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REVEAL AND SYSTEMATIZATION OF QUANTITIES TRANSFORMATION METHODS

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Abstract − The paper presents a procedure enabling to reveal and systematize the techniques of purposeful process realization by classifying verbally described concept reflecting this process per general/particular principle. The focus is made on "generic" methods revelation mechanism. The procedure is exemplified in the revealing general methods of quantities transformation: the process underlying many other processes including measurement, inspection, and control. The picture of the upper classification levels of general transformation methods is drawn up and can be further developed with reference to specific types of this process as well as to other relevant processes.

Keywords: quantities transformation**,** methods, revelation, classification.

1. INTRODUCTION

In view of the growing amount of knowledge the need in its systematization is becoming increasingly important. The development of visible and logically clear conceptual systems for interrelated knowledge (knowledge systems) and, especially, for the knowledge about the general concepts and problem solution techniques is extremely important for knowledge acceptance, usage, and generation. In [1-3], the author developed the so-called interdisciplinary approach to the revelation and systematization of knowledge in the field under investigation and in particular, in Measurement and Instrumentation area. The approach is based on revealing and applying generic mechanisms at the higher level of consideration comprising various purposeful processes.

The approach was first used in [1], and more systematically in [3] for revealing the interrelation of measurement (M), event detection (D), control (C), and other processes, and clarifying their specificity and inherent problems. Reference [1] also mentioned the expediency of distinguishing and organizing the knowledge related with quantities transformation (QT) process, which is fundamental for purposeful processes. QT is an integral and important part of information technologies such as C, D, and M. It is always resorted to when for certain reasons, it is more convenient to deal with some quantity y, which describes sufficiently the quantity x, rather than with x. By the process of quantity x transformation into quantity y we mean the process of physical realization of y's single-valued causal dependence on x according to desirable relationship $y=f(x)$. Generalizing, one could also speak about establishing a family of functional relationships between the sets of input and output quantities, but, for simplicity, we will further consider the case with 2 variables only. Sensors and actuators give examples of QT implementation tools. The application of interdisciplinary approach in [2, 3] outlined the way to solve the 2 key QT problems: (1) realization of causal relationship between quantities, and (2) decreasing its dependency on undesirable factors. This way presumes the revelation (derivation) of desirable solution techniques from some known generic principles and laws using deductive, logically clear procedure. However, the mechanism for revealing these generic principles has not yet been defined.

Against this background, the paper intends to clarify this problem and, in particular:

- present and illustrate the procedure of revealing and systematizing the methods for implementing purposeful process by building a classification reflecting both the content of those methods and their origin and interrelations;
- draw up a picture of upper classification levels of general quantity transformation (QT) methods that could be further detailed and developed with reference to both specific types of this process and other relevant processes.

2. METHODOLOGY

The desirable "rational" picture of revealed and systematized techniques can be drawn using a hierarchical classification of the specific concept with respect to general/ particular principle; the classification should follow some recommendation.

Naturally, the concept should be, first of all, defined adequately, i.e. specified using a set of attributes necessary and sufficient for its identification against other relevant concepts.

To build logically justified and representative classification, the choice of reasons for (i) determining the set and sequence of examination aspects (classification attributes) and (ii) generating possible variants of solutions, is critically important.

The key issue here could be the sequential analysis of qualitatively different generalizations and instantiations (divisions) of the classified concept obtained at various levels of its examination. A family of nested sets corresponds to these generalized and concretized concepts.

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The set related to the classified concept is located in the central region (see Fig. 1). It is encompassed with the sets derived by its generalizations at various levels, i.e., higher-level (generic) concepts, while it contains a set of nested instantiations (lower-level or specific concepts). With such configuration, the rules and laws (such as realization techniques with their merits and drawbacks) revealed while considering an upper-level concept would refer also to a lower-level one, certainly subject to its specific features.

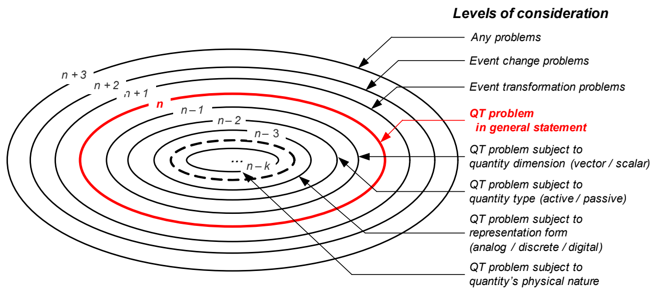

Fig.1. A family of sets obtained by generalization and specification of "QT" concept

As far as we discuss here the revelation and systematization of general QT techniques, we choose the general definition of the classified notion (given above) as a base level (level n). Its attributes are as follows: (i) the availability of 2 quantities of any type, representation, and physical nature, (ii) single-valued causal relationship between them, (iii) the desirable form of the relationship, and (iv) physical realization of the relationship. The initial concept (notion) N_{12} is the relation between the concepts N_1 and N_2 per se, i.e. N_{12} is $N_1 \rightarrow N_2$ (the arrow denotes the above mentioned causal relationship); therefore the generalization/specification of this concept can happen due to the generalization/specification of either N_1 and N_2 or their relationship.

3. REVEALING "GENERIC" SOLUTIONS

To reveal "generic" QT techniques, we begin with sequential generalization of "QT" concept and then go on with revealing and analyzing the methods of these generalized concepts implementation starting at the upper levels.

By considering the availability of a quantity of a certain value at a certain place as an event, i.e., generalizing now the concepts N_1 and N_2 only rather than their relationship $\rightarrow$, we switch to the higher, n+1 level of consideration of the concept: the level of event transformation $E_{in} \rightarrow E_{out}$. (By "event" we, generally, understand anything that may happen or not happen.) Here, E_{in} and E_{out} are the incoming and outgoing events respectively, linked with a single-valued causal relationship meaning that E_{out} will show if and only if E_{in} took place. This is actually the level of automated processes. The next level of consideration, n+2 (see Fig.1), can be attained by generalizing the relationship between N_1 and N_2, i.e., the concept of "$\rightarrow$". This level typical for any target-oriented activity may be called "event change level". Here, the relationship between events may remain still causal though less "strictly" defined as at the levels n and n+1; for example, it may be ambiguous, stochastic, and fuzzy or not mean any *automatic* event change at all. E_{out} could be, say, a consequence of various incoming events E_1, …, E_k; such relationship is typical for the problem of establishing the desirable state.

The higher generalization level for event change problem is the level of solving any problems: n+3. By problem solving we mean finding a set of actions needed for the transfer from the initial event reflecting the basic data to the final event (purpose, the result of problem solving). Higher levels not shown on Fig. 1 comprise any purposeful activities, logical and philosophical regularities.

We do not attempt here to define the upper levels precisely or entitle them adequately; we would rather just certify the existence of such levels and elucidate the procedure of revealing their inherent regularities and their use for revealing the methods of problem solving at lower levels.

Thus, by applying the duality principle at the level n+3, we assert that a problem can be solved: (i) directly or indirectly, (ii) as a whole or by parts, (iii) based on a priori information only or using also a posteriori (experimental) data, (iv) controlling with respect to (w.r.t.) initial or final event.

Direct solving presumes finding immediate solution to the problem, while the indirect solving means switching to another problem whose solution due to causal relationship results in solving the original one. With reference to the level of event transformation, this means either direct solving of $E_1 \rightarrow E_2$ problem, or its indirect solving, by building (an) other event transformation(s) $E_3 \rightarrow E_4$ stipulating the desirable transformation $E_1 \rightarrow E_2$.

Solving the problem as a whole means solving it in view of all problem statement conditions, while solving it in parts means the original problem decomposition into a set of sub-problems and their further solving in series. Here, the problem itself may be split as well as its environment or performance requirements. For example, the concept of problem solving with environment decomposition results in adaptive system design concepts, while the decomposition with respect to performance criterion entails the bitwise balancing principle.

Solving a problem based on a priori information only presumes that all actions required to solve the problem are known in advance, and no experimental (a posteriori) data describing the current state of process participants (object, subject, environment) are needed. An alternative way presumes the use of a posteriori information too. The concept and term "control" is typically related with this alternative way. In this context, it makes sense to discuss problem solving *without* or *with control*.

Dependent on a priori knowledge employed, we can discern at level (n+3) 2 significantly different ways of controlled problem solving: with control w.r.t. initial event and with control w.r.t. final event. Control w.r.t. initial event presumes that the actions resulting in problem solution are determined by specifying the initial event, and if they are accomplished then there is no need to verify the solution.

But if such purposeful actions are unknown, the problem can be solved using trial and error technique by performing an ordered search of actions from a given set until the existence of the desirable solution is detected with the help of a posteriori information. This way of problem solving is called *control w.r.t. final event*.

Now we specify some n+3 level methods for solving any problems with regard to event transformation problem at level n+1 subject to the problem's specificity.

As it was mentioned above, the event transformation

$$E_{in\,i} \rightarrow E_{out\,i} \quad (i = 1, \ldots, k) \qquad (1)$$

presumes rigid causal relationship of events meaning that $E_{out\,i}$ will certainly appear in the presence of $E_{in\,i}$ and only then. As far as $E_{out\,i}$ should happen after (as a result of) the appearance of $E_{in\,i}$, this means that before organizing the event $E_{out\,i}$ one should establish experimentally the fact of $E_{in\,i}$ availability, i.e., detect $E_{in\,i}$. The fact of $E_{in\,i}$ detection will be further denoted as $E_{d\,i}$. The event $E_{d\,i}$ should become a cause of impact on the object (event $E_{a\,i}$). Therefore, the realization of the desirable functioning (1) means that a series of causally related events like

$$E_{in\,i} \rightarrow E_{d\,i} \rightarrow E_{a\,i} \rightarrow E_{out\,i} \qquad (2)$$

will take place that complies with problem solving technique using control w.r.t. initial event revealed at level (n+3). If the actions needed to transfer from $E_{d\,i}$ to $E_{out\,i}$ are not determined in advance, then an opportunity remains to implement the transformation (1) using *control w.r.t. final event*, as described above. Here, after $E_{d\,i}$ is detected, the search of possible $E_{a\,i}$ and the related outgoing events is executed up to the detection of $E_{out\,i}$ corresponding to the earlier detected incoming event $E_{in\,i}$.

Two more methods for solving event transformation problem (1) ensue from the opportunity of its indirect solving after its restatement and reduction to the problem of minimizing the deviation from the desirable functioning:

$$E_{\Delta\,i} \rightarrow \sim E_{\Delta\,i}, \qquad (3)$$

where $E_{\Delta\,i}$ is an event meaning the deviations from the desirable functioning (1), while $\sim E_{\Delta\,i}$ (the negation of $E_{\Delta\,i}$) is the event correspondent to the lack of such deviation. The problem (3) describing the automatic elimination of deviation from the desirable functioning is a problem of event transformation requiring first of all the detection of an incoming event $E_{\Delta\,i} \rightarrow E_{d\Delta\,i}$, and then the continuation of the realization of a sequence of causally related events like (2) with control w.r.t. either initial or final event. In all 4 methods, the information about either these events or about some determinant (stipulating) events (under some single-valued causal relationship) may become the a posteriori information needed for detecting the incoming events $E_{in\,i}$ or $E_{\Delta\,i}$. In the control per the deviation from desirable functioning, such information may be the known perturbation determining unambiguously the corresponding deviation; feed forward control is based on this concept.

It should be emphasized that along with the considered event transformation methods requiring a posteriori information, a transformation method using a priori information only does exist according to the opportunities revealed at the level of any problems solving (n+3). It lies in a priori knowledge-based realization of existence conditions for the desirable rigid causal relationship between events (1). This method is called "natural" and is very important for QT examined at the level n.

The classification attributes and solutions revealed at the upper levels are listed on Fig. 2. Their transfer down to the classified concept "QT" level n in view of its distinctive features allows reflecting the variety of possible generic QT solutions in the classification picture of general QT methods.

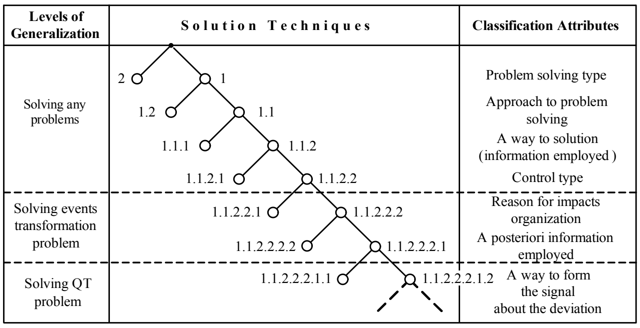

Fig.2. Building a classification of QT methods

1 – direct solving; 2 – indirect solving; 1.1 – solving the whole problem; 1.2 – solving the problem by parts; 1.1.1 – a priori information only; 1.1.2 – a posteriori information also; 1.1.2.1 - with respect to initial event; 1.1.2.2 - with respect to final event; 1.1.2.2.1 – transformed event; 1.1.2.2.2– deviation from the desirable operation; 1.1.2.2.2.2 – on the perturbance; 1.1.2.2.2.1 – on the deviation; 1.1.2.2.2.1.1 – using direct reference converter; 1.1.2.2.2.1.2 – using inverse reference converter

4. CHARACTERIZATION OF THE CLASSIFICATION PICTURE OF GENERAL QT METHODS

The event class considered at the level n is formed by the *quantities*, i.e., the properties showing not only in equivalence relationship but in ordering relationship as well, and even more often also in additivity relationship. Therefore, it makes sense here to use such attributes as "more – less", "worse – better", attributes specified by numerical characteristics, etc. A posteriori information about the deviation sign and/or size or about impact's effectiveness can be easily obtained. At the level n, also the content of the relationship between event types under consideration is rich. Here is not just a rigid causal connection but also a definite functional relationship between the outgoing (the magnitude of y) and the incoming (the magnitude of x) events. All this is taken into account when extending the solutions revealed at higher levels of QT concept generalization down to the level n to establish the upper layers of the classification of general QT methods, which reflect the "generic" QT techniques. Subsequent classification levels form attribute realization methods showing at the level n owing to the above mentioned features and opportunities, i.e., "specific" solutions.

4.1. Some examples of "generic" QT methods realization

Some simple examples of "generic" solutions realization at the level n of QT concept consideration are as follows. The direct solution (Solution 1, see Fig. 2) means here direct implementation of $y=f(x)$ relationship. Indirect solution (Solution 2 on Fig. 2) means the implementation of other relationships from which $y=f(x)$ ensues as a consequence, for example $z=f_1(x)$ and $y=f_2(z)$, subject to $f_1 f_2 = f$.

An approach to solving QT problem by parts with its decomposition enables, in particular, its solution as follows. At the beginning, its first necessary attribute is realized that is the establishment of the causal relationship between the quantities without or partially taking into account the requirements to the desirable functional relationship $y=f(x)$. Then, a new problem is solved that is the transformation of the solution obtained at the previous step in view of the requirements of the desirable function f. This problem (its special case is the problem of synthesizing the systems invariant to the influencing factors) has been being successfully solved at the Institute of Control Sciences of the Russian Academy mainly by V.A. Skomorokhov based on his methodology (see, e.g., [4, 5]).

The "natural" way (see Solution 1.1.1 on Fig. 2) presumes the use of the desirable causal relationship $y=f(x)$ already existing under certain conditions and re-establish these conditions, i.e., the conditions of cause appearance and causal relationship availability, that basically require a priori information only. Such QT implementation called "direct transformation" is shown with an oriented graph on Fig. 3*a*. Here and farther on, graph junctions represent active quantities, the ribs of graph reflect the connections between them; output quantities are denoted by double circle.

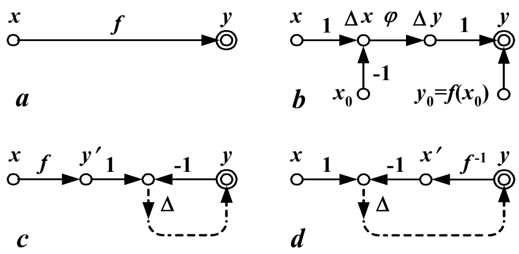

Fig. 3. Structures of quantity transformation $y=f(x)$:
a – direct transformation; *b* – transformation with feed forward; *c* – transformation with balancing and a reference converter $x\rightarrow y$; *d* – transformation with balancing and a reference inverter $y\rightarrow x$

Through control w.r.t. incoming event (Solution 1.1.2.1 on Fig. 2), QT is implemented, e.g., analog processor where each incoming event that is the appearance of an input quantity x with specific magnitude is detected. Using the measured value, the corresponding digital value y is calculated and further converted into output analog quantity of appropriate magnitude.

QT implementation with control w.r.t. final event (Solution 1.1.2.2) is exemplified in the popular technique of DC voltage transformation into a time interval by comparing with the voltage changing with time till the equality of voltages is detected.

Fig. 3*b* shows the structure of $y=f(x)$ QT with control w.r.t. initial event, which is the deviation from the established relationship for the case where the information about the perturbance is employed. The value y_0 at some initial x_0 is known a priori. The cause of y deviation from the desirable relationship $y=f(x)$ at any other x is the deviation $\Delta x=x-x_0$. Therefore, to obtain the appropriate y, one must organize an action $\Delta y=\varphi(\Delta x)$ based on a posteriori information about Δx resulting in the provision of $y=y_0+\Delta y= f(x_0)+\varphi(\Delta x)=f(x)$.

Now, we'll make some steps towards revealing "specific" solutions.

4.2. Revealing "specific" QT methods

To establish the desirable causal relationship by means of feedback control, one should create a signal informing about the deviation of quantities, which determine such relationship. In the general case, one must have a model representing physically the desirable values of these quantities, and determine a posteriori their actual values, i.e. execute the process of parametric identification. Thus, the attributes related with modeling and identification features, will appear among "specific" classification attributes.

In the simplest case of establishing the causal relationship $y=f(x)$ of 2 scalar quantities x and y their actual values are known, it's necessary to model their desirable values. According to the duality principle, one can represent physically either the desirable output quantity with the help of a reference converter implementing the function f under a common input quantity, or the desirable input quantity with the help of a reference inverter implementing the function f^{-1} under a common output quantity (single-valued reciprocal transformation is assumed). The result (Δ) of input or output quantity comparison with the correspondent reproduced one is used for affecting the output quantity with the purpose to eliminate the deviation. This is reflected with dotted lines on Figs. 3*c*, *d* that present the revealed opportunities of active quantity conversion into an active quantity with feedback control (the so-called conversion with balancing).

Among the 4 revealed methods for establishing functional relationship between active quantities x and y represented by the structures shown on Fig. 3, the first 3 presume the availability of the $x\rightarrow y$ converter. But their functions are different: in Fig. 3*a* structure, it is both informational and energetic; in Fig. 3*c* structure, it is purely informational; on Fig. 3*b* it is informational and partial energetic. Fig. 3*d* demonstrates the opportunity of direct $x\rightarrow y$ conversion based on $y\rightarrow x$ inversion. I should be noted that this opportunity is derived here rather than just declared. The variant shown on Fig. 3c can be considered as a combination of direct conversion with a special case of Fig. 3*d* conversion when $f^{-1}=1$.

Each of the revealed methods has its intrinsic opportunities and properties that can be listed and accounted in advance. But to characterize the conversion with balancing, it is significant how its integral part – the deviation elimination process shown by dotted line on Fig. 3*c*, *d* – is organized.

The deviation elimination problem (see (3)) was mentioned when revealing the event transformation methods at the level $n+1$. A wide variety of solution techniques are available at QT level (n). This variety is determined by qualitatively different characteristics of both the information about deviations and the organized impacts. Respectively, deviation elimination techniques (the so-called balancing methods) with qualitatively different characteristics of the employed information and the organized impacts should be a starting point for further design of specific QT classification levels.

Such characteristics can be as follows: the source of information employed (a priori/a posteriori), its subject (deviation or deviation change as function of control impact, time, etc.), its depth (information about the existence/absence of deviation, its sign, magnitude, etc.), purpose of use (for choosing impact direction, its magnitude, start and end times, etc.) [3]. These features in many respects determine the capabilities and features of corresponding balancing techniques and, hence, the QT techniques in which they are implemented. (This should be emphasized as being often forgotten in the corresponding literature).

Additional kinds of QT techniques are revealed with further specification in view of system aspect (object/subject of transformation/environment) and the realizability in time and space.

5. CONCLUSIONS

For practical activities, it is also helpful to switch from the general QT concept classification (level n) to the classification of the concepts, which are its sequential instantiations (see Fig. 1). Thus, in the specification of the "quantity" concept, the following specification levels are formed:

- n–1 – the level of physical quantity's dimension accounting (scalar/vector);
- n–2 – the level of quantity's type accounting (active/passive);
- n–3 – the level of quantity's representation form accounting (analog/discrete/digital);

The levels of specification of the physical nature of the quantities employed in the transformation follow farther.

The classification at each specific level allows for and details the rules and regularities identified at the upper levels.

The above notes about building the classification of QT process may help in building similar classifications for M, D, and C processes. For example, everything mentioned above about the realization of the transformation process of quantity x into quantity $y = f(x)$ is applicable in full to the measurement process as a case (specific subtype) of such transformation where $y = X = N[x]$, i.e., the output quantity y is represented as N measurement units $[x]$ where X is the measurand's value.

The laws and regularities of measurement process are determined by: (i) generic laws of QT process, (ii) the features of its affiliation with one of its subclasses, namely with ADC processes subclass, and (iii) the fact that measurement processes form a subset of ADC processes where $[x]$ is not just a "local" quantization unit for the quantity X but rather its conventional measurement unit. The latter of the above 3 items justifies the inclusion of measurement assurance processes in the generic measuring process concept.

The revealing and systematization work based on the interdisciplinary approach briefly described in the Introduction, is now at its initial evolution phase. Its continuation and extension look very promising. Specifically, the completion of general QT methods classification and its continuation at levels n–1, n–2, and n–3 in the direction discussed herein will establish a framework for further development of the so-called structural transformation theory. The latter means a set of systematized knowledge about generalized mathematical models of QT process providing it with specific properties, e.g., functionalities, invariance to specific factors, etc. The development of the structural theory of automatic measurements is underway. Future research in this area may allow expecting the creation of the general fundamentals for the automation/computerization of purposeful activities as well as innovations in teaching and learning of various engineering sciences.

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