Portable ECG (Electrocardiograph) Device

Mustafa Güçlü, Armağan Ergün, Özkan Akın, Mert Altıntaş

Abstract—An electrocardiogram (ECG) is used to monitor the small electrical changes in the human body caused by heart activities. At least 24 hours of ECG registration is required to get accurate information about the health status of people. In this study, a compact portable ECG device has been designed by integrating two SOC chip with a Neurosky, a cardio chip BMD101 and NRF51822 chip which contains a 32 bit ARM® Cortex™-M0 processor with embedded Bluetooth® low energy (BLE4.1 compatible with BLE4.0). The resulting biomedical signals can be viewed from the smartphone via the Android software interface. A prototype was designed, and its verification was done with real ECG data collected from the human body.

Index Terms—Electrocardiography, Wirele
ss, Android, Smartphone

1 Introduction

Nowadays, heart diseases are one of the biggest causes of sudden deaths. Persons with chronic heart conditions may be required to be kept under constant observation. For this reason, people should be monitored with medical devices. However, the adequacy of these devices is also a matter of debate. There are many academic researchers on the development of these devices.

Humans produce some electrical signals while they perform their vital functions. These signals are generated as a result of the electrochemical events of the cells. These signals, which are formed by the electrochemical activity of the cells, are called bioelectric potentials. The importance of bioelectric signals is significant for understanding the workings of tissues and organs. These signals, usually measured over the body surface, are named according to their source [1]. Electrocardiography (ECG) is the process of monitoring the electrical activity of the heart over a period using electrodes placed on the skin of a patient's body [2].

The examination of ECG signals will facilitate the identification of any irregularities that may occur in the circulatory system. For this reason, electrocardiographic devices have been developed to monitor ECG signals [3].

In recent years, designs of ECG devices with Bluetooth, ZigBee, WiMAX, GSM, and GPRS have become popular, which can be portable and mounted on a human body. These studies are focused on size, weight, and computing performance.

There are different versions of Bluetooth technology, v1.2, v2.0 + EDR, v3.0 + HS and v4.0 with 1 Mbps, 3 Mbps, 24 Mbps and 24 Mbps data rate respectively, which allow devices to communicate with each other without cable connection between distances of approximately 10 to 100 meters [4].

In particular, there are mixed signal ECG System SoC design applications that can implement configurable functionality with low power consumption for portable ECG monitor applications [7-10].

Patient biopotential signals from the ECG sensor were transmitted to the computer on the receiver side using a Bluetooth connection, and the application program was visualized and analyzed graphically using Matlab and LabVIEW [10 - 18].

In many studies, mainly composed of several parts: a sensor unit consisting of ECG Electrode, a signal conditioning unit (AFE) chip, a microcontroller unit (MCU), a Bluetooth module and a smart phone interface have been developed [14, 18 - 21]. There are studies on ECG and EMG data using Bluetooth 4.0 technology with Tablet App [8] and Wireless ECG Recording System with Metal-Skin Contacts Input for Wearable Personalized Healthcare [22].

This paper presents an Android based smartphone real-time ECG monitoring system. The ECG biopotential signals from the patient's body are converted into manipulatable signals by a BMD101, which was introduced by Neurosky [10, 17, and 23]. Bio-signal detection and processing SoC device then sent to nRF51822 ultra-low power 2.4 GHz wireless System on Chip (SoC) integrating 2.4 GHz transceiver, a 32 bit ARM® Cortex™-M0 CPU. It can support Bluetooth® low energy (BLE4.1 compatible with BLE4.0) and a range of proprietary 2.4 GHz for wireless transmission to a smartphone or PC. The Bluetooth module is integrated with the processor and is not a separate piece of hardware, as is the case in some studies in the literature [15 - 17, 19 – 21 and 24 - 28].

The designed system also has an Android interface that allows the ECG data to be viewed graphically on the smartphone. Android is an open platform that allows developers to take advantage of many of the features provided by platform for new applications. Several papers have been done to develop Android based portable ECG devices. Analog ECG signals can be used for diagnostic purposes by displaying them in imaging and recording units [14, 18, 21, 23, and 27].

In this study, Wireless and low-power portable ECG device which allows daily routine heart health events to be monitored easily through the Android software application on the smartphone.

2 System Configuration

An ECG signal is a small biological signal collected from the body surface with an amplitude range of 0.05 to 5 mV and

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a frequency range of 0.05 to 100 Hz [29].

The most important part of ECG measurement is implemented by NeuroSky's 3rd generation biological signal detection and processing SoC device BMD101 as shown in Fig. 1 [30]. The Low-Noise-Amplifier and ADC are the main components of the BMD101 analog front end. Because of the BMD101’s extremely low system noise and programmable gain, it can detect bio-signals and convert them into digital words using a 16-bit high-resolution ADC. The AFE also contains a sensor-off detection circuit. It has a small size and low power consumption features and also has amplification, filtering, and data processing functions. It simplifies the design of the environmental circuit and is very suitable for the portable measurement system.

Fig. 1 Block diagram of the ECG card

In this study, the resulting numerical data from the conversion of the analog ECG electrical signals from the body that is connected to the human chest is sent to the nRF51822 chip via the serial protocol to transmit the obtained ECG signals wirelessly with digital transmission techniques.

NRF51822 is a very flexible SoC that is ideal for Bluetooth® low energy (BLE4.1 compliant with BLE4.1) and 2.4GHz ultra low power wireless applications. The NRF51822 is built around a 32-bit ARM® Cortex ™ M0 CPU with embedded 2.4GHz transceiver supports both Bluetooth low energy and the Nordic Gazell 2.4 GHz protocol stack which is compatible with the Nordic Semiconductor nRF24L series products. The block diagram of the system that works with the portable ECG device is given in Fig. 2.

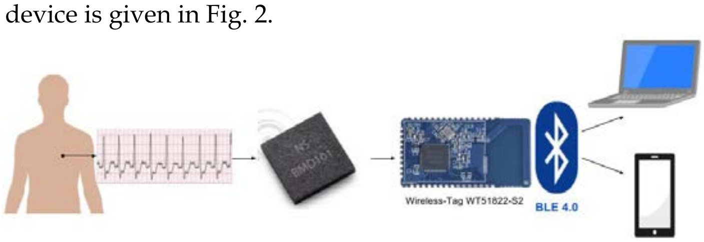

Fig. 2 System block diagram

Targeted and proven features for the designed device are listed below shown in Fig. 3;

- It is a wireless device.
- Can be affixed to the body.
- Operates in the frequency range of 0.5 Hz - 100 Hz.
- The signal sampling rate is 512 Hz. That means 512 samples can be taken in 1 second.
- Has low energy consumption.
- Battery type Lithium-Ion.
- Works with devices with Bluetooth 4.0 and Bluetooth 2.0.
- Can be charged with micro-USB cable used for mobile phones.
- Compatible with Android and IOS operating system and devices.
- ECG data from the human body can be stored.
- Low cost compared to domestic and similar products.

ECG signals on the cardio-chip BMD101, which is the first step of the ECG device, are taken through electrodes. Incoming signals are passed through a notch filter is typically customized to 50 Hz or 60 Hz, or the notch is configured via a redundant configuration. The notch is rejected at -63dB for 60Hz and 50Hz. The cut-off frequency of the Low Pass Filter is 100Hz. It provides a stable passband at the cut-off frequency and provides -40dB at the stop frequency to reject the DC components of the signal.

Subsequently, at the low noise amplifier (LNA), the amplified signal from the microvolt levels to the millivolt levels is converted into a digital value by a 16-bit analog-to-digital converter. The AFE receives low-amplitude differential analog input signals. If this message contains slowly varying DC components, DC is removed with a fully integrated high pass filter (HPF). The signal is then amplified by a programmable gain low noise amplifier (LNA). The LNA output is converted to a digital bit stream by the 16-bit ADC.

This digital signal passes through a filter that stops the 50 Hz and 60 Hz network noise and then passes through the low-pass filter to sift frequencies above 100 Hz. Thus, the ECG signal is transmitted neatly at 57600 bps baud rate through UART, the microcontroller serial communication unit. BMD101 communicates through UART interfaces.

The primary digital interface of BMD101 is the UART interface (TX/RX). It is a standard UART interface that deploys a one start bit, eight data bits, and one stop bit format. Applications of UART can be built, based on this UART interface. Module with eight bits UART communication microcontroller; The 16 bits of data to be transmitted are first eight bits high-valued data and then eight low-valued bits. Then the signal from the microcontroller is sent to the Bluetooth 2.0/4.0 module via UART in the same way. Here, the ECG data is also displayed on the smartphone with Bluetooth or on the computer.

2 Procedure for Paper Submission Design for ECG Device

PCB board designed for ECG device has one regulator battery charging circuit, one push-button for start-stop activity, micro-USB female connector; a cardio chip and an ARM based microcontroller with support for Bluetooth Low Energy (BLE) 4.0 are present in Fig. 3 which is drawn Eagle PCB program.

- *Mustafa Güçlü, Electrical and Electronics Engineering, Ege University, Izmir, Turkey, E-mail: guclumustafa93@gmail.com*
- *Armağan Ergün, Materials Science, and Engineering, İzmir Institute of Technology, İzmir, Turkey, E-mail: armagan@dvlx.com*
- *Özkan Akın, Electrical and Electronics Engineering Department, Ege University, Izmir, Turkey, E-mail: ozkan.akin@ege.edu.tr*
- *Mert Altıntaş, Electrical and Electronics Engineering Department, Ege University, Izmir, Turkey, E-mail: mertaltintas12@gmail.com*

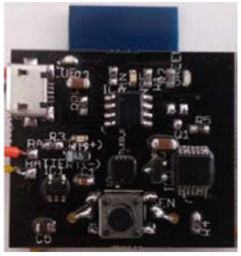

Fig. 3 Design of Modules Used in ECG Device

A plastic box design was printed on a 3D printer, which was drawn in the SketchUp program to be placed inside an ECG card which shown Fig-4.

Fig. 4 Portable wireless ECG Device

The signals from the cardio chip were primarily transmitted by the ARM based microcontroller using UART serial communication unit. For this purpose, the microcontroller was prepared using the C programming language in the online compiler at mbed.org.

In the digital output packet format table given in Fig. 5, at the beginning of the data coming to the microcontroller, there are two one-byte synchronization header bytes and one header showing the data load length. At the end of the packet, there is also a byte checksum header byte. The checksum controls the correctness of the incoming data. If the data load is incorrect, the data is not decomposed. If the incoming data is requested, the unprocessed data in the data load is handled by decomposition.

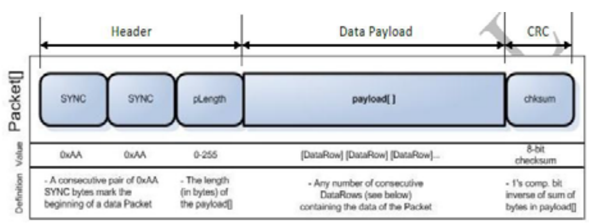

Fig. 5 Digital output packet format [30]

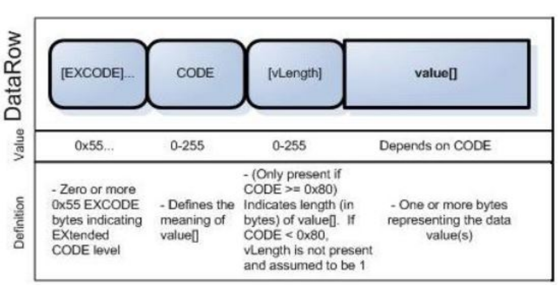

Fig. 6 Raw Data Format [30]

ExCode value is examined first in this data format. This value specifies the extended code level. Then the code tells what type it is given. In vLength, the length of the data value is the value of the incoming signal in Fig. 6.

Table 1 Code identification table [30]

Extended Code Level	[CODE]	(Byte) [LENGTH]	Data Value Meaning
0	0x02	N/A	Signal Quality (0–sensor off, 200–sensor on)
0	0x03	N/A	Real-time Heart Rate (Beats Per Minute)
0	0x08	N/A	Don't Care
0	0x80	2	16-bit Raw Data (2's Complement)
0	0x84	5	Don't Care
0	0x85	3	Don't Care

There is a table that shows whether the electrodes are working, by which code the heart rate and ECG data are coded in Table 1. Fig. 7 also shows the software flow diagram.

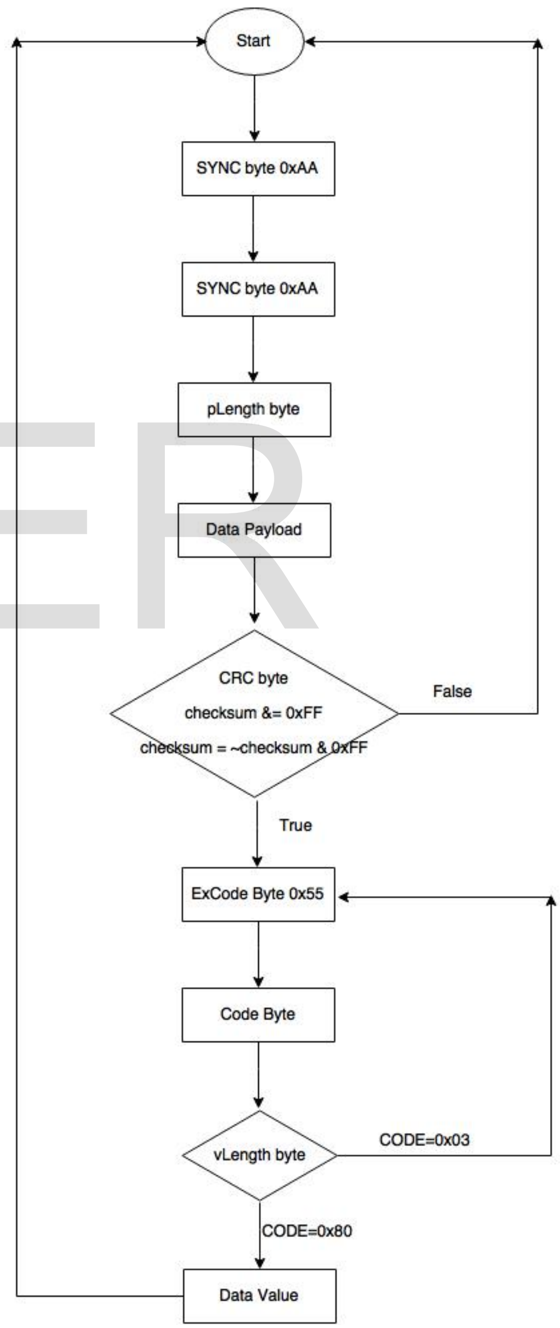

Fig. 7 Software flow diagram

The used wireless microcontroller module has tested with the Android application software provided by the Nordic Semiconductor company. Fig. 8 and Fig. 9 show whether the electrodes that connected for this is evident from the "Signal Quality" data.

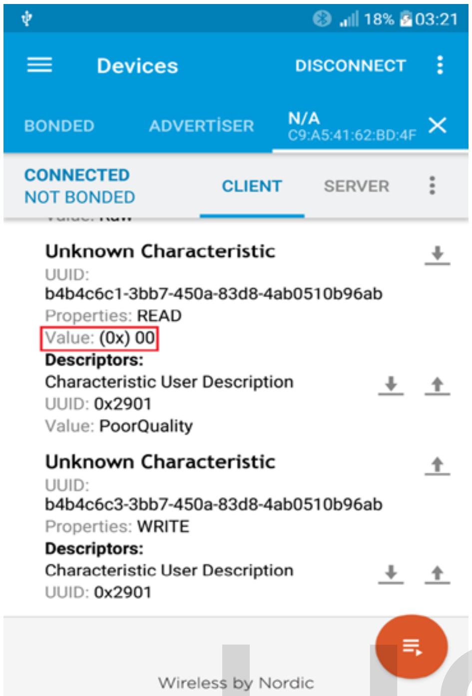

Fig. 8 The electrodes are not connected (0x00=0)

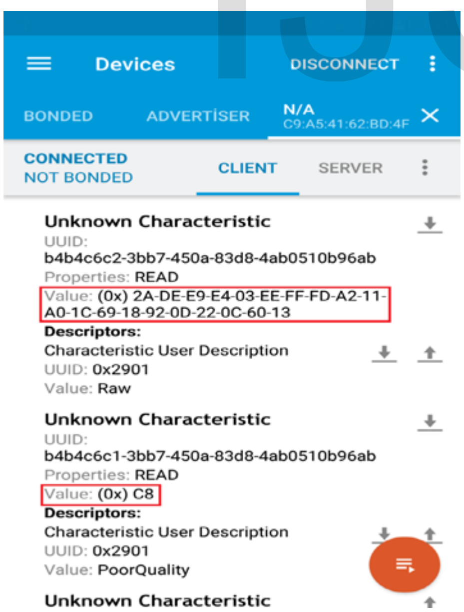

Fig. 9 The electrodes are connected (0xC8=200)

Neurosky, a cardio chip manufacturer, has provided a test program for monitoring EEG signals on a computer. This program displays both the ECG signal and the received data in a text file for testing the chip. Fig. 10 shows the ECG signals on the computer program [30] of the Neurosky chip for testing meauserement.

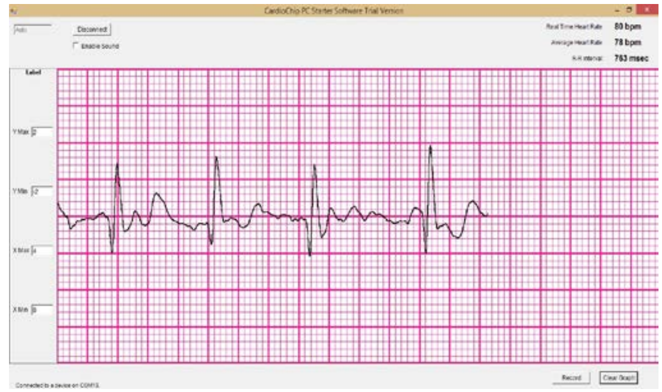

Fig. 10 ECG signal displayed in computer program of cardio chip

4 Results and Discussion

The Android program for the mobile phone is designed in Android Studio, and it is prepared by using Signal Processing Toolbox in MATLAB program. Fig. 11 shows the ECG signal on the Android program.

Fig. 11 ECG signal displayed on Android program

There is a comparison of other ECG devices that have been offered for sale or continue to make abroad. This comparison presented in Table 2 below. The developed EKG has made a difference concerning both the cost and the better features compared to other devices.

Table 2 Comparison of the designed ECG device with other devices

	Designed Device	Zio(Irythm)	AliveCor	HMicro	Vital Connect
Data Storage	Up to 14 days	14 days	Simultane-ous Record	5 days	4 days
ECG Channel	1	1	1	1	1
ADC Resolu-tion	16 bits	10 bits	16 bits	16 bits	10 bits
Sample Rate	512	200	300	250	125
Data Transfer Type	BLE 2./4.0	E-mail	BLE 2.0	Wi-Fi	BLE 2.0

5 Conclusion

As a result of this work, the application smartphone interface that uses the Android software, portable and rechargeable an ECG device introduced a small prototype device with low power consumption. It will be possible to reduce the cost of treatment utilizing measurement at home, early detection of chronic diseases and possible control of diseases such as obesity and hypertension.

Bluetooth® low energy (BLE4.1 compatible with BLE4.0) support makes it possible for devices to automatically reconnect when they reach a sufficient distance. Due to the advanced data transfer capability of the device, the data collected by the sensors can be transmitted collectively, thus consuming less energy and ensuring longevity.

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