Pulse Oximeter Based Monitoring System for People at Risk

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Abstract—**This paper presents a microcontroller based health monitoring system intended to monitor and early detect situations when heart rate and blood oxygen level are out of their safe ranges, or presents uncommon fluctuations in time. The main objective of this project is to prevent emergency situations by informing the patient to take actions before his health condition get worse and needs emergency medical care. The patient can take his medicine or suspend current activity that caused system alerts, like going up the stairs or emotional affecting activities. Monitoring scene is at home, sometimes the patient feels no pain or other symptoms that indicate that he is in danger, when symptoms are present it is more difficult to treat the patient. We purpose a low cost mobile monitoring and alerting device, which communicate with a personal computer located in the range of a wireless or Bluetooth network and automatic analyze and record data into database for later review. In this paper we present hardware and software structure of the system, operation theory, implementing costs, power consumption and experimental results involving adult persons. We made three type of experiments: at first we monitored Pulse and Oxygen saturation level during sleep, then effort while going up the stairs, and in third experiment, we analyzed non regular heart beats.**

I. Introduction

In the hospital environment, patient monitoring frequently is made with expensive equipments, there are two categories of patients, some of them has to be monitored all the time, others health condition is not so severe, their health related values are measured just a couple of times daily. They need hospital care because is too difficult for them to go several times daily to the medical center for measurements. Ambulatory monitoring is the better solution for this category of patients, for this purpose, a non expensive, accurate and easy to use equipment is necessary. If the patient can be ambulatory monitored, maintaining the safety requirements and time scheduled measurements, treatment related costs are significantly reduced. Because professional equipment is too expensive and usually can be handled by the medical staff, just a limited number of patients can use them at home.

This project is intended to offer hardware and software solutions for ambulatory monitoring, we propose a low cost, easy to use and accurate monitoring solution. Common home use personal health monitoring devices are manually operated, after measurements, the patient saves the readings into his computer creating several files, and the results can be reviewed later. The easier solution is when the equipment automatically makes the

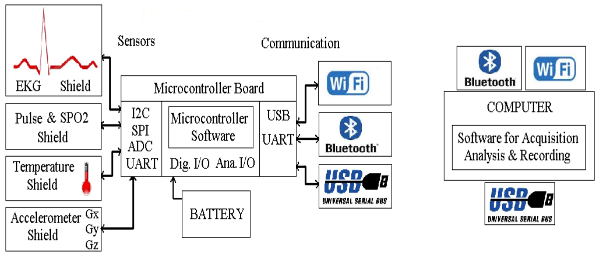

Figure 1. Monitoring systems block diagram

measurements, saves the results into the database and informs the patient if preprogrammed warning levels are close or reached. The concept of early goal-directed therapy emphasizes the need of early diagnosis and intervention to achieve better therapeutic outcomes [5]. This type of equipment is suitable for time scheduled measurements or for continuous monitoring at home or in the range of a wireless network.

Some benefits of the system:

-early prevention of potential severe health issues, instead of emergency treatment, the patient is early warned to take actions to maintain his health condition stable by taking his medicine or suspending effort involving activity;

-reduced number of calls to emergency services;

-additional evaluation tool for non regular heartbeats;

-remote access to personal health record for patient authorized users.

Heart rate and blood oxygen level monitoring is a part of our ambulatory health monitoring project, due to systems modular architecture, several other sensors can be connected as input. Depends on patients monitoring needs, one or more sensors can be connected to the micro-controller board at the same time, data can be sent by USB, Wireless, or Bluetooth. To extend monitoring range, we intend in the future to transfer data using mobile phone. Pulse oximeter function described in this paper is intended for patients with sleep apnea and not so severe heart problems, for more detailed heart monitoring we can use the EKG (Electro Cardio Gram) module. Fig. 1 presents the block diagram of the monitoring system. Microcontroller collects data using sensor shields, and exchange data using communication shields, while embedded software coordinates the operations and generates alerts. After data is sent to the computer, it is recorded and analyzed using monitoring software.

Due to its modular architecture, the mobile device can be easy configured according to the monitoring needs and available communication devices. Bluetooth, wireless Ethernet and USB connection modules are non expensive common data transfer tools and are part of almost all modern notebooks and personal computers.

II. Pulse Oximeter Theory

Pulse Oximeter is a non-invasive device for measuring the percentage of arterial blood that is saturated with oxygen. This device can also measure heart rate [11].

Blood red cells contain a protein called hemoglobin. When oxygen reacts with this protein, it gets attached to it and generates Oxy-hemoglobin (HbO2). Red cells with oxygenated hemoglobin circulate in the blood through the whole body, irrigating tissues. When blood gets in contact with a cell, the red cell's hemoglobin releases oxygen and becomes De-oxy-hemoglobin (Hb) [10]. Fig. 2 presents the blood circulation process through the body [10].

The principle of operation of a Pulse Oximeter is based on measuring the absorption of red and infrared light that

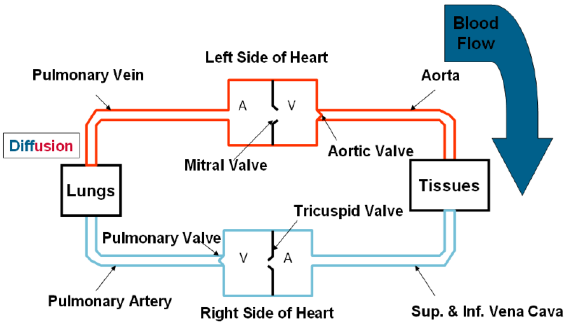

Figure 2. Blood circulation diagram [10]

passes through a patient's finger or ear lobe by utilizing light sensors. Hemoglobin that transports oxygen (oxy-hemoglobin) absorbs infrared wavelength (800-940 nm) of light and hemoglobin that does not transport oxygen (de-oxy-hemoglobin), absorbs visible RED wavelength (600-700 nm) of light [11]. Backgrounds such as fluid, tissue and bone are factored out of the measurement by monitoring the steady state of absorption from bone, tissue, venous blood and arterial blood [11]. LEDs are used as the light source and are sequentially pulsed at a fast rate. During a heartbeat, blood volume increases and this AC component of the photo-detector's current is used to calculate the absorption of oxy- and de-oxy-hemoglobin, Fig. 3 [11].

The Pulse Oximeter performs mathematical calculations based on the Beer-Lambert Law to determine the percentage of blood that is saturated with oxygen [11].

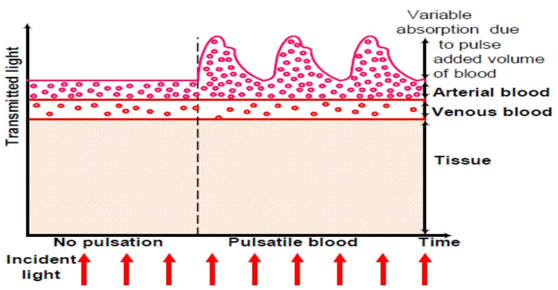

Figure 3. Light Passing Through the Substances of a Finger [11]

Heart rate is determined by calculating the number of volume pulsations per minute, because heart rate is not constant in time, average results are obtained. The optical method to measure the changes in volume during heart beats is called photoplethysmography (PPG). Authors in [3] associate the falling slope characteristics of the PPG to diabetic problems, but can indicate also anemia [9] or non regular heart contractions. Ref. [4] is about contour analysis of the plethysmographic pulse, one of the most important factors affecting PPG waveform is the contact pressure between tissue and PPG probe [6] or fast movements.

III. Hardware Parts

For pulse and blood oxygen level monitoring, we used the following hardware components: microcontroller board based on ATmega 2560 CPU, CMS50D pulse-oximeter, RN-171 WiFly shield, bidirectional 5V to 3V logic level converter, RN-41 Bluetooth shield, DI-524 Wireless router and Notebook computer. According to the distance between microcontroller board and computer, we can use either Bluetooth (20m) or WiFi (100m) shields, the software running on the computer is configured for both communication protocols, hardware parts are shown on Fig. 4.

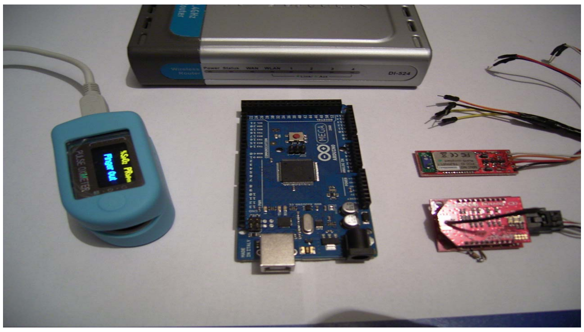

Figure 4. Hardware used for Pulse and Oxygen monitoring

CMS50D Pulse-oximeter works on batteries and supports USB communication with a computer, due to CP210x Single-Chip USB to UART-bridge integrated in the USB cable. To connect it to the microcontroller board, we used UART communication and logic level converter.

Microcontroller board is based on ATmega 2560 CPU, with four serial UART, SPI and I2C interfaces and it operates at 5 Volts [12]. It can be used with both, analog and digital sensors, for data acquisition, digital sensors are connected to direct hardware pins, analog sensors are connected through signal conditioning shield. Signal conditioning section is placed between electrodes and microcontroller where the input signal is amplified and filtered for proper acquisition [8].

IV. Software Parts

In order to implement the monitoring of pulse and blood oxygen saturation functions, we have developed three software modules: serial communication driver for the pulse-oximeter, software for the microcontroller and monitoring software running on the computer.

Pulse-oximeter is factory calibrated, accurate, and was delivered with USB driver and SpO2 monitoring software. To make it work in our monitoring project, we have analyzed the serial communication protocol using Free

Serial Port Monitor and developed our driver software. In order to communicate with the pulse-oximeter, the driver software is based on the following protocol settings: 19200 Baud Rate, 8 Data Bits, Odd Parity and 1 Stop Bit. Data sent by the pulse-oximeter in live monitoring mode consists in a five Byte continuous stream, containing data and control information.

Byte 0 – Control bits and flags for events (Finger Out);

Byte 1 – Detailed PPG data bits;

Byte 2 – Status Flags and reduced PPG waveform;

Byte 3 – Heart Rate calculated value;

Byte 4 – Oxygen saturation calculated value;

The second software module is running on the microcontroller, it was developed using Arduino development tool and operates according to the following simplified algorithm:

```
Initialization serial port 1 for Pulse-oximeter
Initialization serial port 2 for Wireless or Bluetooth
Pulse and SpO2 warning levels setting
while (1)
    Read pulse-oximeter status
    if (finger out = 0) then
        Read serial 1 data and write it to serial 2
        Test Byte 3 and Byte 4 with warning levels
    end if
    if (warning) then Beep and LED flash
end while
```

We have previously configured the Bluetooth and wireless modules, using AT commands, in order to automatically connect to the computer on power on. The RN-171 shield, DI-524 Router and wireless card from the computer supports wireless communication, based on Ethernet TCP/IP protocol.

Monitoring software running on the computer is developed using Lab Windows CVI programming environment, we implemented the following functions:

-live monitoring Heart Rate and Oxygen saturation, and plotting the calculated values on individual Strip-charts;

-live monitoring of the PPG signal waveform;

-live extracting the heart beat moments and presenting on the graph;

-live analyzing the PPG signal to extract additional heart beats, counting and presenting on the graph;

-record data into the database and review option.

In the ECG (Electro Cardio Gram), the highest value in voltage is the R point, the top of the QRS complex, representing ventricular activation, corresponding point in PPG is the maximum point Max 0, according to Fig. 5. In the literature, in order to extract the R moments from ECG or PPG, referenced authors are using Fast Fourier transforms [7], Butterworth band-pass filter and additional filters from Matlab [1], or compare the peaks to predefined maximum amplitude thresholds [2].

Fig. 5 presents the typical shape of the PPG pulse, with an additional rising section where Max 0, Max 1 and Min 0, Min 1 are the maximum and minimum values of the waveform, *d* represents amplitude of a maximum relative to the previous minimum.

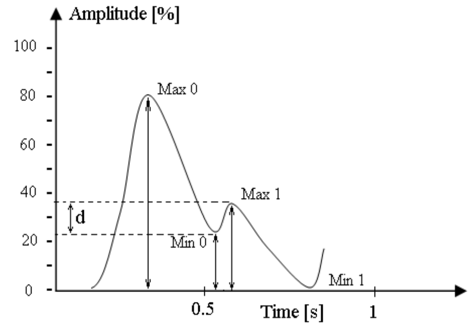

Figure 5. PPG waveform

Computer software developed in Lab Windows CVI runs three independent threads, first for data acquisition, second for plotting pulse and oxygen values on Strip-charts in time, and third for analyze the PPG waveform and display the results. Heart beats and additional beats on the falling side (right) of each pulse are detected using the following simplified procedure:

1: On start, the first PPG points are compared to get the line direction.

2: If line is falling, wait until the line is rising to obtain as first inflection point the first maximum.

3: From this moment, every new PPG point received from the pulse-oximeter is compared to the previous received point in order to detect next inflection points.

4: Detected inflection points are saved in an array in their time order:

A[100] = {Max0, Min0, Max1, Min1, … }, A[0]={Max0}

5: d = A [2n] – A [2n-1], n>0, amplitude of every maximum inflection point relative to the previous minimum.

e.g.: d = Max1 - Min0 (Fig.5.)

6: Classification, based on d criteria and predefined minimum and maximum amplitude ranges for basic and additional beats.

7: If almost every basic heartbeat is followed by a smaller contraction, then smaller contractions are not considered extra beats, in this case T wave is much intensive, where T wave represents ventricular repolarization (from ECG).

Fig. 6 presents the monitoring software running on the computer, SpO2 and Pulse values are represented on the first and second Strip-charts. PPG waveform and heartbeats are represented on the third and forth Strip-charts, while extra beats are countered.

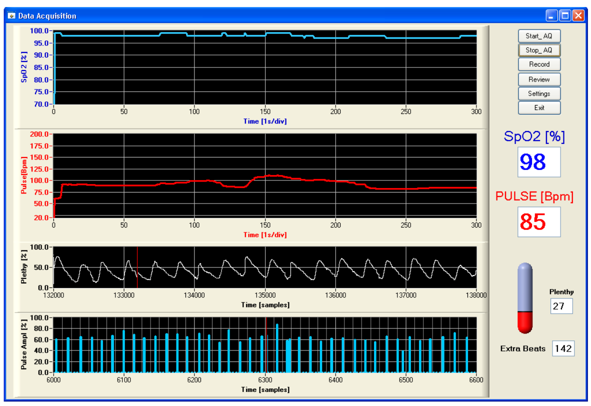

Figure 6. Monitoring software running on the computer

V. Experiments And Results

In order to test the proper operation of the proposed monitoring system, we made experiments involving adult persons, and results are presented in the following section.

First experiment is about heart rate and oxygen saturation monitoring during sleep, 35 year old man with known minor heart problem was monitored. Evolution of the heart rate in this case (Fig. 7) indicates restless sleep because at that time he was cold, breathed with difficulty and awaked several times. Monitoring time interval presented in Fig. 7 corresponds to 2 hours and 26 minutes. Oxygen saturation is less than his normal values, in the [1800 - 3500] seconds interval, saturation dropped under 95%. Oxygen saturation values can be compared to his regular measured values, Fig. 6 presents his regular readings during 5 minute test, where oxygen saturation is [97-99] % and heart rate is more stable. One short alert is present on the graph, where heart rate value is more than 100 Bpm limit.

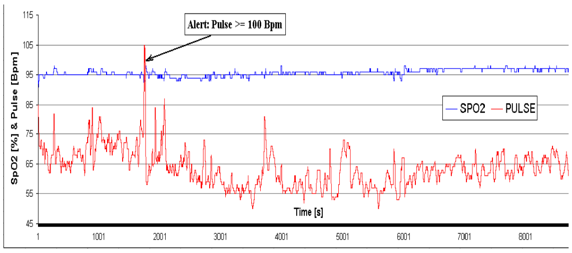

Figure 7. Heart rate and Oxygen monitoring during sleep

Second experiment is about mobile monitoring and alerting, tests are made while going up the stairs to the 10Th floor. Two persons have been monitored, 33 years old women, results on (Fig. 8) and 35 years old man, results on (Fig. 9), heart rate alert was set at 120 Bpm and oxygen saturation alert to 90 %.

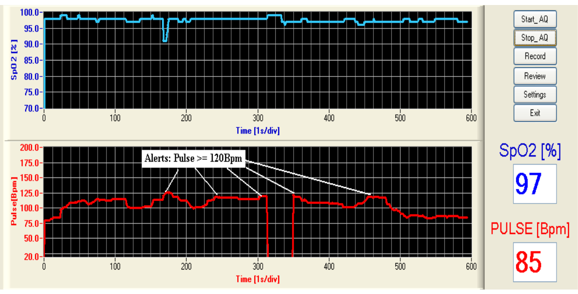

Figure 8. Effort monitoring - Test 1

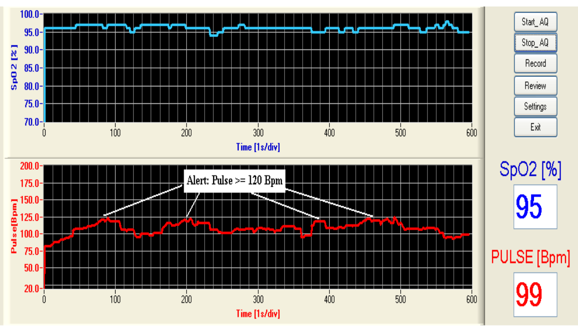

Figure 9. Effort monitoring – Test 2

Table I and Table II presents the events during Test 1 and Test 2.

TABLE I
EVENTS ACCORDING TO TEST 1

	Events description	Time interval [s]
Fig.8	Going up the stairs taking short brakes	[0 – 460]
	Resting at destination	[461- 590]
	Pulse Alert generated	170, 245, 310, 350, 462
	Oxygen alert generated	-
	Pulse calculating error due artifacts	[318-351]

TABLE II
EVENTS ACCORDING TO TEST 2

	Events description	Time interval [s]
Fig.9	Going up the stairs taking short brakes	[0 – 495]
	Resting at destination	[496- 594]
	Pulse Alert generated	81, 198, 382, 455
	Oxygen Alert generated	-
	Pulse calculating error due artifacts	-

The third presented experiment is about analyzing the PPG waveform, in order to extract the heartbeat moments and additional smaller beats. PPG data received from the pulse-oximeter is not a fixed frequency data stream, it varies according to the heart rate instant value. Every PPG pulse is represented by a rising and a falling section of the waveform, we observed that falling section often presents smaller additional artifacts representing additional heart-contractions. The literature describe this artifacts as normal if they are present on each pulse wave , else they are considered extra heart beats produced due to additional heart muscle activity. Specific heart problems, too much caffeine or exercise are the most common causes of the non regular heart beats.

We present two recordings about extracted heart beats and additional smaller beats, Fig. 10 represents data of the 33 year old women and Fig. 11 data of the 35 year old man.

Each graph display data using sweep scroll mode, the actual moment of plotting is marked by the thin vertical red line, to explain the graph we marked the last plotted pulse with "0" label. Earlier pulses relative to "0" pulse are marked with negative labels: -1,-2,-3,-10,-20 and data to the right of the red line represents data from the previous scan period and is deleted by the new plotting when sweep line moves to the right. On Fig. 10 we have no additional beat marked, but during the 5 minute test we found 3 additional beats and the shape of the PPG is normal, is not changing significantly over time.

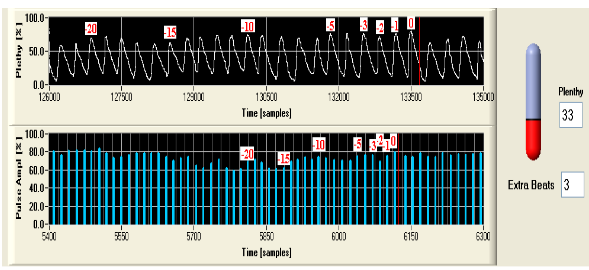

Figure 10. PPG without extra beats

On Fig. 11 we present monitoring results of the 35 year old man, during 2 minutes and 8 seconds. We have stopped the monitoring because it is evident that he presents several non regular beats, counter value was

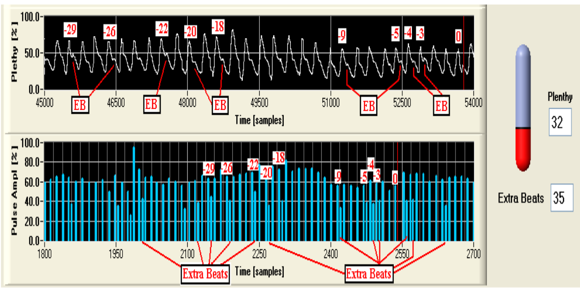

Figure 11. PPG with additional beats

already at 35. In this case PPG wave is more unstable, presents smaller and higher amplitude sections compared to Fig. 10. Each labeled heartbeat presents on the falling section of the PPG pulse an additional smaller rising section followed by a falling section. Detection sensibility can be adjusted from the monitoring software by setting the minimum relevant rising amplitude of the waveform. PPG graph plotting amplitude range is [0 - 100], for the presented experiments we have set minimum sensibility to 5 points.

VI. Costs And Current Consumption

Evaluation from costs and current consumption points of view of any custom built mobile device is useful if is intended to run on batteries for several hours or if similar devices are required. This information is presented in Table III.

TABLE III
Implementing Costs And Current Consumption

Device	Costs (Euro)	Current [mA]
Microcontroller board	37,86	35
CMS50D Pulse-oximeter	34,23	25
Bluetooth shield	19,25	30
Wireless shield	27	40
5v-3v logic level converter	5	0.1

With Bluetooth shield, mobile unit cost is ~ 96 Euro and current consumption is ~ 90 mA in active mode.

Using Wireless shield, mobile unit cost is ~ 104 Euro and current consumption is ~ 100 mA in active mode.

VII. Conclusions

Heart rate and blood oxygen monitoring functions are implemented and tested, the microcontroller software alerts the patient if predefined warning levels are reached. Computer software presents the measured data in time on Strip-charts, records the heart rate and oxygen saturation values and detects additional heart contractions by analyzing the PPG waveform. Monitoring range depends on the selected communication method, Bluetooth for short range (20 m), and wireless within 100 m. The CMS50D pulse-oximeter is small in size, lightweight, accurate, low cost and it has very low power consumption. At rest or during slow and normal walking conditions it is reliable and very useful, but in higher velocity motions like running or fast movements, it is affected by artifacts and data transfer to the computer is delayed or even interrupted, event presented in Fig. 8.

VIII. Future Dirrections

In future work we intend to extend the monitoring range and add mobile phone connectivity and internet based data transfer. On the phone we run a software to create a Bluetooth to internet bridge, in order to send data to a high performance Cloud computing based server. Microcontroller board will be replaced with smaller size and low voltage version CPU to improve portability.

Acknowledgment

This paper is supported by the Sectoral Operational Programme Human Resources Development (SOP HRD), financed from the European Social Fund and by the Romanian Government under the project number POSDRU/107/1.5/S/76945.

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