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3D PRINTED HOLTER ELECTROCARDIOGRAM (ECG)

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ABSTRACT

This study was aimed to design a low cost and ergonomic Holter Electrocardiogram (ECG) that allows remote monitoring of patients who need to be followed up by a doctor with the Covid19 pandemic period, sends SMS to the doctor or relatives of the patient in risky situations, and recordes and stores patient data. In this study, a 55x84 mm PCB electronic circuit was designed. Signals received from the patient through the electrodes are detected with the help of the AD8232 ECG sensor and transmitted to the ESP32, which is the processor of the system, and an SMS is sent to the doctor or relatives of the patient in risky situations, thanks to the UG96 GSM module. In addition, thanks to the wifi feature of the UG96 GSM module, the ECG data recorded in risky situations is stored in the ubidots. The doctor can access the patient's ECG data via ubidots.

Keywords: Holter ECG, Covid19, Remote Monitoring.

1. INTRODUCTION

Diseases related to the heart and circulatory system have increased significantly in recent years. Worldwide, heart and circulatory system diseases are at the top of death statistics. According to the data of the World Health Organization, The cause of 16% of total deaths worldwide is ischemic heart disease. In 2019, 8.9 million people died because of this. As stated by the World Health Organization, the global causes of death can be listed as follows [1].

Table 1. The global causes of death in 2019 [2].

Diseases	Death Statistics
Cardiovascular Diseases	>8.5 million
Stroke	>5 million
Chronic obstructive pulmonary disease	>3 million

On the other hand, the whole world has been struggling with the Covid 19 pandemic for two years. Covid 19 (New Coronavirus Infection) is a viral infection that makes a pandemic and spreads very quickly all over the world and in our country. The first case of coronavirus disease 2019 (COVID-19) was emerged on on December 8, 2019 in Wuhan, Hubei Province, China. Epidemic rapidly spread to other parts of China and overseas. In the early stage, most of these patients reported a history of contact with Wuhan seafood [3,4,5]. The disease progresses more severely in people who smoke, are over 50 years old, and have diseases such as diabetes, chronic lung diseases, cardiovascular diseases, and cancer. Although lung involvement is prominent in the course of the disease, many studies have shown that Covid-19 infection causes cardiovascular disorders, which may be an important factor in disease-related mortality. Many studies have shown that Covid-19 infection causes cardiovascular disorders, which may be an important factor in disease-related mortality [6]. Studies have reported that Covid-19 is associated with acute myocardial damage, and it has been found that it may cause an increase in the risk of acute myocarditis, ventricular arrhythmia, acute coronary syndrome and heart failure [7].

Electrocardiogram (ECG) is designed to examine the heart activity of patients. ECG plays an significant role in the detection of cardiovascular diseases. However, the traditional ECG device is expensive, large and restricts the patient's mobility, preventing the

patient from getting out of bed. On the other hand, the whole world has been struggling with the Covid 19 pandemic for two years. Research shows that at the initiation of the coronavirus disease 2019 pandemic, there was a decrease in the volume of cardiovascular disease diagnostic tests worldwide [8].

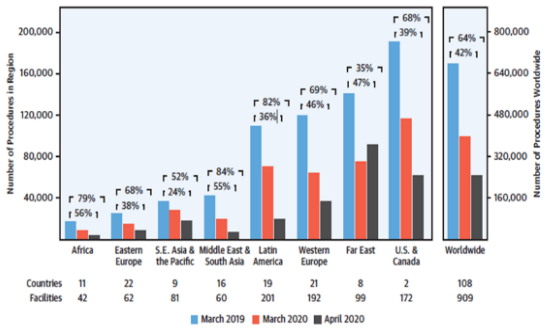


Figure 1. Decrease in worldwide cardiovascular disease diagnostic testing volume in the initiation of the coronavirus disease 2019 pandemic (March and April 2020) [2].

Thanks to the portable ECG, the activity of the heart is recorded while the patients continue their daily lives. Especially during the pandemic period, patients did not want to go to the hospital unless it was necessary. For this reason, remote monitoring of patients has gained critical importance during the pandemic period.

2. LITERATURE REVIEW

The heart is a versatile organ that constantly generates a certain electrical potential and then performs a mechanical work such as contraction. Therefore, the heart can be considered as an electromotive force source [9]. Figure 2 shows the electrical signals generated in consequence of the physical movement of the heart.

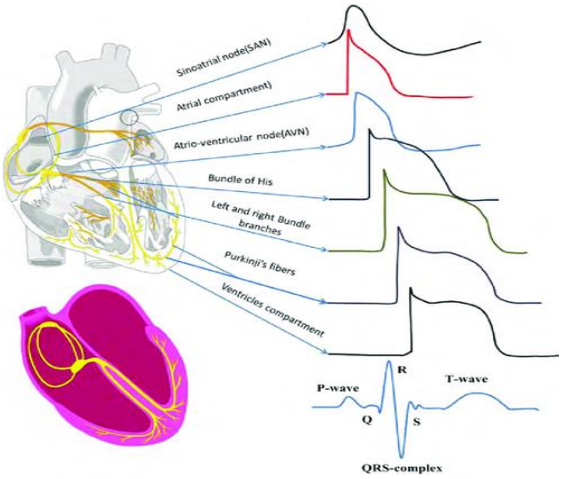


Figure 2. Electrical signals generated by heart movements [2].

The electrical stimulation and conduction system of the heart consists of four parts. These; (SA), (AV) atrioventricular node, bundle of his and its branches and Purkinje fibers. Of these, the (SA) node and (AV) node are the stimulus, the his bundle and Purkinje fibers are the conduction system [10]. The SA and AV nodes are located in the right atrium. The bundle of His is attached to the AV node and divides into right and left branches in the interventricular compartment. The branches of the bundle of His also enter the ventricles and connect with the Purkinje system [11].

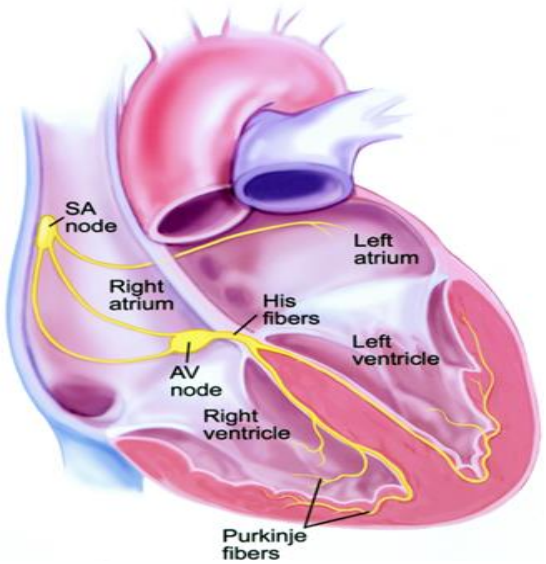


Figure 3. The electrical conduction system of the heart [2].

The signals that occur with the electrical activity during the heart's work and are detected with the help of electrodes from certain parts of the body are called Electrocardiography (ECG).

ECG demonstrates the contraction of the heart muscle, helps to diagnose coronary insufficiency or Myocardial Infarction (MI), allows to detect extension of the heart cavities, evaluates roles of the electronic pacemaker, and effects of some cardiac drugs.

The electrical activity of the heart was first demonstrated by Kölliker and J. Müller (1856). Dutch physiologist Einthoven recorded cardiac action currents with his own galvanometer (1903). He won the Nobel Prize in Medicine for this invention (1924). This first device developed weighed 270 kg.

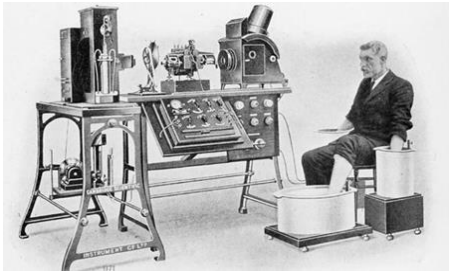


Figure 4. First electrocardiogram [2].

The ECG sign is defined as the electrical signals created by the heart in the form of a P – QRS – T wave sequence.

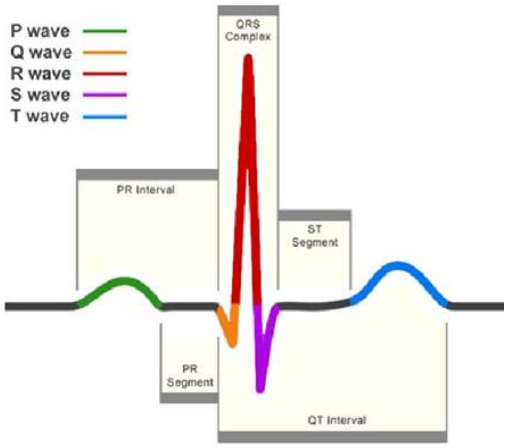


Figure 5. ECG signal [2].

The P wave is created by the electrical potentials generated during the depolarization of the atria earlier they begin to contract. The QRS wave is depolarization waves, which are the components of the wave that causes the ventricles to depolarize earlier contraction, that is, during the propagation of the depolarization wave throughout the ventricles [12]. The T wave is produced by electrical signals formed by the end of the depolarization state of the ventricles. U wave is not seen all the time. It is tiny and closely follows the T wave. It is thought to indicate repolarization of the papillary muscles or Purkinje fibers.

Table 2. Sources of ECG signal [2].

ECG Signal	Sources of ECG Signal
P Wave	Atrial contraction
QRS Complex	Atrium repolarization + ventricular depolarization
T Wave	Ventricular repolarization
P-Q Wave	Warning time delay

Electrodes are generally used for sensing electrical biological signals in living organisms. ECG measurements are perhaps one of the very ordinary measurements in the field of signal monitoring. ECG electrodes are usually manufactured as Ag/AgCl electrodes. The main reasons for choosing Ag/AgCl are the absence of harmful effects on the human body, its stable behavior, and the reliability of the measurement results. These electrodes are in the class of surface electrodes. Because the obtained signs are perceived from the skin surface. It is produced sometimes as gel-impregnated or sometimes dry, depending on the need. There are types produced in different types and sizes for adults, different for children or babies. There are also ones that can be used once and thrown away and used repeatedly [13].

Table 3. Types of ECG electrodes [2].

Types of ECG Electrodes	
Surface Electrodes	Metal Plate Electrodes
Disposable ECG Electrodes	Dry Electrodes
Flexible ECG Electrodes	

Recently, various studies have been conducted to remotely view ECG signals.

Babu et al. [14] proposed an ECG imaging system consisting of three different subsystems. The first subsystem in this imaging system is used to read analog ECG signals. The second subsystem consists of a microcontroller and a bluetooth module and is used to convert ECG signals to digital and transmit them to a phone with Android operating system. The third subsystem is the phone itself, which is used to display ECG signals via appropriate graphs.

Affordable and effective ECG device that can integrate with mobile devices with Android operating system has been developed [15]. In this system, ECG signals from non-invasive sensors are processed with the help of LabVIEW program and noises are removed. The mobile device works as a signal measurement and display system.

An ECG imaging system consisting of three different subsystems has been proposed [16]. The first subsystem in this imaging system is used to read analog ECG signals. The second subsystem consists of a microcontroller and a bluetooth module and is used to convert ECG signals to digital and transmit them to a phone

with Android operating system. The third subsystem is the phone itself, which is used to display ECG signals via appropriate graphs.

Aktas et al. [17] conducted a study on the transmission of physiological signals from patients using KVAAs and sent the ECG signals created in the wireless environment. In the application, a simulation was created using the OPNET Modeler program. Considering the results, it was concluded that the physiological signs obtained from the patients were successfully transmitted according to the quality of service parameters.

Bas [18] developed a design proposal for the monitoring of patients in his study. This system he developed consists of 2 parts. The first of these is the remote monitoring of the patients and the other is the monitoring of the patients in the hospital. The system proposed in the study has a three-layer block structure. The first of these layers is the KVAA block, the second is the body area network server block, and the third is the medical server block.

Can [13] tried to send the data he obtained to the phone by designing a low-cost device. With the Bluetooth module, which is a wireless technology, it transmits the ECG signals to the mobile phone and enables them to be displayed. By using the Bluetooth module, data flow is provided to other devices at a distance of 10 meters or to long distances with GSM operators.

3. MATERIAL AND METHOD

The designed Holter ECG system includes two main parts as hardware and software. The system should be light and portable, so a PCB circuit was used to make the system smaller. EasyEDA PCB design program was used for PCB Circuit design. EasyEDA is free to use. It is an internet and cloud based circuit design program. The program can work in harmony with all operating systems. Since it is internet and cloud-based, it can be used easily without downloading or installing any files on the computer. For these reasons, this program was used for PCB circuit design. A sensor is required for the system to detect heart signals. AD8232 ECG sensor is used in this system. The AD8232 contains out-of-wire detection. It has ac and dc sensing modes optimized for two- or three-electrode configurations, accordingly. The AD8232 has a gate capacitance of 15 pF and resistors of 10 kΩ on each input. This creates a low pass filter on each input that reduces the high frequency correction no adding external elements (Figure 6).

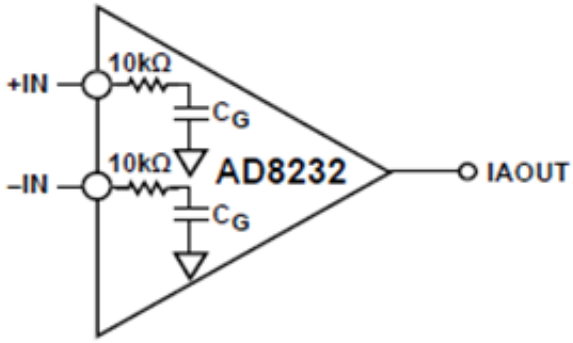


Figure 6. RFI filter without external capacitors [2].

A processor is required to run the software in the designed system. In addition, the reporting of the obtained data will be uploaded to the cloud via Ubidots. For this reason, there must be a wifi network in the environment. The processor will run the algorithm we have determined, decide and send the results to the cloud via wifi. For this reason ESP32 was preferred (Figure 7).

Figure 7. ESP WROOM-32 [2].

In the system, the ECG signals are detected by the AD8232 ECG sensor and then sent to the processor, namely the ESP32. In order for two devices to communicate, they must be on a certain protocol. A protocol is required to send

data to the Ubidots server. In this project, the MQTT protocol was used to send the data. Data is stored in Ubidots.

MQTT (Message Queuing Telemetry Transport) protocol is a machine-to-machine (M2M) message-based protocol widely used on the Internet. It has gained acceptance in the Internet of Things (IoT) ecosystem with its light weight and low resource consumption. Almost all IoT cloud platforms support MQTT protocol to send and receive data from smart objects.

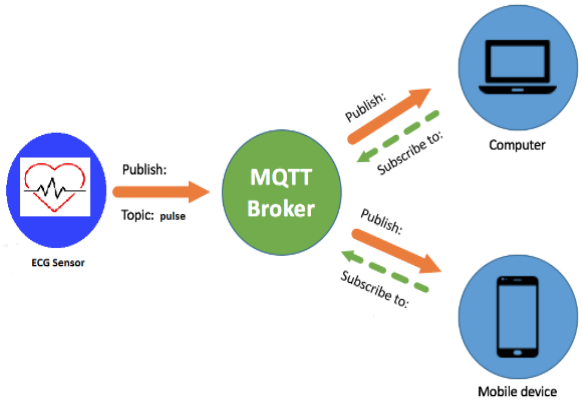


Figure 8. MQTT architecture [2].

The circuit designed for Holter ECG is given below.

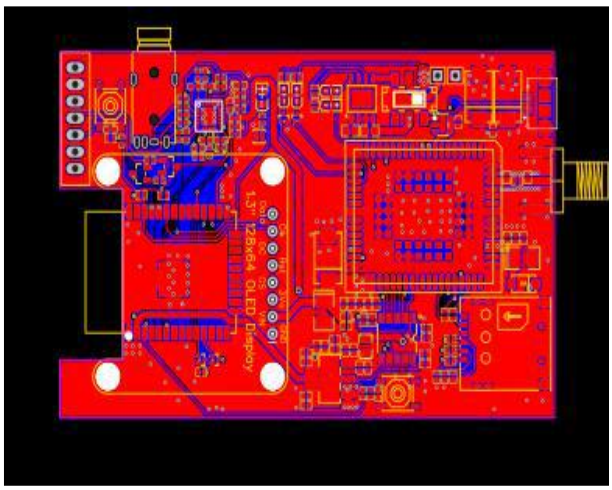


Figure 9. PCB design of holter ECG [2].

Software development was done in C language. It was built on three main algorithms. In the first algorithm, the detected ECG signal is filtered and the heart rate is measured. In the second algorithm, if the heart rate is 40 bpm and below or 120 bpm and above for a few seconds, the ECG signal is recorded and transferred to the cloud via Wifi. The third algorithm is the system, while the doctor or any number registered in the system is notified via SMS.

In this study, the ECG signal related to single-channel LA-RA (Lead I) electrode placement was taken from the state of 3 types of electrode placement in the Bipolar leads, which is one of the standard ECG leads. Accordingly, the points for placing the electrodes on the body are shown in Figure 10. Ag-Cl electrodes were used in this study. The reason for choosing these electrodes is that they are disposable and hygienic, as well as being easy to supply, use and place.

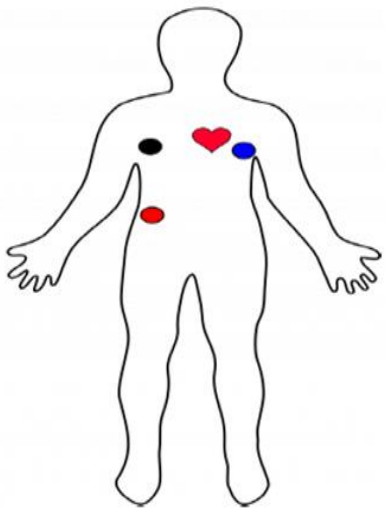
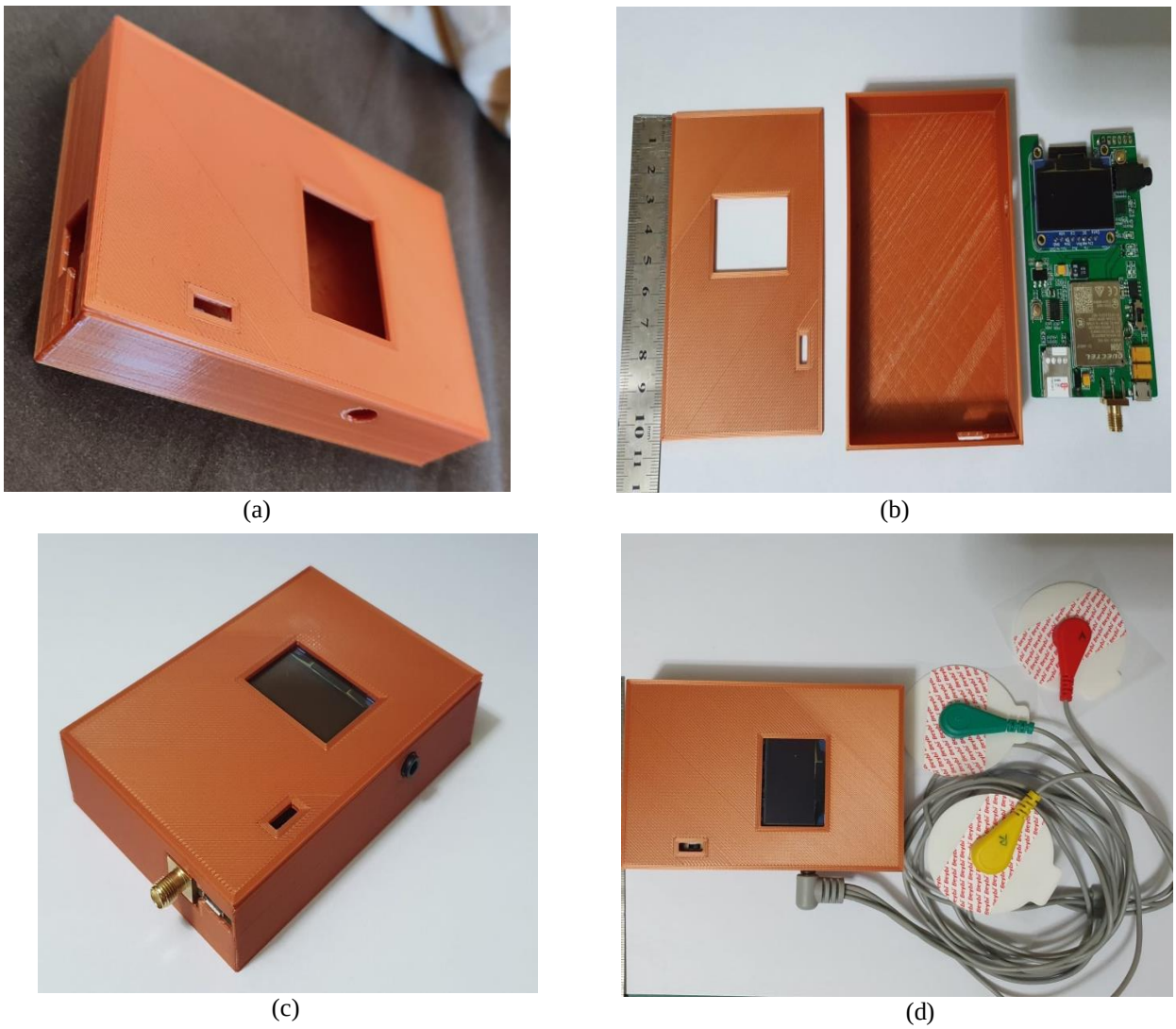


Figure 10. ECG electrodes placements [2].



(a) (b)

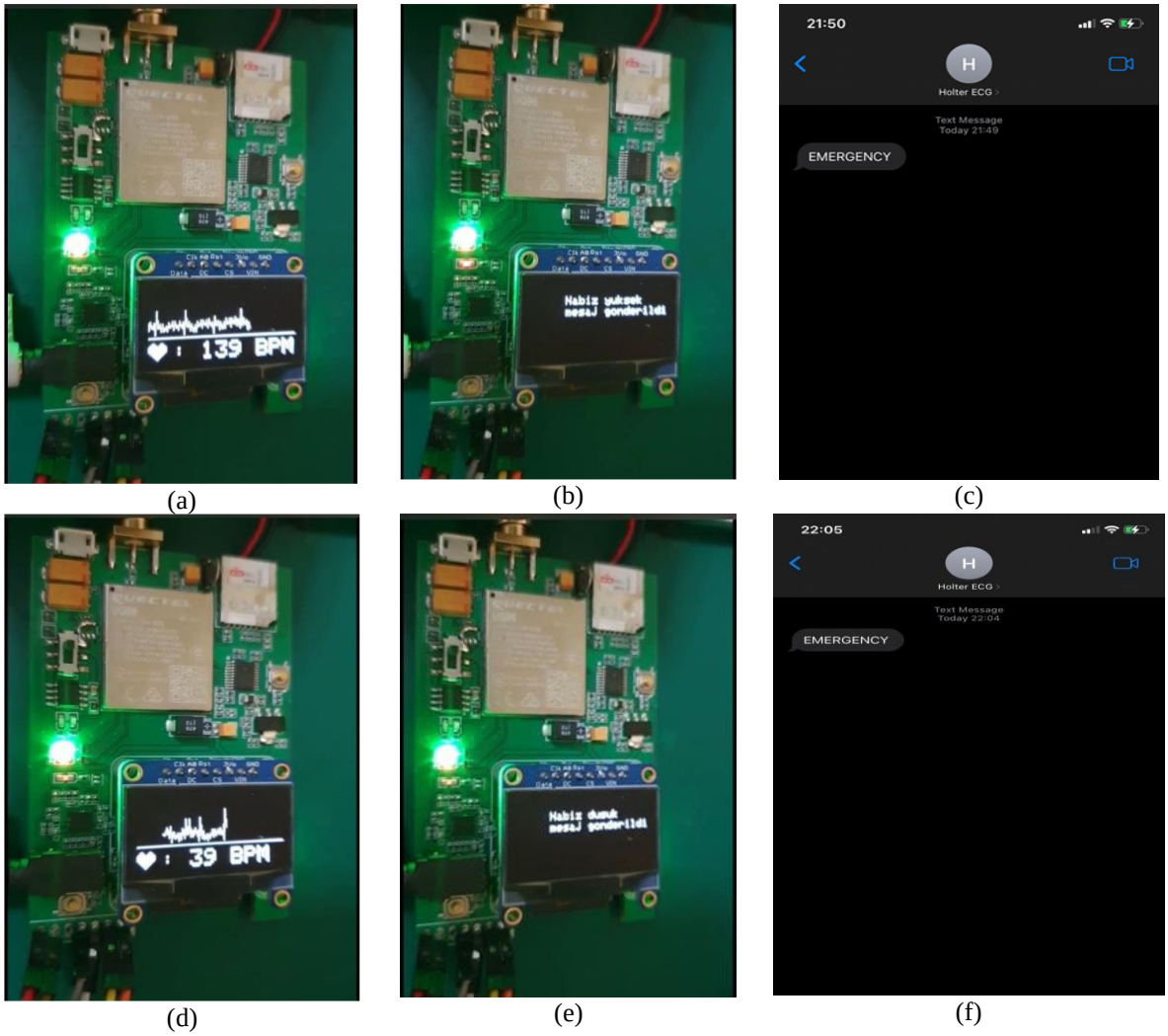
(c) (d)

Figure 11. Whole outer box (a) , Top dimension, box and PCB circiut (b), PCB circiut placed in the box (c), Final version of the Holter ECG (d) [2].

The design for the outer box of this system was done in Solidworks. Today, 3D printers are used in many fields such as medical, automotive, aerospace, architecture and defense industry. Its production was carried out in the 3D printer, which has been popular in rapid prototyping technology in recent years. 3D printing technique was preferred due to its low cost and fast production capability. PLA was used as the filament. PLA was preferred because it is a renewable, odorless and carcinogen-free material as well as beingsuitable for complex designs. The designed ECG prototype has dimensions of 73x105x20 mm. The final version of the prototype is shown in Figure 11.

4. RESULTS AND DISCUSSION

The images of the system working at low and high heart rates are as follows (Figure 12).



(a) (b) (c)

(d) (e) (f)

Figure 12. High heart rate (a), Notification of high heart rate (b), Message delivered to the phone at high heart rate (c), Low heart rate (d), Notification of low heart rate (e), Message delivered to the phone at low heart rate (f) [2].

The heart rate 40 bpm and below or 120 bpm and above for a few seconds ECG signal recorded and transmitted to cloud over Wifi. An SMS notification was sent to the number registered in the system.

Figure 13. Saving ECG data in ubidots [2].

5. CONCLUSION

In this study, a low-cost and ergonomic ECG device was designed. Saving data and sending SMS were carried out under the specified conditions. Considering the storage, battery and processing speed, the data is recorded only when the specified conditions are met. The stored data is accessed via ubidots. Even if recording ECG data in abnormal heart rate values is sufficient for now, in some cases, days of follow-up may be required. The widespread use of portable ECG devices will enable more patients to access ECG data. In future studies, functions such as sending e-mail, GPRS, and tracking with a mobile application can be added to the ECG device, which plays an important role in the diagnosis of many diseases.

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