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MEASUREMENT, CONTROL AND OTHERS PROCESSES: TO THE PROBLEM OF KNOWLEDGE SYSTEMATIZATION

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Abstract – The paper considers measurement, event detection and control from a generic viewpoint of organizing purposeful processes to reveal their interrelation and specificity important for the construction of a knowledge system relevant to each process. Along with them, it also defines and examines a quantity transformation (conversion) process, which underlies both these and some other processes. From this viewpoint, it illustrates the way of structural level deduction of the methods of quantities transformation and of providing their invariance to influence factors.

Keywords measurement, quantity transformation, knowledge systematization

1. INTRODUCTION

The undoubtedly significant problem of knowledge systematization is becoming increasingly important. Among others, this is caused by accelerating augmentation of new knowledge with the increasing need in their quick digestion and application as well as in new knowledge acquisition. In view of new capabilities and tools of data and knowledge storage and processing provided by computer science and artificial intelligence development, their more exact organization and formalization are required.

The problems of knowledge systematization in Measurement and Instrumentation (M&I) area are paid much attention and discussed in a lot of vivid and interesting works, such as [1-3]. These works as well as the ones cited in them have laid the foundation for the systematization of the material accumulated and for singling out the M&I Science as an independent scientific discipline with its distinctive problems and features.

At the same time, the following issues should be also noted:

1. The singled out area of knowledge (e.g., M&I Science) and, in particular, its specificity in view of adjacent areas are determined insufficiently clear. It is not so evident when the goal of systematization is either teaching or writing a systematizing treatise where one strives for presenting everything essentially necessary for the activities in the area under consideration. And this was the most typical situation. The insufficiency becomes clear when we try to single out the basic tasks and their solution techniques *inherent in the specified area* or, moreover, when we attempt to construct a knowledge system or a predictive classification. This concerns not only M&I, but the adjacent areas of knowledge as well.
2. Only several concept levels in the field of M&I are studied: usually the top level, sometimes also some medium ones. The necessity of continuation is apparent: generic problems, methods, mechanisms and interrelations should be identified. In some cases, the parts already studied earlier are to be discussed, revised and connected.

Against this background, this paper now goes on to discuss the problem of knowledge systematization in the field of M&I, present and illustrate some methodical proposals and observations, which contribute to its solution, as well as inspire future discussion.

It seems natural that if we want to construct a knowledge system for some area, the relevant knowledge must be first clarified as well as the specificity of the objects under consideration and the problems to be solved. For doing this, the interesting area of knowledge is to be considered simultaneously with the adjacent fields from the same generic viewpoint.

We suppose that when in some field of activity the knowledge is organized already at the first stage – identification of its specificity – the activity itself should be primary, or rather the process, which expresses that activity, while the system implementing the process should be only secondary. The same system, such as a human individual or an automaton, can realize various processes. The essence of the process does not change with time in contrast to the functions of a technical device or system, which realizes the process: suffice it to remember the revolutionary augmentation of sensor functionality over the past few years. With reference to the field under consideration, it seems more desirable to construct the Measurement or Sensing Science rather than the Measuring Instrument or Sensor Science.

Thus, we start at the processes rather than systems.

As a generic position for simultaneous consideration “from above” of both measurement and “related” processes (such as control, monitoring, etc.) for establishing their distinctive differences and interrelations, we propose to consider them from the viewpoint of organizing purposeful processes (i.e. the chains of causally related events) with fundamentally different objectives.

2. SPECIFICITY AND INTERRELATION OF PROCESSES

First and foremost, we consider 3 “related” processes each one being both an area of broad activities and a recognized discipline: *measurement*, *control*, *checking*. By these terms we mean:

Measurement (*M*) is the process of experimental determining the value of a quantity X for mapping X as $X = N[x]$, where N is a number N and $[x]$ is an appropriate unit of measurement. Here it is essential to ensure the traceability and desired measurement accuracy.

Control (*C*) – is the process of affecting the object with specially organized actions with the purpose of attaining its desired operation. We consider using not only a priori, but a posteriori information as well to be critically important for control.

Checking (monitoring, testing) is the process of establishing a correspondence between some state of the object and its prescribed description; the result could be “correspond” (1) or “does not correspond” (0). In other words, this process reveals one of two alternative events (the situation S either takes place or does not); therefore we will call this process rather **Event Detection** (*D*) than Checking and the like.

Along with the processes *M*, *C* and *D* we would also consider a process, which is “relative” to all 3 of them – Transformation (conversion, mapping) of quantities. In our opinion, this process is worth being singled out into a dedicated area of knowledge. We define this process as follows:

Transformation (*T*) of quantities is a process of physical realization of the desired functional dependence between the quantities x and y, i.e. $y = f(x)$. Quantities, i.e. any measurable or estimated object attributes, are characterized not only by their intensities but by time and space variables as well. Thus, the notion *T* comprises the simplest functional transformation of a quantity, signal conversion and multi-parameter field conversions.

We will further consider each of the processes *M*, *C*, *D*, *T* as a purposeful totality of causally tied events and speak about process objective, ways of implementation and implementation quality.

Thus, in measurements, the availability (appearance) of the quantity X is a primary (input) event, while the output event – the appearance of the quantity $y = N[x]$ – should be a consequence, i.e. the event transformation $E_X \rightarrow E_{N[x]}$ takes place, which characterizes the measurement goal. The way of measuring is characterized with a detailed sequence of this transformations. The measurement process can be considered as a specific case of the process *T*: $E_x \rightarrow \mathrm{E}_{y=f(x)}$, where $y = N[x]$.

The control objective consists in providing the desirable object operation, i.e. in the realization of the desirable causal relationship between the events determined by object’s input and output states (object operation algorithm $E_{\mathrm{in}i} \rightarrow E_{\mathrm{out}i}$, $i = 1, \ldots, n$). This can be accomplished with the help of another set of cause-effect relations – the control algorithm $E_{Dj} \rightarrow E_{Aj}$, $j = 1, \ldots, m$ implemented by the controller. Here, $E_{D\,j}$ is the event under control, E_{Aj} is the control action. The process of $E_{D\,j}$ detection is an integral part of the control process, as it was already shown in [4]. It should be noted here that in case that the event under control E_{Dj} is the appearance of the quantity (or variable) X from a continuous set $\{X\}$ and the corresponding action E_{Aj} is the establishing of $y = f(x)$, then the control algorithm implementation is reduced to the realization of the dependence $y = f(x)$, i.e. of the *T*-process. This is a threshold case, which relates to the proceeding from discrete to continuous.

Each of the processes *M*, *C*, *D*, *T* can be either simple or rather sophisticated. Thus, one has to detect the presence of the state $X > X_0$, or the state of spaceship readiness for the flight, to measure the D.C. or the parameters of a time-dependent distributed complex value (in impedance tomography). But significant distinctive features of the processes and their fundamental interrelations are the same both for the simplest (nondegenerate) cases and for more complex ones. Therefore, they can be studied already in the simplest cases. Here, process interrelations turn out to be much deeper and closer than it was traditionally anticipated (sometimes, it seemed sufficient only to note that the measurement could be necessary for control, monitoring or scientific research).

Thus, even the analysis of the simplest cases evidences that measurement is absolutely impossible without detecting the simplest event: some value is more/less than the other one. The same cases show that measurement should always include control actions. For realizing measurement process with simultaneous comparisons with the quantities whose values are known, the control is reduced to activating the numerical value of some known quantity, which is the closest to the measurand. In the measurements with successive comparisons, the control process also includes varying the values of a known quantity until the event is detected, $\Delta x = X - N_i[x] \leq \varepsilon$. Control theory offers for that various techniques differing action orientation, the nature of information employed for implementing their various elements, etc. [5]. The selection of a specific “control solutions” affects the features of measurement process as a whole, its potentialities and implementation difficulties; control theory provides appropriate knowledge. It may seem that one could do without such knowledge, at least in the simplest cases we face more often. If we wish to build a knowledge system or a theory of a process under consideration, such disregard becomes inadmissible from both viewpoints: completeness provision , i.e. considering all variants, and integrity, i.e. considering both the simplest and more complex cases.

One more vast block of knowledge relevant to the process *T* is incorporated into the knowledge of the measurement process, because the available quantity with the known value can differ by its physical nature, scale, etc. from the measurand (indirect measurements), and an auxiliary transformation of the quantities is required; passive quantity measurement is an example. In the cases where the measurands are determined by sensing and measuring other quantities, a functional transformation of several quantities in analog or digital form is required (and there are the calculations!).

Since the relations between the intensities of quantities, their dynamic behavior and spatial distribution most often serve as event features, the process *T* is one of the baselines of the process *D*. If the event symptoms are specified in the digital form, then the process *D* should be preceded by the process *M*. The measurement process is used more and more as a component of *T*, *C*, *D* and many other processes, in view of the increasing application of digital processing and data communication techniques. Still, in some cases such as analog-to-analog signal conversion with the help of internal digital signal processing (in analog signal processors), one can apply an "internal" unit of measurement in ADC and DAC, and, therefore, it would be better to speak here about A/D transform rather than about measurement.

It should be noted that the events detected can be characterized by the attributes, which are not quantities, e.g. pattern detection or recognition might be necessary.

Considering various processes from unified viewpoint for revealing their specificity and interrelation gives much interesting for interpreting the material accumulated and reorganizing it into a knowledge system for establishing the ways for new knowledge search and for education. Some of these issues are noted below.

As a rule, when any of *M*, *C*, *D*, or *T* processes is considered, one can see other processes of these four as its parts. In fact, the *T* process is a part of the 3 others. In its turn, the *C* process and, more and more often, the *M* process are used in many variants of *T*. In addition to *T*, the *M* process always includes *D* and *C*, while *C* includes *D* and, more and more often, *M*. Consequently, the manifold compatibility of the above processes must be ensured for combining them into a single process with the desired features, including the compatibility of knowledge bases for each process. The latter means that the corresponding knowledge should conform subject to basic concepts, terminology, criteria and methods of quality evaluation, etc.

Incidentally, the importance of fitting the appropriate educational courses should be noted. This would decrease the existing gaps and overlaps in the educational programs. It seems rational to forestall the knowledge statement of any of the aforementioned or adjacent processes, such as diagnosis, communication, identification, etc., with a concise overview of all processes from a uniform viewpoint for demonstrating the distinctive features of each one as well as the interrelations between the processes.

The undertaken simultaneous analysis of *M*, *C*, *D*, *T* processes not only brings to light their interrelations, it also emphasizes the specificity of each one that determines the systematization logic of the knowledge accumulated and reveals the blank spots.

Thus, it is clear that the systematization of knowledge connected with the process *D* lags far behind the same for the processes *C* and *M*. The knowledge related to *D* are neither concentrated nor consistent. It should be extracted from different areas, such as monitoring, supervision, diagnosis, testing, measurement, pattern recognition, etc. Here one must both classify the events detected and establish the detection techniques.

As to the process *T* – quantity transformation (just quantity, i.e. quantitative attributes of objects, in the way they are understood in measurement science, rather than information transformation, etc.), a proposal to distinguish the related knowledge seems to be first made only in this work, though such opportunity was implied by default also in other works, including the author's ones. Among many problems, which arise while studying the *T* process at different levels, such as mathematical modeling, physical, technological, application, we would consider here only one: the problem of establishing and systematizing the ways of attaining the *T* process objective.

3. THE WAYS TO REALIZE THE OBJECTIVE OF QUANTITIES TRANSFORMATION PROCESS

Considering the process *T* without taking into account the specific physical nature of the quantities involved (we call it the structural level), we will draw up a way of deductive construction of the system of initial knowledge related to the process *T*. Here we will again consider this process from a generic viewpoint of purposeful process organization, taking account of the revealed role of control as a process of providing the desirable operation by means of the actions based on a posteriori information.

In order to attain the objective of the process *T* the following 2 interrelated problems should be solved:

(1) connect the quantities x and y with the desirable functional dependence;

(2) remove (ideally) the effect of undesirable factors from this dependence, i.e. ensure the invariance to these factors.

The ways of solving these problems can be derived from the knowledge of some generic regularities and using the rules of logical reasoning.

The first problem is treated as establishing causal relationship between the event E_x (appearance of some x from the set $\{x\}$) and the event E_y (appearance of corresponding y from the set $\{y\}$). There are 2 alternatives for this as well as for solving other problems:

(I) - make use of the dependence $y = f(x)$ already in existence (direct transformation), or

(II) - realize this dependence artificially, by external actions on the quantities involved. i.e. by control (transformation with control).

In case I, one would select an effect where the desirable connection of events $E_x \rightarrow E_{y=f(x)}$, takes place and, what is not less important, ensures the conditions necessary for the appearance of the cause and for the action of causal relationship.

In order to realize case II, one would address to the known regularities of control process. The control actions can be realized either based on the deviation from the desirable dependency (variant II-b – a feedback control) or based on the information about the deviation cause – input variable change, provided there is an unambiguous relationship between the effect and the cause (Variant II-a – a feedforward control). Variant II-a in the case considered can be reduced to realizing a direct transformation $y = f(x)$. And for getting a posteriori information about the deviation (at least the minimum information about presence/absence) in case of II-b, it is necessary to implement physically either the desirable output quantity with the help of a reference direct converter, which implements *f*, under the common input quantity, or the desirable input quantity with the help of a reference inverter, which implements f^{-1}, under the common output quantity.

Based on the results of the input/output quantity comparison with the reproduced one (Δ) the actions on the output quantity are organized with the purpose of reducing the deviation Δ. This is shown with dashed lines in the graphs of Figure 1a,b, which show the revealed opportunities of transforming active quantities with feedback control (transformation with balancing). Among the 2 variants obtained, only one shown in Figure 1b can be considered as fundamentally new: a transformation of x to $y = f(x)$ using an inverse transformation of y to $x = f^{-1}(y)$. The variant depicted in Figure 1a can be considered as a combination of a direct transformation with a special case of the transformation shown in the Figure 1b for $f^{-1} = 1$.

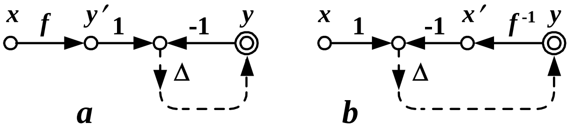

Fig. 1. Structures of active-to-active quantity transformation with balancing:
a using direct transformation $x \to y$
b using direct transformation $y \to x$

The transformation of an active quantity into a passive one can also be either direct or with balancing. In the first case, one would match a material object with the desirable relationship between its material characteristic – passive output quantity – and the active quantity to be transformed. This underlies all parametric sensors.

The structures of an active quantity transformation to a passive one with balancing can be derived from the structures shown in Figures 1*a* and 1*b* by introducing a unit with adjustable transfer *p* (passive quantity *p*), upon which one of the comparable active quantities should depend. Here, the position of this unit relative to the comparator, and to the reference converter, when they both are located on the same side of the comparator, can serve as the diversity sources. The structures obtained are shown in Figure 2. For the structures shown in Figures 2 *b*, *d* and *f*, the availability of a unit realizing either *f* or f^{-1} is non-critical, because it determines here only the conversion constant and can be neglected.

For a direct transformation of a passive quantity into an active one, an energy interrogatinon impact on the object is necessary that would cause a response – an active quantity, which depends upon the passive one to be transformed and, unfortunately, on the active interrogatinon quantity. The opportunities of transforming a passive value into an active or a passive one using balancing, which can be revealed by similar reasoning, would be omitted for short.

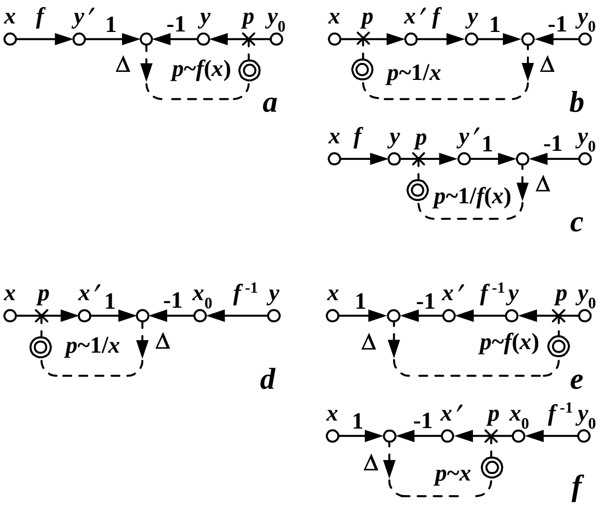

Fig. 2. Structures of active (x) to pasive (p) quantity transformation with balancing derived from the structures shown in Fig. 1*a* (structures 2 *a*, *b*, *c*) and in Fig. 1*b* (structures 2 *d*, *e* and *f*).

The following should be noted here. Each one of the qualitatively different transformation structures derived has its own intrinsic capabilities and attributes, which can be listed and accounted in advance. But the transformation structure is not a complete characteristic of the transformation process – it is very important how the process of deviation reduction is organized. Possible diversity sources can be also derived from some general regularities and logical reasoning. For organizing the process under consideration, the origin of the information applied (a priori, a posteriori), its content (presence/absence of deviation, its sign, value, dependence on control action, time, etc.), and application goal (for selecting action direction, its value, initial and terminal times, etc.) are of primary importance. It would be rational to base the classification of the ways of establishing the desirable relationship (the ways of balancing) on these indicators, as it was done in [4]. As the result, fundamentally different techniques can be distinguished with the preset features and attributes, which provide an integral characteristic of the transformation techniques, in which they are applied.

Similar approach can be applied for determining the ways of solving the problem (2) – ensuring the invariance. The original model presumes that besides the desirable causal relationship *f* between x and $y = f(x)$, an undesirable dependence of x, y and *f* of some disturbing influences – internal and external influence factors – also takes place. In order to exclude the undesirable influences either of the following 2 opportunities can be applied: (a) to exclude the cause, or (b) to exclude the consequence; in case (b) additional compensating actions, i.e. controls, should be organized.

Excluding the cause means the elimination of either the effect or its relations with x, y, or *f* by means of filtering. At the structural level, one can consider here different ways of statistical reduction and averaging, at the physical one – a wide rage of technologies.

The variants of realizing the second opportunity are the variants of control implementation, which differ, first of all, by the source of a posteriori information: the deviation cause, i.e. the disturbing inffluence, or its consequence – the deviation from the desirable condition. The information about the deviation can be obtained either by reproducing the desirable input or output quantity with the help of a reference inverter or converter or by determining actual relationships between the quantities, i.e. by parametric identification; this latter case includes all known reference signal and test methods. The information about the deviation can be used either for introducing an additive or multiplicative correction, or for self-tuning performed by any of the aforementioned ways of balancing.

We have established the sources of the transformation's structural diversity (by no means all of them) only for the simplest case – the transformation of scalar quantity, which does not change in space or time. Some more problems and, hence, possible ways of their solving arise in case of multi-dimensional quantity transformation: two-dimensional (e.g., impedances), three-dimensional (e.g., velocities in space), nine-dimensional (e.g., stress tensors) and others (such as multi-element one-ports). The examples of the most obvious tasks are the transformation of a multi-dimensional quantity into a set of scalars and its inverse transformation, or multi-dimensional quantity balancing.

Specific cases of multi-dimensional quantity transformation are both the transformation of a time-dependent scalar quantity, which is well-known and included into educational courses, and the transformation of spatially distributed variable, which is usually considered only in professional literature.

The knowledge related to solving the problem of quantities transformation on structural level (regardless of either the physical nature of the quantities involved or the technological implementation) should be supplemented with the methods of quality evaluation and of the synthesis of transformation structure, which meet various standard requirements, the methods of equivalent transformation of structures and of revealing the structures, which are theoretically feasible within the scope of some statement of a problem, complete structural theories of specific transformation types, etc. The components of these knowledge are present in many works. The structural regularities of quantities transformation are being investigated for many years in the Institute of Control Sciences, Moscow (see, e.g., [6-11]).

We did not mean to present here a draft of a possible structural quantities transformation theory, nor to characterize the results obtained and the research undertaken. We would only focus on the fact that even when considering the transformation process at the generic, structural level, a vast amount of related knowledge exist that can be organized "from above" on the basis of the known general regularities and presented as a logical, intelligible system.

While considering the quantity transformation process, we assumed that the quantities involved could be analog, discrete, or digital. In the latter case, new diversity sources appear, e.g., connected with digitizing. All knowledge relevant to the process *T* are also relevant to the process *M*, with the sole difference that one of the 2 quantities compared in *M* process must have a known value. This refers also to the knowledge at the structural level, as well as to the knowledge concerning the organization of the transformation of quantities in view of their physical nature (not considered here).

The concentration of all knowledge of the organization of the *T* process in a single, independent area would not make measurement science scanty. First, the vast amount of knowledge of measurement technologies, traceability and accuracy issues, i.e., everything that refers to classical metrology, will remain. Second, the knowledge of *T* process, extracted and logically organized in view of the knowledge of other adjacent processes, will be a part of measurement and, moreover, M&I knowledge as one of its fundamentals. But, at the same time, this knowledge will be one of the basic parts of the knowledge of *C*, *D*, communication and other processes.

4. CONCLUSIONS

Simultaneous study of measurement, control and events detection, as well as quantities transformation process isolated and defined here, from the generic position of organizing purposeful processes reveals their principal tight interrelation yet on the simplest implementations. This needs to be taken into account under construction of the knowledge system relevant to each of these processes. The appropriate knowledge blocks must be consistent (subject to basic concepts, terminology, quality evaluation criteria and methods etc.) for their possible combined application in solving various problems.

The technique of finding the ways to attain the objective of the process under consideration on the basis of the knowledge of general regularities as well as the principles of realizing other processes considered, was presented and illustrated with the example of quantity transformation.

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