DATA ACQUISITION IN MICROPROCESSOR SYSTEM FOR PULSE OXIMETRY

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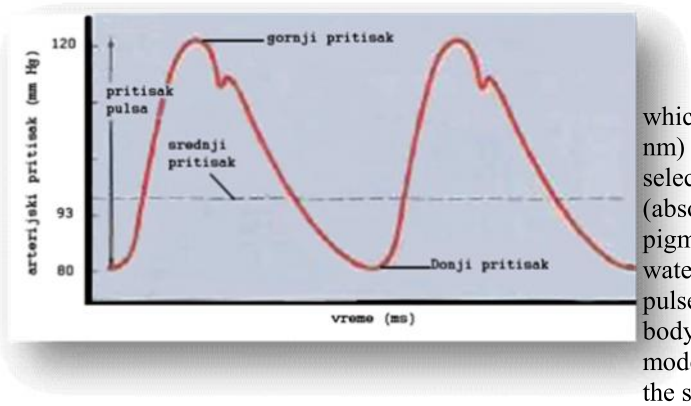
Abstract - *The aim of this presentation is to give a brief review about the experimental research project on the use of microprocessor systems in medical instrumentation. The goal of this research is to prove the concept of designing a simple, cheap but reliable sistem for measuring blood oxygenation and pulse rate. The main goal has been achieved, and the results obtained by this measurement configuration are more than satisfactory.*

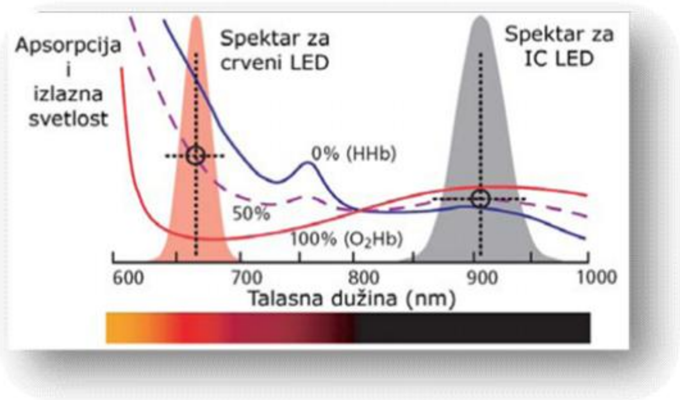
1. INTRODUCTION

In terms of human physiology, oxygen can be seen as the equivalent of life. Functioning of every cell in human body depends on this vital gas. Therefore, the oxygen level in blood is an important indicator of a person's health. That is essentially what pulse oximetry seeks to quantify. Before we move on to engineering design neeeded for the development of the instrument to measure the level of oxygen in blood, it is necessary for us to get familiar with the anatomy of the human heart and circulatory system, so that we can get an idea of the true value of pulse oximetry technology. Pulse oximetry is concerned with the measurement of oxygen in arteries. The pulsating signal which pulse oximetry seeks to measure is a consequence of the existence of arterial blood pressure. The signal obtained in pulse oximetry is a result of blood pressure in arteries.



Picture 1 Arterial pressure measured during ventilation time

The absorption of visible light varies with the level of oxygen in blood. This occurs due to the differences in the optical spectrum between oxygenated (oxyhemoglobin-HbO2) and deoxygenated (Hb) , as shown in picture (Picture 2)



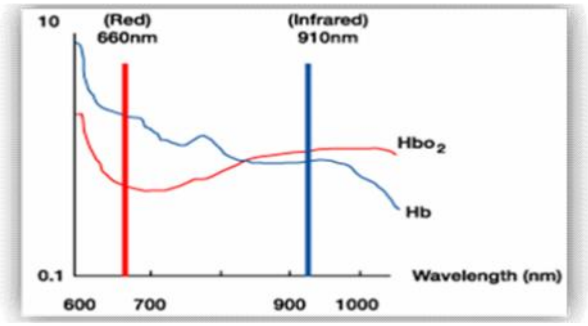
Picture 2 Graphical display of light absorption of different wavelengths

It may be noted that at wavelength corresponding to the red part of the spectrum, Hb has a greater absorption coefficient than HbO_2. Also we can see from the image that absorption coefficient of HbO_2 is higher than absorption coefficient of Hb at infrared light spectrum. Oxygen saturation is defined as the ratio of oxyhemoglobin and total hemoglobin in blood and is given by the following formula:

$$SaO_2 = \frac{[HbO_2]}{[UkupniHb]} \tag{1}$$

which is equivalent to the ratio of output red light (660 nm) and output infrared light (940 nm). Wavelengths are selected according to the minimal attenuation criteria (absorption) of light by the tissues (tissues and pigmentation absorb blue, green and yellow light, and water absorbs infrared light). This is the main reason why pulse oximetry uses red and infrared LEDs. The human body is a complex mechanism, which is very difficult to model based on merely a few parameters, which makes the study of pulse oximetry both interesting and challenging. This paper is devoted to the development of instrumentation for pulse oximetry, as well as its general application in the field of medicine.

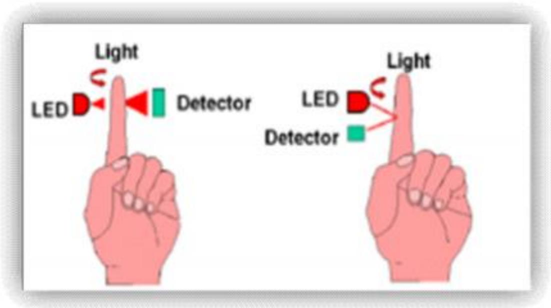
The basic principle of pulse oximetry is based on the characteristics of oxygenated and deoxygenated hemoglobin, that is to absorb light in red or infrared parts of the spectrum. Oxygenated hemoglobin absorbs more infrared light, while red light is largely passed through. Deoxygenated hemoglobin absorbs more red light, while infrared light is largely passed trough. Red light is in wavelength range from 600 nm to 750 nm and infrared part of the spectrum covers the wavelengths between 850 nm and 1000 nm.



Picture 3 Different coefficients of absorption of red and infrared light for Hb and HBO2

Pulse oximetry uses a light emitter with red and infrared LED, which to some extent shines through a clear, well-vascularized spot on the body. Typical places to put on a measuring probe for adults or children are the finger, toe, or the top or bottom of the ear. For newborns these places are the foot , the palm and the thumb of the hand or foot. On the opposite side of the light source is a photodetector that detects light that passes through the measuring point.

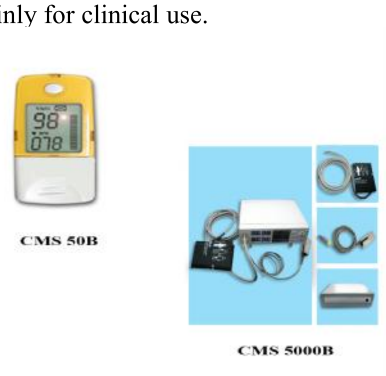
There are two ways of sending light through the measuring point: transmission and reflection. During the transmission method, as shown in the picture (Picture 4), the light source and the photodetector are opposite each other, and between them is a measuring point. In this way, light passes through the measuring point. During the reflection method, the light source and the photodetector are located next to each other at the top of the measuring point. Light is reflected from the source to the detector, passing through the measuring point. The transmission method is commonly used, and the use of this method will be implied in the following text of the review.



Picture 4 Transmission vs. Reflection

After broadcasted red (R) and infrared (IR) signals pass through the measuring point and are received by the photodetector, the R/IR ratio is calculated. R/IR ratio is compared with the "look-up" table (consisting of empirical formulae) which turns this ratio into a SpO_2 value. Most manufacturers have their own look-up tables, based on calibration curves obtained by measurements on healthy patients at different levels of SpO2. Typicaly the R / IR ratio of 0.5 corresponds to approximately 100% SpO_2, the ratio of 1.0 corresponds to approximately 82% SpO_2, whereas the ratio of 2.0 corresponds to 0% SpO2.

Depending on the characteristics, uses, quality, product price and consumers demands, there is a wide range of pulse oximeters to be found on the market. Several commercial oximeters are presented in accordance with the above criteria.
CMS 50B fingertip Oxymeter - a device that belongs to the lowest class of pulse oximeters available on the market.
CMS 60A Hand-Held Pulse Oximeter - a slightly higher class of commercial pulse oximeters.
CMS5000B Vital Signs Monitor - represents the highest class of devices based on a pulse oximeter model. It is intended mainly for clinical use.



Picture 5 Display of different quality oximeters

2. SYSTEM STRUCTURE

The hardware which is included in the gauge (i.e. pulse oximeter), consists of two basic parts:

- Sensor amplifying part - signal conditioning,
- The part for managing and processing data - acquisition.

The part for signal conditioning consists of: sensor - measuring probe, preamplifier level (inverting), DC component filter - implemented as a buffer (inverting) and at the end the amplifier level (non-inverting) [1].

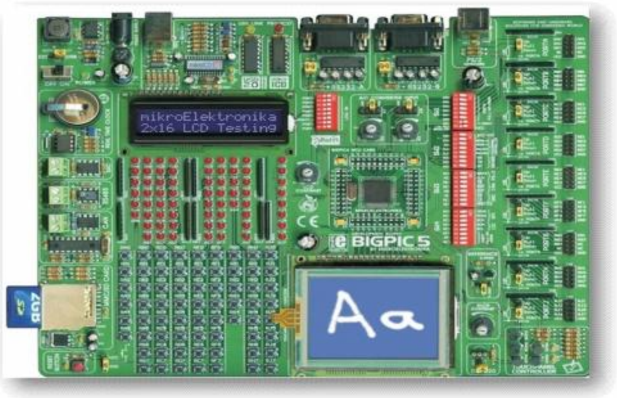
The basic part of the data acquisition section consists of a microcontroller system based on a PIC microprocessor with its peripherals (ADC, RTC, MMC, GLCD). Power supply is common for both parts, and it has been designed specifically for this purpose.

It should be noted that the entire process of measuring, displaying and recording of the results on the MMC is controled by a firmware specifically developed for this purpose.

Each of these parts will be described in detail in the next section.

3. IMPLEMENTATION OF DATA ACQUISITION

Most attention will be devoted to Mikroelektronika's BigPIC5 development system which performs acquisition and processing of data. BigPIC5 development system is a very good tool for programming almost every Microchip's PIC 64-pin or 80-pin microcontroller. It provides a great opportunity for both students and engineers to easily try out and explore the possibilities of a PIC microcontroller [2]. As an additional option, it is possible to connect a microcontroller with external circuits and peripherals. The user can be mostly devoted to developing the software. The following picture (Picture **6**) shows the System BigPIC5. As the figure shows, near each of the components on the board there are identification tags on both sides. These tags provide a description on how to connect to the microcontroller, the operating modes and they also provide additional useful information. Since all the relevant information can be found on the board, there is almost no need for additional schemes.



Picture 6 Development system BigPIC5

The following modules of development system were used in implementation of project task:

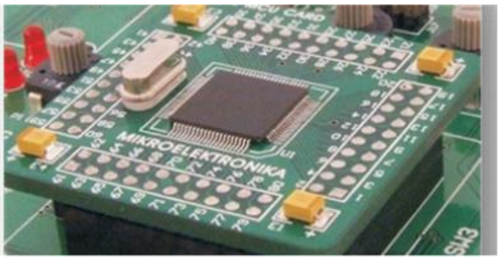
- MCU (PIC18F8520),
- AD converter,
- GLCD module

MCU (PIC18F8520) is a high-performance RISC CPU with the following characteristics:

- Architecture and instruction set adapted for C compiler:
  - o Source code compatible with PIC16 and PIC17 instruction sets
- Linear programmable memory up to 128 KByte
- Linear data memory up to 3840 byte
- 1 Kbyte EEPROM
- Up to 10 MIPs operations:
  - o DC - 40 MHz osc./clock input
  - o 4 MHz - 10 MHz osc./clock input with active PLL
- 16-bit instructions, 8-bit data paths
- Inerrupt levels
- Hardware stack with software access 31 level
- 8 x 8 one-sided hardware multiplier.

CMOS Technology:

- Low power consuption, Flash technology - high speeds
- Static design
- Wide range of operating voltage (2.0 - 5.5)V
- Industrial and extended temperature range.



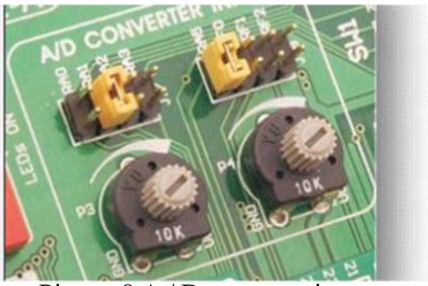
Picture 7 PIC18F8520 Microcontroller

Microcontroller pins are linked to a variety of peripherals. All MCU ports are directly connected to the 2x5 connector for direct access to ports on the right side of the plate. These connectors are typically used to connect external peripherials to panel, or digital probes for testing and measurement. All ports are also connected to LED panel and keyboard, making it easier to monitor and test state of the digital pins.

Analog-to-digital converter has 16 inputs with PIC18F8520 device. This module allows conversion of an analog input signal, which corresponds to a ten bit digital number. Referent analog voltage can be selected via software application and it can be either positive or negative voltage supply (VDD and VSS), or voltage level on RA3/AN3/ VREF+ pin and RA2/AN2/VREF- pin. In order to achieve A / D conversion it is necessary to follow these steps:

1) A/D module configuration:
   a. Analog pin configuration, referent voltage and digital I/O (ADCON1)
   b. Choosing input A/D channel (ADCON0)
   c. Choosing A/D conversion tact (ADCON0)
2) A/D interrupt configuration (if necessary) :
   a. Clear ADIF bit
   b. Set ADIE
   c. Set GIE
3) Wait for data acquisition to finish
4) Start conversion:
   a. Set GO/DONE bit (ADCON0 register)
5) Wait for A/D conversion process to end by:
   a. Calling GO/DONE bit, or
   b. Waiting for A/D interrupt

6) Reading A/D result registers (ADRESH:ADRESL); clear bit ADIF, if necessary
7) For the next conversion, start from step 1 or step 2. The time for 1 bit of A/D conversion to finish is defined as TAD. Before the next acquisition can start, there is a necessary waiting period of 2 TAD.



Picture 8 A / D converter inputs

In order to measure the analog signal without interference, corresponding switches must be turned off from SW1 and SW4 groups. This way, the connection between pins of PORTA / PORTF and external pull-up/down resistors is terminated. The microcontroller takes analog signal from its input pin and converts it into a digital value. In fact, any analog signal input which is in the range acceptable to the PIC can be measured. This range varies from 0 V to 5 V.

Graphic LCD (GLCD) allows for advanced visual messages to be displayed. While character LCD can display only alphanumeric values, GLCD can be used to display messages in the form of drawings or bitmap. The most commonly used graphic LCD has a screen resolution of 128x64 pixels. GLCD display contrast can be adjusted using potentiometer P2, located on the right side of the display.

Picture 9 GLCD module

It should be noted that there is an GLCD upgrade in the form of a touch panel. The touch panel is a thin, self-adhesive, transparent plate that can be placed over a graphic display screen. It consists of two separate plates that form a "sandwich" structure. They are very sensitive to pressure, so that the slightest touch will cause changes in the output signal. It is used in various user-friendly devices, in combination with the GLCD.
CN16 connector allows for this device to be connected with integrated controller for touch-panel, whose active part consists of five discrete transistors. Four switches in the switching group SW2 allow or interrupt the connection between the controller and pin: RA0, RA1, and RJ6 RJ7.

4. FIRMWARE

This chapter will discuss the development environment in which the firmware is written. Much attention will be devoted to the planning and writing of firmware, problems during realization and finished code algorithms. MikroC PRO for PIC development environment is a powerful development tool for PIC microcontrollers rich with options. It is designed to help developers find the easiest possible way to develop applications for embedded systems, without compromising the performance or control over the system.

To better understand the general idea on which firmware was realized, we need to briefly look back at our project assignment. Basically, requirements of project are as follows:

1) System should be able to measure SpO_2 level (oxygen saturation),
2) System should be able to measure PR (pulse rate),
3) Choosing the type of measurement by using two buttons,
4) Display results on the GLCD.

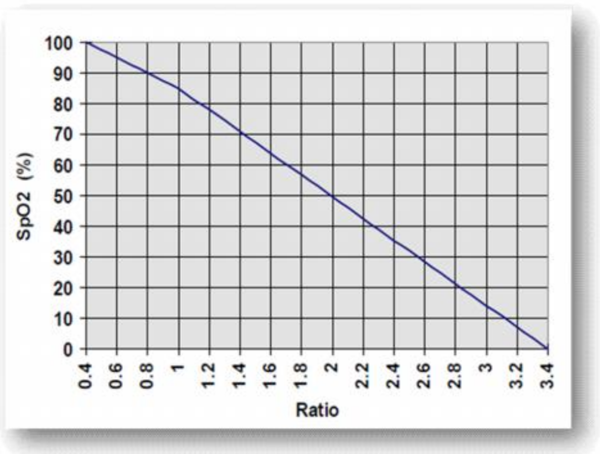
Writing of firmware was done in stages and according to the project requirements. In order for the measurement system to function, it was necessary to write parts of the code that would guide the work of certain hardware modules (GLCD and A / D converter). In accordance with this, the first step involved writing separate software modules to work with these pieces of hardware. What certainly facilitated the process were lots of examples and prototypes of specific functions provided in the development environment. After that, the integration of these modules in a more complex entity was attempted. It is important to note that prior to bringing the signal from the sensor to A / D converter, a piece of code that performs a simulation of the measurement was written. The signal which is brought to the A / D converter is regulated by one of the potentiometers on the evaluation board. The system has shown good results when working with simulated input values (without the associated measuring hardware). After this step, we started with writing the code for the actual measurement.The piece of code that is responsible for the measurement consists of two units (two loops): one for measuring SpO2 and the other for measuring pulse rate. SpO2 is not the size that can this way be measured directly, but by the mathematical formula, which is a function of two voltages SpO2 = f (R) = f (UR / UIR).

$$U_R = U_{R\max} - U_{R\min} \quad (2)$$

$$U_{IR} = U_{IR\max} - U_{IR\min} \tag{3}$$

$$R = \frac{U_R}{U_{IR}} \tag{4}$$

Voltages that are directly measured are: U_{Rmax}, U_{Rmin}, U_{IRmax} i U_{IRmin}.
UR voltage is the voltage at the input of A / D converter during red LEDs luminance and UIR voltage is the voltage at the input of A / D converter during infra-red LEDs luminance. If we recall that the LEDs have alternating mode that is controlled by a microcontroller, it is clear that at the input of A / D converter voltages UR and UIR are appearing alternately. By recording the signal at input A / D converter (with oscilloscope), it was found that besides these two signals a short jump or drop of voltage appears at the entrance, as a result of changes in luminance. To avoid the error in measuring the voltage signal that is not the useful signal, we had to make sure that this signal is not measured. This problem is solved by adding the time delay function (during the "parasitic signal").
Experimentally it was found that the frequency of voltage UR (UIR) moves around f = 1 Hz. For good measurement result Nyquist sampling theorem has to be fulfilled, that is that the sampling frequency (fS) of signal at input of A / D converter is at least twice as big as the input signal's frequency, which gives the fs value 200 Hz. The measurement is carried out in such a way that sampled signal pieces are stored in arrays, then the software determines the maximums and minimums of the array, and they represent the voltages Urmax (Urmin), Uirmax (Uirmin).



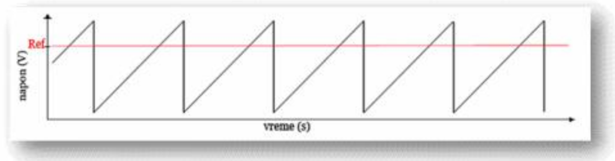
Picture 10 The dependency graph of R and SpO2

The next step is to determine the relationship of the obtained voltages UR and UIR, which directly affects the value of SpO2. There are several different ways (formulas) for calculating the value of blood oxygen saturation, but we pointed out two mostly recommended. The first way is SpO2 given as the ratio of R and the so-called extinction coefficient or light absorption of hemoglobin, and the other way suggests using the formula for SpO2 that is obtained empirically. This formula is actually a function of the linear part of the curve in the graph (Picture 10), in the range of (80 - 100)%.

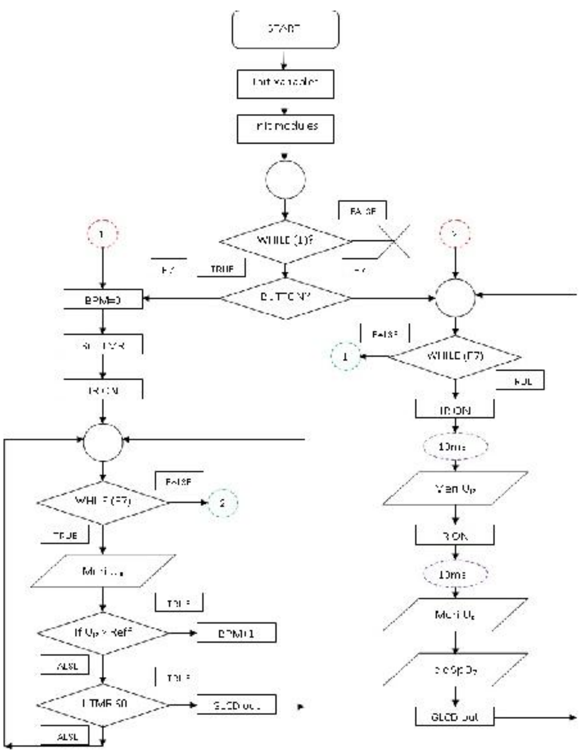
$$R = \frac{U_R}{U_{IR}}, \quad S_pO_2 = 110 - 25R \tag{5}$$

Light absorption coefficients of hemoglobin and deoksyhemoglobin for wavelengths of 660 nm and 940nm respectively amount to: 3.226 i 0.693 ; 0.319 i 1.214.
The second method was chosen to calculate SpO2 using the formula above. The program calculates eight consecutive saturation values and stores them in an array. The end result for saturation represents the average value of the mentioned array, which is printed on the GLCD.

The second part of the code deals with the measurement of pulse, counting heart beats in a time interval of 60 seconds. The idea for measuring the pulse is quite simple. The nature of the signal that we bring to the A / D converter is such that the signal has a maximum (peak) at the moment when a heartbeat happens, and by simply counting maximums in the range of 60 seconds we get the value of the pulse.



Picture 11 Graphical presentation of method for determining pulse



Picture 12 Firmware algorithm

Numerical results are printed to the display after 30 seconds (temporary) and after 60 seconds (final).

Picture 12 shows a simplified version of a software algorithm, responsible for system operation.

5. RESULTS

In this chapter results obtained by repeatedly measuring the oxygen saturation of blood of more subjects will be displayed (Table **1**).

Table 1 Display of measurement results

Ordinal number	Measured value	Ordinal number	Measured value
1	95	**5**	95
2	94	**6**	93
3	95	**7**	95
4	96	**8**	96

Measurement results must be accompanied with appropriate measurement uncertainty. For specific measurements, uncertainty of measurement has two components: A (statistical) and B (deterministic). The procedure for determining measurement uncertainty is discussed in [1].
The final result is accompanied with combined uncertainty which is 15.17, so the final result is:

$$\overline{SpO_2} = u(SpO_2) = (95 \pm 15.17)\% \quad (6)$$

However, if the result is given for confidence interval of 95%, the combined uncertainty is multiplied by k (for a confidence interval of 95% it is 2). Now, the final result is:

$$\overline{SpO_2} = u(SpO_2) \pm 2k, SpO_2 = (95 \pm 30.34)\% \quad (7)$$

6. CONCLUSION

Achieved results show that the initial idea of this experimental research project was verified. The current version of the measurement system is implemented as a proto-board tile, hand-made measuring probe and development environment BigPIC5. The results obtained by this measurement configuration are more than satisfactory. The plan is to further develop the system, which can be conducted according to the following scheme:

- preparation of printed Circuit Board for digital part of measuring system,
- preparation of printed Circuit Board for analog part of measuring system,
- purchase of quality measuring probe,
- preparation of stabilized adapter power source ,
- preparation of backup - battery power source and
- preparation of housing.

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