

PROCEEDINGS OF SPIE

[SPIDigitalLibrary.org/conference-proceedings-of-spie](https://spiedigitallibrary.org/conference-proceedings-of-spie)

Means for measuring relative humidity of municipal solid wastes based on the microcontroller Arduino UNO R3

Bereziuk, Oleh, Lemeshev, Mykhailo, Bogachuk, Volodymyr, Duk, Mariusz

Oleh V. Bereziuk, Mykhailo S. Lemeshev, Volodymyr V. Bogachuk, Mariusz Duk, "Means for measuring relative humidity of municipal solid wastes based on the microcontroller Arduino UNO R3," Proc. SPIE 10808, Photonics Applications in Astronomy, Communications, Industry, and High-Energy Physics Experiments 2018, 108083G (1 October 2018); doi: 10.1117/12.2501557

SPIE.

Event: Photonics Applications in Astronomy, Communications, Industry, and High-Energy Physics Experiments 2018, 2018, Wilga, Poland

MEANS FOR MEASURING RELATIVE HUMIDITY OF MUNICIPAL SOLID WASTES BASED ON THE MICROCONTROLLER ARDUINO UNO R3

¹Oleh V. BEREZIUK, ¹Mykhailo S. LEMESHEV, ¹Volodymyr V. BOGACHUK, ²Mariusz DUK
¹Vinnitsia National Technical University
²Lublin University of Technology

ABSTRACT

A tool has been proposed that allows rapid analysis to measure relative humidity during experimental research on the decomposition of municipal solid wastes for the development of highly efficient garbage trucks as the main link in the structure of machines for the collection and primary processing of municipal solid wastes. The structural scheme of the device for measuring relative humidity is given. A block diagram of the microcontroller control program algorithm for measuring relative humidity has been developed. The main characteristics of the proposed device are given. Calibration and experimental tests to measure the relative humidity of municipal solid wastes were conducted. As a result of the experimental studies presented in the work, the reliability of the measured parameter is confirmed.

Key words: measurement, low cost, Arduino, relative humidity, dehydration, municipal solid wastes.

INTRODUCTION

One of the points of the Association Agreement between Ukraine and the European Union is the creation of a municipal solid wastes (MSW) management system [1], the annual volume of which in settlements of Ukraine exceeds 46 million m³[2]. Burial in landfills and dumps (96.5%), incineration at wastes incineration plants (2.2%) and processing (1.3%) are the most widespread among technologies of solid wastes management in Ukraine. 4100 garbage trucks are used for the collection and transportation of solid wastes to landfills and incinerators. They are capable of condensing solid wastes, reducing transportation costs and required area of landfills [2], but at the same time associated with significant financial costs, including due to the significant relative humidity of solid wastes, which is 39-53% by weight, and organic fraction – 72-80% [3]. One of the ways to reduce the relative humidity of food industry wastes is their vibrational dehydration on stationary equipment [4, 5]. In works [6, 8], it was discovered that dewatering of solid wastes can significantly increase the degree of their sealing, as well as reduce the mass of wastes that is to be transported. In addition, reducing the relative humidity of solid wastes to 20% allows them to be burned down at the thermal power station with the utilization of heat energy [9-14].

According to the Resolution of the Cabinet of Ministers of Ukraine No. 265 [15], ensuring the application of modern high-performance garbage trucks in the municipal economy of the country, as the main link in the structure of machines for the collection and primary processing of municipal solid wastes, is a relevant scientific and technical problem. The development of tools for measuring the relative humidity of solid wastes is one of the important tasks for solving this problem.

The aim of the research is to develop a means for measuring the relative humidity of municipal solid wastes. A review of literary sources has shown that many studies focus on the use of sensors and data recording systems in many fields of science and technology. For the development of digital measuring devices, Arduino's microcontrollers have recently become popular [16, 17]. They, along with many other similar brands, such as RaspberryPi and BeagleBone, are among the small, low-cost, single-board computers. The programming and development of such applications is supported by a large community of developers and users who provide various open source libraries, case studies, and forums covering a variety of thematic and additional aspects [18]. The advantages of the Arduino microcontroller include: low project cost, interconnection with sensors and expansion cards for more complex tasks, low power consumption, autonomy, small dimensions, low installation requirements. The work [19] describes a low-cost device for mobile determination of atmospheric electric field parameters, temperature and relative humidity based on Arduino Uno with GPS function. Along with the common way of outputting measured data through a graphical user interface to a personal computer screen, it is added the ability to observe the measurement results with the help of an LCD display and a laptop computer. Article [20] proposes a general data logger for the Arduino Mega 2560 photoelectric monitoring system, which can store large amounts of data on the SD card from the input channels. In the work [21], the Arduino-based scanning system for non-destructive testing is considered. The monograph [22] is devoted to the development of methods and the creation on their basis of continuous monitoring of the moisture content of powdered materials in the conditions of the technological process of their production.

METHODS

During the study, the following methods were used: contact resistive method for measuring physical quantities, analysis and synthesis, analog and digital methods of signal processing, computer processing of information, conducting an experiment, regression analysis.

To convert the value of the digital signal of the humidity sensor to the relative humidity value, the following conversion equation is used

$$W = \frac{100}{\sigma_M - \sigma_D} \left[\frac{I(2^n - 1)}{U_R N l} - \sigma_D \right] [\%], \quad (1)$$

where N – the value of the digital signal of the humidity sensor (0...1023);

n – bit analog-to-digital converter (ADC), bit;

I – amperage, A;

U_R – reference voltage, V;

σ_M – specific electrical conductivity of moisture in the MSW, Sm/m;

σ_D – specific electrical conductivity of dry solids in the MSW, Sm/m;

l – the distance between the electrodes of the contact sensor of the humidity sensor, m.

Values σ_M , σ_D were determined during the calibration of the device for measuring the relative humidity of the solid wastes.

The total error of reproduction of the real value of the relative humidity of the solid wastes is composed of systematic and random errors in the elements of the measuring channel and can be determined by the quadratic dependence

$$\delta_\Sigma = \sqrt{\delta_{in}^2 + \delta_{dn}^2 + \delta_{qe}^2 + \delta_{ce}^2 + \delta_{ze}^2} [\%], \quad (2)$$

where δ_{in} – integral nonlinearity, %;

δ_{dn} – differential nonlinearity, %;

δ_{qe} – quantization error, %;

δ_{ce} – conversion factor error, %;

δ_{ze} – zero bias error, %.

In the documentation on the microcontroller [23] the values of the individual parameters of accuracy are given. Integral nonlinearity characterizes the deviation of the real characteristic of the ADC from the ideal in the middle of the quantization step and is no more than 0.5 units of junior grade, that is, 0.05%. Differential nonlinearity characterizes the deviation between the centers of neighboring steps of quantization on real and ideal characteristics and is no more than 0.25 units of junior grade, that is 0.025%. The error of the conversion factor shows how the slope of the line between the first and the last point of the actual conversion characteristic corresponds to the ideal value and is not more than 2 units of junior grade, that is, 0.2%. The bias error of zero indicates the value of the signal at the input of the ADC at the source code equal to 0 and is not more than 2 units of the junior grade, that is, 0.2%.

After the mathematical transformations of expression (1), the quantization error of the device for measuring the relative humidity of solid wastes is estimated as

$$\delta_{qe} = \frac{1}{N} \cdot 100\% = \frac{U_R [W(\sigma_M - \sigma_D) + 100\sigma_D]}{I(2^n - 1)} [\%]. \quad (3)$$

Using expression (3), we determine that the maximum quantization error of the device for measuring the relative humidity of the solid wastes does not exceed 0.385%.

Substituting known values in expression (2), we determine that the total error of the device for measuring the relative humidity of solid wastes is 0.481%.

MAIN MATERIALS OF THE RESEARCH

Figure 1 shows a structural diagram of a device for measuring the relative humidity of a solid wastes, consisting of a humidity sensor (HS), microcontroller unit (MCU), indication and controller module (ICM) LCD Keypad Shield. The

scheme also indicates the object of measurement (OM). The structure of the scheme includes a clock pulse generator G and the reference voltage source (RVS) to ensure the operation of the microcontroller.

Distribution of microcontroller ports is as follows:

- port 1 – indication of measurement results and control of display parameters;
- port 2 – communication with the personal computer via USB interface;
- port 3 – selection of measurement channel.

The humidity sensor consists of the touch probe YL-69, the control circuit of the sensor YL-38 and designed to determine the resistive method of moisture of the bulk medium in which it is immersed. Between the two electrodes of the contact probe, on the printed circuit boards of which there are metal strips, a small voltage is created. Power supply is 3.3 V. The lower the relative humidity of the medium, the greater the resistance and the less power of the current. When working the sensor current consumption of about $I = 35$ mA. At the final analog signal of 0-4.2 V (when powered by $U_R = 5$ V) we can make conclusions about the degree of humidity.

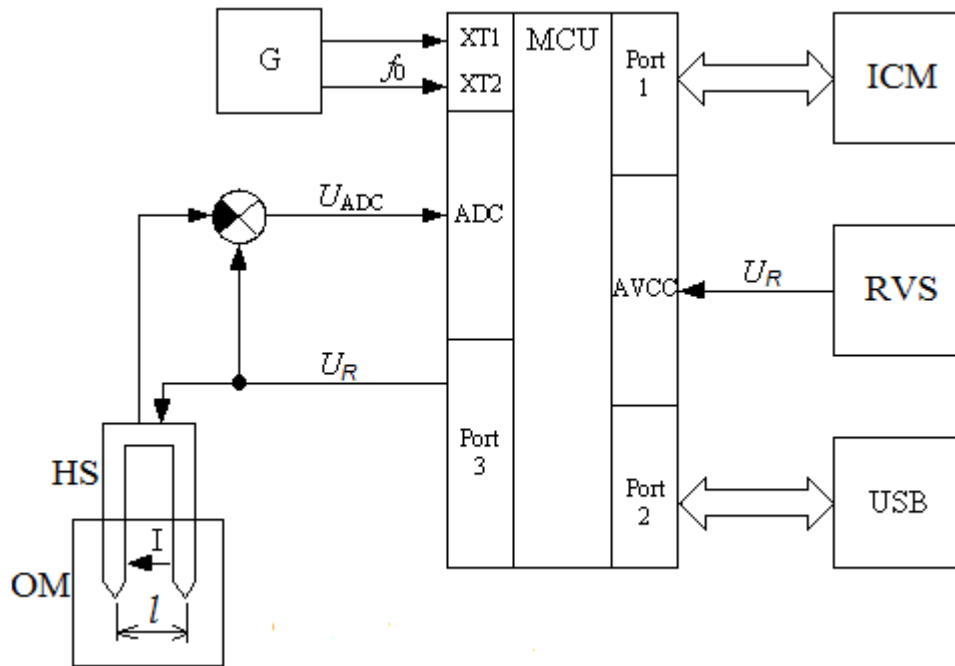


Fig. 1. The block diagram of the device for measuring the relative humidity of MSW

Connection of the humidity sensor is carried out through 3 wires to the microcontroller board Arduino. The power line + 5V (VCC) is connected to the 5V Arduino power supply. Ground GND is connected to the ground Arduino. Analogue output of module A0 is connected for further processing to one of the analog inputs, for example A1, Arduino boards, which is an ADC with a resolution of 10 bits. This allows the output to get values from 0 to 1023, allowing you to measure the relative humidity to within 0,1%. The humidity sensor board has a red LED that burns when the sensor transmits data to the controller.

Control of the sensor from the Arduino controller or from another control microprocessor device is carried out using a special program.

As the controller, the Arduino UNO R3 board is chosen, the most widely used version of the Arduino controllers. Arduino UNO R3 is executed on ATmega328 microcontroller and has 14 digital I / O ports (6 of them support 8-bit PWM modulation mode), 6 analog inputs, 16 MHz clock frequency, USB port, power connector, in-circuit programming connector, reset button. Each of the 14 digital outputs can be used as output or input. The voltage level at the terminals is 5 V. It is recommended that the output and input of each output be limited to 20 mA. The maximum value of this parameter is 40 mA. Each output has an internal tensile resistor with a resistance of 20-50 k Ω . The resistor can be disabled by software. The Arduino UNO R3 microcontroller has three types of memory: 32 kB of flash memory (FLASH), 2 kB of RAM (SRAM), 1 kB of non-volatile memory (EEPROM).

The board has all the necessary components for the operation of the microcontroller. It is enough to connect the USB cable to the computer and power. The Arduino UNO card can be powered from a USB port or from an external power source. The power source is selected automatically. The voltage of the external power supply can be in the range of 6-20 V.

The controller is programmed from the integrated software environment Arduino IDE. Block diagram of the program algorithm is shown at the fig. 2.

The programming takes place under the control of the resident bootloader via the STK500 protocol. A hardware programmer is not needed at this time. It is necessary to write to the controller a special program (sketch) that allows you to work with the sensor. After flooding the sketch with the sensor values, you can watch through the serial port monitor at a speed of 1200-9600 bit/s.

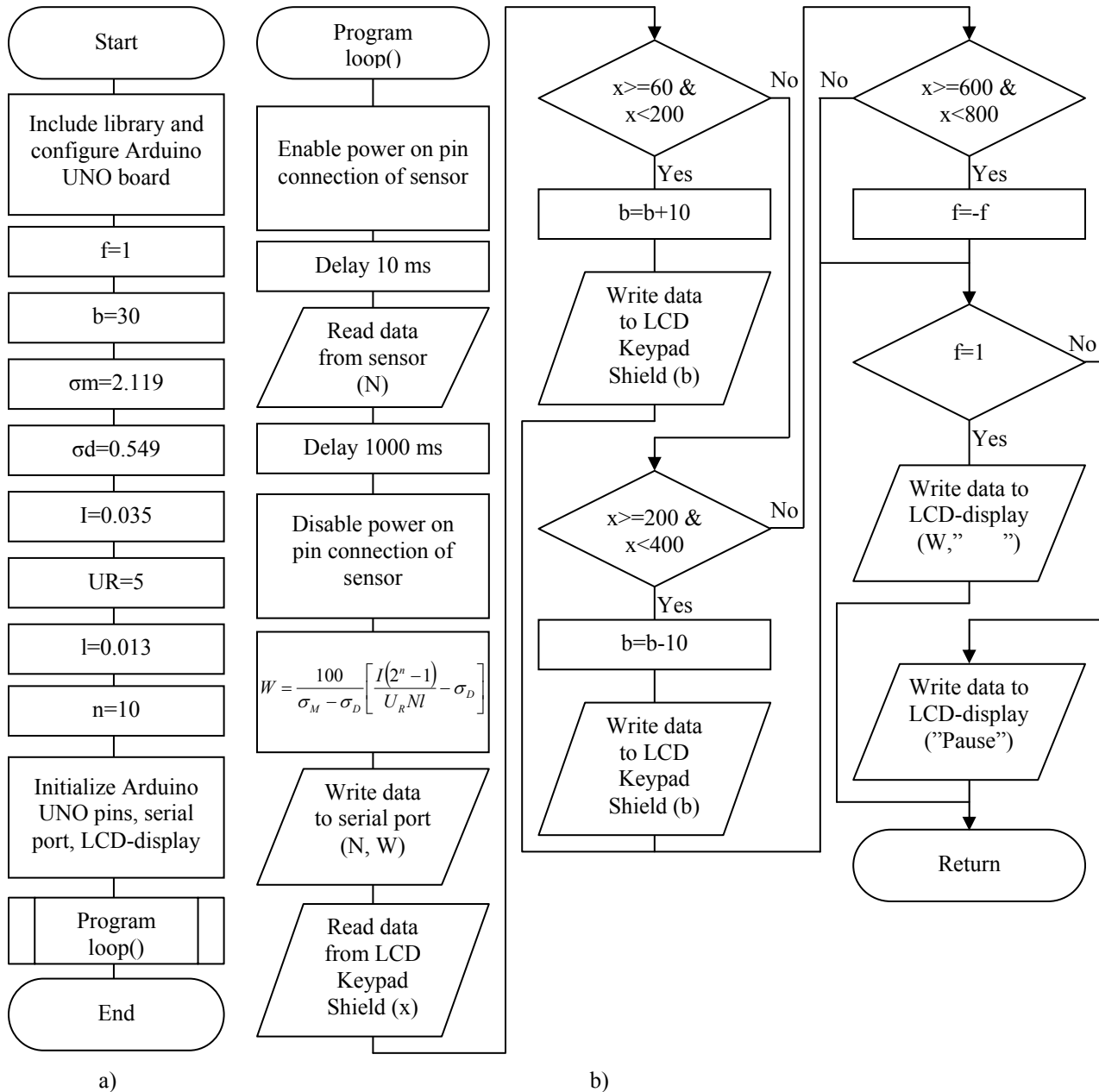


Fig. 2. Block diagram of the main program (a) algorithm and the loop program (b)

The LCD Keypad Shield, one of the most popular expansion cards for Arduino, is used to output the relative humidity measurements. It can greatly simplify the work of LCD screens, allowing the developer to focus on other tasks. The mentioned shield is a board with built-in indication and control modules. The display is carried out using the LCD display TC1602, control – through the built-in 6 buttons (5 control buttons and the Reset button to reboot the controller). In LCD Keypad Shield all five control buttons are connected through resistors of varying resistance to the analog pin A0, which saved 4 discrete pins for other needs. The shield uses a fairly common method of simple signal coding, in which each button generates a specific voltage value, which after an ADC is converted to the corresponding value from 0 to 1023. Thus, it is possible to transmit information about pressing different buttons in one pin, read it using the function `analogRead()`. The value of the signal level on the pin A0 depending on the selected button is given in the table. 1

It is possible to adjust the contrast of the display directly on the board with the help of an adjustment resistor through the digital pin D10. The board is equipped with connectors that can be connected to other devices, such as sensors. The D4-D10 pins are used to work with the screen. Only one analog pin A0 is used to determine the key press. Digital pins D0-D3, D11-D13 and analog pins A1-A5 are free. The LCD display TC1602 on the basis of the HD44780 controller with the LED backlight and 180° viewing angle is a monochrome symbolic 4-bit display with a resolution of 16 × 2 (two lines of 16 characters each) and a sign of 5 × 8 pixels. The screen refresh rate is 5 Hz.

The connection of the shield to the Arduino board is carried out by carefully joining the legs of the shield with the corresponding connectors of the Arduino UNO board.

The LiquidCrystal library is used to work with an LCD screen.

One of the drawbacks of this type sensors is the short-livedness of their sensitive elements. If the sensor is permanently energized, then its sensitive elements in the shortest time begin to rust. At the same time, if the humidity of the freezing medium is higher, then corrosion will occur more quickly. One of the options for extending the lifetime of the sensor is to feed it directly when taking off the displays by feeding the HIGH signal to the pin to which the sensor is connected. After that, turn off the LOW signal at the same pin, adding a delay in 1 second between the two successive take-offs.

Connection of the indicating and controlling module, the sensor for measuring the relative humidity of the solid wastes to the Arduino Uno R3 board is shown at Fig. 3.

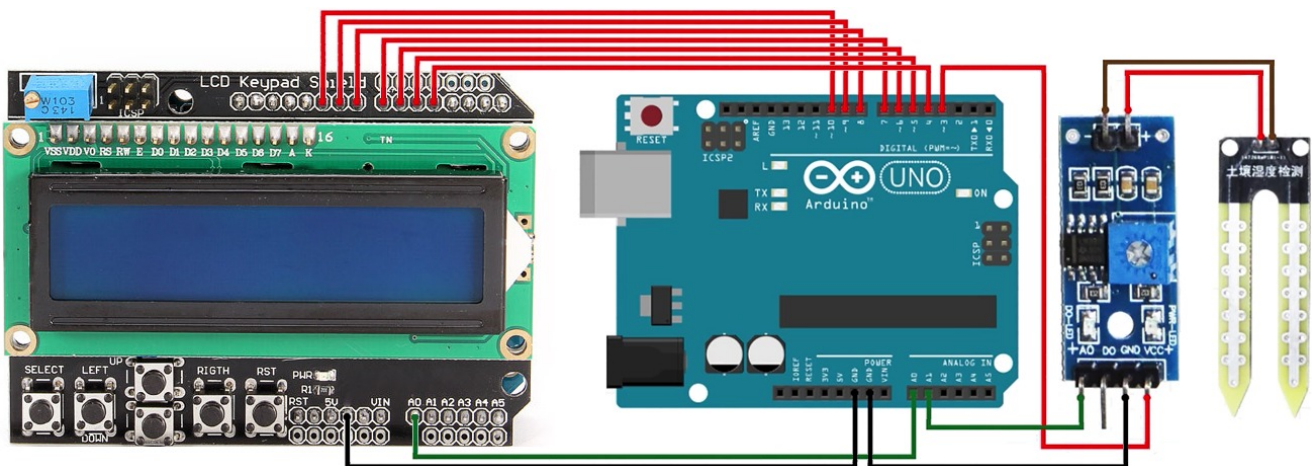


Fig. 3. Connection of the indicating and controlling module, the sensor for measuring the relative humidity of the solid wastes to the Arduino Uno R3 board

The UP and DOWN buttons of the LCD Keypad module are used to increase and decrease the brightness of the screen, respectively, in order to improve the visibility of measurement results under different lighting conditions. The SELECT button is used to implement the pause/start function to fix the current value of the relative humidity of the solid wastes.

EXPERIMENTAL PART

Before conducting an experiment on the dewatering of solid wastes by screw press, a calibration of the device for measuring the relative humidity of solid wastes was conducted. To do this, set the value of conductivity: $\sigma_M = 2.119$ Sm/m, $\sigma_D = 0.549$ Sm/m.

With the help of the developed device for measuring relative humidity, an experimental research was carried out on the dependence of the relative humidity of the solid wastes after dewatering the screw press W from their initial relative humidity W_0 . The results are shown in the table. 2.

Table. 2. Results of the experiment on the dewatering of MSW by screw press

$W_0, \%$	43.4	44.1	46.5	51.6	53.2	55.1	58.2	60.0	62.2	64.9	68.5	73.0	75.6	77.0	80.6
$W, \%$	24.3	23.0	21.8	19.4	17.1	18.2	17.0	18.6	17.1	17.6	18.7	19.8	21.5	22.1	22.5

At fig. 4 the graphical dependence of the relative humidity of the solid wastes after dewatering the screw press W from their initial relative humidity W_0 is shown. Figure 4 shows the regression equation in the free field. It theoretically describes this dependence, as well as the determination coefficient, the value of which confirms the sufficient accuracy of the obtained dependence.

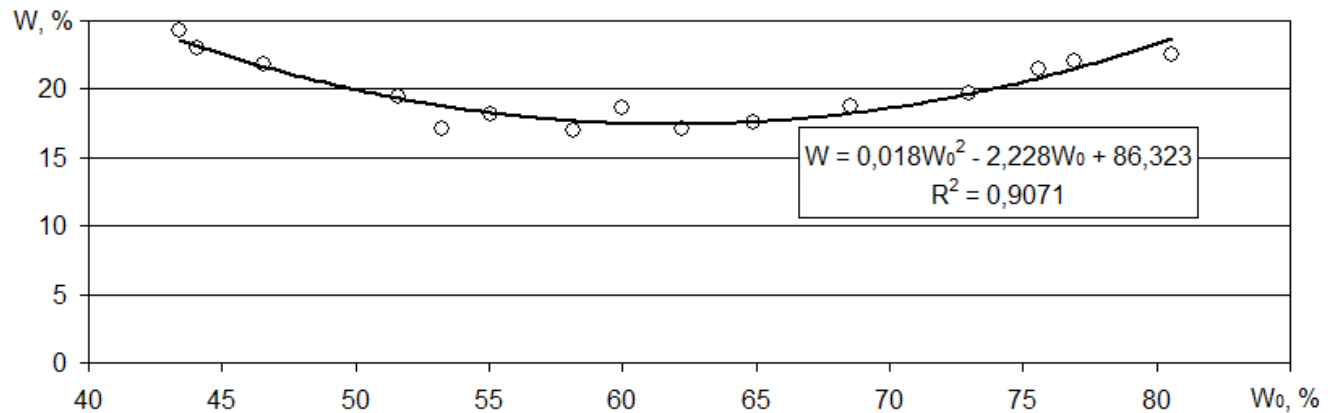


Fig. 4. Dependence of relative humidity of solid wastes after dehydration by screw press W from their initial relative humidity W_0 : experimental \circ , theoretical —

Consequently, experimental research of the relative humidity of solid wastes after dewatering the screw press from their initial relative humidity showed that the developed device for measuring relative humidity meets the requirements for the design of measuring control means.

CONCLUSIONS

1. The proposed method allows to conduct measurements of relative humidity during conducting of experimental researches on dehydration of municipal solid wastes for development of highly efficient garbage trucks, as the main link in the structure of machines for the collection and primary processing of municipal solid wastes.

2. The block diagram of the program algorithm is developed, which allows to control the operation of the device microcontroller for measuring relative humidity.

3. The developed device for measuring the relative humidity of municipal solid wastes has the following main characteristics:

- range of measurements 0...100%;
- resolution 0.1%;
- measurement error is not more than 0.5%;
- power supply voltage 5 V from USB or 6...20 V from an external power supply;
- current consumption not more than 200 mA;
- interfaces: USB, LCD+Keypad.

4. Experimental researches on depending the relative humidity of solid wastes after dewatering screw press from their initial relative humidity showed that developed a device for measuring the relative humidity meets the design of the measuring control.

Authors: Candidate of Technical Sciences, docent of the Department of Safety of Life and Security Pedagogy, Oleh Bereziuk, E-mail: berezyukoleg@i.ua; Candidate of Technical Sciences, docent of the Department of Safety of Life and Security Pedagogy, Mykhailo Lemeshev, E-mail: mlemeshev@i.ua; Candidate of Technical Sciences, Deputy Vice

REFERENCES

- [1] Verkhovna Rada Ukrainy. (2015, Lyst. 30). Uhoda pro asotsiatsiiu mizh Ukrainoiu, z odnii storony, ta Yevropeiskym Soiuzom ta yoho derzhavamy-chlenamy, z inshoi storony. [Elektronnyi resurs]. Dostupno: http://zakon2.rada.gov.ua/laws/show/984_011/page.
- [2] Bereziuk O. V., “Matematychni modeliuvannia prohnozuvannia obiemiv utvorennia tverdykh pobutovykh vidkhodiv ta ploshch polihoniv i smittiezvalyshch v Ukraini” u Suchasni tekhnologii, materialy i konstruktzii u budivnytstvi: naukovo-tekhnichniy zbirnyk, No. 2 (7), 88-91 (2009)
- [3] Moroz O. V., Sventukh A. O., Sventukh ta O., T., “Ekonomichni aspekty vyrishennia ekolohichnykh problem utyli-zatsii tverdykh pobutovykh vidkhodiv: monohrafiia”, Vinnytsia, Ukraina: UNIVERSUM-Vinnytsia, 110 (2003)
- [4] Iskovych-Lototskyi R. D., Obertiukh R. R., Polishchuk ta O. V., “Hidroimpulsnyi pryvod ustanovky dlia vibratsiinoho znevodnennia vtorynykh produktiv kharchovykh pererobnykh vyrobnytstv”, u Visnyk Vinnytskoho politekhnichnoho instytutu, No. 2, 71-75 (2010)
- [5] Sevostianov I. V., “Teoretychni osnovy protsesiv ta obladnannia dlia vibroudarnoho znevodnennia vidkhodiv kharchovykh vyrobnytstv” avtoref. dys. na zdobuttia nauk. stupenia dokt. tekhn. nauk, Natsionalnyi universytet kharchovykh tekhnologii, Kyiv, Ukraina, 43 (2013)
- [6] Bereziuk O. V., “Hidropryvod znevodnennia ta ushchilnennia tverdykh pobutovykh vidkhodiv u smittievozi”, MPK(2016.01) B65F 3/00, Patent Ukrainy No. 109036 U, Serp. 10 (2016)
- [7] Bereziuk O. V., “Shliakhy pidvyschennia efektyvnosti presuvannia tverdykh pobutovykh vidkhodiv u smittievozakh”, u Suchasni tekhnologii, materialy i konstruktzii u budivnytstvi: naukovo-tekhnichniy zbirnyk, No. 1 (6), 111-114 (2009)
- [8] Bereziuk O. V., “Struktura mashyn dlia zbyrannia ta pervynnoi pererobky tverdykh pobutovykh vidkhodiv”, u Visnyk mashynobuduvannia ta transportu, No. 2, 3-7 (2015)
- [9] Wójcik W., “Application of fibre-optic flame monitoring systems to diagnostics of combustion process in power boilers”, Bulletin of The Polish Academy of Sciences-Technical Sciences, Vol. 56, Issue 2, 177-195 (2008)
- [10] Stolarczuk P., Yatsuk V., Majewski J., Małaczywski P., Michalewa M., “Usage of capacitive sensors for Fast checking of parameters of multicomponent solutions”, Przegląd Elektrotechniczny Vol. 86, Issue 10, 92-95 (2010)
- [11] Majewski J., “Low humidity characteristics of polimer-based capacitice humidity sensors”, Metrology and Measurement Systems, Vol. 24, Issue 4, 607-616 (2017)
- [12] Zyska T., Wójcik W., Imanbek B., Zhirmova O., “Diagnosis of the thermocouple In the process of gasification of biomass”, Rocznik Ochrony Środowiska, Vol. 18, 652-666 (2016)
- [13] Ryzhyi V. K., Rymar T. I., Tymofieiev ta I. L., “Utylizatsiia tverdykh pobutovykh vidkhodiv na naiavnykh komunalnykh TETs”, u Visnyk Natsionalnoho universytetu Lvivska politeknika, No. 712 serii Teploenerhetyka. Inzheneriia dovkillia. Avtomatyzatsiia, 17-22 (2011)
- [14] Wójcik W., Cąkała S., Kotyra A., „Analysis of the operations of an electrooptical Pockles effect sensor”, Proc. of SPIE 3189, 110-121 (1997)
- [15] Kabinet Ministriv Ukrainy (2004, Berez. 4). Postanova No. 265, “Pro zatverdzhennia Prohramy povodzhennia z tverdymy pobutovymy vidkhodamy”. [Elektronnyi resurs], <http://zakon1.rada.gov.ua/laws/show/265-2004-%D0%BF>.
- [16] Sydoruk O. O., “Realizatsiia tsyfrovyykh prykladiv na bazi Arduino”, na XLV reh. nauk.-tekhn. konf. profesorsko-vykladatskoho skladu, spivrobotnykiv ta studentiv VNTU. [Elektronnyi resurs], <https://conferences.vntu.edu.ua/index.php/all-fksa/all-fksa-2016/paper/view/961/1070>.
- [17] Kozlovska T.I., Sander S. V., Zlepko S. M., Vasilenko V. B., Pavlov V. S., Dumenko V. P., Klapouschak A., Maciejewski M, Dzierzak R., Surtel W. “Device to determine the level of peripheral blood circulation and saturation”, Proc. SPIE 0031, (2016)
- [18] Cvjetkovic V. M., Stankovic U., “Arduino Based Physics and Engineering Remote Laboratory”, in International Journal of Online Engineering, No. 13(1), 87-105 (2017)

- [19] Sidik M. A. B., Rusli M. Q. A., Adzis Z., Buntat Z., Arief Y. Z., Shahroom H., Jambak M. I., "Arduino-Uno based mobile data logger with GPS feature", in *Telkomnika (Telecommunication Computing Electronics and Control)*, No. 13(1), DOI: 10.12928/TELKOMNIKA.v13i1.1300, 250-259 (2015)
- [20] Mahzan N. N., Omar A. M., Rimon L., Noor S. Z. M., Rosselan M. Z., "Design and development of an arduino based data logger for photovoltaic monitoring system", in *International Journal of Simulation: Systems, Science and Technology*, No. 17(41), DOI: 10.5013/IJSSST.a.17.41.15, 15.1-15.5 (2017)
- [21] Kim J., Udpa L., "Development and application of arduino based scanning system for non-destructive testing", in *International Journal of Applied Engineering Research*, No. 11(14), 8217-8220 (2016)
- [22] Bohachuk V. V., Mokin ta B. I., "Metody ta zasoby vymiriuvalnoho kontroliu volohosti poroshkopodibnykh materialiv" monohrafiia, Vinnytsia, Ukraina: UNIVERSUM-Vinnytsia, 141 (2008)
- [23] "ATmega328 8-bit AVR Microcontroller with 4/8/16/32K Bytes In-System Programmable Flash: Datasheet, San Jose: Atmel, 32 (2010)
- [24] Vedmitskiy Y.G., Kukharchuk, V.V., Hraniak, V.F., "New non-system physical quantities for vibration monitoring of transient processes at hydropower facilities, integral vibratory accelerations" *Przeglad Elektrotechniczny*, R 93 NR 3, 69-72 (2017)
- [25] Kukharchuk V.V., Kazyv S.S., Bykovsky S.A., "Discrete wavelet transformation in spectral analysis of vibration processes at hydropower units" *Przeglad Elektrotechniczny*, R 93 NR 5,65-68 (2017)
- [26] Kukharchuk V. V., Hraniak V. F., Vedmitskiy Y. G., Bogachuk V. V., "Noncontact method of temperature measurement based on the phenomenon of the luminophor temperature decreasing", *Proc. SPIE 10031, Photonics Applications in Astronomy, Communications, Industry, and High-Energy Physics Experiments*, (2016)
- [27] Kukharchuk V. V., Bogachuk V. V., Hraniak V. F., Wójcik W., Suleimenov B., Karnakova G., "Method of magneto-elastic control of mechanic rigidity in assemblies of hydropower units", *Proc. SPIE 10445, Photonics Applications in Astronomy, Communications, Industry, and High Energy Physics Experiments 2017 104456A*, (2017)
- [28] Azarov O., Chernyak O., "High-speed counters in Fibonacci numerical system", *Proc. SPIE 10445, Photonics Applications in Astronomy, Communications, Industry, and High Energy Physics Experiments 2017, 1044522*, (2017)
- [29] Azarov O. D., Troianovska T. I., "Quality of content delivery in computer specialists training system", *Proc. SPIE 10445, Photonics Applications in Astronomy, Communications, Industry, and High Energy Physics Experiments*, (2017)
- [30] Azarov O. D., Krupelnitskiy L.V., Komada P., "AD systems for processing of low frequency signals based on self calibrate ADC and DAC with weight redundancy" *Przeglad Elektrotechniczny*, R. 93 NR 5, 125-128 (2017)
- [31] Osadchuk V. S., Osadchuk A. V., "Radiomeasuring Microelectronic Transducers of Physical Quantities", *Proceedings of the 2015 International Siberian Conference on Control and Communications (SIBCON)*, 21-23 May 2015, Omsk, (2015)
- [32] Osadchuk A.V., Osadchuk I.A, "Frequency transducer of the pressure on the basis of reactive properties of transistor structure with negative resistance" *Proceedings of the 2015 International Siberian Conference on Control and Communications (SIBCON)*, 21-23 May 2015, Omsk, (2015)
- [33] Osadchuk A., Osadchuk I., Smolarz A., Kussambayeva N., "Pressure transducer of the on the basis of reactive properties of transistor structure with negative resistance" *Proc. SPIE 9816, Optical Fibers and Their Applications 2015, 98161C*, (2015)