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Research Article

Design of A Novel IoT Based Mobile ECG Data Transmission System using ESP8266

Harun Sumbul[1*]

[1*]Ondokuz Mayis University, Yesilyurt D.C. Vocational School, Tekkekoy, Samsun, Turkey. (e-mail: harun.sumbul@omu.edu.tr).

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Corresponding author: *Harun Sumbul*

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ABSTRACT

The Covid-19 pandemic, declared a global pandemic by the World Health Organization, has adversely affected nearly everyone physically, mentally, and socially. During this period, an increase in cardiovascular diseases has been observed, attributed to factors such as changes in dietary habits, physical inactivity due to staying at home, increased consumption of frozen processed food, psychological stress, lack of social interaction, and consequently, rising alcohol and tobacco consumption. This has led to a significant increase in cardiologists' workload and a shift from traditional technologies to remote patient monitoring models.

In this context, remote Electrocardiogram (ECG) monitoring-based approaches have become widely used in recent years for the detection of heart diseases, owing to their reliability and non-invasive nature.

This study introduces an SMTP-based tele-monitoring approach that facilitates remote monitoring of ECG signals and supports a medical simulator, aiming to alleviate the workload of healthcare professionals. The primary objective of this research is to develop a wireless monitoring framework for ECG signals, aiming to enhance patient monitoring and safety, reduce the workload of healthcare providers, and ensure equitable access to healthcare services. Our research focuses on implementing a portable, real-time, and cost-effective ECG monitoring system.

1. INTRODUCTION

COVID-19 can significantly impact patients' cardiovascular systems. Mortality from COVID-19 is strongly associated with cardiovascular disease, diabetes, and hypertension [1]. COVID-19 has the potential to cause heart failure, and cases of severe myocarditis with reduced systolic function have been reported following COVID-19 [2, 3]. Post-COVID patients have exhibited myocardial deformation and reduced heart rate variability, which have subsequently increased the burden of ventricular arrhythmias [4].

The workload of cardiologists has significantly increased, particularly in the post-COVID era, accompanied by a rise in the number of monitored cardiac patients. Certain cardiac patients require periodic electrocardiogram (ECG) examinations, which contributes to hospital overcrowding. ECG signals, providing critical information about heart function, are widely utilized in the medical field to assess cardiovascular health and to monitor patients' treatment progress regularly [5]. Usually, the amplitude of the ECG signal peaks at approximately 1 millivolt (mV). It exhibits a distinctive waveform pattern consisting of P-QRS-T waves, as depicted in Figure 1 [6].

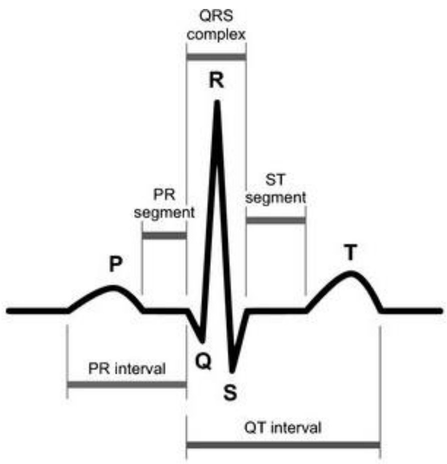

Figure 1. Standard pattern of a PQRST complex in ECG waveforms

The ECG waveform exhibits a characteristic pattern that repeats periodically. This pattern allows physicians to visually analyze the ECG and extract valuable information based on the observed morphological shape. The "normal" rhythm of the heart, known as sinus rhythm, represents the physiological activation of the atria followed by the ventricles, initiated by the sinus node. In adults at rest, sinus rhythm typically exhibits a regular heart rate ranging from 60 to 80 beats per minute. On the ECG, sinus rhythm is characterized by a sequence of P-waves representing atrial activity, followed by ventricular activity indicated by the QRS complex and T-wave. Any disturbances or delays observed in this pattern can provide crucial information about the presence of cardiovascular disease (CVD). If the waveform deviates from the expected healthy morphology, it indicates the presence of an anomaly related to cardiovascular diseases, leading to the classification of the signal as arrhythmia. The ECG is extensively utilized in diverse medical contexts, playing a critical role in diagnosing various conditions such as chest pain, tachycardia, bradycardia, hypertension, hypotension, myocardial injury, atrial fibrillation, ventricular fibrillation, and more.

Based on the most recent research conducted by the World Health Organization (WHO), CVD has emerged as a major cause of worldwide fatalities. Recent studies suggest that a substantial portion, around 90%, of CVD cases, including conditions like arrhythmia, ischemia, ventricular hypertrophy, bundle branch block, and myocardial infarction, could be prevented through effective preventive measures [7,8]. Therefore, ECG recording is mandatory both at the time of the attack and during routine periods (especially for heart patients). Since this class of patients is generally elderly, it is vital that patients can transmit the ECG data they take from home to doctors remotely without going to the hospital. This will both reduce hospital density and provide patients with the opportunity to access treatment on equal terms. This study focused on normal ECK and several major forms of arrhythmia, which are summarized below:

Atrial Fibrillation Coarse: AF stands as the most prevalent form of cardiac arrhythmia. It can be identified on the surface ECG by two types: fine (AfibF) and coarse (AfibC). Fibrillatory waves may be observed, which can be categorized as either AfibF (amplitude < 0.5mm) or AfibC (amplitude > 0.5mm). AfibC is distinguished by the absence of P waves and the presence of fibrillary waves. In some cases, the fibrillary waves may be very fine and difficult to recognize in certain leads. In such situations, the absence of P waves and a completely irregular RR interval can indicate the presence of underlying atrial fibrillation [9].

Atrial Fibrillation Fine: These waves are typically associated with impaired atrial function, such as enlarged atrial size and reduced left atrial appendage flow. It is crucial to acknowledge that in certain cases, fine V-fib can bear a resemblance to asystole on a defibrillator or cardiac monitor that is set to a low gain [10, 11].

Bradycardia: Bradycardia is identified by a heart rate that is below 60 beats per minute (bpm). It is important to note that bradycardia can pose a life-threatening condition if the heart is unable to maintain a rate that efficiently circulates oxygen-rich blood throughout the body [12].

Tachycardia: Tachyarrhythmia refers to a heart rate that surpasses the normal resting rate. In adults, a resting heart rate above 100 beats per minute is generally classified as tachycardia. It is important to note that heart rates higher than the resting rate can be either normal, such as during exercise, or abnormal, indicating underlying electrical abnormalities within the heart [13].

Ventricular Fibrillation: Ventricular Fibrillation is the ventricular counterpart of atrial fibrillation. In Vfib, the ventricles of the heart contract in a completely asynchronous and disorganized manner, leading to the absence of effective cardiac systole. The ECG recording of Vfib displays irregular, chaotic, and rapid ventricular activity, resulting in an oscillatory appearance. It is a life-threatening condition that requires immediate medical intervention, such as defibrillation, to restore a normal heart rhythm [14].

Regular surveillance of ECG readings assumes a pivotal function in the effective management of CVDs. By enabling continuous monitoring, it becomes possible to improve the diagnosis, control, and prevention of CVDs. In fact, ECG signals often provide more precise and accurate information compared to radiological images. Researchers are actively exploring new technologies in ECG monitoring systems to develop more efficient and effective solutions. Significant efforts have been dedicated to monitoring ECG waves for the diagnosis of arrhythmia [15, 16]. Nevertheless, there is a clear demand for the development of intelligent, energy-efficient, and cost-effective ECG tele-monitoring systems that can aid healthcare professionals and be used by individuals for preliminary checks.

This study aims to bridge this gap by introducing a novel system for detecting cardiovascular diseases. The suggested framework utilizes contemporary advancements like SMTP, telemonitoring, IoT and cloud computing to deliver a cost-effective, interconnected, and encouraging solution for ECG monitoring.

2. MATERIAL AND METHOD

This study employed a professional ECG simulator to generate normal sinus beat signals as well as various rhythm disturbance signals. These signals were then transmitted to a receiver using the SMTP Protocol. An interface software was developed using the C# programming language to visualize the data for analyzing and interpreting the received signals. The proposed framework of the ECG data transmission system, based on a microcontroller (ESP8266), is illustrated in Figure 2, providing an overview of the system architecture.

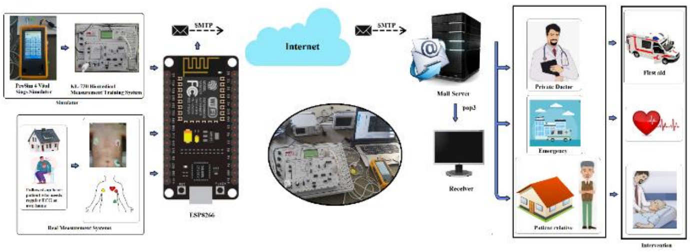

Figure 2. The architecture of the proposed study

In the implemented system, instead of using real patient data, signals were generated from the ProSim Vital Signs Simulator (v4), a professional ECG simulator device. This approach allowed for data augmentation and the inclusion of various patient scenarios, saving time and resources. The simulator data closely resemble real patient data, providing a reliable input for the system. The recorded and transmitted subsystem is responsible for transmitting the simulated ECG signals to the receiving party. The results are then presented to the doctor for evaluation and decision-making. It's important to note that the final decision ultimately rests with the doctors in the decision-making process.

2.1. ECG data generation subsystem

The ECG data employed in this research was generated utilizing the ProSim 4 Vital Signs Patient Simulator (ProSim™ 4), a meticulously calibrated and manufactured device developed by Fluke Biomedical, headquartered in Cleveland, OH, USA. This device is commonly utilized for calibration purposes in medical devices such as bedside monitors. The ECG simulator operates by producing a 60 ms 1 mV square wave format at 2 Hz. It is a professional-grade device extensively employed in the biomedical field for generating ECG data [17, 18]. However, since the Simulator does not have a built-in data transfer function, the generated ECG data was transferred to a computer using the KL-730 Biomedical Measurement Training System. These devices were briefly introduced in this section to provide an understanding of the system's development and highlight the transition to a cloud-based framework.

KL-730 presents Bio-electronics sensors that are widely utilized and beneficial for students studying electronics and biomedical fields. Additionally, KL-730 gathers all the necessary equipment for measuring various body signals and performing experiments related to 12 different types. KL-730 consists of twelve modules, which encompass the measurement of ECG signals [19]. The System can establish a connection with the computer through a USB port, enabling seamless integration with the Simulator. Through the integration of these two devices, a system for generating ECG data has been created, allowing for the practical production and transfer of various types of ECG data to the computer. The ECG data generation system is illustrated in Figure 3.

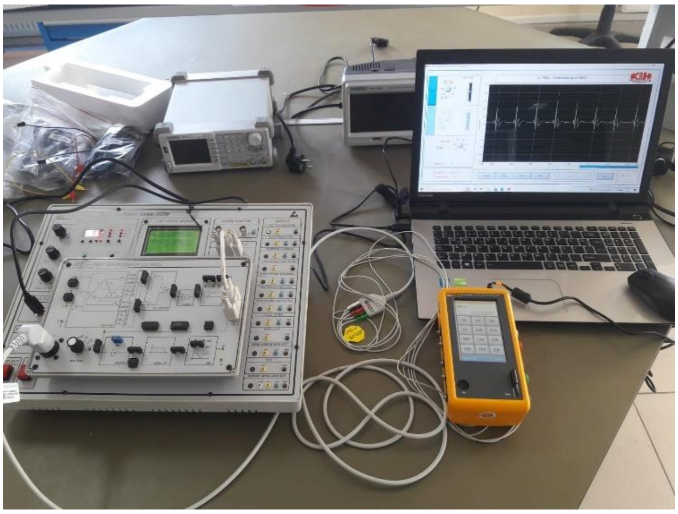

Figure 3. The ECG data generation system

2.2. Generating ECG Dataset

Cardiac arrhythmias are among the most common diseases that affect the heart rhythm. However, before discussing arrhythmias, it is important to understand the characteristics of the normal rhythm, also known as sinus rhythm. In a state of rest, the heart typically beats between 60 and 80 times per minute, which is referred to as the pulse or heartbeat. Arrhythmias can manifest in various forms, including accelerated heart rate (tachycardia), slowed heart rate (bradycardia), or irregular heart rhythm. In the study, 6 types of ECG data (normal beats and arrhythmias) were generated by using ECG data generation subsystem and transmitted to test the performance of the system and whether there is any loss in the transmitted data. A total of 446 data were produced for use in short-term ECG transmission, and a total of 6,894 data were produced for long-term ECG transmission, thus creating a database. Sample ECG data graphs produced by the simulator to be transmitted to the receiver module are shown in Figure 4.

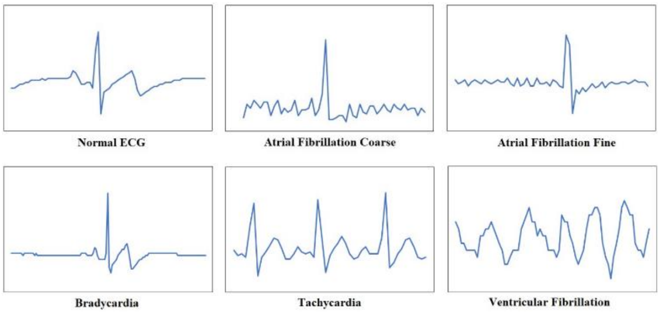

Figure 4. Short-term ECG signal patterns

2.3. Data transmission using Smtp protocol

The Internet of Things (IoT) is a concept that allows different devices to communicate with each other over networks such as the Internet and Bluetooth, and to have the ability to collect, process and share data [20]. In this way, communication between devices becomes easier and efficiency increases. IoT is a technology that is used in many sectors and has an impact on many areas of our lives. There are important studies on monitoring important medical data such as ECG and EEG with IoT [21, 22].

ESP8266 was configured and connected to the internet with the objective of transmitting the real-recording. The Simple Mail Transfer Protocol (SMTP) has been employed for email transmission due to its simplicity, reliability, flexibility, and security mechanisms. SMTP server is responsible for launching the SMTP protocol and delivering email messages. The Outlook SMTP server was selected for implementation due to its ability to handle large volumes of emails without performance issues and excellent support from Microsoft [23]. ECG data, saved in (.csv) format, was appended to an email message through the email client software.

2.4. Pseudocode

Pseudocode serves as a fundamental tool in the realm of computer science and software engineering. It provides a structured format for explaining the logic of an algorithm or program, bridging the gap between natural language and programming languages. Pseudocode can be defined as a structured textual representation of an algorithm that outlines its logic without adhering to the syntax of any specific programming language. Its primary purpose is to describe what a piece of code should accomplish rather than precisely how it should be implemented. This language-independent nature of pseudocode facilitates clearer communication among developers and analysts, allowing them to focus on the logic of algorithms rather than language-specific syntax. Below are the

Pseudocode codes of the software codes of the embedded system in the developed system.

BEGIN
SETUP:
Initialize Serial communication
Connect to Wi-Fi network
Configure input and output pins

LOOP:
READ ECG signal from simulator device
APPLY filters to clean the signal
CONVERT analog signal to digital (ADC)
STORE digital data in FLASH memory
IF time to send data:
SEND data to doctor using communication protocol (SMTP)
END IF
WAIT for next reading interval
END

2.5. ECG feature extraction

The feature extraction phase plays a crucial role in capturing the distinctive information from physiological signals and representing it concisely. By extracting relevant features from significant waveform patterns, the ECG signal is analyzed to detect and classify various cardiac conditions [24]. In this research, the Pan-Tompkins algorithm was employed to perform feature extraction on ECG data [25,26]. The Pan-Tompkins algorithm was utilized in order to calculate the time interval between consecutive R peaks. This time duration between R peaks plays a crucial role in the early detection of cardiovascular disorders, providing valuable information for diagnosis. The RR interval refers to the time duration between two consecutive beats, specifically the distance from one R peak to the R peak of the following beat, which could be either its precursor or successor. Feature extraction algorithms that have shown the highest accuracies in existing literature encompass features extracted from both the time/frequency domain and characteristics related to the RR interval [27]. While the RR interval may vary among individuals without heart disease, it tends to be relatively consistent. However, in individuals with heart conditions such as tachycardia or bradycardia, the RR interval can become irregular, displaying intermittent periods of very short or very long durations [28]. Figure 5 illustrates the block diagram of the Pan and Tompkins Algorithm employed in the study.

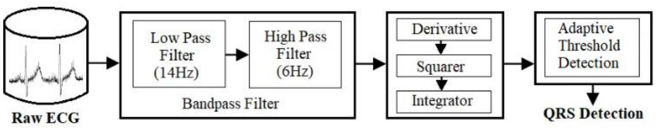

Figure 5. Pan and Tompkins Algorithm block diagram

3. EXPERIMENTAL RESULTS

An interface was developed in C# program in order to monitor and analyze the data. The interface screen is seen in Figure 6. The short-term ECG patterns produced from the simulator is as follows; 72 for normal ECG; 58 for Atrial Fibrillation Coarse; 60 for Atrial Fibrillation Fine; 135 for Bradycardia; 49 for Tachycardia and 72 for Ventricular Fibrillation. A total of 446 data were transmitted to the receiver via SMTP protocol and visualized in the developed interface. The Long-term ECG patterns produced from the simulator is as follows; 72 for normal ECG; 1149 for Atrial Fibrillation Coarse; 1149 for Atrial Fibrillation Fine; 1149 for Bradycardia; 1149 for Tachycardia and 1149 for Ventricular Fibrillation. A total of 6.894 data were transmitted to the receiver via SMTP protocol and visualized in the developed interface.

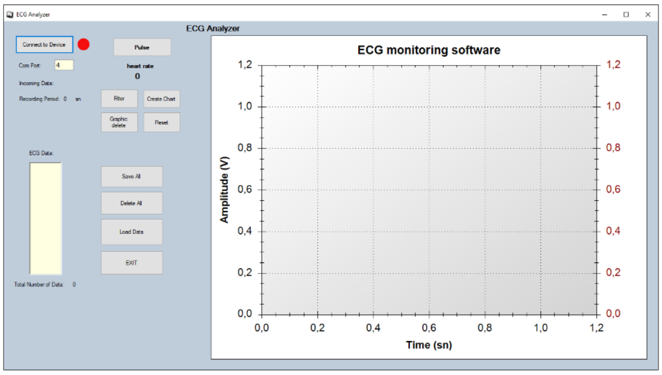

Figure 6. The improved interface screen

The email was directed to the designated recipient (like doctor) and transmitted utilizing the SMTP Protocol. ECG records sent via Gmail using the SMTP protocol with a duration of approximately 7 seconds, as shown in Fig. 7.

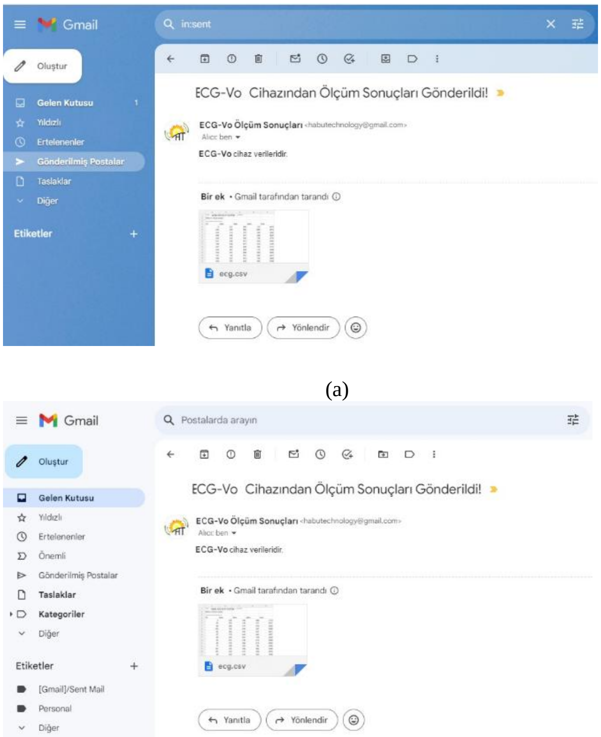

Figure 7. Transmission (a) and received (b) of signal using SMTP

ECG signals generated from the simulator were transmitted through the system and were successfully reconstructed through the developed interface. Accordingly, the ECG images of the 6 signals received are seen in Figure 8.

EUROPEAN JOURNAL OF TECHNIQUE, Vol.15, No.1, 2025

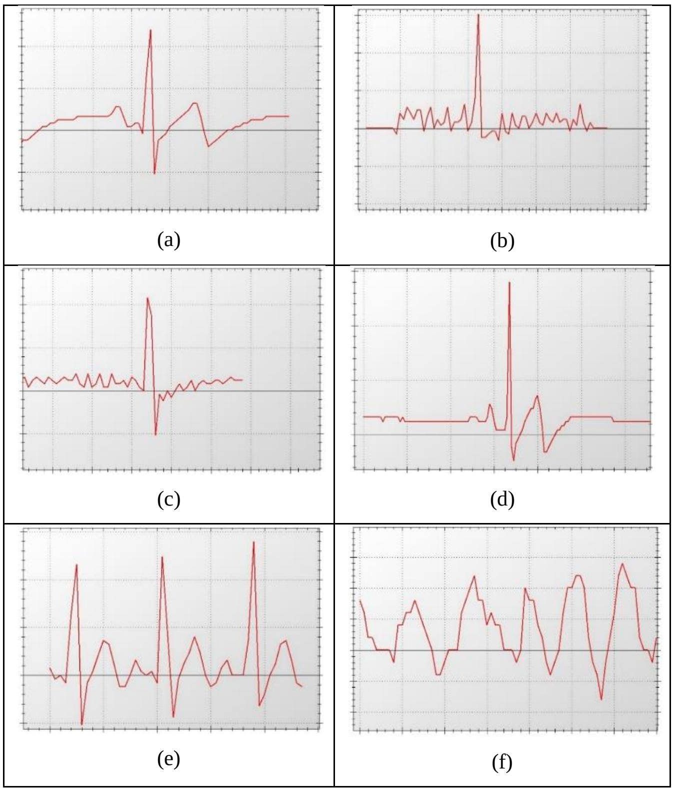

Figure 8. Short-term ECG signal patterns, (a) Normal, (b) Atrial Fibrillation Coarse, (c) Atrial Fibrillation Fine, (d) Bradycardia, (e) Tachycardia, (f) Ventricular Fibrillation

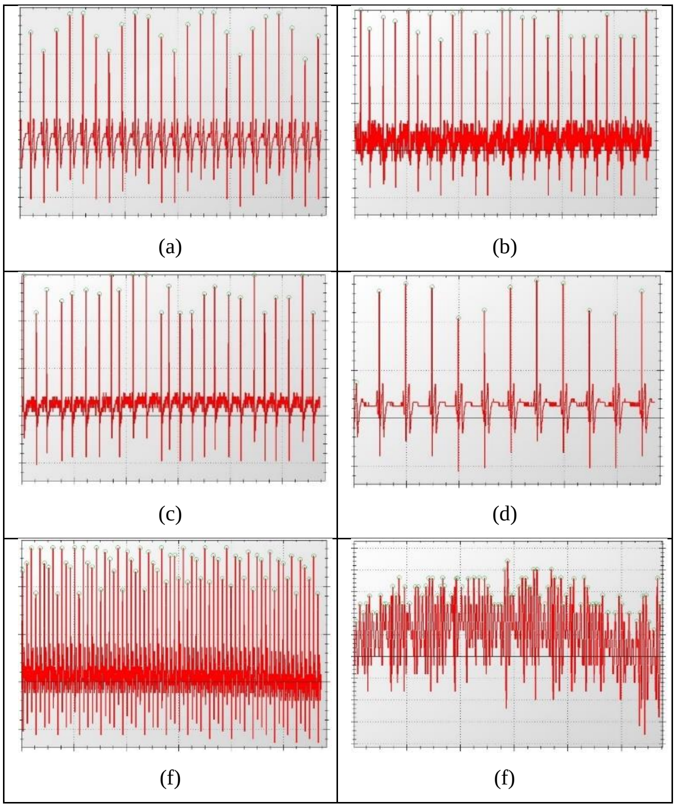

Figure 9. Long-term ECG signal patterns, (a) Normal, (b) Atrial Fibrillation Coarse, (c) Atrial Fibrillation Fine, (d) Bradycardia, (e) Tachycardia, (f) Ventricular Fibrillation

Long-term recordings were created for ECG classes and the Pan-Tompkins algorithm was applied to these signals. The purpose of using the Pan-Tompkins algorithm is; is to measure the time between successive R peaks. The time from one R peak to the next R peak provides important data for the early diagnosis of cardiovascular diseases. Although this period is generally not the same in normal people, it is close to each other. In people with heart disease such as Tachycardia or Bradycardia, it may occur irregularly, with very short intervals or very long intervals. Figure 9 shows the ECG signal with the Pan-Tompkins algorithm applied. As can be seen, the R-R intervals have been marked successfully.

The integration of mobile devices for vital sign monitoring by healthcare professionals can offer significant benefits to both patients and doctors. The developed prototype in this study is not only cost-effective but also capable of real-time operation and robust performance. It can be utilized for experimental research and data collection of ECG signals. The reduced costs associated with this prototype can also facilitate and encourage further research in this field.

The number of Short-Term ECG signal patterns is given in Table 1.

TABLE I
NUMBER OF SHORT-TERM ECG SIGNAL PATTERNS

Normal	Atrial Fibrillation Coarse	Atrial Fibrillation Fine	Brady cardia	Tachy cardia	Ventricular Fibrillation
72	58	60	135	49	72

4. DISCUSSION

Cardiovascular disease currently ranks as the leading cause of mortality. The ECG analysis serves as the predominant method for detecting these diseases by capturing cardiac activity through medical monitoring technology. However, the reliance on experts to analyze vast amounts of ECG data can strain medical resources significantly. Nevertheless, traditional methods possess limitations such as manual feature recognition, complex models, and lengthy training times. In this research paper, a data transmission system has been developed that can be used to transmit the ECG signals taken by heart patients at home to their doctors without the need to go to the hospital. Although there are medical data measurement and transfer systems in the literature using microcontrollers such as Arduino, our approach is more professional and more applicable.

5. CONCLUSIONS

Arrhythmia, a chronic cardiovascular disorder with potentially fatal consequences, presents a significant challenge when using ECG signals for detection. An accurate architecture capable of identifying abnormal ECG signals plays a crucial role in providing early and accurate diagnoses for patients. This study introduces a comprehensive framework that automates the collection of ECG signals, transmitting via SMTP, analysis via the developed interface and presentation of results, thereby enhancing the diagnostic efficiency of doctors. In this state, the system has successfully transmitted ECG data. In future studies, a system design that will measure real ECG data will be integrated into this study. Thus, it is planned to produce an integrated device. Additionally, the developed system is intended to be implemented in hospitals to address any potential practical usage side effects, will making it a valuable tool in clinical settings.

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BIOGRAPHIES

Harun SÜMBÜL received B.S. degree in Electronic sciences from the Selçuk University, Konya, Turkey, in 2008, the M.S. degree from the Selçuk University from Electrical and Electronics Engineering, Konya, Turkey, in 2011, and received the Ph.D. degree in electrical and electronics engineering from Karabük University, Karabük, Turkey. His primary areas of research are biomedical engineering and biomedical signal processing. He is currently a Lecturer at the Yeşilyurt Demir Çelik Vocational School, department of biomedical device technologies at Ondokuz Mayıs University, Turkey.