CZECH TECNICAL UNIVERSITY IN PRAGUE

FACULTY OF BIOMEDICAL ENGINEERING
Department of Biomedical Technology

Pulse oximeter controlled by microprocessor

Bachelor thesis

Study program: Biomedical and clinical technology

Study branch: Biomedical technician

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Kladno, August 2017

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Bachelor's thesis title: Pulse oximeter controlled by microprocessor

Abstract: Two important clinical measurements that indicate the state of a patients' vital functions are blood oxygen saturation and pulse rate. Oxygen saturation is determined by measuring the amount of oxygenated hemoglobin in the blood. This is done effectively and non-invasively with the help of a pulse oximeter, consisting of LED's and photodetectors.

The primary objective of this project was to design a prototype of a pulse oximeter with commercially available SpO2 sensors and microprocessor of the Arduino type. The designed equipment was to be tested and compared to commercially available devices of the same type.

Název bakalářské práce: Pulzní oxymetr řízený mikroprocesorem

Abstrakt: Dvě významná klinická měření, která ukazují stav životních funkcí pacienta, jsou nasycení kyslíkem v krvi a pulzní frekvence. Saturace kyslíkem se určuje měřením množství kyslíku v krvi. To se provádí efektivně a neinvazivně pomocí pulzního oxymetru sestávajícího z LED a fotodetektorů.

Hlavním cílem tohoto projektu bylo navrhnout prototyp pulzního oxymetru s komerčně dostupnými senzory SpO2 a mikroprocesorem typu Arduino. Navrhované zařízení mělo být testováno a porovnáno s běžně dostupnými zařízeními stejného typu.

Klíčová slova: Pulzní oxymetr, biomedicína, Arduino, saturace kyslíkem, oximetrie, design

Contents

List of symbols and abbreviations

Abbreviation	Meaning
BPM	Breaths Per Minute
SpO2	Oxygen saturation of arterial blood
Hb	Deoxyhemoglobin, which does not contain oxygen
HbO2	Oxyhemoglobin, which binds four molecules of oxygen
PPG	Photoplethysmogram
MCU	Microcontroller
LED	Light Emitting Diode
LIFA	LabVIEW Interface for Arduino

Symbol	Meaning	Unit
I	Light intensity	Lx
I_0	Intensity of the incident light	Lx
ε	Molar absorption coefficient	
c	Concentration of solute	Mol
d	Layer thickness	cm

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1 Introduction

1.1 Methods of evaluation of the oxygen in blood

The presence of oxygen in the blood is an essential part of whole organism functionality and condition for the life. The transport of oxygen to the tissues and the removal of carbon dioxide out of the body is ensured by the respiratory system together with large and small blood circulation. Oxygen binds to the red blood dye hemoglobin (Hb) and is distributed through the body by blood.

Determination of oxygen saturation in the blood is a very valuable diagnostic value and therefore the measurement of oximetry has become a standard process during anaesthesia, intensive care units and surgery and postoperative care. Because of its simplicity they are often used as a standard measurement and should not be a burden for patients. For this reason, spectrophotometric methods using non-invasive optical probes are used. These probes are placed in well-accessible places such as the finger or earlobe. Such a method is the pulse oximetry.

Measurement of the oxygen in blood is performed in two ways: invasive and non-invasive.

The invasive method is based on taking a sample of arterial blood and performing laboratory tests to determine quantity percentage of oxyhemoglobin. This method is the most accurate, but it takes a long time and cannot be used for continuous monitoring. It is also uncomfortable for the patient and impractical.

Pulse oximetry is a non-invasive method for measuring the percentage of oxyhemoglobin in arterial blood. It is widely used in immediate diagnosis hypoxia (low oxygen in the blood), respiratory failure, etc. This method is highly informative, non-invasive, simple and economical in use. Pulse oximetry is an essential part of mandatory monitoring requirements for any anaesthesia, surgical interventions.

The basic principle of pulse oximetry is based on the usage of two radiation sources (with a wavelength of 660 nm and 940 nm) and two photo-elements operating in these ranges. The intensity of the radiation measured by the photodetector depends on many factors, most of them are constant. Pulsations in the arteries occur continuously and cause changes in the absorbing capacity of tissues. Changes in the amount of light that is absorbed in the tissues correspond to changes in the quantity of oxygenated hemoglobin in the arteries.

Pulse oximeter continuously calculates the difference between signal absorption in the red and infra-red spectrum. It calculates saturation value based on the formula obtained experimentally using the Lambert-Beer law. The change in the absorbent capacity of tissues, caused by pulsations in the arteries, is fixed in the form of a plethysmography curve. The pulse oximeter calculates the heart rate from measuring the distance between the two crests of the curve.

The aim of the bachelor thesis is to acquaint with methods of blood oxygen saturation measurement and the principle of measurement of pulse oximetry. Practical part of the bachelor thesis is to design a pulse oximeter system using Arduino microprocessor and verify its functionality.

1.2   History review

The relationship between absorption of light and the concentration of the absorbent was first described by Heinrich Lambert in 1760. This was further investigated by August Beer, who published the Beer-Lambert law in 1851. The history of pulse oximetry begins in 1874, when the researcher A. Virordt determined the dependence of the flow of red light passing through the arm, when a tourniquet is applied.

In 1972, Takuo Aoyagi, an engineer from the Japanese corporation NIHON KOHDEN, studied a non-invasive method for measuring cardiac output and found that, fluctuations in absorption of light, oxygenation (saturation with oxygen) of arterial blood can also be calculated.

The first pulse oximeter was released by the corporation NIHON KOHDEN in 1975. In 1977, in Japan, MINOLTA Corporation released a model with a fiberglass cable that transmits light flux of LEDs from the monitor to the finger sensor.

Later, American researcher Scott Wilber used T. Aoyagi's principle, but took LEDs as sources of radiation, which allowed to create an easy and compact ear clip sensor.

The absorption spectrum of hemoglobin appeared to be in the range of radiation of silicon light-emitting diodes, possessing a miniature, reliability, negligible energy consumption and the ability to produce very bright radiation in a narrow frequency range.

Scott Wilber was the first to use a microprocessor to process data and calibrate the monitor.

Combining semiconductor technology and the principle of Japanese engineer T. Aoyagi, S.

Wilber invented the first modern pulse oximeter.

1.3   Theory

When considering the method of pulse oximetry, the following terms are used. Hemoglobin is the name of the blood proteins that is contained in red blood cells and consists of four chains of the globin protein, each containing one hem group. Types of hemoglobin have their own names and designations.

The pulse oximetry technique proposed in the 1970s is based on the use of the principles of photoplethysmography, which makes it possible to isolate the arterial component of light absorption to determine oxygenation of the arterial blood.

Photoplethysmography is a method of investigating peripheral hemodynamic, based on the study of the absorption of light passing through the tissue site with pulsating blood.

A study of the spectral characteristics of blood, has shown that at wavelengths of 600-700 nm the greatest difference is observed between the optical density of almost completely oxidized blood and blood with a reduced content of oxyhemoglobin.

Moreover, the oxidation of blood reduces the optical density of the blood, at the same time, in the wavelength range 810-960 nm (the nearest region of infrared spectra), the optical density of the blood rises from its saturation with oxygen. [1]

Photoplethysmogram (further - PPG) - a curve that reflects changes in the volume of the arterial channel, obtained after amplification and processing of the photodetector signal. It characterizes the blood flow at the sensor location. When the blood pressure rises, the amplitude of the PPG increases, with decreasing pressure, the amplitude also decreases.
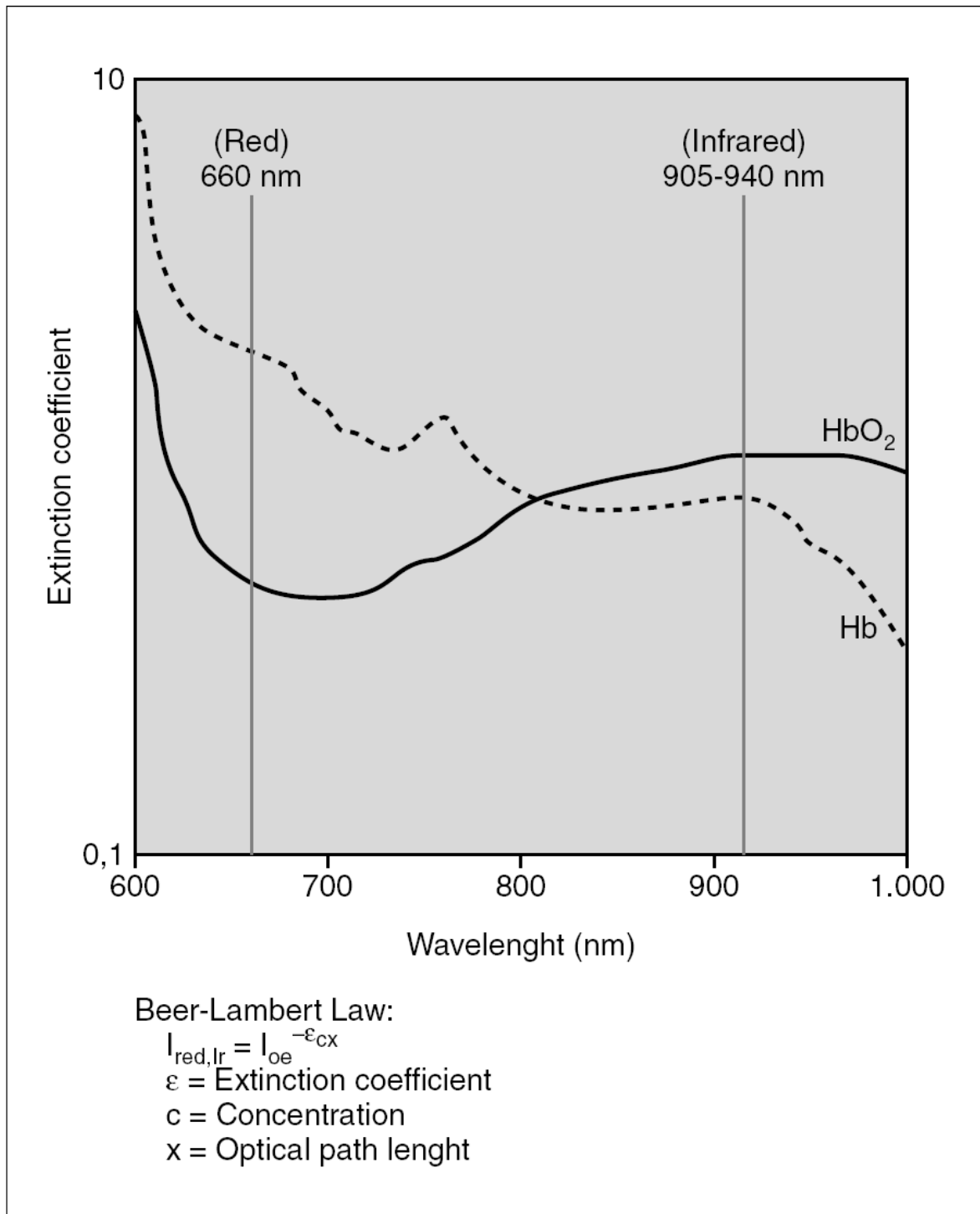
Figure 1 Extinction coefficient on wavelength dependency

http://www.analesdepediatria.org/es/pulse-oximetry-in-neonatal-care/articulo/13071844/

Therefore, a spectral region with a wavelength of about 660 nm is usually used for the red spectral band, and more than 940 nm for the infrared band.

In accordance with the technique of photoplethysmography, the tissue site in which the blood flow is examined is in the path of the light beam between the radiation source and the sensor photodetector.
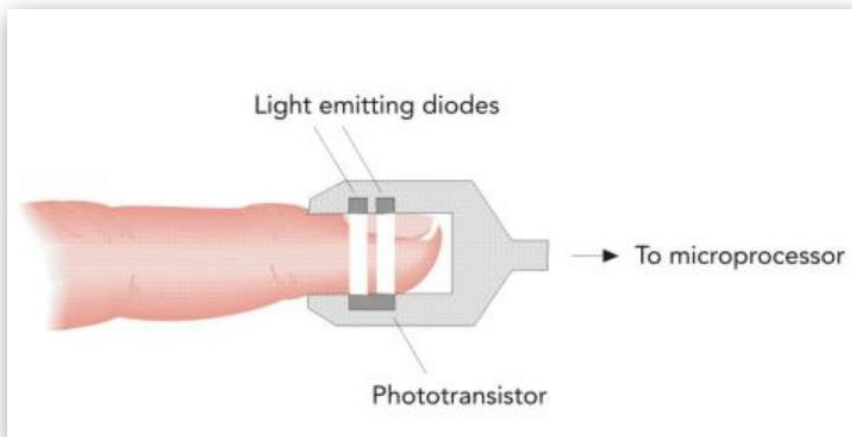

Figure 2 Photodetector during the study of blood flow in the finger

Pulse oximetry gives diagnostic values as:

1. Heart rate (BPM).

2. PPG.

3. SpO2

Measuring heart rate is simpler than measuring oxygen saturation. It requires only thresholding a certain level of wavelength and counting the pulse signal from the phototransistor.
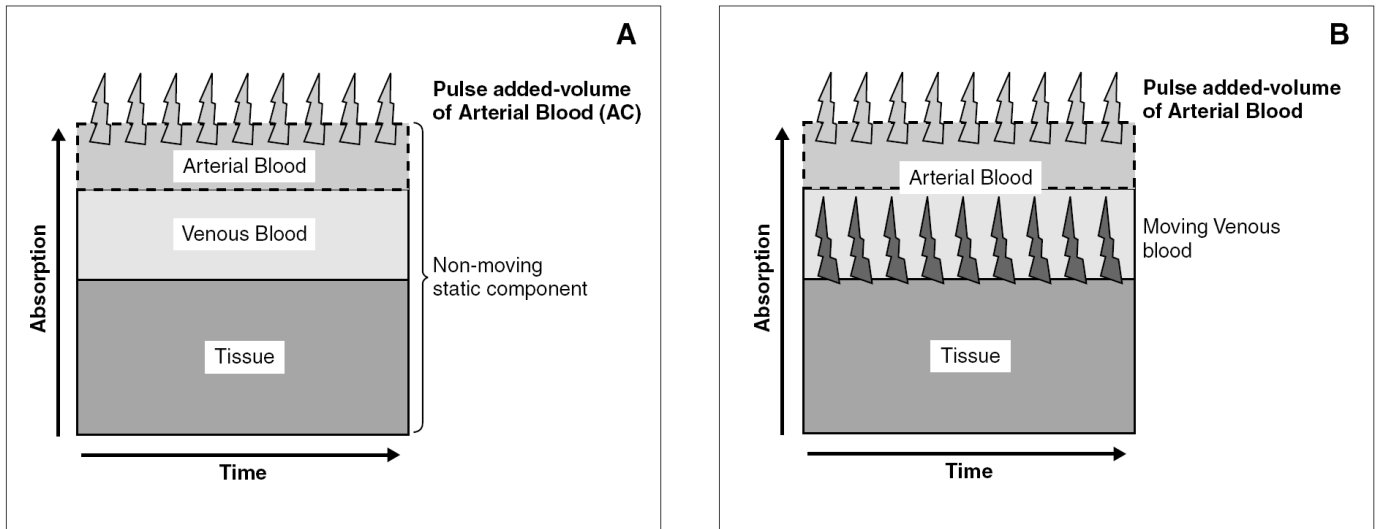
Figure 3 Photoplethmograph of peripheral pulse

Photoplethysmogram (PPG) used in patient monitors to determine heart rate, the intensity of pulsation of blood flow, and oxygen saturation in pulse oximeters. Measurement of this component makes it possible to use spectrophotometry (a method based on the absorption of monochromatic radiation, i.e., radiation from one wavelength in the visible ultraviolet regions of the spectrum) for non-invasive transcutaneous monitoring of arterial oxygen saturation with oxygen. [2]

For non-invasive determination of blood oxygenation, a tissue site containing arterial vessels is placed at the sensor location. The signal from the sensor output is proportional to the absorption of light passing through the tissue and includes two components: a pulsating component due to a change in the arterial blood volume with each heartbeat, and a constant component determined by the optical properties of the skin, venous and capillary blood and other tissues of the site. To determine the saturation, a two-beam spectrophotometry technique is used.

Measurement of light absorption is performed at the moments of systolic ejection for two wavelengths of radiation. For this purpose, the sensor uses two radiation sources with different spectral characteristics.

The Beer-Lambert law is the linear relationship between absorbance and concentration of an absorbing species. The general Beer-Lambert law is usually written as:

$$A = \ln\left(\frac{I_{out}}{I_{in}}\right) = \varepsilon * c * l$$

Radiation from red or infrared light (intensity of incident light) through and detecting the intensity of the transmitted light (I) by a photodetector circuit, a photoplethysmography (PPG) signal will be generated.

Experimental measurements are usually made in terms of transmittance (T), which can be defined as:

$$T = \frac{I}{I_0} = e^{-\varepsilon(\lambda)cd}$$

The relation between A and T is:

$$A = -\ln T = \ln\left(\frac{I_{out}}{I_{in}}\right)$$

Rate of decrease in the intensity of the light during flow through given substance is absorption coefficient. Absorption coefficient depend on the wavelength as shown in following formula:

$\alpha(\lambda) = \varepsilon(\lambda)$

Saturation is indicated by the symbols: SaO_2 or SpO_2. SaO_2 stated as functional value of arterial oxygen saturation. The oxygen saturation is the ratio of the amount of oxyhemoglobin to the total amount of hemoglobin in the blood, expressed as a percentage.

The determination of the oxygen saturation can be made using formula:

$$SaO_2 = \left(\frac{C_{HbO_2}}{C_{Hb} + C_{HbO_2}}\right) \times 100\%$$

In each channel from photodiode signal, two components of the PPG signal are measured. Due to continuously pulsating absorption, components necessary to calculate the ratio (R) of the ratio values and determine the saturation from the calibration curve. The R is a function of light intensities at these points. Constant proportion can be calculated from AC and DC components, for different wavelength respectively.

$$R = \frac{AC_{RED}/DC_{RED}}{AC_{IR}/DC_{IR}}$$

AC_{RED} and AC_{IR} are AC components of the red and infrared radiation sources.

AC_{RED} and AC_{IR} are AC components of the red and infrared radiation sources.

Pulse oximeters able to detect effect of the arterial pulsation. The arteries contain more blood during systolic period in comparison with diastolic period. This in turn increases pressure and the diameter of the arterial walls as well. Such an effect is only applicable in the arteries, but not in the veins. Based on Lambert-Beer's law in pulse oximetry, the amount of light transmitted form the tissue to the photodetector corresponds to the pulses of arterial blood.

During systolic period, a large amount of hemoglobin is present, so that implies transmitted light decreases and has a low peak (I_L), and can be expressed as (d_{max}), as the length (d) in the arteries increases. During diastolic period, the diameter of the arterial vessels is minimal (d_{min}), so that arterial hemoglobin is minimal as well, from that statement follow the amount of the transmitted light has a high peak (I_H).
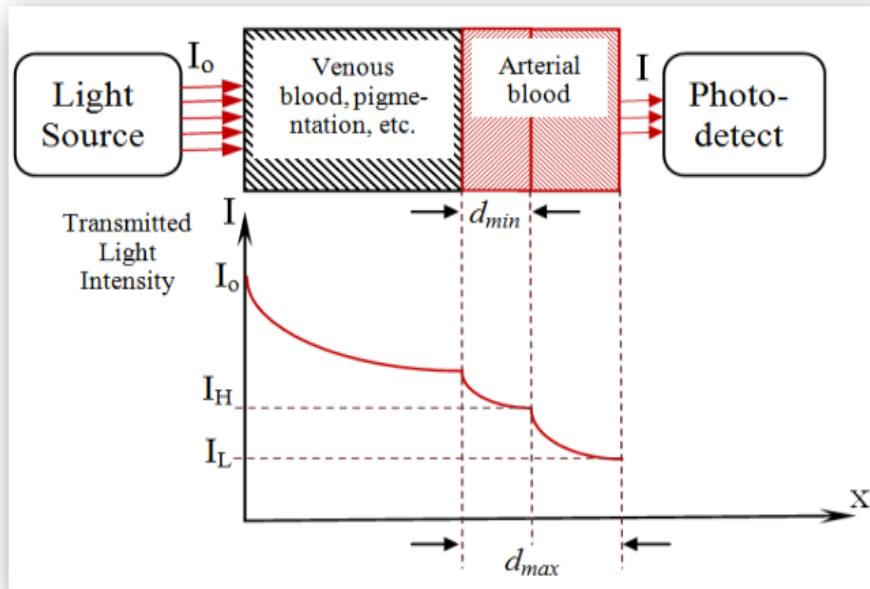

Figure 4 Lamber-Beer`s law in pulse oximetry

According to Lambert-Beer`s law, the transmitted red light for systole and diastole can be expressed as following:

$$I_{H,RED} = I_{0,RED}\, e^{-\alpha(\lambda_{RED})d_{Rmin}}$$

$$I_{L,RED} = I_{0,RED}\, e^{-\alpha(\lambda_{RED})d_{Rmax}}$$

To get the same expression of transmitted infrared light, the following mathematical operation is made:

$$\frac{I_{H,RED}}{I_{L,RED}} = \frac{e^{-\alpha(\lambda_{RED})d_{Rmin}}}{e^{-\alpha(\lambda_{RED})d_{Rmax}}} = e^{-\alpha(\lambda_{RED})d_{\Delta R}}$$

$$\ln\left(\frac{I_{H,RED}}{I_{L,RED}}\right) = -\alpha(\lambda_{IR})d_{\Delta IR}$$

As a result of combination following formula obtained:

$$SpO_2 = \frac{\varepsilon_{Hb}(\lambda_R) - \varepsilon_{Hb}(\lambda_{IR}) * R}{\varepsilon_{Hb}(\lambda_R) - \varepsilon_{HbO_2}(\lambda_R) + \left[\varepsilon_{HbO_2}(\lambda_{IR}) - \varepsilon_{Hb}(\lambda_{IR})\right] * R} \; x \; 100\%$$

, where $\varepsilon_{HbO2}(\lambda_R)$, $\varepsilon_{HbO2}(\lambda_{IR})$ – oxygenated hemoglobin absorption coefficient for red and infrared light;

$\varepsilon_{Hb}(\lambda_R)$, $\varepsilon_{Hb}(\lambda_{IR})$ - deoxygenated hemoglobin absorption coefficient for red and infrared light.

In practice, empirical formula for the oxygen saturation is:

$SpO_2 = a - b * R$

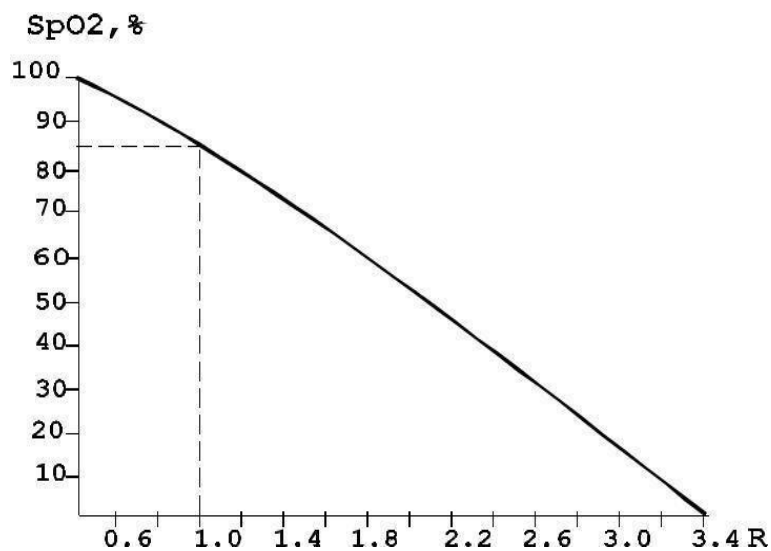where a and b are coefficients determined during calibration and following calibration

curve.

Figure 5 Common calibration curve

An approximate formula for calculating oxygen saturation would be:

$SpO_2 = 110 - 25 * R$

But in fact, calibration formula is calculated during measurement processes and depends on many factors such as type of probe, data received from the photodiode and others.

2 Pulse oximetry.

Pulse oximetry is a test used to measure the oxygen saturation of the blood. Pulse oximeter is the device used for the patients especially with asthma, emphysema, chronic obstructive pulmonary disease (COPD), chronic obstructive airway diseases (COAD), and other respiratory conditions. Patients with serious respiratory problems should have their SpO2 levels check regularly.

Oximeters and their sensors ensure the proven accuracy of results in a wide range of patients, regardless of sex and age. However, these aren't the only reasons why the devices are so popular. To additional benefits also belong:

- compact size
- non-invasiveness
- the ability to detect hypoxemia earlier than when using eyes to see cyanosis
- affordability

Principle of pulse oximeter is same in every type, differences are construction types of pulse oximeters and probes.

2.1 Types of pulse oximeters by design.

1. Portable desktop unit

Figure 6 Portable desktop unit

2. Fingertip/mobile pulse oximeter

Figure 7 Fingertip/mobile pulse oximeter

3. Pulse oximeter as a part of anesthetic machine

Figure 8 Pulse oximeter as a part of anesthetic machine

2.2 Types of the pulse oximeters probes.

Pulse oximeter sensor contains two light-emitting diodes operating one in the RED light emitting diode, the other in the infrared region of the spectrum, and a broadband photodetector. Structurally, the sensor is designed in such a way that when it is placed on

the surface of a person's body, the light emitted by the site of tissues containing the arterial vessel enters the photodetector.

Since the measurement is made by the transmission of tissues, the method is called transmission pulse oximetry. The emitting and receiving sensors are located opposite each other. For investigation, the light source and the photodetector are fixed on the so-called "thin parts skin of the body" i.e. on the finger, ear, nose wing.

There is a second method of diode and detector placement in a row. The method is based on analysis of the light flux reflected by tissue (reflected pulse oximetry).

Reflected pulse oximetry, can be used as an alternative to transmission pulse oximetry. The emitting and receiving sensors are located side by side (Figure 9 . Diode placement for different construction of oximeters). This method does not require a "thin part of the skin " and therefore is well suited for more universal application on such parts of the body as legs, forehead and chest.

The main advantage of reflected pulse oximetry is convenience of use. The accuracy of the reflectance and transmission pulse oximetry is approximately the same.
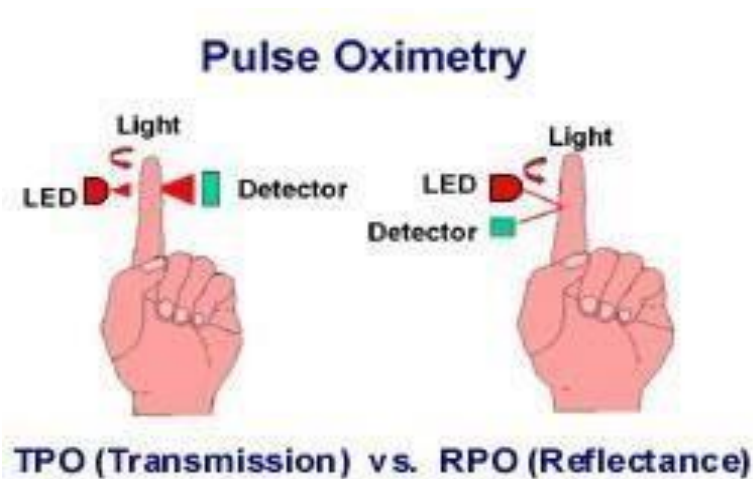

Figure 9 . Diode placement for different construction of oximeters

3   Limitation of the pulse oximeters

Oximeters have several limitations that can lead to inaccurate measurements. These restrictions must be known to avoid misdiagnosis or misuse of the oximeter.

Basically, limitations can be prevented by the correct measurement procedure. Explanation of the limitation given below.

Low blood circulation and congestion

The function of pulse oximeters depends on good blood circulation and adequate pulsation of the peripheral weaving. Low blood flow can be caused by several factors. These include low blood pressure, vasoconstriction, or even cooling may cause the signal to be too small to reliably evaluate the oximeter. In general, low - perfusion oximetry is more sensitive to

Movement artifacts.

If the tissue is skewed, venous blood flow begins to pulse. In this case, it will count

Even the venous blood absorption and the oximeter will show false values.

Motion interference

Movement of the probe across the skin can cause artefacts that the oximeter cannot distinguish from normal arterial pulsation. Movement can usually be seen on different shapes of the plethysmograph curve and sudden change in heart rate. Removing this interference is by adequately attaching the probe and reassuring patient movement.

Parasitic light sources

Other interference is an external light sources. Removal of the external light sources can be performed by tight fastening of the probe and the cover of the sensor with opaque material, so that no external light can enter the detector.
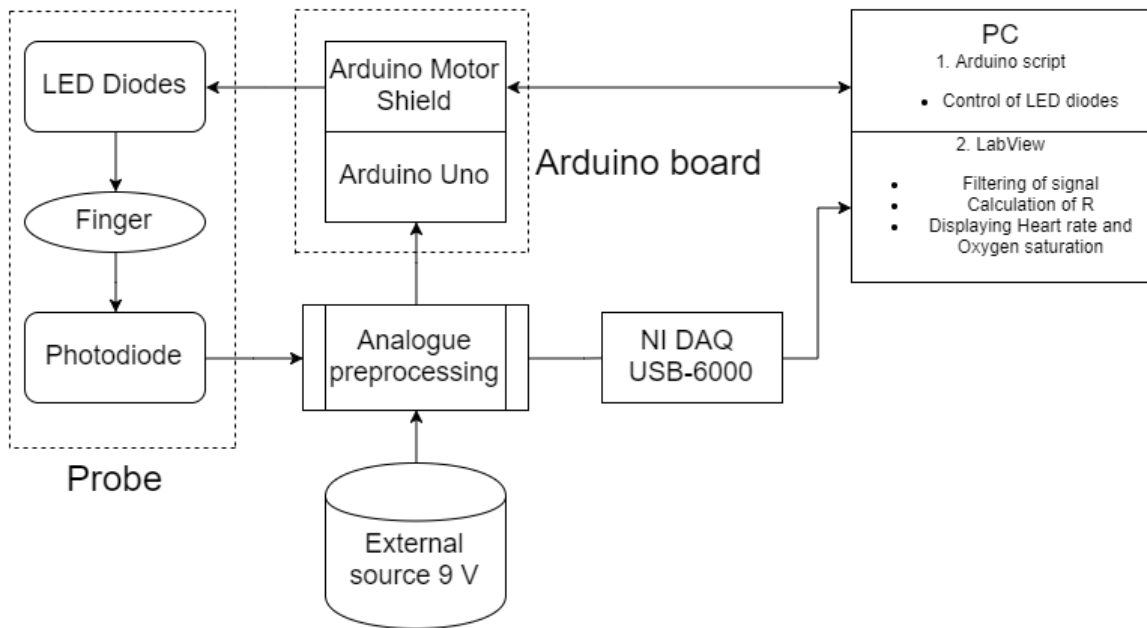
4 Methods

Figure 10 . Block diagram of the main parts of commercially available pulse oximeter

4.1 Optical probe

Optical sensor consists of a combination of the two antiparallelly connected light-emitting diodes and photodetector. As a sensor for project Nellcor Covidien Max-N self-adhesive probe were used because of its availability and simpler construction. The most important were to find out pins responsible for feeding LED`s and pins for photodiode output. Nellcor Covidien Max-N has DB9 connector with pinout same that valid for all Nellcor probes. This probe was connected to a circuit for analogue signal pre-processing.
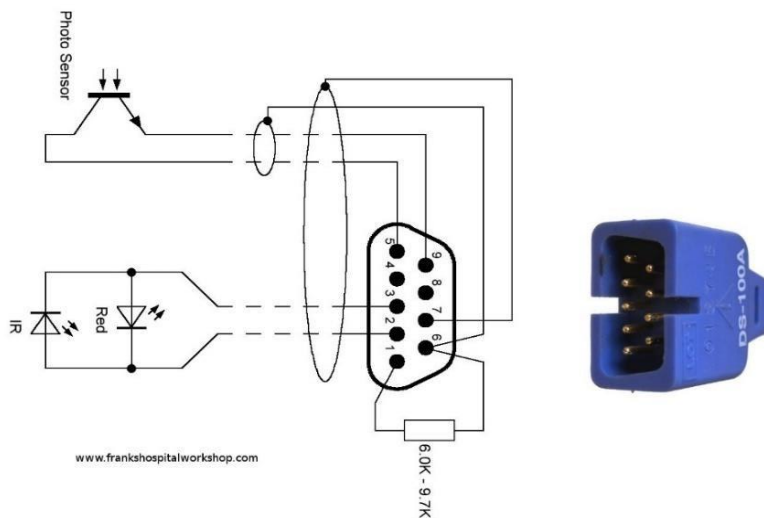

Figure 11 Pinout scheme for Nellcor probes

Table 1 Pinout description

Connector end pin	Pins name	Description
1,6	Calibration	Connection to resistor, that tells device which calibration curve to use.
2	LED 2	anode of the IR LED, cathode of the red LED
3	LED 1	cathode of the IR LED, anode of the red LED
4,8	NC	not connected
5	Photodiode anode	Circuit input for photodiode
7	Shield	cable shield
9	Photodiode cathode	Ground for photodiode

http://pinouts.ru/visual/gen/nellcore_pulse.jpg

The current that is flowing through the LED`s is sensed by Arduino Motor shield, thus maintaining a constant current proportional to voltage and independent of the +5 V supply that powers the bridge. Maximum LED current is approximately 50 mA (from service manual of the Nellcor devices). [19]

4.1.1 LED`s

One of them emits a visible red spectrum 660 nm, another – near infrared radiation

spectrum 940 nm, and a photodetector that determines the intensity of the light flux passed

through soft tissues and blood, depending on the oxygen concentration in hemoglobin.

4.1.2 Photodetector

The photodetectors serve for converting the light energy into electricity, which we process further. When choosing a detector, we must consider its properties:

• Range of wavelengths of radiation that the detector can detect,

• Response to the received optical signal,

• Own detector noise,

• Dimensions of the detector.

Photodiodes are widely used for their features such as small dimensions, durability and simple connectivity. Phototransistors or photoresistors are also used.

4.2   Microprocessor

Arduino Uno is a microcontroller that receives measurements from pulse oximetry sensor

and stores them. This is a small board with its own processor and memory.

Arduino processor is device where the code can be uploaded and that will manage all applied components and devices according to a given code.

Arduino/Genuino Uno is a microcontroller based on the ATmega328P. Microcontroller Arduino has 14 digital in/out pins, 16 MHz quartz crystal, Power jack, USB connector and an ICSP header. The USB interface is used to program and to supply power at the same time.

For the convenience of working with Arduino there is a free official programming environment "Arduino IDE", running on Windows, Mac OS and Linux.

The Arduino development environment consists of a built-in text editor for code, a message area, a text output window (console), a toolbar with buttons of frequently used commands and several menus. To download programs and communication, the development environment connects to the Arduino hardware.
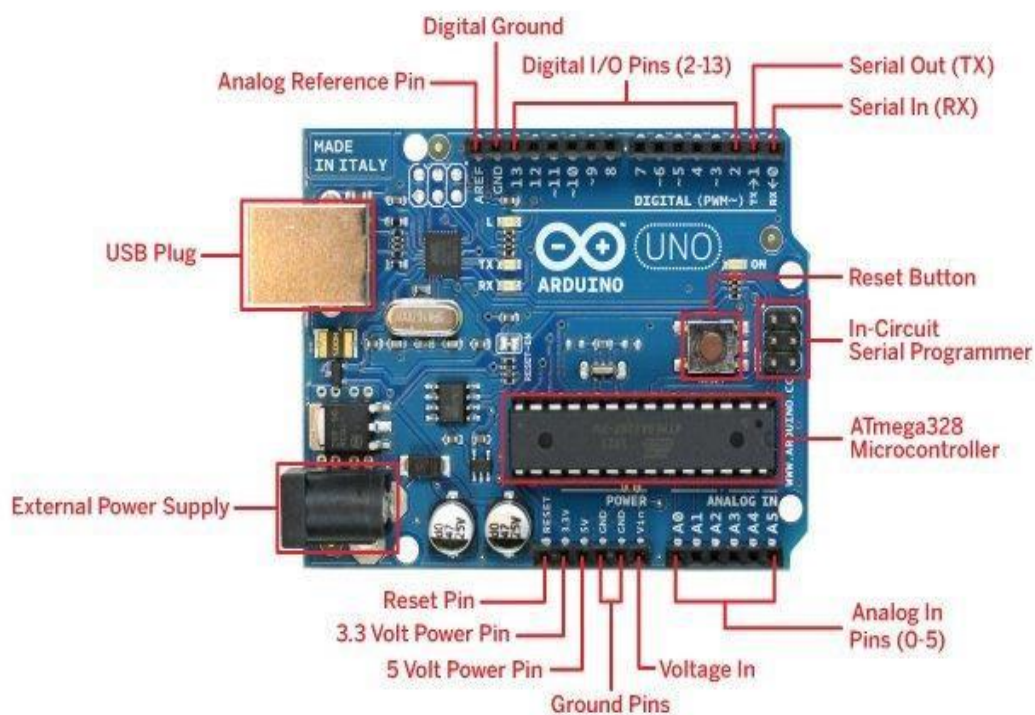

Figure 12 Arduino Uno description
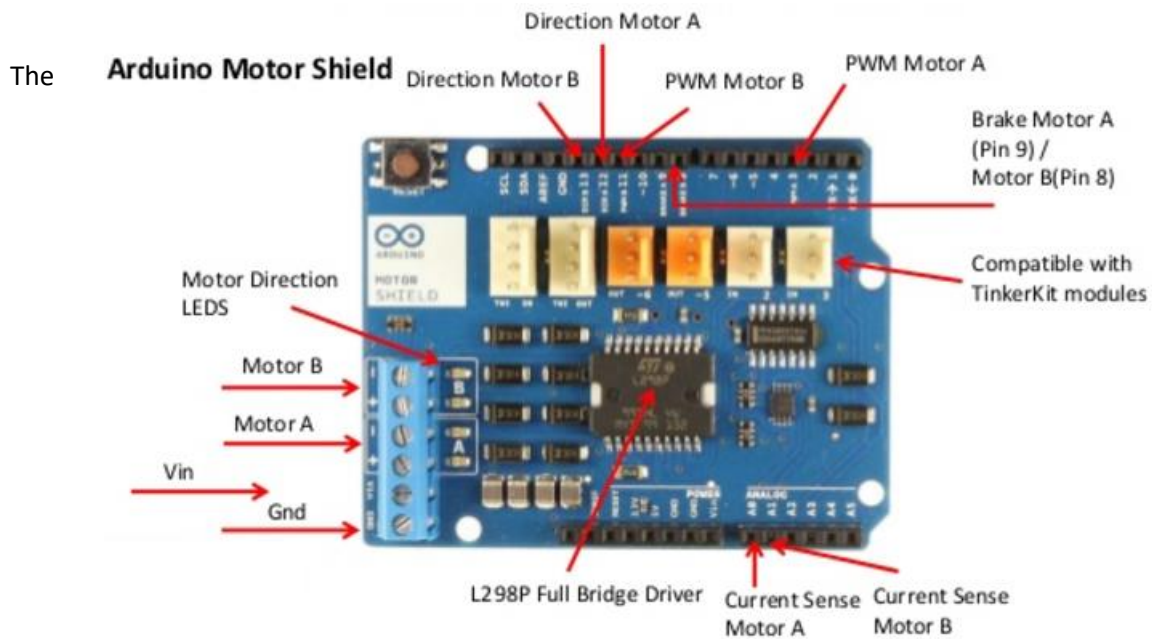
4.3   Arduino Motor Shield

The

Figure 13 Arduino Motor Shield Rev3

Arduino Motor Shield is based on the L298, which is a dual full-bridge driver designed to drive inductive loads such as relays, solenoids, DC and stepping motors.

It lets to drive two DC motors with your Arduino board, controlling the speed and direction of each one independently. [https://store.arduino.cc/arduino-motor-shield-rev3].

4.4   LED timing control

Control of LED`s on and off period were required to prevent error when LEDs will be switched on all the time. There are some options to control LEDs timing. Software solution of LED timing implies control by software as LabVIEW where switches are performed by adding loops for feeding input of LEDs.

However, there were technical difficulties during the connection of LabVIEW and Arduino. Then hardware solution of LED timing control was performed.
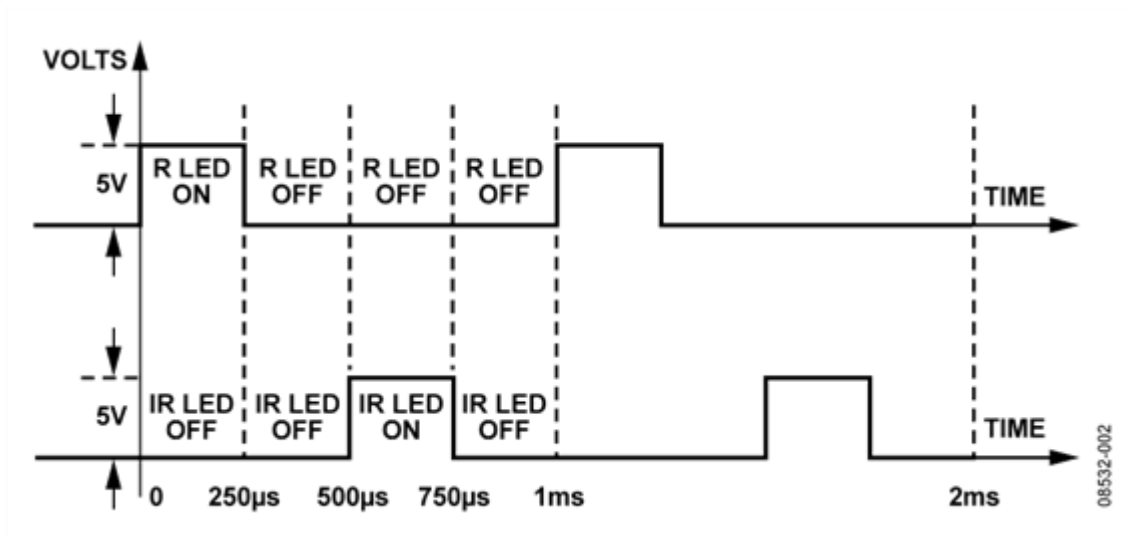
Figure 14 Oximeter timing diagram

The hardware solution is based on the use of the H-bridge connection for feeding LEDs.

Arduino Motor Shield Rev3 was used to replace the H-bridge. Instead of a DC motor, there are LEDs that are switched on and off by programming speed and direction parameters.
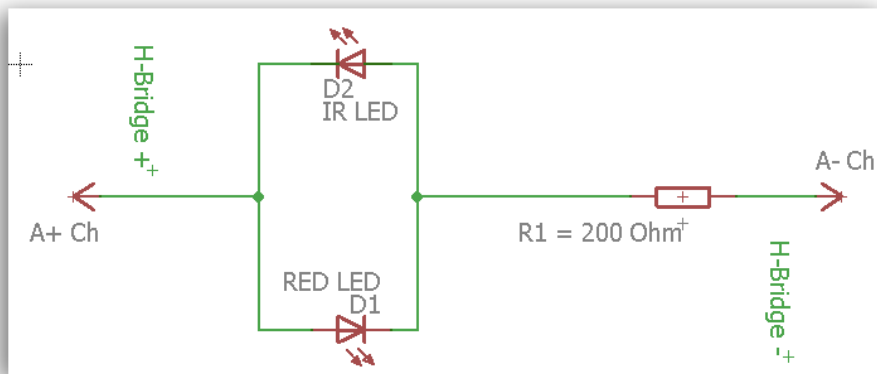

Figure 15 Scheme of probe connection to Motor shield

4.5 NI USB - 6000

Figure 16 NI USB-6000 data acquisition measuring instrument.

The National Instruments USB 6000 data acquisition measuring instrument is used to convert the analogue signal to digital, allowing for computer processing. This card is connected to the computer via a USB port cable. Measuring card inputs and outputs to the card are simply connected using a series of screw connectors. LabVIEW control cards can be implemented in LabVIEW software via DAQ blocks, which allow you to define the individual inputs and outputs of the card, select which pins to use, and what output voltages the card will generate.

8 AI (10 kS/s), 4 DIO USB Multifunction I/O Device—The USB-6000 is a low-cost, multifunction DAQ device. It offers analogue I/O, digital I/O, and a 32-bit counter. The USB-6000 provides basic functionality for applications such as simple data logging, portable measurements, and academic lab experiments. The device features a lightweight mechanical enclosure and is bus powered for easy portability. The included NI-DAQmx driver and configuration utility simplify configuration and measurements. [http://www.ni.com/cs-cz/support/model.usb-6000.html]

4.6 LabVIEW

Laboratory Virtual Instrument Engineering Workbench (LabVIEW) is a system-design

platform and development environment for a visual programming language from National

Instruments. LabVIEW is systems engineering software for applications that require test,

measurement, and control with rapid access to hardware and data insights.

4.7 Code

Digital part (code) written in Arduino IDE, were used for project, to provide controlling of LED timing using Arduino Motor shield Rev3. Code was taken as sample code from Arduino IDE and then edited to control LED`s and print out information about current usage during RED and IR switches.

4.8   Analogue pre-adjusting of signal

The signal from the optical probe, which is located at the analogue circuit input, must be pre-adjusted sufficiently for measurement. The diode in the optical probe is connected anti-parallel, so it is important to correctly connect the lead cables from the analogue signal pre-processor that contains the probe connector. Therefore, a signal-conditioning circuit is used, which can be further processed by the software LabVIEW.

The basis is the signal coming from the optical probe where its capture is provided by the photodiode.

One photodiode outlet is connected to pin 5 and the second pin 9 is fed to the common ground. The main component of the circuit is the two TL081CP operational amplifier.

For the current generated on the photodiode to be further processed, it must be converted to electrical voltage. Therefore, the first part of the operational amplifier is connected as a current voltage converter.
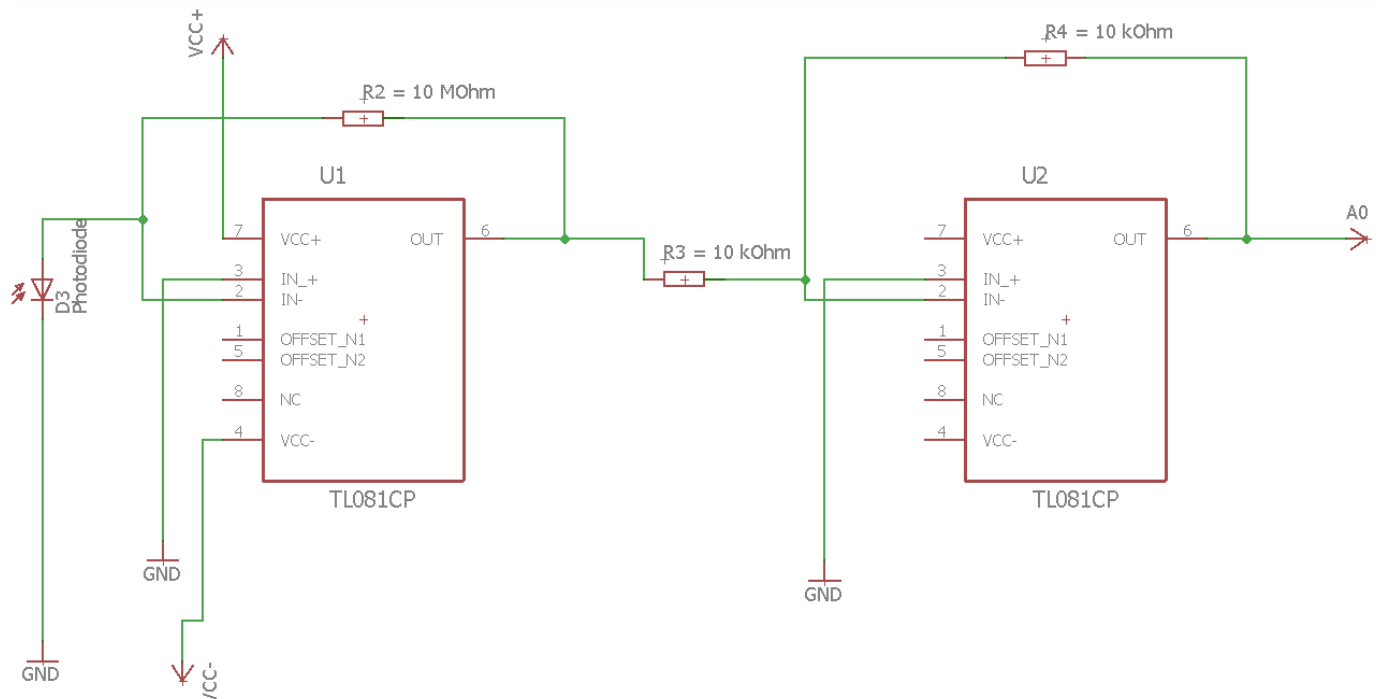
The output voltage of the first stage is proportional to the photodiode current and the feedback resistor, so the feedback is used in the megaohm line.

Parallel to the feedback resistor, such capacitors use a coupled capacitor with pico-capacities to compensate for the photodiode's capacitance. In the project engagement, this capacity was omitted because the capacitance of the circuit board connections would replace this capacity.

The signal from the first stage of the amplifier is inverted. Therefore, the signal is subsequently inverted by the second stage of the operational amplifier. The second stage has no gain since it could cut off the higher components of the useful signal.

Circuit power supply is separated by capacitors to suppress potential source interference. The useful signal of the pulse curve is in the frequency range of 0.5 - 8 Hz. This filtering is done by the LabVIEW software. The lower boundary frequency removes the DC signal component as well as the artefacts caused by the patient's movement. Therefore, a frequency of 0.5 Hz is chosen, which seems to be ideal for suppressing these components. The upper limit frequency eliminates components that are not essential to display.

Before starting the measurement, it is necessary to connect the entire system according to the scheme [Annex 3]. Then, it is necessary to verify that the LED controlling code is uploaded on Arduino board than switches on and off a diode.

4.9   LabVIEW script

4.9.1   First sequence of the LabVIEW script.

The first sequence of LabVIEW script (Figure 17 First sequence of the LabVIEW script) comprises DAQ assistant block, which subsequently enables the signal coming from A0 of analogue pre-adjustment to be processed. In the project script, the number of samples is 10000 and the frequency is 1 kHz. This signal is divided into other blocks performing individual tasks. The first block allows to filter the signal and is set as a bandpass filter. This filter passes the signal at the limit frequencies of 0.5 to 8 Hz, which selects the alternating signal component representing changes in the volume of arterial blood.

Then, the filtered signal is proceeded to the "Extract portion of signal" block, which selects a portion of the signal from 4000 to 4500 number of samples.

In order to find peaks "Curve Fitting" block were implemented with quadratic model type, that minimizes the residual under the weight. The residual is the distance between the data samples and f(x). A smaller residual means a better fit to get more precise result.

It is needed of using the "Amplitude and level measurement" blocks, which allows to find waves according to the set threshold values and their widths. The threshold is set to the value from the lowest amplitude of the pulse wave to its highest value and further reduced to a third so that the largest wave is always selected.

The width of the search wave is set to 150 samples, so the detector only records waves of the appropriate width. This is the number of pulses per second. Additionally, the value is multiplied by 60 to obtain the minute heart rate displayed on the front panel of the program application. Next, the heart rate is calculated in the first sequence.

The values of the DC signal component as well as the mean values of the alternating component (RMS_{AC}) are saved, and the oxygen saturation is calculated by means of them and later calculated values when the IR diode is switched on.

After all the partial tasks in this sequence have been completed, the program switches to the second half represented by the second sequence.
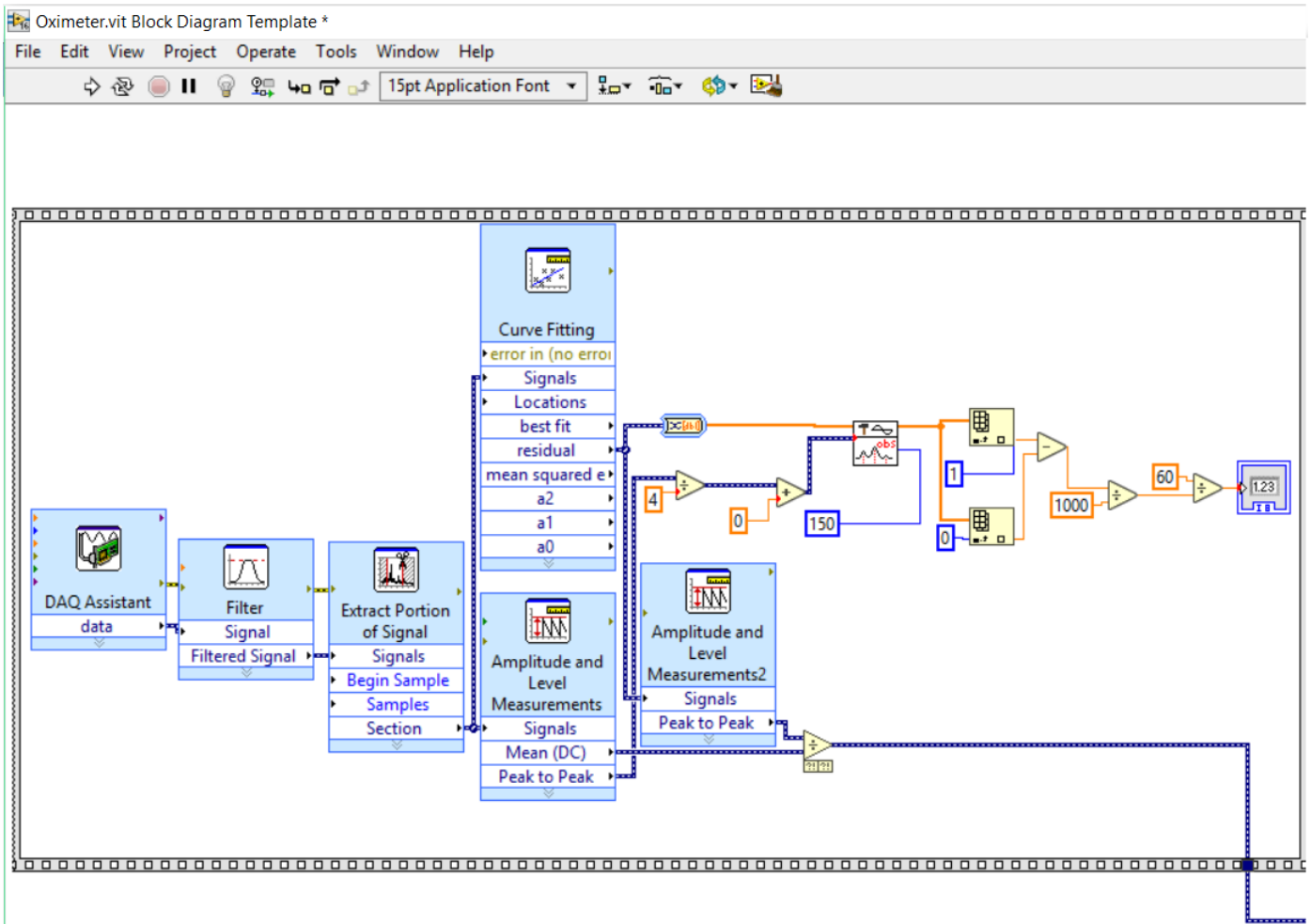
Figure 17 First sequence of the LabVIEW script

4.9.2 Second sequence of LabVIEW script.

The second sequence is based on a similar principle to the first sequence (Figure 18 Second sequence of LabVIEW script). However, the amplitude of the voltage will be different, so infrared diodes are measured. The measurement also in range of 4000-4500 samples, as set in the "DAQ assistant" block. The pre-adjusted signal is recorded by the USB-6000 measuring device and further processed by the DAQ Assistant second block.

As in the first sequence, the signal is filtered by bandwidth. In the same way, the values of the DC component and mean values of the alternating signal component are calculated using the amplitude and level measurements.

These values are mutually divided and the resulting value together with the calculated value from the first sequence is re-divided. The proportion of these two values represents the ratio R. During measurement, standard formula for calculation of SpO_2 has been replaced to fit the received data.

Difference between sequences is that, the heart rate is no longer calculated. At the end of the entire measuring cycle, values of heartrate and oxygen saturation are displayed (see.)
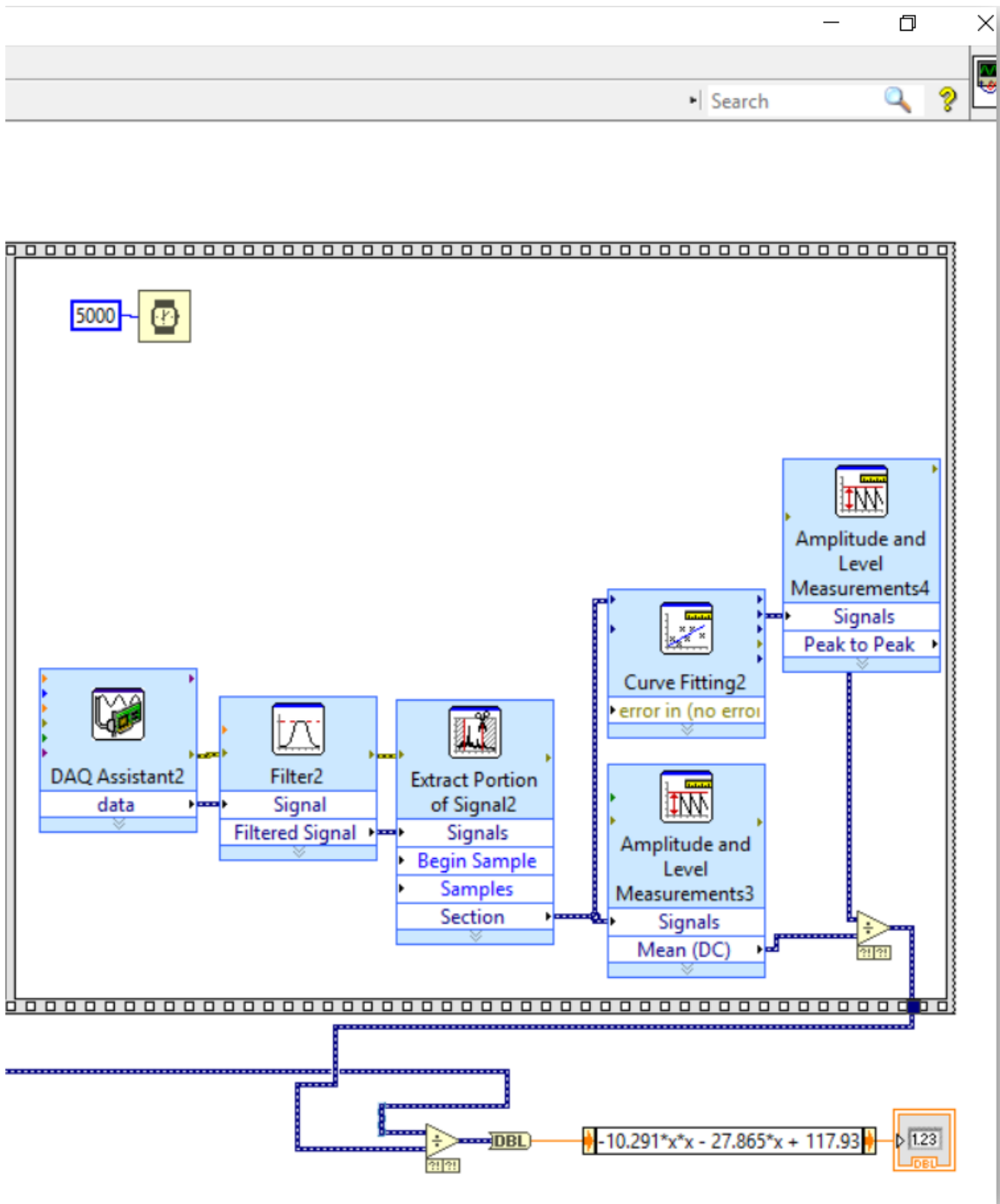
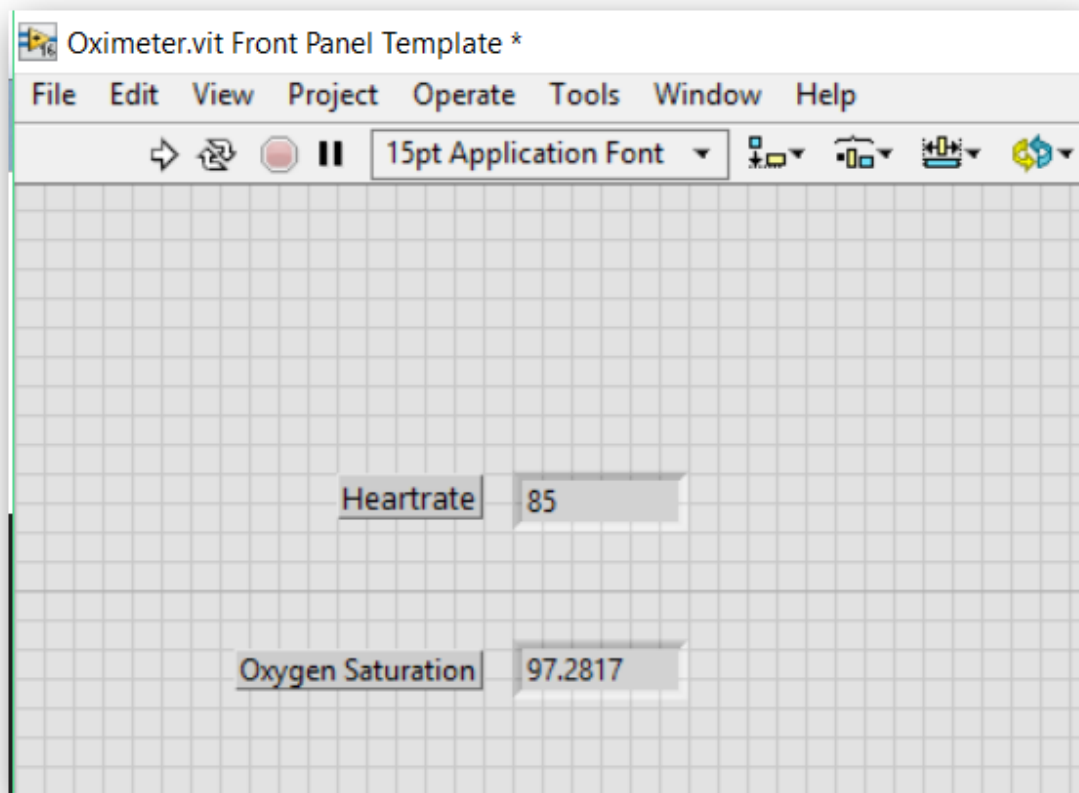*Figure 18 Second sequence of LabVIEW script*

Figure 19 Front Panel of LabVIEW script

5   Results

5.1   Validation of calculated values

Validation of the designed pulse oximetry system was performed on the Fluke ProSim 8 instrumentation for vital sign simulation (see Annex 4). To verify functionality of the probe and accuracy of the vital sign simulator, measurement was repeated with aid of Nellcor PM100N Bedside Patient monitoring system.

The measurements were performed separately for HR measurement with constant SpO_2 and for SpO_2 measurement with constant heartrate. Set values and measured values are different for heartrate. For measurement of SpO_2 accuracy dramatically decrease after reaching 95% value. Nevertheless, measurements on Nellcor PM100N show full functionality of the vital sign simulator and same probe that were used in designed pulse oximeter.

 The measured values can be [see in Table 2,3]

Table 2 Designed pulse oximeter

Table 3 Nellcor PM100N

HR measurement for SpO$_2$ = 97%

HR measurement   for SpO$_2$ = 97%

Set values (BPM)	Measured (BPM)
60	57
80	73
100	87
120	71

Set (%)	Measured (%)
60	60
80	80
100	100
120	120

SpO$_2$ measurement for HR = 80 BPM

SpO$_2$ measurement   for HR = 80 bpm

Set values (%)	Measured (%)
80	83
85	80
90	86
95	93.7
97	82.2
99	119.5

Set (%)	Measured (%)
80	80
85	85
90	60
95	95
97	97
99	99

6 Discussion

6.1 Issues during project development.

1. Designing of pulse oximeter data processing on Arduino platform require great skill in coding, it is complicated because of lack of GUI and self-check.

2. Arduino processing delay affect result values of measurement.

3. In order eliminate previous issues author tried to perform connection of Arduino microcontroller with LabVIEW software using the LabVIEW Interface for Arduino (LIFA) Toolkit, but failed to perform connection. LIFA drivers installation were successful but afterwards implementation of any LIFA block in LabVIEW failed. Same happened with LINX, which is successor of LIFA, but more designed to be a generic hardware abstraction layer for embedded devices such as chipKIT, Arduino, myRIO, etc.

4. LabVIEW script issue is that these values are calculated not continually. During measurement delay physiological values of oxygen saturation as well as pulse rate may change. Therefore, the resulting values do not have as much telling value and it is necessary to perform measurements on patients who are at rest and relaxed.

5. The patient should also not move or talk during the measurement to avoid distortion of the data by movement artifacts.

6. It was also important to select a suitable source for powering the analog signal preprocessing amplifier. During the project development, laboratory power source was replaced by serial connection of two 9 V batteries.

6.2   Issues needed to be prevented

1. During development of LED timing control there appeared difficulty to detect IR light radiation. For that reason, camera were used because of its ability to detect IR radiation.

Figure 20 Switched on RED and IR LED`s

2. During project development lid on the probe for photodiode were shifted and so photodiode did not give any output current. There is needed to test photodiode using simple multimeter.
3. Using rubber finger cuff or self-adhesive band is needed to prevent external radiation.

7   Conclusion

During bachelor thesis, author got acquainted with the pulse oximeters, probes its principle and the types of their construction.

 The author has learned "Arduino IDE" and the "LabVIEW" programming environment, with the possibility of its connection with motor shield the measuring card. Although the basics of creating analog circuits, constructing amplifiers and filters using analog components, checking these circuits using oscilloscopic measurements, and observing the influence of noise on analog circuits and the possibilities of its removal.

The aim of the bachelor thesis was to design a pulse oximeter system using Arduino board and commercially available pulse oximeter probe. Because of repetitive errors in Arduino IDE code to process signal, and connection issues of the Arduino board and LabVIEW using LIFA and LINX (see Discussion) signal processing were held in LabVIEW using USB-6000 to obtain result and fulfill requirements.

 The circuit also included a power supply for feeding operational amplifier which was mainly used to convert the low level current signal from an optical probe to a needed voltage signal that was further processed.

The signals from probe were filtered, processed, numerically calculated and displayed by the LabVIEW program.

The main drawback of this program was that it could not measure the values with higher accuracy and measure values over time, because it was limited to display values in set time spans. Therefore, these values were not so accurate as they could change during the measurement cycle. This issue could be eliminated with a succeeded connection of Arduino board and LabVIEW software.

The measured values of SpO_2 were close to set values up to 95% while heartrate measurement were more inaccurate at 97% of oxygen saturation.

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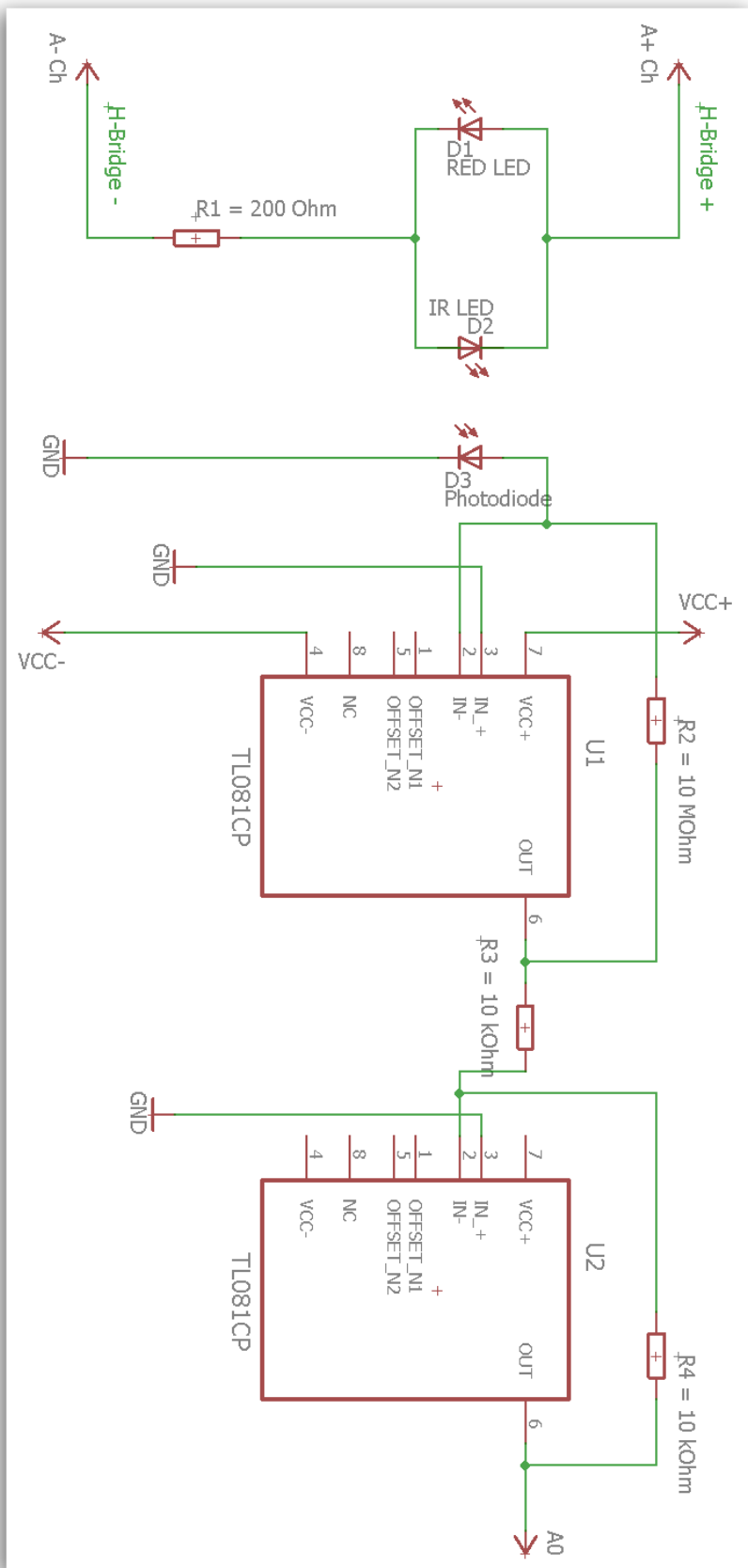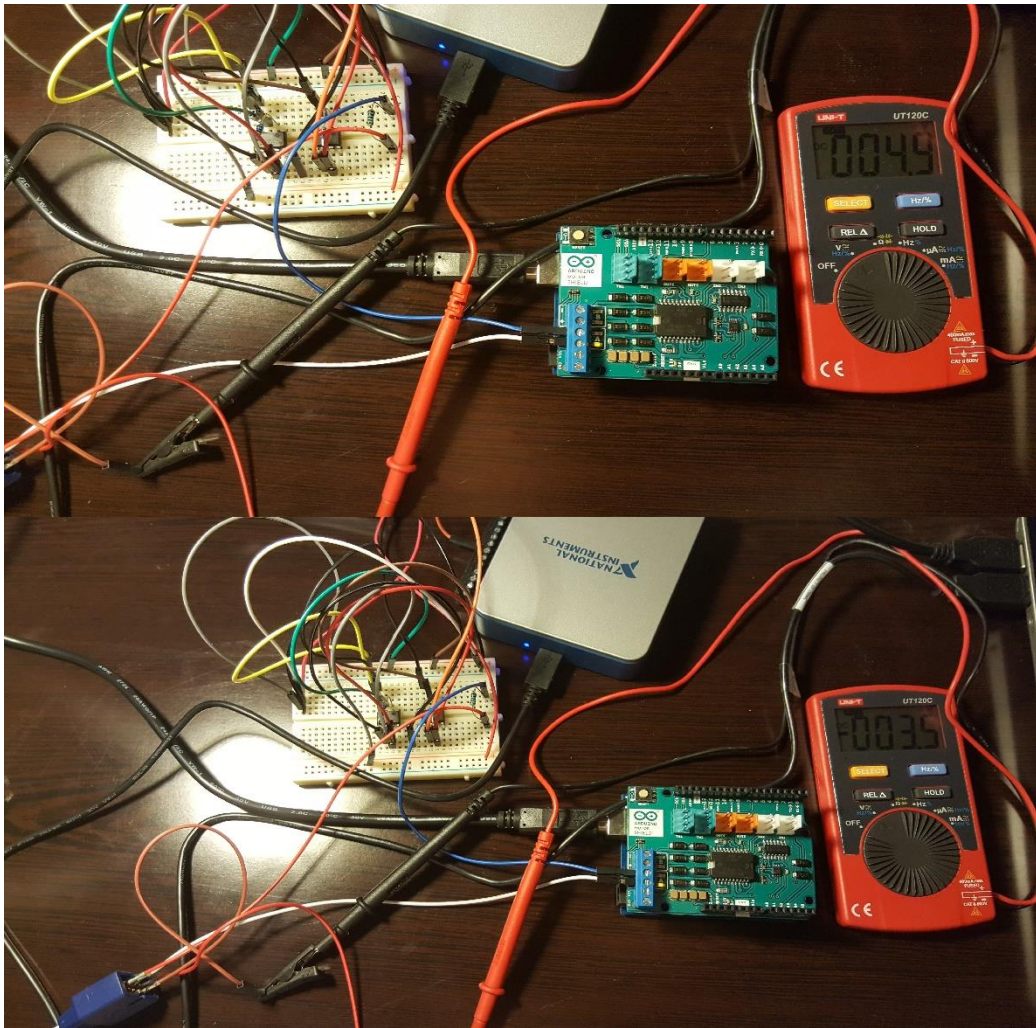
Annex

1. H-Bridge
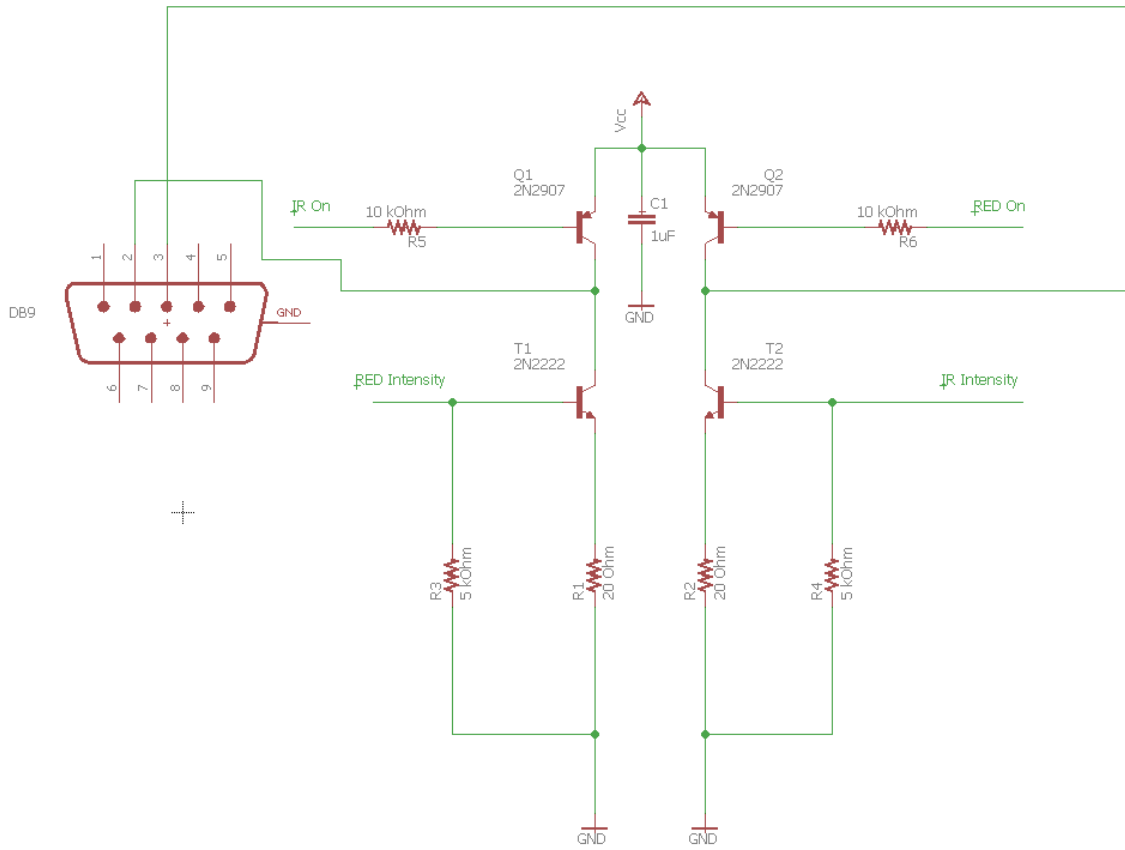
2. Battery connection
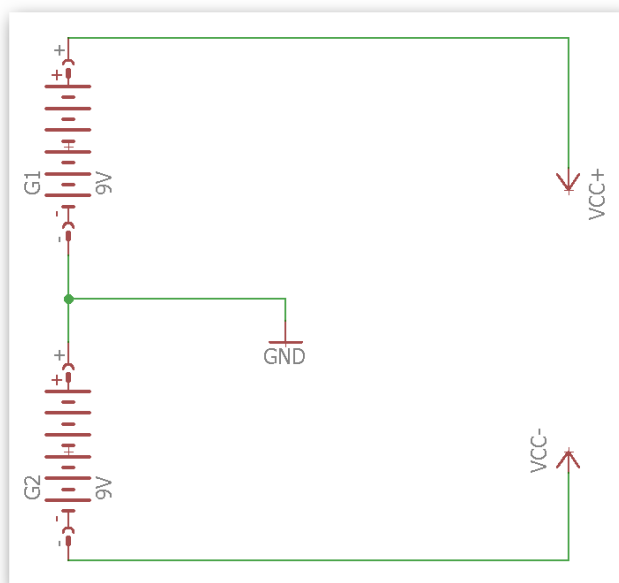
3. Whole circuit

4. Vital signs monitor simulator

5. Photodiode measurement.

6. Arduino code

const int

PWM_A   = 3,

DIR_A   = 12,

BRAKE_A = 9,

SNS_A   = A0;

void setup() {

  // Configure the A output

  pinMode(BRAKE_A, OUTPUT); // Brake pin on channel A

  pinMode(DIR_A, OUTPUT);   // Direction pin on channel A

```
  // Open Serial communication

  Serial.begin(9600);

  Serial.println("Motor shield LED Control:\n");

}

void loop() {

// Set the outputs to run the RED

  digitalWrite(BRAKE_A, LOW);

  digitalWrite(DIR_A, HIGH);

  analogWrite(PWM_A, 255);

  delay(0.25);            // switch ON time RED

  Serial.print("current consumption at RED: ");

  Serial.println(analogRead(SNS_A));

   // Set the outputs to run the delay

  digitalWrite(BRAKE_A, HIGH);

  digitalWrite(DIR_A, HIGH);

  delay(0.25); //Delay inbetween switches

 // Set the outputs to run the IR

  digitalWrite(BRAKE_A, LOW);

  digitalWrite(DIR_A, HIGH);


  analogWrite(PWM_A, 255);


  delay(0.25); //switch ON time IR

  Serial.print("current consumption IR: ");

  Serial.println(analogRead(SNS_A));


  analogWrite(PWM_A, 0);      // turn off power to the motor

  Serial.print("current brake: ");

  Serial.println(analogRead(A0));

  Serial.println("End of the motor shield LED Control. Thank you!");}
```