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Intellectual system for automated determination of the quality of natural stones surfaces processing

This automation of determination of the quality of natural stone surfaces processing is a relevant problem. It provides an intellectual system for automated determination of the quality of processing surfaces of natural stones (ISADQSS), which allows rapid assessment of the quality of stone surfaces, including roughness, with high accuracy and quick action in automatic mode and real time. The measurement result is independent of the humidity and cleanliness of the outer surface. The root mean square error of the proposed ISADQSS does not exceed 5%, the time to determine the value of the roughness is not over 2 s. ISADQSS is based on the principles of synergetic integration of various technical automation devices with different properties – artificial neural networks (ANN) (in the case of their implementation in the form of neuroprocessors), as well as the so-called registrar of main drive currents (RMDC), which is used as a sensor sensitive to changes in the rubbing force of the stone-cutting tool depending on changes in the roughness value of the machined surface. The proposed ISADQSS is an innovative and promising development that combines such advantages as high accuracy and speed, versatility and ease of use.

Keywords: artificial neural networks, roughness, quality, automation, accuracy, speed, measurement.

Introduction

Formulation of the problem. Measuring the roughness of treated surfaces, in particular natural stones, with high accuracy and speed in automatic mode without stopping the technological process, is a paramount and specific task to ensure the quality of stone production. The ever-increasing requirements of international standards for product quality determine the extreme importance and urgency of this task. Its successful solution contributes to the stability of technological processes, the required product quality and the competitiveness of modern enterprises in general.

The peculiarity of the technological process of grinding the surface of natural stone is the sequential treatment of its surface with an abrasive tool with different grain size, which gradually decreases with each subsequent operation when the final result is a polished flat surface. A sign of completion of each stage of processing is to obtain a certain microprofile evenly over the entire surface of the stone. Here, in the case of failure to achieve at any of the stages of processing the same roughness over the entire plane of the treated surface in subsequent operations, there are defects that cannot be eliminated. As a result, the quality of the finished product is lost, which obviously leads to economic losses in enterprises. Undoubtedly, it is important to measure the quality of surface treatment of stones, in particular the amount of roughness at each stage of processing. However, the problem is that high humidity, dust and dirt, which are an integral part of the technological operations of stone surface treatment, limit the application of traditional measuring devices directly in the production conditions of modern stone processing enterprises.

As a rule, at stone processing enterprises the determination of the roughness of natural stone surfaces is performed with the use of specialized laboratory equipment – gloss meters and profilometers [1, 2].The latter, according to scientists and manufacturers [1, 2] have a relatively low accuracy in determining the roughness, involve a number of time-consuming and long-term operations that significantly slow down technological processes. In particular, when using gloss meters, the accuracy of measurement is affected by the level of luminous flux of the lamp, the color of natural stone, contamination and the level of humidity of the treated surface and the test sample. Therefore, it is impossible to use gloss meters directly in production conditions. Assessment of the quality of stone surface treatment with the use of glitters requires a long-term stop of technological processes for cleaning and drying of the studied surfaces. The preparatory stage of measurement, which consists in removing grinding head from the working area and turning off the machine for the time of measuring (1-2 min), while the further washing of stone sludge residues from the treated stone surface, depending on the plate size, an average of 3 -5 minutes, and the subsequent cleaning of the surface from residual water and drying can take up to 2-3 hours, depending on the level of humidity in the production environment. Taking into account results of the research [16], the linear speed of stone quality assessment with an optical profilometer is 20 mm/sec at a measurement distance without rearranging measuring instrument (travel range) 100 mm. In terms of a unit of standard stone facing product, the minimum dimensions of which is 300x300 mm (modular tile), the measurement time per line is 15 seconds, and in terms of tool relocation and coating the entire area of the slab is 75 sec. Accordingly, the preparatory stage is the longest in time comparing to direct measurement and data processing. The duration of the measurement is comparable to the duration of processing the obtained data.

Similar requirements for dryness and cleanliness of the investigated surface are put forward in the case of mechanical profilometers. It should be emphasized the inadmissibility of the use of profilometers due to low accuracy of measurements, due to the accumulation and increase in the error due to the registration of micro-irregularities formed at the contact of grains of minerals in rocks and due to vibration of grinding equipment.

Given the above, the need to improve the accuracy and speed of assessing the quality of surface treatment of natural stones in an automated mode without stopping the technological processes at stone processing enterprises is not in doubt.

One of the current ways to improve the accuracy and speed of assessing the quality of surface processing of natural stones in an automated mode without stopping technological processes at stone processing enterprises is the application and synergistic integration of the proposed ISADQSS new approaches, methods and techniques for obtaining and processing measurement information, including artificial neural networks and functional converter [3].

Despite the accumulated experience in the development and successful use of ANN for information processing in conditions of high environmental dynamics, including production, environment, their high accuracy and speed [4–8] advantages and efficiency of their application in the proposed ISADQ-OSS for rapid assessment of the quality of stone surfaces, in particular roughness, with high accuracy and speed, automated mode and real-time mode, directly during the execution of technological processes and without stopping the technological equipment, there is no doubt.

The analysis of researches and publications has shown that application of the traditional specialized laboratory equipment, particularly gloss meters and profilometers for an estimation of quality of processing of surfaces of natural stones, in particular roughness, directly in production conditions is impossible. Thus, in [1, 2, 9, 10], the principles of operation of these tools are described and the experience of application in stone processing industries, in particular in granite surface treatment, is given. The authors [9, 10] indicate the possibility of using gloss meters and profilometers only in laboratory conditions of measurements. The above information allows us to draw unequivocal conclusions about the low accuracy of measurements and speed of gloss meters and profilometers, as well as indicates the obvious limitations of their application in dynamic and continuous production processes.

The literature [11] describes the experience of using laser profilometers or scanners, which have a relatively high measurement accuracy, but their use is due to the need for the absence of dirt, sludge, and water on the surface, which is impossible in industrial conditions.

There is a method of determining the surface roughness, based on the degree of polarization of the beam reflected from the studied surface [12]. The authors indicate that the method is devoid of such disadvantages as reduced accuracy due to high humidity and contamination of the test surface, but its accuracy depends on the homogeneity of the test material. Therefore, it is used only in determining the roughness of metals, ceramics, and other homogeneous materials and can not be used to determine the roughness of stone surfaces.

The work [13] provides an application of the combined method for determination of surface roughness that combines the existing contact and non-contact methods with informational methods of processing the topographic image of the surveyed surface. The essence of the method lies in the use of mathematical methods of processing data of interference of the broken surface. The results of this research allow us to conclude that further mathematical processing increases the accuracy of shortness measurements. However, this method is not beyond the scope of laboratory research because of its sensitivity to the dryness of the stone surfaces. Also, during wet grinding of stones it becomes impossible to use the method of wavelet rendering of the obtained data described in the work [14]. In spite of the efficiency and prospects of this method of information processing, the factor of non-uniform texture and color of stones remains, and in combination with the wet and sludge clogging of the examined surface makes it impossible to use it in the production conditions of stone-processing enterprises.

Selection of unresolved parts of the problem. Thus, it can be argued that despite the significant scientific and practical achievements, the problem of defining the roughness value with high accuracy, speed, in automated mode and real-time mode when evaluating the quality of natural stone surfaces at stone processing enterprises without stopping the production process, has not yet been completely solved.

This study aims is to propose an intellectual system for automated determination of the quality of processing of surfaces of natural stones (ISADQSS) with increased accuracy and speed.

Description of the proposed intellectual system for automated determination of the quality of stone surfaces

The intellectual system for automated determination of the quality of stone surfaces (ISADQSS) was developed on the basis of the latest achievements of science and technology in the spheres of artificial neural networks, informatics, automation, and microcircuitry engineering. It is based on the principles of synergetic integration and capacity by using new methods (artificial neural network) of information processing and technical devices (artificial neural network and functional transformer). At the same time, the principles of modularity and the concept of uninfection have been observed in the construction of the tested ISADQSS, including the ANN and the functional transformer. This means using unified nodes and elements in its composition, including asynchronous motor, control mechanism, which are serially produced by the industry. This allows for interoperability and unification, which is a prerequisite for increased operating hours, improved modernization, etc.

ISADQSS combines the advantages of high accuracy and speed, a wide range of natural materials that can be studied, ease of use, and versatility, possibility of automated measuring and processing of the measuring information in real time without interruption in the technological operations on the technological equipment. In this case, the use of the ISADQSS does not require special preparation of the investigated surfaces, their preliminary cleaning and drying.

Figure 1 shows the block diagram of the ISADQSS, which includes the electronic and electromechanical subsystems. Electromechanical subsystem consists of ultrasonic sensors S1 and S2 for distance measurement, sensor S3 of current, PPM – processor power module, A – main actuator with grinding head, MC – microcontroller, functional transformer (not shown in Figure 1). Integral subsystem contains ANN – artificial neural network, implemented in the form of a specialized software add-on, and integrated into the operating system of the portable computer (PC), Wi-fi module for data transmission over a distance, PC – portable computer for displaying data and displaying them in smartphones that support Android.

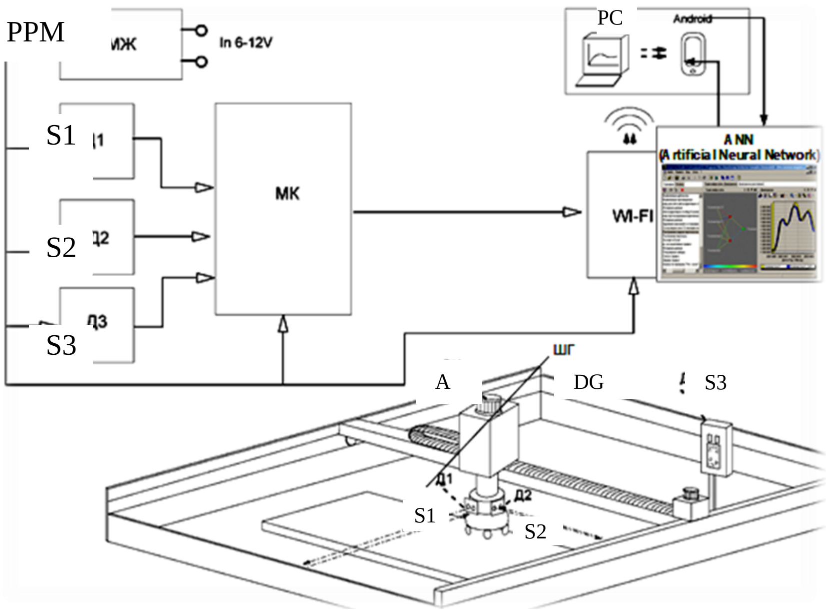

Figure 1. Structure diagram of the ISADQSS: S1, S2 – distance sensors, S3 – current sensor, PPM – processor power module, A – main actuator with grinding head DG, MC – microcontroller, Wi-fi module for distance data transmission, ANN – artificial neural network, PC – portable computer for displaying data and displaying them in smartphones that support Android

Ultrasonic distance sensors S1, S2 are used to determine the coordinates of the movement of the working shaft of the main engine and mounted directly on the machining grinding head DG drive cutting tool and form two mutually perpendicular axes of the flat coordinate system along which DG moves. When grinding or polishing the surface of natural stone, the roughness of the treated surface changes (Figure 2), which correlates with the amount of current consumed on the shaft of the main actuator A. This current is consumed by the drive of the main movement of the stone processing machine during processing of a stone surface. When the tool of the stone processing machine processes a certain area of the stone, the drive of the main movement consumes current. The magnitude of the oscillation amplitude and the instantaneous value of the current depend on the load on the drive shaft of the main motion.

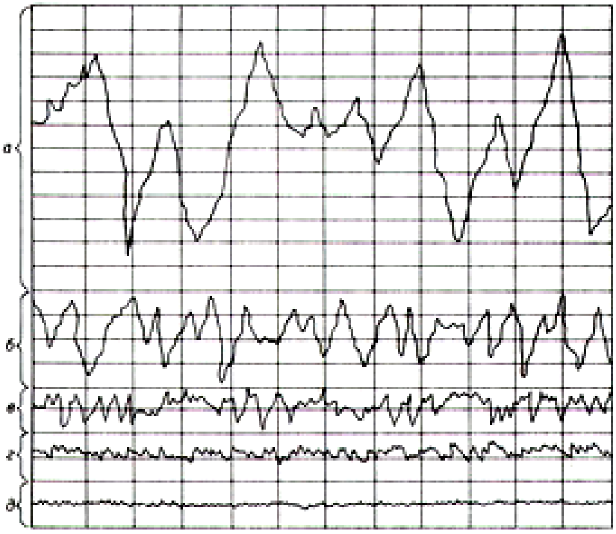

Figure 2. Change of the consumed current on a shaft of the main executive mechanism
of A at various stages of processing of a granite stone by the grinding tool: a - rough grinding (peeling),
b - medium grinding, c - fine grinding, d - finishing grinding (polishing), d - polishing

The load is caused by mechanical resistance from the surface of the stone, which is a function of roughness (Figure 2). Continuous measurement of the current consumption allows to monitor changes in roughness in real time. Continuous measurement of instantaneous current values is performed by the current sensor S3 and is transmitted to the implemented microcontroller, Arduino Nano V3.0 based on the Atmega328P microcontroller.

Figure 3 presents a block diagram of the electromechanical subsystem ISADQSS. The functional converter (FC), implemented using classical control methods, forms the task ofvoltage amplitude $U_{зUm}$, based on the task signal $U_{зf}$.

The voltage U_0 at zero frequency ("boost") provides a constant amount of magnetizing current and increases the overload capacity at low frequencies. Its value is chosen at the level of 6÷25 % of the nominal value [15]. The actuator is considered as an inertial link with a single gear ratio.

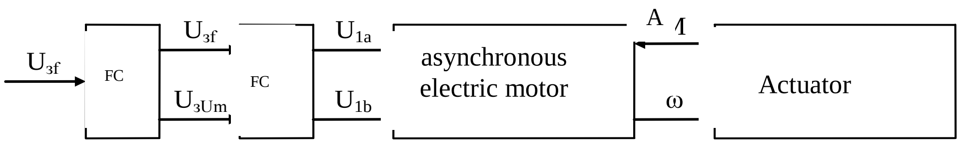

Figure 3. Block diagram of the electromechanical subsystem ISADQSS

Voltage $U_{зUm}$ applied to the input of the FC is determined by the expression (1):

$$U_{зUm} = U_0^{/} + k_{fc} U_{зf}, \quad (1)$$

where

k_{fc} – coefficient of the FC, which is determined by the expression (2);

$U_{зf}$ – task signal.

$$k_{fc} = \frac{k_f}{k_{Um}} \frac{U_{mн} - U_0}{f_н}, \tag{2}$$

where k_f, k_{Um} – frequency and voltage transfer coefficients of the converter;

$U_{mн}$, $f_н$ – rated voltage and frequency of motor supply;

U_0 – voltage at zero frequency (“boost"), $U_0 = kU_{mн}$, where k=(0,06÷0,25).

Figure 4 illustrates block diagram of the FC. Figure 5 represents the structural scheme of the FC, and its mathematical model is based on the equations of a three-phase symmetric system of voltages and transformations and is described by expressions (3) - (8).

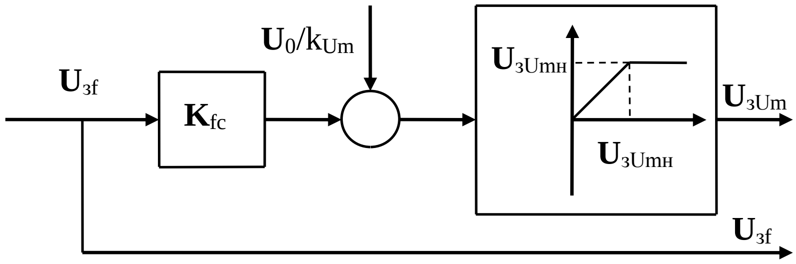

Figure 4. Block diagram of FC ISADQSS

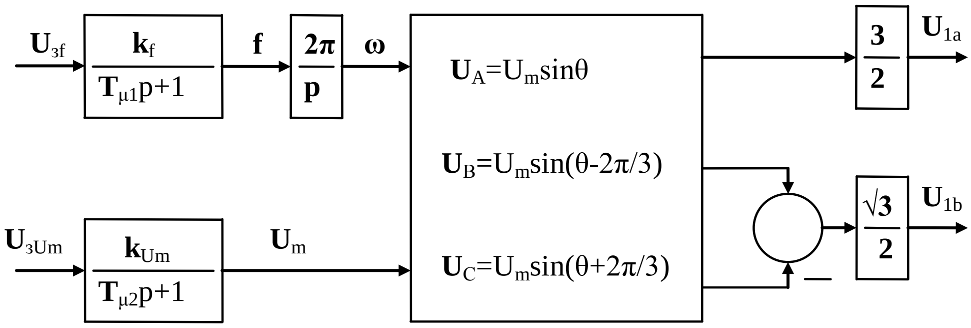

Figure 5. Block diagram of FC ISADQSS

$$U_A = U_m \sin\theta. \tag{3}$$

$$U_B = U_m \sin(\theta - 2\pi/3). \tag{4}$$

$$U_C = U_m \sin(\theta + 2\pi/3). \tag{5}$$

$$\theta = 2\pi \int_0^t f dt. \tag{6}$$

$$U_{1a} = 3U_A/2. \tag{7}$$

$$U_{1b} = \sqrt{3}(U_B - U_C)/2. \tag{8}$$

where U_A, U_B, U_C are voltages of the respective phases of the motor stator; θ – electric angle; U_{1a}, U_{1b} – projections of the stator voltage vector on the axis *a*-*b*of the fixed stator coordinate system.

The inertia of the transducer is approximated by aperiodic links by expressions (9), (10) in which $T_{\mu 1}$, $T_{\mu 2}$ are small uncompensated time constants.

$$f = \frac{k_f}{T_{\mu 1} p + 1} U_{зf}. \tag{9}$$

$$U_m = \frac{k_{Um}}{T_{\mu 2} p + 1} U_{зUm}. \tag{10}$$

The data received from the current sensor S3 is filtered from interference and converted into digital form. Then the difference between the maximum and minimum instantaneous values of the current in the same area of the stone is determined.

During the research, an electric motor with data [1] was used: $P_{2nom} = 11\,\text{kW}$; $\omega_{1nom} = 314\, rad/s$; $U_{1f} = 220\,V$; $f_{1nom} = 50\,Hz$; $\eta_{nom} = 0,88$; $\cos\phi = 0,9$; $s_{nom} = 0,03$; $x_{\mu} = 4,2\, rel.unit$; $R_1^{/} = 0,04\, rel.unit$; $x_1^{/} = 0,061\, rel.unit.$; $R_2^{//} = 0,025\, rel.unit$; $x_2^{//} = 0,12\, rel.unit$; $J_{\partial} = 0,023\, kg \cdot m^2$.

With the following parameters of the block diagram of the induction motor $I_{1nom} = 21,04\,A$; $R_1 = 0,418\,\Omega$; $R_2^{/} = 0,261\,\Omega$; $x_1 = 0,638\,\Omega$; $x_2^{/} = 1,25\,\Omega$; $x_{12} = 43,91\,\Omega$; $M_{nom} = 41,04\,Nm$; $L_{12} = 0,1398\,H$; $L_1 = 0,1419\,H$; $L_2 = 0,1438\,H$, and the following parameters of the structural diagram of the FC: $U_0 = 31,1\,V$; $k_f = 5\,Hz/V$; $k_{Um} = 31,1\,V/V$; $k_{fn} = 0,9\,1/V$.

Graphs of transients in the conditions of stabilization of the speed of the drive motor of the main motion were obtained in the Simulink environment and are presented in Figure 6.

The study was conducted for 10 s. A random signal source with a normal Random Number distribution is used to simulate the moment of resistance on the shaft. The speed ω1 and the moment M1 correspond to the mode of operation of the machine during medium grinding, ω2, M2 - respectively, fine grinding of granite stone. The range of load deviations ranged from 41.42% to 70.68% relative to the nominal in the mode of medium grinding. At the penultimate stage of workpiece processing, the value of the torque of the drive motor was between the marks of 19.49% - 53.65%.

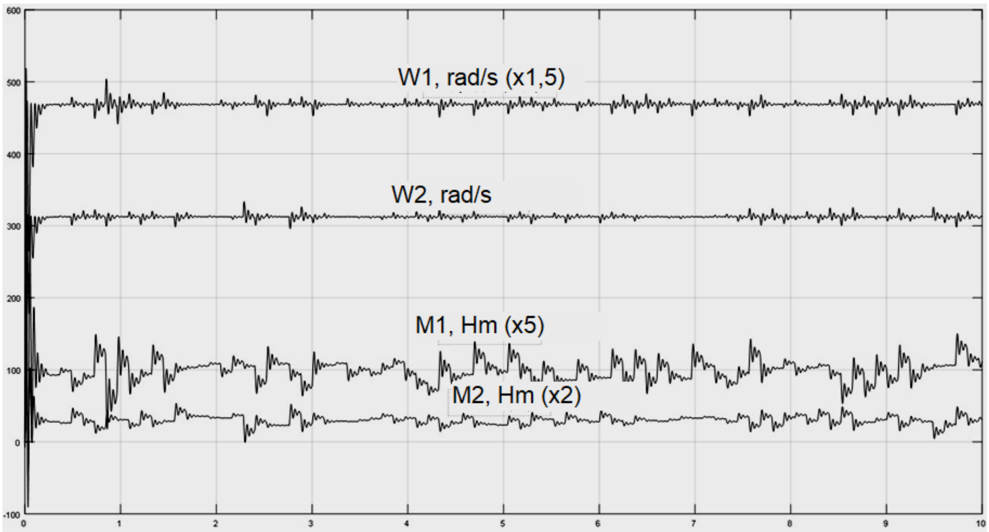

Figure 6. Graphs of transients in the conditions of stabilization of frequency of rotation of the driving engine of the main movement

Graphs of changes in the value of the output power of the main motor for the two modes of operation of the machine are shown in Figure 7.

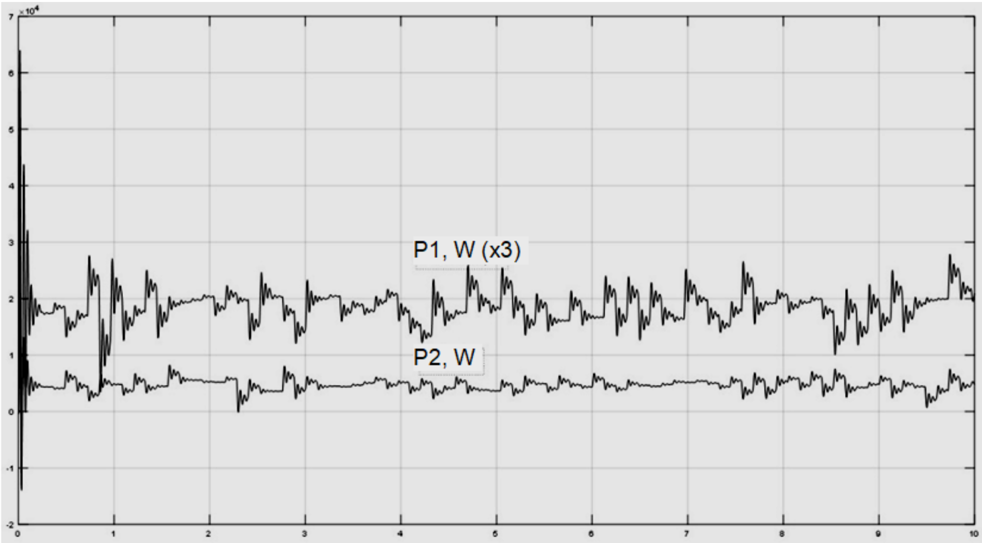

Figure 7. Graphs of change of size of output power of the electric motor
of the main movement for two operating modes of the machine

The obtained voltage values are fed to the input of the ANN, which determines the quality of surface treatment of the stone. Figure 8 presents the principle of transmission of the measured roughness data when assessing the quality of stone surface treatment at the ANN input for its processing and subsequent provision of information about the quality and stage of stone surface treatment [3].

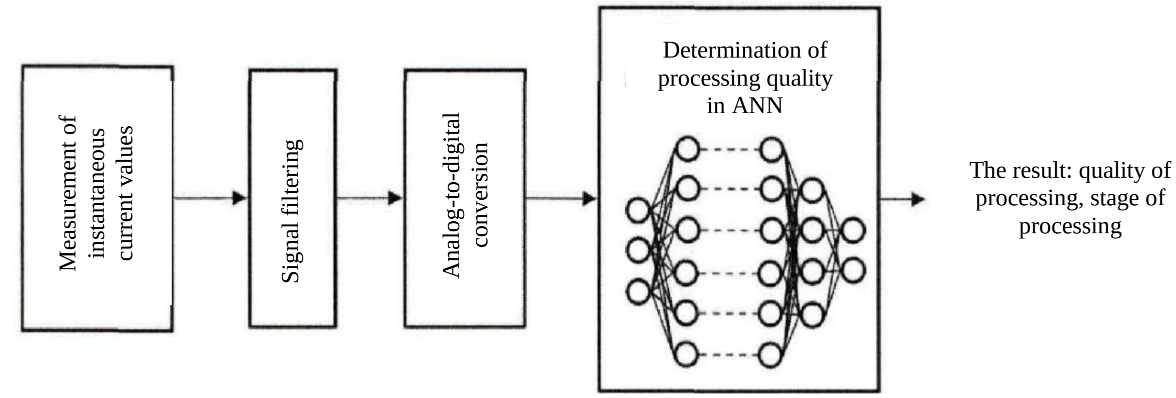

Figure 8. Block diagram of ensuring the determination of the quality
of surface treatment of the stone ANN as a part of ISADQSS [3]

ANN can be implemented in one of two ways - a reprogrammed neuroprocessor or a neuroimulator, with a customizable structure of neurons according to one of the known models. At this stage of development, the ANN is implemented as a neuroimulator, which is integrated as a specialized software application to the operating system of the PC ISADQSS. The structure of the developed ANN is built on the principles of construction of a multilayer perceptron. ANN is trained by the method of "teaching with a teacher" according to the algorithm of "reverse propagation of error". The basic unit of information processing in ANN, including ANN as a structural element of ISADQSS is a neuron that produces the output OUT, forming the sum of the products of the weights *w* of the inputs *x*. The mathematical model of the neuron is represented by an expression given in [7].

Overall, the rapid assessment of the quality of surface treatment of natural stones proposed by ISADQSS is described by a rather complex mathematical model. Therefore, in general case, the problem of assessing the quality of surface treatment of natural stones, on the example of granite, can be represented as follows.

Based on the data of multiple measurements of the value of instantaneous values and the amplitude of the current consumption at different stages of grinding, the achieved quality is automatically determined during the processing of the stone surface in real time. Figure 9 shows an example of the results of measuring the instantaneous values of current consumption by the drive of the main movement of the grinder at different quality of processing at the respective stages of grinding.

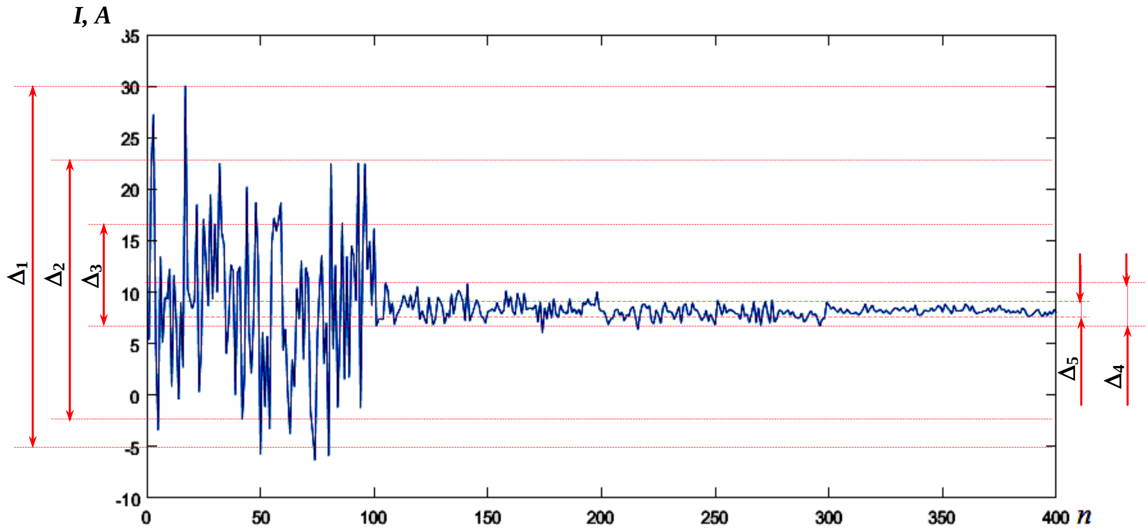

Figure 9. The result of measuring the instantaneous values of current consumption by the drive of the main motion at different quality of granite surface treatment at the appropriate stages of grinding: Δ_1 is scatter of instantaneous values of a stum at rough grinding (peeling), $\Delta_2$is scatter of instantaneous current values at average grinding,$\Delta_3$is scatter of instantaneous values of a stum at thin grinding,$\Delta_4$is scatter of instantaneous values of current at finishing grinding (ravines), $\Delta_5$is scatter of instantaneous current values during polishing

Based on the set of results of measuring the values of instantaneous values of current consumption, which were obtained by field experiment at an existing stone processing plant in the Zhytomyr region (Ukraine) was formed a database of examples for training ANN proposed ISADQSS covering many variants of scatters$\Delta_i \mid i = \overline{1; I}$ instantaneous values of current at different quality values at the respective stages of grinding. The set of scatter of instantaneous values of current consumption forms the input vector $X = \{x_n \mid n = \overline{1; N}\}$,supplied to the ANN inputs. The result is a vector of digital signal Y formed at the outputs of the ANN, which reflects the stage of processing the surface of the stone and the achieved quality: $Y = \{y_m \mid m = \overline{1; M}\}$, where y_m is the output signal of the ANN, which corresponds to the implementation of the m-th stage of grinding and the achieved quality; M is the number of grinding stages that can be determined. The maximum value of y_m at the m-th corresponding output of the ANN corresponds to the implementation of the corresponding stage of grinding and achieving a given quality. The signal from the ANN is transmitted to a PC, where automated information processing with the presentation of results in a user-friendly formis carried out.

Schematic model of ANN is shown in Figure 10. ANN is organized as a multilayer perceptron with a 3-layer structure, the number of neurons in each layer is determined by the conditions of the task. In particular, it is taken into account that the determination of the achieved quality during the processing of the stone surface in real time is carried out by ANN based on the results of continuous measurement of instantaneous values of current consumption, continuously supplied to its input.

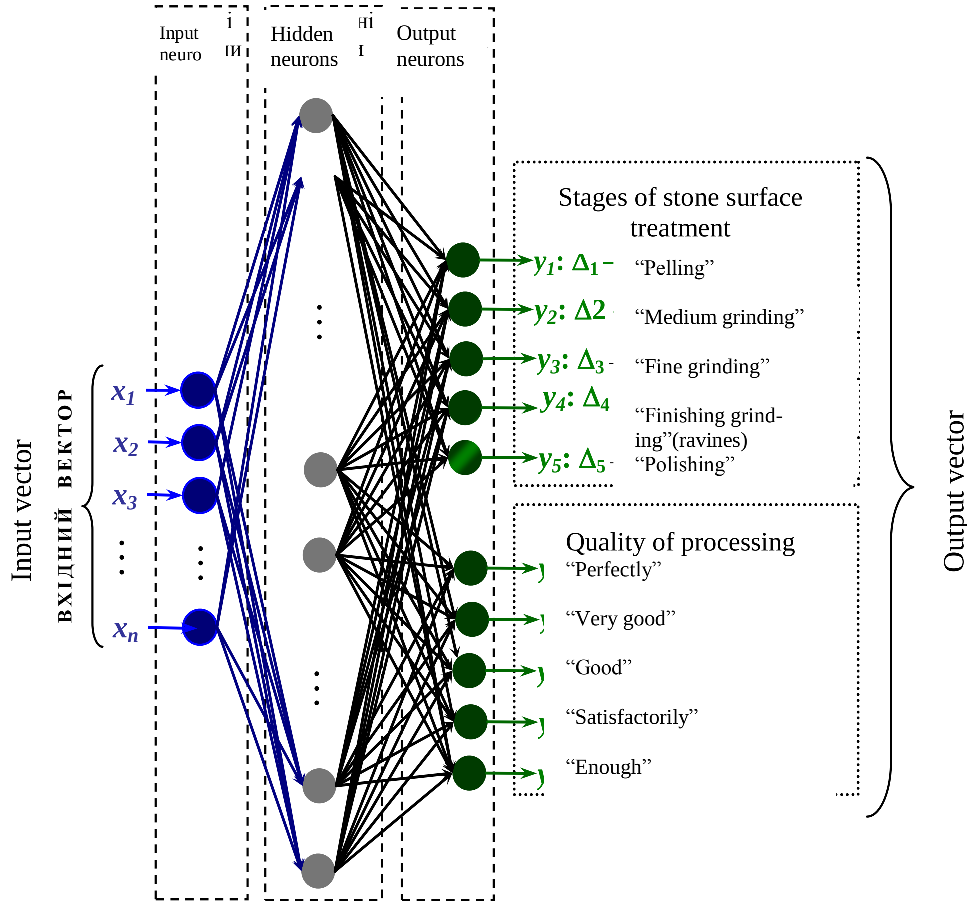

Figure 10. Schematic model of ANN of the offered ISADQSS for the automated express assessment of quality of processing of surfaces of natural stones according to a grinding stage

The number of output neurons at the output of the ANN is determined by the structure of the output vector Y. The decision on the quality achieved at the appropriate stage of grinding is made by the interpreter of the answer "winner gets everything", so the number of output signals corresponds to the number of response options which gaves the maximum signal at the output.

The hidden neurons that form the hidden layer of the ANN intermediate processing of information in such a way that the output layer of neurons is fed to linearly separated sets. The dimension of the hidden layer is determined empirically by the learning results of ANN. The value of the mean square error E, which should not exceed 0.05, is accepted as an evaluative functional of ANN training.

Computer modeling of the work of ISADQSS, in particular the developed ANN, was carried out. The obtained results indicate high speed and accuracy of work.

Thus, the time of quality assessment and determination of the stage of stone surface treatment does not exceed 2 s., which corresponds to the real time mode, and the value of the root mean square error of training and operation of ANN does not exceed the specified value - $E \leq 0{,}05$.

Conclusions

1. The description and results of experimental researches of intellectual system for automated determination of the quality of processing of surfaces of natural stones (ISADQSS) is innovative development in the field of instrument making and is intended for stone processing for express estimation of quality of processing of surfaces of stones, in particular roughness, with high accuracy in real-time and automatic mode in production conditions directly when performing technological operations of grinding and polishing.

2. According to the results of experimental studies of ISADQSS work, it was found that the value of the root-mean-square error does not exceed 0.05, and the speed does not exceed 2 s, which corresponds to the real-time mode. The measurement results do not depend on the condition of the outer surface of the stone or its humidity.

3. The proposed system has high productivity due to the use of ANN, which performs simultaneous processing of many digital data by parallel information processing, as well as a functional converter that captures the dependence of voltage on roughness in real time.

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Табиғи тастардың беттерін өңдеу сапасын автоматтандырылған анықтаудың интеллектуалды жүйесі

Мақала өзекті мәселеге – табиғи тастардың бетін өңдеу сапасын анықтаудың автоматтандыру деңгейін, дәлдігі мен жылдамдығын арттыруға арналған. Табиғи тастардың беткі қабатын өңдеу сапасын анықтаудың автоматтандырылған интеллектуалды жүйесі ұсынылған (ТБСАИЖ). Бұл әртүрлі сипаттағы беттерді тегістеу және жылтырату үшін тас өңдеу өнеркәсібінде қолдануға арналған аспап жасау саласындағы инновациялық әзірлеме. ТБСАИЖ тас бетін өңдеу сапасын жоғары дәлдікпен және жылдамдықпен автоматты режимде және нақты уақыт режимінде тікелей, тегістеу және жылтырату процесінде орындауға мүмкіндік береді және технологиялық жабдықты тоқтатуды қажет етпейді. Бұл жағдайда өлшеу нәтижесі өңделген беттің ылғалдылығы мен тазалығына байланысты емес. Ұсынылған ТБСАИЖ жылтыр өлшегіштер мен профилометрлер сияқты дәстүрлі мамандандырылған зертханалық құралдарға балама болып табылады, оларды пайдалану көп еңбекті қажет етеді және қымбатқа түседі. Басқалардан айырмашылығы, ұсынылып отырған ТБСАИЖ үлкен дәлдікке ие (орташа квадраттық қателік 5%–дан аспайды) және тез әрекет етеді (кедір–бұдырлықты анықтау уақыты 2 с-тан аспайды). ТБСАИЖ әртүрлі автоматтандыру құралдарын гетерогенді қасиеттері бар синергетикалық интеграциялау қағидаттарына сәйкес құрылған – жасанды нейрондық желілер (ЖНЖ), сондай-ақ, өңделетін беттің кедір–бұдыр мөлшерінің өзгеруіне байланысты тас өңдеу құралының үйкеліс күшінің өзгеруіне сезімтал сенсор ретінде қолданылатын негізгі қозғалыс жетегінің ток тіркеушісі (НҚЖТТ). Ұсынылған ТБСАИЖ бұл жоғары дәлдік пен жылдамдық, әмбебаптылық және пайдалану жеңілдігі сияқты артықшылықтарды біріктіретін инновациялық және перспективалы даму болып табылады.

Кілт сөздер: жасанды нейрондық желілер, кедір–бұдыр, сапа, автоматтандыру, дәлдік, жылдамдық, өлшеу.

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Интеллектуальная система автоматизированного определения качества обработки поверхностей природных камней

Статья посвящена актуальной проблеме – повышению уровня автоматизации, точности и быстродействия определения качества обработки поверхностей природных камней. Предложена интеллектуальная система автоматизированного определения качества обработки поверхностей природных камней (ИСАКПК). Это инновационная разработка в области приборостроения, предназначена для применения на камнеобрабатывающих производствах при шлифовании и полировании поверхностей различной природы. ИСАКПК позволяет выполнять экспресс-оценку качества обработки поверхностей камней с высокой точностью и быстродействием в автоматическом режиме и режиме реального времени непосредственно, во время выполнения технологических операций шлифования и полирования, и не требует остановки технологического оборудования. При этом результат измерения не зависит от влажности и чистоты обрабатываемой поверхности. Предложенная ИСАКПК является альтернативой традиционным специализированным лабораторным средствам, например, блескометрам и профилометрам, применение которых является трудоемким и дорогостоящим. В отличие от них, предложенная ИСАКПК имеет большую точность (средняя квадратическая погрешность не превышает 5%) и быстродействие (время определения шероховатости не более 2 с.). ИСАКПК построена по принципам синергетической интеграции разных средств автоматизации с неоднородными свойствами – искусственных нейронных сетей (ИНС), а также так называемого регистратора токов привода главного движения (РТПГД), который применяется в качестве датчика чувствительного к изменению силы трения камнеобрабатывающего инструмента в зависимости от изменения величины шероховатости обрабатываемой поверхности. Предложенная ИСАКПК является инновационной и перспективной разработкой, которая объединяет такие преимущества, как высокая точность и быстродействие, универсальность и простота использования.

Ключевые слова: искусственные нейронные сети, шероховатость, качество, автоматизация, точность, быстродействие, измерения.

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