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VIRTUAL REALITY AND REAL MEASUREMENTS IN PHYSICAL TECHNOLOGY

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ABSTRACT

Information is transmitted by signals that have a material-and-energy nature, but it is not matter and not energy. The information ensures communication of interacting objects of alive and inanimate nature. Information and communications technology underlie the new production paradigm called the “Industry 4.0”. In accordance with this paradigm, increased attention is paid to the pre-production phase on which relevant comprehensive solutions for the automation of design and production are taken, ranging from receiving an order for the product and ending with its shipment to the consumer. At the same time, issues of production management and efficient control of technological processes are solved, including scheduling and material requirement planning. At the pre-production phase, a virtual product is created (the information model of the real product in the form of a “virtual reality”), and at the execution phase a real (physical) product appears, which has a use value (possession utility). The implementation phase begins only after systemic computer modeling, simulation, and optimization of the technological process and operations, that is, after assessing both the time and the cost of virtual technological processes. In this regard, this research discusses topical issues of interaction between virtual information at the pre-production (preparatory) phase and new information arising at the implementation phase of physical technology in terms of improving the efficiency of computer-integrated production. It is shown that the information is a basic category not only in information (virtual) technology for its transformation and transmission, but also in physical technology of material production at the stage of manufacturing the appropriate material product, on the one hand, and (by analogy) in the process of distance learning of specialists, on the other hand (although information is not knowledgeable yet). Particular attention is paid to measuring procedure and assessing its accuracy; this work is not formal and requires the use of an intellectual system to ensure the accuracy of the information received.

Keywords: Virtual reality; virtual technology; physical technology; material processing; information processing; intelligent system; measurement error analysis; virtual instruments

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1. INTRODUCTION

The last 40-50 years, without exaggeration, can be called the time of development of information industries. Information technology covers all areas of human activity, including politics, economics, industry, education, art, etc. We are used to working in different social networks, “entering” some pages, clicking some settings and buttons as well as playing computer games. All this is the world of “virtual reality”.

As a result, we witnessed the concept of “virtual reality”, on the basis of which information technology as well as information and communications technology are rapidly developing in the everyday life of people. Besides, such technology includes video conferencing and distance learning as well, i.e., “virtual reality” procedures in industry, science, and education.

In the art world, for example, producers have created a specific genre of “virtual reality”, in which the characters are endowed with various emotional qualities to the extent that the audience likes it. To some extent, this corresponds to the principle of “wishful thinking” when the producers create a magical universe that is inhabited by fairies, witches, and other mythical creatures. However, this is more related to the field of artistic creation, psychology and emotional experiences. For economics, more acceptable terms are ex-ante control and ex-post control. There are two alternative methods of defining economic quantities such as incomes, savings, and investments. Quantities defined in terms of measurements made at the end of the period in question are referred to as ex-post; quantities defined in terms of action planned at the beginning of the period in question are referred to as ex-ante. Not so in manufacturing industry.

To the present, manufacturing has been recognized as a skillful function which is implemented in a workshop. Manufacturing is no longer merely machining or fabrication. Moreover, manufacturing systems are covering everything from order receipt to the product shipment. There is no need to assert (this is clear from the very beginning) that all the phases (stages) of developing an integrated manufacturing system, including CAD/CAM/CAE, correspond to the product life cycle, on the one hand, and are based on information and its meaning depending on the phase, on the other hand. In this regard, great (and over time increasing) importance is attached to improving the efficiency of productive technologies based on virtual technology and physical technology.

A physical (not virtual) product is created at the phases of pre-production and production itself. In both of these phases, the so-called information flow takes place. In the first case, this flow refers to the type of “virtual reality”, and in the second – to the results of measurement and control of the actual (physical) state of the product or production process. Thus, “virtual reality” information is used at the phase of preparing material production. In turn, the production process is implemented by the so-called a technological system which contains a machine tool, a fixture, a tool, and a workpiece being machined.

During the functioning of a technological system, new information appears, consisting of two components: predictable (in accordance with “virtual reality” and unpredictable, i.e., revealed when measuring the parameters of the process or/and product. The idea of this research is to show that progress and sustainable development in the technology of material production are possible through the use of unpredictable but true information to control a technological system, e.g., a grinding system.

Production processes as well as scientific researches involve numerous measurements to confirm or refute a relevant scientific hypothesis or theory. This is an example of information obtained by measurements or measurement information. Besides, there are and widely used both the management and control of processes and systems based on the received measurement information. Needless to say that obtaining false information during measurement will result in corresponding (sometimes irreparable) losses. The most common waste is additional production time and associated economic costs that could have been avoided. What objective factors determine the degree of falsity (or truthfulness) of the information obtained during production measurements? How do these factors depend on the so-called measurement technology? These and other issues are discussed in this research. Of course, there is no need to point out that the task of increasing the trustfulness of measurement information in automated production is a complex and systemic one based on artificial intelligence. There are two main types of production information: pre-empirical (inferred) and post-empirical (actual). How to use both of these types of information effectively will be discussed further.

2. LITERATURE REVIEW

A literary review allows determining the place of the problem being solved (virtual reality and real measurement in physical technology) in the general system of product quality assessment and product quality management. The development of “virtual reality” brings an old and historic question on the difference between the real world and unreal world. What we call “virtual reality” is a representation of an actual or non-actual world and the criterion of difference between the “real world” and “virtual reality” is whether we present it with the intention of using it as a representation. In other words, “virtual reality” is presented as a simulation or representation of an actual or non-actual world, whereas what we call the “real world” is not presented as such [1].

The observed information process, creating its “observer”, connects reality, information, and the “observer”. What do the observers actually observe? Do they observe reality? What is the information they observe? And how is the observed information connected with the reality of observation? What is the scientific path to uncovering the fact of reality through its observed information? All these questions are still unanswered in known publications [2].

The linguistic meaning of information includes issues of modeling and simulation [3], on the one hand, and issues of automation of technological processes and technological systems [4], on the other hand. That is why this research deals with conception, principles, and procedures needed to explain both the essence of and the difference between two production flows, namely the flow of information and the flow of materials. The objective of research is to establish the necessary and sufficient conditions for ensuring the progress of an integrated manufacturing system in terms of efficient product design and manufacturing.

Production is basically the creation of economic goods, including tangible products and intangible services [5]. Concerning tangible products, this activity is called “manufacturing” that means “conversion” of a design into a finished product and covers all phases of product life: planning and design, procurement, production as itself (making the product), inventory, management, distribution, marketing and sales. Material production converts raw materials into finished products with the aid of factors of production such as materials, machines, labor force, money, and information (Fig. 1).

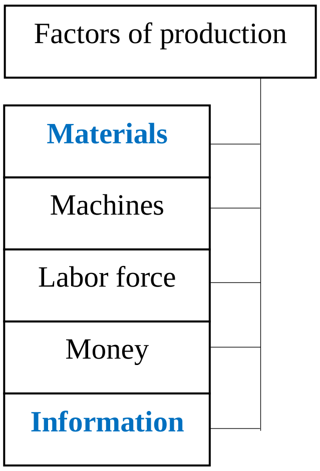

Fig. 1. **Factors of material production**
***Source*: compiled by the author**

This is "physical material production" (as opposed to information on production) which constitutes the "flow of materials" as one of the main flows in production (Fig. 2).

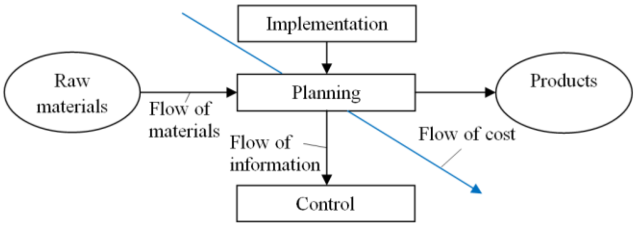

Fig. 2. **Materials, information, and cost manufacturing flows [5]**
***Source*: [5]**

In turn, the "flow of materials" constitutes a serial functional chain: procurement of raw materials from outside suppliers (including procurement management), production of products in the workshop, distribution and sales of the product, including inventories of raw materials, works in process and products themselves (Fig. 3). Flow of materials gives the possession utility (commodity) from the products for ultimate consumers.

Material flow becomes possible by a coordinating (reconciling, concurrent) and guiding control process (management activities) which constitutes the flow of information (Fig. 2). The flow of information is important to win in the present severe competitive environment. The importance of these two flows was noted and stressed as early as 1913 by A. H. Church in his paper "Practical principles of rational management" [5].

The considered work [5] is important from the point of view of separation and interaction between two production flows, namely the flow of materials and the flow of information. A number of the following conclusions follow from the analysis of the data presented.

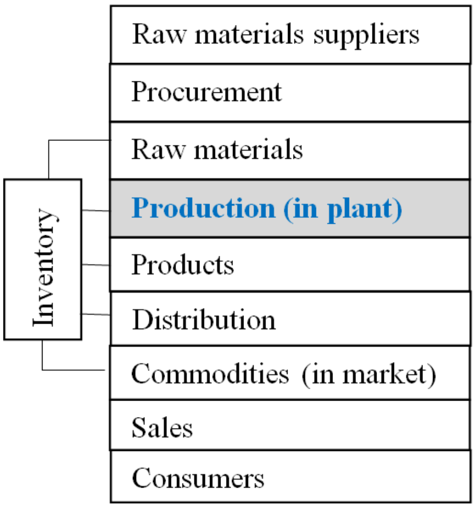

Fig. 3. **Flow of materials in manufacturing systems [5]**
***Source*: [5]**

1. The flow of information is interconnected with other flows (Fig. 2) and allows (when used for control) to direct or coordinate other flows to achieve the production goal at the lowest cost.

2. It can be assumed that the connecting process between information flows and other flows is the control process (not shown in Fig. 2), i.e., the interconnection between information processing and materials processing is carried out through the control process.

Analysis of the information and material flows (Fig. 3 and Fig. 4) shows that they have a common block (production implementation phase), which affects both of these flows and is a confirmation of their continuity (in Fig. 3 and Fig. 4, this block is shaded). In addition, it can be seen that the structural diagrams of these flows characterize the information and material aspects of the product life cycle system.

Next step in "virtual reality" is going from integrated manufacturing system to virtual one, i.e., to more high integration degree based on computer. A virtual manufacturing system is the integrated application of modeling, simulation, and analysis technologies and tools to enhance manufacturing design and production decisions and control at all process levels. The virtual manufacturing has been successfully applied to many fields such as, automobile manufacturing, aeronautics and astronautics, railway locomotives, communication, education and so on, which has an overpowering influence on industrial circles [6].

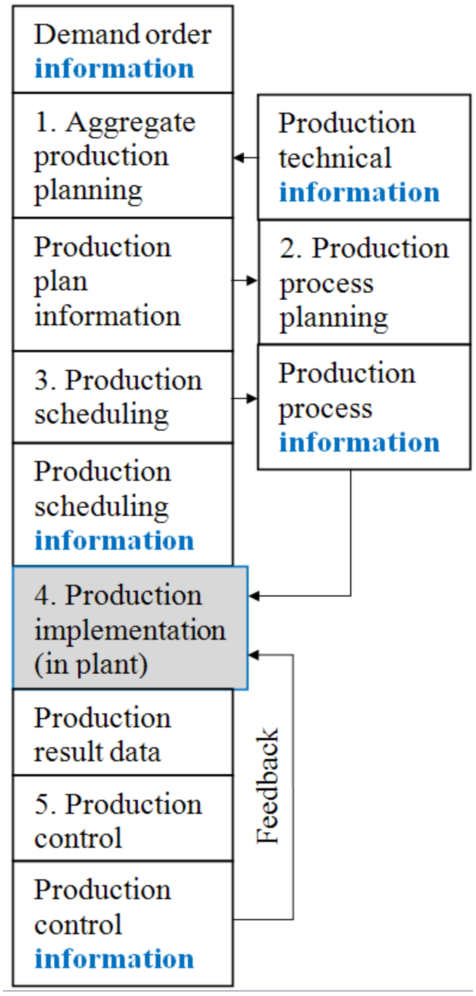

Fig. 4. **Flow of information in manufacturing systems: planning stage (1, 2, 3), implementation stage (4), and control stage (5) [5]**
***Source*: [5]**

Healthcare is one of the biggest adopters of virtual reality which encompasses surgery simulation, phobia treatment, robotic surgery and skills training. One of the advantages of this technology is that it allows healthcare professionals to learn new skills as well as refreshing existing ones in a safe environment. Plus it allows this without causing any danger to the patients. Virtual manufacturing applications in the healthcare industry are associated with many leading areas of medical technology innovation including robot-assisted surgery, augmented reality surgery, computer-assisted surgery (CAS), image-guided surgery, surgical navigation, multi-modality image fusion, medical imaging 3D reconstruction, pre-operative surgical planning, virtual colonoscopy, virtual surgical simulation, virtual reality exposure therapy, and virtual reality physical rehabilitation and motor skills training. Stent design influences the post-procedural hemodynamic and solid mechanical environment of the stented artery by introducing non-physiologic flow patterns and elevated vessel strain. This alteration in the mechanical environment is known to be an important factor in the long-term performance of stented vessels. Because of their critical function, stent design is validated by methods such as finite element analysis (FEA) [6].

The literature review allows us to formulate the following conclusions.

1. Further development of the information direction in "virtual reality" systems leads to well-known scientific directions, namely game theory, operation research, project management, etc. At the same time, the information direction in physical technology is associated with metrology, quality management, adaptive and intelligent control systems, etc. For example, quality management ensures that an organization, product or service is consistent. It has four main components: quality planning, quality assurance, quality control and quality improvement (as a progress in sustainable development results).

2. Quality management is based on an elementary operation of evaluating the simplest (indivisible) property of an object which is called measuring operation. The measuring operation is a part of technological process wherein new information (as opposed to information in virtual reality) is arisen to control of both the product being created and the process to create the product.

3. Project management is the process of leading the work of a team to achieve goals and meet success criteria at a specified time. The primary challenge of project management is to achieve all of the project goals within the given constraints [7]. This information is usually described in project documentation, created at the beginning of the development process. The primary constraints are scope, time, and budget, i.e., cost (Fig. 5) [8].

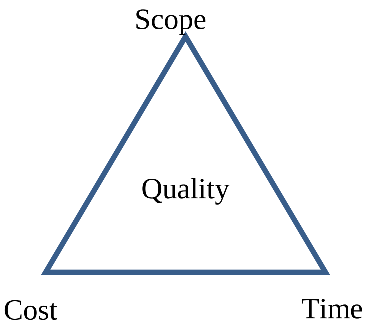

Fig. 5. **The project management triangle [8]**
***Source*: [8]**

The secondary challenge of project management is to optimize the allocation of necessary inputs and apply them to meet pre-defined objectives. That is why this research deals with conception, principles, and procedures needed to explain both the essence of and the difference between two production flows, namely the flow of information and the flow of materials. **The objective of research** is to establish the necessary and sufficient conditions for ensuring the progress of an integrated manufacturing system in terms of efficient product design and manufacturing. **The tasks to be solved** relate to two main directions. The first direction is to reveal a linguistic meaning of information in the kind of terms and concepts, ranging from artificial intelligence to education (see conclusion). The second direction is to establish how progress is ensured in production systems when manufacturing a product with information support for the stages of production and its preparation. To some extent, the second direction takes into account the peculiarities of distance learning, when the physical (not virtual) process is the learning process itself.

3. RESEARCH METHODOLOGY

3.1. General

On analyzing over figures mentioned above, the following production flows can be distinguished as shown in Fig. 6. Next, it is possible to build a diagram of the interaction of flows and processes (Fig. 7). This diagram shows the relationship between measurement (real action), information processing (real action) and control (real action).

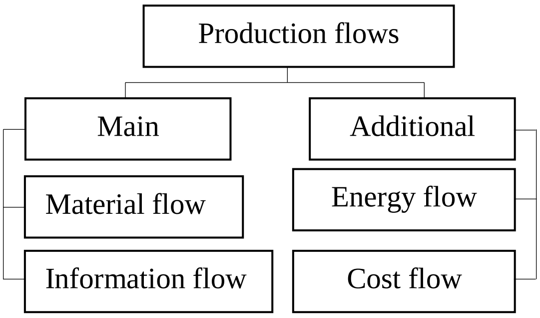

Fig. 6. **Production flows classification**
***Source*: compiled by the author**

It can be seen that the production information contains both a priori and a posteriori components. The posterior component of information appears as a result of both physical (i.e., non-virtual) material processing and measurement processes.

The fundamental solution to the problem of computer-aided design and production in accordance with intelligent numerical control at the production stage involves the use of an integrated CAD/CAM/CAE system [9]. Let's introduce some definitions. Firstly, a process as a technical and/or technological system is a set of elements that are located in time, i.e., in a time sequence of ordered actions, e.g., the sequence of operations, operation steps, working passes, etc. Secondly, a technological system is a space structure, i.e., not a process that is, assembled by a technologist for the technological process (operation) duration. This structure (as a technical system-device) is a collection of elements that are located in space (machine, fixture, cutting tool, workpiece).

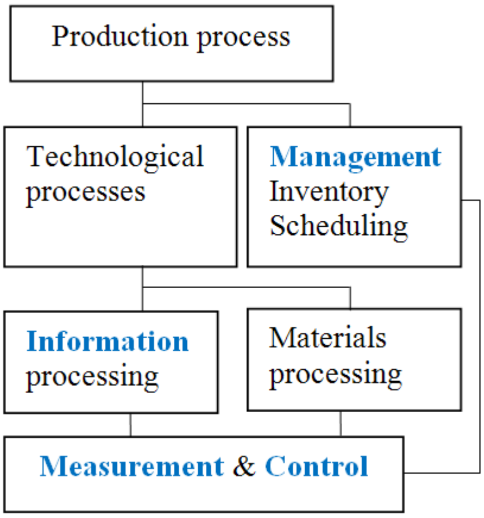

Fig. 7. **Information and material processing in material production**
***Source*: compiled by the author**

The modern understanding of CAD/CAM/CAE automation is considered taking into account the product life cycle, which contains a number of time stages, including product design (CAD), process design (CAM), and process systematic engineering calculations (CAE) with special computer software packages, as well as the product testing and the process assessing (Fig. 8).

At the CAD stage of the product life cycle the product design is performed with computer packages (Compass, Solid works, AutoCAD, Inventor, etc.). According to Fig. 8 optimization of the product constructive parameters is carried out using the constructive systematic engineering calculations (ANSIS, MATLAB, etc.) of CAE-system (construction).

At the CAM stage of the product life cycle, process design is performed with special computer packages, namely COMPASS Auto-project, Vertical, Mastercam, T-flex, etc. According to Fig. 8 optimization of the process parameters is carried out using the constructive systematic engineering calculations (COMSOL Multiphysics, MathCAD, MATLAB, etc.) of CAE-system (technology). It makes it possible to justify the adopted technology from the product quality assurance point of view, for example, the thermal fields and thermal stresses calculations in grinding to predict grinding burns and microcracks, etc.

At the post-processor stage (Fig. 8) a control program for CNC machine is prepared to control the machine at the production stage. This is the stage of actual implementation of work, for the sake of which all the previous stages of the product life cycle have been completed.

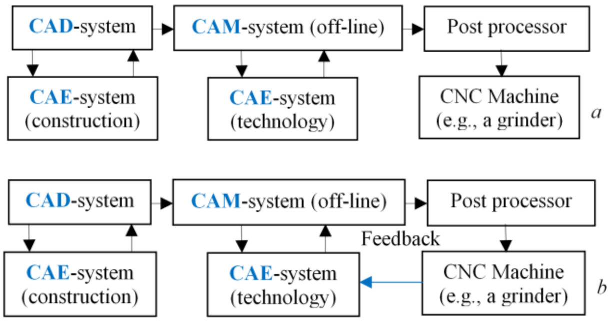

Fig. 8. **Integrated system CAD/CAM/CAE in mechanical engineering technology without (*a*) and with (*b*) feedback**

***Source*: compiled by the author**

In accordance with the general systems theory methodology, the structure and parameters of the developed technological system are found based on the goal that must be achieved during the development and operation of this system. For multi-stage technological design processes at each of the intermediate design stages, there is an intermediate goal, the achievement of which is the task of these intermediate stages. Thus, a multi-stage design procedure corresponds to a "tree of goals", the top of which is the ultimate (final) goal facing the developer of the technological system.

Methods for process modeling discussed further. Besides the model definition mentioned above another term to explain "model" may be as follows: a model is the abstract representation of a manufacturing process which serves to link causes and effects [10]. Therefore, ensuring the correspondence between the model of a real (physical) system and this system itself must be ensured, for example, by training this model using signals from sensors built into the real (physical) system. This applies not only to technological systems in mechanical engineering, but also to civil engineering and architecture [11].

In grinding, the dependences of settings on process quantities such as grinding forces F, temperature T, and acoustic emission AE as well as on output quantities such as surface roughness and surface integrity (surface layer quality like grinding burns and residual stresses) may be mapped too on the basis of F. Klocke' representation [12]. Taking into account this representation, a model of technological grinding system can be represented as it is shown in Fig. 9. The model consists of the following state parameters: Q'_w, V'_w, F, T, AE, where Q'_w is the specific material removal rate in mm^3/(s·mm); V'_w is the specific material removal in mm^3/mm; F and T are the grinding force in N and temperature in °C; AE is the acoustic emission signal.

It can be seen that even a separately considered grinding system contains several subsystems (workpiece, grinding wheel, dressing tool, cutting fluid, etc.) whose interaction cannot be predicted in the category of "representation" and "virtual reality", not to mention the additional influence of technological inheritance from previous operations [13].

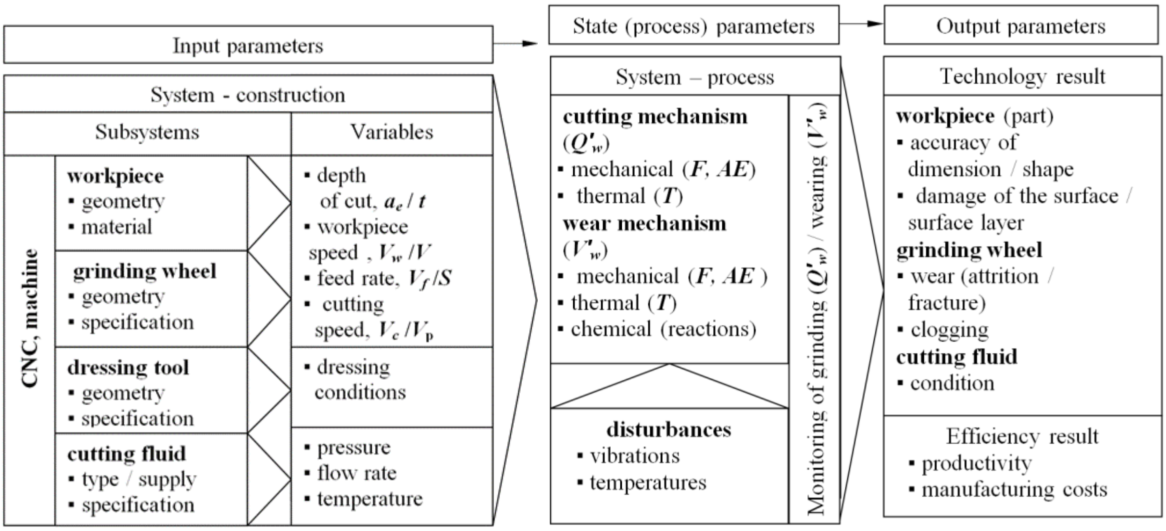

Fig. 9. **Grinding system model (in fractional notations the input variables are listed in overseas [10] and domestic designations)**

***Source*: [10]**

Therefore, for effective control of the technological system, e.g., grinding system, it is necessary to use new information arising during machining, e.g., grinding, as provided in Fig. 9. In this regard, a new problem appears – the problem of obtaining reliable (true) information for the intelligent numerical control of a technological system, e.g., grinding system. Such information manifests itself in the form of signals that have a material-and-energy form, although information is neither matter nor energy. From the point of view of the objective being achieved, information can be true and false. True information can be useful and useless. Useful information can be more or less productive. In turn, false information is either deliberately false or false due to its high noise level.

It should be noted here that the technological operations for the manufacture or repair of a man-made product – machines, mechanical structures, buildings and structures [9, 11] – differ from technological operations related to the restoration (or repair) of a non-technical product, for example, surgical operations (medicine). The proportion of the work planning stage (past experience, virtual reality) in this case is minimal. The information that the surgeon (for example, the dentist) uses for the next action appears online, taking into account the continuously changing situation. Here we are dealing with the so-called situational management with using natural intelligence. For example, a dentist is dealing with a living human jaw. The jaw is a special construction in which each of the upper and lower bony structures in vertebrates forming the framework of the mouth and containing the teeth.

A dentist has a computer tomography scan (analogue of technical design drawing) as a starting material for planning future surgery. But the main work of the dentist is performed at stage “implementation” and this work cannot be planned in details in advance, since such work (and these are thousands of mechanical actions using specific equipment and tools) is performed taking into account the situation that arises.

Summarizing the literature review, we note the following. Information in the narrow sense is a source of data for decision making in the control of an object. Information in a broad sense is a piece of knowledge in learning theory: both in education and in artificial intelligence. In this regard, let us consider the errors that arise during measurement and methods of evaluating the measurement information in the physical (not virtual) technology.

3.2. Measurement error analysis information support

According to the sources and nature of the errors, when estimating the error of direct measurement, the following steps can be distinguished [14]: (1) identification and accounting of corrections related to the presence of systematic errors; (2) determination of errors of measuring instruments; (3) calculation of random error; (4) detection of rough errors; (5) determination of the total error of direct measurement.

The total error of direct measurement Δx is determined by the magnitude of the random error Δx_{ran} and the magnitude of the error of the measuring instrument Δx_{in}. The values of Δx_{ran} and Δx_{in} which are called components of the error of direct measurement are due to independent reasons. In the case of independent components, the total error of direct measurement can be calculated by the formula

$$\Delta x = \sqrt{\Delta x_{ran} + \Delta x_{in}} \,. \qquad (1)$$

Let, as a result of measurements of n a certain quantity x, we obtained the values $x_1, x_2, \dots x_n$ which differ from each other due to the presence of random errors. The result of each direct measurement x_i is recorded in the appropriate Table.

1. Calculate the arithmetic mean of the series of *n* measurements, i.e.

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \,. \qquad (2)$$

2. Find random deviations of individual measurements $\Delta x_i = x_i - \bar{x}$.

3. Calculate the squares of individual deviations Δx_i^2 and their sum. $\sum_{i=1}^{n} \Delta x_i^2$

4. Determine the root mean square error of S_x for the series from the measurements n.

$$S_{\bar{x}} = \sqrt{\frac{1}{n(n-1)}\sum_{i=1}^{n}(x_i - \bar{x})^2} \,. \qquad (3)$$

Formula (3) has this form with a small number of observations [15-16] and characterizes the so-called uncertainty related to repeatability. The standard uncertainty related to repeatability is the standard deviation of the estimated mean error value.

5. Set the reliability α of the measurement result. Usually take $\alpha = 0.95$.

6. Analyze the measurement results for the presence of misses. If there are misses, the corresponding individual measurements are discarded and the calculations are repeated with the new value n.

Practically for verification in a series of n measurements for the result x_k of the k-th measurement which is similar to the miss with a given reliability α, the coefficient of the miss is calculated as

$$\nu = \frac{\left|\overline{x} - x_k\right|}{S_{\overline{x}}\sqrt{n-1}}. \qquad (4)$$

Then, compare it with the corresponding limit value $\nu_{\max}$ [14]. For $\nu > \nu_{\max}$, the result of the k-th measurement x_k is declared as an error and must be rejected, after which new values $\overline{x}$ and $S_{\overline{x}}$ are calculated. Otherwise, x_k is saved.

7. From the corresponding Table, find the Student's coefficient $t_{\alpha;n}$ and use the formula to calculate the random component Δx_{ran} of the measurement error:

$$\Delta x_{ran} = t_{\alpha;n} S_{\overline{x}} = t_{\alpha;n}\sqrt{\frac{1}{n(n-1)}\sum_{i=1}^{n}(x_i - \overline{x})^2}\;. \qquad (5)$$

8. Determine the instrument measurement error Δx_{in} for the value x. If the accuracy class of the device is known, then Δx_{in} it is calculated by the formula

$$\Delta x_{in} = \frac{\lambda_\alpha}{3}\,\frac{k}{100\%}\,x_{\max}\,, \qquad (6)$$

where: λ_α is the coefficient; k – accuracy class of the device; $x_{\max}$ – the maximum value of the value measured by the device.

Otherwise, it is worth using the appropriate recommendations [14].

9. According to the formula (1), find the total absolute error Δx in measuring the value x. In the case when one of the components is Δx_{ran} or Δx_{in} at least three times less than the other, then it can be neglected in the calculation.

10. Calculate the relative measurement error.

11. Record the final measurement result in the form $x = \overline{x} \pm \Delta x$; $\varepsilon = \ldots$; $\alpha = \ldots$.

Assessment of a real situation on the basis of measurement (data presentation unlike representation) is carried out along the chain: measurement-calibration-assessment-decision making. Here, the calibration is a set of additional operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument or measuring system (computer station), and the corresponding standard values. The result of a calibration permits either the assignment of values of measurands to the indications or the determination of corrections with respect to indications. Consequently, even such work in an automated production environment requires the use of an intelligent control system on CNC machines [17] including augmented reality applications [18].

3.3. Virtual instruments using for real data acquisition

The development environment LabVIEW for laboratory virtual instruments allows performing graphical applied programming for measurements, conversion of sensor signals and data collection for subsequent control of instruments itself and objects under study – technical systems. LabVIEW means Laboratory Virtual Instrument Engineering Workbench and is not the only one for virtual systems of this type. There are also Proteus, VisSim, etc. But unlike the indicated analogs, program NI- LabVIEW and the corresponding data acquisition device NI-DAQmx can be used to automate research work, e.g., during the research of both cutting dynamics and grinding thermophysics, including grinding temperature determination [19-20]. To do this, the appropriate sensors are connected to the device NI-DAQmx, for example, vibration sensors (AP 2019) or grinding power sensor.

4. RESULTS

The roughness of the surface in the cross ($R_{a\,c}$) and longitudinal ($R_{a\,l}$) directions was measured on the Profilers (Fig. 10) three times.

The results of measurements were processed according to the above method for prismatic samples No.1-No.5. According to the recommendations given in [12], when measuring the value of a digital device, the instrument error is taken equal to the price of the scale division. In this case, for a digital device of model 170621 we have $\Delta R_{a\,c.in} = \Delta R_{a\,l.in}$ = 0.01 μm.

The results of the calculation of the error of measuring the surface roughness on the samples No. 1 – No. 5 are entered in the table: sample 1 (top) – $R_{a\,c}$ ($R_{a\,c} = (1.98 \pm 0.56)$ μm; $\varepsilon_{R_{a\,c}}$ =28.23 %; α =0.95); sample 1 (top) – $R_{a\,l}$ ($R_{a\,l} = (0.4 \pm 0.02)$ μm; $\varepsilon_{R_{a\,l}}$ = 4.34 %; α =0.95); sample 1 (side) –

R_{ac} ($R_{ac} = (0.92 \pm 0.24)$ µm; $\varepsilon_{R_{ac}}$ =25.59 %; α =0.95); sample 1 (side) – R_{al} ($R_{al} = (0.33 \pm 0.03)$ µm; $\varepsilon_{R_{al}}$ =8.11 %; α =0.95); sample 2 (top) – R_{ac} ($R_{ac} = (1.71 \pm 0.25)$ µm; $\varepsilon_{R_{ac}}$ =14.5 %; α =0.95); sample 2 (top) – R_{al} ($R_{al} = (0.49 \pm 0.06)$ µm; $\varepsilon_{R_{al}}$ =12.99 %; α =0.95); sample 2 (side) – R_{ac} ($R_{ac} = (1 \pm 0.11)$ µm; $\varepsilon_{R_{ac}}$ =10.86 %; α =0.95); sample 2 (side) – R_{al} ($R_{al} = (0.37 \pm 0.08)$ µm; $\varepsilon_{R_{al}}$ =20.86 %; α =0.95); sample 3 (top) – R_{ac} ($R_{ac} = (0.74 \pm 0.38)$ µm; $\varepsilon_{R_{ac}}$ =50.96 %; α =0.95); sample 3 (top) – R_{al} ($R_{al} = (0.45 \pm 0.08)$ µm; $\varepsilon_{R_{al}}$ =16.86 %; α =0.95); sample 3 (side) – R_{ac} ($R_{ac} = (0.79 \pm 0.02)$ µm; $\varepsilon_{R_{ac}}$ =2.19 %; α =0.95); sample 3 (side) – R_{al} ($R_{al} = (0.33 \pm 0.04)$ µm; $\varepsilon_{R_{al}}$ = 50.96 %; α =0.95); sample 4 (top) – R_{ac} ($R_{ac} = (0.91 \pm 0.05)$ µm; $\varepsilon_{R_{ac}}$ =5.76 %; α =0.95); sample 4 (top) – R_{al} ($R_{al} = (0.35 \pm 0.05)$ µm; $\varepsilon_{R_{al}}$ =14.89 %; α =0.95); sample 4 (side) – R_{ac} ($R_{ac} = (0.79 \pm 0.1)$ µm; $\varepsilon_{R_{ac}}$ =12.7 %; α =0.95); sample 4 (side) – R_{al} ($R_{al} = (0.39 \pm 0.03)$ µm; $\varepsilon_{R_{al}}$ =10.35 %; α =0.95); sample 5 (top) – R_{ac} ($R_{ac} = (0.44 \pm 0.01)$ µm; $\varepsilon_{R_{ac}}$ =2.27 %; α =0.95); sample 5 (top) – R_{al} ($R_{al} = (0.22 \pm 0.03)$ µm; $\varepsilon_{R_{al}}$ =13.97 %; α =0.95); sample 5 (side) – R_{ac} ($R_{ac} = (0.51 \pm 0.03)$ µm; $\varepsilon_{R_{ac}}$ =5.92 %; α =0.95); sample 5 (side) – R_{al} ($R_{al} = (0.61 \pm 0.05)$ µm; $\varepsilon_{R_{al}}$ =8.16 %; α =0.95).

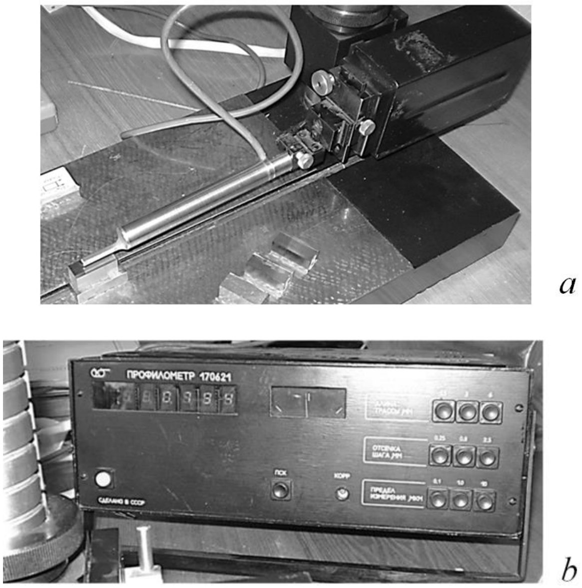

Fig. 10. **Profilometer for measuring surface roughness: setting (*a*) and measuring part (*b*)**
***Source*: compiled by the author**

Suspicious value is R_{aci} = 0.92 µm (Table 1). We calculate for it by the formula (4) the corresponding coefficient of the miss, i.e.

$$\nu = \frac{\left|\bar{R}_{ac} - R_{aci}\right|}{S_{\bar{R}_{ac}}\sqrt{n-1}} = \frac{0.177}{0.088 \cdot \sqrt{3-1}} = 1.422 .$$

The threshold value of the miss coefficient $\nu_{\max}$ at α = 0.95 and n = 3 becomes 1.41. Because $\nu < \nu_{\max}$ then the result of the first measurement is the miss and should be turned off. The procedure for calculating the determination of the measurement error is then repeated. The results are entered in Table 2.

Table 1. **Processing of measurement results for the sample No.3 (top)**

No. п/п	R_{aci}, µm	ΔR_{aci}, µm	ΔR^2_{aci}, µm	$S_{\bar{R}_{aci}}$, µm	$\Delta R_{ac\,rand}$, µm	$\Delta R_{ac\,in}$, µm	$\bar{R}_{ac} \pm \Delta R_{ac}$ µm
1	0.92	0.176	0.031	0.088	0.3785	0.01	0.74 ± 0.38
2	0.65	-0.093	0.0086				
3	0.66	-0.083	0.00689				
n =3	$= \bar{R}_{ac}$ = 0.743	$\sum_{i=1}^{3} \Delta R_{aci} = 0$	$\sum_{i=1}^{3} \Delta R^2_{aci} =$ = 0.0465	$t_{0.95;3} =$ = 4.3	ΔR_{ac} =0.3786		$\varepsilon_{R_{ac}}$ = 50.96%
Note: $R_{ac} = (0.74 \pm 0.38)$ µm; $\varepsilon_{R_{ac}}$ =50.96 %; α =0.95							

***Source*: compiled by the author**

Table 2. **Processing of measurement results for the sample No. 3 (top) after correction**

No. п/п	$R_{a\,n\,i}$, μm	$\Delta R_{a\,n\,i}$, μm	$\Delta R^2_{a\,n\,i}$, μm	$S_{\bar{R}_{a\,n\,i}}$, μm	$\Delta R_{a\,c\,rand}$, μm	$\Delta R_{a\,c\,in}$, μm	$\bar{R}_{ac} \pm \Delta R_{ac}$ μm
1	0.65	-0.005	0.000025	0.005	0.0635	0.01	0.66 ± 0.06
2	0.66	0.005	0.000025				
n =2	$\bar{R}_{ac}$ = = 0.655	$\sum_{i=1}^{2} \Delta R_{a\,c\,i}$ = 0	$\sum_{i=1}^{2} \Delta R^2_{a\,c\,i}$ = = 0.00005	$t_{0.95;2}$ = =12.7	$\Delta R_{a\,c}$ = 0.064		$\varepsilon_{R_{a\,c}}$ = 9.78%
Note: $R_{a\,c} = (0.66 \pm 0.06)$ μm; $\varepsilon_{R_{a\,c}}$ =9.78%; α =0.95							

***Source*: compiled by the author**

The largest value of the relative error when measuring the surface roughness in the cross direction is $\varepsilon_{R_{a\,c}}$ = 28.33 %. The largest value of the relative error when measuring the surface roughness in the longitudinal direction is $\varepsilon_{R_{a\,l}}$ = 20.84 %.

Thus, the data on the measurement error obtained during the roughness measurements indicate that the direct measurement procedure contains the elements of artificial intelligence [21], the implementation of which requires appropriate hardware [22-23] and software [24-25]. Therefore, such intelligent data processing must be provided on CNC machines, for example, grinding machines with an intelligent control system [26-27].

5. CONCLUSIONS

1. It is shown that the linguistic meaning of information and information processes is one of the important aspects that must be taken into account when studying virtual reality and artificial intelligence. When studying the linguistic meaning of information, it is necessary to use the following terms, which can compose a minimum glossary on the issue under study: artificial intelligence (AI), virtual reality (VR), augmented reality (AR), present (noun), represent (verb), representation (noun), a priori – a posteriori, pre-empirical – post-empirical, pre-production – production – reproduction – post-production, quality control, measure (noun, verb) – measurement (noun) – metrology, modelling – simulation, information and its meaning, ontological information, virtual technology – physical technology, reversible (information, virtual) and irreversible (material, physical) processes, game theory – operations research, labor intensity (laboriousness) – cost, optimization (procedure), epistemology (theory of knowledge) – cognition, certainty and uncertainty in science, sustainable development, education – teaching – training, etc.

2. The virtual reality is secondary, based on previous knowledge and corresponds to category “representation”. Its development and improvement along the path of progress is possible only when receiving new information that arises from the physical technology of online product manufacturing. Consequently, an integrated manufacturing system, including CAD/CAM/CAE system can have progress and sustainable development provided the physical technology for the product manufacture are implementing as a matter of fact and there is a possibility to obtain and use for control the information being arisen.

3. A similar conclusion about the progress of development can be made in relation to the sustainable development of the modern system of higher education and to that part of it called distance learning. As a temporary measure for the period of a pandemic, distance learning is possible and even necessary, however, it is only possible to preserve existing knowledge, since the transfer of knowledge from teacher to student during distance learning is carried out only in virtual reality mode, i.e. corresponds to category “representation” (transmission of available information). However, information itself is not yet education. This is a necessary, but not a sufficient condition for successful training and acquisition of relevant competencies. At the same time, the use of augmented reality technologies in the design of educational materials is a profitable acquisition for distance learning.

4. The measurement information reliability characterizing physical reality (as opposed to virtual reality information) is determined by the measurement error, namely absolute and relative ones. This error consists of two components: systematic and random ones. The systematic component can be reduced by correcting the measurement data by calibrating the measurement system, i.e. when converting the measured parameters to their standard units of measurement.

5. The uncertainty of the information received based on the measurement (category of “presentation” unlike “representation”) is due to the absolute and relative measurement error. These errors can be estimated with the known law of the probability distribution of a random variable or on the basis of the Student's distribution law, which, in contrast to the Gaussian distribution law, takes into account a limited number of measurements n. With an increase in the number of direct measurements of the same type, performed under the same conditions and other things being equal, the absolute measurement error decreases in accordance with the change in the parameter $t/\sqrt{n}$, where t and n are the Student's criterion and the number of repeated measurements, respectively.

6. The use of virtual measuring devices (in contrast to the corresponding real devices) allows performing a large amount of processing of primary measuring information (information processing, signal conditioning): increasing the signal-to-noise ratio by filtering the measured data, amplifying the useful signal, performing mathematical transformations of these data, for example, spectral analysis, etc.

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ВІРТУАЛЬНА РЕАЛЬНІСТЬ І РЕАЛЬНІ ВИМІРЮВАННЯ В ФІЗИЧНИХ ТЕХНОЛОГІЯХ

АНОТАЦІЯ

Інформація передається сигналами, що мають матеріально-енергетичну природу, але це не матерія і не енергія. Інформація забезпечує комунікацію взаємодіючих об'єктів живої і неживої природи. Інформаційно-комутаційні технології лежать в основі нової парадигми виробництва, що отримала назву «Індустрія 4.0». У відповідності до цієї парадигми підвищена увага приділяється етапу підготовки виробництва, на якому приймаються відповідні комплексні рішення по автоматизації проектування і виробництва, починаючи від отримання замовлення на продукт і закінчуючи його відвантаженням споживачу. Одночасно вирішуються питання організації виробництва і ефективного управління виробничими і технологічними процесами, включаючи календарне планування та управління виробничими запасами. На підготовчому етапі створюється віртуальний продукт (інформаційна модель реального продукту у вигляді «віртуальної реальності»), а на виконавчому етапі з'являється реальний (фізичний) продукт, що має споживчу вартість (корисність володіння). Власне етап реалізації виробництва починається тільки після системного комп'ютерного моделювання, симуляції та оптимізації технологічного процесу і операцій, тобто після того як стане відомою трудомісткість і собівартість віртуальних технологічних процесів. У зв'язку з цим в даній статті розглянуті актуальні питання взаємодії віртуальної інформації на підготовчому етапі і нової інформації, яка виникає на етапі реалізації фізичних технологій, з точки зору підвищення ефективності комп'ютерно-інтегрованого виробництва. Показано, що інформація є базовою категорією не тільки в інформаційних (віртуальних) технологіях її перетворення і передачі, але і в фізичних технологіях матеріального виробництва на етапі виготовлення відповідного матеріального продукту, з одного боку, і (за аналогією) в процесах дистанційного навчання фахівців, з іншого боку (хоча інформація це ще не знання). Особливу увагу приділено вимірювальним процедурам і оцінці їх точності, які не є формальними і вимагають застосування інтелектуальної системи для забезпечення достовірності одержуваної інформації.

Ключові слова: віртуальна реальність; віртуальні технології; фізичні технології; обробка матеріалів; обробка інформації, інтелектуальна система; аналіз помилок вимірювання; віртуальні прилади

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