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VIRTUAL DESIGN OF A MEASURING DEVICE INTEGRATED IN ELECTROACUPUNCTURE STIMULATOR ON ARDUINO

The object of research is the electrical conductivity of biologically active points. Biologically active points as a method of non-traditional medical procedures and diagnostics, as well as being used for therapeutic purposes. Although this method has become the subject of mass research, a complete theory of the method has not yet been formed. Based on research, it is possible to say that there are different approaches to explaining the mechanism of action. These independent studies suggest the existence of unique electrical properties in the areas of the skin where biologically active points are located. However, due to technical and methodological problems, it was not in the interest of the scientific community, and as a result of solving the problem mentioned in recent history, interest in research in this field has increased.

Nerve endings, called biologically active points or acupuncture points, are widely used in alternative medicine. The first step in electrostimulation of acupuncture points is the localization of the point. Localization is based on measuring the electrical conductivity of acupuncture points. The article discusses the virtual design of the measuring device, which is expected to be integrated with electrostimulators. As a result of the simulation, measurements were made and the accuracy class of the device was determined. Thus, it is possible to accurately measure electrical conductivity in biological objects through this device.

The proposed device is designed on the basis of a modern element base. The basic element of the device is Arduino. A voltage divider scheme was used to determine the electrical conductivity of Arduino-based biologically active points. The purpose of using a voltage divider circuit is to protect the Arduino's analog input from overvoltage. Based on the measurements, the accuracy class of the proposed device was determined. As a result of the simulations, it was determined that the absolute error of the device is 0.463056, the relative error is 0.005742, and the accuracy class is 0.0463056.

Keywords: *electrical conductivity, biologically active points, electrostimulation, Arduino Uno, electroacupuncture, voltage divider scheme.*

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1. Introduction

Varieties of reflexology, in which the effect on acupuncture points is carried out by electric current, are called electropuncture (superficial transcutaneous electrical stimulation) and electroacupuncture (deep electrical stimulation through inserted needles). These methods of reflexology have become especially widespread as a result of the successful use of electroacupuncture for the purpose of pain relief during surgical interventions [1, 2].

A more pronounced effect of electrical stimulation of acupuncture points compared to acupuncture is primarily due to the fact that when passing an electric current, a more effective effect on receptor formations is possible even if the localization of the point is not quite accurate [1].

Electroacupuncture uses pulsed current, not direct current, because when the pulses are given at high intensity, each current pulse must be followed by a pause in order for the body to perceive the stimulus. When a direct current is applied, the body's capabilities are depleted much faster. The therapeutic part of the device consists of a low-frequency current generator with a variable frequency from 0.8 to 10 Hz, which is manually adjusted or constantly changed using a small electric motor in the «Electropuncture» device. This device is called «wave swing» in electroacupuncture. Experience has shown that the therapeutic effect during treatment is achieved much faster by changing the frequency from 0.8 to 10 Hz from one current pulse to the next, using a wave pendulum, instead of using a fixed frequency of 10 Hz. By constantly changing the frequency from 0.8 to 10 Hz, low frequencies are obtained for the treatment of blood and lymph, medium frequencies for the treatment of the autonomic, central and peripheral nervous systems, while high frequencies are used for the treatment of organs [3, 4].

The biophysical parameters of the BAPs (Biologically Active points) differ from the surrounding points.

Below are the so-called differences:

1. They are distinguished by their strong absorption of ultraviolet rays.
2. Causes pain during mechanical impact.
3. The temperature is relatively high.
4. Electrical potentials are different. Thus, the potential of BAPs during illness increases.
5. Electric resistance is small.

The distinctive features of biologically active points became the basis for the use of electrical methods in research. Thus, the method of electropuncture, which is a method of studying biologically active points, has become widespread. The unique (main) advantage of the electroacupuncture research method is the ability to assess the state of the internal and external organs of the human body without the need for irradiation, without the inclusion of probes and contrast agents [5, 6].

One of the problems encountered in electroacupuncture research is that acupuncture methods and stimulation parameters vary depending on therapeutic experience, personal preference, and individual pain sensitivity threshold. In addition, commercially available electroacupuncture stimulants are large in size and require the patient to remain relatively still during treatment. This can cause undesirable stress reactions in animals or cause the animal to be sedated with drugs. Both of these provisions completely change the physiological state of the patient and as a result have the potential to significantly affect the results of the experimental process. From the point of view of therapists and scientists, electroacupuncture instruments are not designed to conduct modern experiments using computational techniques from smart mobile devices or computers. There is a need to design devices that offer opportunities for both therapists and scientists to overcome these problems.

Thus, *the aim of the study* is to develop an electroacupuncture device with microcontroller-based application in accordance with engineering standards, and consideration of trade-offs based on economic, functionality, and manufacturability constraints.

2. Materials and Methods

2.1. Acupuncture research methods. Acupuncture is a technique used to treat pathological conditions by stimulating certain points in the body's nerve channels, lymphatic channels, or nerve control centers [7]. Stimulation can be done with a variety of techniques, and because of the benefits of using electrical current and stimuli (incentives), there has been more interest in electroacupuncture than in others [8–10]. Electroacupuncture has been a growing field in parallel with various medical applications [1, 2]. Among the possible pathological conditions, electroacupuncture therapy has found application in areas such as pain relief, gastrointestinal, musculoskeletal system, neurology, cancer symptoms, obstetrics, cardiovascular and surgical anesthesia. Although research in this direction is intensive, the problems and questions of the scientific study of the application of the electroacupuncture method in biology-medicine remain unanswered.

The proposed electroacupuncture stimulator is a Bluetooth module designed to be placed on the patient during the treatment process and a smart mobile device for management purposes. The advantages of the device are its small size and wearable features, the freedom of movement of the patient during the treatment process and the continuation of normal activity. These features make it possible to reduce the stress on animals, especially during animal husbandry practices. It is possible to set the voltage and frequency of the active signal with high precision through a smart mobile device. It combines data analysis methods with a smart mobile device to record patient and treatment outcome data.

The use of an electroacupuncture stimulator allows an injection cannula to be located without the cooperation of the patient. Regional anaesthesia thus becomes safer because the basic condition «no paraesthesia, no anaesthesia» becomes irrelevant. In accordance with the basic electrophysiological conditions, a stimulator should have the following properties:

1) adjustable constant current at resistances of 0.5–10 kΩ;
2) monophasic square-wave initial impulse;
3) impulse duration selectable (0.1 ms+1 ms), and exactly adjustable;
4) impulse amplitude (0–5 mA) exactly adjusted, unequivocal scale graduation or current indicator, in particular in the range of 0.05–1.0 mA;
5) impulse frequency 1–2 (–3) Hz;
6) alarm at high impedance and check on electrical circuit;
7) battery test (indication of battery voltage);
8) unequivocal assignment of load end;
9) high-quality connecting cable and plug;
10) instructions for use with relevant parameters (tolerated variations, steady-state characteristic curves, etc.).

2.2. Measurement of electrical conductivity of biologically active points. When examining an organism, it is necessary to use correct methods to obtain more accurate information so that the structure of the organism is not damaged during the research process. In other words, the method or method used in the research should not cause any change in the physical-biophysical and physicochemical processes in the body. It is a method of measuring electrical conductivity (resistance) that meets this principle and has a wide application area in medical and biological research [9, 10]. The advantage of this method is that the current used does not cause any change in the physical and biophysical processes occurring in the bio-object and at the same time does not damage the research object.

As mentioned, the problem of localization of BAPs is solved by the resistance measurement method, which has a wide application area.

Electrical conductivity measurement is used in medical and biological research for the following purposes:

- in the examination of physiological characteristics of living organisms;
- in the study of changes related to the physiological state;
- it is used to examine biological tissue structure. As a result of the data obtained by measuring the electrical conductivity, it is possible to examine the bio-tissue structure and to detect the pathological changes that occur there.

Biological objects have passive electrical properties: capacitance and resistance (dielectric constant). To study the structural structure and physical and physical state of biological objects, it is essential to know their passive electrical properties. Biological objects have the properties of both wires and dielectrics. The presence of free ions in cells and tissues ensures their electrical conductivity.

The value of dielectric properties and dielectric constant is determined by the structural elements and polarization of biological objects.

Electrometric medical-biological research generally uses the concept of electrical resistance of tissues, not the concept of electrical conductivity, in studies of biological tissues. The electrical conductivity is denoted by g is equal to the inverse of the resistance of biological tissues [8, 10]:

$$g = \frac{1}{R}. \tag{1}$$

While electrical resistance is calculated by the equation:

$$R = \rho \frac{l}{s}, \tag{2}$$

where ρ is the specific resistance of the biological tissue, l is the length of the biological tissue and S is the cross-sectional area of the biological tissue. On the other hand, the difference in resistor potentials is the proportionality coefficient of the current density I to U (Ohm's law):

$$V = R \cdot I. \tag{3}$$

While a potential difference is constant when a steady current flows through living tissue, the intensity of the current decreases over time. It drops to a steady level after a while. In this case, the value of the current density is one hundred times less than the initial value. Unlike inanimate objects, living beings violate Ohm's law (Fig. 1) [8].

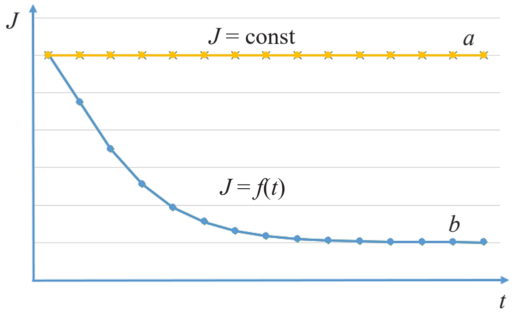

Fig. 1. A change of the constant current across the tissue under constant voltage: *a* – in the presence of polarization; *b* – change in value of current in the absence of polarization

This is explained by the phenomenon of polarization occurring in living tissues. Thus, when a constant current flows through the tissue, an axial EMF equal to the electromotive force (EMF) of polarization is formed, causing the supplied current to drop to a certain value. The EMF of polarization is a function of time $P(t)$. Therefore, Ohm's law for biological objects should be written as:

$$I = \frac{V - P(t)}{R}. \tag{4}$$

The reason for EMF polarization is the ability of living cells to accumulate electrical charge when a current flows through them, in other words, the polarization of biological objects is mainly the result of their capacitance and dielectric properties.

Currently, to find out more about biological objects, electrical conductivity is measured with alternating current, not direct current. They have the ability to store electrical charge when current flows through biological systems. Therefore, when studying the electrical properties of biological systems, it is necessary to use electrical capacitance in combination with ohmic resistance.

When a current flows through an object, a polarization capacitance is formed. The electrical capacity of a biological object is determined by the polarization capacity. The polarization capacity is the ratio of the change in the electric charge to the potential change as an alternating current passes through the object. Since the change in charge at time T is $\Delta q = \int_0^t I\mathrm{d}t$ and potential change $\Delta\varphi = R(I_0 - I_t)$, the polarization capacity C_p is found by the following equation:

$$C_p = \frac{\int_0^t I\mathrm{d}t}{R(I_0 - I_t)}, \tag{5}$$

where I_0, I_t are initial and fundamental values of current respectively, I is current and R is ohmic resistance.

The static capacity of the membrane adds to the polarization capacity of the biological object. The polarization resistance depends on the exposure time of the field, and low frequencies can be greater than the static resistance. At higher frequencies (greater than 10 kHz) the static capacity is several times greater than the polarization capacity. Since these capacitances are combined sequentially, the total capacitance at high frequencies is determined to be smaller than the polarizing capacitance. Since biological objects have both electrical conductivity and electrical capacity, they are characterized by active resistance and reactive resistance. R_x reactive resistance is determined by the equation:

$$R_x = \frac{1}{\omega C}. \tag{6}$$

This is also called capacitive resistance. ω is the rotation frequency of the current.

Resistances of biological objects are called total impedance and denoted by Z. Impedance in case of successive combinations of C and R in the case of parallel connection is determined by the equations:

$$Z = R - j\frac{1}{\omega C} \text{ or } Z^2 = R^2 + \frac{1}{\omega^2 C^2}, \tag{7}$$

$$\frac{1}{Z} = \frac{1}{R} + j\omega C. \tag{8}$$

2.3. Diagnostic parameters. Skin impedance is the skin's opposition to the flow of current. The impedance of skin is a function of both resistive (frequency independent) and capacitive (frequency dependent) elements. The practice of measuring skin impedance is based on the widely held assumption that biologically active points are loci of decreased impedance compared to skin sites where there are no known biologically active points. Research performed in an unblinded manner several decades ago first demonstrated evidence of these phenomena [5, 10, 11]. More recent studies, performed under stricter conditions, confirmed these findings.

Three groups of researchers, however, using blinded evaluators and rigorous statistical analyses, concluded that, based on skin impedance measurements, biologically active points could not be distinguished from non-biologically active point sites. The latter investigators point out the many possible sources of error associated with skin impedance measurements.

Skin impedance measurements also vary with the frequency of applied current and with several instrumentation parameters, including whether a multichannel system, a concentric probe a four-electrode system or a two-electrode system is used.

Resistance and reactance measurements were taken at PC-4, PC-5, PC-6, and PC-7 BAPs on the left forearm in research [12]. All four BAPs and non-BAPs were used. The resistances of four BAPs were found to decrease to about 29–59 % of non-BAPs and reactance of BAPs was found to decrease to about 23–41 % of non-BAPs. Skin impedances at BAPs were lower than those at non-BAPs.

In the analysis of the status of BAPs, the cell membrane shows conductive and dielectric properties depending on the frequency of the applied current. At low frequencies, the cell membrane acts as a capacitor and prevents the flow of electricity. Therefore, it is possible to collect information about the fluid surrounding the cell in low frequency currents. At high frequencies, the capacitive properties of the cell membrane are lost and an electric current flows both around and inside the cell. Theoretically, the impedance produced by high frequency current applications reflects the sum of the cell's internal and external fluids.

When an alternating current is discharged from a substance, the electrical resistance shown in relation to the current is called impedance (Z). The resistance of biological substances to alternating current is called bioimpedance. Electric current flows more easily to tissues where water is scarce (bone, fat and skin) than body tissues (blood, urine and muscle).

In biological systems, impedance has two aggregates, active (R) and reactive (X_c). That is, the body resists two types of electric current. Impedance is mathematically defined by the following expression:

$$Z^2 = R^2 + X_c^2. \tag{9}$$

Active aggregation indicates the presence of intracellular and extracellular fluids. Resistance is related to the water and electrolyte properties of the tissue. Reagent accumulation is due to the resistance created by the cell membrane. At high frequencies, this value is proportional to the amount of intact cell membranes and is a direct measure of body cell mass.

The ratio of reactive aggregate to active aggregate with arctangens is 57,296, i. e. the phase angle calculated by the formula:

$$\arctan = \left(\frac{X_c}{R}\right) \cdot \frac{180}{\pi}. \tag{10}$$

It is a parameter of bioelectrical impedance analysis that provides a highly accurate estimate of death from various diseases with impaired clinical conditions [11]. The phase angle has been found to be used in the prognosis of diseases such as hemodialysis, cancer, immunodeficiency syndrome and liver.

Low values of the phase angle indicate a low value of reactive aggregate, cell death or impaired permeability of the cell membrane. The higher the phase angle, i. e. the cell membrane, the cell fulfills its full function. Therefore, it has been noted that the phase angle is the best indicator for assessing the functional status of cells. For a cell membrane with ideal structure, the phase angle should be between 5 and 70. It should be noted that there is still no reference value for the phase angle for various pathologies.

In a study significant results were obtained in measuring the reactive resistance of biologically active points [11]. The effective tension applied was of 2.05 V and the signal shape was square wave.

As can be seen from equations (7) and (8), the impedance of biology objects changes as the current frequency changes. Thus, as the current frequency increases, the reactive part of the impedance decreases. One of the reasons impedance depends on current frequency is that frequency capacitance is frequency dependent. Another reason is that polarization depends on the duration of the alternating current.Biologically Active points (BAPs) are very important for medical therapy and diagnosis. The malfunction of the internal organ correlated with the biologically active points lowers the electrical resistance of the biologically active points. The biologically active points have a lower electrical resistance and a greater electrical capacitance than normal skin. In literature is stipulated a biologically active points resistance of tens kilo ohms, with 20–50 % lower than the normal skin and an biologically active points capacitance few hundred times greater than that of the normal skin [13–17].

2.4. Designed electroacupuncture stimulator system. The designed Electroacupuncture Stimulator system is microcontroller-based and software designed. Usually connected to the microcontroller, the input-output module consists of a two-component digital-to-analog converter (DAC) module, an LCD display module, a timer, and an amplifier block [16].

The microcontroller module is the main component that controls the frequency and voltage values of the main circuit of the system, selects the type of signal sent to the output, measures the frequency and voltage value, and performs all operations related to the timer module.

In addition to these basic features, there are Flash program memory up to 8K×14 words, 368×8 byte data memory (RAM) and 256×8 byte EEPROM data memory, 14 internal/external cuts, 8 degree feed stack, Watchdog timer operation with RC generator for reliability, power saving sleep mode. Also in the initial scale there are 8-bit timer/counter Timer0 and 16-bit timer/counter Timer1; periodic register, 8-bit timer/counter with initial scale and final scale; 10-bit multi-channel ADC; synchronous serial port; There are also a number of additional features such as PWM modules.

Thus, *the object of the study* is an electroacupuncture stimulator designed to stimulate and treat the functions of the body, it is designed with a wide range of capabilities. The stimulator is based on the 16F877 microcontroller. The device has a frequency range of 2–10 Hz. Initially, the device will be used for stimulation in the primitive state. The next step will be to regulate the energy flow on the meridians that affect the human bioenergetic system.

3. Results and Discussion

In the Tinkercad software environment, a virtual simulation circuit for electrical resistance measurement was built based on the Arduino Uno (or Atmega) microcontroller (Fig. 2). The circuit is powered by 9 V. A single potentiometer was used to model the resistance of the biological object, i. e. the measured resistance. Measurements were made on different floors of the potentiometer. The other resistor that makes up the voltage divider circuit is selected in the 1 KΩ configuration.

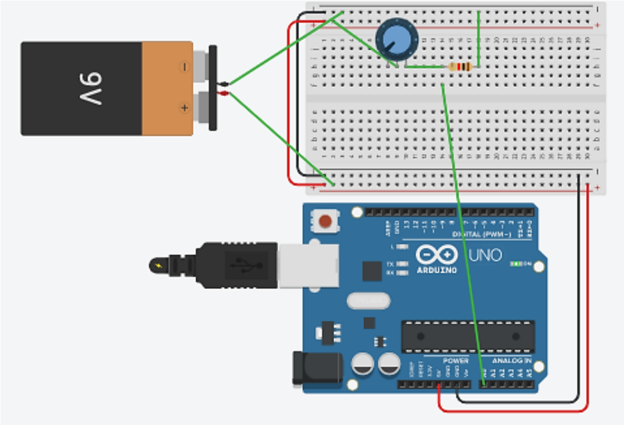

Fig. 2. Realistic view of the measurement information formation block in the Tinkercad environment

The following code is written to make the given scheme work:

```
int analogPin=0;
int raw=0;
int Vin=5;
float Vout=0;
float R1=1000;
float R2=0;
float buffer=0;
void setup(){
Serial.begin(9600);
}
void loop(){
   raw=analogRead(analogPin);
   if(raw){
      buffer=raw*Vin;
      Vout=(buffer)/1024.0;
      buffer=(Vin/Vout)–1;
      R2=R1*buffer;
      Serial.print(“Vout:”);
      Serial.println(Vout);
      Serial.print(“R2:”);
      Serial.println(R2);
      delay(1000);
   }
}
```

An LCD is designed to display the output information in the bioimpedance meter. Recoded by adding an LCD monitor to the device:

```
LiquidCrystal lcd(2,3,4,5,6,7);    //rs,e,d4,d5,d6,d7
int Vin=5;           //voltage at 5V pin of arduino
float Vout=0;      //voltage at A0 pin of arduino
float R1=1000;     //value of known resistance
float R2=0;         //value of unknown resistance
int a2d_data=0;
float buffer=0;
void setup()
{
 lcd.begin(16,2);
}
void loop()
{
   a2d_data=analogRead(A0);
   if(a2d_data)
   {
      buffer=a2d_data*Vin;
      Vout=(buffer)/1024.0;
      buffer=Vout/(Vin–Vout);
      R2=R1*buffer;
   lcd.setCursor(0,0);
      lcd.print(“Bioimpedansmeter”);
      lcd.setCursor(0,1);
      lcd.print(“R(ohm)=”);
      lcd.print(R2);
   delay(1000);
   }
}
```

The value of the R_x resistance was changed to determine the accuracy class of the device that measures the electrical conductivity of biologically active points. The readings of the meter were recorded at different values of the R_x resistance (Fig. 3–5). Table 1 was created according to the results obtained.

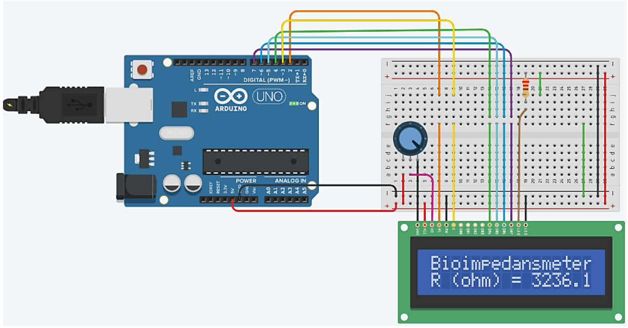

Fig. 3. Attaching the LCD monitor to the unit

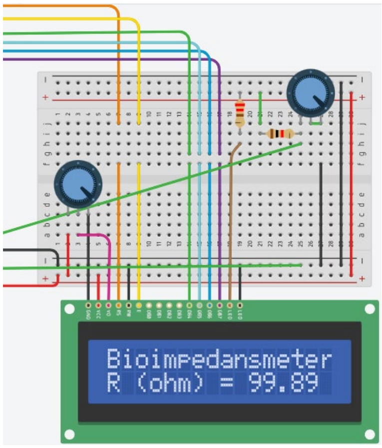

Fig. 4. Measurement result at R_x=100 Ω value

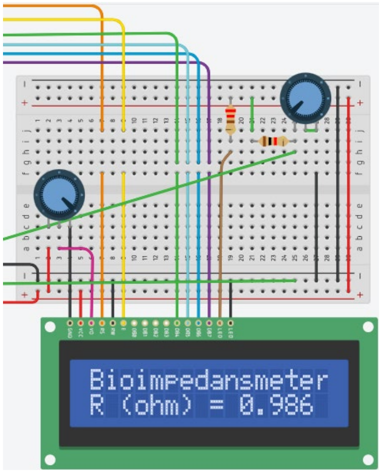

Fig. 5. Measurement result at $R_x = 100\ \Omega$ value

Table 1

Measurement results of biologically active point resistance

Standard	Measurement result (Ω)	Absolute error	Relative error	Accuracy class
1	0.981	0.019	0.019368	0.0019
2	1.961	0.039	0.019888	0.0039
4	3.921	0.079	0.020148	0.0079
5	4.911	0.089	0.018123	0.0089
10	9.861	0.139	0.014096	0.0139
20	19.92	0.08	0.004016	0.008
25	25.03	–0.03	–0.0012	–0.003
30	30.18	–0.18	–0.00596	–0.018
100	99.89	0.11	0.001101	0.011
150	149.27	0.73	0.00489	0.073
250	250.31	–0.31	–0.00124	–0.031
390	389.42	0.58	0.001489	0.058
500	499.27	0.73	0.001462	0.073
600	600	0	0	0
700	698.18	1.82	0.002607	0.182
800	799.65	0.35	0.000438	0.035
900	899.81	0.19	0.000211	0.019
1000	996.1	3.9	0.003915	0.39
Average value		0.463056	0.005742	0.0463056

As a result of the simulations, it was determined that the absolute error of the device is 0.463056, the relative error is 0.005742, and the accuracy class is 0.0463056. As it is possible to see, the device has an accuracy class of ≅0.05. Thus, it is possible to accurately measure electrical conductivity in biological objects through this device.

Although the accuracy class and overall dimensions of the measuring device are quite good, its functional capabilities are somewhat underdeveloped. For the first design, only the diagnostic process was taken into account in the device, and the code was compiled accordingly. Accurate measurement of diagnostic indicators in the obtained parameters means correct treatment of the disease. When the treatment process is added here, the capabilities of the device will expand and the software will be more complicated. The achieved accuracy class of ≅0.05 provides savings compared to existing measuring devices. The conducted virtual analyzes serve to improve this indicator. But in a real measurement environment, the acquisition of that accuracy class should be proven. Because systematic and random errors during real measurement affect the measurement result.

4. Conclusions

Various apparatuses are used to determine the electrical conductivity used to affect biologically active points. In addition to low measurement sensitivity, existing devices do not have integrative properties. The proposed device will have both point localization and impact properties. As a preliminary prototype, the electrical conductivity determination scheme was assembled and the software was compiled based on the Arduino platform. Using different nominal resistors, the accuracy class of the device is determined. The obtained results allow saying that the device is suitable for localization in electrotherapy centers for people of different body sizes.

The designed measuring device is assembled at the expense of a modern element base. The accuracy class of the device is determined in the second stage of designing. Based on simulation modeling, the analog resistance of the biological object was measured. The obtained values allow assembling a real model of the device. For the next phase of research, comparative analysis of models and practical possibilities will be investigated.

Conflict of interest

The author declares that he has no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript has no associated data.

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