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Non-invasive measurement of chemical compounds levels in human body

Abstract

The paper presents a system for measuring substances in human body by a combined technique: using visible light and near infrared spectroscopy. The approach is non-invasive, attenuation of radiation by tissues is evaluated. Measurement of two chemical compounds levels is described: that of glucose and of ethylic alcohol (ethanol). The presented measuring system is self-calibrating. Due to this, it is possible to measure changes of compound concentrations in different parts of body, e.g. wrist, arms or legs. The main measurement is done in infrared light (up to 1000 nm), auxiliary ones are performed in visible light (narrow band between 600-680 nm and wide spectrum from around 420 nm to 780 nm - white light). This allows for measurement not only a compound level, but also characteristic properties of tissues in place where measurement is done. Results of measurements are provided and advantages of multi-wavelength measurements discussed.

Keywords: Glucose level measurement; Ethanol level measurement; NIR spectroscopy; non-invasive diagnosis.

1. Introduction

Traditional measurement of blood components is done by taking its sample and testing it in a laboratory. This is costly, time-consuming and impossible to do for real-time analysis. Human blood consists of 90% water, 8% organic components (e.g. protein), 1% organic compounds (e.g. glucose, lactic acid) and 1% nonorganic (ions) [1]. Then, it is very important what we want to measure and where. Best place for locating non-invasive measurement systems are fingers [2]. Proposed in the paper infrared spectroscopy is only one among many non-invasive techniques, e.g. Raman spectroscopy [3], polarimetry [4], bioimpedance [5] or radio and radio-optical methods [6]. The techniques can be used for measurement of more than one substance level, e.g. that of glucose, and lactic acid [7]. They are particularly many approaches to detect glucose level. In spectroscopy many researchers are concentrating on near infrared (700…2000 nm) [2], or medium infrared (over 2500 nm) [8] radiation. Some of them use single wavelengths in visible light, but only in narrow bands, e.g. around 660 nm.

The main idea of this research is to use some wavelenghts in visible light, in infrared, and wide spectrum of white light to detect changes in human tissue. This combination of radiation sources allows for measurement of chemical compounds levels in virtually any part of human body. The aim is a non-invasive analysis of their concentration change, continuously, in real-time.

2. Theory

2.1. Spectroscopy and absorption of human tissues

Spectroscopy is used in chemistry, biology and medicine to determine type and concentration of chemical compounds [9]. Spectroscopy can be done in: near infrared, infrared, UV/VIS or Raman scattering [9]. This article focuses on combined NIR and VIS spectroscopy.

It matters what substances are in blood and tissue where we want to take a measurement. Absorbances of the most important ones are shown in Figure 1 – melanin, oxyhemoglobin, deoxyhemoglobin and water. As can be seen, there is a range of low absorbances, called “Optical Window” [10].

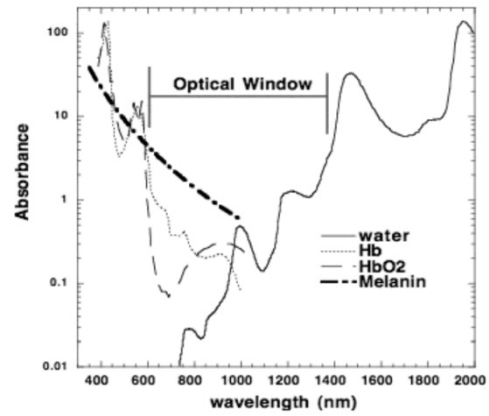

Fig. 1. Absorbances of substances in human body [10]

Table 1 provides absorption peaks of substances in human tissue that can disturb glucose and ethanol measurements [11, 12].

Tab. 1. Absorption peaks (nm) for main substances in human tissue [11, 12]

Water	Hemoglobin	Fat	Protein	Lactic acid
	580			
749				747
		770		
				823
880				
	910	920	910	923
980				
		1040	1020	1047

2.2. Ethanol

Etylic alcohol (ethanol, C_2H_5OH) is a substance that is normally absent in human body. It can be taken only from outside, but its level in blood is important for metabolism and state of organism. Its level can be measured in a non-invasive way, but only from air (level of alcohol in air is proportional to that in blood [13]). With optical sensor we can measure its concentration in real-time, and continuously without taking air samples. Ethanol have absorption peaks for wavelengths: 669 nm, 881 nm, 1050 nm, 1090 nm, 1274 nm and some higher (not being interesting, as our system works up to 1000 nm) [12].

2.3. Glucose

Glucose ($C_6H_{12}O_6$) is the main source of energy in human body, hence, this substances is transported to any cell in organism by blood. Optimal level of this compound is controlled by two hormons: insulin and glucagon [14]. Any distortion of nautral balance between them can be caused by a disease, the most serious being diabetes. A diabetic should frequently measure blood glucose level by taking a drop of it on special disposable test strip. It is painful and non comfortable, especially at night. Glucose has characteristic absorption peaks at wavelenghts: 623 nm, 646 nm, 722 nm, 728 nm, 733 nm, 777 nm, 839 nm, 939 nm, 996 nm, 1015 nm, 1024 nm and higher [12].

3. Measuring system

3.1. Detectors and emitters

In the research six emitters and one detector (on a special measuring head) were used. As a detector a silicon PIN diode with very wide spectrum band (300…1300 nm) was chosen. Emitters were spectrum LEDs (30…40 nm) and emission maxima at: 620 nm, 640 nm, 660 nm, 875 nm, 950 nm, and a white warm led. The wavelengths were chosen to detect peaks of absorption that we were looking for, and to avoid other appearing in human blood (see Table 1). The most important in this research was to find independent peaks for substances that we want to measure and those for disturbing factors. White light was used to measure tissues condition (done in the same place as main NIR measurement). Transmitters and detector were spaced 5 mm from each other. It is shown in Figure 2.

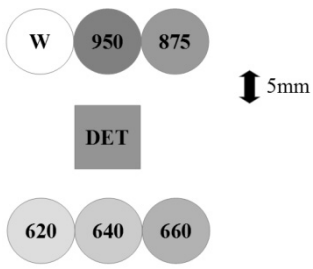

Fig. 2. Measuring head – view of emitters and detector

In the proposed system reflectance measurement was done. This kind of solution had more problems than the transmission mode, but measuring device could be used in different places on human body. Maximum penetration depth of NIR and visible light is around 10…15 mm (penetration depth increases with wavelenght up to ca 1000 nm) [15]. This was the reason, why it was decided to use this spectrum range. Photon path in human tissue is "banana-shape," it is shown in Figure 3.

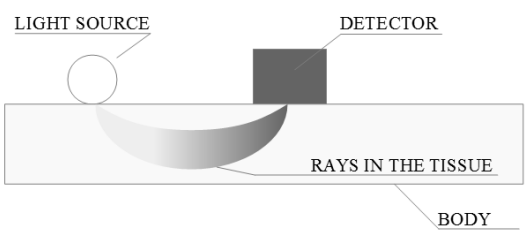

Fig. 3. Light path in tissue

This shape is caused by scattering of light in tissue. Scattering in biological tissues attenuates light to 80% (only 20% is absorbed). This is the reason, why distance between emitters and detector is so small.

3.2. Measuring system

The measuring system was built from six transmitters, that were controlled by a control unit (to control voltage and current in diodes). The diode currents were very low, as power of emitted light was reduced to minimum (for health reason – minimization of light influence on tissue) to level under 25 mW/cm^2. But it was very important to maintain the same level of voltage (to assure constant light emission in time), hence, LDO voltage stabilizer (Low Drop Out) was used to stabilize voltage at 3.3 V. The detector output was low pass filtered to reduce high frequency noise from environment (e.g. form wireless communication). It was a simple RC filter, as signal to noise ratio is quite good in proposed measuring system and better solutions are not necessary. To convert data 16-bit analog to digital converter with programmable gain amplifier was used. Due to this, it was possible to exploit all measuring range of ADC – after fitting light power of emitters to detector susceptibility. Full 16 bit conversion was done, but the lowest 2 bits were treated as erroneous. Frequency 868 SPS (Samples per Second) was enough because maximum speed was reduced to 1 survey per 100 milliseconds. Conversion error was much lower than changes in output voltage during measurement, so it was no need for more precise type of converter. The SPS number was important in other tests, which were done with high frequency. The control unit was a microcontroller Atmel ATMega 8. The chip had low power consumption, a lot of input/output ports, SPI, IIC, and UART terminals, PWM modulator to control light intensity and many other advantages. ATMega 8 was also small (TQFP-44 package), cheap and very popular, as it had good quality to price ratio. It forms a very good base for prototypes with semi-complicated circuits and different battery modes.

4. Results

The research was focused on compensation of tissues conditions on measurements. This problem appears when changing location of measurement system on human body, as different places have different conditions. We have tested locations where measuring is useful and comfortable for patient (arms, forearms, wrists and legs). Results of measuring the same level of substance in blood in different places with and without correction is shown in Figure 4 (three values for each point).

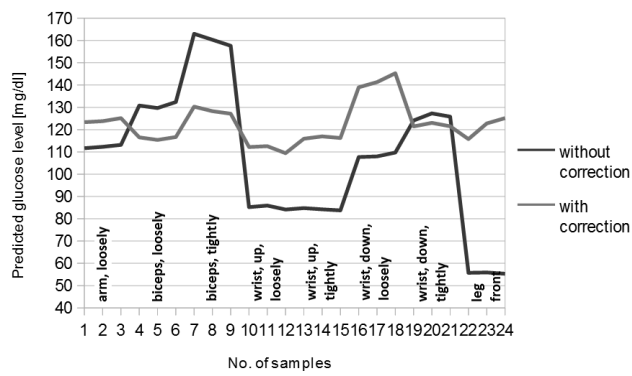

Fig. 4. Measurement distortions with and without corrections

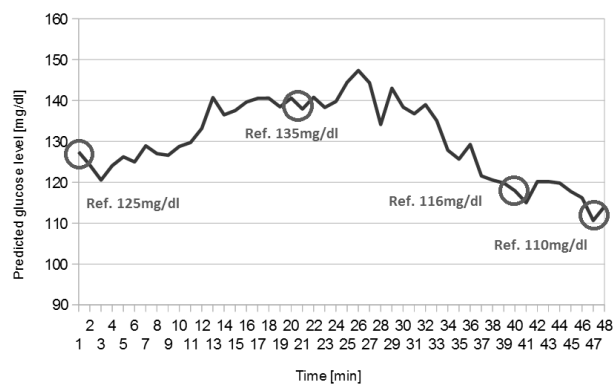

Fig. 5. Changes of glucose level in blood in real-time

To correct measurements an algorithm was used that reduces information noise by analysis of visible light spectrum (main survey was done in NIR). In Figures 5 and 6 examples of noninvasive, continuous measurements of glucose and alcohol (respectively) levels in human blood (time step 1 minute)

compared to reference measurements (traditional methods) are shown.

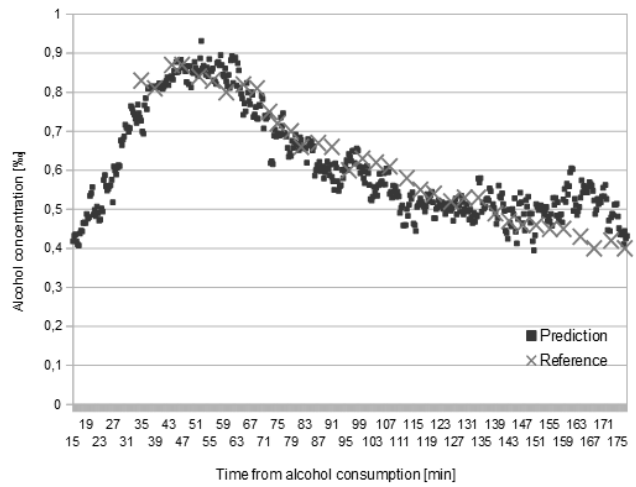

Fig. 6. Changes of alcohol level in blood in real-time

5. Conclusions

The proposed solution to non-invasive substances levels measurements in human body gives satisfactory results. Combined measurements using many wavelengths reduce methods susceptibility to varying conditions of tissues. The effect was proven empirically. Results given by proposed measuring system are not ideal, nevertheless they are sufficiently informative and open a way to build a device that can detect signals in different places on human body. Measuring system using many wavelengths can form a base for future research and building better and more precise devices.

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