Optimum Place for Measuring Pulse Oximeter Signal in Wireless Sensor-Belt or Wrist-Band

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Abstract

This study was done in order to solve the optimum place for integrated pulse oximeter in case of a belt around human chest or wrist so that it would provide reliable oxygen saturation (SpO_2) readings for non-invasive constant health monitoring in modern wireless applications. In the study four spots on the wrist and on the chest were chosen and measurements from these spots were done by using a special device with an adjustable angle between light detector and the light sources. Then resulted signals were analyzed by calculating the average amplitude, normalized amplitude and signal-to-noise –ratio (SNR). Considerably clear signals were achieved both from wrist and chest and best resulted SNR was 27dB from the chest. The highest normalized signal amplitude was detected from the wrist appearing as big as 5.9% of the total measured signal, which was relatively high compared to other values. Results were promising and showed that an easy portable monitoring device is possible but also many problems, that should be overcome, were detected.

1. Introduction

Pulse oximetry is used universally in the supervision of critically ill patients in intensive care units and operating theatres to provide a reliable oxygen saturation reading [1]**.** Signs and symptoms of decreased ability to ventilate are, for example, cyanosis, dyspnea, tachypnea, decreased level of consciousness, increased work of breathing and loss of protective airway reflexes [2]. If some of these symptoms occur, patient assesment will determine the need for continuous oxygen saturation monitoring. Nowadays measurements are normally done by using a finger probe which can be considered reliable and practical in case the patient is hospitalized or lying steadily. Though, technologies and needs for different kind of healthcare are constantly changing. That is why it is extremely important to be able to offer solutions which can be used also when supervising moving patients in different kinds of environments. Especially, different modern home healthcare and sport applications recall for wireless, reliable and easy-to-use –methods so that testing could be done continuously also in real-life situations and not only in hospitals. In addition, elderly people healthcare is changing markedly because of internet and high technology telemedicine. It is already possible to see patient's physiological state or some parts of it by transferring information through sensor networks and servers straight to doctor's mobile phone or work station. That would make it easy for old people to stay home alone even though they have some disease which requires continuous supervision.

In this study, pulse oximeter device, which was built in the University of Oulu (see Fig 5), was used in order to find the best place on human's chest or wrist to provide the highest accuracy for pulse oximeter signal with lowest noise and disturbances. This study aims to optimize integration of pulse oximetry to wireless sensor belt and wrist band development.

2. Principle and instrumentation

2.1. Pulse oximeter principle

Haemoglobin consists of four subunits joined together. When an oxygen molecule binds to one subunit, the other subunits become more likely also to bind oxygen. Haemoglobin saturation curve is characterized in to its S-form by this feature of haemoglobin. Shift to the right in the curve indicates that oxygen is bound less tightly – less is taken up in the lungs but is more easily released in tissues. The

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oxyhaemoglobin dissociation curve is the relationship between the partial pressure of oxygen in the blood and the percentage of oxygen bound to haemoglobin compared to the maximum. Factors such as decreasing carbon dioxide concentration, increasing pH and decreasing temperature will shift the curve toward the left. A left-shifted curve implies that the haemoglobin molecules will be more saturated at lower partial pressure of oxygen. Figure 1 shows the oxyhaemoglobin dissociation curve in three different cases [3].

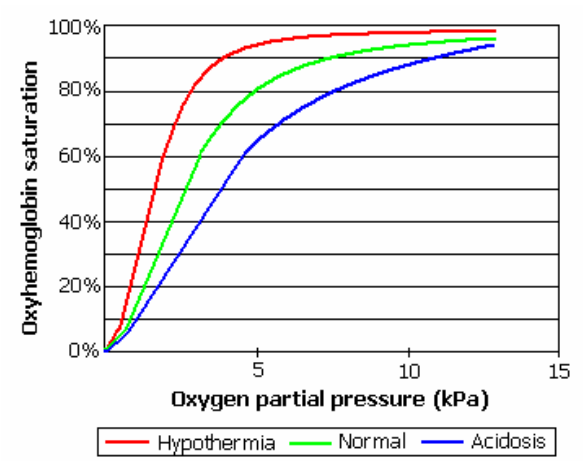

Figure 1. Oxyhaemoglobin dissociation curve.

Clinical measurement of the arterial oxygen saturation of haemoglobin has been dominated lately by pulse oximetry – a non-invasive technology that is common practice under anaesthesia in operating theatres worldwide [4]. Dual-wavelength illumination of arterial blood results in an absorption contrast that depends upon the proportion of haemoglobin that is chemically combined with oxygen. Pulse oximeters differentiate between optical absorption by blood and other anatomical constituents by observation that pulsating arterial blood induces dynamics into the absorption characteristics of well-perfused peripheral sites [5]. The sensor is based on the fact that the colour of blood varies depending on the oxygen it contains. In particular the haemoglobin molecules reflect more red light when they are oxygenated than when reduced while its behaviour is the opposite when the light is infra-red. The oximeter shines two beams of light through a finger or earlobe or etc and those beams are finally received in the photodetector. By comparing the light intensity that is received for each wavelength, the oximeter is able to derive the light that is being absorbed by the blood and, consequently, the oxygen saturation. Moreover, the heart rate can be estimated from the slight change in the colour provoked by a beat of the heart pushing arterial blood into the finger [6].

Pulse oximetry utilizes the plethysmographic principle in combination with the optical absorption characteristics of haemoglobin [7]. Photoplethysmoraphy (PPG) is an electro-optic technique to measure the pulse wave of blood vessels. In pulse oximeter, which is the measuring apparatus for PPG, motion artefacts can limit the accuracy of the measured PPG signal during movement [8]. The typical pulse oximetry sensor contains two LEDs that emit red and infrared light into a pulsatile tissue bed. The scattered light is collected with a photodiode positioned on an opposite surface (forward scattering method) or an adjacent surface (reflection method). The "pulse" comes from the time-varying amount of arterial blood in the tissue during the cardiac cycle. Then the signals which are collected by the photodetector, crate a plethysmographic waveform due to the resulting cycling light attenuation. The relative modulation of the collected red and infrared light signals, referred to as the modulation ratio R, is used to estimate arterial oxygen saturation, SpO_2, based on an empirical calibration relationship expressed within the oximeter [9]. Figure 2 shows a model of a pulse oximetric assumption in which pulsatile signal change is due to arterial blood volume change. In the figure alternative current and direct current can be calculated by using two equations given below [7].

$$AC = Rd - Rs \quad \text{and} \quad DC = \frac{Rd + Rs}{2}.$$

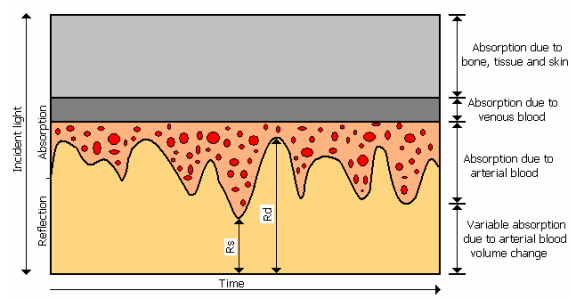

Figure 2. Conceptual tissue model for pulse oximetry.

2.2. Measurement device introduction

When designing our device, we aimed to an easily and diversifiedly adjustable prototype. To reach this goal, programmable electronics was used to get the system adjustable straight from the computer. In addition, separate transmitter and receiver units were used to make different kinds of measurement geometries possible. The instrumentation which is used

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to form the pulse oximeter is built by PC, LabView 8.2 –program, National Instrument Data Acquisition Card 6211, voltage supply and the sensor part which was built in our university.

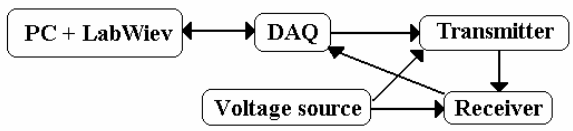

Figure 3. Instrumentation

In executing pulse oximetry, the controlling signals for the photo diodes are generated by the Data Acquisition Card. The photo diodes are time multiplexed by a frequency of 312.5 Hz by turns and when one is emitting light, it simultaneously transmits carrier wave whose frequency is 20 kHz. If the volume of blood in the measurement spot is changed, an amplitude modulation to the carrier wave is triggered and this modulation is demodulated by using coherent expression. The signal which reaches the receiver is high-pass filtered, rectified synchronously by using a demodulator.

The phase shift of the carrier waves at the photo diodes is 180°. After low-pass filtering the voltage at the red photo diode is negative and for the infrared light diode positive. Because of this, no multiplexing is needed because differentiating these two different signals is based on the fact that one is negative and the other one positive.

Now we have a curve which has minimum and maximum peaks which change their values by the change of the blood volume at the measurement spot. The peaks which are obtained at the frequency of 312.5 Hz are identified by using the LabWiev-program created for this task. Minimum and maximum peaks are collected both to their own curves and from these two curves the amplitude modulation, caused by the blood volume change, can easily be seen. After this the program finds AC and DC components of red and infrared lights and calculates the ratio R which is used to determine the actual oxygen saturation value.

The pulse oximeter execution principle is presented in figure 4.

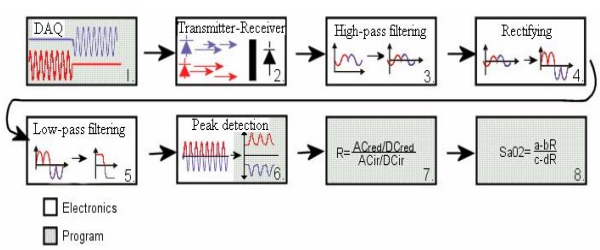

Figure 4. Pulse oximeter execution principle

In our measurements we concentrated on studying SNRs and signal amplitudes instead of finding out actual SpO_2-readings. That was done because of looking for an optimum spot that would provide strong noiseless signal from which actual SpO_2 reading could later be calculated in our sensor belt or wrist band development.

All measurements were done by using a special pulse oximeter device which was built in the University of Oulu. Device was built so that the adjusting angle, α, can be changed as big or as small as needed due to the location of the sensor on patient's skin. By using this adjustable probe, it was possible to obtain visible pulse oximeter signal from almost every spot on patient's skin by adjusting the angle and simultaneously checking the signal on computer screen. For each patient this angle in all measurement spots was a little bit different so it had to be specified separately every time.

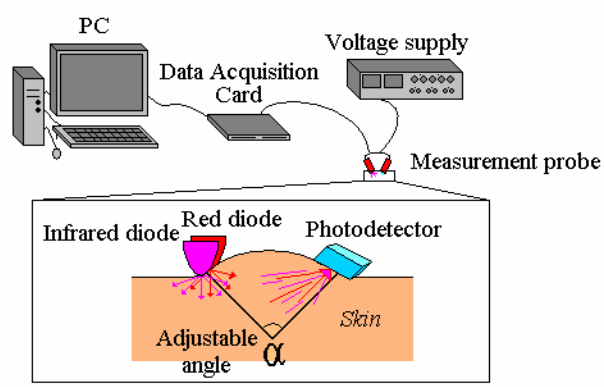

Figure 5. Measurement setup and principle from patient's skin by using a special device with an adjustable angle between light sources and a detector

3. Experiments

In the experimental part of the study we only concentrated on measuring spots around human chest and wrist in order to find the most optimal places for the integrated SpO_2 sensor. Before real measurements, some preliminary tests were accomplished in order to find the spots which would give the most clear saturation curves. Four spots from both wrist and chest were chosen (figures 6-9) and measurements from those areas were done. Measurement setup was built in a dark room to avoid external light interference. Also

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target vibration was tried to eliminate as well as possible. The age distribution of the measured patients was 23-29 and their body structures were normal. 20% of the patients were Asian and 80% were Finnish but skin colour did not seem to make any affect on the results. More problems occurred if the thickness of the fat tissue in the measurement spots was bigger than others and that is why the spots were chosen locating near bones so that the distance between the sensor and the bone was small enough to provide good returning signal for the photo detector if the probe without too many reflections and refractions.

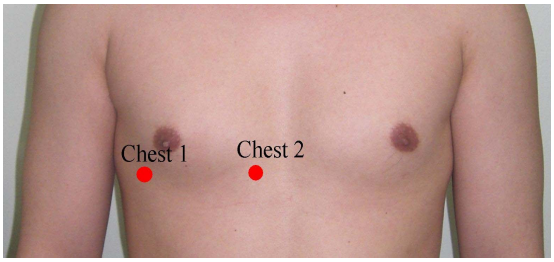

Figure 6. Measurement spots on the chest

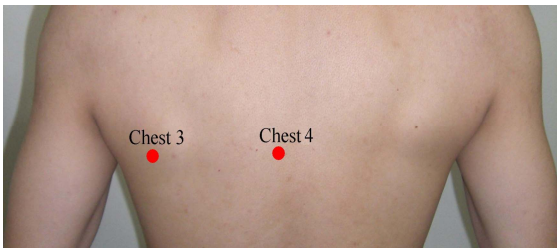

Figure 7. Measurement spots on the back

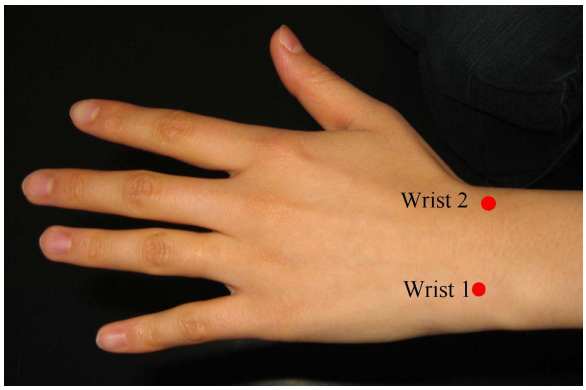

Figure 8. Measurement spots on the outer wrist

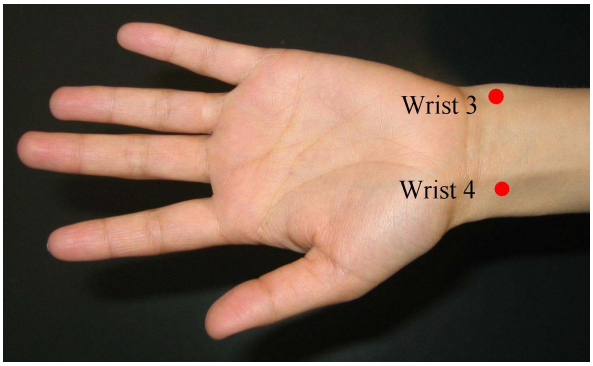

Figure 9. Measurement spots on the inner wrist

Figures 10 and 11 are demonstrating how normalized amplitudes and SNRs were resulted in the measurements. Measurements from the wrist area were easier to accomplish because unfortunately chest area is extremely sensitive for disturbances because of a constant movement caused by breathing. Still all 8 measurement areas were resulting close to each others and gave similar results. The basic rule was that big amplitudes were achieved by using wrist spots and higher SNR by using chest spots.

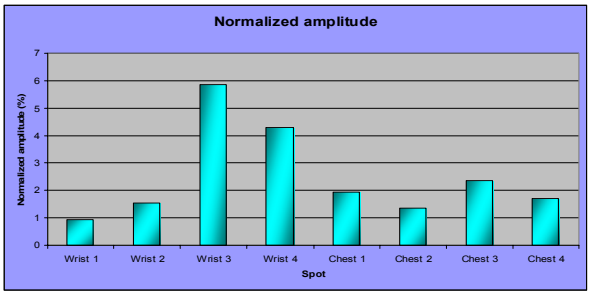

Figure 10. Normalized amplitude of the pulse oximeter signal in all eight measurement spots

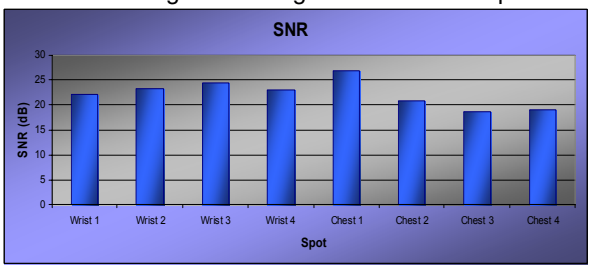

Figure 11. The signal-to-noise –ratio of the pulse oximeter signal in all eight measurement spots

The signal analysis showed that if the device is wanted to be integrated in a chest belt, the optimum place for integration would be chest 1 -spot. It

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provided SNR almost as great as 27dB, which tells that signal recorded from this spot is really clear. Promising SNR, 26dB, was also recorded from the wrist 3 –spot which offered also relatively big amplitude, 0.8V, and normalized amplitude, 5.9% of the total measured signal. In case of chest 1 –spot normalized amplitude was only 1.9% of the total.

4. Errors

Few of many possible facts that may have caused errors in the measurement results given above are perfusion problems, target movement and wrong target, detecting errors, optical interference and broken fibers. Perfusion problems are caused usually by a significant decrease in peripheral vascular pulsation, such as in hypothermia, vasoconstriction, hypotension, during cardiopulmonary bypass or cardiac arrest and they may result in a plethysmographic signal which is insufficient to be processed reliably by the oximeter [3]. Patient movement reduces the reliability of a pulse oximeter severely. Even small patient movements, such as shivering, can cause powerful artifacts that swamp the pulsatile absorption signal [10]. Also any dislocation of the nail bed for example can affect the transmission of light through the digit in case the measurement is done through a finger. Dark nail polish and bruising under the nail can also severely limit the transmission of light and result in an artificially decreased SpO_2-value [11]. Detecting errors happen because pulse oximeters are unable to differentiate between oxygen and carbon monoxide bound to haemoglobin. Readings in the presence of carbon monoxide will be falsely elevated. Pulse oximetry should never be used in suspected cases of carbon monoxide exposure and an arterial blood gas reading would also be good to obtain. In addition they should never been used in a cardiac arrest situation because of the extreme limitations of blood flow [11]. Bright external light sources are known to affect pulse oximeters and all pulse oximeters share this sensitivity. This occurs because these instruments use optical means to make their measurements. Consequently, to obtain accurate measurements, potential sources of optical interference must be controlled. Because pulse oximeters' optical components are located in the probe, proper probe application and use are key factors in reducing optical interference. Optical interference occurs when bright light from an external source reaches the photodiode or when light reaches the photodiode without passing through a pulsatile arteriolar bed [3]. In case of intra-vascular fibre optic oximetry sensors, optical fibres which are used to guide the light into the target may suffer several damages before reaching the target. This may cause severe measurement errors [7].

5. Discussion

This study concentrated on finding out the most suitable spot for the integrated pulse oximetry sensor which would make measurements not only when the patient is lying down but also while he or she is moving. That forces us to take into account the principal factor which limits both the practical accuracy and general applicability of pulse oxymetry – poor photoplethysmographic signal [12]. It is caused usually by low perfusion states or artifact corruptions arising from ambient light or subject movement [13], which lead usually to interpretation errors and false alarms [14].

These days especially motion artifacts are tried to minimize because many applications are wanted to design for moving patients. Also measurements which were done in this study were affected by these artefacts for example by moving chest or shivering wrist. In case the interface between the measurement probe and the skin was moving, the signal immediately showed the movement by temporarily fading or peaks. That is why all measurements from all spots had to be taken many times from each patient so that reliable results could be recorded. Also the person executing the measurements was affecting the results by giving some small vibrations to the probe.

Before the sensor can be reliably integrated to a chestbelt or wrist device, more experiments with moving patients should be done in order to see how movement in these spots affects the signal and can results be trusted. Also many signal processing steps still have to be completed in order to eliminate motion artifacts Many problems still have to be overcome but this study proves that wireless integrated pulse oximeter implanted in a chest belt or wrist band is possible to achieve with many benefits and practical applications.

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