Biomedical Sensor Systems

Laboratory

Laboratory Tutorial: Pulse Oximetry

Place: BMT02002, Stremayrgasse 16, 2.OG

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Short Description:

In this Lab students will perform arterial blood oxygen measurements based on pulse oximetry. The students will apply basic signal processing techniques.

Learning Objectives:

The students are able to …

- … name the components of a pulse oximeter and describe their functionality
- … unterstand the principle of (finger tip) pulse oximetry
- … determine the pulse rate from raw oximeter signals
- … detect and evaluate errors in pulse oximetry signals

Content

1. Theory

A (pulse) oximeter is a device intended for the *non-invasive measurement* of arterial blood oxygen saturation and pulse rate. A finger tip pulse oximeter uses the finger tip to acquire the signal.

1.1. What is Oxygen Saturation (SpO_2)?

Oxygen saturation is defined as the ratio of oxy-hemoglobin to the total concentration of hemoglobin in the blood, (oxi-hemoglobin + reduced hemoglobin). A hemoglobin molecule can carry a maximum

of four oxygen molecules. If 1000 hemoglobin molecules together were carring 3800 oxygen molecules, then the oxygen saturation level would be (3800/4000).100 or 95%.

What is the difference to SaO_2? Generally, the term SaO_2 defines the percent saturation of oxygen bound to hemoglobin in arterial blood. When arterial oxy-hemoglobin saturation is measured by an arterial blood gas, it is called SaO_2, SpO_2 describes the non-invasive measurement of arterial oxy-hemoglobin by a finger pulse oximeter.

$$SaO_2 = \frac{[HbO_2]}{[Hb]+[HbO_2]}.100\% \quad (1)$$

What is the relation to PaO_2? PaO_2 is given in mmHg and describes the partial pressure of oxygen dissolved in arterial blood (Sauerstoffpartialdruck). Figure 1 shows the relation between PaO_2 and SaO_2.

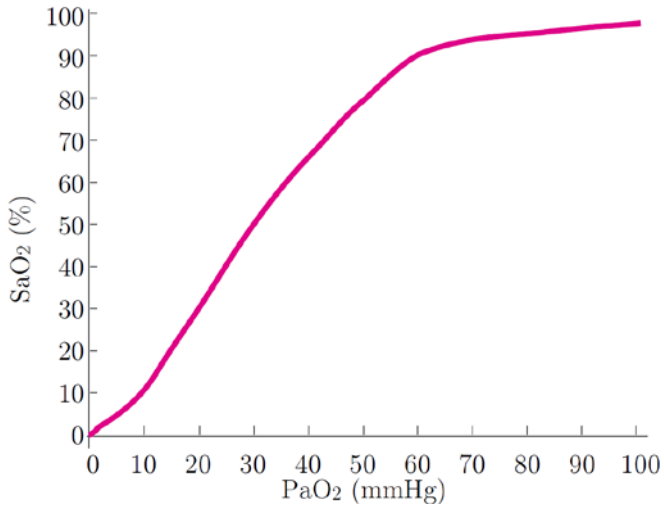

Figure 1: Relation between PaO_2 and SaO_2

1.2. What is a pulse oximeter?

Oximetry is a term that refers to the optical measurement of oxyhemoglobin saturation in the blood in general, pulse oximetry describes one special technique, taking advantage of the pulsatile flow of arterial blood. A finger tip pulse oximeter generally contains a dual light source and sends light through translucent part of the body. Typically, the decive uses two LEDs generating red (ca. 650 nm) and infrared lights (ca. 950 nm), and photo detectors (c.f Figure 2).

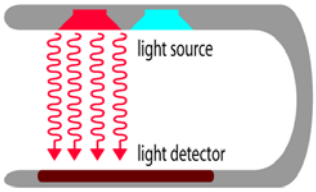

Figure 2: Basic set-up of a finger pulse oximeter

The idea behind is to employ the fact that oxyhemoglobin and its deoxygenated form have significantly different light absorption patterns and thus, the light absorbance of oxygenated hemoglobin (HbO_2) and deoxygenated hemoglobin (Hb) at the two wavelengths (red/infrared) is different as illustrated in Figure 3.

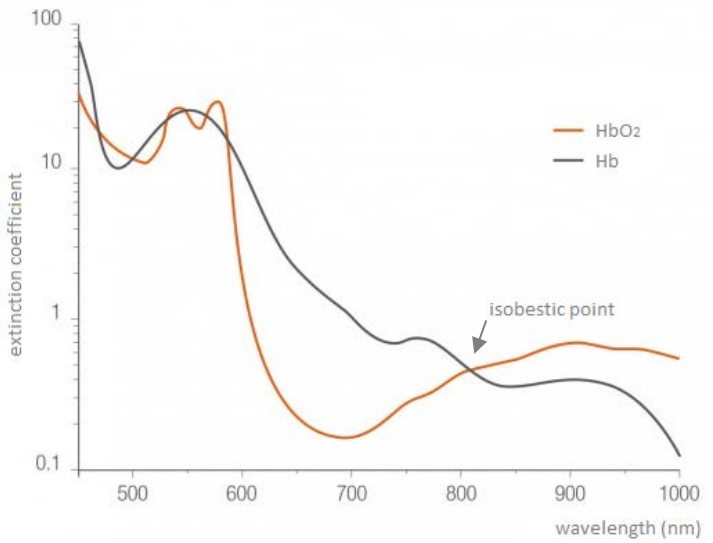

Figure 3: Absorption spectra of Hb and HbO_2 (the isobestic point is the wavelength at which the absorption by the two forms of the molecule is the same)

Oxyhemoglobin absorbs more infrared light than red light, deoxyhemoglobin more red than infrared light and the difference is quite big at the mentioned wavelengths. Secondly, the pulse oximetry is also based on another physical principle – the plethysmography, where the absorbance of both wavelengths has a pulsatile component. Bone, tissue, pigmentation, and venous vessels normally absorb a constant amount of light over time. Since the arteriolar bed pulsates, it absorbs variable amounts of light during systole and diastole, as blood volume increases and decreases. The ratio of light absorbed at systole and diastole is translated into an oxygen saturation measurement. The absorption changes can also be used to estimate blood volume of patient.

1.3. Oxygen saturation and the absorption of light in tissues

In pulse oximetry, the oxygen saturation in blood (SpO_2) is the ratio between the concentration of oxygenated hemoglobin and the overall hemoglobin concentration (c.f. equation 1).

The detection of oxygen saturation of hemoglobin is done by spectrophotometry and is based on Beer-Lambert law

$$I = I_0 . e^{-\varepsilon(\lambda)[C]d} \tag{2}$$

where I is the intensity of transmitted light, I_0 is the intensity of incident light, ε(λ) is the extinction coefficient of solute, C the concentration and d is the optical path distance. Beer-Lambert states that the absorbance of light as it passes through a sample is proportional to the thickness of the sample and the concentration of the absorbent.

1.4. What do pulse oximeters really measure?

Pulse oximeters only measure a ratio of transmitted red and infrared light intensities and relate this to a reference table of empirical oxygen saturation values (c.f. Figure 4).

$$R = Ratio = \frac{\frac{ac_R}{dc_R}}{\frac{ac_{IR}}{dc_{IR}}} \tag{3}$$

ac = pulsatile arterial blood, dc = tissue, capillary blood, venous blood, non-pulsatile arterial blood

The values in the reference or look-up table depend on the manufacturer's purpose of estimating functional or fractional oxygen saturation. In reality they will be neither of these unless the dyshemoglobin levels and the pH levels of the arterial blood of the subject is exactly the same as the average values of those used in the empirical calibration to create the look-up table. The data used for calibration processes are usually obtained from healthy adults breathing hypoxic gas mixtures. Pulse oximeters cannot measure fractional SO_2 nor functional SO_2.

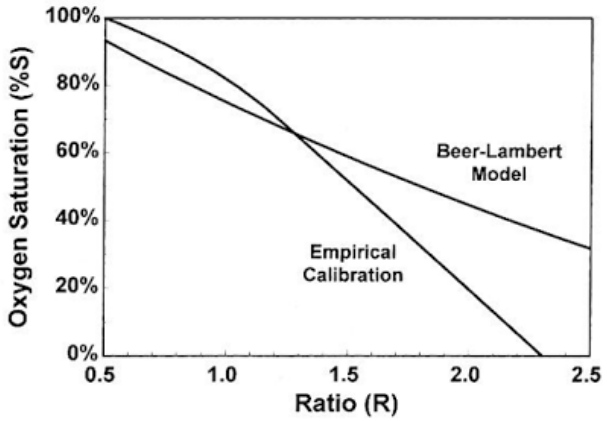

Figure 4: Calibration graph

1.5. Motivation of pulse oximetry

The instrument transcutaneously estimates oxygen saturation of arterial blood and thus provides vital information about the cardiorespiratory function of the patient. The advantage of this technique is the noninvasiveness and the continuous, immediate availability of the data. It provides real-time oxygen saturation monitoring and can be used in a wide range of medicine, such as anesthesia, emergency medicine, intensive care medicine or even monitoring of patients at home.

1.6. Oxygen transport in blood

The blood is composed of 55% plasma and 45% solid components, of which 99.5% are red blood cells. The hemoglobin in the red blood cells can bind oxygen and so the transport of oxygen is ensured. The natural frequency of the molecules depends on the oxygen binding, so optical methods for measuring the oxygen content is possible.

1.7. Blood oxygen measurement – principles of operation

„A pulse oximeter shines light of two wavelength through a tissue bed such as the finger or earlobe and measures the transmitted light signal. The device operates on the following principles:“

- The light absorbance of oxygenated hemoglobin and deoxygenated hemoglobin at the two wavelengths is different.
- The pulsatile nature of arterial blood results in a waveform in the trasmitted signal that allows the absorbance effects of arterial blood to be identified from those of nonpulsatile venous blood and other body tissue.
- With adequate light, scattering in blood and tissue will illuminate sufficient arterial blood, allowing reliable detection of the pulsatile signal.

When the heart beats, blood is pushed into the arteries and this pulse propagates throughout the body to the extremities, which can be detected as a momentary increase in the volume of blood in the finger. If a red LED shines through the finger, more light will be absorbed by the blood at the moment the pulse passes through it. Each change in the amount of red light absorbance can be counted as a pulse.

1.8. Components and architecture of a pulse oximeter

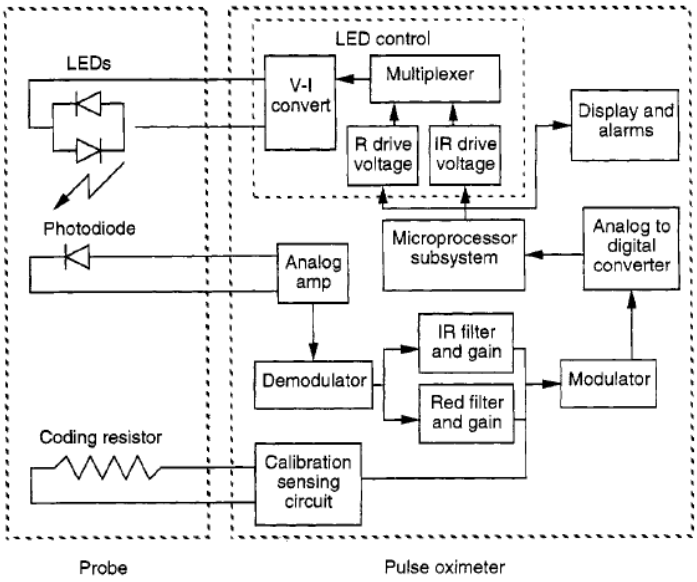

Figure 5: Block diagram of a pulse oximeter system. The microprocessor also provides control and timing for the demodulator, modulator and LED control circuits.

1.8.1. LEDs

Typically, pulse oximeters use two different LEDs generating red and infrared lights. The timing of the pulsations of the LEDs is critical, since the photodiode cannot distinguish between different wavelengths. The two wavelengths chosen for pulse oximetry are typically 660 nm and 940 nm, first, because LEDs at these wavelengths are available and second, because the extinction coefficients of Hb and HbO_2 vary as much as possible. HbO_2 has a higher extinction coefficient than Hb at 940 nm and a lower extinction coefficient than Hb at 660 nm. As a result, as SaO_2 increases (more HbO_2), the absorbance of light increases at 940 nm and decreases at 660 nm. A disadvantage of LEDs as light source is that the exact wavelength of any single LED can vary by as much as +-15 nm. For that reason, some manufacturer characterize each LED and code it with a resistor value.

1.8.2. Photodetector

The photodetector is the main input device of the pulse oximeter system. It produces a current which is linearly proportional to the intensity of incident light. This current is then converted to a voltage which is passed on to the pulse oximeter unit for processing. A variety of devices can be used to sense the intensity of a light source, e.g. photocells, photodiodes, phototransistors and integrated circuit (IC) sensors. The choice of a photodetector depends on factors such as performance, packaging, size and costs. Most pulse oximeters currently use silicon photodiodes.

Since a photodiode cannot distinguish between red and infrared light, the system alternately turns each LED on and off. The pulse oximeter repeatedly samples the photodiode output while the red LED is on, while the infrared LED is on and while both are off in order to be able to abstract any

ambient light that may be present. The pulse oximeter measures absorbances at the two wavelengths and uses data from CO-oximeters to empirically look up a value for SpO_2.

1.8.3. Probes

There are two main types of probes on oximetry: transmission probes and reflectance probes. The difference is in the position of the photodetector of the probe, as shown in Figure 6. A reflectance probe has the LEDs and the photodetector on the same side. It must be placed over a point with underlying bone.

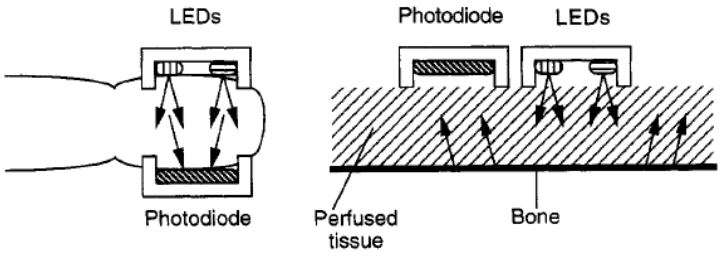

Figure 6: Transmision and reflectance pulse oximeters

1.8.4. Signal processing

The output generated by the photodetector is a current that represents the light absorption. This current gets converted to a voltage by the analog amplifier. The change in voltage, due to the pulsation of the arteries is small in comparison to the dc portion of the signal, so the dc component of the signal is subtracted from the rest of the signal by the demodulator. The demodulator also uses a sample-and-hold timing circuit to seperate samples from the red LED from the samples of the infrared LED. The ac portions of these signals are low-pass filtered to remove electromagnetic interference. The signals go through a multiplexer with another sample-and-hold circuit, which modulates the red and infrared signals back into one to go through an analog-to-digital converter. Using the data gathered from the ADC, the microprocessor calculates the so called „ratio of ratios“ (R_{OS}). From this R_{OS} and the value of the coding resistor, the microprocessor goes to an empirical look up table for S_pO_2 values, which is generated by the manufacturer through tests with a CO-oximeter.

1.9. Accuracy and error

1.9.1. Accuracy, Bias, Precision, and Confidence Limit

Accuracy is a measure of systemic error or bias; the greater the error, the less accurate the variable. The accuracy of a measurement is the degree to which it actually reflects what it should represent. Accuracy of pulse oximter oxygen saturations can usually be tested by comparing with the reference technique – CO–oximeter. Paramters frequently used to represent the degree of accuracy are bias and absolute mean errors. Bias, in this case is defined as the mean of the differences between the pulse oximeter readings and the CO- oximeter readings, expressed as

$$\text{bias} = \frac{\sum_{i=1}^{N} x_i}{N} = \bar{x} \tag{4}$$

where x_i is calculated by subtracting the *i*th CO-oximeter measurement from the corresponding oximeter saturation displayed by a pulse oximeter. N is the total number of measurements. Units are percent saturations.

Precision is a measure of variation of random error, or degree of reproducibility. The dispersion of points around the mean reflects the precision of the measurement. The precision is often described statistically using the standard deviation (SD) of the differences between the pulse oximeter readings and the CO-oximeter readings of repeated measurements as in the following equation. Units are percent saturation.

$$\text{precision} = \text{SD} = \sqrt{\frac{\sum_{i=1}^{N} (x_i - \bar{x})^2}{N-1}} \tag{5}$$

Most frequently, 95% confidence limit is used, which is equal to 1.96 times SD for a normal distribution:

95% confidence limit = 1.96 x SD = 2 x SD

The use of bias and precision is helpful in getting a clear picture of a pulse oximeter's performance and how this compares to other units or other studies. A unit may be very precise, so that the results are highly reproducible with a low scatter, but have a high bias so that the results are not centered on the true values. In contrast, a unit may have a very low bias, but have poor precision, with values swinging widely from side to side of the true value. In clinical practice a 95% confidence limit of less than $\pm 3\%$ is considered acceptable for most cases.

1.9.2. Sources of errors

Accuracy depends on many effects, e.g.

Saturation: Accuracy at different levels of oxygen saturation is not the same:

i. ***Normal saturation (90% – 97.5%)***
Most models of pulse oximeters have a reliable performance in this range, and are well calibrated in this range since it is the most commonly found condition.

ii. ***High saturation (greater than 97.5%)***
Pulse oximeter are designed to give a saturation reading of 100% or less. This limits the potential for positive errors and makes precision calculations difficult to interpret in this high range. Even though precision calculations cannot be determined in a biased way due to the

positive errors, the correct oxygen saturation is not critical in this range, because since the oxygen saturation is over 97%, the patients are in favorable conditions and require no urgent medical attention.

iii. ***Low (hypoxic) saturation (less than 80%)***

Pulse oximeters have a high potential for errors at low saturations. They are poorly calibrated for saturations below 80 % and the accuracy and precision are worse. First, ethically manufacturers cannot stimulate severe hypocia repeatedly in volunteers for calibration purposes and the error can also be explained by a reduction in the signal-to-noise ratio. As saturation decreases, less red light is able to penetrate through the tissues due to a high absorbance of Hb, thus the AC signal becomes weaker. For compensation, the LED-driving current and the photodiode amplifier gain are increased to maintain the AC signal in a usable range. As the gain increases, incidental electrical and physiogical noise also increase, thus resulting in a decline in the pulse oximeter's accuracy.

Perfusion: Pulse oximeters require adequate plethysmographic pulsations to differentiate arterial blood absorbance from the other substances (venous blood, tissue, bone…). Significant decrease in peripheral vascular pulsation, like in hypothermia, vasoconstriction or hypotension may result in insufficient signals to be processed reliably by the oximeter. Most oximeters have the ability to recognize a weak waveform and alert the user of possible problems.

Motions artifacts: As with most medical devices, motion artifacts contribute a significant error to pulse oximetry. The motion artifact is a major problem that is usually due to the patient's muscle movement proximate to the oximeter probe inducing false pulses that are similar to actual pulses. The false pulses when processed can produce incorrect results. Partically, these artifacts can be reduced by digital signal processing and averaging the SpO_2 values over several seconds before they are displayed.

Optical interference: Ambient light affects pulse oximeters and leads to weak signals. To obtain accurate measurements, potential sources of optical interference must be controlled. Pulse oximeters are designed to reject ambient light by covering the probe site with some tight materials.

Intravenous dyes: During medical procedures, the use of substances such as dyes may be necessary, which can affect the absorbances of the light.

Dyshemoglobin: Dyshemoglobins (carboxyhemoglobin (COHb), methemoglobin (MetHb)) are abnormal hemoglobins which cannot transport oxygen. The presence of those hemoglobins can cause inaccuracy in pulseoximetry.

Temperature: Exposing the body to cold temperatures may cause changes in peripheral perfusion which also may cause inaccuracy. The temperature dependence of LEDs in pulse oximeter probes is unlikely to affect the measured values. The effect of shifts in wavelength of the LEDs on pulse oximeter accuracy is negligible as the temperature increases from 0°C to 50°C. Inaccuracies in pulse oximeter readings at extreme temperatures are more likely to be caused by reductions in peripheral perfusion, rather than a result of the temperature dependence of the LEDs in the pulse oximeter

probe. Equally a decrease in a patient's temperature does not result in a significant error increase in pulse oximeter readings.

Probe position: Ear and forehead probes generally have a much faster response to changing SpO_2 than finger probes.

Medical conditions: Fortunately, pulse oximetry works well in the majority of cases. Some frequent encounters where the accuracy of pulse oximetry is often questioned are cardiac arrhythmia and myxoma.

Other effects on accuracy:

- exercise
- nail polish
- anaemia
- abnormal pulses
- non-pulsatile flow (bypass)
- signal to noise ratio (shocked, hypothermia, vasoconstrictors)
- Radiofrequency interference (MRI)

1.10. Signal processing algorithms

Regulary sources of errors dealt with by signal processing algorithms are motion artifacts, reduced saturation levels (<80 %) and low perfusion levels. Further significant problems are poor blood circulation and a weak pulse strength, that occurs in cases of insufficient blood pressure or reduced body temperature. Here it is difficult to separate the true pulsatile component from artifact pulses because of the low signal-to-noise ratio.

The amount of light that is transmitted is recorded as an electric signal. The signal is then processed using several signal processing algorithms to estimate the arterial oxygen saturation reliably in the presence of motion and other artifacts. Hence, the algorithms play a major role in transforming the signals collected by the sensors and extracting useful information. To enhance the performance several time- and frequency-domain signal processing algorithms are proposed, e.g.:

Estimation of oxygen saturation using the Beer-Lambert law
In case of using the law of Beer-Lambert to measure oxygen saturation in blood, it is necessary to take the following factors into account. The volume of blood at the sensor site varies with the arterial pulse. Also the thickness of the finger varies slightly with each pulse and thereby the path length for the light that is transmitted through the finger. Also, the precise intensity of the incident light applied to the finger is not easily determined. Thus, it is desirable to elimate those effects when estimating the oxygen saturation. Therefore, the Beer-Lambert law (c.f. equation 2) gets modified to eliminate the input light intensity and length of the path as variables.

Eliminating the input light intensity as a variable:

The light emerging from the baseline component can be written as a function of the incident light intensity I_0

$$I_1 = I_0.e^{-\alpha d} \tag{6}$$

where α is the absorption coefficient and d the thickness. Likewise, the intesity of light I_2 emerging from the pulsatile component is a function of its incident light intensity I_1 and can be written as

$$I_2 = I_1.e^{-\alpha_A \Delta d} \tag{7}$$

Substituting the expression of I_1 in the expression for I_2, the light emerging from the finger as a function of the incident light intensity I_0 is

$$I_2 = I_0.e^{-[\alpha d + \alpha_A.\Delta d]} \tag{8}$$

The effect of light produced by the arterial blood volume is given by the relationship between I_2 and I_1. Defining the change in transmittance produced by the arterial component as $T_{\Delta A}$, we have

$$T_{\Delta A} = \frac{I_2}{I_1} \tag{9}$$

Substituting the expressions for I_1 and I_2 in the above equation yields the following

$$I_2 = \frac{I_0.e^{-[\alpha d + \alpha_A.\Delta d]}}{I_0.e^{-\alpha d}} \tag{10}$$

The term I_0 in the numerator and the denominator can be canceled by eliminating the input light intensity as a variable in the equation. Therefore, the change in arterial transmittance can be expressed as

$$T_{\Delta A} = e^{-\alpha_A.\Delta d} \tag{11}$$

A device employing this principle in operation is effectively self-calibrating, and is independent of the incident light intensity I_0.

Eliminating the thickness of the path as a variable:

To simplify the equation, the logarithmic transformation is performed on equation 11.

$$\ln T_{\Delta A} = \ln\left(e^{-\alpha_A.\Delta d}\right) = -\alpha_A.\Delta d \tag{12}$$

The variable Δd can be eliminated by measuring arterial transmittance at two different wavelengths. The two measurements at two wavelengths provide two equations with two unknowns. The particular wavelengths selected are determined in part by consideration of a more complete expression of the arterial absorbance α_A

$$\alpha_A = (\alpha_{OA}).(S_a O_2) - (\alpha_{DA}).(1 - S_a O_2) \tag{13}$$

where α_{OA} is the oxygenated arterial absorbance, α_{DA} the deoxygenated arterial absorbance and SaO_2 the oxygen saturation of arterial Hb. α_{AO} and α_{DA} are unequal at all light wavelengths in the red and near infrared wavelength regions except for the isosbestic wavelength of 805 nm. At the isosbestic wavelength, the relative contribution of these two coefficients to the arterial absorbance α_A is of minimal significance in that both α_{OA} and α_{DA} are equal. Wavelengths selected are in a range away from the approximate isosbestic wavelength that is sufficient to allow the two signals to be easily distinguished. The ratio of the transmittance produced by the arterial blood component at red and infrared wavelengths follows from equation 12

$$\frac{\ln T_{\Delta AR}}{\ln T_{\Delta AIR}} = \frac{-\alpha_A(\lambda_R).\Delta d}{-\alpha_A(\lambda_{IR}).\Delta d} \tag{14}$$

where $T_{\Delta AR}$ equals the change in arterial transmittance of light at the red wavelength λ Rand $T_{\Delta AIR}$ is the change in arterial transmittance at the inrared wavelength λ_{IR}. If the two sources are positioned at approximately the same location on the finger, the length of the light path through the finger is approximately the same for light emitted by each LED. Thus, the change in the light path resulting from arterial blood flow Δd is approcimately the same for both the red and infrared wavelength sources. For this reason, the Δd term can be canceled

$$\frac{\ln T_{\Delta AR}}{\ln T_{\Delta AIR}} = \frac{\alpha_A(\lambda_R)}{\alpha_A(\lambda_{IR})} \tag{15}$$

Equation 15 is independent of the incident light intensity I_0 and the change in finger thickness. Because of the complexity of the physiological process, the ratio indicated in equation 15 does not directly provide an accurate measurement of oxygen saturation. The correlation between the ratio of equation 15 and actual arterial blood gas measurement is therefore relied upon to produce an indication of the oxygen saturation. Thus, if the ratio of the arterial absorbance at the red and infrared wavelengths can be determined, the oxygen saturation of the arterial blood flow can be extracted from independently derived, empirical calibration curves in a manner dependent on I_0 and Δd. For simplicity, a measured ratio R_{OS} is defined from equation 15 as

$$Ratio = R_{OS} = \frac{\alpha_A(\lambda_R)}{\alpha_A(\lambda_{IR})} \tag{16}$$

Determination of the oxygen saturation based on ratios R_{OS}

- Peak and valley method
- Derviation method – noise reduction software

Peak and valley method:

A photodiode placed on the side of a finger opposite the red and infrared LEDs receives light at both wavelengths transmitted through the finger. The received red wavelength light intensity varies with each pulse and has high R_H and low R_L values. Figure 7 shows the light intensity for red and infrared light through the finger. R_L occurs during systole when arterial blood volume is at its greatest, while R_H occurs during diastole when the arterial blood volume is lowest.

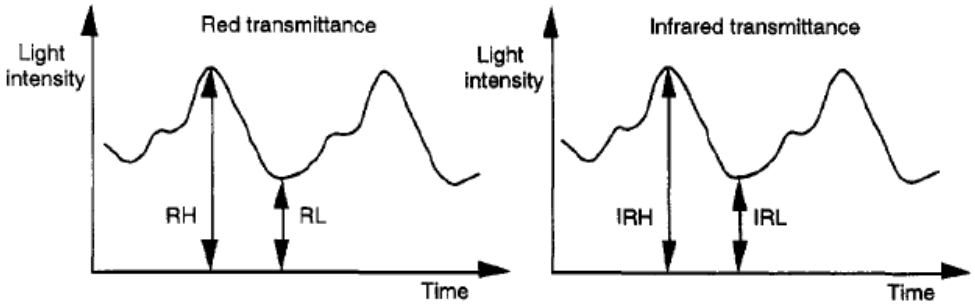

Figure 7: Transmitted light intensity converted into voltage.

Considering the exponential light decay through homogeneous media (c.f. 8), it is observed that

$$R_L = I_0 . e^{-[\alpha(\lambda_R).d + \alpha_A(\lambda_R).\Delta d]} \tag{17}$$

R_H can be written by following equation

$$R_H = I_0 . e^{\alpha(\lambda_R).d} \tag{18}$$

Taking the ratio of this two equations and simplify it, we have

$$\frac{R_L}{R_H} = e^{-\alpha_A(\lambda_R).\Delta d} \tag{19}$$

Taking the logarithm of both sides of equation 19 yields

$$\ln\left(\frac{R_L}{R_H}\right) = -\alpha_A(\lambda_R).\Delta d \tag{20}$$

Similar expressions can be produced for the infrared signal

$$\ln\left(\frac{IR_L}{IR_H}\right) = -\alpha_A(\lambda_{IR}).\Delta d \tag{21}$$

The relation of equation 20 and 21 yields

$$\frac{\ln\left(\frac{R_L}{R_H}\right)}{\ln\left(\frac{IR_L}{IR_H}\right)} = \frac{-\alpha_A(\lambda_R).\Delta d}{-\alpha_A(\lambda_{IR}).\Delta d} \tag{22}$$

The Δd terms in the numerator and denominator of the right side of equation 22 can be canceled which leads finally to

$$Ratio = R_{OS} = \frac{\alpha_A(\lambda_R)}{\alpha_A(\lambda_{IR})} = \frac{\ln\left(\frac{R_L}{R_H}\right)}{\ln\left(\frac{IR_L}{IR_H}\right)} \tag{23}$$

Thus, by measuring the minimum and the maximum emergent light intensities of both the red and infrared wavelengths (R_L, R_H, IR_L, IR_H), a value for the term R_{OS} can be computed. Empirically derived calibration curves are then used to determine the oxygen saturation based on R_{OS}.

ECG synchronization algorithms

With the ECG synchronization, the pulse oximeter uses the electrocardiographic QRS complex as a timing indicator that the optical pulse will soon appear at the probe. The R portion of the ECG signal is therefore detected and the time delay determined. This method of signal processing passes those components of the signal that are coupled to the ECG (i.e. the peripheral pulse) and attenuates those components that are random with respect to the ECG, like for example motion artifacts or other noise in the signal.

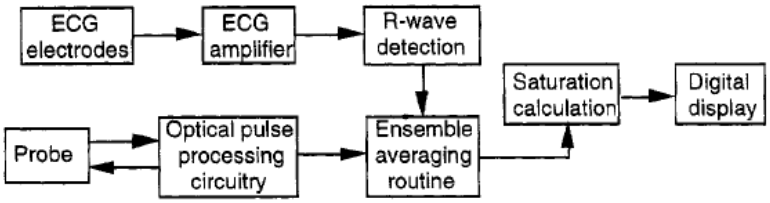

Figure 8: Block diagramm illustrating the ECG processing components

Spectralmethods of estimating SpO_2

SpO_2 values are currently computed using weighted moving average techniques. These methods process the time domain signals and give a precision of no better than +/- 2% (+/- one standard deviation). By contrast, the fast Fourier transform (FFT) and discrete cosine transform (DCT) lead to an improved estimation of SpO_2 and are useful to optimize the portability of pulse oximetry systems.

2. Preparatory activities for the lab

In this lab you will assemble your own simple heart rate monitor. Therefore, follow the instructions of the Nationale Instruments tutorial carefully that you can find here: http://www.ni.com/tutorial/14246/en/ . Please read the instructions before the laboratory begins.

3. Implementation in the lab

3.1. Build Your Own Heart Rate Monitor

3.1.1. Preparation of the sensor

In the first step, you will prepare the sensor for measurements. The following material will be provided:

- 1 12-inch piece of phone wire, at least 4 wires wide
- 1 Photoresistor with peak sensitivity near 650 nm
- 1 Red LED, recommended brightness of 10,000 mcd or higher
- 1 Header with at least 4 pins
- Waterproof medical tape
- Double-sided tape
- Soldering Iron and Solder
- Heat-shrink
- Scissors
- Wire stripper/wire cutter

3.1.2. Hardware design

For signal acquisition and processing you will get a pre-built board with all necessary circuit components for the detection of the pulse rate.

a) Describe the electrical circuit and try to explain the function of each circuit component.
b) Connect the sensor to the board and make sure it works. Analyse the signal and dimension appropriate filters for noise removal and elimination of the DC components.
c) Choose an appropriate amplification for your signal.

3.2. Measurements using the Pulse Oximeter

a) Registration of pulse rate
With the subject seated, attach the transducer to the palmar surface of a finger tip. Record the pulse with the subject's arm resting on the lab table. Plot the signal and determine the pulse rate.

b) Interferences in Pulse Oximetry

Examine the following possible impact factors and describe briefly their effects on pulse oximetry based on your observations:

- motion artefacts
- light artefacts
- nail polish