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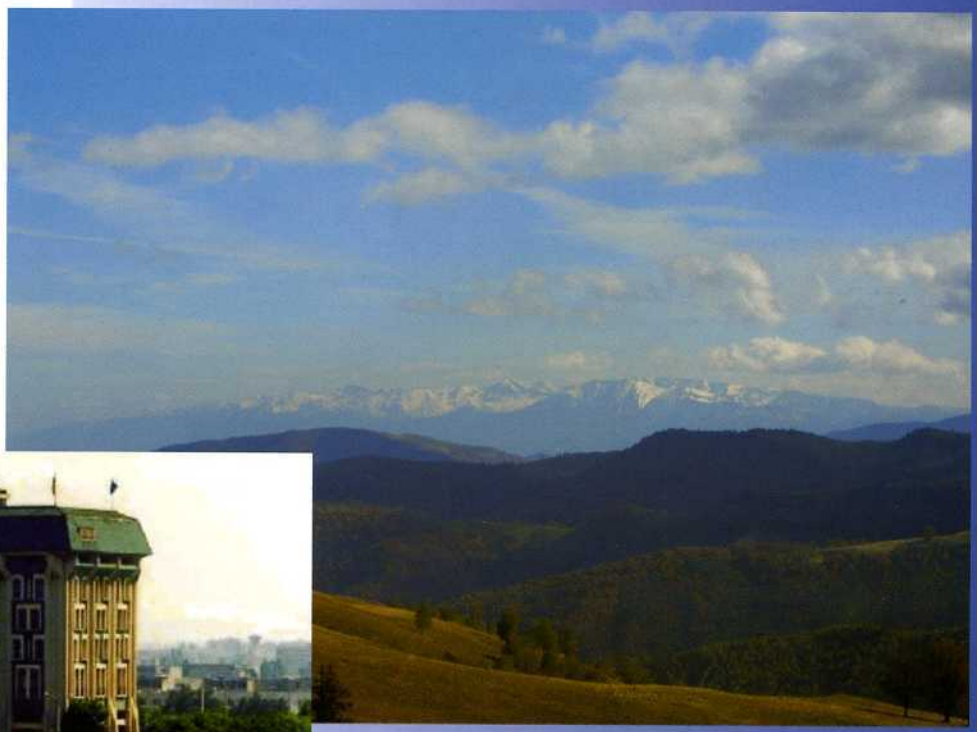

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Pulse Oximetry, a Method of Monitoring Heart Disease Patients

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Abstract

Pulse oximetry is defined as a noninvasive method of monitoring the blood's oxygen saturation. The implemented system combines two methods: spectrophotometry, which measures the concentration of hemoglobin and optic plethysmography that measures the pulsatile changes in the volume of arterial blood. The biophysical signal is captured at a body segment (index finger or ear lobe) by using a LED-photodiode pair. We used LED's with different wavelengths because of the different absorption coefficients of the component elements of hemoglobin: oxyhemoglobin and reduced hemoglobin. LED's functionality is time multiplexed, the impulse period is 50 µs and the frequency is 1kHz, much higher than heart frequency. All this elements contributed to create a real time acquisition system. The acquired signal, synchronous with the sisto-diastolic cardiac cycle, was processed over conversion, amplification and filtering stages resulting in the necessary signal to be used in the software analysis. Optimizing and calibrating the system involved direct comparative tests with commercial and hospital used pulse oximeters. Therefore we realized a reduced dimension system (at a mobile phone dimension), which allows the patient the possibility of permanently wearing the device (portability) and has the role of monitoring and transmitting the bio-physical signal to a data concentrator and afterwards to the hospital server. The final product has a large public use range, offering a comfortable, portable and mobile monitoring system.

1. Introduction

The advance of current technologies and the new challenges demanded by current medicine have led to the necessity of researching new ways of patient monitoring, particularly *remote and mobile monitoring systems*. We propose a system which combines portability with the need for small dimensions and low consumption, also assuring a high degree of adaptability and user friendly interfaces.

The challenge of our research was to provide a *remote monitoring system*, capable to acquire several vital signals such as ECG, blood oxygenation, glucose level and blood pressure. To obtain an adequate result, there appeared a need for introducing a 3D accelerometer which had the purpose of determining the patient's state (while resting, moving or sleeping). The system incorporating the above acquired signals must provide an efficient processing and interpretation, while minimizing errors.

Our system is structured on four levels of processing the acquired bio-physical signal accordingly with the image in figure 1 [1]. Signals transmission between each level is done via wire or wireless.

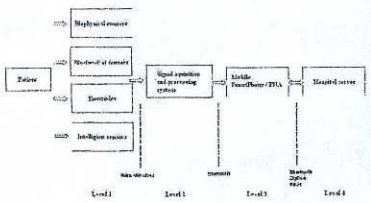

Fig. 1 Level structured system.

At ***level 1*** all the biophysical signals are acquired by a series of sensors. This is the level where the 3D accelerometer information about patient movement state, is acquired too. **Level 2** role is to pre-process, intercorrelate signals and to reduce or eliminate movement artifacts and signal interferences. **Level 3** uses SmartPhones or Personal Digital Assistants (PDAs) for displaying results, messages and very

important, based on trend analysis and pattern recognition techniques it will alarm the patient and the hospital server about severe health dropdown situations. Hospital server or **level 4**, allows the physician that monitors the patient to evaluate his health condition and to act accordingly. The link between level 3 and 4 is bi-directional to allow a proper communication between patient and physician.

Paper outline. Section 2 introduces the main ideas and principles regarding pulse oximetry. Section 3 presents the development of the prototype and the steps flow of the bio-physical signal from detection to filtering and amplification. Section 4 presents the results of the first experiment developed on the oximeter's prototype. Section 5 will take the first preliminary conclusions related to the whole work of the project.

2. Principles of Pulse Oximetry

One of the main components of the system is the pulse oximeter subsystem, which has the role of providing the blood's oxygen saturation. To determine the oxygen saturation, the device combines two methods: spectrophotometry (measuring the concentration from hemoglobin) and optic plethysmography (measuring the pulsation changes in the volume of arterial blood).

For better understanding of the functionality principles of the oximeter we will detail below the laws and methods used to accurately determine the SpO_2.

2.1. Blood

Adult blood contains four types of hemoglobin: oxyhemoglobin (O_2Hb), reduced hemoglobin (Hb), methemoglobin (MetHb) and carboxyhemoglobin (COHb). MetHb and COHb have a small concentration amount present inside blood, except for pathologic cases. Therefore, only the first two types of hemoglobin were measured.[2]

2.2. Blood Circulatory System

Three elements present a particular importance for our system:

1. arterial blood saturated with 87- 97 % oxygen
2. capillaries, tissues, where the amount of oxygen is discharged
3. venous blood which has a reduced amount of oxygen at about 75 %.

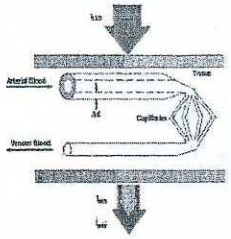

Fig. 2 Circulatory system [3].

2.3. Light Absorption

Light absorption (A) depends on a few elements and has a different value at different wavelengths. It also has a direct implication in **Beer-Lambert's** law [2]:

$$I_{out} = I_{in} - A \quad (1)$$

$$A = D \cdot C \cdot E \quad (2)$$

The dependency is given by three coefficients:

1. distance (D) or path length of the transmitted light
2. concentration (C) of hemoglobin, in tissue elements, where the amount of oxygen is discharged
3. extinction (E) coefficient of hemoglobin

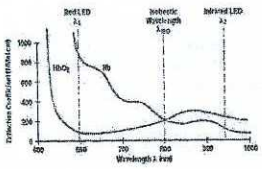

Fig. 3 Extinction coefficient at different wavelengths[3].

Blood cells change color, when hemoglobin absorbs different quantities of light, depending on its oxygen saturation.

Hb offers a maximum light absorption for red light (660 nm) and HbO2 for near infrared light (940 nm).

2.4. Pulsatile and non-Pulsatile Components of the Absorbed Light

Light absorbed by the tissues has two components: a non-pulsatile component (DC) given by non-pulsatile arterial blood, venous blood and tissue and a pulsatile (AC) component due to the pulsing blood in

arteries. Both these components present interest in computing oxygen saturation (SpO_2) value.

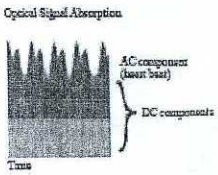

Fig. 4 The two components of the absorbed light[4].

2.5. Ratio, Oxygen Saturation

Ratio is defined as:

$$R = \frac{\frac{AC\ (660\ nm)}{DC\ (660\ nm)}}{\frac{AC\ (940\ nm)}{DC\ (940\ nm)}} \Leftrightarrow R = \frac{\ln\left(\frac{I_{out}\ (660\ nm)}{I_{in}\ (660\ nm)}\right)}{\ln\left(\frac{I_{out}\ (940\ nm)}{I_{in}\ (940\ nm)}\right)} \quad (3)$$

Oxygen saturation in pulse oximetry is defined as:

$$SpO_2 = \frac{O_2Hb}{O_2Hb + Hb} \cdot 100\% \quad (4)$$

The result equation given by equations (3) and (4) is[3]:

$$SpO_2 = \frac{R \cdot E(Hb,940nm) - E(Hb,660nm)}{R(E(Hb,940nm) - E(Hb,940nm)) + E(HbO_2,660nm) + E(Hb,660nm)} \quad (5)$$

3. Development of the Prototype

In this section we will explain how we applied the principles explained in section 2, onto a hardware device and the role of all the main component blocks and circuits that formed the pulse oximeter system.

Detecting the bio-physical signal is made *non-invasively* because we used, as an acquisition sensor, a commercial probe with two Light Emitting Diodes (LEDs) and a photodiode, elements that do no harm to the human body.

Bio-physical signal is acquired at human body segment level, such as finger tip, ear lobe or forehead by using the pair LED-photodiode (optical principle). The probe uses two LEDs that have different wavelengths 660 nm (red) and 940 nm (infrared), given by O_2Hb and Hb different light absorption coefficients. Dependently of the patient body weight and clinical characteristics there are a few sensor types that can be used [5]:

1. *Adhesive sensors* present the advantage of high accuracy, eliminates the risk of cross-contamination from patient to patient (as in the reusable sensor case) and offer the possibility of long period monitoring.
2. *Non-adhesive sensors* are used on skin trauma or fragile skin (neonates, burn injuries) patients, weak cardiac pulse or darkly pigmented skin patients.
3. *Reusable sensors* are appropriate for monitoring relatively immobile patients, on short or medium periods of time.

Functionality of the LEDs is alternate, the period of time when the LED is ON is about 50 µs and the frequency is approximately 1 kHz (few orders higher then the cardiac frequency). All this elements contributed to *real-time acquisition* characteristics of the system.

Driving current through the LEDs, controlling ON/OFF state and the light intensity of the LEDs was problematic issue of the system, because all the data found used a parallel led driver way of doing the above mentioned operations [6][7]. Forced by the way that LEDs and photodiode were designed in the probe we developed an anti-parallel schematic to drive the two LEDs as shown in figure 5.

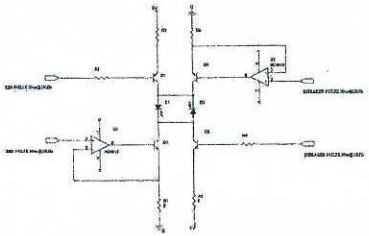

Fig. 5 Anti-parallel LEDs driver.

After the acquisition stage, the bio-physical signal was converted into voltage and amplified in a transadmitance amplifier stage[8]. The next step involved demultiplexing and splitting the signal into three channels: red, infrared and dark. Each of the red and infrared signals passed through filtering stages. Two types of filters were used: low pass filter and band pass filter [9]. The low pass filter allows only frequencies below 0.1Hz to pass thorough, corresponding to the DC component of the signal. This component is used in the feedback loop that controls the LED's light intensity and in calculating ratio and SpO_2 values. The band pass filter with pass band of 0.6-2.1Hz permits only the AC component to pass. Designing the pass band was made under medical advice:

- Adult, healthy person: 60-100BPM
- Adult, during sleep: 40BPM

- Athlete, under physical effort: 150-200BPM
- Athlete, at rest: 40-60BPM
- Neonate, children: medium 110BPM

The AC component of the signal was further more amplified and used to determine cardiac pulse and SpO_2 value.

Another important issue of the system was the *feedback loop*. Its role was to keep the DC level constant regardless of the thickness of the finger. Ideally, when a thick finger is placed between the LEDs and the photodiode, the light intensity must be brighter and with a thin finger the light intensity has to be dimmer.

The references used for implementing this calibration circuit present systems implemented with Automatic Gain Controll (AGC) or Programable Gain Amplifier (PGA) circuits[6][7].

We developed a feedback loop circuit implemented with a AVR8 (ATMega128) and a Digital to Analog Convertor (DAC) that controlls LEDs light intensity.

4. Results and Future Developments of the System

This section presents testing aspects of system's prototype, from theoretical to real testing. We will present a few ideas of improving this prototype, too.

The pulse oximeter system prototype is shown in figure 6.

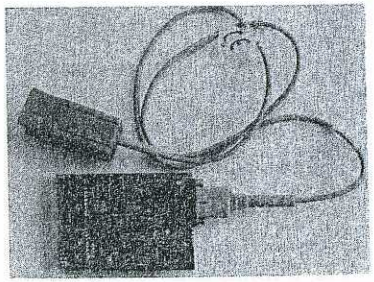

Fig. 6 Pulse oximeter prototype.
As you can see it has two main components: the probe and the circuit board.

Theoretical AC component of the bio-physical signal, simulated in both cases: ideal (figure 7 A) and after being processed through all the system stages (figure 7 B).

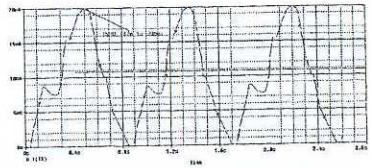

Fig. 7 A Ideal AC component.

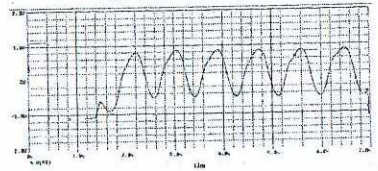

Fig. 7 B Processed AC component.
Y axis represents Amperage in A case and Voltage in B case and X axis represents Time in both cases. The pulse frequency is about 1.2 Hz.

Real AC component obtained on the oscilloscope is shown in figure 8.

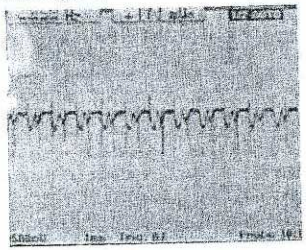

Fig. 8 Real AC component.
Y axis represents Voltage and X axis represents Time.

Peak-to-peak Voltage amplitude is about 170mV. Two aspects got our attention:

- peak-to-peak Voltage amplitude differs from the simulated one by an order of magnitude
- we also observed that the signal was saturated in a repetitive mode

Signal's shape was also distorted from ideally signal presented in figure 7A. A main cause of this situation is that the LED's light intensity was too high, and the signal detected by the photodiode was higher than the one we expected. For auto adapt LED's light intensity on each individual patient we propose an auto-

calibrate circuit. Auto-calibrating system's diagram is shown in figure 9.

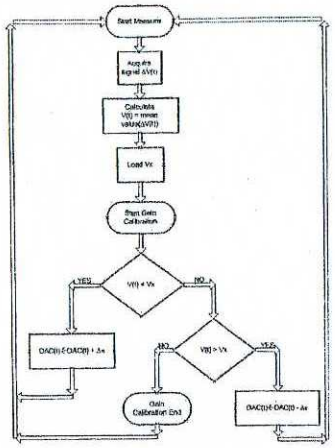

Fig. 9 Auto-calibration diagram.

In the diagram presented in figure 9, $\Delta V(t)$ is the signal acquired at a t moment of time, V(t) is the mean value of the signal, Vx is a fixed mean value or the reference value, DAC(t) is DAC's output signal that controls LED's light intensity and Δn is a fixed increment/decrement value. All this elements form an auto-adaptive feedback loop, for calibrating the system on each particular individual's index finger independently of it's thickness.

The next step will involve more tests, minimizing noise, testing and implementing the auto-calibrate loop, obtaining a proper and accurate signal and digitalizing the signal for future use.

An important factor for a portable-mobile system is its energy consumption and energetic management. We evaluate a current consumption of 35 mA which is a little too much for a portable unit. Two ideas that will be applied on the future developments of the system are: power management and implementing digital filters to replace the analog ones implemented in the prototype. We expect a half cutoff of the amount of energy consumption from this moment, only by implementing digital filters.

The power management will include a few phases that we are working on now: a *standby phase* which will maintain only de microcontroller and few elements active and a *recording phase* at a fixed period of time for lower power consumption.

5. Concluding Remarks

This paper presented the steps for implementing a pulse oximeter system included into a much complex portable monitoring system, from idea to prototype.

In this stage we focused on implementing a system from pulse oximetry principles, getting a useful pulse signal and prime tests, both theoretical and real, of the system. We also sketched a few ideas of energetic management for further implementation in the system.

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High Accuracy Multi-Channel Digital Potentiometer

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Abstract

Often in mixed-signal applications it is necessary to digitally control analog signals, and the common solution is to use integrated digital potentiometers. However, those components use multiple resistors switched by integrated transistors that alter the signal characteristics, so this approach might not be acceptable for high precision applications that requires pure-analog signal path. This paper presents a different approach to the problem of digital control of analog signals, which uses a static RAM to generate PWM control signals for optocouplers with resistor output, a solution that allows high resolution control of multiple analog channels without introducing any transistor in the signal path.

1. Introduction

Digital potentiometers are electronic components that mimics the function of analog potentiometers, used to allow a digital system to control analog parameters such as amplifier gain, offset adjustment or small-signal audio balancing. The commonly used solution in such situation is the integrated digital potentiometer, basically a resistive network switched by integrated transistors, as illustrated by figure 1.

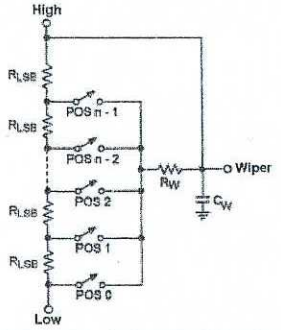

Fig. 1 Electrical model of an integrated digital potentiometer

Integrated digital potentiometers are commercially available since mid 80s, so they're not exotic components, but they have some significant limitations that justify the need to search for an alternative.

Some of the most important drawbacks of integrated digital potentiometers are:

- The voltage swing between terminals High and Low is limited by the input supply, typically 5V; ±15V voltage swing can be achieved by using a separate differential supply of the digital potentiometer.
- The analog and digital grounds of the circuit cannot be separated, which can be a problem because low amplitude analog signals are easily perturbed by digital signals.
- Due to the fact that a change in the control code requires a large number of transistors to switch simultaneously, the analog signal will be affected by switching transients (*zipper noise*), as illustrated by figure 2.

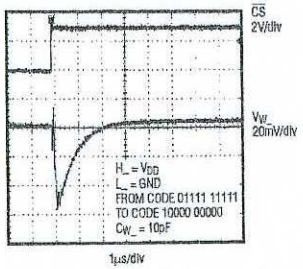

Fig. 2 Switching transient noise of a digital potentiometer [3]