Implementation of STEM learning technology in the process of calibrating an NTC thermistor and developing an electronic thermometer based on it

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Abstract
The rapid development of information technology, robotics, nanotechnology, and biotechnology requires modern education to train highly qualified specialists who can support it, preparing students and students for producing creative work. The need to reform education to modern challenges is an urgent problem today. It is predicted that the most popular professions soon will be programmers, engineers, roboticists, nanotechnologists, biotechnologists, IT specialists, etc. STEM education can combine these areas into a complex, which can be implemented in different age groups. One example of the use of STEM technologies is the development and implementation of scientific and technical projects using the Arduino hardware and software complex. With the help of STEM technologies, a method for calibrating an NTC thermistor in the operating temperature range is proposed and a working model of an electronic thermometer is presented using the example of an NTC thermistor and an Arduino microcontroller.

Keywords
digital transformation, STEM education, physics teaching methodology, research and design activities, NTC thermistor, Arduino

1. Introduction

The information revolution is changing the relevance of modern professions. Routine work is replaced by jobs that require flexible work algorithms. Professions that were popular for another 10 years are no longer relevant, they are being replaced by more modern ones.

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In the world, one can observe a shortage of specialists in technical areas, the demand for them is growing much faster than for other specialties, which is why this type of education is popular. Professions related specifically to STEM come to the fore, i.e. professions related to science and technology, as well as at the intersection of disciplines. Today, it is IT and engineering graduates receive the highest salaries.

Modernization and transformation of the educational process is unrealistic without the introduction of innovative technologies [1]. One of the promising areas for improving the educational process is STEM technologies (short for Science, Technology, Engineering, and Math).

STEM is an educational program based on the idea of teaching students about four specific disciplines using an interdisciplinary and applied approach. Instead of teaching the four disciplines as separate subjects, STEM combines them into a single learning paradigm based on real-world application.

It is important to understand that STEAM is not just a comprehensive technical education. It covers a much broader concept and the most successful combination of creativity and technical knowledge.

STEM technology contributes to the motivation of learning, because STEM is experiments, scientific experiments, studying the structure of the world and the universe, and creating your games and projects. It is also an opportunity to make a unique discovery, to save and make life easier, and to create something really important for all of humanity.

Developed countries have timely paid attention to the prospects of STEM technologies. Australia, Great Britain, Israel, China, Korea, Singapore, and the United States have been implementing state programs in the field of STEAM education for a long time.

2. Theoretical background

The theoretical discourse of the problem of STEM education is reflected in the works of Hrynevych et al. [2], Lukychova et al. [3], Martyniuk et al. [4], Merzlykin et al. [5], Miller et al. [6], Mintii [7], Pylypenko [8], Shapovalov et al. [9], Valko et al. [10]. Scientists explore the existing problems and promising directions for the development of STEM education, reveal the features of the use of non-traditional educational technologies in STEM, and highlight the problems of STEM training for teachers and lecturers.

The popularity of STEM education in the world has led to the emergence of various variants of the abbreviation itself and its various modifications, in particular: EST**E**M (environment), ST**R**EM (robotics), STEM**M** (Medicine), STE**A**M (arts), ST**RE**A**M (religion and arts), MET**AL**S (arts and logic) [6].

One of the promising areas of STEM is STREM (Science, Technology, Robotics, Engineering, and Mathematics), where robotics is a central component among other STEM elements and is engaged in the development and implementation of automated technical systems [6].

The problems of introducing robotics elements into modern education are highlighted in the works of Alimisis [11], Atwood and Shoop [12], Eguchi [13], Flot et al. [14], Negrini [15].

Alimisis [11] presents a training program for teachers developed in the context of the ERASMUS + ROBOESL project, which reveals robotics-based learning methodologies based on the principles of constructivism and project-based learning and implemented within the educational activities of ROBOESL.

Atwood and Shoop [12] organized Carnegie Mellon's Robotics Academy and developed educational programs for students aged 10-17, which deal with introductory materials on programming robots for the LEGO, VEX, and Arduino hardware platforms, teaching materials programming languages for relevant platforms, robot math, robot science, introductory intermediate engineering, etc.

In 2010, a new term "cloud robotics" was introduced by Kuffner [16], after which Google developed the Google Cloud Robotics platform. The platform combines artificial intelligence, robotics, and cloud technologies to provide an open ecosystem of automation solutions that use cloud-connected collaborative robots. Artificial intelligence and machine learning services imply an unpredictable physical world, providing efficient robotic automation in highly dynamic environments [17, 18].

Eguchi [13] proves the importance of integrating educational robotics as a technological learning tool into educational programs for students and explains how it helps them prepare for the future.

Negrini [15] developed a PReSO pilot project with preschool and primary school teachers to introduce children to computer-based thinking and foster interest in ICT and STEM disciplines through educational robotics. For this, the research group developed the concept of teacher training in educational robotics and trained teachers, most of whom integrated robotics into their annual program.

Flot et al. [14] suggest that a robot simulation environment is a better tool for learning computer science than a real robot. A collaborative study between Carnegie Mellon University and the University of Pittsburgh demonstrated better efficiency in teaching programming when teachers used a simulated robotic environment rather than actual physical work.

The analysis of scientific research by leading scientists, the study of their experience shows the need to improve and supplement the development of the methodological system for the implementation of STEAM education in Ukraine based on the study and implementation of advanced foreign experience and proven practices for the implementation of STEAM education [11].

It is the elements of robotics that create the prerequisites for the high-quality preparation of modern youth for the design, programming and use of automated systems.

Robotics is one of the areas of development of modern STEAM education. Learning with the help of robotics enables pupils and students to solve real life problems that require knowledge of STEAM subjects [19].

3. Methodology

The process of modernizing the natural and mathematical profile of education is possible using STEM technologies for the development and implementation of scientific and technical projects using the Arduino hardware and software complex. This platform organically combines physics, mathematics, computer science, and robotics [20, 21].

Arduino is a family of different technologies and an open platform that includes both hardware devices (controller boards and related equipment) and software designed to control electronic circuits. Arduino is a framework and environment in which you can assemble compatible electronic and mechanical components into a single device, and then program the behavior of these devices. The program allows you to control not virtual objects, but real sensors, motors, indicator lights, and screens.

The thermistor is a solid-state electronic element that looks like a constant resistor and is capable of changing its electrical resistance depending on temperature.

Thermistors are divided into two groups: PTC – with a positive temperature coefficient, and NTC – with a negative one. A positive coefficient means that the resistance to the thermistor increases with increasing temperature, and a negative coefficient means vice versa [22].

The thermistor also has a nominal resistance that corresponds to a room temperature of 25 °C. For example, thermistors with a nominal value of 10 kΩ and 100 kΩ are popular.

NTC thermistors are negative temperature coefficient resistors. This means that their resistance decreases as the temperature increases. More often they are used as resistive temperature sensors and current limiting devices. The temperature sensitivity factor is about five times that of silicon temperature sensors (silistors) and about ten times that of resistance temperature sensors (RTDs). NTC sensors are typically used in the temperature range from -55 °C to 200 °C.

The nonlinearity of the relationship between resistance and temperature poses some challenges for using analog circuits to accurately measure temperature, but modern digital ICs can help solve this problem. This allows accurate calculations to be made by interpolation or by solving equations close to the typical NTC curve [23].

In an experimental study, we used the KY-013 analog thermistor module from the Arduino microcontroller kit (figure 1).

The KY-013 module is designed to determine the air temperature in the environment. The module board consists of an SMD resistor with a value of 10 kΩ and a temperature sensor KY-013. The KY-013 thermistor and resistor are assembled according to the resistor voltage divider circuit. When the temperature changes, the resistance of the temperature sensor changes, which leads to changes in the electrical voltage at the output. The microcontroller measures the received voltage and, using the logarithmic conversion formula, converts the voltage into temperature.

There are three outputs on the module for connecting the sensor to the Arduino board. The VCC pin is used to supply power to the module board, respectively, the GND output is ground. The S pin is used to transmit sensor data from the microcontroller and is connected to the analog outputs of the Arduino Uno board.

Digital processing of data from the thermal array in our project will be carried out by Arduino Nano (figure 2) – this is a small, complete, and convenient electronic board based on the ATmega328 processor (Arduino Nano 3.x) [24].

The Nano platform has 8 analog inputs, each with a resolution of 10 bits ($2^10 = 1024$ values). Some pins have additional functions: I2C: A4 (SDA) and A5 (SCL). Through the outputs, I2C (TWI) communication is carried out [25].

We offer comprehensive laboratory work in physics and methods of teaching physics for calibrating a thermistor. This work can be carried out with students in physical circles, and electives; with students of physical and mathematical specialties in the disciplines “General physics”, “Methods of teaching physics”, “Workshop on school physical experiment”, and

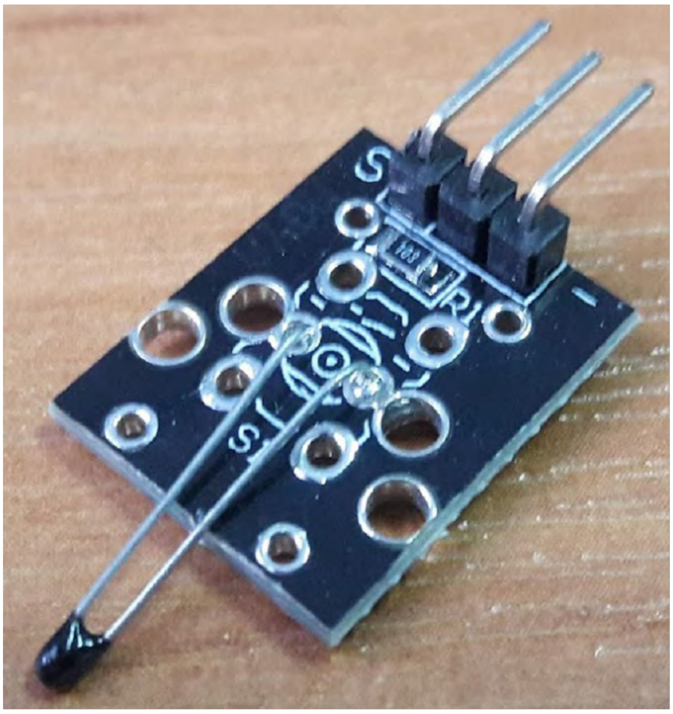

Figure 1: Appearance of the thermistor module KY-013.

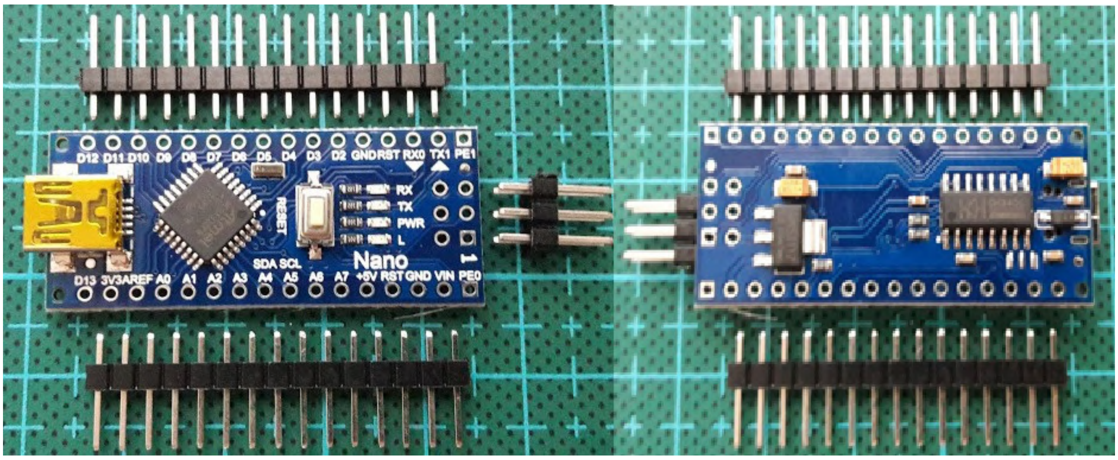

Figure 2: Arduino Nano 3.x.

"Fundamentals of robotics".

The theory and practice of this study combine three educational components: physics, mathematics, and computer science. The physical component should include knowledge of the foundations of thermodynamics, electric current, the dependence of the resistance of conductors on temperature, and the principles of temperature measurement. The mathematical component should include: drawing graphs of dependencies between physical quantities and drawing up a formula for the dependence of physical quantities based on the existing graph. The informatics component should include the basics of working with spreadsheets, the drawing of graphs, and the derivation of the formula for the dependences of physical quantities according to the existing graph.

Research plan:

1. Drawing up an electronic circuit for calibrating the thermistor.
2. Writing a program for calibrating a thermistor and programming a microcontroller.
3. Graduation of the thermistor using a laboratory thermometer.
4. Drawing up an equation for the dependence of the thermistor resistance on temperature.
5. Writing a program for temperature measurement and microcontroller programming.
6. Design and creation of an operating model of an electric thermometer.

The schematic diagram of connecting the thermistor for calibrating the thermistor is shown in figure 3.

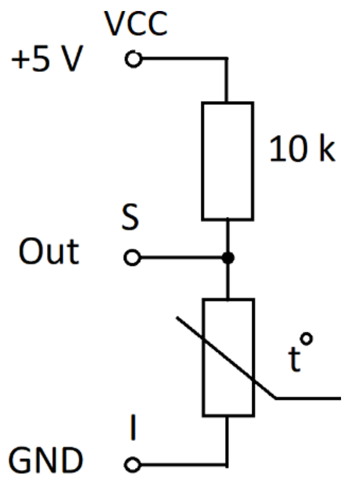

Figure 3: Schematic diagram for calibrating the thermistor.

4. Results

4.1. Graduation of an electronic thermometer

A mercury laboratory thermometer and a thermistor connected to an Arduino microcontroller are installed on the site. In the process of heating (or cooling) water, thermometers are in thermodynamic equilibrium with the liquid. In the course of the experiment, we found that during the heating process, convective fluid flows are created that make it difficult to fix the temperature. Therefore, we calibrated the thermometer in the process of liquid cooling and

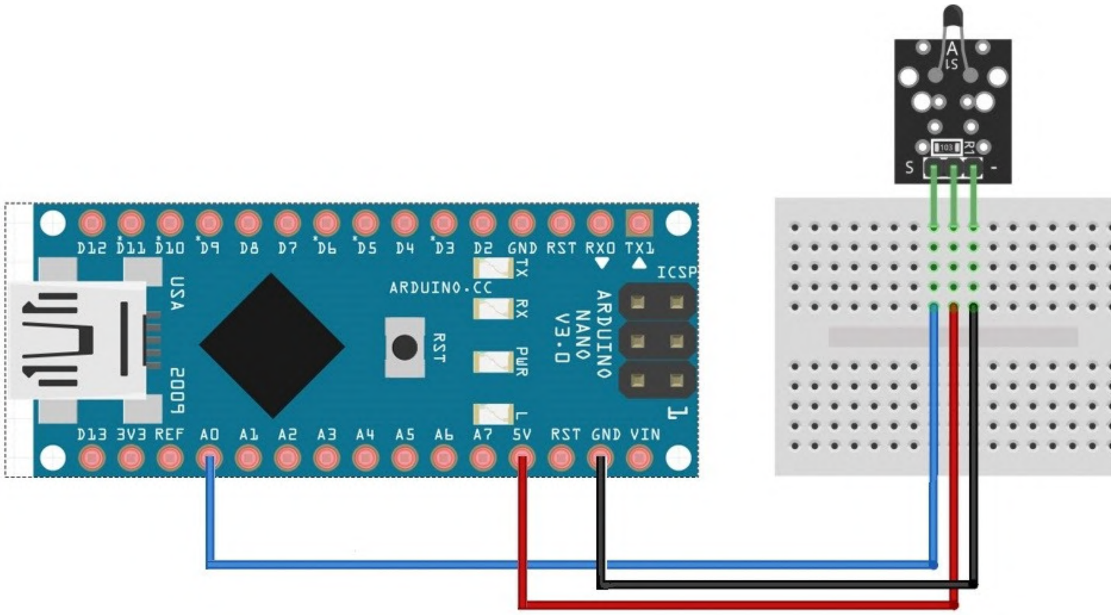

Figure 4: Scheme for calibrating the thermistor.

observed a smoother temperature change. The disadvantage of this approach is the long time intervals (about an hour) compared to the heating (15 minutes).

Using a microcontroller, we read the thermistor readings and enter them into an Excel spreadsheet by the readings of a mercury thermometer. Reading data is possible in several ways: 1) using the Serial Port Monitor function; 2) displaying information on the screen. The first method is simpler and does not require an indicator and its programming, but this method requires a computer.

To conduct the study, we created a program for calibrating the thermistor using the built-in serial port monitor.

Program for calibration of the thermistor:

```
int analogPin = 1; // analog port connection A1
int Uin = 5;       // set the total voltage to 5 V
int data = 0;      // variable for reading the signal from the sensor
float Uout = 0;   // set a variable and clear the output voltage register
float R1 = 10000;  // set the resistance of the ballast resistor
float R2=0;// set a variable and clear the register of desired resistance

void setup() {
  Serial.begin(9600); // connect port monitor
}

void loop() {
  data = analogRead(analogPin);
```

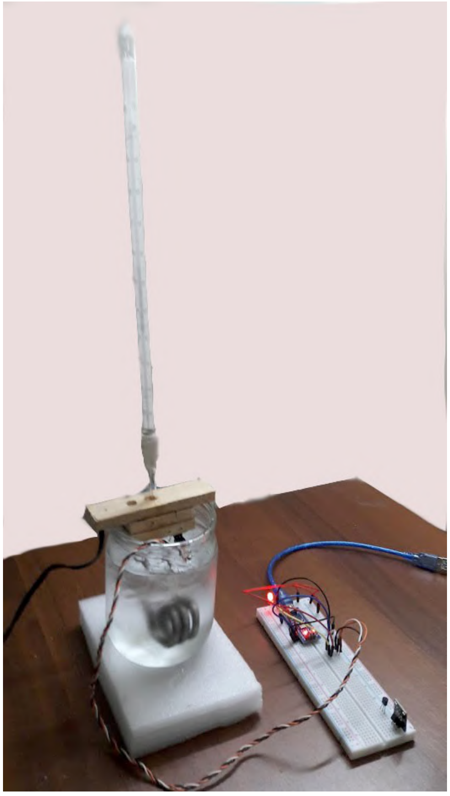

Figure 5: Appearance of the installation for calibrating the thermistor.

```
  Uout = analogRead(analogPin)*Uin/1023.0;
  R2 = R1*Uout/(Uin - Uout);
  Serial.print("Data = "); Serial.print(data); Serial.print("     ");
  Serial.print("R = "); Serial.print(R2); Serial.print("     ");
  Serial.print("Uout = "); Serial.print(Uout); Serial.print("     ");
  delay(1000);
}
```

Based on the data obtained, a table of correspondence between the temperature and the data obtained by the thermistor was compiled (table 1).

4.2. Processing the results of the experiment and creating a mathematical formula for calculating the temperature

Based on the results entered, it is possible to identify the mathematical relationship between the above parameters using the trend line (figure 6). We have obtained the following dependence:

$$y = -0{,}012x^3 + 2{,}9871x^2 - 269{,}88x + 9853{,}2$$

Table 1
Temperature dependence of thermistor resistance.

T, C°	R, Ω	T, C°	R, Ω	T, C°	R, Ω	T, C°	R, Ω
0	9853						
1	9586	26	4644	51	2265	76	1326
2	9325	27	4507	52	2208	77	1302
3	9070	28	4374	53	2152	78	1279
4	8820	29	4245	54	2099	79	1256
5	8577	30	4120	55	2048	80	1234
6	8339	31	3999	56	1998	81	1212
7	8106	32	3882	57	1951	82	1189
8	7879	33	3768	58	1906	83	1167
9	7657	34	3658	59	1862	84	1145
10	7441	35	3551	60	1820	85	1123
11	7230	36	3448	61	1780	86	1101
12	7024	37	3348	62	1741	87	1078
13	6823	38	3252	63	1704	88	1055
14	6627	39	3158	64	1668	89	1032
15	6436	40	3068	65	1634	90	1009
16	6250	41	2981	66	1601	91	985
17	6069	42	2897	67	1569	92	960
18	5893	43	2816	68	1539	93	935
19	5721	44	2738	69	1509	94	909
20	5554	45	2663	70	1480	95	882
21	5391	46	2590	71	1453	96	854
22	5233	47	2520	72	1426	97	825
23	5079	48	2453	73	1400	98	796
24	4930	49	2388	74	1375	99	765
25	4785	50	2326	75	1350	100	733

This will be the formula for calculating the temperature of the thermistor depending on its resistance.

By programming the microcontroller, we get an electronic thermometer. To check the correctness of the calibration, we experiment to compare the temperatures of mercury and an electronic thermometer. As a result of improving the system, we have developed a two-channel electronic thermometer with information output to a digital indicator. This development makes it possible to simultaneously measure the temperature at two different points. The results are displayed alternately after a few seconds. The appearance of such a device is shown in figure 7.

The program of an electronic two-channel thermometer based on two thermistors:

```
#include "TM1637.h"
#define CLK 3
#define DIO 2
TM1637 disp(CLK, DIO);
int analogPin0 = 0; // connecting data from thermistor to analog port A0
int analogPin1 = 1; // data connection with thermistor to analog port A1
```

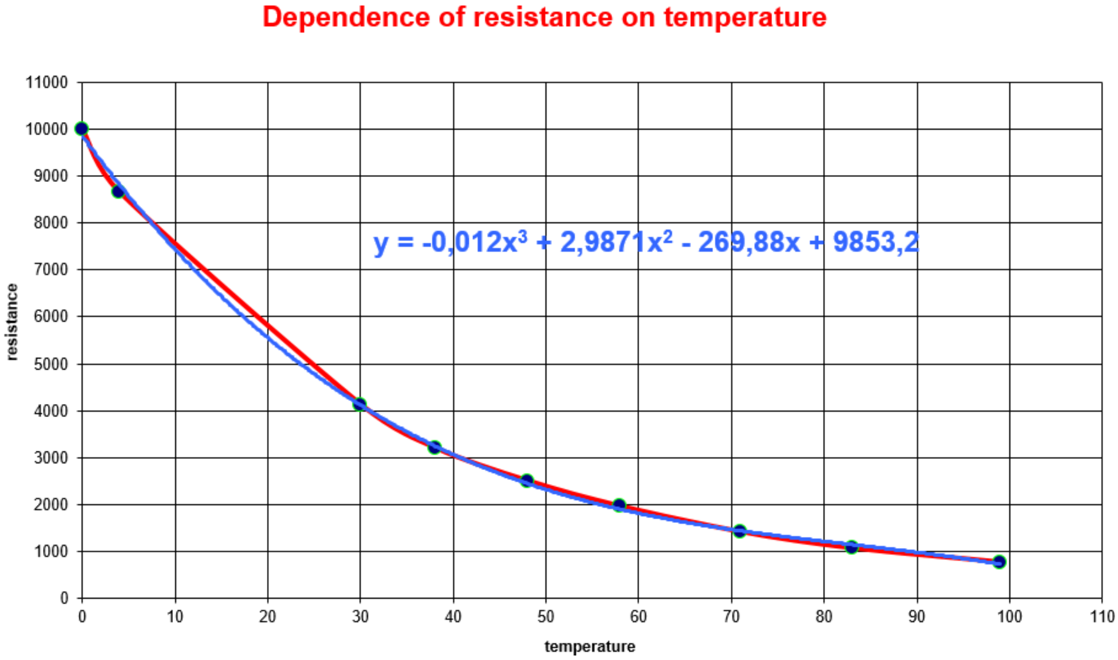

Figure 6: Graph of thermistor resistance versus temperature.

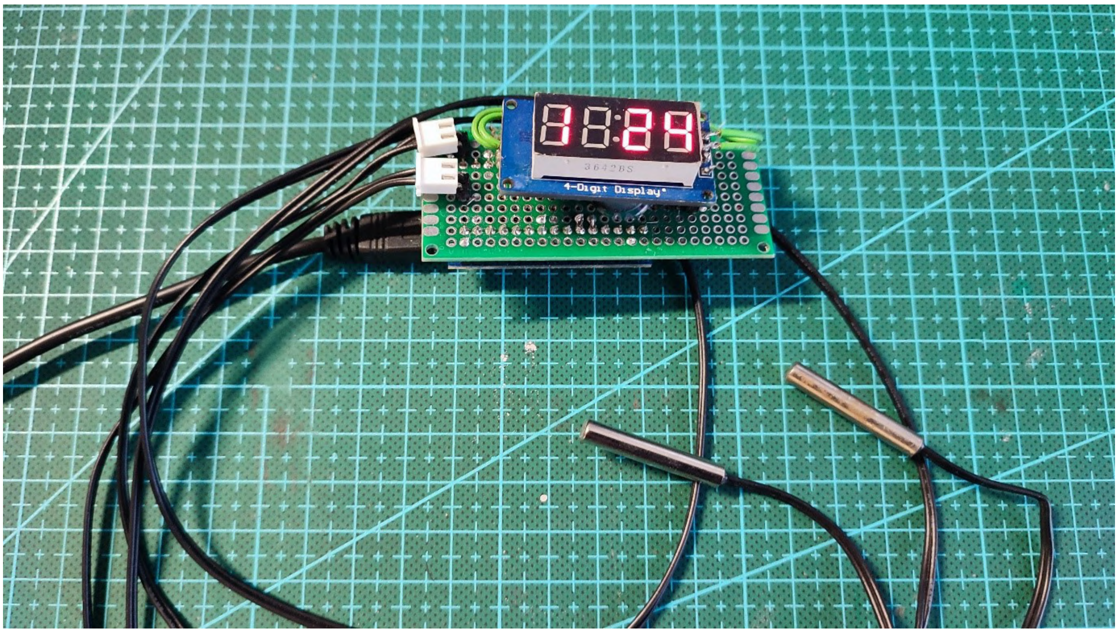

Figure 7: Appearance of a two-channel electric thermometer.

```
int Uin = 5;        // total voltage 5 V
float R1 = 10000;   // set the resistance of the ballast resistor
```

```
// Stable values for resistance calculation
float x = 0; double c1 = -0.00000002; float c2 = 0.000009;
float c3 = -0.0011; float c4 = 0.0549; float c5 = -2.1727;
float c6 = 342.63;

void setup() {
  // We connect the serial port to display information
  Serial.begin(9600);
  // We connect the TM1637 indicator to display information
  // indicator brightness min=0, max=7
  disp.clear();
  disp.brightness(3);
}

void loop() {
  // To reduce data scatter and improve accuracy, we calculate the
  //average value of the data variable for 5 values within 2 seconds
  // For the first thermistor
  long data = 0;
  for (int i=1; i<6; i++) {
     data += analogRead(analogPin0);
     delay(800);
  }
  data = data/5;
  // calculation part for resistance, voltage, and temperature
  float Uout = data*Uin/1023.0;     float R2 = R1*Uout/(Uin - Uout);
  // intermediate conditional scale with EXCEL
  float x = data/10 - 16;
  //6th-degree polynomial calculation with EXCEL
  float temp = (((((c1 * x + c2) * x + c3) * x + c4) * x + c5) * x + c6);
  // Convert temperature from Kelvin to Celsius
  int celsium = abs (temp-273);
  // we display data on the indicator TM1637
  disp.displayByte(0, _1); // 1st thermistor
  if (temp-273<0)
    disp.displayByte(1,_dash);
  else
    disp.displayByte(1,_empty);
  disp.display(2, celsium/10); // first temperature digit
  disp.display(3, celsium%10); // second temperature digit

  // For the second thermistor
  data = 0;
  for (int i=1; i<6; i++) {
```

```
    data += analogRead(analogPin1);
    delay(800);
  }
  data /= 5;

  Uout = data*Uin/1023.0;
  R2 = R1*Uout/(Uin - Uout);
  x = data/10 - 16;
  temp = (((((c1 * x + c2) * x + c3) * x + c4) * x + c5) * x + c6);
  celsium = abs (temp-273);

  disp.displayByte(0, _2); // 2nd thermistor
  if (temp-273<0)
    disp.displayByte(1,_dash);
  else
    disp.displayByte(1,_empty);
  disp.display(2, celsium/10); // first temperature digit
  disp.display(3, celsium%10); // second temperature digit
}
```

5. Conclusions

The development and implementation of Arduino creative projects is possible within the framework of such disciplines as “Computer Science”, “Programming”, “Computer Science Teaching Methods”, “Physics Teaching Methods”, “General Physics”, “Fundamentals of Modern Electronics”, “New Information Technologies and Technical learning tools”, “ICT in education”, etc.

Examples of Arduino applications can be different: the development of an electronic thermometer, a device for measuring air humidity, and atmospheric pressure, a device for checking gas laws, smart home devices, an electronic pulse oximeter, etc.

So, STEM is interesting experiments, scientific experiments, studying the structure of the world and the universe, creating your games and your projects, the opportunity to make a unique discovery, save and make life easier, and create something really important for humanity. The use of the Arduino hardware and software complex in educational and research activities is a productive tool for increasing interest in such fields of activity as computer science, mathematics, physics, and engineering.

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