Design A Wireless Patient Monitoring System

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Abstract

Observation of bioelectric and physiologic signals is rather important for the diagnosis and treatment. In particular, pursuit of many physiologic parameters is critical for incentive care unit patients, burn patients and first activity attempt of patients after surgery. The aim of this study is the observation of electrocardiography (ECG), pulse values and instantaneous fever measurements received from electrophysiological signals through radio frequency (RF) wireless communication. It is targeted to receive signals from the patient, transfer it to the patient observation room, display and record them with suitable interface programs, and warn the healthcare personnel with sound signals. This application, which will set a good example in the healthcare field, is implemented with a design suitable for the purpose by considering the software and hardware point of view.

1. Introduction

In recent years, remote patient monitoring has been one of the quite popular research subjects in mobile health and telemedicine practices. It provides staff saving by allowing monitoring patients without being with them all the time. In addition, it is capable of monitoring instantaneous changes occurring in patients through tracking critical electrophysiological data continuously. Many academic and sectoral studies have been carried out in this field [1, 2, 3].

The critical point in remote monitoring systems is the faultless collection of target signals from patients [4]. Displaying the collected signals on the screens of doctors or other medical staff members and giving critical warnings when necessary refer to the communication and the visual warning aspects of such systems [5, 6].

The literature contains many sectoral practices besides academic studies. Oweis and Barhoum (2010) transferred the ECG signal into the receiving unit wirelessly by the RF (434 MHz) standard and displayed the transferred signal via MATLAB [7]. Toral et al. (2007) transferred pulse, SpO2, and temperature signals into computer and displayed it via LabVIEW. But they did not employ wireless communication technologies. The bio-signals taken from the prepared electronic unit were transferred into computer directly and monitorized via LabVIEW [8]. Hashim and Sizali (2013) set up a wireless patient monitoring system through Visual Basic Net. 2010 and the PIC16F877 microcontroller. Communication between hardware and software systems was provided via XBee modules. The study revealed that the XBee module succeeded in providing the connection between the entire system and the monitoring software and the system could be improved more by using a real ECG device [9]. Prema (2013) designed a system taking such patient values as ECG, pulse, respiratory rate, temperature, and oxygen and entering them in the database. The study also dealt with transferring the received signals and physiological data into a web-based host computer and transmitting such signals and data to doctor's cell phone through android technology. The system also ensured the conveyance of necessary instructions of doctors to nurses' center [10].

Eriş et al. (2010) monitored three vital signals detected in the patient wirelessly: oxygen saturation percentage, pulse, and body temperature. The 8000AA model finger type detector produced by Nonin® measured SpO2 and pulse. The DS18B20 digital temperature sensor produced by Dallas® was used for measuring body temperature. The user interface was developed by means of LabVIEW 7.1. The coverage area was expanded by using internet infrastructure in the network. The developed portable wireless device and mobile application allowed the simultaneous remote monitoring of maximum 10 patient data and gave alarm through the interface when any unexpected data was detected. Furthermore, obligation for patient and doctor to be in the same space at the same time, which was the case in the classic method, was removed [11].

Today, such studies are frequently encountered in the literature. The present study mainly aimed to design a remote system allowing monitoring pulse and temperature data received from the patient based on the ECG signals by means of RF wireless communication method.

As distinct from the systems found in the literature, this system was intended to be used in intensive care patients, patients from whom an attempt is made to remove the narcosis effect in the post-operative period, and other patients who need precise monitoring. Some other aims intended to be achieved with the system were transferring the received data into patient observation room, displaying and recording such data via an interface program, and warning medical staff members and people accompanying the patient by giving a auditory signal in case of a physiological risk.

2. Material and Methods

Temperature, pulse, and heart's electrical activity (electrocardiography - ECG) are some of signs indicating a person's state of health. These signs show the physiological state led by such vital organs of body as brain, heart, and lungs. Any change in body functions cause deviations from normal values. Since body temperature indicates an abnormal situation affecting the electrical activity of heart and pulse, it is very important for the observation of the patient and making an overall evaluation of his/her state of health. This is why such important indications are called “Vital Signs”. These signs have to be monitored by nurses continuously as they show any possible change to occur in the state of the patient.

2.1. Body Temperature

Accurate measurement of body temperature is important if a patient is about to be hospitalized; if findings about the patient are being evaluated; if there is a suspicion of infection; and if antibiotics are to be managed. Body temperature can be measured in four different regions of the human body [12]. These regions are axilla, ear, oral region, and rectal region. Axilla was preferred in the present project as it was easy to use and provided good measurement. In axilla measurements, normal values vary between 35°C and 38°C.

2.2. Pulse Data

Pulse refers to the rhythmic beat of heart that causes arteries to enlarge and contract as a result of the pushing of blood into arteries through the contraction of heart’s left ventricle. Pulse is measured in the arteries that are close to body surfaces. A healthy male has a smaller number of pulses than a healthy female. It is 70-80 per minute among females, 60-70 per minute among males, 120-140 per minute among babies, and 60-70/per minute among aged peoples [13]. It was aimed to design a finger probe for pulse measurement.

Pulse signals would be obtained through the optical receiving and transmitting sensors to be used. Since the only aim was to measure pulse, one wavelength would be adequate [14]. In theory, when there is no blood flow in the finger, the quantity of light falling on photodiode is constant. However, when blood starts to circulate in veins as a result of heartbeat, the quantity of light will change. If such change is detected, filtered, and reduced to a logical level, the amount of beats per minute (i.e. pulse data) can be obtained via microcontroller. Figure 1 demonstrates the method to be employed for taking the pulse.

Wavelength is critical in measuring the pulse. Red blood cells absorb light between 750nm and 900nm. Red blood cells absorb light depending on the oxygen saturation, and the pulse can be measured based on the change resulting from blood circulation. Figure 1 presents the positioning of photodiode and IR used in the designed finger probe.

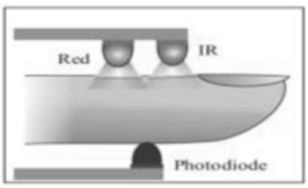


Figure 1. Heart rate information to be taken from the finger to be used in the design of the IR source with photodiode positioned [15]

2.3. Receiving Of ECG Signal

ECG refers to recording electrical activity taking place in heart aimed at examining the functioning of cardiac muscle and neural transmission system. Changes occurring through heart’s electrical activity spread body-wide thanks to the tissues around the heart and blood in particular [16]. To obtain such signals, electrical changes are amplified and recorded by means of conductive ends (electrodes) put in several places on the body. ECG devices can detect electrical stimuli of 1mV in average [16].

The periods and amplitudes of the signals obtained from the body surface inform of heart’s physiological health. The use of 3-channel electrodes is adequate for ECG measurement. They should be put on the chest so that cardiac rhythm signals can be detected more clearly. The frequency bandwidth of ECG signal is 0.5Hz to 100Hz; and its amplitude value is between 0mV and 5mV. The AD 624 instrumentation amplifier produced by Analog Devices® was used for designing the ECG circuit. It could achieve a gain of 1 to 1000. It had an input impedance of around 10^9 Ω. The main reason for the use of AD624 in the present study was that it had very good connection conductivity and produced very little interior noise. In addition, its working temperature could reach 125°C.

2.4. Electronic Design Of Temperature Circuit

Used for measuring body temperature, SHT-11 is a digital heat and humidity sensor. SHT-11 contains a 14-bit AD convertor and a serial communication unit. The temperature value is conveyed to the microcontroller at a resolution of 14-bit (it is the default value; 12-bit can be selected if desired).

Temperature can be measured between -40°C and +128°C with an error margin of ± 0.5°C, and humidity can be measured with an error margin of ± 3.5%. The board involves two different outputs whereby both temperature and humidity can be measured. PIC18F252 having a 10-bit ADC was used as a microcontroller. It has 3 ports, 4 different clocks, and a 32 KB storage unit.

The SHT-11 temperature sensor produces digital results and answers quite rapidly. The temperature output equation of the sensor is,

$$T = d_1 + d_2 . SO_T \quad (1)$$

The values of constants in the formula are seen in Table 1. What is critical here is sensor’s source supply (VDD) value. The digital output of the sensor changes the d_2 coefficient depending on the selected bit value [17].

Table 1. Variance of temperature sensor supply voltage and temperature constants

VDD	d_1(°C)	d_1(°F)	SO_T	d_2(°C)	d_2(°F)
5V	-40.1	-40.2	14 bit	0.01	0.018
4V	-39.8	-39.6	12 bit	0.04	0.072
3.5V	-39.7	-39.5			
3V	-39.6	-39.3			
2.5V	-39.4	-38.9			

2.5. Electronic Design Of Pulse Circuit

The optical transmitter SFH 4550 and the optical receiver SFH 203FA were used for measuring the pulse. SFH 4550 was produced by Osram®. Its working temperature is -40°C to 100°C. Its reverse voltage is 5V, and its forward current value is 100 mA [18].

Figure 2 shows the change in the current value and in the wavelength. There is a linear relationship between relative current value and wavelength (equation 2).

$$I\_rel=f(\lambda) \quad (2)$$

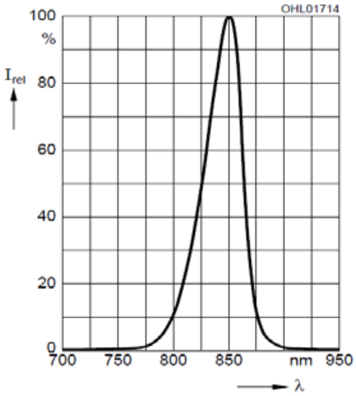


Figure 2. Current vs. wave length of IR light source [18]

The SFH 203FA optical receiver (photodiode) is a sensor containing a daylight filter on it. This photodiode was produced by Siemens. Its working temperature is -55°C to 100°C and its supply voltage is 5V. As the quantity of light falling on photodiode changes depending on hemoglobin concentration, output voltage changes, too.

2.6. Electronic Design Of Wireless Communication Circuit

ATX-34S series RF transmitting module is quite advantageous for short-range remote control applications. The module was designed for printed circuit board (PCB) installation without the need for any RF component apart from antenna. Antenna connection can be made by using a simple cable. The frequency range is 433 to 434 MHz. Through many RF module trials, this module was found to be the most appropriate module yielding the best result. The digital ECG, pulse, and temperature data arriving in ATX34 via the microcontroller are sent to the receiving module via universal asynchronous receiver transmitter (UART) communication. Standard data protocol is shown in equation 3.

$$TX: preamble + sencron + data_1 + \cdots + data_n \quad (3)$$

Preamble is a bit index composed of 1s and 0s (01010101...) as data. It can be 5 bytes 0x55 or 0xAA. The 1s and 0s sent must have equal durations.

In short, preamble ensures hardware synchronization. Sencron helps software synchronization (figure 3). It must be used for ensuring bit synchronization and determining the start of message correctly. The length of this bit index may vary depending on application requirements or limitations, but it can be 5 byte 0x00 + 5 byte 0xFF or can be decided by the person himself/herself.

There must be no gap when data are being sent. If there is any gap, preamble and sencron must be sent. The preamble is not sought on the side of RX. Only the sencron is sought, and then data are read [19]. Figure 3 presents the way of transmitting data.

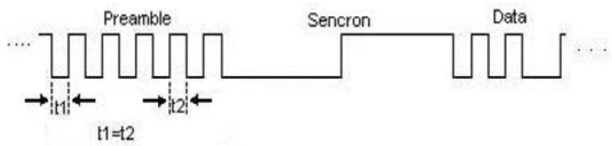


Figure 3. ATX-34 Data transmitting format

NRX-34U is the RF receiving module and is advantageous for use in short-range distant control applications thanks to its narrow-band feature. Figure 4 demonstrates NRX-34U's way of receiving data. Its way of receiving data is the same as that of ATX-34 [20].

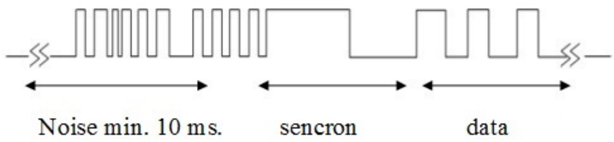


Figure 4. NRX-34U Data receiving format

NRX-34 does not contain any voltage regulator. It was designed by considering battery use. Thus, the values specified in the supply voltage must be taken into consideration. When the supply is lower than the values indicated, the module will operate unstably. If the supply voltage is +5 VDC and ground (GND) connection is over the specified values or is reverse, there may be permanent destructions in the module. There is not placed any circuit to protect the reverse polarization in the module for supplying low current consumptions. During the operating time in the supply voltage, changes over ±100 mV cause the module to work unstably. It is recommended to use IC regulator in the supply circuit.

The most important two points necessary for data reception are a good antenna and the selection of correct RF grounding. Without an antenna, it is not possible to transmit the data to long distances. The module has a simple antenna connection pin. A proper UHF antenna can be connected to this pin directly. The simplest antenna that can be connected to the NRX-34U module is shown in equation 4.

$$\text{Antenna Length} = \lambda/4 \quad (4)$$

$$f=v/\lambda \quad (5)$$

The relationship of wave frequency between wavelength λ and wave velocity v, is shown in equation 4. If equation 5 is put in its place in the equation 4;

Antenna Length= v/(f.4) (6)

When the values from equation 6 are put in their places, it is found that a 17.3 cm cable must be brazed to the antenna input. If the antenna needs to be connected to a point far from the module, it must be used a 50 Ω Coax antenna cable.

The antenna cable must be grounded at a point close to the antenna input of the module.

Figure 5 indicates the block diagram of the wireless patient monitoring system designed. The designed temperature circuit, pulse circuit, and ECG receptor go to the microcontroller following the amplification and filtering processes. The obtained data are displayed on the patient by LCD and are sent to remote monitoring computer through wireless communication. Figure 6 presents the electronic components used for collecting body temperature, pulse value, and ECG signal.

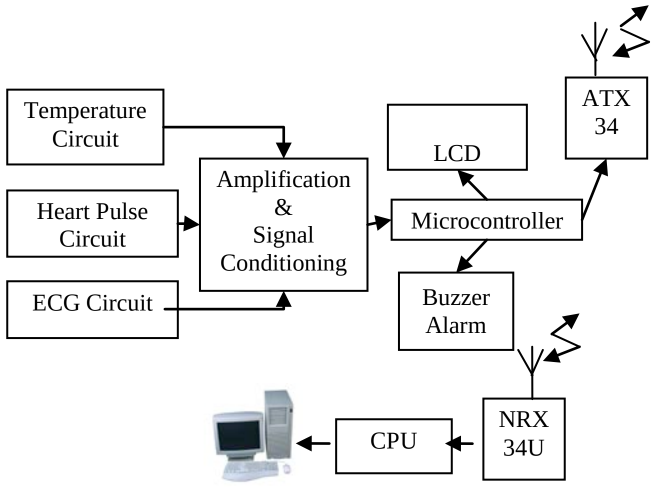


Figure 5. Block diagram of wireless patient monitoring system

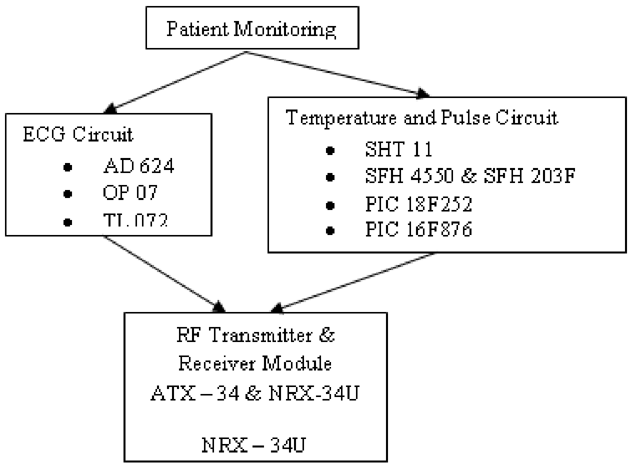


Figure 6. The electronic components using in wireless patient monitoring system

3. Results

All the electronic systems designed for use were drawn via Proteus™, thereby creating their simulations. Firstly, electronic designs were completed to measure body temperature and pulse. Then design for the reception of ECG data was completed.

The electrophysiological parameters taken from the body surface were moved to the module to be transferred.

After that, the data were transmitted to the requested computer via RF wireless communication block.

3.1. Measuring Body Temperature And Pulse

In the pulse measurement design, the section composed of the SFH203F photodiode optical receiver and the SFH4550 optical transmitter shows the designed finger sensor (Figure 7). The photodiode is continuously supported with suitable resistances (Figure 7). Two successive 1st degree high pass filters were designed in order to clear the signals taken from the photodiode of noises and make them in appropriate magnitudes. This circuit is shown in Figure 8.

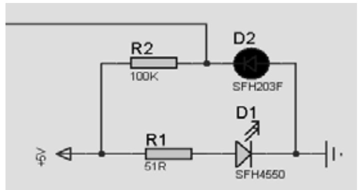


Figure 7. Designed finger probe used to get pulse data

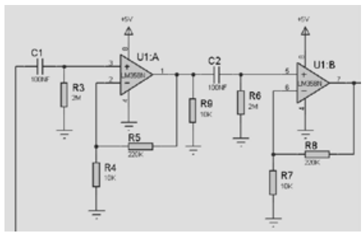


Figure 8. Filtering for pulse circuit

In the designed filter, total gain is 549 (the 1st level gain is 23; and the 2nd level gain is 23). It is

$$K1 = K2 = 1 + \frac{R5}{R4} \quad (7)$$

The cut-off frequency of the filter is;

$$f1 = f2 = \frac{1}{2\pi R3C1} = 0{,}796\ Hz \quad (8)$$

Since pulse could not be higher than 4 Hz, a low pass filter was applied to prevent noise at the end of the circuit.

The BAT85 diode used in the pulse circuit output saturates the signal and cuts off the negative area. Such port is connected to the PORTC 0 leg of the microcontroller. This is because; this port is a digital port and counts each pulse (Figure 9).

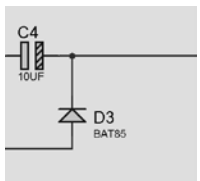


Figure 9. Diode circuit

A crystal of 20 MHZ was connected to the leg 9 and the leg 10 of the microcontroller. It divides 20 MHZ into four within itself as Timer0, Timer1, Timer2, and WatchDog Timer, and counts 4 pulses. It considers all of them a single pulse. This is because; the microcontroller takes rapid action at a time. One clock pulse runs in 0.2 microseconds. In other words, one cycle time is 0.2 microseconds. The PORTB legs (23, 24, 25, 26, 27, and 28) of the microcontroller are connected to the appropriate connecting terminals of LCD. In this way, pulse counting is performed.

The designed buzzer section consists of a resistance of 1kΩ, a NPN transistor, and 1 buzzer. The buzzer spends 100mA power, and the microcontroller can take maximum 20mA. Thus, a transistor was connected as a power amplifier so that PORTC4 would not burn.

Digital SHT-11 sensor is used for measuring temperature. Figure 10 shows temperature sensor connection.

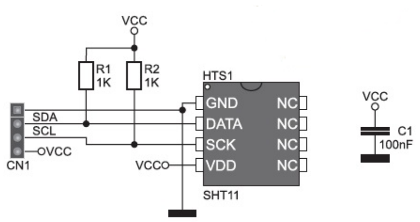
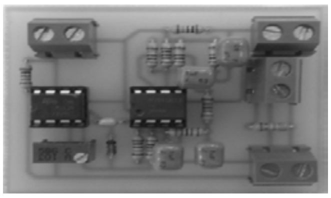


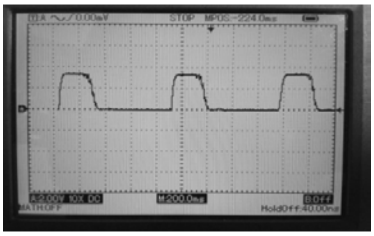
Figure 10. Temperature circuit connection

The measured temperature and pulse values are received by the PIC16F876 microcontroller. This microcontroller conveys the pulse values and the temperature values to the PIC18F252 microcontroller in the collection and transfer circuit. The designed pulse circuit, the finger probe, and the oscilloscope output of the system are shown in Figure 11.



(a)

(b)



(c)

Figure 11. (a) Designed pulse circuit PSB. **(b)** Finger probe designed with IR and photodiode. **(c)** Oscilloscope output of the pulse signal.

3.2. ECG Circuit Design And ECG Signal

10kΩ resistances were taken from the Rg1 and Rg2 legs of the AD 624 instrumentation amplifier, thereby creating the reference line. 3-end probes were put in the input legs of the amplifier with resistances of 1kΩ. The reference leg was connected to the output leg of the OP07 amplifier. Null resistance of 10kΩ was connected to the leg 4 and the leg 5. 1 kΩ resistances were connected to the IN+ and IN- legs in order to protect the amplifier from the noise. Way is made from the legs Rg1 and Rg2 of OP07 (the reference leg amplifier) to the reference leg amplifier having a low pass filter with 10 kΩ resistances. The band-pass filter was added to the output of the instrumentation amplifier. In the circuit design, FET amplifier TL072 is used for this filter. There are 2 amplifiers in the package. FET amplifiers perform for suppressing DC voltages (Figure 12).

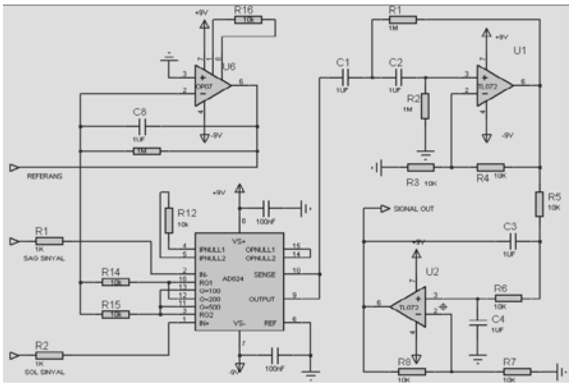
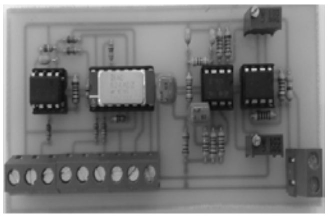


Figure 12. Electronic design of ECG system

The cut-off frequencies of the band-pass filter designed along with the OP07 amplifier in the output of the instrumentation amplifier are f_L= 0.159 Hz and f_H=15.9 Hz. Filter gains are 2. The system gain is 1000. The frequency range and the gain values were chosen from the most efficient trials after many trials were carried out. Figure 13 demonstrates the designed ECG circuit and the ECG signal taken through such circuit.



(a)

(b)

Figure 13. (a) Designed ECG circuit PCB**. (b)** ECG signal is taken from the body oscilloscope output.

3.3 Operation Of RF Receiving And Transmitting Modules

The analog ECG signals received from the body were digitized via ADC included in the PIC18F252 microcontroller used. Digital ECG signals and the temperature and pulse values collected in PIC18F252 were transferred into ATX34 (the RF transmitting module) via UART communication. The electrophysiological data collected here were sent to the receiving module though radio-frequency waves. Figure 14 presents the designed and produced printed circuit of the transmitting module.

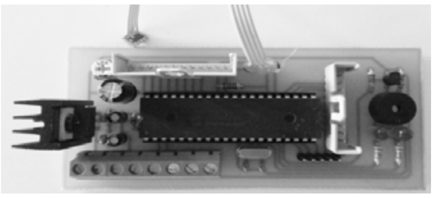
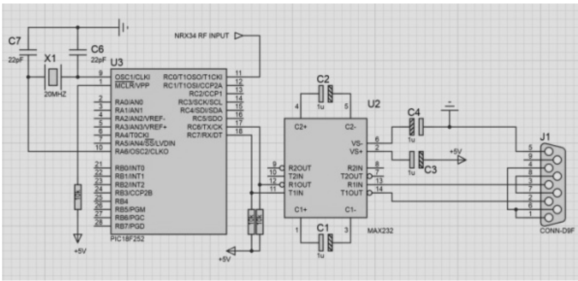


Figure14. Designed transmitter module circuit

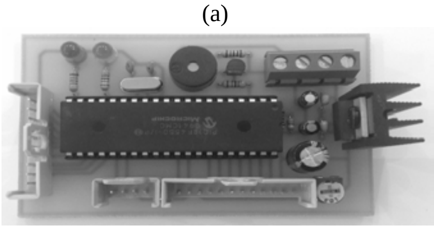
The receiving module is located in the room where the computer which the doctor or the medical staff member can use to monitor the patient is. The data are received by RF NRX34, and the received digital signals are transferred into the integrated Max232 via PIC18F252 (UART communication). MAX232 converts the digital signals in the 0V-5V range between -10V and +10V. Thus, communication distance increases. Max232 transfers the received data into the RS232 hardware. In this way, data come to be observable on the computer screen via this hardware.

The RS232 hardware contains the integrated MAX232 and the integrated USB. The integrated USB receives the data and matches them with the USB in the port of the computer.

This USB received the data and transferred them into RAMs. Universal 9-core connecting cable was connected to MAX232 output legs and integrated into the RS232 hardware. Figure 15 shows the designed receiver circuit.



(a)



(b)

Figure 15. (a) Designed receiver module circuit electronic simulation layout. **(b)** Receiver Module PCB output.

3.4 Wireless Communication System And Interface Design

UART communication takes places when data are being transferred into the transmitting module. UART ensures dual asynchronous communication. It can be used in 8- or 9-bit data length. It ensures one-way communication over a single line.

In UART data transmitting, data are sent from the lowest value bit to the highest value bit. Firstly, the ACK bit is sent. ACK is the verification bit. Then 8-bit data are sent. This process is repeated. UART communication speed is 9600-bit per seconds.50-byte data are sent per seconds due to delays. UART data reception receives the incoming bits at the baud rate set and writes them in its memory. Data arriving in the memory through ACK bit are considered written. Signals and the Visual Studio used in interface design are demonstrated in the program.

With Visual Studio, an interface design with the C# source code was used. This program allows reducing corners by creating straight lines between the ADC signals coming to the computer. Two points are captured in the signal produced by ADC. Figure 16 presents the outputs of the designed interface program.

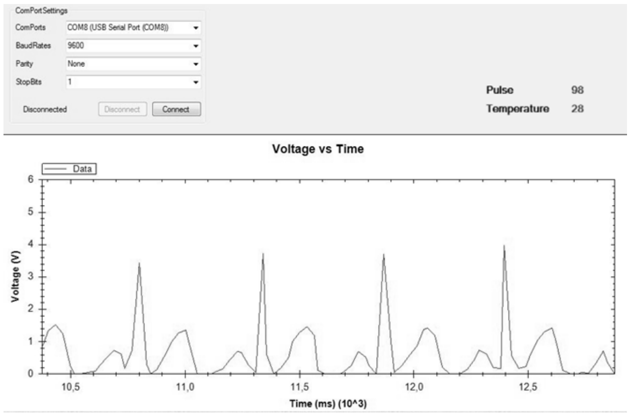


Figure 16. The output is acquired by the designed interface program

4. Conclusions

At the end of study firstly, pulse, temperature, and ECG signals received from the human body were cleared of noises and digitized. The received electrophysiological values were displayed by LCD. The sensors and the RF modules most appropriate for medical use were preferred based on detailed research and trials.

The received signals were collected on the RF transmitting module (ATX34) through the used microcontroller via UART communication. The data were transferred.

They were received by the RF receiving module (NRX34). From there, the data were again transferred into the integrated MAX232 via the microcontroller through UART communication and from there into computer through the RS232 hardware. The designed interface program and electrophysiological signals were observed in the computer environment.

Improvements on the signals may be enhanced. The electrophysiological data obtained from the patient were conveyed through RF communication wirelessly and were transferred into computer environment. When any risk factor emerges in physiological parameters, alarm circuit steps in and warns the doctor or the medical staff member.

In this way, the danger to life situation of the patient can be prevented through fast intervention. Whereby this project developed, a different perspective is introduced to the monitoring of patients in the hospital. As distinct from the approaches found in the literature, the designed system monitors not only the ECG parameter but also temperature and pulse data. The system was designed to obtain data from the patient both in the lying position and in the walking position.

Accordingly, instantaneous changes that can occur during walking are both reported to the patient and the person accompanying him/her through aural warning and communicated to the center wirelessly. Figure 17 shows the final version of the system prior to usage.

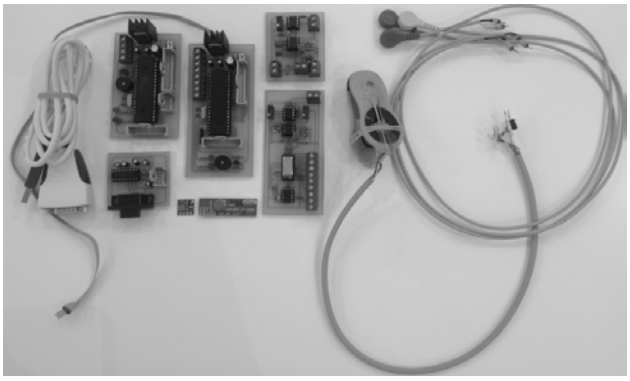


Figure 17. Wireless electrophysiological data tracking system: finger probe and all the other modules is seen altogether

5. References

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