Simple signal processing method for pulse oximetry

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***Abstract* – This paper presents a simple signal processing method used in the pulse oximetry laboratory kit. The laboratory kit was designed for research and educational purposes in the medical equipment oriented areas. The presented device allows to show not only the oxygen saturation and the heart rate as a standard oximeter, but also the whole oximetry signals. It means there is a possibility to study the impact of set-up parameters and ambient surroundings on the measured values. This paper also includes the principal description of the laboratory kit.**

I. INTRODUCTION

Pulse oximetry is a commonly used non-invasive method, mainly in the intensive-care medicine, allowing the monitoring of oxygenation of blood. The principle of pulse oximetry is based on the fact that reduced haemoglobin and oxygenated haemoglobin have different absorbance on red and infrared wavelength.

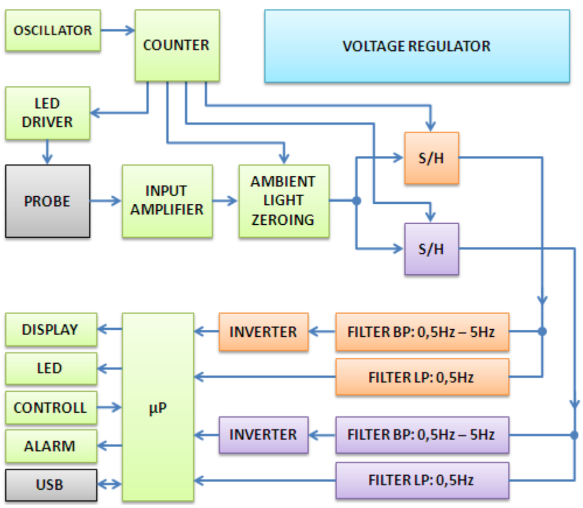

Fig. 1: *Block diagram*

Pulse oximeters are usually designed as small devices able to display only the oxygen saturation and the heart rate. Oximeter units built in more complex devices such as monitors of vital functions are often able to display also the photoplethysmographic curve. This curve is displayed only if the device parameters are set and the signal has typical behavior. As a result, there is nearly no chance to see and measure which parameters of the device are critical for pulse oximetry measurement. In addition, it is not possible to monitor how the artifacts (mainly motion artifacts) affect the measurement on professional devices.

For research and educational purposes, it is necessary to study the sensing techniques, oximetry signals and the methods used for oximetry signals processing. In practical constructions, sophisticated algorithms allowing excellent methods of computing are used. To achieve accuracy, many periods of measured signals are included in the calculation and it takes quite a long time to see the actual condition. It is appropriate for precision, but not very useful for research and educational purposes.

For the purpose of understanding these things, a new laboratory kit has been developed. This kit allows the user to interfere in adjusting inner parameters and observe the response. The block diagram of the whole device is in the Figure 1.

Additional software for a PC offers to control the whole device, displays all important signals in real-time and also store the signals into a file.

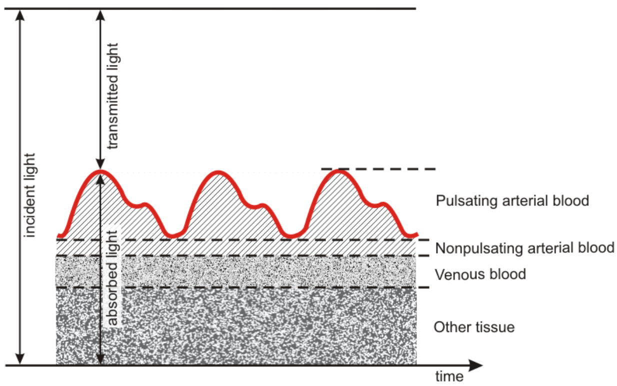

Fig. 2: *Light path*

II. METHOD

In pulse oximetry, the light illuminates venous and arterial blood and the light must pervade through the tissue. The length of light path is constant. Figure 2 represents the path between source and receiver which is important for measurement. It is necessary to illuminate a sensed place with two wavelengths which secures that SpO_2 value is possible to calculate.

The transmitted light consists of a constant (DC) and a variable (AC) component. Constant component is usually influenced by ambient light which must be eliminated before the actual processing.

Measured signal from a photodiode contains information about transmitted red and infrared light and ambient light. After zeroing the parasitic ambient light, the signal is split into two branches, corresponding red and infrared light, using Sample and Hold circuits. Constant and variable components are separated by Butterworth filters. For the DC component, second order low pass filter 0.5Hz is used. AC component is separated by band pass filter, being composed of second order Butterworth high pass and low pass filter from 0.5Hz to 5Hz. Since the plethysmographic curve is displaying absorbed light, not transmitted, variable components of signal must be inverted.

All signals are converted by microprocessor and SpO_2 and the beat rate are calculated.

III. LABORATORY KIT

For understanding of pulse oximetry, it is important to know the physiological principle of oxygen transport in blood, inner signals in the device and the basic principles of oximetry signals processing. One part of digital signal processing is the calculation of the required values - the oxygen saturation and the beat rate.

Laboratory kit is designed as an educational module with markedly separated function blocks allowing direct measurement of inner signals in a few points of the device with an oscilloscope. Each block is illustrated in the Figure 1. It enables users to investigate all commonly inaccessible signals in detail. Users can monitor the whole signal path step by step from the LED drive signals to the input of the A/D converters.

The board communicates with the PC via USB interface as HID (Human Interface Device), no drivers required. Operating software allows to control the device and record the signal. It is possible to use more sophisticated algorithms, such as Pan-Tompkins algorithm, to find local peaks in noised signal.

IV. SIGNAL PROCESSING

The microprocessor samples four signals – AC and DC components of IR and red signals. In order to simplify the signal processing, sampling frequency is 100Hz, even though the maximal frequency of a useful signal is roughly 5Hz. This sampling frequency guarantees capturing of the minimum and the maximum of each period as a number without any future processing. When the samples of the AC components of IR and red signals are taken, they proceed to the peak detector. A flow chart of the algorithm is on the Figure 3

Signal from the 10-bit A/D converter (no sign, range 0-1023) can be slightly noisy and the well-known zero-derivate method may cause false detection.

Several local peaks can occur in the oximetry signal and this detector has to be able to distinguish the right ones. As soon as we have measured several periods, we can recognize the trend of the signal and thereby create the scale of the signal. In fact, we don't care much about the mathematical minima and maxima, but we deal with the peaks and valleys in the signal.

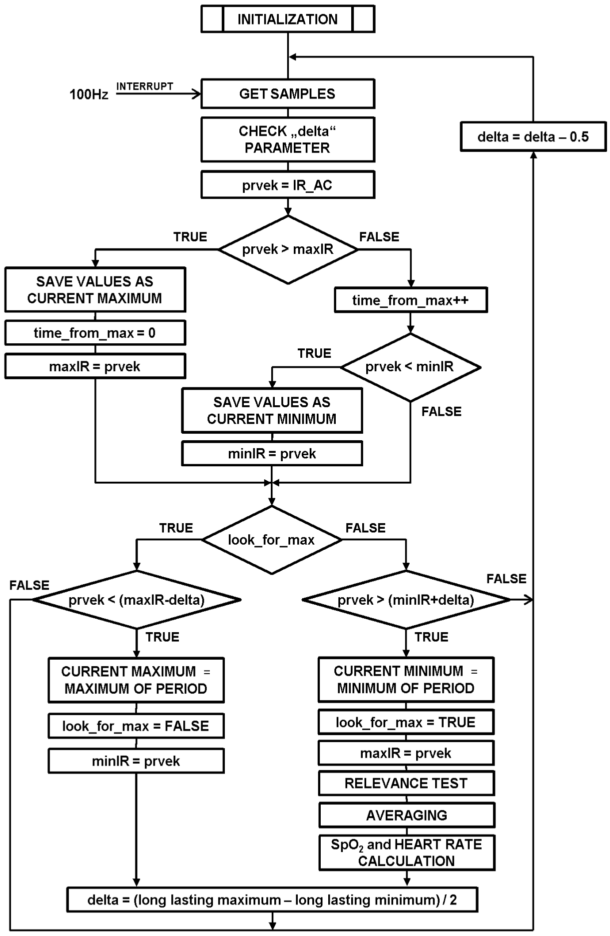

Fig. 3: *Peak detector flow chart*

The principle is based on the fact that local maxima and minima have to alternate and there is some minimal difference between these two points. So the technique is to find the highest or lowest point around which there are points lower (or higher) with a minimal difference on both sides. This minimal difference is determined by "delta" parameter and it is quite adaptive. In every single cycle (100 cycles per second), the "delta" parameter decreases by approximately 0.05% of the A/D converter range (it is 0.5 using the 10-bit converter) and in case of finding a local minimum or maximum, the "delta" parameter is recalculated. It means that if the light intensity changes rapidly, the algorithm can adapt very quickly. This real-time algorithm is very easy to implement both to a PC and any basic microprocessor. The algorithm detects peaks only from the IR signal, the red one has just the same shape but with different amplitude. However, when we save current values (minimal or maximal), it is necessary to save both red and infrared signals and also the DC component of both signals.

When the maxima and minima of period are found, it is necessary to perform a relevance test. It should prevent false detects from affecting the results. The duration of a period, the minimum-maximum distance and the relative difference in comparison to previous results are checked.

When a valid period is located, averaging process takes several latest periods and calculates the Ratios (see section V. SpO_2 computation). The acquired set of Ratios is averaged and the final ratio is converted to SpO_2, the average time between two neighboring maxima peaks is converted to the heart rate value.

The real pulse oximetry signals with typical motion artifact are displayed in the Figure 4.

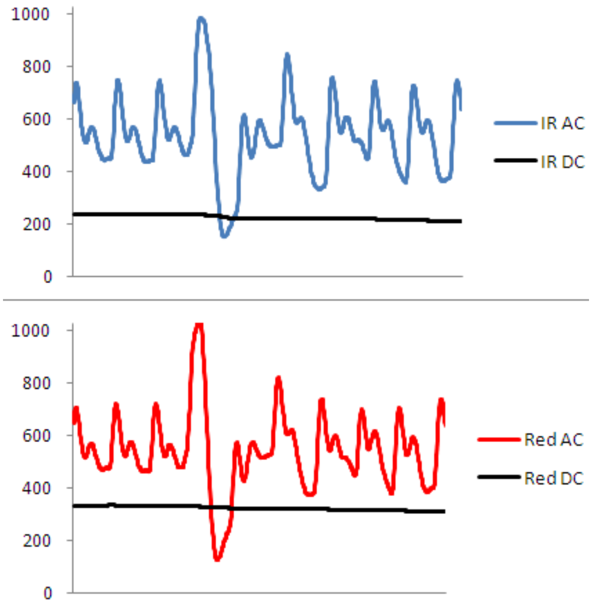

Fig. 4: *Real oximetry signal with motion artifact*

V. SpO_2 COMPUTATION

The oximetry signal is measured on two wavelengths and consists of a constant (DC) and a variable (AC) component. To calculate the normalized ratio *R*, we use the red and infrared time signal. The ratio value is given as a fraction of red and IR constant and variable components

$$R \approx \frac{\dfrac{dI_R/dt}{I_R}}{\dfrac{dI_{IR}/dt}{I_{IR}}} \approx \frac{\dfrac{AC_{red}}{DC_{red}}}{\dfrac{AC_{IR}}{DC_{IR}}}. \qquad (1)$$

To calculate the SpO_2 value from normalized ratio, an empirical linear approximation can be used. This linear approximation is given as

$$SpO_2 = 110 - 25R. \qquad (2)$$

Theoretical calibration curve results from Beer-Lambert law and the relation between theoretical and empirical curve is displayed in the Figure 5. The estimated error using the empirical equation (2) is less than about 2 % for SpO_2 higher than 50 %.

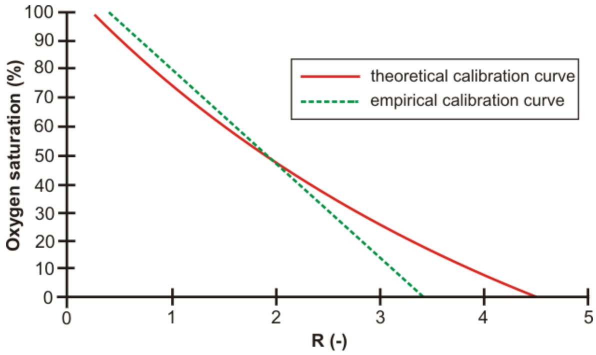

Fig. 5: *Calibration curve*

VI. CONCLUSION

A new laboratory module for pulse oximetry was developed. The module allows to measure not only the oxygen saturation and the heart rate as the standard oximeters but also to study the oximetry signals. It means it is possible to study the impact of the change of set-up parameters on the measured signals and values. The sensed oximetry signals could be processed within the module or stored to a PC via USB for future processing.

The important advantage of the presented pulse oximeter is the implemented peak detector, which is resistant to signal artifacts - mainly to the motion artifacts. The peak detector is completely described in section IV. Signal processing.

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