The use of artificial intelligence and information technology for measurements in mechanical engineering and in process automation systems in Industry 4.0

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Abstract. The article provides a critical review of the research topic under consideration in the context of the principles laid down in the concept of the fourth industrial revolution. Attention is paid to "value chains". Value chain is a new form of justifying the processes of product development, production and structuring of measurement operations. The formalization of a hybrid control measuring system of a new generation, combining the principles of integration of information security, information technologies and the mathematical apparatus of graph theory and set theory is given. The importance of artificial intelligence methods in the control, commissioning and operational monitoring of dynamic measurements in automation systems and mechanical engineering in the framework of Industry 4.0 is substantiated.

1. Rationale
The issue of conjugation of various technological bases of measurement and their control into a single centralized environment is associated with minimization of economic costs from large enterprises and determination of a visible connection with sources of errors.

Metrological systems in traditional automation systems of technological production do not reduce the system-forming role of the measurement process, assigning it the place of a verification confirming
conjunct. The superposition of measuring devices and instruments is not performed. In fact in most cases they act together.

Joint measurements are expressed through one aggregation system (a one-factor control system). One-factor metrology systems are considered to fulfill their role in defining both a sufficient and necessary threshold of operational benefit.

2. Review of the current problems of improving metrological indicators in systems based on the principles of optical, electrical, electromagnetic and complex nature

For example, in precision instrumentation, the multi-parameter and dynamic nature of the measurement environment reduces the usefulness of one-factor verification and control systems. A systematic approach to the design of digital means of metrological nature does not provide a dedicated and compositional role for parameters. Multichannel systems are subjected to input perception from a variety of random variables and physical parameters that affect the accuracy and measurement result, and the available noise suppressing tools remove the symptomatic nature of the stochastic environment.

In addition, systems that investigate and control the measurement process in systems with an acoustic character of manifestations, for example, those oriented towards the nature of oscillatory disturbances or a magnetic field, are coupled with not always predictable and adequately perceived feedback behaviour. The existing methods for improvement of the measurements and standardization quality are based on the accumulation experience as the only, or the simplest (priority) way of solving the problem. In addition, stigmatization of methods for increasing the accuracy and quality of measurements by increasing computing or hardware power (or its formal analogues) is not applicable in systems based on the principle of reflectometry [1].

![Figure 1](image1.png)

**Figure 1.** Differential and pulse pair technique based on two-stage subtraction in optical fiber reflectometry of an automated control system.

In such information systems or in optical devices (for example) used everywhere in heavy or light industry, implementing communication and switching protocols, it is important to determine not only the level of approximation of the operating optical signal, but also the attenuation depth. It is also
important to determine parameters that violate a certain logic behaviour or the level of admissible or
effective deviation from the real value. In addition, there are such complex parameters as pulse reflected
from a branch or ohmic reflection, Stokes or anti-Stokes light. The existing uncertainty in the
mathematical modelling of introduced systems is still determined by an insufficient degree of discretion,
both on the part of measuring devices and regulators, actuators, relays, and analogue sensors. A
comparative role in automated systems has the right to exist, but only under the conditions of the
declaration of complete control of the environment or, within the framework of a vacuum [2].

Such a method can more effectively detect faults, including any point in the measurement resolution
range, taking into account the Fast Fourier Transform (FFT). Its basic schematic diagram is shown in
figure 1.

In addition, such systems have forced oscillations generated by equipment that are difficult to track.
It is impossible to take into account all the specifics of the acting world in physical and biochemical
perception, when there is no single space of resolvable states defined in parametric and dynamic
diversity.

3. Changing of measurement principles in terms of the transition to designing of cyber-physical
systems

Thus, at this stage, it is implied that it is actually impossible to improve the accuracy of the metrological
apparatus in the current realities, which still combine a single space of analog and discrete quantities of
various nature and nature of manifestations.

To a large extent, this is determined by the inertia of the transition period, the impossibility of prompt
replacement of the economic sector and service culture (professional education) due to the rather slow
change of human generations. Metrology of digital measurements, on the contrary, is more ready for the
transition to a qualitatively new paradigm of this kind of interaction [3].

In view of the awareness of compatibility problems, further discretization of production and real
processes, in order to ensure industrial and national security, the paradigm of the fourth industrial
revolution (Industry 4.0) is being developed [4,5].

It includes pre-existing components that dynamically determine the digital transformation of the
economy and the final sampling. Its indispensable attributes are:

- The presence of a global telecommunication and industrial interaction environment
  (ControllerAreaNetwork, PROFINET, EIB, PROFIBUS FMS + Internet).
- Isochronism of measuring devices.
- Reduction of the economic and computational costs of processing data generated in the process
  of continuous production activities, simplification of the technical and economic feasibility of
  industrial automation systems and machine-building units.
- Cyber-physical approach to the design of all systems.

The last principle is the most significant in the considered problems of metrological support. Based
on figure 2, accounted groups of specifications or the so-called descriptors of the measuring environment
(1-5) can be seen. If earlier, the design of automated systems has been reduced to the system analysis
and expression of system specifications, and the choice of the architecture of the future device, then,
within the framework of Industry 4.0, the need for "StabilityChecking" was demonstrated in relation to
the design contour of the designed system, the mechanism for extracting parameters from the
architecture and system implementation at the system level, which determines the semantics of a
cybernetic experiment [6,7].
4. Value chains and application of discretionary delineation analysis in a measurement management system in a new paradigm of exclusively digital measurements

The switch to improvement of principles of systems functioning is not a revolutionary process, but an evolutionary one. It was necessary.

However, the discrete-multiple nature of the elaboration of components for cyber-physical systems of the industrial Internet of things does not allow the direct use of new tools in metrological support \[8,9,10\]. First of all, new components abut upon standardization. Secondly, the systems of the previous generations (that arranged differently) are still functioning. Fortunately, the evolutionary nature of measurements implies a fairly simple modernization of existing systems of complex automation, however, even there, it takes time to coordinate it with the communication system (see figure 3).

Figure 2. Graph diagram of the process of cyber-physical systems designing.

Figure 3. General model of a cyber-physical system, including a sensory (receptive) unit and an assessment and control device.
The simplest and most adequate way to simplify the elaboration of econometrics and the solution of the measurement problem of already fully deterministic discrete components of new generation systems, within Industry 4.0, is to create software or formal algorithms that generate "value chains" for the above components shown in figure 1 (including for "Technology Partitioning" and "Constraint analysis") [11].

Value chains in systems reduced to a discrete state are equivalents of graph-oriented descriptions of individual modules of data processing and storage systems. It is due to the fact that a digital system or its component is a parameter of a physical quantity. In SCADA systems, they are defined as objects of analysis (i.e. they act as units, aggregates). But how to solve the issue of the unity and supremacy of measurements with a declarative approach to the organization of systems and formalization of the finite nature of the measuring nature, carrying out a useful (from the metrological point of view) interaction in a cybernetic system?

This problem requires a systematic approach. It is proposed to consider a cyber-physical system as an informational two-layer neural network.

To ensure control of the uniformity of measurements, it is recommended to apply the formal Take-Grant model. Such a system is used when it is necessary to implement the principle of information security in document-oriented non-relational databases. From the diagram of the development process for the design of cyber-physical systems, the native embodiment of metrological support (reliance on specifications integrated into the essence of this type of systems) can be seen.

The Take-Grant model represents the entire system (in our case, system of a measurement control in a discrete technological process) as a directed graph, where the vertices are objects or subjects of metrological value. The arcs between them are labelled and their weights indicate the rights of the unit. The model is dominated by two rules: “take” and “grant” rules [12,13].

They play a special role in it, rewriting the rules that describe the permissible ways of changing the graph (see figure 4):

- O is a set of objects (files, memory segments, etc.);
- S is a set of subjects (users, system processes);
- R = \{r_1, r_2, r_3, \ldots, r_n\}
- U \{t, g\} is a set of access rights;
- t [take] is the right to take "access rights";
- g [grant] is the right to grant “access rights”;
- G = (S, O, E) is a final, labelled, directed graph without loops;
- \times - objects, elements of the set O;
- \bullet - subjects, elements of the set S;
- E \in O \times O \times R are graph arcs.

The described graph shows the introspection of the model of the control and assessment device providing joint or inconsistent measurement [14].

A graphological model with a finite (binary) number of orders (rights) allows the system to process multiple (multifactor) measurements. Delegation and disaggregation of multiparameter discrete functions in this case is possible through machine learning algorithms and artificial intelligence, for example, through the Bayesian algorithm or through the so-called decision trees. The Bayesian classifier is one of the simplest classification algorithms to implement. Nevertheless, very often it works no worse, or even better than more complex algorithms, since it is categorically simple in graphic (vector) data.
representations [15,16]. In the languages of control systems, the full cycle of the algorithm operation takes only a few tens of cycles [17].

5. Findings

Thus, the use of such a methodology for the indicated mathematical apparatus of application, based on the Take-Grant information security model during designing of work of operational control and accounting systems (with a minimum response time, achieved by the simplicity of the device of the above algorithms) for digital measurements will give a more accurate classification and actual ranking. At the end it will allow to form metrological and econometric expert systems in the industrial sector.

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