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Modeling of the blood oxygen and heart rate measurement system

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Monitoring heart rate and blood oxygen content is an integral part of monitoring health and physiological parameters of a person's condition. Thus, measurement of oxygen content and heart rate becomes a rather popular problem. To solve the task set in this work, it is necessary to conduct a detailed analysis of the area and determine the main physical properties of blood at different indicators of the oxygen content in it. Also, when conducting this study, attention should be paid to the influence of the oxygen content in the blood on the heart rhythm of a person**.**

Keywords: measurement system, sensor, metrological parameters.

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Introduction

Monitoring heart rate and blood oxygen content is an integral part of monitoring health and physiological parameters of a person's condition [1]. Thus, measurement of oxygen content and heart rate becomes a rather popular problem. To solve the task set in this work, it is necessary to conduct a detailed analysis of the area and determine the main physical properties of blood at different indicators of the oxygen content in it. Also, under conducting this study, attention should be paid to the influence of the oxygen content in the blood on the heart rhythm of a person.

This work is devoted to the measurement of oxygen content in human blood and heart rate based on the impact of red and infrared light on blood in a non-contact manner. The property of blood to absorb red and infrared light depending on its oxygen content was first discovered and studied in the 1930s on the basis of which Karl Metes created the first medical prototype for measuring oxygen in the blood saturation with two waves [2]. The connection between oxygenated hemoglobin and its absorption of the world in different zones of the spectrum was established. These studies became the basis for the development of oximetry, the technology used in this work.

Measurements of tissue oxygen saturation and tissue hemoglobin content are determined by the difference in intensity between transmitted and received light delivered at specific wavelengths, as described by the Beer–Lambert law. Based on research [3], it can be concluded that oxygenated hemoglobin absorbs more infrared light and reflects red light, while deoxygenated hemoglobin absorbs more red light and reflects infrared light.

I. The physical principle of measurement. Purpose of the device and selection of main components

The oximetry method allows non-invasive and effective measurement of blood oxygen level, which is important for medical diagnosis and monitoring of patients. By exposing the blood to appropriate types of light and reading the reaction from such exposure, it becomes possible to calculate the oxygen content in the blood.

It is a well-known fact that the heart rate will depend on the oxygen content in the blood [4]. The dependence of the heart rate on the content of oxygen in the blood is studied by many scientists and clinicians in the field of medicine and physiology. Such studies are performed to understand the relationship between oxygen levels and heart function, as well as to diagnose and treat various heart diseases and respiratory problems.

The scientific literature on the influence of oxygen content in human blood on heart rate has been analyzed. Changes in heart rate and blood flow rate at different levels of CO_2 in arterial blood are shown. It is noted that, in contrast to the direct vasodilator effect of the oxygen content in the blood, there is also a change in heart rhythm, heart rate, and heart function under such effects [5, 6].

Thus, based on the research results of this work and the ability of hemoglobin to absorb red and infrared light, we can conclude that oxygen-saturated hemoglobin absorbs more infrared light.

By understanding the dependence of the heart rate on the oxygen content in the blood and the property of oxygen-saturated hemoglobin to absorb more infrared light - with the help of a sensor that will expose the blood to red and infrared light and a photocell that will read the reflected light, you can calculate the oxygen content in the blood and the heart rate at the touch of a finger.

This work describes a device that determines oxygen saturation by measuring the absorption of light through blood. By rationally using this device, you can provide all the necessary data on health parameters and prevent threats to the body's health in time.

The main task of the device is to read data by direct contact of the phalanx of the finger with the surface of the device and display this information on the screen for monitoring the readings and the computer in real time.

One of the conditions for choosing the type of device sensor is its price category and compatibility with budget microprocessor platforms of the Arduino family.

For the hardware implementation of the element of obtaining information on the level of blood oxygen saturation, a serial model of a digital budget serial transmitter of the MAX 30100 type can be used [7].

The MAX30100 sensor allows you to measure the level of blood oxygen saturation (blood oxygen saturation, SpO2) and pulse (heart rate) and transfer this information to the microcontroller via the I2C interface. Thus, the sensor contains two functions integrated into it – monitoring the pulse and measuring the level of blood oxygen saturation in a non-invasive way.

II. Measurement of oxygen concentration in blood and heart rate.

To determine the concentration of oxygen in the blood (%), it is important to note that in the blood hemoglobin is responsible for the transfer of oxygen. A connected pulse oximeter passes light through the blood in the fingers. This is used to detect the amount of oxygen by measuring changes in light absorption in both oxygenated and defatted blood. As a method of measuring oxygen in the blood, pulse oximetry is based on the principle that the amount of red and infrared radiation absorbed varies with the amount of oxygen in your blood.

The MAX30100 sensor consists of two LEDs (red and IR) and a photodiode. Both of these LEDs are used to measure SPO2. These two LEDs emit light at different wavelengths, ~660 nm for the red LED and ~880 nm for the IR LED. At these particular wavelengths, oxygenated and deoxygenated hemoglobin have very different absorption properties [7,8].

The following dependence of light absorption by hemoglobin (Fig. 1) is taken from the MAX30100 IC datasheet. You can see the difference shown in the graph between HbO_2, which is oxygenated hemoglobin, and Hb, which is deoxygenated hemoglobin, at two different wavelengths.

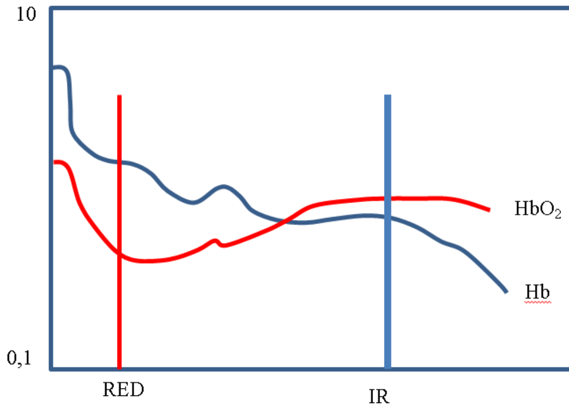

Fig. 1. Light absorption by saturated oxygen and deoxygenated hemoglobin [2].

Oxygenated hemoglobin absorbs more infrared radiation (880 nm) and reflects red light, while deoxygenated hemoglobin absorbs more red light (660 nm) and reflects infrared light. The reflected light is measured by a photodetector. The MAX30100 sensor reads these different absorbance levels to determine the blood oxygen concentration (SPO2). The ratio of IR and red light received by the photodetector gives us the concentration of oxygen in the blood [9].

The ratio of absorbance at these two wavelengths is empirically calibrated against direct measurements of arterial blood oxygenation, and the calibration algorithm is stored in the digital microprocessor in the pulse oximeter. In further use, the calibration curve is used to estimate arterial saturation (SpO2) with a pulse oximeter (Fig. 2).

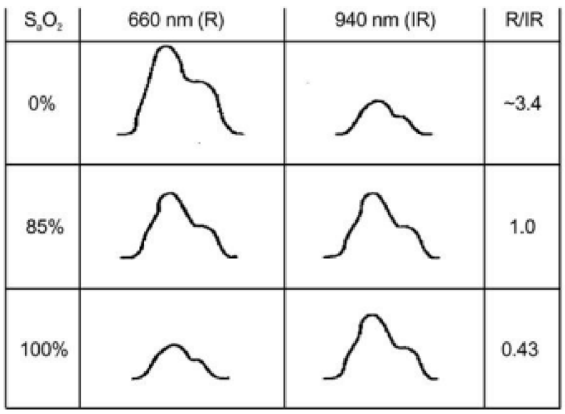

Fig. 2. Calibration curves.

We don't need a red LED to measure heart rate, we only need an IR LED. This is because oxygenated hemoglobin absorbs more infrared light.

Oxygenated hemoglobin (HbO2) in arterial blood has the ability to absorb IR rays. The redder the blood (higher hemoglobin), the more IR rays are absorbed. As blood is pumped through the finger with each heartbeat, the amount of reflected light changes, creating a changing waveform at the output of the photodetector. By continuing to shine and take the readings of the photodetector, we get pulse readings (HR).

Heart rate is the ratio of time between two successive heart contractions. Similarly, when human blood circulates in the human body, this blood is compressed in the capillary tissues. As a result, the volume of capillary tissue increases, but after each heartbeat, this volume decreases. This change in the volume of the capillary tissue affects the infrared light of the sensor, which transmits light after each heartbeat.

By placing a person's finger in front of the pulse sensor, the reflection of infrared light changes depending on the volume of blood change inside the capillary vessels. This means that the volume of blood in the capillaries will be high during the heartbeat and then decrease after each heartbeat. So, changing this volume changes the LED light. This change in LED light measures the heart rate of the finger. This phenomenon is known as "photoplethysmogram" [10,11].

Design of the device and operation of the MAX30100 sensor

The main components of the device (Fig. 3) for measuring oxygen in the blood and determining the heart rate are:

1. The Arduino NANO controller is the main control controller, it processes information from the sensor and sends it to the screen and computer;

2. The MAX30100 heart rate sensor is an accurate, compact and fast-acting sensor, as well as quite budget-friendly;

3. OLED display is a high-quality and energy-efficient solution, which is quite necessary in this kind of device. Thanks to OLED technology, it takes up very little space.

The MAX30100 sensor (Fig. 4) consists of a chip on which LEDs (red and IR), a photodetector, and various optical elements are embedded. Also, the sensor module has a built-in signal processing circuit, which is characterized by a low level of inherent noise and provides protection against external lighting.

The MAX30100 is controlled using internal software registers. Digital output data can be stored in a 32-bit FIFO buffer, allowing the digital stream to be serialized to an external controller via a common bus.

Consider the block diagram of the module built on this sensor.

The optical sensor is a photodiode that receives reflected red and infrared radiation from two LEDs that are connected to LED drivers. In the analog unit there is a temperature sensor that shows the operating temperature of the entire device and prevents overheating by warning the user. It is connected to an analog-to-digital converter. The photodiode is also connected to an analog-to-digital converter. The analog block also filters the signal from ambient light. The analog-to-digital converter of the photodiode is connected to a digital filter that filters the quantization errors of the analog-to-digital converter. The analog-to-digital converter of the temperature sensor and the digital filter of the photodiode are connected to a memory register where the values from these sensors are stored for some time. After that, the digital signal processing unit is connected to the I2C connection interface, through which this module is connected to the microcontroller.

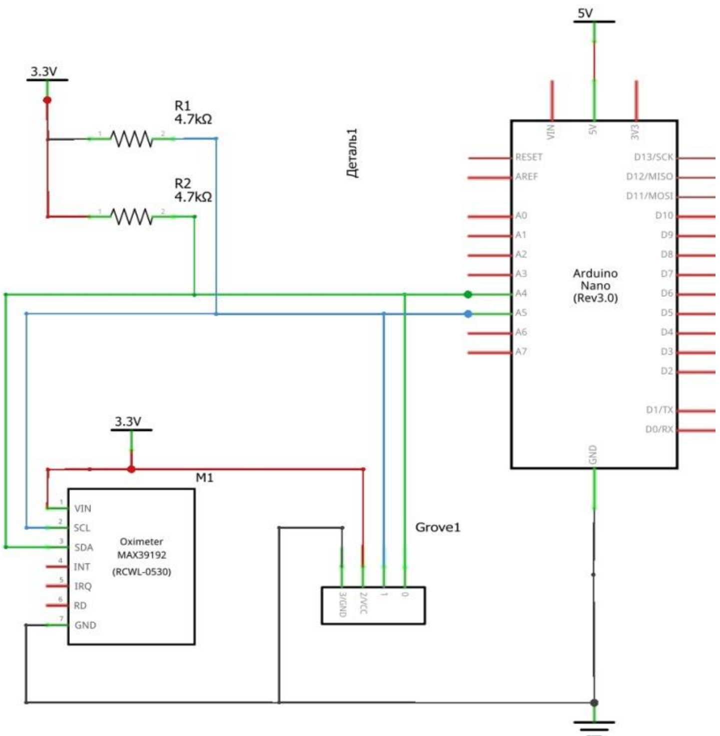

Fig. 3. Typical electrical diagram of connection of the oxygen content sensor in the patient's blood of the MAX 30100 model to the microcontroller module of the Arduino type.

Fig. 4. Max30100 heart rate sensor.

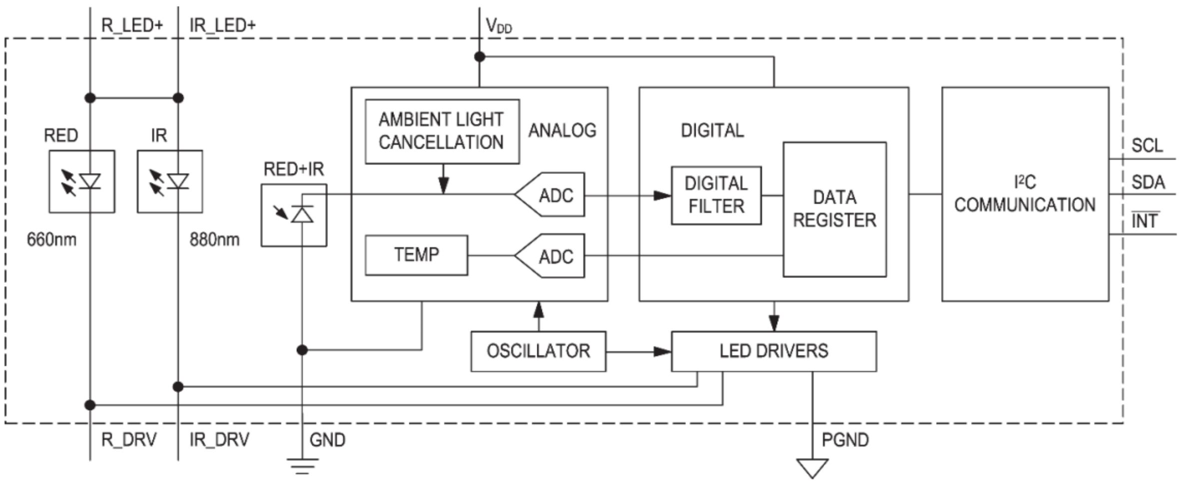

Fig. 5. Block diagram of the module for measuring pulse and blood oxygen saturation level based on the MAX30100 sensor [5].

Conclusions

Based on a thorough description with further analysis of the nominal metrological parameters and technical and functional indicators of the digital content of oxygen in the patient's blood of the MAX 30100 model, it can be concluded that it is capable of being used when solving the problems of developing and designing the researched health monitoring system patients in hospitals after implementation of regulated procedures of individual graduation / calibration and metrological attestation / verification.

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Моделювання системи вимірювання кисню в крові та частоти скорочення серця

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Моніторинг ЧСС і вмісту кисню в крові є невід'ємною частиною моніторингу здоров'я та фізіологічних параметрів стану людини. Таким чином, вимірювання вмісту кисню і частоти серцевих скорочень стає досить популярною проблемою. Для вирішення поставленої в даній роботі задачі необхідно провести детальний аналіз місцевості та визначити основні фізичні властивості крові при різних показниках вмісту в ній кисню. Також при проведенні цього дослідження слід звернути увагу на вплив вмісту кисню в крові на серцевий ритм людини.

Ключові слова: вимірювальна система, датчик, метрологічні параметри.