ORIGINAL PAPER

VITAL PARAMETERS MONITORING SYSTEM AND ALERT SIGNAL TRANSMISSION TO EMERGENCY MEDICAL CENTERS

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Abstract. *One of the major issues faced by chronic patients is real-time monitoring of vital parameters and early warning of emergency medical units when these parameters go out of the normal range. Most chronic patients suffer from heart disease. In this regard, the present paper introduces a system of monitoring vital parameters, arterial blood pressure and heart rate with 3 EKG electrodes and a GPRS / GSM communicator controlled by an Arduino Uno board. Upon the occurrence of abnormal values of these parameters that may be dangerous to the life of the person in question, the data transmission device that sends a GSM alarm signal to the surveillance medical service to which the patient is assigned is activated. To validate the actual EKG signals, a heart rate measuring device based on photoplethysmography was used. The experimental results show that the projected system has low power consumption, so the lifetime of the power battery is high and the time of transmitting the alert signal of the tenths of a second.*

Keywords: *monitoring, signal transmition, GPRS.*

1. INTRODUCTION

The number of chronic patients, ever-increasing worldwide, has always been a priority for researchers and for all involved in health care. Common chronic diseases are arthritis, diabetes, asthma, pre-infarction, and infarction. This type of illness puts a significant footprint on the life of a person and his family, being propounded with the aging. At the same time, older people are major consumers of social security resources [1].

The need to develop and organize new directions of efficient healthcare delivery has been accompanied by major advances in the field of information and telecommunications. This has led to a rapid increase in the use of ICT applications in health services, commonly known as e-Health, tele-health, telemedicine, tele-health. A particular category is those with sensory and/or mobility deficiencies, where modern technology embodied in hardware and software solutions allows them to use the computer and communication technique (ideally) at least as effectively as a non-disabled user. As early as the Renaissance, physicians turned to scientific observation of the body to understand its functioning. The starting point for introducing scientific methods into medicine is the concept of measuring it.

This type of technology ensures the independence of people with disabilities - enabling them to perform tasks that are impossible or difficult to accomplish, by improving the way they interact with the technological means to achieve the goal [2].

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In recent decades, the need to develop and organize new directions for the efficient delivery of health services has been accompanied by major advances in the field of informatics and telecommunications. This has led to rapid growth in the use of ICT applications in health services, commonly known as e-Health, tele-health, telemedicine, and tele-health. A particular category is those with sensory and / or mobility deficiencies, where modern technology embodied in hardware and software solutions allow them to use the computer and communication technique (ideally) at least as effectively as a user without disabilities.

This type of technology ensures the independence of people with disabilities - allowing them to perform tasks that are impossible or difficult to accomplish by improving the way they interact with the technological means to achieve the goal [2].

Thus, the concept of telemedicine - which provides various medical services based on information technology and telecommunications - can be defined. It offers the possibility to transmit a series of medical information, in different forms (image, text and/or sound) of the specialized medical staff to help the patient (whether it is diagnosis, treatment, prevention or monitoring) located in another location. Telemedicine involves a range of advanced, modern technologies that can convey all the information and medical data with a certain certainty [3].

Among the most important telemonitoring systems existing at international and national level we can mention:

a) The EPI-MEDICS (Enhanced Personal Intelligent and Mobile System for Early Detection and Interpretation of Cardiological Syndromes) system, co-operated by researchers from France, Italy and Sweden (2001-2004), consisting of a telemonitoring device (ECG or EKG) called PEM (Personal ECG Monitor) to detect various cardiac conditions [4, 5].

b) Code Blue is the most publicized telemonitoring system and is based on a network of wireless sensors capable of communicating radio. Sensors transmit data over distances that can reach 100 m to devices such as PDAs, laptops, ambulance terminals, etc.

c) The MobiHealth project, applied in Germany under the FP5 program (2002-2003), consisted in the development of a telemonitoring system that contains sensor networks (BANs) applied to the patient’s body. They acquire data and transmit them continuously to a PDA using the wireless-Bluetooth protocol, and then to the GPRS / UMTS monitoring center [5].

d) At our country level, telemonitoring is perceived as a technology of medical interest adopted by centers capable of providing the necessary technical support. The national project, CardioNET (Integrated System for Continuous Surveillance in the E-Health Intelligent Network of Patients with Cardiovascular Diseases) focuses on the telemonitoring of patients with cardiac disease (ischemic heart disease, rhythm disorders) to optimize the patient - the family, the clinic, the hospital, the health insurance, house and the management of the medical history, the treatments and the degree of evolution of these pathologies [6].

e) „TELMES” system is a multimedia platform dedicated to complex medical services. It was intended to provide a secure system for the implementation of tele-medical and telemonitoring teleservices [7].

As a result of analyzes and statistics in the US, the so-called „Sudden Cardiac Death” (SCD) syndrome has been found to be one of the most important causes of mortality [8].

The risk of SCD is mainly reported among adults, with a growth rate proportional to age. This risk, regardless of the age category, is predominantly higher among men than women [9]. It has also been found that the survival rate is extremely low when this phenomenon (SCD) occurs outside a sanitary unit, hospital (on the street, in public places, at home, and so on) [10, 11] comparatively with the situation where a SCD occurs at a location that has an external automatic defibrillator (AED), such as an airport, airplane, or other location (easily accessible). The AED can be used until the Emergency Medical Service

(EMS) arrives, resulting in a substantial increase in survival (over 61% in reported cases) [12].

In this context, a group of researchers from universities in the USA and India have laid the foundation for a concept to prevent SCD by establishing a patient-based system using electronic circuits, systems, technologies and a network of sensors capable of detecting and recognizing a cardiac event and may alert an emergency service personnel [13].

They conceived an electronic ‘vest’ made of a textile material, elastic conductive fibers, special materials that can be worn by patients. This type of waistcoat is especially designed for people who run marathons but can also be worn by people of all ages with different heart conditions. The proposed system is basically composed of: Electronic Materials, Analog Circuits, Radio Frequency Circuits, Flexible Antennas, Sensors and Signal Processors [14, 15].

The objective of this work is to develop a compact system that can be worn by a patient with heart problems, under medical observation, even when practicing a daily activity. The system monitors the heart rate and blood pressure of the patient, and when abnormal values of these parameters occur, dangerous values for the life of the person in question, activates the data transmission device, sending an alarm signal to the attending physician or the medical surveillance service to which he is the patient.

The article is organized as follows: Chapter 2 presents the electrical scheme of the vital parameter monitoring system realized with the Arduino platform. The method proposed by authors for biomedical signal processing and the functioning of the monitoring system are described in Chapter 3. Chapter 4 is dedicated to presenting the data transmission system to emergency medical services with a GPRS / GSM communicator and power consumption analysis of the power battery. The conclusions are drawn at the end of the paper.

2. MONITORING SYSTEM OF VITAL PARAMETERS

The proposed system consists of a heart rate measuring device, an EKG measuring device with 3 electrodes and a GPRS / GSM communicator managed by an Arduino Uno platform based on microcontroller Fig. 2.1.

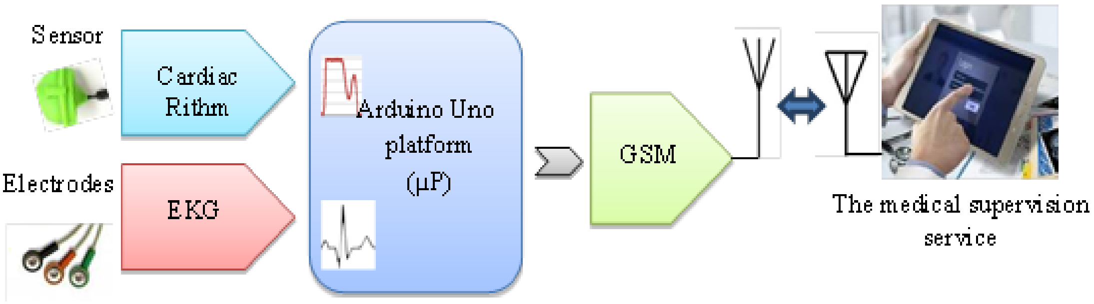


Figure 2.1. System block diagram monitoring vital parameters and remote transmission.

2.1. PULSE MONITORING SYSTEM AND ECG USING ARDUINO UNO

The heart rate and ECG monitoring system consist of a pulse monitoring device using the photoplethysmography method using a transmissive sensor, a three electrode EKG device and an Arduino Uno platform for the acquisition and processing of the signals.

Heart pulse monitoring device

Cardiac rhythm measurement is performed with a light sensor and a photoplethysmography (PPG) detector, which is a non-invasive method of measuring blood flow variation in tissues [16].

Changing the volume of blood in tissues is consistent with heartbeat, which can be used to calculate heart rate. Transmission and reflection are two fundamental types of photoplethysmography. We can use a transmissive measurement method in which a light source is emitted into tissue and a light detector (phototransistor) is placed on the opposite side of the tissue to measure the amount of light resulting. Because of the limited penetration of light through organ tissue, the method can only be applied to certain parts of the body, such as the finger or ear lobe. However, we can also use a reflexive method in which the light source and the light detector (phototransistor) are placed on the same side of a part of the body. In this case, the light emitted in the tissue is reflected being measured by the detector.

The electrical signal obtained from the light detector is a biosignal containing an AC component and a DC component, in which the AC component represents the information about the cardiac frequency. The biosignal, being of very low value, requires amplification and for this purpose we used an operational amplifier MCP6004, CMOS technology manufactured by Microchip.

The circuit (Fig. 2.2) contains two identical blocks, each containing an (AO) for filtering and amplifying the biosignal [18].

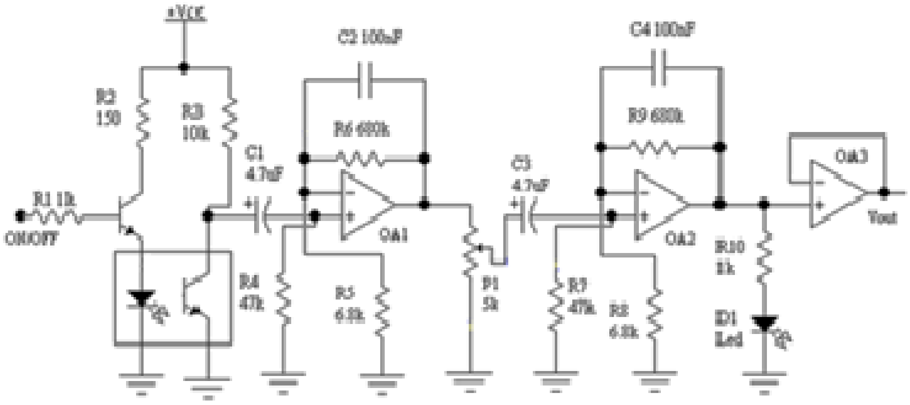


Figure 2.2. The circuit diagram for the biosignal processing.

The sensor output is connected to the first amplifier channel through a high pass filter (HPF) with a cut-off frequency of 0.7 Hz to eliminate the DC component. The next block is a low-pass active filter (LPF) with a cut-off frequency of 2.34 Hz [18].

To calculate the frequency of the filter we used the relation (2.1):

$$f_{c(LPF/HPF)} = \frac{1}{2\pi RC}(Hz) \tag{2.1}$$

Amplification of the block (amplifier filter) is calculated with the relation (2.2):

$$A_{uk} = 1 + \frac{R_{6,9}}{R_{5,8}}, k = \overline{1,2} \tag{2.2}$$

and the total amplification of the two blocks connected in series represents the product of the individual amplifications given by the relation (2.3):

$$A_u = \prod_{k=\overline{1..2}} A_{uk} \tag{2.3}$$

The total gain (Au) of the circuit is 10201 and the maximum value can be adjusted from the semiconductor resistor P1. The block 3 of the circuit uses an OA connected in a noninverting configuration used to adapt the impedance to the next acquisition circuit, in this case the microcontroller on the Arduino Uno development board. The impulse train of the obtained signal has a frequency proportional to the heart rate.

The mathematical relationship for calculating heart rate / beats per minute (BMP) is:

$$BMP = 60f \tag{2.4}$$

where f represents the frequency of impulses visualized by the oscilloscope [3], Fig. 2.3.

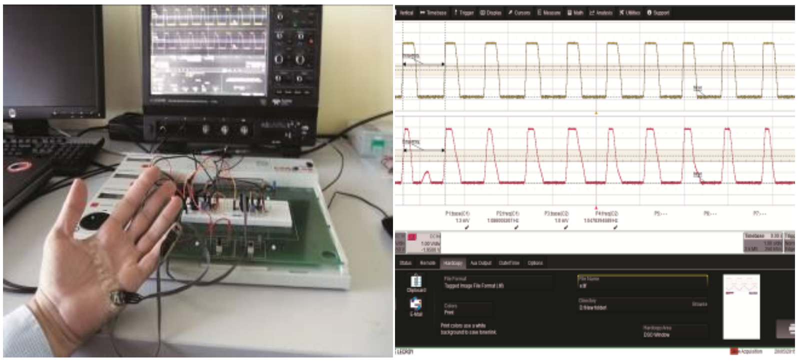


Figure 2.3. Pulse train obtained at the output of the measuring device of heart rate.

EKG with 3 electrodes

The heart is a muscle tissue that generates electrical potential (bio-potential) with each beating. Potentials measured at the body surface due to repolarization and depolarization of the heart tissue are called electrocardiograms (ECGs). The ECG is a process that monitors the electrical activity of the heart over a period of time, using electrodes attached to the skin to detect electrical variations. Biosensors, such as the ECG, measure very small electrical signals emitted by the human body (mV or even μV). This signal is also obstructed by muscle activity in the rest of the body.

When medical signals are acquired, useful information may be contaminated by factors such as interference caused by the instrumentation amplifier, the signal recording system, and the electromagnetic waves coming from nearby electronic devices. In this case, the noise from the grid (50 or 60 Hz) and its harmonics can also be added, the interference (50/60 Hz) can be considered as a high-frequency artefact if we take into account the spectrum of the ECG signal is a low-frequency one (up to 100 Hz). This requires the use of appropriately amplifying circuits and filters the electrical signal to obtain the desired output. The three electrodes are placed on the left arm (LA), the right arm (RA) and the left leg (LL). Generally, the LL electrode is not placed on the foot, but on the left side of the body (immediately below the heart), Fig. 2.4.

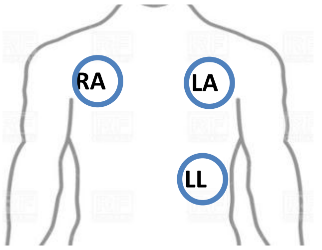


Figure 2.4. Positioning the electrodes on the patient's body.

The protective circuit is intended to protect the device from the intrusion of parasitic signals such as radio waves due to the electromagnetic field, and protecting the patient from possible overvoltages and overcurrents [19]. The LA electrode is connected to the DRL circuit in order to reduce common mode interference.

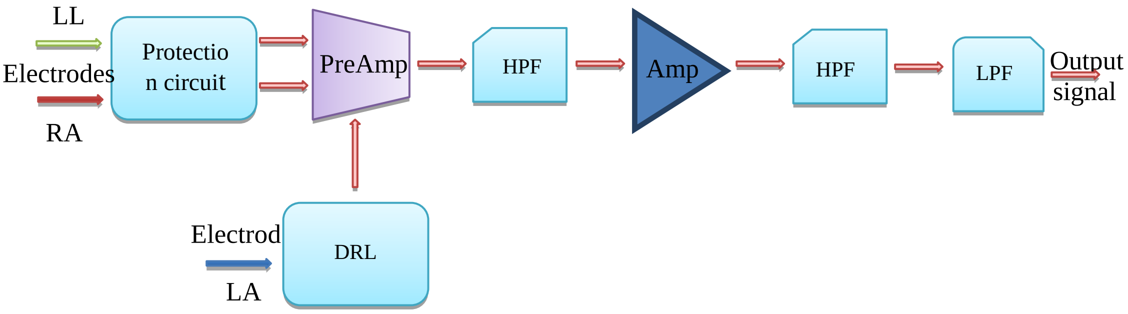


Figure 2.5. EKG device block diagram.

A typical ECG signal of a heart cycle consists of a P wave, a QRS complex, a T wave and a U wave which is normally invisible in 50-75% of the ECGs because it is hidden from the T waves and of the new waveform P following the baseline of the electrocardiogram (flat horizontal segments). The ECG signal consists of a series of cardiac cycles, basically a repetition of an EKG wave [20]. The duration between two consecutive waves (the RR interval) corresponds of heart rate (Fig. 2.6).

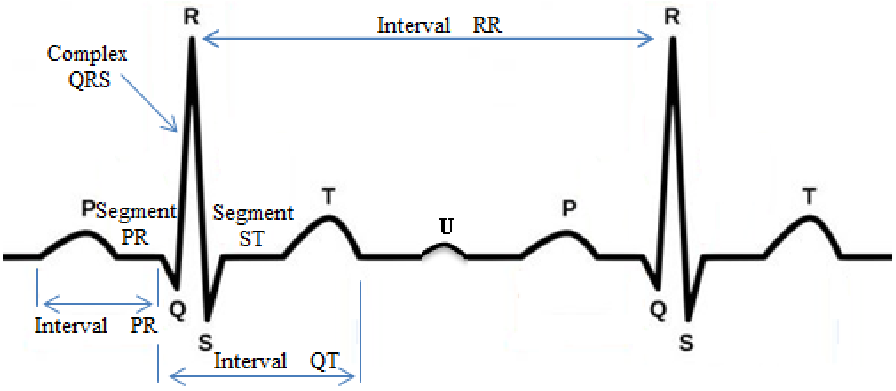


Figure 2.6. Form of a normal ECG signal.

3. SYSTEM OPERATION AND SIGNAL PROCESSING

The cardiac pacemaker output signal and the ECG signal are applied to the Arduino Uno development board microcontroller for processing and analysis to transmit the appropriate signals to the GPRS / GSM module. The system will send an alert signal in case of a pre-infarction or infarction, containing information related to pulse value and ECG. The ECG device uses three electrodes positioned on the patient's body via an adhesive tape. Due to the patient's movement or other factors such as sweating, they can detach or move from the fixed position. This phenomenon results in errors of measurement and implicit errors in the results obtained.

The ECG signal (Fig. 2.6) provides patient information on blood pressure and heart rate [21]. Upon the occurrence of a pre-infarct or infarction, the signal will undergo a change in the waveform to be sensed and interpreted by the processing device, and the system will send an alert signal. With respect to this aspect, in the event of an electrode being detached or moved, the shape of the ECG signal will undergo modifications that may trigger the alert system; in this case, it is a false alarm.

To distinguish between a real and a fake alarm signal, we also used a measuring device based on photoplethysmography to determine the heart rate. If the ECG signal is affected due to electrode failure/movement at the time of patient monitoring, the information about the ECG signal shape will be altered, the system detecting the alarm status. Instead, the signal from the heart rate measuring device (pulse) will be interpreted by the system and transmitted with the alarm signal. This signal will not be affected by poor electrode operation. The operator or physician interpreting the alarm message will notice the pulse at the time, making a distinction between a false alarm and a real alarm. The existence of the pulse will confirm that there are heart beats and that the patient's life is not in danger.

Processing the signal from the pulse measurement device

The impulse train signal (Fig. 3.1) obtained at the output of the heart rate measuring device by the photoplethysmography method is converted by the CAN of the microcontroller on the Arduino board to a numerical value and then transmitted with the alert signal. The microcontroller's CAN is capable of converting the 10-bit signal.

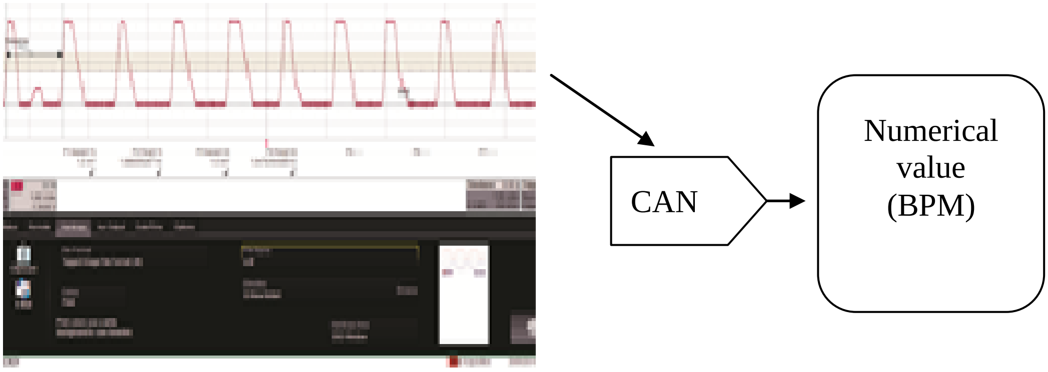


Figure 3.1. The shape of heart rate measurement signal, visualized with oscilloscope and converting it to numerical value.

EKG signal processing

The proposed system includes elements that give it functional qualities comparable to certified medical devices. The shape of the ECG signal for normal heart function is shown in Fig. 3.2. An analysis of the characteristics of the ECG signal is a novelty. Starting from the premise that a normal, healthy biomedical system presents a high complexity, and when anomalies occur complexity decreases, the features extracted from ECG signals contain valuable information about blood pressure. This signal has an analogue shape, requiring an analog-to-digital conversion for processing and analysis.

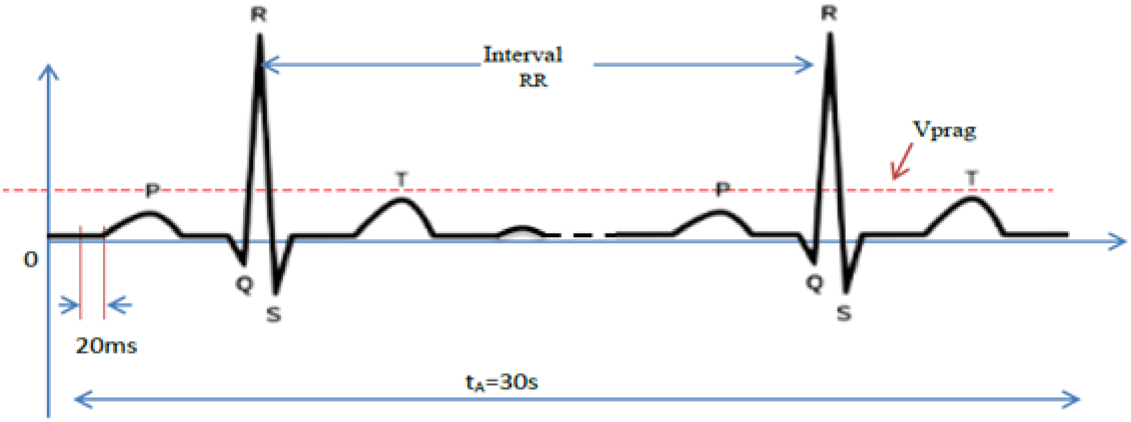


Figure 3.2. Processing of the ECG signal.

The ECG signal is analyzed over a period of 30 seconds in which we make readings of the amplitude of the signal at a range of 20ms. Samples obtained with values corresponding to a certain threshold (considered as a logical 1 level) are counted. In the case of an ECG signal corresponding to a normal heart function, we have set a sample interval of 1, ranging between a minimum threshold (pmin = 15) and a maximum threshold (pmax = 500) according to the relationship (3.1)

$$\mathrm{P}_{\max} = \mathrm{t}_{\mathrm{A}} 1000/20/3 \qquad (3.1)$$

This interval was established as a result of the analysis of a significant number of ECG signals. Normally using the threshold value (Vprag) set in the analysis of an ECG signal will result in more than 1/3 of the samples with the value 1.

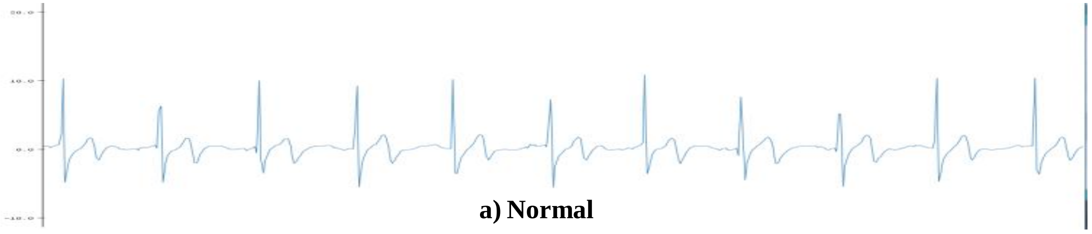
$$V_{prag} = A_{max}\mu \qquad (3.2)$$

where: Amax - represents the maximum amplitude read in the previous tA interval; µ - a coefficient characteristic of the individual EKG waveform of each patient.

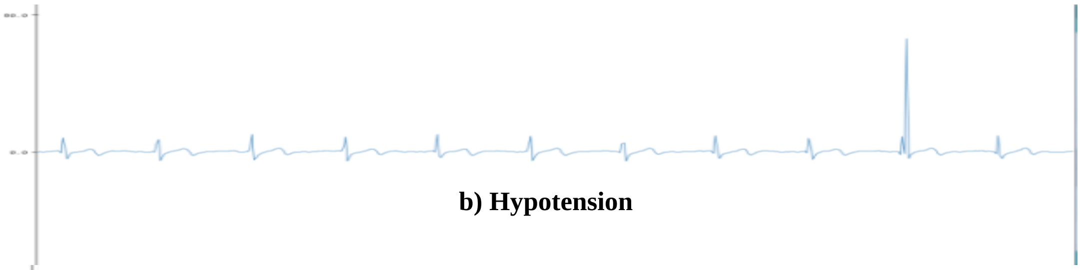
The coefficient (µ) is around the threshold of 0.6, depending on the magnitude of the ECG signal. For example, the shape of the EKG signal may vary from one patient to another, depending on each person’s health problems. The distribution of the characteristics changes according to the different classes of blood pressure. In this context, the measurements made on patients with heart problems, we found the following:

1. In the case of patients with normal heart rate and blood pressure, the shape of the ECG signal is as shown in Figure 3.3a;
2. For patients with cardiac problems (hypotension), the ECG signal is shown in Figure 3.3b;

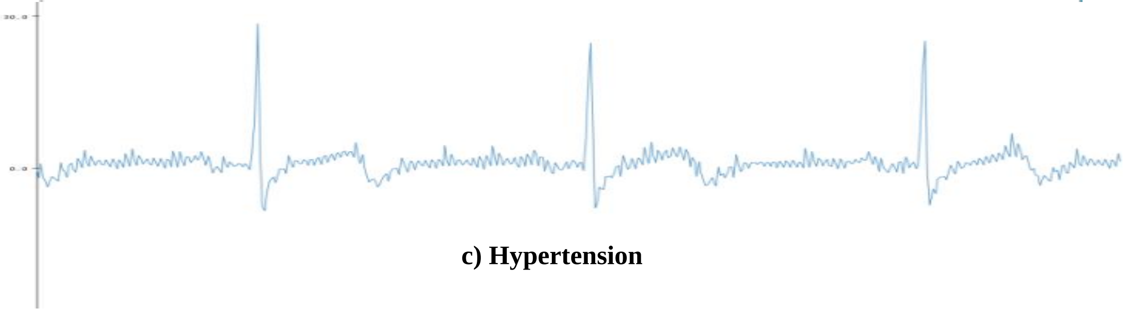
3. For patients with cardiac problems (hypertension), the ECG signal is shown in Figure 3.3c.



a) Normal



b) Hypotension



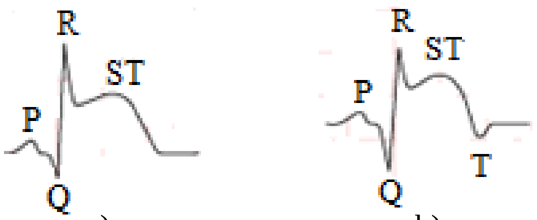
c) Hypertension

Figure 3.3. The form of the ECG signal for various cardiac problem.

These forms of the ECG signal were obtained with the proposed monitoring device and viewed through a PC. When cardiac problems such as a myocardial infarction or ischemia occur, the shape of the ECG signal implicitly shows the heart rate value, see Fig. 3.4.

In the case of a cardiac cycle, the R wave will decrease as amplitude, the Q wave will increase (in negative value), and the S-wave (ST segment) will withstand a strain in the sense of a positive increase in amplitude, as in Figure 3.4a.

ST overdrive can persist for a period of minutes, and later a T wave inversion may occur, as in Figure 3.4b [22]. This form of signal is analyzed and interpreted by the monitoring system.



a) b)

Figure 3.4. PQRST waveform: a) Myocardial infarction, b) Ischemia.

If the number of samples corresponding to the logic level 1 is in the range (15-500), the vital parameters are listed as having values within the normal range and the system will not transmit. If the number of samples with values of 1 is less than 15 or greater than 500 (relation 3.1), the Arduino board microcontroller will activate the GSM module to send the alert message. On the other hand, the system is capable of emitting a patient warning light signal at the time of transmission of the alert signal.

4. SYSTEM TRANSMISSION OF ALERT SIGNAL TO EMERGENCY MEDICAL CENTERS

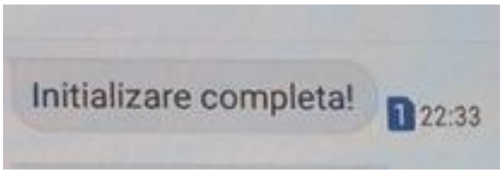
The data transmission system consists of a GPRS / GSM communicator provided with a small external antenna compatible with the mobile telephony systems and transmits an SOS signal through an SMS message containing patient identity data, heart rate value, and reference at arterial pressure. The SM5100B-D module is a two-band GSM / GPRS EGSM900 / DCS1800 module that supports the multi-slot GPRS class. Based on an advanced design scheme, the SM5100B-D integrates the RF baseband. Can perform all RF reception and transmission functions, broadband signal processing [23]. Working bands are specified in Table 4.1.

Table 4.1. Working frequency of GSM device.

Working Frequency	Reception	Transmission
EGSM900	925 MHz-960 MHz	880 MHz-915 MHz
DCS1800	1805 MHz-1880 MHz	1710 MHz-1785 MHz

The GSM module also contains 3 ADC interfaces that can be used to detect values of external parameters such as voltage, temperature, etc. Characteristic of this is that it has a low power consumption in the standby mode (tens of millions of times) and higher power consumption at the time of transmission. Also, the power consumption is different, depending on the working frequency, being smaller when operating in a higher frequency band. This is very important, given the source of supply of the proposed monitoring and transmission system.

The GSM module will transmit the SOS signal transmitted by the Arduino Uno board as a result of a command signal received from Arduino as well. When the monitoring system is put into operation, the GSM module will send a confirmation message informing the medical service (the doctor) that the patient is in the process of monitoring (Fig. 4.1).



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1 22:33

Figure 4.1. Monitoring system operation confirmation message.

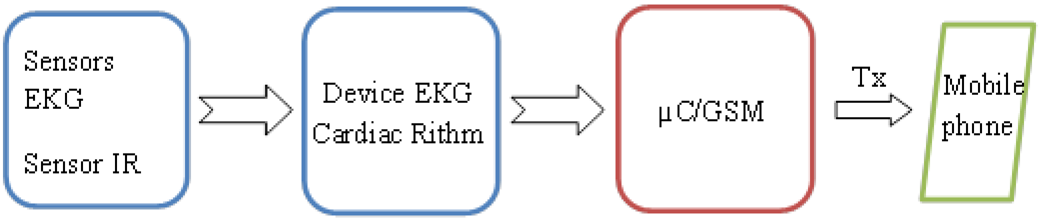
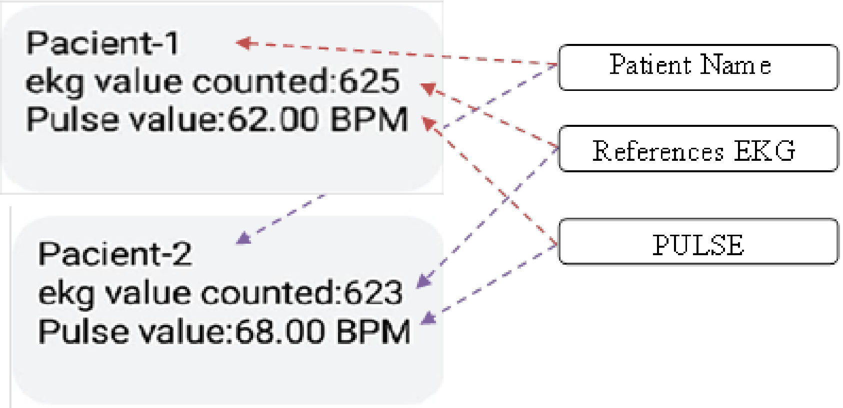


Figure 4.2. The vital parameters monitoring system (Pulse, EKG) and alert signal transmission.

Sending the alert message

The system performs permanent monitoring of the patient’s EKG and heart rate. The signal received from the sensors and processed by the corresponding devices is subjected to digital conversion and transmitted by the GSM module to the medical service.

When an abnormality occurs in the functioning of the heart, there are significant changes in the shape of the ECG signal, highlighted by the monitoring system, and as a result, the procedure of transmitting the SOS signal to a mobile telephone terminal is triggered. In the event of such a situation, the transmitted message contains the patient’s name and information about ECG and pulse. As an example, in Fig. 4.3, such a message is presented.



Pacient-1
ekg value counted:625
Pulse value:62.00 BPM

Pacient-2
ekg value counted:623
Pulse value:68.00 BPM

Figure 4.3. SOS messages sent by the GSM module to the mobile phone.

The SOS messages presented in Fig. 4.3 were transmitted following the simulation of patient’s cardiac problems. In the present case, we changed the position, releasing the electrodes from the body surface, thus changing the shape of the EKG signal.

The transmitted information reveals abnormalities in heart operation and on the other hand that the transmitted pulse value is within the normal range confirms that the SOS signal is false, due to abnormal sensor operation (EKG electrodes). The operator (the doctor) will contact the patient to remedy any technical problems.

Battery power consumption analysis during vital parameter monitoring and alert transmission

The power consumed by the battery during the process of monitoring the vital parameters and transmitting the alarm signal is variable depending on the operating state of the system at a certain time. In the first phase the system is in the monitoring state when it basically reads the heart rate values, the ECG signal and performs their analysis.

System current consumption varies between 140 and 160 milliamps, falling to an average consumption of 150 milliamps. In this case, the power absorbed by the battery is given by the relation (4.1), being 630 mW.

$$P = UI = 630 mW \tag{4.1}$$

At the moment of detecting dangerous values of the vital parameters, the system will activate the transmission system (GSM) of the alert message where the current consumption of the system will increase considerably to a value of about 300 milliamps.

The power absorbed from the battery according to the relation (4.1), in this situation, is 1260 mW, twice as high as in the monitoring state.

The transmission time of the message is very small in the order of tens of milliseconds so that the energy consumed by the system is not very high, which makes a LiPO battery capable of transmitting about 15 alerting signals during its use. The variation in power consumed by the monitoring and transmission system of the alert message is shown in Fig. 4.4.

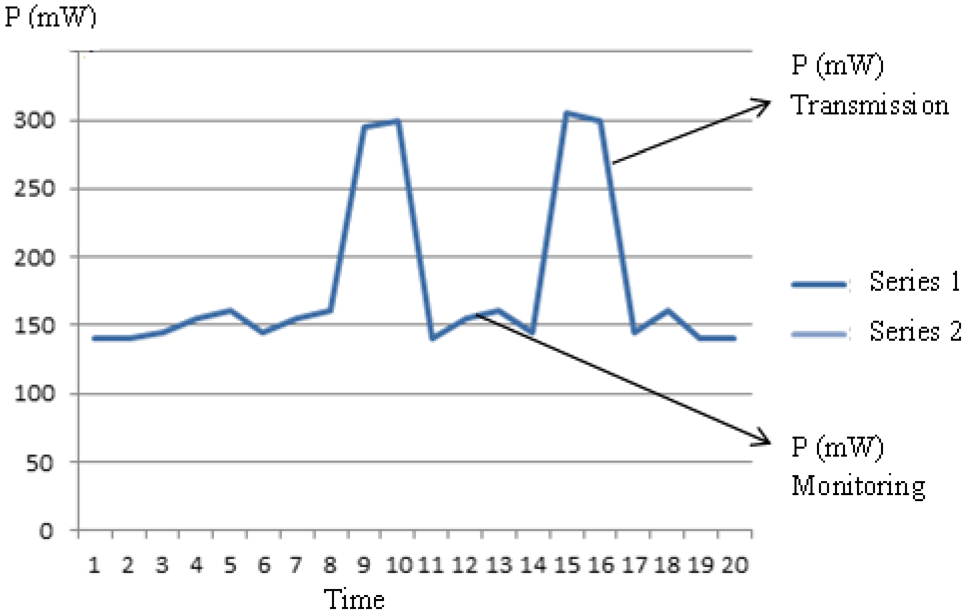


Figure 4.4. Variation of power consumed by the battery by the monitoring and transmission system of the alert message.

5. CONCLUSIONS

This work includes issues related to monitoring patients with heart problems and providing healthcare in a timely manner. The targeted patients are those without the possibility of having a companion, those immobilized in a trolley and those who are forced to move for various activities. In this context, it was envisaged to approach the latest generation of technical means (circuits, systems, technologies), methods and technologies for monitoring the vital functions of a person, in order to reduce as much as possible the deaths caused by the impossibility of granting the first aid due time.

In the context, a new method of processing the analogue signals corresponding to parameters (heart rate, arterial pressure) of cardiac activity is presented to become compatible with a GSM signal. We have also set up a data transmission system consisting of a GPRS / GSM communicator with a small external antenna compatible with mobile telephony systems and transmitting a warning signal (SMS) containing patient identity data, cardiac rhythm value and blood pressure references.

Consequently, after functional tests of the system, it can be successfully categorized as patient monitoring systems /devices and medical service alerts. Of note is the low cost of achieving this kind of monitoring system, vital parameters and warning compared to other systems in this category.

A feature of this type of system is the possibility of being improved by attaching sensors and other devices, making it a much more complex and more reliable system to provide medical services, much more data on the state of health patients, even its rapid location.

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