aesthetic and smoother transitions were created in the infant-child model. The system weight has been reduced to 100-150 g, and the device dimensions are (46 mm * 105 mm * 23 mm) for adults and (58 mm * 101 mm * 16 mm) for children. The developed test device will be placed on the user's chest area, as determined by medical research.

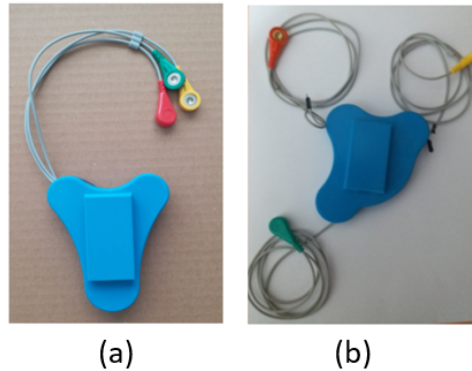


Figure 10. Adult and child-baby model external prototype 3D printout of the test device

4. Conclusions

In our study, unlike many studies in the literature, all system components are integrated onto a single PCB. The embedded system microprocessor ESP32, the ECG sensor, the acceleration sensor measuring respiration, the energy protection, and the battery charger are integrated onto a single PCB board, rather than separately. The greatest advantage of this is the elimination of cable connections and power circuit differences, and the reduction of noise. Additionally, two separate ergonomic cases were created for children and adults. The product is considerably lighter than its counterparts, which are located in the center of the chest, and is easy to carry. One of the greatest advantages of the designed test device is the small number of electrodes. Such portable systems typically have 5-7 electrodes. In our study, the same signal can be read with three electrodes. Similar studies typically record data for a period of time and then transfer it to a computer. In this study, the data will be read, filtered, transmitted in real time, and transferred to a database. Data can be monitored in real time using software developed for mobile phones. At the end of the data collection process, the patient/physician will be able to view ECG/Pulse data stored in the cloud as numerical values and graphs via mobile devices and computers.

Following the study, ethics committee approval will be obtained for the device's trial process on human data. The intelligent fault detection system will then send an alert to the user in the event of electrode misalignment or unintentional displacement. Additionally, the accelerometer integrated into the device will integrate respiratory rate measurement into the system. Signal processing methods will be used to identify arrhythmia, tachycardia, bradycardia, atrial fibrillation, and other conditions on the recorded graphs, and feedback will be generated.

Ethics in Publishing

There are no ethical issues regarding the publication of this study

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Author Contributions

Aslı AVCI carried out the implementation part of the study, data collection and statistical analysis. Ahmet TURAN carried out the literature review. The authors wrote, read and approved the article together.

Conflict of interest

The authors declare that there is no conflict of interest.

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