Laboratory Kit for Pulse Oximetry

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***Abstract*—The paper deals with design and realization of a laboratory kit for pulse oximetry. The designed laboratory kit is a unique device that allows showing inner oximetry raw signals. It enables to study principles of pulse oximetry and methods for processing of oximetry signals. The device is usable both for research and educational purposes.**

I. Introduction

At present the pulse oximetry is a commonly used non-invasive method allowing the monitoring of oxygenation of blood and having very wide area of use. The principle of pulse oximetry is based on the fact that reduced haemoglobin and oxygenated haemoglobin have different absorbance on red and infrared wavelengths [1].

The currently most frequent applications of pulse oximetry are applications in intensive care, mainly continual monitoring of oxygen saturation in intensive care units as a prevention of severe hypoxemia, monitoring during the invasive procedures and monitoring during and after anaesthesia [2].

Another application of pulse oximeters in hospitals is universal surveillance for early recognition of patient deterioration in postoperative care. It was shown that universal oximetry surveillance reduced need for patient rescue and intensive care unit transfers [3].

In last decades the pulse oximetry has gained wider ulitization. Pulse oximeters are used not only in hospitals, but also in homecare. Typically, pulse oximetry is used for monitoring of sleeping hypoxemia caused by Obstructive Sleep Apnea [4] or Sleep Apnea Hypopnea Syndrome [5].

Pulse oximeters have also many applications in special types of medicine such as aerospace medicine [6].

The modern and very interesting utilization of pulse oximetry are telemedicine applications such as Global Pulse Oximetry Project [7]. This project is a project of World Health Organization (WHO) focused on improvement of the quality of anaesthesia care globally by looking at ways how to develop affordable, robust pulse oximetry devices for operating rooms in the developing world. The part of this WHO project is also a project Wireless Pulse Oximeter on a Cell Phone (iPleth) [8] for safe perioperative care in Uganda.

Standard pulse oximetry uses two wavelengths (red and infrared) for measuring tissue light transmission. It means that the standard oximetry is able to recognize only two different absorbers in blood, oxyhaemoglobin and reduced haemoglobin. The presence of other types of haemoglobin (carboxyhaemoglobin and methaemoglobin) produces wrong values of oxygen saturation [9]. The effect of methaemoglobin were discussed for example in [10] and the effect of carboxyhaemoglobin in [11].

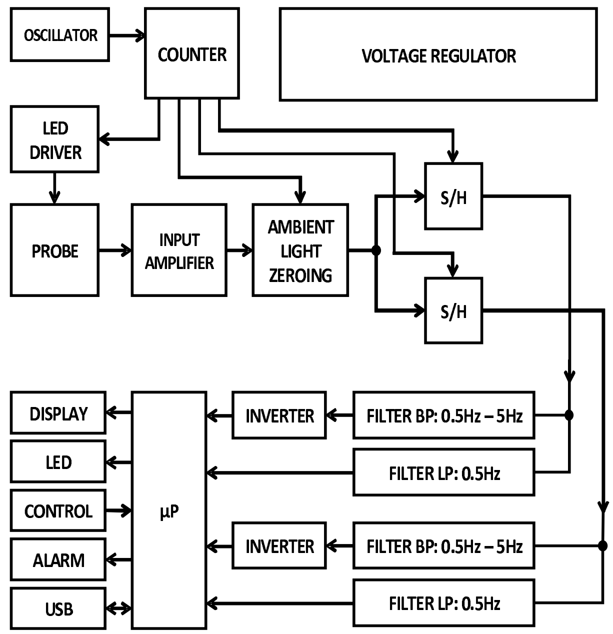

Fig. 1. Block Diagram

There are many limitations in pulse oximetry which lead to inaccurate values of saturation [1]. The most important ones are motion artifacts and ambient light. The effect of limitations could be decreased using proper signal processing. The most frequently used methods of processing of pulse oximetry signals are digital filtering, wavelet decomposition and autoregressive (AR) modelling [12].

For the full comprehension of pulse oximetry principle and properties of oximeters it is necessary to study the sensing techniques, oximetry signals and the methods used for oximetry signals processing.

Standard oximeters are designed as small devices able to display only the oxygen saturation and the heart rate.

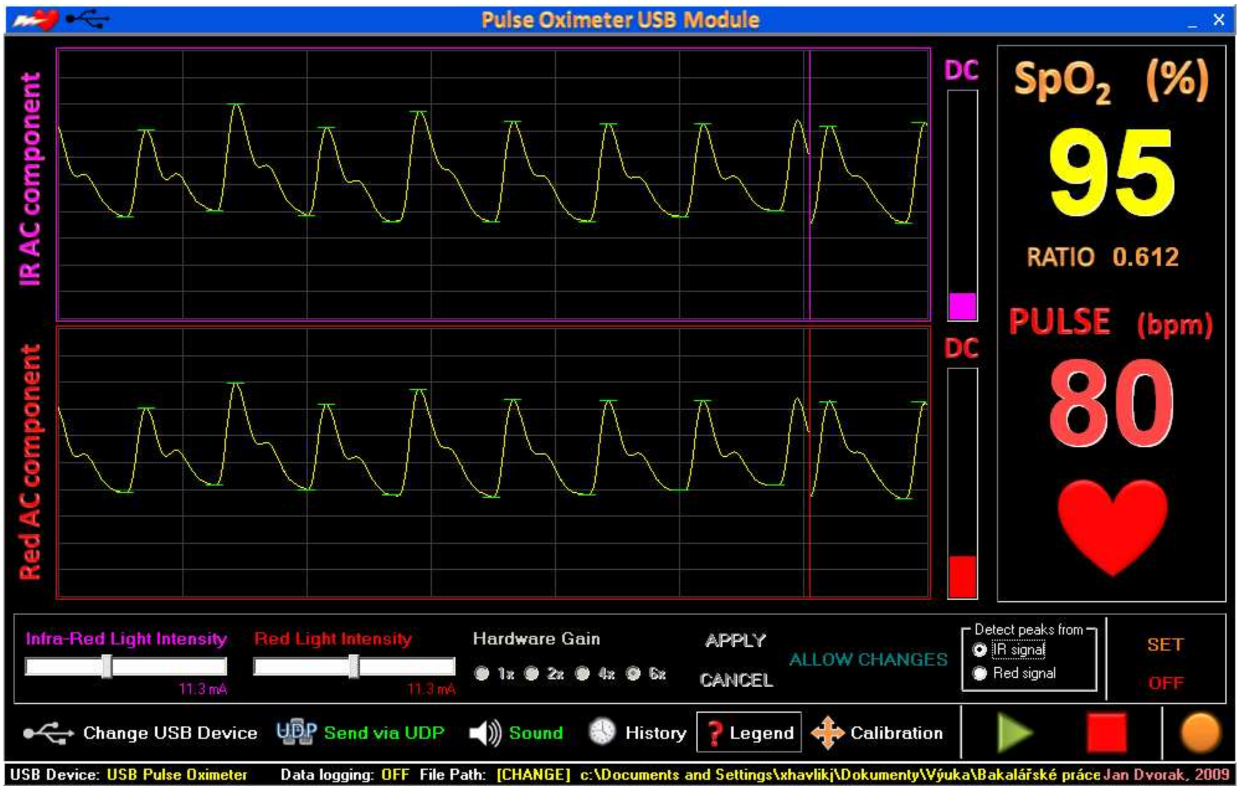

Fig. 2. Main Window of Application

Oximeters built in more complex devices such as monitors of vital functions are often able to display also the photoplethysmographic curve. Unfortunately there is no chance of displaying the inner signals needed for comprehension of the function such as raw signals from the red and infrared sensors and pre-processed oximetry signals. This is very inconvenient for understanding pulse oximetry principles.

Due to described features of standard oximeters, a new pulse oximetry laboratory kit has been designed. This kit allows monitoring of all crucial signals and values in real-time and records them to a PC for future processing.

II. Methods

The main task is to design and to realize the laboratory kit that allows detailed investigation of oximetry principles and properties of oximeters and illustrative education in the medical equipment oriented seminars. For easy understanding of pulse oximetry it is important to describe four items: the physiological principle of oxygen transport in blood, signals in a few points of the pulse oximeter, the principles of oximetry signals processing and the calculation of required values (the oxygen saturation and the heart rate) and finally the effect of hardware set-up parameters like amplification and filtration of signals on the output values.

The most interesting signals in pulse oximetry are the drive signals for red and infrared LED, the raw signals from the detector in the red and infrared bands and the pre-processed red and infrared signals - separated DC and AC part of signals in both bands. Monitoring these signals is impossible with standard oximeters. The designed laboratory kit has to allow both direct monitoring of signals using oscilloscope and recording of signals to a PC for successive processing.

Due to the unequal finger absorbance with different patients (which is mainly caused by different thickness of probed finger) and also due to the changes of ambient lighting, the drive circuits has to allow changes of the LED current.

For the wide usage in laboratories and lectures it is appropriate to be able to use the kit both as a stand-alone equipment for direct monitoring of the signals and as a slave device for monitoring and recording the signals to a PC.

III. Realization

The laboratory kit is realized in a form of two printed circuits boards – the main board consists of all necessary circuits (power supply, LED driver, input amplifiers, sample/hold circuits and filters, processor unit with integrated A/D converters and USB interface and seven-segment display), the second one includes a LCD display. The display board is not required for the function of oximeter, but it is appropriate for stand-alone use without a PC for more transparent display of the results. The block diagram of the device is shown in Figure 1.

The main board is designed with distinctly separated function blocks. The board contains a lot of test pins allowing direct monitoring of the important signals with an oscilloscope. It enables students to investigate all commonly inaccessible

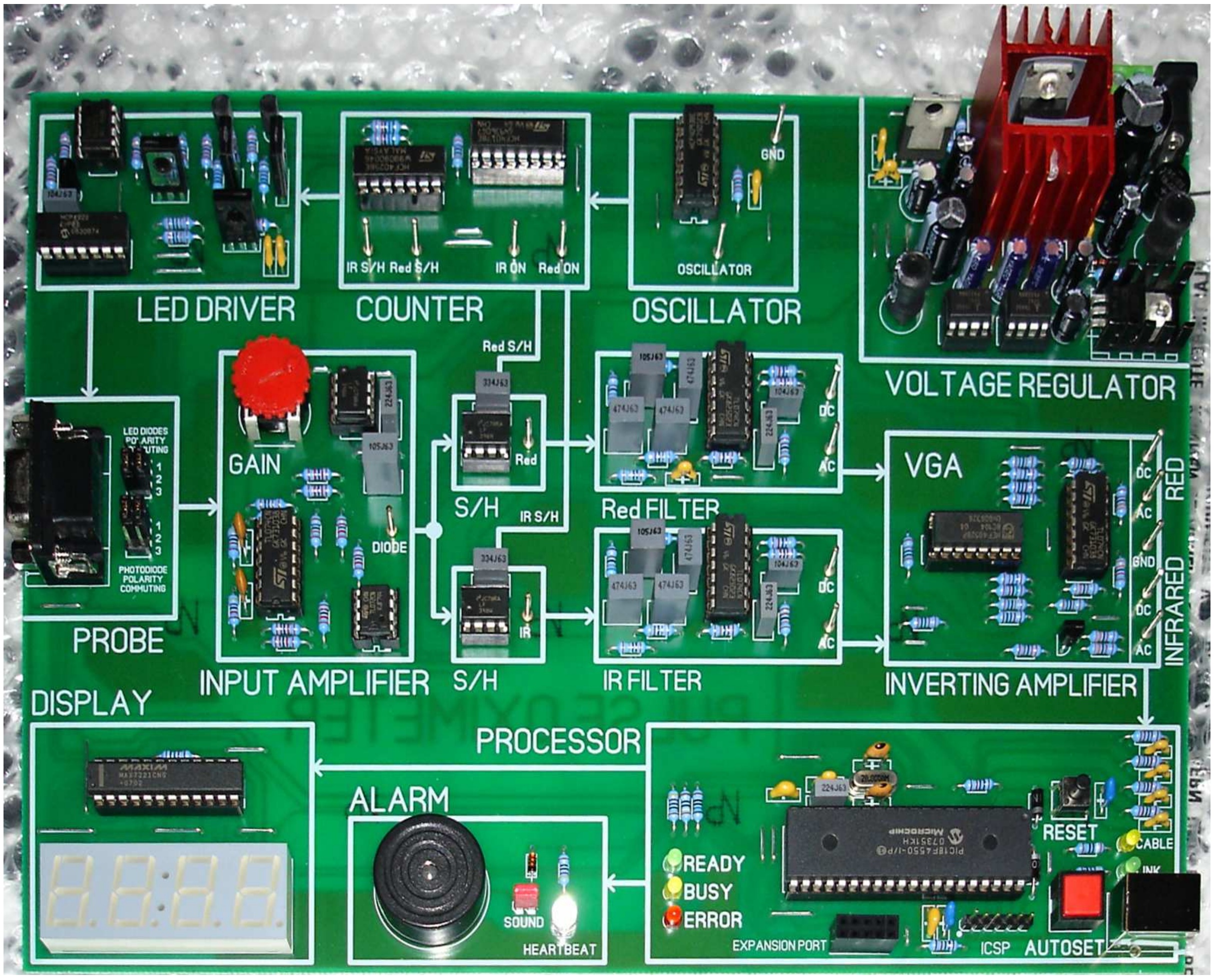

Fig. 3. Final Realization

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.

For brief displaying of the pulse oximetry output values (oxygen saturation and the heart rate) and basic configuration parameters, the main board is equipped with a four digit seven-segment display. Detailed parameters can be displayed using the expansion board with character LCD display or in a PC using the supporting application. The application allows not only displaying the output values and configuration parameters but also displaying the pre-processed signals in red and infrared bands, and changeing all configuration parameters and selecting the methods for computing output values.

For better transparency, each block of the main board is marked with a label showing its function. Final realization is shown in Figure 3.

Hardware realization is supported by a software application for Windows based PC (the main window of application is shows in Figure 2). The application can display red and infrared DC and AC signal in real time (two signals in left upper part of window). These signals are parameterized and total maximums and minimums are labeled. Values of oxygen saturation (SpO_2) and hearth rate (pulse) are continually computed.

The application also allows to set up hardware parameters such as red and infrared light intensity and gain of pre-amplifiers.

For further processing of signals, the application is able to store sensed values of red and infrared DC and AC signal to hard drive or memory storage. Example of 500 stored samples (about 5 periods of signals) are shown in Figure 4.

The application is also able to send samples via UDP packets. It means it is possible to measure with one oximeter connected to a PC and to show the signals in other PCs in network. It is only necessary to know IP address of PC with oximeter.

Finally, the application allows changing the convert function between normalized ratio R (which is measured in pulse oximery in fact) and oxygen saturation SpO_2 which is displayed.

IV. Conclusion

The presented laboratory kit is the unique requisite which allows describing the theoretical principles of pulse oximetry

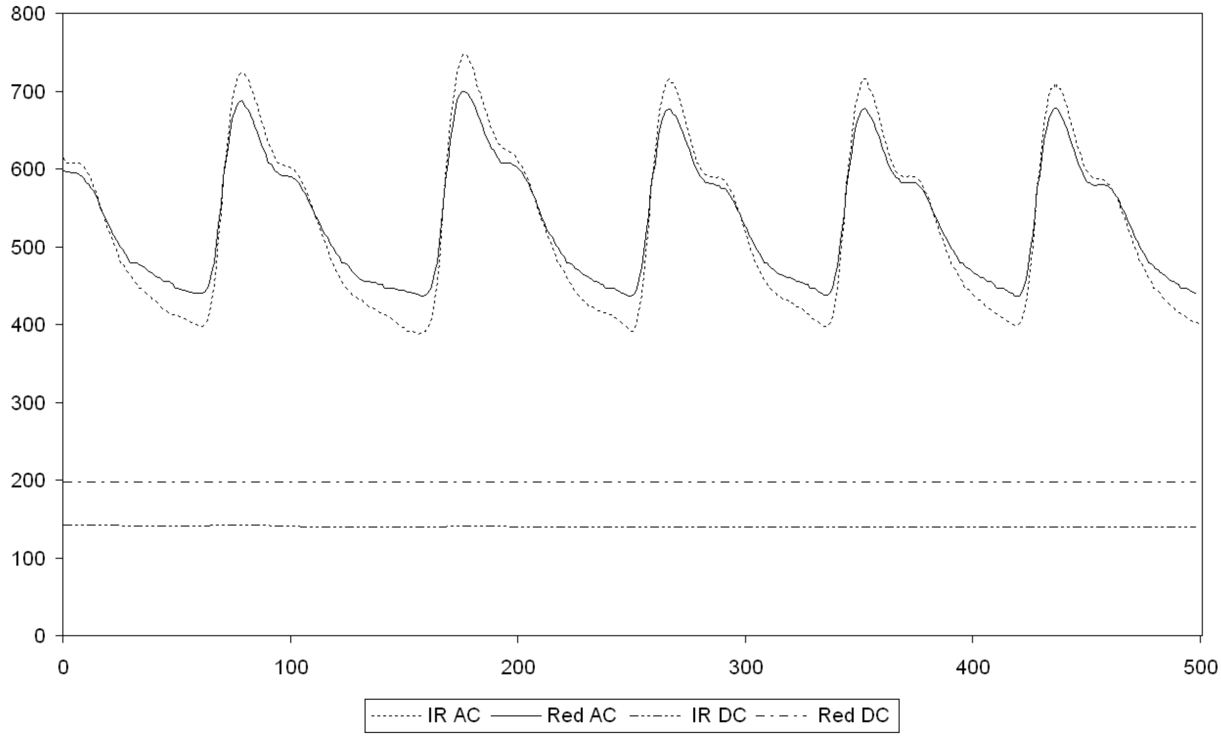

Fig. 4. Example of Signals

and the design principles of pulse oximeters very easy. The kit is designed both as a research instrument, as a laboratory module for independent student works and as a demonstration tool for lectures.

Furthermore the oximeter can be used for recording of the raw signals to a PC. It is not the primarily intended purpose, but it extends the possible usage. For instance, the oximeter kit could be used as a part of a polygraphical recording device.

The presented laboratory kit has been used in laboratories of medical equipment at the Department of Circuit Theory Faculty of Electrical Engineering Czech Technical University in Prague, at present in the courses Medical Instrumentation and Basics of Medical Electronics.

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