Measurements with a Non-Invasive Pulse oximetry Module

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Abstract— **The pulse oxymeters are commonly used devices in medical practice. With their help, the oxygen saturation of the haemoglobins, or in other words, the oxygen saturation of arterial blood can be measured with a few percentage of error. The pulse oxymeters can measure continuously, in a non-invasive way. By monitoring the oxygen saturation, reduced oxygen supply can be diagnosed. The medical term of this condition is hypoxemia. The most common use of pulse oximeters is to help doctors diagnose hypoxemia.**

I. INTRODUCTION

Normal blood oxygen levels in human arteries are considered between 95-99%. This means that the average percentage of haemoglobin molecules that deliver oxygen is 97%. In other hand, this percentage in the veins is only 75%. It's irrelevant, if someone runs, or sleeps, only the blood flow of blood vessels change, the oxygen saturation remains constant. Reduced oxygen saturation is usually a result of an abnormal physiological process.

In medical practice, pulse oxymeters are used to monitor the patient in numerous cases: during anaesthesia, child-birth, emergency intervention, operation, or in case of cardiovascular problems, or pulmonary disease, but pulse oxymeters are in everyday use in hospital rooms, during patient transport, and in maternity ward.

Pulse oxymeter sensors, hereinafter SPO2 sensors can be found in everyday life in the form of wearable bracelets. They can be a really useful tool in forecasting diseases or emergencies.

II. THEORY

A. Hemoglobin

Haemoglobin is a type of protein that is carried by red blood cells. The proportion of blood occupied by red blood cells is usually 45%. The haemoglobin's main role is to deliver oxygen from the lung to the tissues, and to carry the end products of metabolism, such as carbon-dioxide (CO_2) from the tissues to the lung. The haemoglobin protein contains iron molecules, that can bind oxygen molecules. This process is called oxygenation. This term is not the same as oxidation. One iron molecule is able to bind four oxygen molecules. In this case, the oxygen saturation is 100%. A fully saturated haemoglobin is called oxyhaemoglobin, it's short form is HbO2. The fully depleted, oxygen-free haemoglobin is called deoxyhaemoglobin, in short form: Hb.

Haemoglobin gives the distinctive red colour of the blood. The oxygen-rich blood in arteries is bright red, the oxygen-poor blood in veins has a colour between brown and dark red, observed trough the skin, it's blueish. It can be observed that the haemoglobin's colour, or in other words the absorption spectra is closely related to its oxygen saturation. At a given wavelength, the haemoglobin, depending on its oxygen saturation absorbs more or less light. This property of the haemoglobin is used to measure blood oxygen levels. The oxyhaemoglobin and deoxyhaemoglobin 's absorption spectra can be seen on fig.1. On the left side the wavelength is 450-1000 nm, on the right side 650-1000 nm is highlighted.

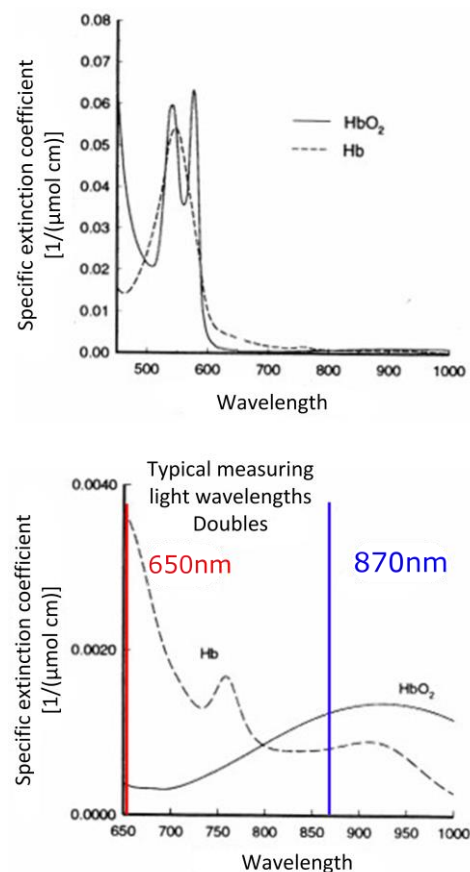The human eye is sensitive to light in the interval of

Figure 1. The absorption spectrum of hemoglobin [1]

light in the interval of 400-700 nm. The oxyhaemoglobin and deoxyhaemoglobin 's absorption curves can be distinguished on different wavelengths. It can be seen that the difference between the curves is greater by an order of magnitude in wavelengths below 600 nm. On the first

glance, it would seem like a better alternative to measure absorption, however it's an incorrect assumption.

B. The „Oximetry Window", or the decisive factors of the measured light's wavelength

The 650-1000 nm interval in the electromagnetic spectrum of the light is the most suitable for oxymetric measurements. It's causes will be discussed in the following.

The upper limit: The water's absorption:

An adult human's body consists of 60% of water. The water is present in every tissue, such as in blood. Around 900nm the absorption of water starts to rise as the wavelength increases. When the wavelength reaches 1400 nm, the absorption is greater by an order of magnitude compared to absorption of the 650-1000 nm interval. The absorption of haemoglobin is relatively small, when measurement takes place, the light's wavelength can't go above 900-1000 nm, because the water would absorb a large part of the light instead, making the signal-to-noise ratio unacceptable. [7]

The lower limit: The skin's absorption:

In the 450-600 nm interval, the oxyhaemoglobin and deoxyhaemoglobin 's absorption are well separated (fig.1 left side), this way, changes in oxygen saturation are well distinguishable. This would result in a better signal-to-noise ratio than the 650-1000 nm interval, but again, it's an incorrect assumption. In 450-600 nm interval, the measurement is prevented by the skin itself. The human skin has a great absorption of light in 400-650 nm interval, but above that, the skin's absorption decreases greatly, therefore using light above 650 nm wavelength for measurements is recommended. [5], [6]
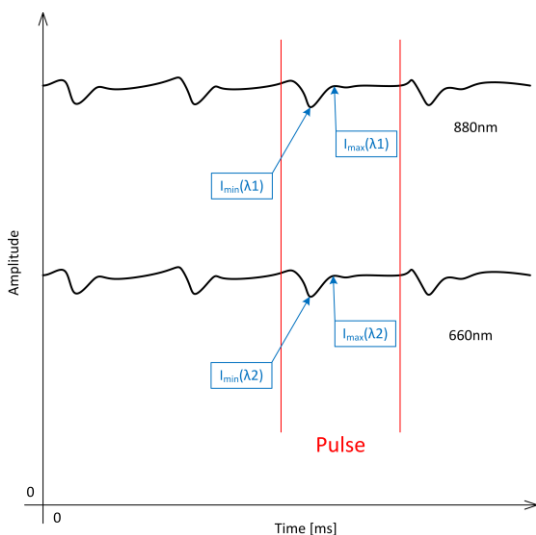
C. Determining oxigen saturation

Figure 2. Typical pulse oximeter probe waveform used in two wavelengths

In pulse-oxymeter devices, at least two, different wavelength light sources must be present. On Fig.2 two measuring light wavelengths in the absorption spectra of haemoglobin are displayed.

Two specific measuring light wavelengths can be seen on Fig.1 in the absorption spectrum of haemoglobin. In case of 870 nm, with the decrease of oxygen saturation, the curve moves towards the dashed line, that is, the absorption decreases. This way the light's intensity, that passes through the blood vessels, decreases. In case of 650 nm things work the opposite way, since the oxyhaemoglobin's absorption is lower than the deoxyhaemoglobin 's.

The phrase pulse oxymeter is originated from the pulsating nature of arterial blood. Every tissue has constant light absorption properties, only the arteries pulsate. Each heartbeat means that the fresh, oxygen-rich blood replaces the oxygen-poor blood, therefore changes the artery's light absorption. If tissue interwoven with arteries is illuminated with two different wavelength light sources, and the light is detected and converted into electrical signs, we can get a figure similar to Fig.2.

The arterial pulsation modulates the light passing trough. The large DC component is a result of the absorption of tissues, therefore they are not pulsating. Imax and Imin are in compliance with the systolic and diastolic states. The effect of the non arterial components can be eliminated by separating and amplifying the pulsating component, therein lies pulse-oxymetry's greatest advantage.

The dominant light absorbent material in 650-1000 nm range is the oxyhaemoglobin and deoxyhaemoglobin, therefore it is sufficient to write down the equation of the oxygen saturation with only these components.

The Lambert-Beer Law takes the form of the following Equation (1): [2], [3], [8]

$$I = I_0 e^{-\sum \alpha_i c_i l_i} . \qquad (1)$$

Where I0 is the intensity of the light entering the tissue, that is emitted by the LEDs. The measurement of this intensity would be too complicated, so we look on its magnitude as an unknown. ai and ci are absorption coefficients and concentrations of tissue-components, li denotes the distance traveled by light in said tissue-component. Measuring li is also problematic, therefore let's consider it as an unknown.
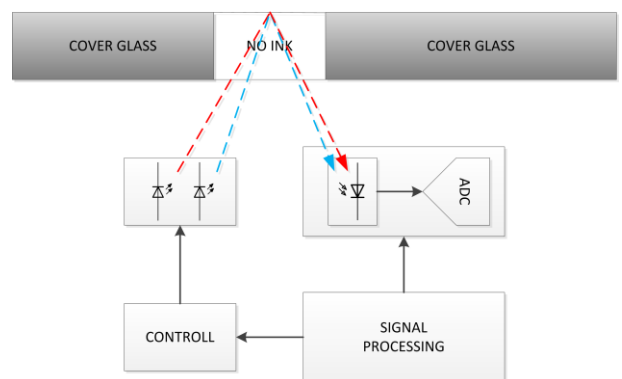

Figure 4. Introducing the principle of Measurement

Next, we have to write down Eq. (2) on one pulse's systolic and Eq. (3) diastolic points (see on fig. 2) Assuming the artery's thickness, and thereby the distance

travelled by the light in the artery changes by λl between the systolic and diastolic points. On this route, the attenuation can only be caused by the arterial blood, therefore we can write down the HbO2 and Hb's absorption coefficients and concentrations next to λl. Imax and Imin correspond to figure above.

$$I_{max} = I_0 e^{-\sum \alpha_i c_i l_i} \ . \qquad (2)$$

$$I_{min} = I_0 e^{-\sum \alpha_i c_i l_i + \Delta l(\alpha_{Hb} c_{Hb} + \alpha_{HbO_2} c_{HbO_2})} \ . \qquad (3)$$

Variables indexed by "i" describe the impact of tissues that are irrelevant from the perspective of pulse oxymetry, moreover they include attenuation of the blood found in a relaxed arteries. Two equations quotient, and logarithm takes the form of the following Equation (4):

$$\ln \frac{I_{max}}{I_{min}} = \Delta l(\alpha_{Hb} c_{Hb} + \alpha_{HbO_2} c_{HbO_2}) \ . \qquad (4)$$

It is clear to see that the entry intensity, generated by the LEDs is not needed, this way the first unknown is eliminated. The distance travelled by the light (Δl) remains an unknown. It can be eliminated by measuring on two, different wavelengths. This is why two different light sources are needed. The absorption coefficient depends on the wavelength, and accordingly the indexes λ_1 and λ_2 indexes are displayed accordingly.

The two wavelength equation's quotient is the so called "R-ratio" (Ratio of the ratios) Eq. (5). In this equation, the distance travelled by the light is eliminated. This ratio is measured by the pulse-oxymeters. The R-ratio is the ratio of the amplitude of two pulsating components, with different wavelengths. The arterial oxygen saturation can be determined from the R-ratio. [3]

$$R = \frac{\ln \dfrac{I_{max}(\lambda_1)}{I_{min}(\lambda_1)}}{\ln \dfrac{I_{max}(\lambda_2)}{I_{min}(\lambda_2)}} = \frac{\Delta l(\alpha_{Hb\lambda_1} c_{Hb} + \alpha_{HbO_2\lambda_1} c_{HbO_2})}{\Delta l(\alpha_{Hb\lambda_2} c_{Hb} + \alpha_{HbO_2\lambda_2} c_{HbO_2})} \ . \qquad (5)$$
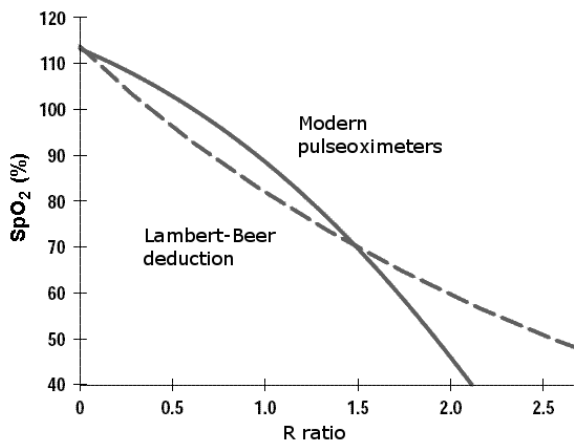

Figure 3. Modern pulse oximetry measurement graph [4]

Where the SpO2 is the saturation of oxygen in the blood, c_{HbO2} is the oxygenated hemoglobin concentration and c_{HB} is the deoxygenated hemoglobin concentration.

The Lambert-Beer Law's boundary conditions are never totally met in practice. The model does not take into account the multi-scattering- phenomenon on red blood cells, the inhomogeneous tissue structure, and the fact that the light emitted by the LEDs is not monochrome. Therefore today the correlation between the R-ratio and SpO2-value is not determined with the help of the absorption coefficients. Instead it is deduced from hundreds of SpO2 measurements of volunteers, with statistical methods. After blood sampling, the samples undergo a blood gas analysis, accurate SaO2 concentration is determined, after that, the results are compared to the R-ratio measured by the pulse-oxymeter. The result of this process is called "Calibration-table". After the measurement of R-ratio, the oxymeter reads from the pre-programmed Calibration-table [7]

III. A INTRODUCTION OF HARDWARE

Msp430 is a perfect microcontroller for handling SpO2 measurements, it even has resources to handle additional peripherals, such as OLED dispaly, bluetooth module, thermometer. These can be the elements of a smartwatch.
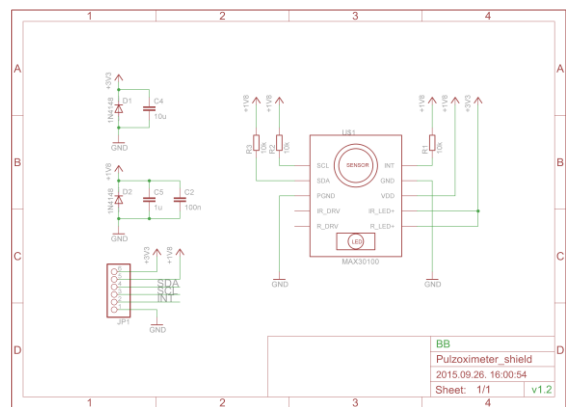

Figure 7. Measuring with the devices

Figure 6. Schematic of the device

The operating principle of the sensor is shown on Fig. 4 and Fig. 5. The device combines an infra-red and a red LED light with a photodetector. It includes an optimized lens and low noise analog signal processing unit. The sensor is able to communicate with a microcontroller trough an I2C bus (Fig.6).

The results shown in Fig. 8 and Fig. 9 were measured with the measurement setup shown in Fig.7. The measurements provide similar results on fingertips, and on wrists as well. The results mainly differ in amplitude, but heart rate periods are well distinguishable.

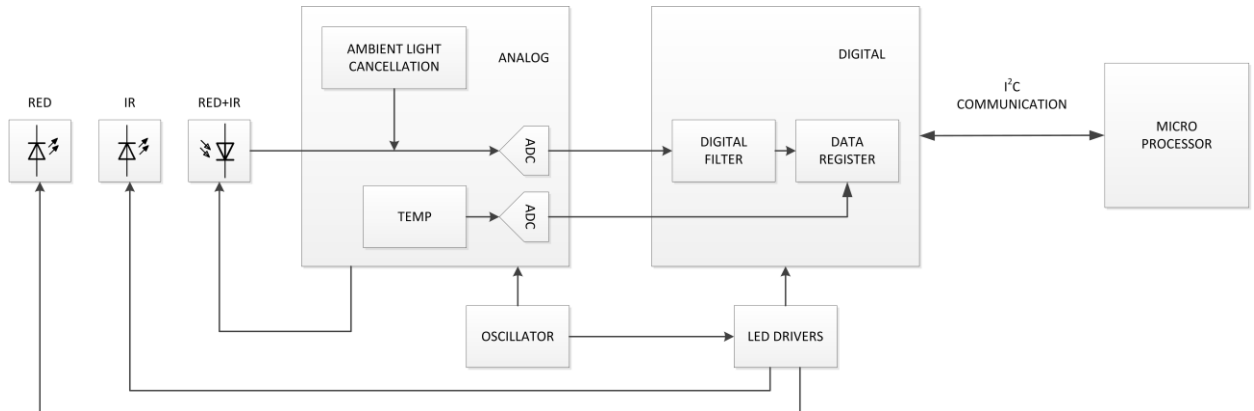continuous monitoring of cardiac arrhythmias and other cardiac events.

Figure 5. The device structure

Figure 8. Measuring on fingertip

IV. CONCLUSION

Generally pulse oxymeters are used in hospitals, for monitoring patients. Our measurement results showed that they are also able to produce good results on wrist, therefore, pulse oximeters can be introduced in everyday life, for instance for fitness-wellness purposes.

The actual heart rate can be calculated, using the results of the measurements. Measurements can be also used for
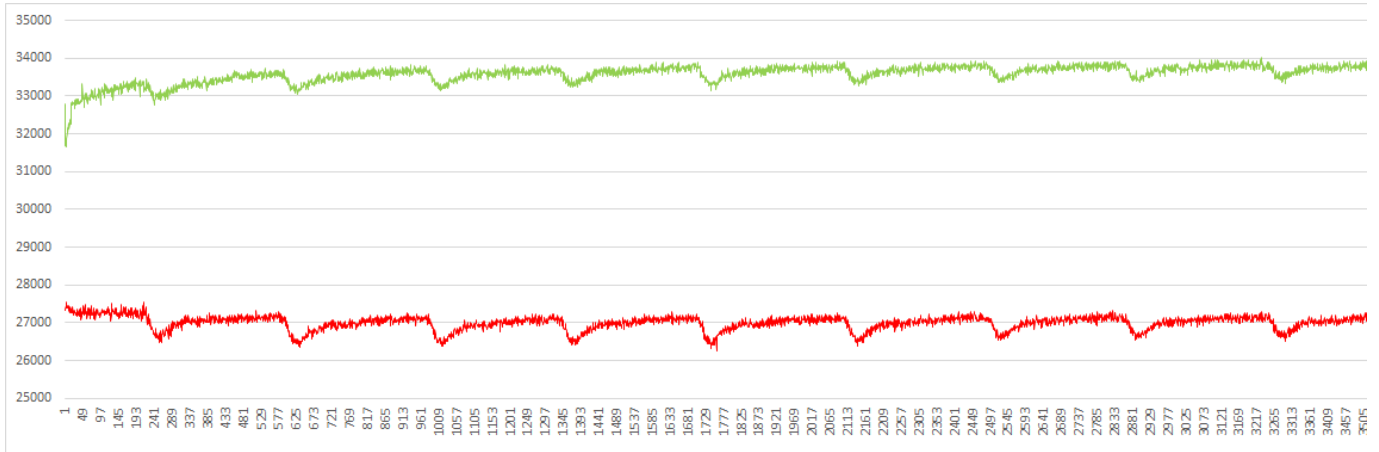
Figure 9. Measuring on wrist

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