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DESIGN OF REMOTE CONTROLLED HEART MONITORING SYSTEM

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Abstract

The biological signal generated by the pulse is taken to the PC environment by means of an electrode, a preamplifier and a data acquisition (DAQ) card. An image is presented on the graphical display applying signal processing methods on the electrocardiogram (ECG) signals obtained on the PC. It has an easy-to-use interface supported by graphics on both the patient side and the specialist side. The ECG data is sent to the long-distance terminal via the GSM modem. The biggest advantage of using a GSM modem is to ensure that the specialist is independent of the place. Thus, the specialist can contact the patient at any time and at any place. The specialist analyzing ECG data can remotely manage the defibrillator device, if needed.

Keywords

Telemedicine, Electrocardiography, LabVIEW, Heart Attack

1. Introduction

The majority of sudden deaths taking place in a short time consist of heart diseases. Sudden cardiac death may occur without any previous indication, even sudden death may be the first signal of a heart disease. According to Turkey Statistical Institute's (TSI) 2017 data, heart disorders have the highest share by 39.7% among diseases that cause death in Turkey (TUİK, 2018). According to the World Health Organization's 2016 data, cardiovascular diseases, which account for 31% of the world's 18 million deaths, take the first place. And, sudden heart attacks account for 85% of the deaths from cardiovascular diseases (WHO, 2016).

Avoiding the danger of deaths due to sudden heart attack depends on the promptness of the resuscitation procedures. Ambulances are used as mobile coronary care units since the deaths caused by heart attacks outside the hospital occur within a few minutes of the onset of the crisis. Since responding to patients with a full-fledged ambulance in a short period of time reduces the time to reach the emergency care units, successful results have been achieved in reducing the rate of patients who died before reaching the hospital. According to the data of US National Center for Biotechnology Information, decreasing the average ambulance intervention time from 14 minutes to 8 minutes, increases the number of patients who survived by 6-8% (Pell, Sirel, Marsden, Ford, & Cobbe, 2001).

Three types of delay must be minimized in order to save the heart at risk. 1. Delay in calling for help by patients and their relatives, 2. Delayed response of health personnel to emergency calls, 3. Delay in bringing the patient to the hospital. In the process starting with the call of the patient's relatives for help, the steps of responding to call and bringing the patient to the hospital, which cause delays, can be minimized by telemedicine applications. Defibrillator device can be used easily by educating the patient's relatives. Thus, the delay caused by the health personnel in the ambulance will be prevented. Even if the health personnel in the ambulance are required to reach the patient, he or she can be responded by a doctor without being hospitalized.

There are many benefits of telemedicine to users, such as; immediate access to data on demand, efficiency, accuracy, self-help, and providing services from miles away to patients in specialization branches not available in hospitals. In addition to increasing the patient's survival, telemedicine applications facilitate access to health services, reduce treatment costs thus increasing quality of service. In short, the aim of telemedicine is to be a tool for providing a widely available, inexpensive and high quality health service. In 1996, American Medical Institute defined telemedicine as the use of electronic information and communication technologies to provide and support health care services in cases where distance creates a problem (Willson, 2016). Telemedicine applications in fields such as radiology, pathology, dermatology, cardiology, neurology, dentistry, psychiatry, ophthalmology, oncology and surgery are gradually expanding with the development and falling prices in information and communication technologies. Wittson et al., in 1959, became the first to use interactive televisions for medical purposes, which communicated over a microwave network to diagnose tele-psychiatry between the Nebraska Institute of Psychiatry in Omaha and the state mental hospital, 112 km away. In the 1960s, transferring certain biological data of astronauts by telemetry methods in NASA's space research projects was the first example of telemedicine applications (Perednia & Allen, 1995). Measurement and instrumentation procedures are at the forefront in the collection and transmission of vital biological data.

LabVIEW is a programming medium with a graphical interface, developed with a focus on measurement and instrumentation. Kho et al. transferred the ECG and blood oxygen data to a remote system simultaneously for remote monitoring of biological signals in the LabVIEW platform (Kho, Saim, & Soon, 2002). Reske and Moussavi designed a system that allows ECG signals to be delivered in web-based manner in order to ensure continuous service and cost reduction in areas far from big cities which were devoid of equipment and specialists. In the designed system, intermediate devices such as amplifiers and filters, two personal computers with network connection, an analog-digital converter data acquisition card were used. LabVIEW programming language was used for server-client communication in TCP/IP protocol (Reske & Moussavi, 2002). Mendoza et al., designed a system that could obtain, record, view and send special signals such as ECG, temperature and oxygen status to any server via internet. The designed system consisted of sensors, an analog signal processing unit and a graphical user interface. The user interface design of the system was developed in the LabVIEW environment (Mendoza, Gonzalez, Villanueva, Haltiwanger, & Nazeran, 2004). Warren et al., attempted to reduce the cost of imaging systems. In practice, electrocardiogram signals and oximeter pulses were sent from a local computer to a remote database in the LabVIEW environment using bluetooth communication (Warren, Yao, Schmitz, & Lebak, 2004).

In this study, a portable cardiac device design that is able to send ECG data to remote terminals via computer networks, thus providing continuous monitoring of patient data, as well as allowing the specialist to intervene in the patient with the help of those around him/her was proposed in order to increase the survival chance of patients at risk of heart attack.

2. Coverage and Contribution of Research

Hundreds of people die because of sudden heart attacks every year in the world. If patients who are having heart attack can be intervened with a defibrillator device within a few minutes, their chances of survival increase. However, lack of a coronary care units in each healthcare facility, and the difficulty of access to healthcare facilities that are equipped with coronary care units for people living in rural areas are disadvantages in this respect. For this reason, there is a need for devices that will be developed to continuously monitor and control patients who are at risk remotely, especially those who have chronic heart diseases.

In this study, a remote-controlled heart monitoring system was designed. The NI-LabVIEW was employed as the software development medium in the system. The ECG signals were transferred to the PC through a Bio-Amplifier and NI-6036E DAQ Card. A GSM modem was used as the communication device between terminal units. The ECG signals coming from the patient were submitted to the expert on the graphic display.

In the present study, the purpose was to inform the people and institutions like healthcare institutions, doctors and relatives of patients in a possible heart attack situation in case risk appears for patients who have chronic heart disease due to old age or genetic reasons and to make the patient benefit from healthcare services independently from place. In addition, it was ensured that the data of the patient were stored and analyzed by a specialist at any time with continuous medical monitoring. In this way, its use may be considered in clinical decision support systems (Al-Garni, 2018).

3. Material and Method

3.1 The Designed System

The block diagram of the system, which is designed in two blocks as patient side and expert side, is given in Figure 1. The patient side of the system consists of one ECG preamp to receive ECG signals, DAQ equipment (terminal board, cable and DAQ card) used to transfer incoming signals to the PC, software designed to process the data transferred to the PC (visualization, recording and preparing for transmission), the communication hardware (GSM modem) needed to receive the data from the remote PC and the defibrillator components to be used to shock the patient if necessary. And, the system designed on the specialist side consists of the communication hardware (GSM modem) used for communication with the remote computer and the software designed for processing of incoming data and providing feedback.

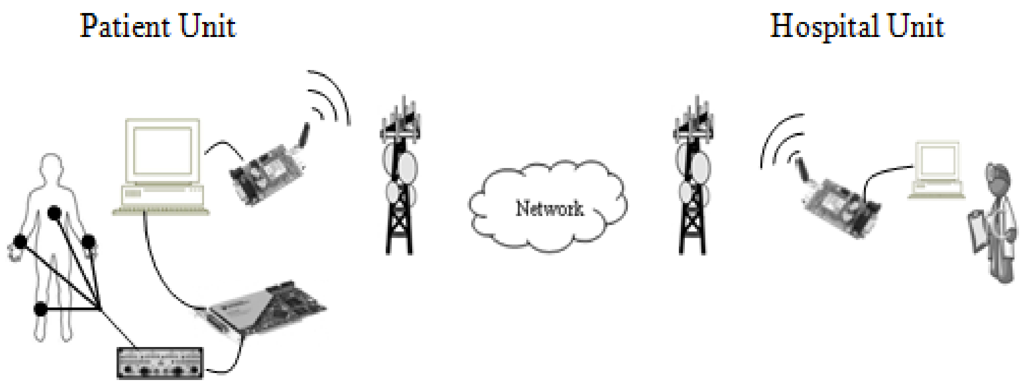

Figure 1: *Block Diagram of the System*

In the system, it is necessary to offer an easy to use, uncomplicated software interface to both the patient and the specialist. This software supports online or save-send method for transmission of ECG signals. The system allows for data archiving on both the user and the specialist side. It uses error reporting mechanisms for uninterrupted and error-free transmission of data online. It provides database support for later access and re-evaluation of archived patient data. A software environment that is fully compatible with the hardware has been selected for these features. The software was created in the LabVIEW graphical programming environment by using 6036E DAQ card produced by National Instruments not only for compatible components of the data collection unit used but also for the convenience it offers in the programming process.

3.2 LabVIEW Graphical Programming Environment

One of the National Instruments' two most important factors in designing LabVIEW graphical programming language (GPL) is to find solutions to measurement and instrumentation problems. Another factor is the challenges in learning the language structure in text-based programming languages, memorizing the language command set, writing a command composed of many lines, and so on. LabVIEW commands, developed on a C basis, are presented in an iconic modular structure (Unsacar & Esme, 2009). Since the programming logic is based on the data flow structure, the source codes are similar to a flowchart. LabVIEW programs are called virtual instruments (VI) because they are similar to physical instruments such as the oscilloscope and signal generator used in laboratories. Figure 2 shows the LabVIEW coding environment (Johnson, 2018).

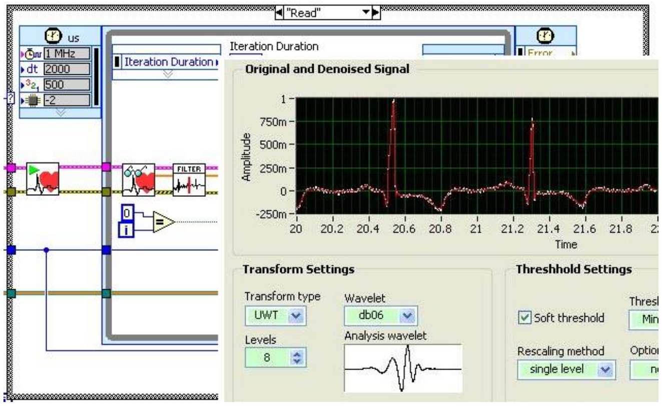

Figure 2: *LabVIEW User Interface*

3.3 Measurement of Biological Signs

The signals that occur as a result of the electrochemical activity of cells, tissues and organs are called bioelectric potentials. Although how the bioelectric signs reach the body surface cannot be explained exactly, the potentials measured from the surface are in the form of the sum or resultant of the electrical activity of the cells that make up that organ. The amplitude of bioelectric signals is very small, and electrodes are used to measure it. An electrode is a kind of sensor that converts the ionic potential on the body to electrical potential. Micro-electrodes are used to measure the bioelectric potential within a cell. Internal electrodes are those through which bioelectric potentials are obtained by immersing them in the skin. Surface electrodes are those that obtain bioelectric potentials from the skin surface. Figure 3 shows various types of electrodes (Esme, 2006; Köker, 1996).

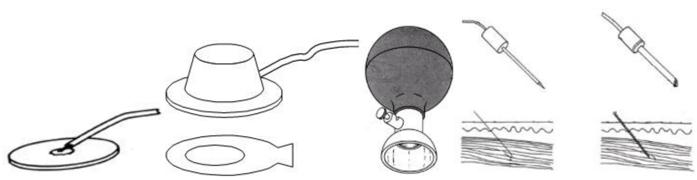

Figure 3: *Various Electrode Types*

At least two electrodes are used to measure bioelectric potentials. The measured voltage is the potential difference between the two electrodes. The heart is like a voltage source in the body. Since the body is a volumetric conductor, ECG signals can be obtained by connecting the electrodes between various points on the body. Figure 4 shows the various attachment patterns of the electrodes (Kemaloğlu, Kara, & Tezcaner, 2001).

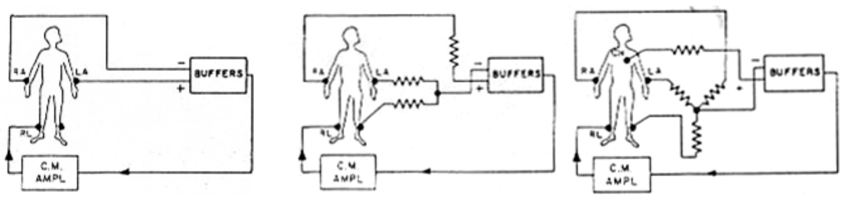

Figure 4: *(a) Standard Bipolar Derivation, (b) Reinforced Derivation, (c) Unipolar Chest Derivation*

3.4 Structure of the Electrocardiograph

The change in electrical potentials generated by the contraction of heart muscles is called ECG, recording these changes by plotting against time is called electrocardiography, and the device which is a kind of advanced galvanometer used during electrocardiography is called an electrocardiograph. The normal ECG signal shown in Figure 5 is composed of the waves named P, Q, R, S, T, U, which are arranged on the baseline (Alpman, 2018; Kemaloğlu et al., 2001).

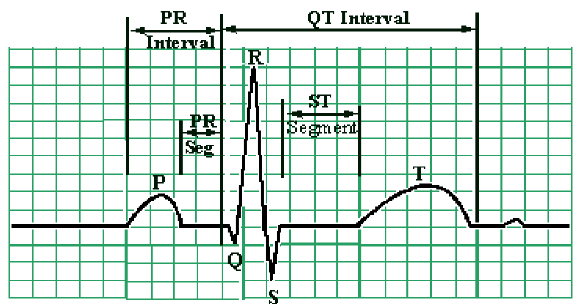

Figure 5: *Signal of Electrocardiogram*

The PQRST complex is in the frequency band of 0.1 - 150 Hz and at the voltage levels of 10-2 - 10-4 volts. Some important ECG parameters are shown in Table 1 (Kemaloğlu et al., 2001).

Table 1: *ECG Parameters*

Wave	**Time (s)**	**Wave**	**Amplitude**
P	0.06 s	P	0.25mV
PR	0.1 – 0.16 s	R	1.6mV
QRS	0.12 s	Q	%25R
QT	0.35 – 0.44 s	T	0.1 – 0.5mV
ST	0.05 – 0.15 s		

The voltage and frequency levels of the ECG signal determine the structure of the electrocardiogram. When designing an electrocardiograph, it must have an amplifier in accordance with the ECG signal and filtering circuits for unwanted noise. Figure 6 shows the general structure of the ECG device as a block diagram.

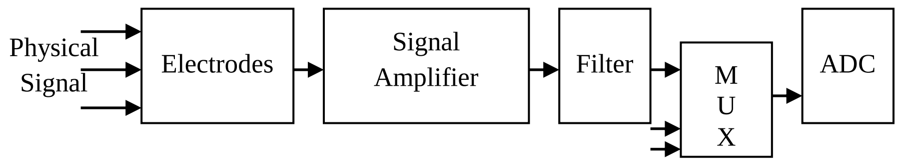

Figure 6: *General Structure of the ECG Device*

The non-electrical analogue amplitudes are converted to electrical signals by means of a converter electrode. The frequency band of the ECG signal obtained from the body surface is in the range of 0.1 - 150 Hz and the amplitude is in the range of 1-2 mV. The instrumentation amplifier is used to strengthen the weak ECG signals in Figure 7 (Kemaloğlu et al., 2001; Oktay, 1991).

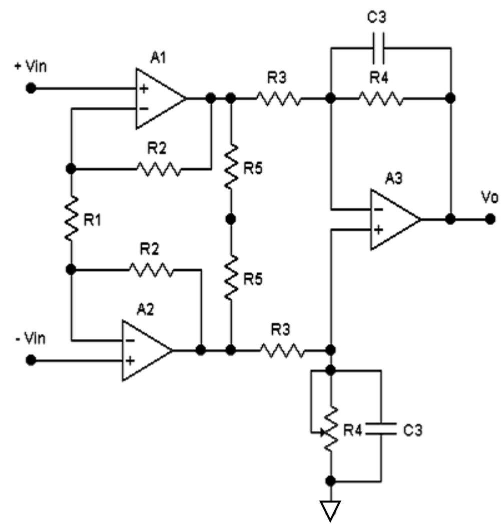

Figure 7: *A Simplified Instrumentation Amplifier*

A lot of noise is involved in the ECG signals that are captured and amplified by the instrumentation amplifier. Foremost among these signals comes the noise caused by patient's breathing and muscular movements. Along with them, noise due to the electric supply system, other high-frequency electrical interferences and the electromagnetic waves captured by the amplifier circuit from the air are involved in the ECG signals despite the high CMRR value of the amplifier (Baykal, 2000). Such noise generally arising from muscle movements has a higher frequency than that of ECG signals. This kind of noise has no component under 40Hz. For this reason, a low pass filter can prevent such noise. The high-pass filter prevents the baseline shifts in ECG signal by removing the DC component of the previous signal before amplifying it with a cut-off frequency of 0.1 Hz. Thus, the signals pass through a 0.1 - 150 Hz bandpass filter. Figure 8 shows an active filter (Aksu, 2000).

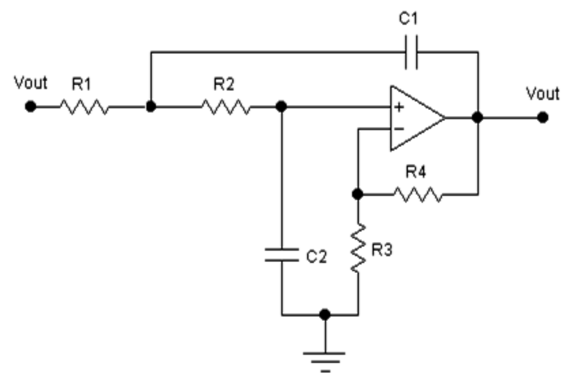

Figure 8: *Filter for other Biological Noise Signals*

3.5 Defibrillator

Defibrillator devices enable the heart to pump more blood by slowing down and normalizing the fast and ineffective irregular heart rhythm by means of a strong electric shock. The most important arrhythmias that can be treated with defibrillators are ventricular fibrillations. If rapid defibrillator intervention does not occur, ventricular fibrillation will result in complete loss of the heart function and death within a few minutes. Atrial fibrillation, atrial flutter and ventricular tachycardia with more regular rhythm disorders can be improved with more basic methods. Although they do not cause sudden death, insufficiently filled heart chambers weaken the cardiac output. Improvement of ventricular fibrillationis called defibrillation, improvement of atrial flutter and other arrhythmias is called cardioversion (Bronzino, 2000). Figure 9 shows a block diagram summarizing the structure of a medical defibrillator.

Most of the defibrillators that perform chest shocking have synchronization capability. The synchronization circuit has an electronic sensing and triggering system to provide shocking along the QRS complex of the electrocardiogram. This adjustment is necessary to improve the arrhythmias other than ventricular fibrillation. If performed during the T wave by carelessness, the shock initiates ventricular fibrillation. When synchronization is selected by the user, the shock is automatically performed along the QRS complex. In addition, the moment that the shock is performed can also be seen on the graphic display, the specialist is sure that the shock is performed at the right moment.

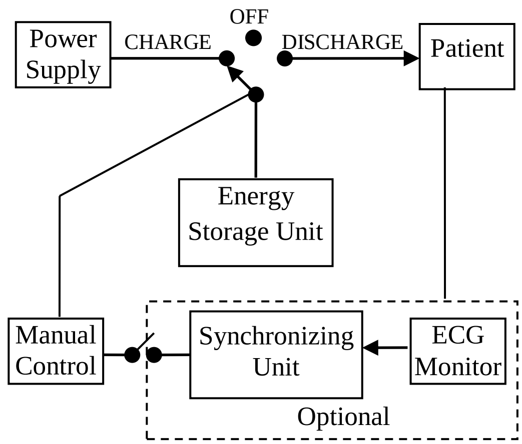

Figure 9: *The Block Diagram of the Defibrillator*

4. The Implemented System

4.1 Digitalizing the ECG Signal

The ETH-256 shown in Figure 10 is a general purpose amplifier. Thanks to the high input impedance and high CMRR value, low-distortion recording, analysis of bi-directional signals (ECG, EMG, EEG), collecting information from a wide variety of converters (force, distance and pressure) are also possible (Wilhjelm, 2007).

In order to obtain ECG signals in the experimental study, it was planned to use National Instruments' 6036E DAQ card and iWorx ETH-256 preamplifier and its additional hardware. However, since the preamplifier could not be obtained, a signal generator was used in experimental studies and ECG signals were generated by simulation.

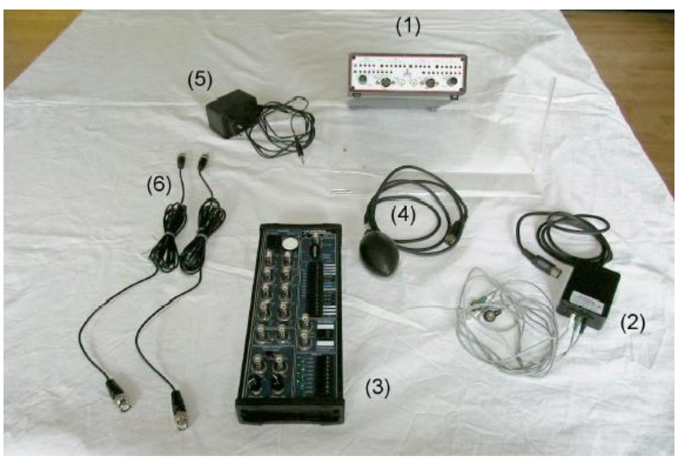

Figure 10: *(1) Bioamplifier: iWorx ETH - 256, (2) Isolation Amplifier, (3) Junction Box: NI, BNC - 2120, (4) Dynamometer, (5) Power Supply, (6) Coaxial Connection Cables*

4.2 The Designed Software

The developed software has two parts as patient side and specialist side. On the patient side, the ECG signals obtained by the data acquisition card are transmitted to the server via the internet protocol provided by the GSM modem connected to the serial port. On the patient side, the software has data acquisition card settings, serial port settings, TCP protocol settings and a graphical display as shown in figure 11. A simplified screen shot of the source code that performs data collection and transmission task is shown in figure 12.

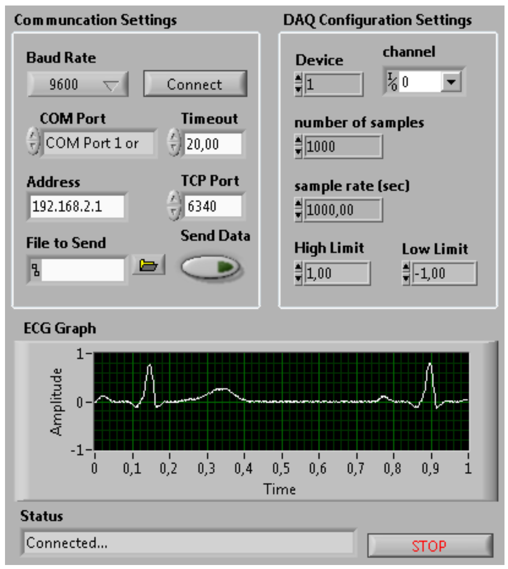

Figure 11: *Data Collection and Transmission Screen*

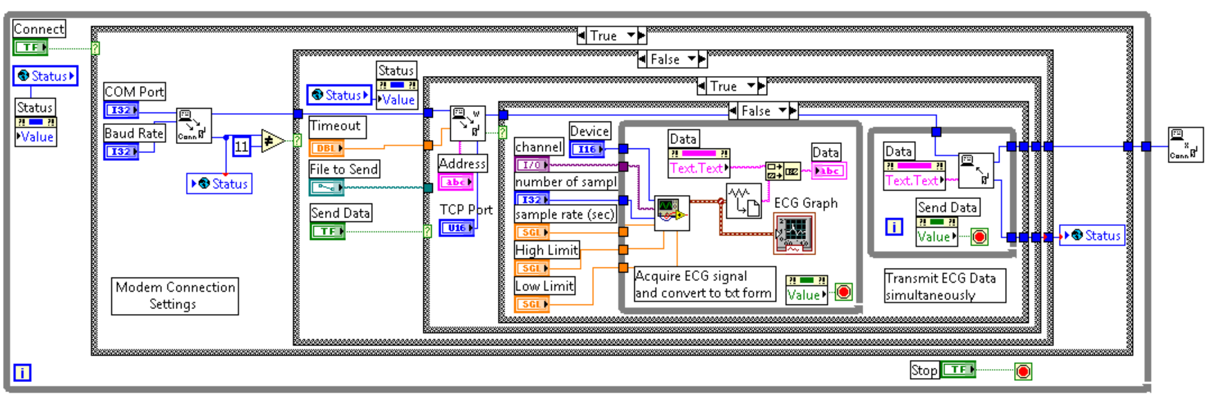

Figure 12: *The Source Code of Data Collection and Transmission Software*

On the specialist side, the software accesses patient data on the server via the internet provided by GSM modem. The data can be written to the file or displayed on the screen according to the user's preference. On the specialist side, the software has serial port settings, TCP protocol commands and a graphical display as shown in Figure 13. The simplified source code of the specialist software is shown in Figure 14.

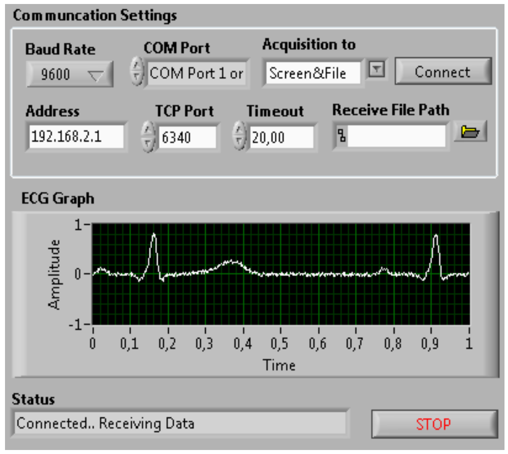

Figure 13: *The Specialist Screen*

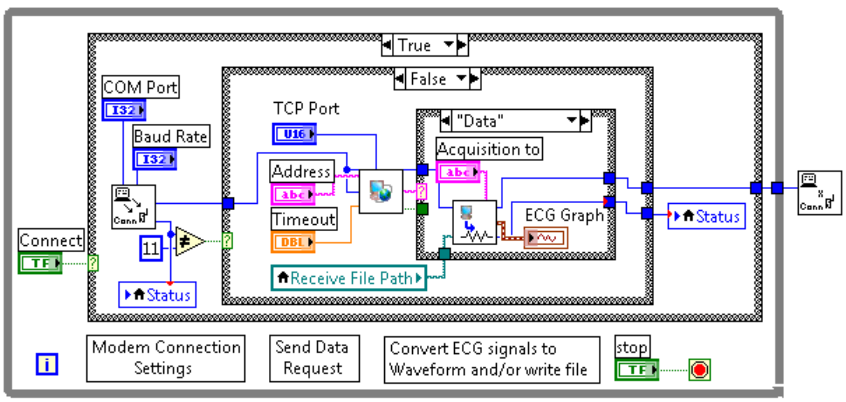

Figure 14: *The Source Code of Specialist Screen*

5. Discussion

In the present study, it was also aimed to use the defibrillator remotely by the expert in addition to sending the data of the patient who are at risk of heart attack to the specialist. However, automatic control of the defibrillator from a remote unit appears as a limitation at the time of heart attack. In case data packets are transferred incorrectly or a failure occurs in this transfer, repetition of transfer request causes instant delays in communication. For this reason, a delay occurs for the computer-controlled remote control of the defibrillator. The timing errors at the time of defibrillation give rise to different arrhythmias instead of placing the heart into normal rhythm. In such a situation, it is impossible for the patient to survive. It is impossible for semi-automatic defibrillator devices to work independently from an expert or a healthcare team. In critical situations, the specialist intervenes in the patient on telephone communication with the medical team waiting by the patient. Despite this limitation, Automatic External Defibrillators (AEDs) are capable of automatic or semi-automatic decision-making and improving arrhythmia rapidly. It is not necessary for the user to be trained in manual defibrillators as well as in ECG and arrhythmias. The user attaches the electrodes to the body, turns on the AED, and signal-processing circuits decide whether or not it is necessary to perform a defibrillation. The user follows the ECG signal on the monitor and watches the process. It is not possible to use automatic AEDs manually. In semi-automatic models; however, the confirmation of the specialist is required for the process.

Another limitation is that the connections of the defibrillator are carried out by the patient or by his/her relatives. People like relatives of patients, firefighters, policemen, hostesses, and airport employees must be trained for using such devices. It is recommended that Automatic External Defibrillators are commonly available in places where people exist in crowds like airports, airplanes, shopping centers, stadiums, entertainment areas etc.

6. Conclusion

In this study, a portable heart device design was performed which can send ECG data to remote-end units over computer networks and provide continuous monitoring of patient data; and additionally, to enable the distant intervention of specialist with the help of people near the patient to increase the survival rates of those who are at risk of heart attacks. In this way, the time is minimized to bring the patient to life by interfering remotely to conditions like vertebral fibrillation, which results in death in a short time.

LabVIEW eliminates the difficulty of developing text-based codes with its graphical functions that look like icons. In this way, it facilitates program development in less time compared to other programming languages. Thanks to its easy integration that have been facilitated with commercial equipment for measurement and instrumentation, and speed and practicality have been achieved in software development. Using the GSM network instead of Wi-Fi, Ethernet and Bluetooth, which are used as communication method in similar studies, eliminated space dependence (Nair & Mohan, 2014).

The designed device brings with it several benefits like reducing the delays in intervention processes to a minimum level and increasing the chances of survival of the patient, as well as facilitating access to healthcare services, reducing the intensity of central healthcare units, decreasing treatment costs and thereby improving service quality (Akbaş, Sürücü, Akça, & Köroğlu, 2017).

There are artificial intelligence studies conducted in the field of detecting arrhythmia (Marinho et al. 2019; Qin, Li, & Liu, 2019). Studies that store biomedical signs in cloud database are also common (Al-Badarneh, Husari & Najadat, 2016; Fong & Chung, 2013). Future studies may be conducted to determine whether the defibrillation will be carried out or not by the defibrillator, defibrillation parameters and the moment of defibrillation may be investigated by using artificial intelligence methods in order to eliminate the limitations that stem from delays. The Cloud Database may be used to store data. Intelligent imaging and diagnostic devices may be developed by integrating other imaging devices in the medical field with computer networks and by adding Artificial Intelligence methods to this field.

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