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Noninvasive method for measuring blood glucose using MSP430x microcontroller

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(Communicated by prof. A. Bekyarski)

Abstract

The paper propose an improved method to determine the level of blood glucose in the human body, using data from the peripheral temperature, galvanic skin-resistance, heart rate, saturation and perfusion of the skin.

Keywords: *noninvasive, metabolic heat conformation (MHC), blood glucose.*

1 Introduction

The paper presents the analytical solution of the problem for the non-invasive measurement of blood glucose. The metabolic heat conformation (MHC) method was elected to create a device for monitoring blood glucose. MHC method consists in measuring physiological indexes related to metabolic heat generation and local oxygen supply, which corresponds to the level of blood glucose in the bloodstream. The proposed method uses data from the peripheral temperature, galvanic skin-resistance, heart rate, saturation and perfusion of the skin to determine the level of blood sugar in the human body.

2 Existing methods for measuring blood glucose

2.1 invasive methods

Invasive method consists in the measurement of blood glucose by glucometer and blood. Recent advances in invasive blood glucose monitoring are:

- "Alternative measure”: uses test strips and device and allows painless blood sampling.

- "Uncoded systems": older systems require coding of test strips, which carries the risk of errors in coding and hence the measured values. There are two approaches: "auto coding": each test strip is coded and the "single code”: all test strip are coded with the same code, thus avoiding errors.

- "Multi-test" systems: systems use tape or disk containing multiple test strips.

- "Recordable" parameters: systems accompanied with software that allows the user to record the measured results to the computer.

2.2 Noninvasive methods

- Near IR (NIR) spectroscopy - near infrared spectroscopy

  The method uses infrared range of the electromagnetic spectrum - from 800 nm to 2500 nm. The advantage of this method is that NIR penetrates much further in samples than mid-infrared spectroscopy.

- Ultrasound Technology

  Ultrasound is cyclic sound pressure wave with a frequency greater than the upper limit of human hearing - 20 kHz. Ultrasound can reveal details of the structure of the investigated object. Advantage is that you do not need direct contact.

- Dielectric Spectroscopy

  This method measures the dielectric properties of the object as a function of frequency. It is based on the interaction of the external field with the electric dipole moment of the sample and expressed by the permeability.

- Metabolic heat conformation (MHC)

MHC method is based on the amount of heat dissipated (peripheral temperature), blood flow (perfusion) and the degree of oxygenation of the blood.

3 Improved MHC Method

It is a new proposed method that extends the measured parameters in the MHC and provides correlation between them, from which is determined the level of glucose in the blood. The method consists of measuring the physiological parameters of the human body, together with an improved method to calculate the parameter "perfusion", the error is minimized and the accuracy of the measurement is increased in the lower range for values below 1.

Noninvasive thermal and optical sensors are used to measure the peripheral temperature, velocity of blood flow, the concentration of hemoglobin and oxyhemoglobin concentration. Mathematical transformations are used to determine the level of glucose in the blood. Mathematical procedures are multivariate statistical analysis, including values of sensor signals, polynomials from different values of the individual patient and cluster analyzes of patient groups. Glucose is calculated individually for each patient, using a cluster through discriminant analysis.

The oxidation of glucose is associated with the generation of energy that can be released into the environment as heat, so the amount of heat dissipation is related to the levels of glucose and oxygen. Since the amount of oxygen supplied is a function of the level of oxygen in the blood and the rate of blood flow in capillaries, then the amount will be dissipated heat (1):

$$H = f(G, FB, O) \qquad (1),$$

where: H - Heat dissipation, G - glucose level, BF - velocity of blood flow, O - level of oxygen saturation in the blood.

The measurement of heat dissipation by evaporation is proposed to use on the principle of skin-galvanic reaction (SGR). It is also known as BSR (basal skin response), measuring the activity of sweat glands and electrolyte balance of the body fluids. In a state of stress, the sweat glands increase the secretion of salt solution, resulting a change in the electrical (between electrodes) resistance of the skin. Sensors are silver plates placed in specially made holders. SGR is measured through generation of DC current. In the state of stress the SGR change ranged from 150 to 500 KΩ.

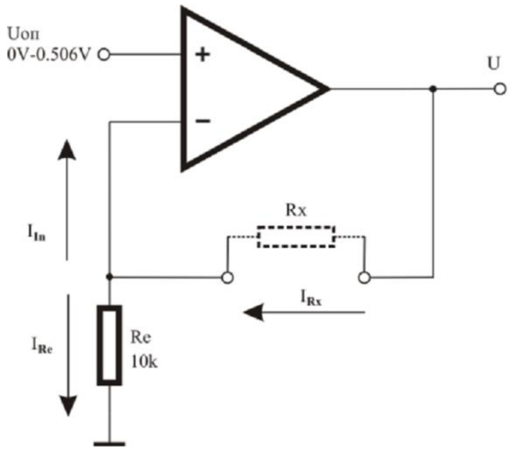

Fig.1. Measuring principle of the SGR

The measurement is based on the DC generator and can be implemented with the operational amplifier (OA), a voltage source, an 8-bit digital-to-analog converter (DAC) and 12-bit ADC. The current IRx that flows through the patient is the sum of the currents IRe and Iin:

Iin is the input current of the (OA) and IRe current flows through the reference resistor Re. The value of Rx is determined by the relationship (2):

$$R_x = \frac{U}{I_{Rx}} - R_e \qquad (2),$$

To measure perfusion, oxygen saturation levels in blood and pulse of the research entity is used pulse oximeter. The measurement method is based on recording the absorption of missed Light through the tissue (finger, ear, etc..) at two different wavelengths. In accordance with law of Bugger-Labert, the relationship between emitted light *Io* and light *I* passing through the absorbent material or tissue with the same wavelength is given by expression (3):

$$\frac{I}{II_o} = e^{-Ecd} = e^{-A} \quad , \; I = I_o e^{-Ecd} \qquad (3),$$

Where c - is the concentration of the absorber, d - thickness of material, E - molecular extinction coefficient of the respective wavelengths, Ecd = A - absorption.

After the logarithm of both sides of the equality, for A is obtained (4):

$$\ln I = Ecd - \ln I_o \qquad (4),$$

If the light passes through a mixture of different substances, the total damping will be the sum of damping caused by all substances. If the CHb and CHbO denote respectively the concentration of hemoglobin and oxyhaemoglobin in the blood, Cn - concentration of all permanent absorbers such as skin, hair, etc.., dHb, dHbO and dN - corresponding thickness of the absorption layer, EHb, EHbO, EN– molecular extinctions coefficients for these substances, we can write the following dependence (5):

$$-\ln\frac{I}{I_o} = E_{Hb}d_{Hb}C_{Hb} + E_{Hbo}d_{Hbo}C_{Hbo} + E_N d_N C_N = A \qquad (5),$$

In pulsating blood through the tissue, absorption of light for given wavelength will change over time and can be described by the formula (6):

$$-\frac{d}{d_t}\ln\frac{I}{I_o} = \frac{d}{d_t}E_{Hb}d_{Hb}C_{Hb} + \frac{d}{d_t}E_{Hbo}d_{Hbo}C_{Hbo} + \frac{d}{d_t}E_N d_N C_N = \frac{d}{d_t}A \qquad (6),$$

To determine the saturation of blood oxygen SO2, it is necessary to determine the absorption of light from Hb of that from HbO2. If we use two different wavelengths light eg 650 nm - red and 800 nm - infrared, the ratio of the amplitudes of these two wavelengths can be presented as a ratio of equation (7):

$$\frac{\mathrm{a}\Delta lnI_R}{\mathrm{a}\Delta lnI_{IR}} = \frac{\Delta \mathrm{a}E_{R_{Hb}}C_{Hb}d_{Hb} + \Delta \mathrm{a}E_{R_{HbO2}}C_{HbO2}d_{HbO2}}{\Delta \mathrm{a}E_{IR_{Hb}}C_{Hb}d_{Hb} + \Delta \mathrm{a}E_{IR_{HbO2}}C_{HbO2}d_{HbO2}} \qquad (7),$$

The thickness and concentration of absorber substance is the sum of all absorbing components. Suppose that absorption components Hb and HbO2, percentage can be presented as (100-x) and x, yielding equation (8):

$$\frac{\mathrm{a}\Delta lnI_R}{\Delta lnI_{IR}} = \frac{\Delta E_{R_{Hb}}\ (100-x) + \Delta E_{R_{HbO2}}\, x}{\Delta E_{IR_{Hb}}\ (100-x) + \Delta E_{IR_{HbO2}}\, x} \qquad (8),$$

4 Hardware realization

The developed system is built on 16-bit RISC microcontroller (MCU) MSP430F149 [5]. The MCU consist of 16-bit RISC core, 16-bit registers and big sets of peripherals. The Timer modules have similar functions although some of them could be very different. The Timer system includes other devices with timer functions – Watchdog timer, pulse-width modulation (PWM) module, Pulse Accumulator. The basic functions used in the experiments are:
1) Input Capture (IC) - to capture the timer value when an external event occurs.

Applications of Timer Input Capture include: counting pulses from external sources, and measuring the parameters of input signals (wave form analysis).

2) Output comparison (OC) - to program an action to occur at a specific time when 16-bit counter reaches a specific value. The value of the Capture/Compare Register is compared to the value of the free-running counter on every bus cycle. When matching occurs, a programmed event takes place, such as changing the state of output, or generating an interrupt.

Generalized block diagram of the device to monitor glucose levels in the blood is given in Fig. 2.

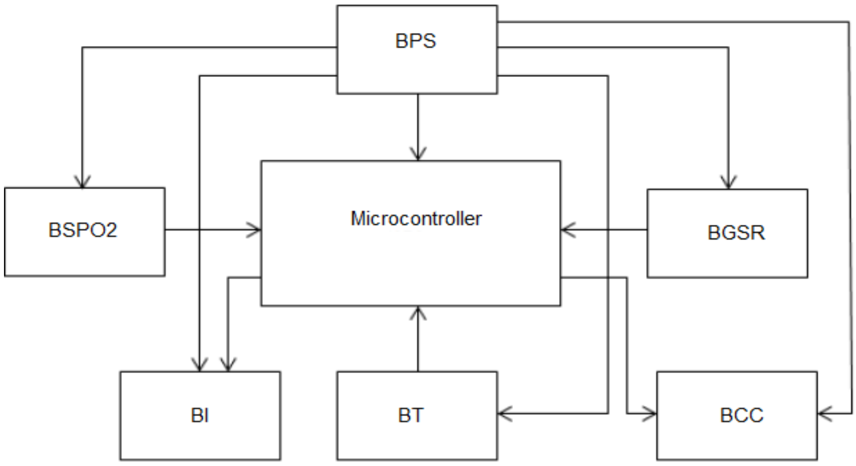

Fig.2. Block diagram of the glucose-meter.

The unit is controlled by a microcontroller, in which a data is measured by following blocks: Block-galvanic skin response (BGSR), block temperature (BT), block saturation, perfusion and oxygen (BSPO2). Block indicator (BI) shows the results of measurements at the display. Block PC connection (BCC) providing connection of the device to a PC to transfer data. Block Power Supply (BPS) supplying device with power.

The purpose of development is that through the device to assess the trend of increase or decrease in blood glucose.

5 Conclusion

Improved MCH method is developed, that uses data from the peripheral temperature, galvanic skin-resistance, heart rate, saturation and perfusion of the skin to determine the level of blood sugar in the body. The proposed method reduces the error of measurement of perfusion and allows to take into account the very small changes in this parameter in the range from 0.1 to 1, which significantly improves the accuracy in the determination of blood glucose by the method MHC.

The suggested method was developed portable pulse oximeter measuring the degree of saturation of blood oxygen, pulse rate and perfusion rate of blood flow in peripheral tissues. Tests were conducted to prove the reliability of measurement of the device.

6 Open Problem

Diabetes is a disease characterized by high blood sugar. High levels of glucose in the blood are due to the fact that the body does not produce enough insulin or the cells respond to insulin produced weakened. When cells do not absorb enough glucose, it accumulates in the blood and leads to hyperglycemia.

Every diagnosed diabetic need to monitor the level of glucose in their blood to know how his treatment goes and how much insulin the body needs, glucosemeter is using for the measurement of the blood glucose.

As a result of the advances in the upcoming technologies for measuring vital signals from the human body, noninvasive methods for measuring blood glucose become a very active research area. In recent years, several noninvasive methods have been successfully implemented over various technologies (Near Infrared Spectroscopy, Ultrasound Technology, Metabolic heat conformation, etc.).

Appropriate analytical solution for monitoring blood glucose, measuring the physiological indexes related to metabolic heat generation and local oxygen supply, which corresponds to the level of blood glucose in the bloodstream, is the use of an improved Metabolic heat conformation device.

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