APPLICATION OF ARDUINO-LIKE SYSTEMS FOR DETERMINATION OF PHYSICAL AND MECHANICAL INDICATORS OF FLAX FIBER

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***Abstract:** Ways of application of Arduino-like systems in devices for measurement of physical and mechanical indices of quality of long flax fiber that will allow to improve process of measurement and to reduce time for its carrying out are described. Different approaches to determining of the average length of flax fiber are analysed. The developed method for determining the average length of flax fiber using Arduino systems is considered.*

***Keywords:** flax fiber, quality indices, average length, rating number, algorithm, microcontroller, measurement methods, Arduino.*

1 INTRODUCTION

Product quality is determined by the properties of raw materials, proper technological process, product structure and its properties. But no less important are the validity of the requirements for the level of quality indices, as well as the correctness and reliability of the evaluation results, which depend on the accepted methods of quality assessment. Therefore, when assessing or determining the quality of products it is necessary to determine and justify the following:

- a sufficiently reliable method of assessing the compliance of material properties with regulatory requirements, taking into account errors in determining these properties;
- the choice of quality indices that fully characterize the suitability of the material for its intended use;
- rational level of regulatory requirements taking into account the capabilities of the supplier.

There are various methods for determining the quality of materials, which include the following: measuring (experimental or instrumental), registration, calculation, organoleptic, sociological and expert. The most common method is a measurement method based on the measurement and analysis of indices using instruments and expressed in quantitative terms. Measurement methods are sometimes divided into: physical, chemical, physicochemical, microscopic, biological, physiological and technological and others.

The purpose of the article is: a) to develop an automated method for measuring and calculating the average length of flax fiber, which consists in passing a handful of fibers through a pair of cylindrical rollers and determining the height of the longitudinal section in various regions along the length of the bundle; b) to develop an automated method for determining the colour of flax fiber, which consists in the analysis of light reflected from the test sample.

In recent years, there has been a steady trend towards the use of natural fibers for the manufacture of high quality light industry products, with special attention paid to hemp and flax fibers. The practice of the primary processing of bast raw materials shows that the quality of the obtained fiber depends on the objective determination of the characteristics of the raw material that comes for processing.

The need for a comprehensive assessment of the quality of bast materials in modern conditions is of particular interest. This is due to the fact that flax fiber has a wide range of applications: in the manufacture of textiles and building materials, in mechanical engineering, medicine and many other industries.

However, the analysis of scientific and technical literature and production experience showed that new technologies for processing or modification of fibers are more often developed, and methods for assessing their geometric, physical-mechanical and other quality indexes remain unchanged or borrowed from regulatory and technical documentation for other similar materials. In general, the methods of analysis used today to determine the quality of bast raw materials and products do not take into account the latest changes in processing technologies. Therefore, now in the textile industry it is necessary to introduce additional qualimetric instrumental and sensory methods for assessing the quality of fibrous materials.

Based on the above, the development of methods for assessing the quality of bast fibers is an urgent problem, the solution of which will contribute to obtaining high-quality raw materials that can be used to produce competitive products that meet high consumer requirements. Also, it should be noted that these methods are used to determine indicators for fiber flax (*Linum usitatissimum L.*).

2 DISCUSSION OF IDEAS

To determine the number of scutched flax (*Linum usitatissimum*, long flax), it is necessary to calculate the sum of points that correspond to the arithmetic mean values of length, breaking load, flexibility of the fiber and its number by colour group. The next step is to determine the number of scutched flax by the sum of the scores of the four indicators. Sometimes a combined quality assessment is used, when a comprehensive quality index does not fully characterize all the features of the product.

The fiber number shows what number of skeins of singing yarn can be trimmed from one fiber weight. The basis for a good quality assessment of the fiber is its spinning quality, so that the quality of the fiber is reworked in the yarn of the given production and with the singular characteristics, as it is possible to change it on the main, additional and attendant. Up to the main properties, which directly influence on the quality of the yarn, are carried out the breaking load, flexibility and linear density. Additional properties are injected into the intensity and nature of the production process. These properties include content of scutch, bumping and underprocessing. The attendant properties do not influence on yarn quality but convey its main properties. Attendant properties are the colour, the weight, the oiliness and brightness. The unevenness of the fiber in any property significantly reduces its value as a spun material.

The main features of high quality fiber include sufficient length, high strength, elasticity, weight, ribbon, thinness and evenness. The longer the elementary fiber, the narrower the cavity will be, the more it is multifaceted in cross section, the more fibers in the bundle, the higher the quality of the fiber.

Waterbury and Drzal [1] developed a method for determining the strength of a fiber at short calibration lengths by monitoring the process of fiber fracture during a single fiber fragmentation test. A computerized model of the weakest fiber was used to analyse the data. Data on the strength of the fiber at short calibration lengths can be obtained directly using this method without the need for extrapolation from longer samples.

Charlet et al. [2], in the process of studying the properties of natural flax fiber inserted that the beginning of the stress-strain curve of flax fiber during stretching is markedly nonlinear, which the authors explain by the progressive alignment of cellulose microfibrils with the axis of stretching. Two methods of fiber size measurement are compared to test their effect on the scatter of properties and reduction of mechanical properties of fiber as a function of fiber diameter.

Baley [3] notes that flax fibers which come from renewable resources are an interesting alternative to mineral fibers. Their low cost, together with their low density, high specific weight, rigidity and recyclability are the main incentives for their use in composite materials. A common feature of natural fibers is their heterogeneous geometric characteristics, so in the process of determining of the strength it is important to take into account the change in geometric dimensions, i.e. the transverse and longitudinal dimensions of the fibers.

Methods for determining the properties of composite materials based on flax fiber are being actively studied. Flax fiber composites with thermoset and thermoplastic polymer matrices have been manufactured and tested for stiffness and strength under uniaxial tension. Andersons and Joffe [4] found that the unidirectional orientation of natural fibers in the polymer composite provides the highest reinforcement efficiency. To estimate the upper tensile strength of a composite of natural flax fiber, a statistical model of the strength of solid composites reinforced with UD fiber is used.

In order to explore the long-term reliability of flax fiber reinforced composites under fluctuating loads through high cycle fatigue strength (HCFS), fatigue tests were conducted on unidirectional flax fiber reinforced thermoset composites at different percentages load of ultimate tensile strength (UTS) with a loading frequency of 5 Hz [5].

Romhany e al. [6] demonstrated that the strength of flax corresponds to the two-parameter Weibull model. The mode and sequence of failures were studied in situ (i.e. during loading) using SEM and acoustic radiation (AE). The failure sequence (axial splitting of the technical fiber along its elementary constituents, radial cracking of the elementary fibers, multiple fracture of the elementary fibers) concluded reflected the hierarchical build-up of the flax bast fibers.

Barton et al. [7] measured the fiber content of flax stems by near-infrared spectroscopy (NIRS) using whole pieces of stem in a large cell, in reflectance mode. Compared to the conventional method, the standard error of performance of the NIRS method was between 0.96 and 1.45% (dry matter basis), depending on the model and data processing used.

Tebmann et al. [8] presented a new, automatic and non-destructive approach for the determination of fiber length distribution in fiber reinforced polymers. For this purpose, high-resolution computed tomography is used as imaging method together with subsequent image analysis for evaluation. The image analysis consists of an iterative process where single fibers are detected automatically in each iteration step after having applied image enhancement algorithms.

Depuydt et al. [9] have developed a new type of fiber-reinforced fibrous materials for fused deposition modeling applications. Polylactic acid (PLA), compounded with two types of plasticizer, is reinforced with bamboo and flax fibers. The fiber fractions are characterized by measuring their length (*l*) over diameter (*d*) before and after compounding so that the effect of the *l/d* on the final filament properties can be systematically studied.

Bourmaud et al. [10] studied the flax fiber orientation in the skin and core layers, and, to quantify the impact of fiber bundles. They evidenced their presence in injected specimens and they focused on their effects on the tensile properties. They correlated this morphology with the tensile properties of the various areas. Finally, they investigated the initiation and propagation of cracks into the PP/flax composite in tensile mode by using in situ SEM observations.

In a composite eco-design approach, flax fibers could be good candidates for glass fiber substitution. However, their use in industrial applications could be restricted due to their scattered mechanical properties. Baley and Bourmaud [11] compared tensile properties of 50 batches of flax (*Linum usitatissimum*) fibers, cultivated in France between 1993 and 2011. Thus, 2954 fibers were tested in the same conditions according to the XP T 25-501-2 standard. Reliable specific data are suggested to be a basis for design calculation.

The aim of Sohn et al. study [12] was to develop a standard calibration model for determining shive content in retted flax by using near-infrared reflectance spectroscopy. Calibration samples were prepared by manually mixing pure, ground shive and pure, ground fiber from flax retted by three different methods (water, dew and enzyme retting) to provide a wide range of shive content from 0 to 100%. Partial least-squares (PLS) regression was used to generate a calibration model, and spectral data were processed using various pretreatments such as a multiplicative scatter correction (MSC), normalization, derivatives, and Martens' Uncertainty option to improve the calibration model.

Weisnerova and Weisner [13] applied computer image analysis to group together flax cultivars (*Linum usitatissimum L.*) according to their similarity in commercially important dry seed traits. Both the seed shape and seed-colour traits were tested on 53 cultivars from world germplasm collections. Four shape traits (Area, Perimeter, MeanChord, and MinFeret) and three colour traits (L*, a*, b* calculated from original RGB colour channels as CIE colour space coordinates) were computer extracted from digital images of 62349 seeds with 1200 seeds per cultivar in average. Cultivar clustering was generated by two independent methods of multivariate analysis.

Colour measurements are made of various kinds of flax retted by dew, water or enzymes [14]. Two sets of samples are analysed under different conditions using different spectrophotometers and by reflectance in the visible and near infrared spectral regions. Sample set one consists of 55 samples of various flax types retted by traditional dew and water methods and various experimental enzyme retted samples. Means and standard deviations of CIELAB colour values for each of the classes are displayed as spheroid plots. The enzyme retted fiber flax class forms a separate group that is substantially lighter and slightly yellower than dew retted flax [14].

3 METHODS

Sensory analysis is used to determine the quality of flax fibers, which can be described using the senses.

To determine the average length of a handful, 30 handfuls of chopped flax after determining the colour group are use. Each of the selected handfuls is spread on the table in an even layer and a sample weighing 25±1 g is taken from it. The average length of these handfuls is determined using a meter ruler with centimeter divisions.

During the measurement, individual fibers protruding in the handful are not taken into account. The test result is the arithmetic mean of the results of thirty measurements, calculated to the first decimal place, followed by rounding to an integer.

However, the sensory or organoleptic method has a significant disadvantage, which is its subjectivity. In order to avoid the dependence of the accuracy of quality assessment on the experience of experts and the identity of their senses, some manufacturers have begun to produce electronic devices that replace the human senses. Using such devices, you can get more accurate results when determining the quality indicator. In some cases, instead of methods of sensory analysis, instrumental express methods for determining the quality of raw materials and products are used. This is due to the fact that there are certain connections between some of the physical and mechanical properties of flax fibers. Some developed devices use this dependence.

Today, existing measuring devices from different manufacturers are very expensive and require training to work with them. But noteworthy are the hardware and software measuring systems based on the Arduino system, are much cheaper and allow you to measure the average length of flax fiber, fiber colour and other physical and mechanical quality indicators depending on the sensors used, circuit solutions, algorithm and algorithm processing of the received data.

According to modern technology, the long scutched fibers of different quality are obtained from a flax stalk. Long flax fibers are divided into numbers 8-14 in accordance with the State Standard of Ukraine 4015-2001. To determine the number of scutched flax according to the standard, it is necessary to calculate the sum of points that correspond to the arithmetic mean values of length, breaking load, flexibility of the fiber and its number by colour group. The study was performed using different batches of scutched flax fibers of different numbers, obtained from flax stock of *Charivnyi* variety of different degrees of aging. The average values of fiber quality are shown in Table 1.

For example, the developed automated method of measuring and calculating the average length of flax fiber is to pass a handful of fibers through a pair of cylindrical rollers and determine the height h_i of the longitudinal section in different areas along the length of the handful (Figure 1a). According to the obtained measurement data, the average fiber length is calculated, and the calculations are performed automatically in accordance with the compiled algorithm of the microcontroller. This method includes the preparation of a handful, its testing and determining the value by which the average length of flax is judged. The chosen method allows to increase the accuracy of estimating the average length of flax and will automate the process of testing and analysis of the results through the use of computer technology and elements of modern electronics.

The use of a pair of rolls to move the handful and measure the height of the sections allows to automate the test process by controlling the distance between the rolls at different times and using a set of these values to calculate the parameters needed to determine the average length of the handful. This system consists of a mechanical part (Figure 1b), an Arduino system (Figure 1c) and software. Such a system can work either separately or connected to a computer to provide automated measurement, perform the necessary calculations and save the measurement results. This device uses Arduino system with an ATmega328 microcontroller, a liquid crystal display with a working field of 2 lines of 16 characters, a stepper motor driver and a bipolar stepper motor. A variable resistance resistor is used as a sensor, the axis of which rotates depending on the lifting height of the measuring roller.

Table 1 Initial indicators of scutched flax fibers

№ of parties	Average values of quality indexes of different batches of fiber				
	The average length of a handful [cm]	**Breaking load [daN]**	**Colour group**	**Flexibility [mm]**	**Linear density [tex]**
1	75.8	29.1	2.2	42.7	12.5
2	70.1	26.8	1.7	43.5	9.9
3	71.7	32.3	2.9	42.8	13.0
4	72.0	29.3	3.0	37.4	12.5
5	59.9	31.7	2.2	41.9	12.7
6	78.2	26.4	2.2	43.1	10.9
7	54.7	28.2	3.0	43.1	10.7
8	65.4	31.5	2.4	38.7	12.5
9	88.6	29.7	1.9	34.8	13.7
10	54.1	37.4	3.2	46.5	11.3
11	80.0	32.0	3.0	40.5	14.7
12	55.2	22.2	2.6	65.6	7.1
13	64.9	24.5	3.1	49.0	8.9
14	63.3	24.6	3.0	45.2	11.0
15	71.2	20.1	1.8	51.9	10.2
16	80.1	33.1	1.9	41.4	13.5
17	69.5	27.4	1.8	49.0	11.9
18	77.3	40.3	1.9	32.5	19.8
19	69.5	32.6	2.3	40.3	14.4
20	42.0	27.6	2.1	50.1	10.4
21	54.1	24.4	2.9	54.3	8.9
22	41.1	15.2	3.0	70.0	7.2
23	63.2	21.6	2.2	50.3	9.7
24	72.8	24.3	2.4	54.2	8.9
25	45.0	5.0	2.9	82.1	6.0
26	41.5	18.4	2.8	55.8	7.9
27	64.3	24.7	1.5	46.9	9.0
28	66.0	25.5	2.0	50.2	9.4
29	57.8	28.1	2.8	50.1	9.6
30	69.1	17.1	1.5	47.0	10.3

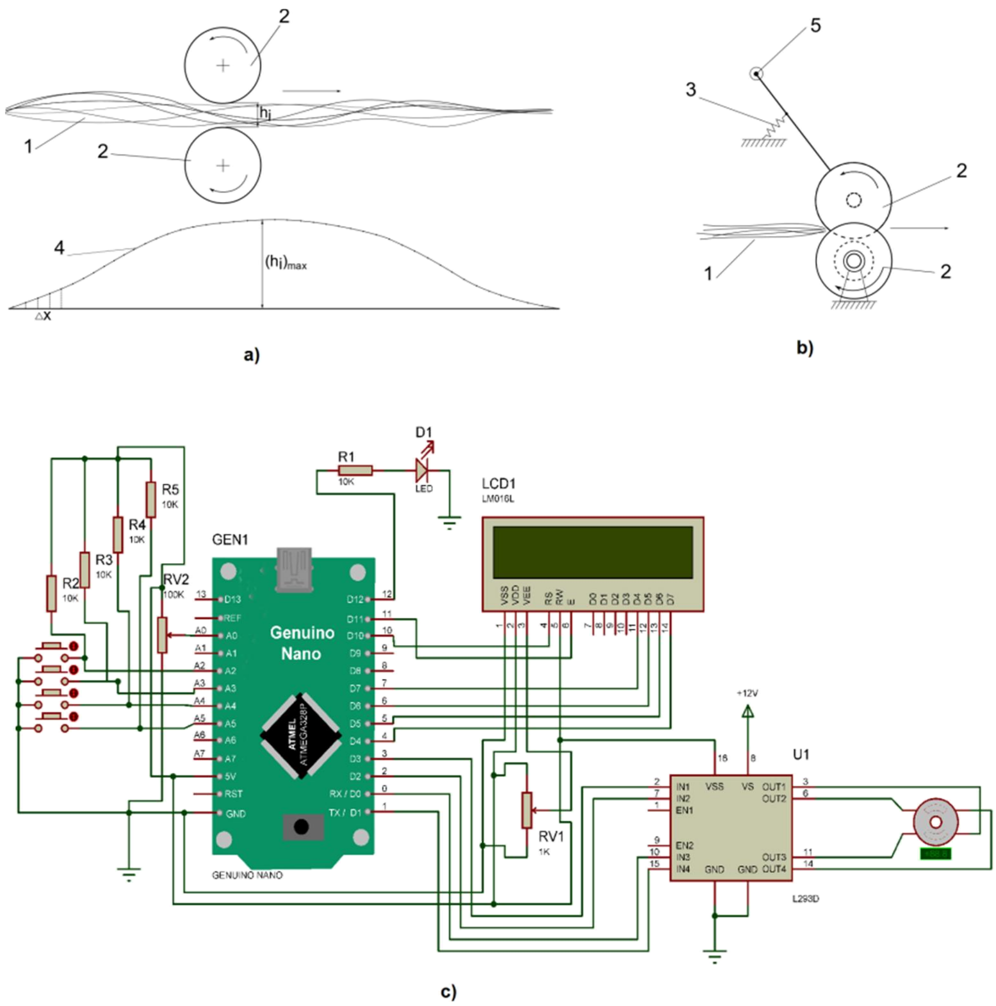

Figure 1 Scheme of the method of determining of the average fiber length. a) general scheme, b) kinematic scheme, (1 - fiber sample; 2 - roller; 3 - spring; 4 - a curve describing the measurement process, where Δx - the measurement interval, h_i - the i-th value of height [cm], $(h_i)_{max}$ - the maximum value of height; 5 - axis with analog sensor); c) electrical schematic diagram of the device

The implementation of this method involves the formation of a sample 1 of a certain mass, passing it between a pair of rotating rolls 2 and determining the height of the longitudinal section in different areas along the length of the handful at regular intervals (Figure 1b). These intervals should be such that the path x that the fiber has traveled during this time does not exceed 1 cm.

The area of the longitudinal section of the handful S is determined by the formula (1):

$$S = \Delta x \cdot \sum_{i-1}^{n-1} \frac{h_i + h_{i+1}}{2} \quad (1)$$

where: S - the area of longitudinal section [cm^2]; n – the number of measurements; Δx - measurement interval.

The average length $\bar{L}$ is determined by formula (2):

$$\bar{L} = \frac{S}{(h_i)max} \quad (2)$$

where: $(h_i)_{max}$ - maximum height [cm].

The sensor is a variable resistance resistor with a nominal value of 5 kΩ, the axis of which is connected to the moving axis of the device. Lifting the measuring roll allows you to change the resistance of the measuring resistor. The dependence of the resistance of the resistor on the lifting height of the roll was established experimentally (Figure 2). The established dependence is linear:

$$R = 29.9h - 11.64 \quad (3)$$

Practically to determine the lifting height of the measuring roll it is necessary to determine the resistance and calculate the height. For this calculation we use the inverse equation, which will look like this (4):

$$h = \frac{R + 11.04}{29.9} \quad (4)$$

where: h – the lifting height of the measuring roll [cm]; R – the resistance of the measuring resistor [Ω].

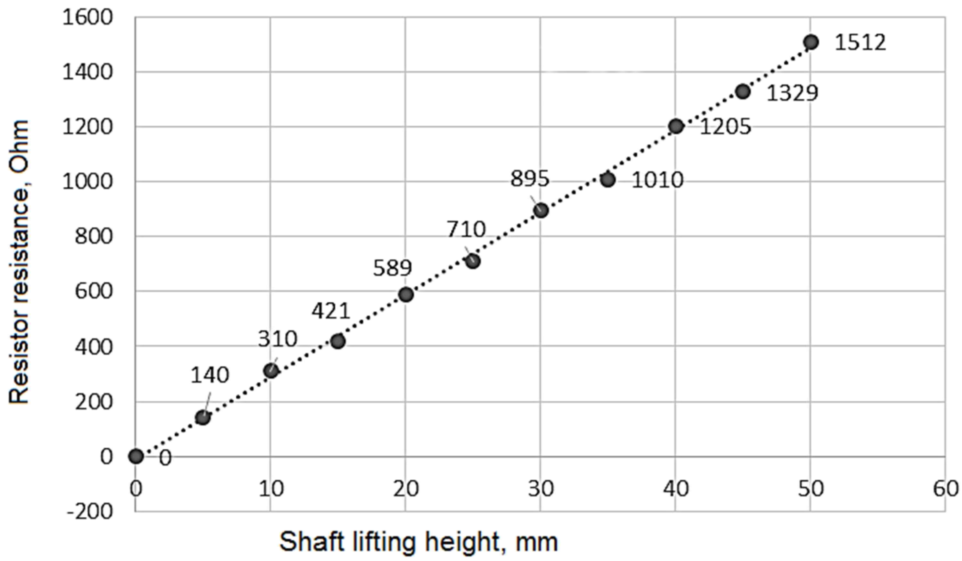

Figure 2 The dependence of the resistance of the resistor on the lifting height of the measuring roll

In this device, every second the voltage from the measuring resistor enters the analog-to-digital converter (ADC), from which the information goes to the microprocessor unit, where it is processed according to the developed algorithm (Figure 3) and output to a digital indicator as the average length of the test sample.

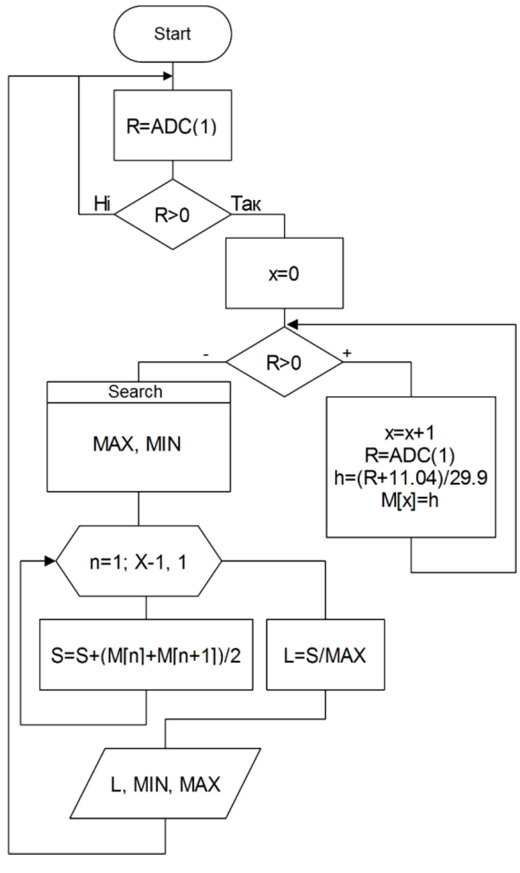

Figure 3 Block diagram of the main algorithm of the developed device

The use of the proposed method together with computer equipment with special peripherals or elements of modern electronics in practice will automate the process of measuring the length of flax, increase the objectivity of measurements and reduce the time for research.

Based on the results of theoretical research and analysis of patent sources, a digital autonomous device was created which allows to automatically measure and calculates the average length of the sample, to do statistical processing of the results.

The principle of operation of the developed device is based on measuring of the resistance of the measuring resistor, the axis of which is connected to the axis of the measuring roll.

The following example of the use of Arduino systems in measuring instruments can be presented in the developed automated method for determining the colour of flax fiber, which consists in the analysis of light reflected from the test sample (Figures 4 and 5).

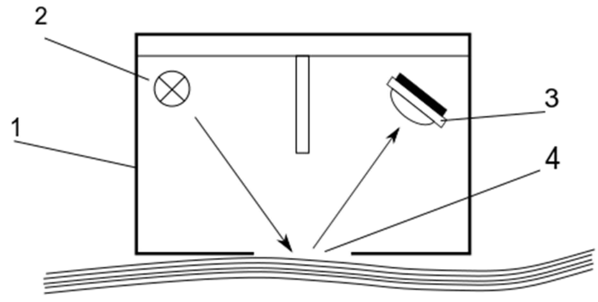

Figure 4 General scheme of the method of determining the colour of flax fiber; 1 - the case of the device; 2 - light source; 3 - photoresistor; 4 - fiber sample

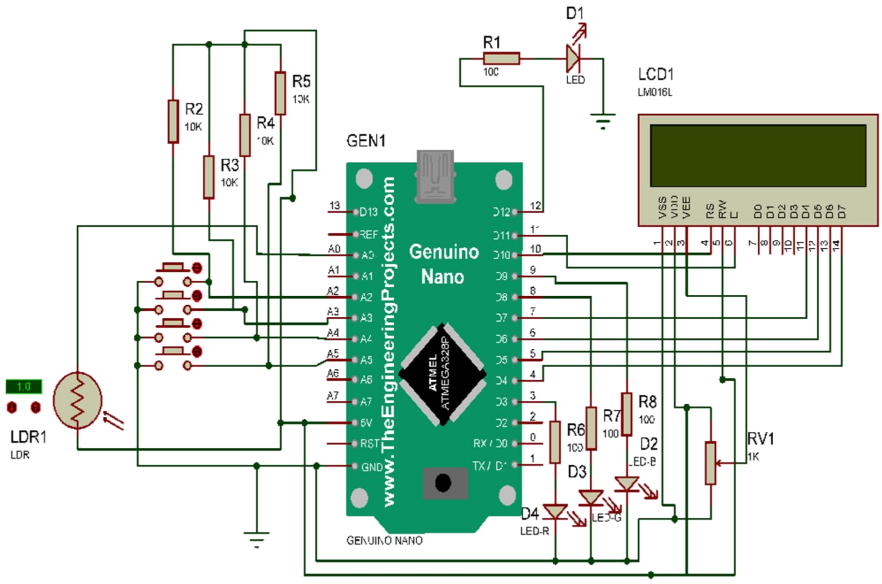

Figure 5 Electrical schematic diagram of the device for the method of determining the colour of flax fiber

This device uses an Arduino system with microcontroller ATmega328, liquid crystal display with a working field of 2 lines of 16 characters, RGB LEDs, photoresistor as a sensor that changes its resistance depending on the intensity of the light flux reflected from the sample.

During determining of the physical and mechanical parameters of flax fiber, the devices should be installed in a clean and dry place, away from heat sources and strong electromagnetic fields. For reliable operation of the device, the following conditions must be meet: a) storage temperature from -25 C to +70°C (from -13 to 158 F); b) operating temperature from -10 +60°C (from 14 to 140 F); c) relative humidity 5 to 95% non-condensing. The devices must be installed separately from other equipment. Adequate clearance should be provided for cooling them with vertical upward airflow. The temperature of the cooling air must be lower than the operating temperature of the device.

Design and research work and testing of devices were performed on the basis of the Institute of Bast Cultures of the National Academy of Agrarian Sciences of Ukraine. In the process of approbation (testing) of the equipment it is established:

a) results of measurements by the developed devices of samples of the fiber taken from one party and homogeneous on the physical and mechanical properties are stable and statistically controlled. The expected level of inconsistency of the obtained results is for the device for determining the average fiber length 0.02% and for the device for determining the colour of flax fiber 0.01%;
b) the calculated extended relative uncertainty of the measurement results for the developed devices is 4.22% and 4.7%, respectively;
c) the size of the measurement error of both devices is less than 5%.

The developed methodology of practical use of devices in the process of quality assessment of scutched flax fiber allows: to reduce the duration of the analysis on 40-45%; due to the obtained mathematical dependences to predict separate physical and mechanical parameters of the fiber; increase the objectivity of sample evaluation by increasing the number of measurements and their accuracy; reduce the cost of purchasing and maintaining of measuring equipment.

4 CONCLUSION

The use of Arduino systems in measuring devices will allow obtaining objective measurement results, reducing the time for research, significantly reduce the cost of devices, simplifying the design and adapting them to use in certain conditions. Such devices can work either individually or in conjunction with a computer with certain software.

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