Wireless ECG Device with Arduino

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***Abstract*– Electrocardiography is the process of recording heartbeat. The output is typically represented as a scaled graphical figure called Electrocardiogram (ECG). In this study, we present an experimental device that obtains ECG signal using AD8232 sensor board. The device operates real-time and transmits data wirelessly using nRF24L01+ RF modules located on Arduino Mega2560 I/O boards. The received ECG data was filtered and processed with Matlab.**

Keywords*–*Wireless ECG monitoring, Arduino, nRF24L01, AD8232, Online ECG, Low-cost biosensor

I. Introduction

Heart sound auscultation, heart rate variability and electrocardiography are the common monitoring techniques for heart conditions [1]. ECGs present variation of electrical activities of heart. The heartbeat signal has P and T waves and QRS complexes which describe the electrical forces generated by ventricular depolarization. R-R intervals are obtained using time interval between consecutive R-R peaks. HRV can be described as the variation of R-R intervals with respect to the time or beat number [2]. ECGs have long been around in the hospitals and many healthcare centers to diagnose cardiac activities and screening for heart diseases. ECG is used to measure heart rate, regularity of heartbeat, size and position of chambers and presence of any heart damage. Also, it is used to observe cardiac activity for people with impairment and the effects of drugs or devices used to regulate the heart, such as pacemakers [3]. Throughout the decades, there were a number of attempts to develop clinical information systems, which are reliable, affordable and accessible over the entire hospital. The situation is made possible today with the development of the wireless technologies, powerful personal computers, and international standards. These factors also have enabled data acquisition from a wide range of medical equipment, such as electronic stethoscope and ECG devices. With the advent of technology, IoT-driven bioacoustic sensors can be utilized for continuous monitoring [4]. Wearable devices enable continuous monitoring of patients anywhere within the hospital environment. On the other hand, further research is required to develop continuous monitoring tools [5]. Similarly, health industry is using smart technologies for patient monitoring (e-health), management, maintenance and security to achieve more efficient hospitals [6]. In order to be able to observe ECG signal, electrodes are required to be in contact with the human body where they measure bio-potentials emanating from the heart. The ECG sensors measure voltage differences that are created by the heart. These small voltage differences can be measured from the skin of the wrists (right, left) and leg through electrodes. The voltages are amplified and transferred to a measurement interface [7]. For years, wireless ECG devices have been using frequency modulation (FM) based [8] RF for wireless body network [9], [10], [11] ad-hoc network based [12], PIC circuit and RF based [13], 3G and TCP/IP based [14], ZigBee and Android based [15], [16], [3], analog circuit based [17], as a app of IOS [18], [19] and bluetooth based with textile electrodes [20]. It is stated in [21] that Wireless ECG systems can be used as a very good tool for clinical diagnosis, also, can be used to detect epileptic seizures in real time [22]. A review of the wearable and wireless ECG systems can be found in [23].

In this study, the ECG signal received real-time with the AD8232 sensor card connected to the electrodes was transmitted wirelessly and simultaneously using nRF24L01+ RF modules and Arduino Mega2560 I/O cards. Data was transferred from the receiver I/O card to the PC via USB interface and signals were processed using Matlab. Finally, PQRST waveforms were obtained.

II. Materials and Methods

1.1. Electrocardiography

It is the process of recording the electrical activities during the contraction and relaxation of the heart on special paper or digital environment. Generally, the frequency range is 0.1~100Hz and the maximum amplitude of a normal ECG signal is 1mV. It consists of PQRST waveforms.

1.2. Arduino Mega2560

It is a physical programming platform consisting of an I/O board and development environment containing an implementation of the Processing/Wiring language. It consists of the development environment (IDE), Bootloader (Optiboot), Arduino libraries, AVRDude (software to program microcontroller on Arduino) and compiler (AVR-GCC).

1.3. AD8232

AD8232, which is the base of the sensor board, is designed for ECG and other biopotential measurement applications. It has been developed to work stably with measurement probes and can eliminate ambient external noise. It is used by connecting the measurement cable to 3.5mm TRS audio plug on the card. In addition to these connections, it is possible to take these measurements by connecting sensor pads to LA (left arm) left arm, RA (right arm) right arm and RL (right leg) right leg connections. There is a flashing LED on the card which shows the heart rate [24].

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1.4. nRF24L01+

NRF24L01 wireless module, developed by Nordic company, is a module with low power consumption that enables wireless communication at 2.4GHz frequency. It has a communication speed of 0.25, 1 and 2 Mbps and supports SPI (Serial Peripheral Interface) interface [25].

III. Device Design

The design part has been examined separately as Transmitter and Receiver. Table I shows the types and numbers of equipment used for design. The transmitter and AD8232 sensor connections are made as in Table II and Fig. 1. As shown in Table III, the following pin connections are made with nRF24L01+.

TABLE I. DESIGN EQUIPMENT

Equipment	Quantity
Arduino Mega2560	2
nRF24L01+	2
AD8232 sensor	1
EKG pads (High Quality)	6
9V battery	1

TABLE II. TRANSMITTER AND AD8232 CONNECTIONS

ARDUINO MEGA 2560	AD8232
GND	GND
3.3V	3.3V
A0	OUTPUT
3	LO-
2	LO+
Not used	SDN

TABLE III. BOTH RECEIVER AND TRANSMITTER CONNECTIONS WITH NRF24L01+

Tx or Rx ARDUINO MEGA 2560	nRF24L01+
GND	GND
3.3V	VCC
50	MISO
51	MOSI
52	SCK
8	CE
7	CSN
Not used	IRQ

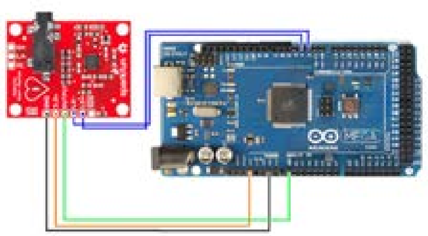

Fig. 1. Transmitter with AD8232

3.1. Transmitter Design

The code developed according to these pin connections is loaded into Arduino using the IDE interface. The steps of algorithm of the transmitter is shown below.

- Begin/Set pins and libraries: Choose RF pins for transmitter, communication channel and input pins of the sensor
- Radio setup and begins as a transmitter: Set data rate, RF power level and # of channel
- Begin loop: Read analog port value of pins of the sensors, Write port value as a input of RF module, Send port value in Mbits via RF
- End

In some cases, there is noise during recordings. Some of these noise reasons are movement noise, noise caused by electrodes not properly placed, 50 Hz noise, breathing noise, quantization noise and channel noise.

3.1.1. nRF24L01+ RF module as Transmitter

nRF24L01+ is one of the cheapest module that enables multiple Arduino devices to communicate with each other. It works with SPI serial communication protocol. The device uses "pipe" communication addresses, which means small tunnels. SPI is a full duplex (simultaneous bi-directional), synchronous (simultaneous transmission of data with clock pulses) serial communication standard and is supported by many integrated circuits hardware. In this type of communication, data (bits) transfer takes place with a master-slave relationship. After the data transfer is initiated by the master, data can be transferred in both directions simultaneously. The device and the protocol does not guarantee the delivery of data to the destination and it is software's responsibility to make sure the content is correct.

There are three SPI lines, MISO (Master In Slave Out), MOSI (Master Out Slave In) and SCK (Serial Clock), which are connected to master and peripheral devices. MISO: is the line on which the data is sent from peripheral devices (slave) to the master device. MOSI: is the line on which data is sent from master device to peripheral devices. SCK: is the line with the clock signal that provides synchronization in SPI communication. The clock signal is generated by the master device. Both AD8232 and nRF24L01+ are connected to Arduino and Arduino board is connected to computer via USB.

3.1.2. Transmitter Design Notes

SPI protocol library was used in the design. SPI, developed by Motorola, can broadcast from 1 Master device to n Slave devices over an address tunnel. In this design, the first address pipe is used for the 2401 MHz band for both the receiver and the transmitter. NRF24L01+ 2.4 GHz wireless communication module library developed by Nordic Semiconductor is used. ISM (Industrial Scientific Medical Band, SBT in Turkey- industrial, scientific and medical devices, tape), without the need for certificates or licenses to radio communications in many countries by following a specific output power limitation, is used for communication.

nRF24L01+ can broadcast up to 100 meters in open field at 250 Kbps, 1 Mbit and 2 Mbit. In this design, the lowest communication speed, 250 kbps, was used to extend the communication distance. Min. signal detection thresholds are -82dBm (2 Mbit), - 85dBm (1 Mbit) and -94 dBm (250 Kbps). The device can communicate on 6 different channels at the same time. Address (6) "00001" channel is used on both the receiver and the transmitter. It can transmit in the range of 1-32 bytes. Analog values are transmitted as 1 byte binary. The transmitter transmits the received data to the receiver by placing 1 millisecond between each byte. Transmitter transmits data as long as it is received, and if there is data above the threshold value in the receiver pipe, it receives it without exception.

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As in Table III, CSN and CE pins on nRF24L01+ are connected to 7 and 8th digital pins of Arduino board. They are used to set the module in standby or active mode, as well as switch between send or command mode. Arduino transmits the broadcast command to nRF24L01+ from these pins. Transmitter installation is complete after the code is loaded. Before proceeding with the receiver installation, 9V or external 5V power supply is made available for the final stage of the design.

3.2. Receiver Design

3.2.1. Receiver Design and nRF24L01+ RF module

Arduino device at the receiver and nRF24L01+ RF module pin connections are as shown in Table III and Fig. 2.

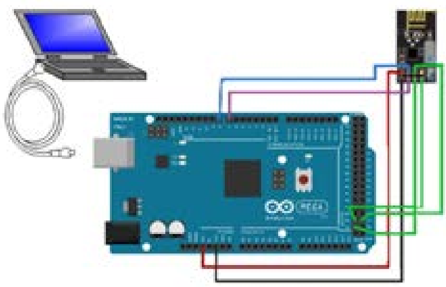

Fig. 2. Receiver with nRF24L01+ and PC

3.1.2. Receiver Design Notes

Similar to the transmitter design, the SPI protocol library is used. The broadcast channel address (pipe) is 125 channels, there is 1 MHz bandwidth for each channel. As with the transmitter, the 2401 Mhz band, which is the 1st pipe, was used. The receiver is set to 9600 BAUD ~ 1 kHz Read rate.

2.400 -> 0, 2.401 -> 1, ..., 2.525

Wireless modules with programmable output power of 0, -6, -12 and -18dBm; 0 dBm max adjusted to the maximum range with the output power. In this case, the wireless module draws 11.3 mA of current. Receiver initialization as follows: If there is a signal in the channel, read the portValue variable value, write to the screen. If there is a signal on the channel, the receiver signal is written to the screen without exception. The steps of algorithm used in the receiver design is shown below. The final wireless ecg device is shown in Fig. 3.

- Begin/Set pins and libraries: Choose RF pins for receiver and communication channel
- Radio setup and begins as a receiver: Set data rate, RF power level and # of channel
- Start listening
- Begin loop: Read port value of receiver coming from the sensors, write port value serial to the PC
- End

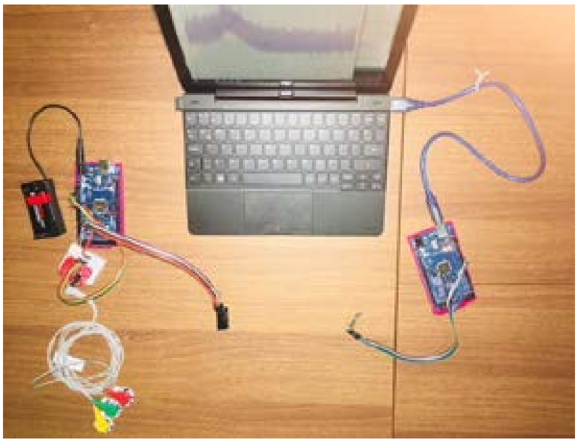

Fig. 3. The final wireless ecg device

IV. Experiments and Results

The initial experiments repeated to observe errors, noise, output performance and sensor responses. Next case, it has been tried to reduce the circuit source noise by placing a coupling capacitor between the source and ground. Electrode pads were replaced with their counterparts with better quality gels with adhesion and retention ability to eliminate the sources of noise. The output data were analyzed in Matlab. Signals were examined using different filter methods. The ECG data of 45 seconds recorded from a real subject was filtered in Matlab. The effect of filters are shown in Fig. 4.

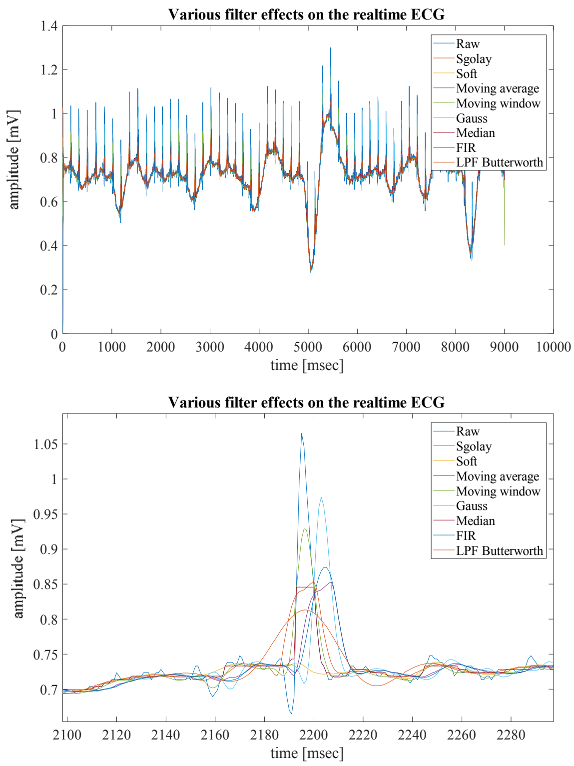

Fig. 4. Various Matlab filter effects on the received ECG via PC serial; Raw data, Sgolay, Soft, Moving average (MA), Moving window, Gauss, Median, FIR, Low pass Butterworth filtered ECGs

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V. Conclusion

In this study, by using Arduino boards and RF wireless modules, real-time continuous ECG signal was transferred between receiver and transmitter, Matlab noise analysis were applied to the recevied signal. In the experiments, in case the bit rate of the wireless modules were decreased and the output power was maximum, although there were obstacles between the transmitter and receiver modules, it has been observed that there is no interruption. The biggest challenge in analyzing such very low amplitude (mV) signals were the minimization of the noise factor that occurs when acquiring/transforming and transmitting the signal. Also, this study differs from others in ways such as; for the propose system is cost-effective, no circuit/pcb design needed, suitable for wireless body network like some studies [9], [10], [11], the device can operate in environments with obstacles such as walls, doors, etc., RF modules has the low-power mode, thereby, ability to carry signals up to 100 meters distance in an open area.

VI. Future Work

As a future work, various versions of the study could be designed that it can transfer instant data to smart devices, with the new designing of the transreceiver, electrode or pads, to obtain noiseless signal.

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