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Hardware-software complex for detection of weak optical signals on probing biological transparent mediums

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The key terms, which are used in current exploration – biological media and weak optical signals. Biological media is the biological environment that is created in the living organism and has physical and chemical properties. Weak optical signals - extremely small optical signals that photodetectors are able to register at the noise level.

Operation of the hardware-software system is based on the optical properties of the studied biological media, in particular, on the ability of some substances to rotate the plane of polarization during the passage of the optical radiation through them. The environment having this property is called optically active, and the method, respectively, polarimetry.

Optically active media consisting of a mixture of active and inactive molecules rotates the plane of polarization, and this rotation is proportional to the concentration of optically active substances. This is the basis of polarimetric method for measuring the concentration of substances in solution; proportionality factor which links rotation of the polarization plane with the length of the beam and concentration of a substance is called the specific rotation of the substance.

Main ratio used in our work, is called the law of Biot. The angle of rotation of the plane of polarization in solutions of active substances depends not only on the length of the path (l), but also on the concentration of the active ingredient (c):

$$\alpha = l \cdot C \cdot \varphi. \quad (1)$$

The table shows the values of the specific rotations of different materials depending on the solvent under normal conditions - in yellow rays at 20 ^{0}C.

Table 1 [5]

Specific rotations of some substances

Substance	Solvent	Specific rotation
Sucrose	Water	+66,462
Glucose	Water	+52,70
Fructose	Water	-92,40
Menthol	Ethyl alcohol	-50,60
Strychnine	Ethyl alcohol	-139,30

Determination of glucose

The main idea of the hardware-software complex is to study a homogeneous liquid biological media of a person in order to identify high or low blood glucose. This allows to diagnose hypoglycemia or hyperglycemia and, as a consequence, diabetes.

Diabetes mellitus — a chronic condition of the body, which occurs when the pancreas cannot produce enough insulin or when the body cannot effectively use the insulin it produces. According to the World Health Organization (WHO), in 2000 there were an estimated 171 million of diabetics, and the forecast for 2030 is 366 million people. WHO estimates that in 2005 1.1 million people died from diabetes, and half of diabetes deaths occur in the age of patients was 70 years. Table 2 shows the values of the normal concentration of glucose in human blood.[7]

Table 2 [7]

Normal concentration of glucose in human blood

Fasting, mmol/l	After meal, mmol/l	In 2 hours after meal, mmol/l
3,5 – 5,0	3,5 – 8,0	3,5 – 5,0

It is obvious that the control of the concentration of glucose in the human body is a priority aimed at the prevention of complications associated with the effects of diabetes [4].

In current work, it was decided to use tear fluid as a liquid organic medium of the body. Table 3 shows the compositions of blood plasma and human tear fluid.

Table 3 [5]

Compositions of blood plasma and tear fluid

Component	Plasma	Tear fluid
Electrolytes, мM		
Na^+	137,5	135,0
K^+	4,3	36,0
Cl^-	108,5	131,0
HCO_3^-	27,0	27,0
Ca^{2+}	2,3	0,5
Mg^{2+}	0,2	0,36
Organic substances, mg/ml		
Glucose	0,8	0,05

From a comparison of composition of blood plasma and tear fluid can be concluded that it is possible to use tears in this study.

Collection of tear fluid from patients also is a significant problem. To collect tear fluid it is possible to use pipetting. Tear fluid collected in sterile tubes. With plastic nozzle, which has a rounded edge and is fixed to pipetting, tear fluid is collected from lower conjunctival sac.. It is not recommended to use any chemicals substances that stimulate tearing. Patients are asked to look up during the entire procedure. Tear fluid is collected within 7-15 min. from the lower conjunctival sac of both eyes, about 1 ml of tear fluid is sufficient. [6]

Development of the diagram of hardware-software complex

In order to determine the minimum signal that might be got in the laboratory, has been conducted a number of experiments. In the experiments, we used the following equipment:

• as a transmitter helium-neon laser with a power of 30 mW;

• polarizing filter;

• photodetectors;

• as an amplifier and signal meter - selective microvoltmeter V6-9.

In the beginning it was supposed to use a glass capillary tube. But while the experiment had been carried out, it was proved that this entails difficulties: within the passage of the laser beam through the packed tube, it was impossible to get a clear signal. Apparently, due to the proximity of the refractive indices of the glass and the water signal underwent scattering. Thus, it was decided to replace the glass tube with metal.

Table 4 presents the results of an experiment in three directions: the laser illuminates empty "capillary", water-filled "capillary", and a "capillary" filled with glucose solution with a concentration of 0.05 mg/ml.

Table 4

Results of experiment

The experimental conditions	Signal, uB
Filled "capillary"	600
"Capillary" with distilled water	4
"Capillary" with glucose solution	0,3

The results show that when the optically active substance is illuminated, in this case a glucose solution, the signal level drops. This indicates the rotation of the polarization plane. As can be seen from the data presented in the table, the signal obtained when the capillary tube is illuminated, is very small. This means that in order to achieve maximum accuracy of the results it needs to take various measures to improve the accuracy of the hardware part of the device: use the radiation modulation, use amplifying devices, as well as a more powerful transmitter.

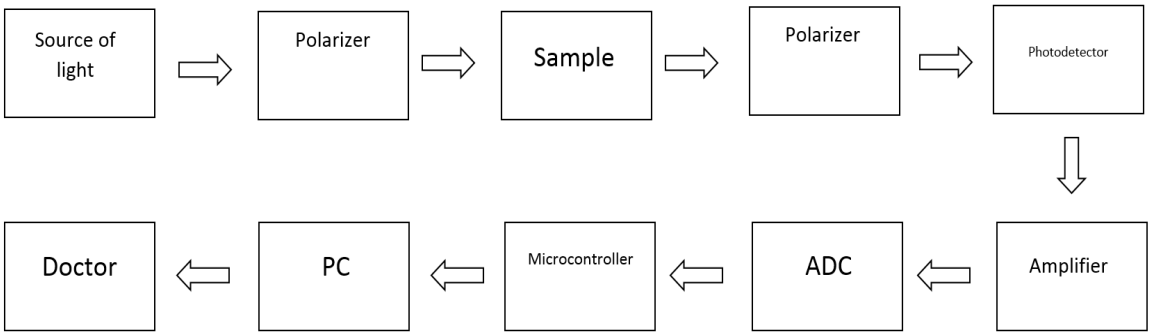

Fig.1 Block diagram of hardware-software complex

Fig. 1 is a block diagram of hardware-software complex. As a sample is offered the usage of thin-walled tube with length of 10 cm with a hole diameter of 1 mm (dimensions of such small volumes due to tear fluid, which may be taken from the patient). The tube must be made of a material whose refractive index is significantly different from the refractive index of the liquid medium to prevent excessive scattering.

The measurements are fulfilled in two stages: firstly the channel, containing no glucose, is introduced into the apparatus, then, under the same conditions, comes the “working sample” with glucose. Channel transmission coefficients are calculated relative to the values of the photocurrents, which are determined by the flux and transmission coefficients of the filters.

According to the law of Malus, the ratio of transmittance of two samples is equal to the cosine of the angle of rotation of the polarization plane square. In this case, photocurrent value can be replaced by the values of signals at the photodetector.

The formulas used in the calculations were obtained in a study of non-health-care polarimeters.

$$T_1 = \frac{I_{1cn}}{I_{1xn}} = \frac{0{,}5 \cdot \Phi_1 \cdot T_{n\phi 1} \cdot T_{cn} \cdot T_{n\phi 2} \cdot \cos^2 \alpha \cdot K}{0{,}5 \cdot \Phi_1 \cdot T_{n\phi 1} \cdot T_{xn} \cdot T_{n\phi 2} \cdot K} = \frac{T_{cn}}{T_{xn}} \cdot \cos^2 \alpha, \qquad (2)$$

where I_{1cn}, I_{1xn} – values of photocurrents;

Φ_1 – radiation flux;

$T_{n\phi 1}$, $T_{n\phi 2}$ – transmittance of polarizing filters;

K – conversion factor of optical radiation in photocurrent;

T_{cn} – transmittance of working solution;

T_{xn} – transmittance of empty solution.

Appearance of $\cos^2 \alpha$ is due to the law of Malus, where α —the angle of rotation of the polarization plane.

Transmittance of the second optical channel will be calculated according to the formula (3):

$$T_2 = \frac{I_{1cn}}{I_{1xn}} = \frac{0{,}5 \cdot \Phi_1 \cdot T_{n\phi 1} \cdot T_{cn} \cdot K}{0{,}5 \cdot \Phi_1 \cdot T_{n\phi 1} \cdot T_{xn} \cdot K} = \frac{T_{cn}}{T_{xn}}, \qquad (3)$$

The ratio of optical transmittances of two channels is equal to (4):

$$\frac{T_1}{T_2} = \frac{T_{cn} \cdot \cos^2 \alpha}{T_{cn}} = \cos^2 \alpha. \qquad (4)$$

$$\sqrt{\frac{T_1}{T_2}} = \cos \alpha, \arccos \sqrt{\frac{T_1}{T_2}} = \alpha.$$

Further, according to the Biot (1) the desired concentration of the optically active compound is determined (5):

$$C = \frac{1}{l \cdot \varphi} \arccos \sqrt{\frac{T_1}{T_2}} . \quad (5)$$

Photocurrent value can be expressed by the values of signals removed from photodetectors. These signals are very small due to the sharp decline in the intensity of the radiation as it passes through the hole of the tube diameter and 1 mm. Previously calibration signal of 0.2 mV was obtained, which makes it possible to determine low concentrations of the optically active substances in the solutions.

As a result of work has been formulated the basic ideas for the implementation and application of hardware-software complex for the detection of weak optical signals on probing transparent biological media. Also identified the requirements that complex must be satisfied.

It has been found possibility of using the tear fluid in this study. Tear is the most transparent of all human body fluids, thus contains the same elements as blood plasma.

The advantage of this hardware-software complex is the fact that you are using a capillary, and not a ditch, which would contain a large amount of fluid, as well as the passage of radiation would interfere with the cell wall.

The possibility of using tear fluid for determining glucose levels in the body will allow to approach the question of treatment of diabetes not only in terms of quality (high definition or low glucose) but also in terms of quantitative (how much specifically the concentration of units derived from the norm). Also, the use of tear fluid will make the process of determining the concentration of glucose non-invasively. Furthermore, by using this complex it is possible to measure the dynamics of glucose in the body, which plays a major role in the diagnosis of cancer. Involves the use of hardware-software complex both in the laboratory and in clinical settings.

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