

Quantities transformation: general techniques and accuracy improvement

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Abstract- The process of quantities transformation, which underlies many other processes such as measurement, control, etc. is considered. It is defined as a process of physical realization of the desired functional dependence between the quantities x and y , i.e. $y = f(x)$, interpreted as the specific target-oriented family of causally related events and considered regardless of the physical nature of the participating quantities, i.e. at the structural level. The general methods for realization of the main components of quantities transformation – connecting y and x with a desirable functional relationship and reducing the effect of undesirable factors on this relationship – are revealed and systematized in deductive, logically clear way starting from several known generic principles and mechanisms.

I. Introduction

This work concerns the problem of knowledge systematization in the field of Measurement and Instrumentation, which is becoming increasingly important now. Naturally, if we wish to build a logically conclusive knowledge system for some area, we must first identify the knowledge relevant to this area and investigate the specificity of its objects and the problems to be solved. For this purpose, the knowledge area of interest should be examined together with adjacent areas from the same generic viewpoint. The analysis of measurement, control and other processes undertaken in [1] from a generic viewpoint of organizing purposeful chains of causally related events allowed to disclose fundamental interrelation of these processes, to clarify the specificity of each one and to reveal several new problems. The expediency of extracting the knowledge related to quantities transformation (mapping) process and examining it independently as a scientific discipline was also discussed in [1] as well as the systematization logic of this knowledge.

This paper develops, adjusts and elaborates the approaches offered in [1] with reference to physical quantities transformation process, and, first of all, to the revelation and systematization of the key ways to achieve its objective.

II. Quantities transformation process and its examination

We define *quantities transformation* (T) as a process of physical realization of the desired functional dependence between the quantities x and y , i.e. $y = f(x)$. (Generalizing, we could also speak about establishing a family of functional relationships between the sets of input and output quantities). Quantities, i.e. any measurable or estimated object attributes, are characterized not only by their intensities but also 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.

Quantities transformation is one of the fundamentals of measurement, control, monitoring, communication and many other processes. The knowledge relevant to its organization and technical implementation comprises and exhausts the knowledge related to sensors and transducers.

The important methodological feature of both this paper and [1], is the understanding the process of quantities transformation as well as other processes considered as a target-oriented family of causally related events. The primary (input) event E_x here is the appearance of the quantity x , while its consequence $E_{y=f(x)}$ should be the output event – the availability (appearance) of the quantity $y=f(x)$. Thus, the objective of quantities transformation is the transformation of events:

$$E_x \rightarrow E_{y=f(x)}. \quad (1)$$

The transformation method is characterized by a detailed chain of (1) type, which reflects significant transformations of the participating quantities.

As a whole, the quantities transformation problem is solved with reference to the quantities of specific physical nature and presumes a hardware implementation based on a specific technology. At the same time, the establishment of the desirable interrelation between the specified quantities is connected with performing specific mathematical operations (transformations) with the quantities

concerned to ensure the desirable casual relation and the independence from undesirable factors, i.e. with the implementation of a specific mathematical model of the transformation. If we consider the process T regardless of the physical nature of the participating quantities, i.e. at the level of its mathematical models (we call this “at the structural level”), we can reveal some general mechanisms of model structure that provide specific transformation features, such as the invariance to some quantity. These mechanisms can be represented as a set of possible models (structures) of quantities transformation, which reflect possible ways of its implementation at the structural level and can be treated as general transformation methods. The knowledge of these methods is necessary for providing the desirable interrelation between the quantities of specific physical nature, i.e. for implementing the desirable transformation when building the appropriate structure and/or algorithms of the transformation system.

Thus, the knowledge system related with physical quantities transformation must include also a block with systematized structure knowledge that is connected only with the features of participating values rather than with their physical nature, and provide the desirable transformation’s functionality. In the sequel, we will discuss only this block of knowledge.

It should be noted that the quantities involved in the process T can be analog, discrete or digital, and that the measurement is considered [1] as a specific case of the process T : $E_x \rightarrow E_{y=f(x)}$, where $y = N[x]$. (N is a number and $[x]$ is a unit of measurement of x), i.e. as the process $E_x \rightarrow E_{N[x]}$. Of course, when considering the measurement, its specificity should be a primary issue, including possible specific discretization errors and the methods for their reduction. But the general transformation and its accuracy improvement methods considered here concern also the measurement process as a part of the whole.

In order to attain the process goal the following two interrelated problems should be solved:

- A. Connect the quantities x and y with the desirable functional relationship (the transformation problem);
- B. Reduce (theoretically – eliminate) the effect of undesirable factors on this relationship (the transformation accuracy improvement problem).

Further, we illustrate the way of deductive revelation and systematization of the methods used to solve both the above problems, i.e. the generic methods of transformation and the improvement of transformation accuracy. The term *revelation* is important here, because we would not only specify any variants of methods classification but determine (derive) these methods in deductive, logically clear way starting from several known generic principles and mechanisms.

The approach to solving both tasks is essentially the same. The differences are caused only by the fact that a relationship, which never existed before, should be created in the first case, while in the second one must change the type of the existing connection in order to relieve it (ideally) from the undesirable dependence on the influencing quantities.

III. Transformation methods

When solving the problem A, considered as the establishment of a causal relationship (1), we have, as when solving many other problems, the following 2 alternatives:

- I. make use of the desired causal dependence $y = f(x)$, which already exists in the real world under specific conditions and provide these conditions (direct transformation, Figure 1a);
- II. realize this dependence artificially, by external impacts 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 very important, ensures the conditions necessary for the appearance of the cause and for the action of causal relationship. To implement all this, only a priori information is sufficient; there is no principal necessity in any experimental (a posteriori) information.

To implement the second way, one uses the known capabilities and principles of control process organization, which can be elicited from numerous publications on automatic control. But here we will try to derive the necessary control principles also from some generic principles and premises.

Control is understood as a process of affecting the object with specially organized impacts to eliminate deviations from its desirable operation. Of course, the information about such deviations is needed. This cannot be a priori information only – at least some a posteriori information is also necessary, such as the presence or absence of the deviation from the desirable behavior. Otherwise, the deviation could be compensated in advance using the opportunity I per above. Due to the known duality principle, the information about either the deviation itself (the result of an undesirable disturbance) or its cause (the disturbance) can be used as a posteriori information critically important

for control. The second case naturally presumes that the cause and its relationship with the effect are known. The known principles of feedback and feedforward control ensue hereupon.

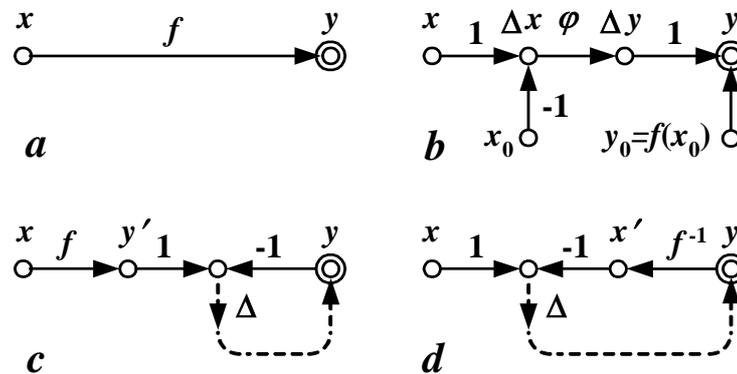


Figure 1. Structures of active to active quantity transformation
a – direct transformation
b – transformation with feedforward
c – transformation with balancing and a reference converter $x \rightarrow y$
d – transformation with balancing and an inverse reference converter $y \rightarrow x$

Figure 1b shows the structure for establishing the causal relationship (transformation) $y=f(x)$, derived from the feedforward control principle. The value y_0 at some specified x_0 is a priori known. The cause of y deviation from the desirable relationship $y=f(x)$ for any other x is the deviation $\Delta x=x-x_0$. Hence, for getting the appropriate y we must organize the impact $\Delta y=\varphi(\Delta x)$ based on the a posteriori information about Δx ; as the result $y=y_0+\Delta y=f(x_0)+f(\Delta x)=f(x)$ will be ensured.

In order to establish the desirable causal relationship by means of feedback control we must form a signal about the deviation of the quantities determining the relationship. Generally, to do this we must have a model that physically reproduces the desirable values of these quantities, and determine a posteriori their actual values, i.e., implement the parameter estimation process. Here we consider the simplest case of establishing the causal relationship $y=f(x)$ between two unchanging in space and time scalar quantities x and y . Their actual values are accessible directly, it is necessary only to model their desirable values. Again, according to the duality principle, we can 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 (we consider the case of single-valued inverse transformation). Based on the result (Δ) of the input/output quantity comparison with the reproduced one 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 1c,d, which present the revealed opportunities of transforming active quantities with feedback control (transformation with balancing).

Among the revealed four methods for establishing a functional relationship between active quantities x and y represented by the structures shown in Figure 1, the first three presume the existence of a direct converter $x \rightarrow y$. But the converter's function is different: for the structure shown in Figure 1a it is both informational and energetic, for structure 1c only informational, while for 1b it is informational and partially energetic. The structure 1d demonstrates the possibility of the transformation $x \rightarrow y$ based on the inverse one $y \rightarrow x$. It should be noted that this possibility is “derived” here rather than declared only. The variant shown in Figure 1c must be considered as a combination of the direct transformation with a special case of 1d transformation for $f^{-1}=1$.

Each method from the revealed ones has its own inherent capabilities and properties that can be listed and allowed for in advance. But to characterize the transformation with balancing, it is important how its essential part – the process of deviation elimination shown in dotted line in Figures 1c and d – is organized. Possible methods of deviation elimination and of establishing the desirable operation, state, etc., shortly, the balancing methods can be also derived from some generic mechanisms and logical reasoning. Here, we must issue from the most significant characteristics of the information employed and the impacts organized. In our opinion, such are the information origin (a priori / a posteriori), its subject (deviation or its variation as a function of control action, time, etc.), depth

(existence or lack of deviation, its sign, absolute value, etc.), application objective (choosing the action's direction, value, start and termination moments, etc.).

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 [2]. As the result, fundamentally different methods can be distinguished with the preset features and attributes, which provide an integral part of characteristic of the transformation methods, in which they are applied.

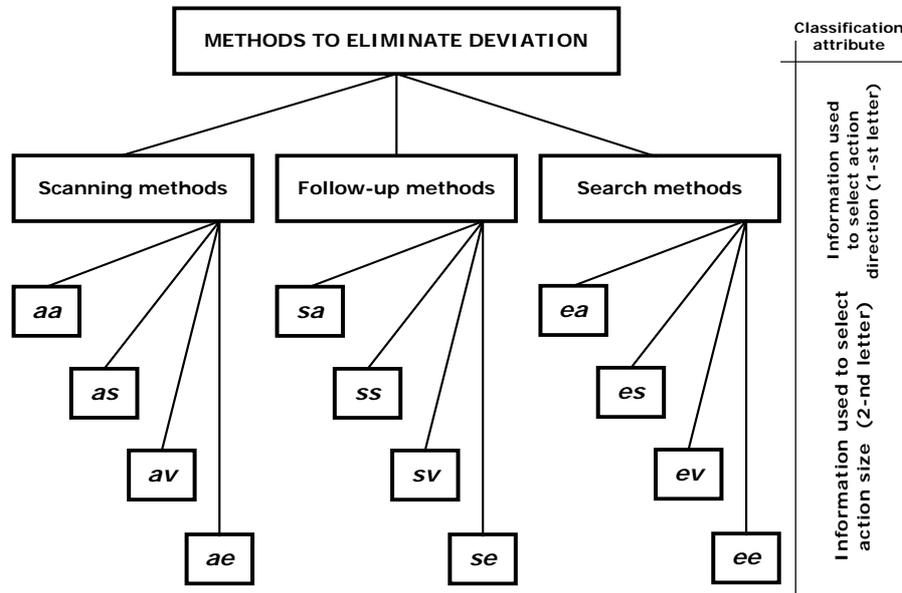


Figure 2. Methods for eliminating deviations

- a* – a priori information
- s* – a posteriori information about the deviation sign
- v* – a posteriori information about the deviation value
- e* – a posteriori information about the impact effectiveness

Figure 2 shows a deductively designed simplified classification of the deviation elimination methods with respect to a single parameter. The classification comprises both known and some possible but currently not applied methods [2]. One can continue the classification by adding lower levels of consideration, for example, by introducing a new classification feature: the information used for impact termination. In such case, the group *aa* of the methods that presume enumeration (searching) of the control variable's values will include the subgroups *aa_v*, of the methods which presume impact termination at $|\Delta| < \epsilon$ where ϵ is some sufficiently small value, and *aa_s*, of the methods which presume the impact termination with respect to sign Δ , etc.

In the case more general than the above, one must ensure not only the value y determined by the function f for each x , but also the desirable structure of this function, for example the specific form of y 's dependency on x or time, or the transfer function's dependency on the Laplace transformation parameter. In this case we must also consider the control variables other than y , and enable their variability, i.e., provide the appropriate transformation structure. And while speaking about deviations, we must distinguish the information about deviations with respect to each controllable variable together with the integral information about the deviation from the desirable behavior. Now, when considering possible balancing methods which significantly differ qualitatively from each other, such feature as the availability of information about the deviation with respect to each controllable quantity comes to the foreground. If such information is available separate balancing with respect to each variable (independent or dependent) is possible, while only "blind search" is possible, i.e., the enumeration of all possible combinations of the controllable quantities' values until their combination is found, which ensures no deviation with respect to any variable (e.g., up to $|\Delta y| < \epsilon$). In the intermediate case, when the reliability of the available information about the deviation in each controllable quantity is insufficient, matched balancing using various kind information (*a*, *s*, *v* or *e*) can be applied to match the impacts in each quantity [2]. The ways shown in Figure 2 are used for the impacts in each variable.

In the more general case the deviations of the controllable quantities are determined based on the deviations of other, directly observable quantities, while the changes of the controllable quantities are organized by changing other, directly manipulated variables. The situation becomes more complicated here, but the essence of the problems revealed remains the same.

IV. Methods of transformation accuracy improvement

Assume now that the desirable relationship between x and y was established using any of the above methods. But generally, this relationship depends also on some other quantities – internal and external influencing factors. In other words, there also exist undesirable causal relationship as follows:

the deviation of the influencing quantity \wedge the deviation of the quantity that determines the desirable relationship.

Just these are the source of transformation errors.

To solve the problem B – improve the accuracy of the transformation $y=f(x)$ – we must reduce (ideally eliminate) its dependency on the influencing factors. To do this we must consider according to the duality principle the possibility of eliminating either the error's cause – each undesirable causal relationship, or its consequence – the corresponding error. The latter can be accomplished by organizing additional compensating actions, i.e., again by means of control.

To eliminate the undesirable causal relationship it is sufficient to exclude the conditions either of the cause appearance or of the causal relationship's effect. This statement is very important from the methodical viewpoint, and can be filled with specific content while considering the physical nature of the phenomena employed, participating variables and implementation technology. This can be illustrated by a simplest example.

Assume the error occurs because a resistor in some transducer's circuit is affected by the ambient temperature. Then the way to exclude the effect of causal relationship might be the elimination (in real life – the reduction) of the relationship between resistor's resistance and temperature by appropriate material selection, while the way to exclude the conditions of the cause occurrence should be the elimination (reduction) of temperature changes at the resistor location under ambient temperature changes by means of, e.g., appropriate thermostating.

Appropriate systematization of generic structural methods for undesirable causal relationships elimination may be a good distance in the future. It should reflect also various filtering techniques for time-dependent influencing values, statistical minimization, etc. It should be emphasized that for implementing the methods which presume the elimination of undesirable causal relationships (Methods Group I) only a priori information is basically sufficient.

If we fail in eliminating the undesirable causal relationship we have nothing to do but try to compensate it by creating with the help of a specially organized control action an additional causal relationship between the deviation of the influencing quantity and the deviation of the quantity, which specified the desirable relationship. The variants of realizing this option that form the Methods Group II are the variants of control implementation, which differ first of all in the source of the a posteriori information applied: deviation cause – the deviation of the influencing quantity (feedforward control), or its consequence – the deviation from the desirable relation (feedback control).

For both variants, to organize the compensating (control) impacts in the general (nondegenerate) case, one must build a model that physically implements a priori information about the converter's relationships and parameters and identify actual values of deviations based in a posteriori information.

For feedforward control, one needs a model representing the a priori known relationship between control impacts and the changes of influencing quantities based on which such impacts are implemented using the a posteriori information about the changes of influencing quantities. The identification of the deviations of each influencing quantity in specific cases where the quantities sensed directly depend on several deviations is a rather sophisticated task.

For feedback control, a model is needed, which represents nominal values (i.e., the values that take place in the absence of influencing quantities' deviations) of the controllable quantities as well as the actual values of those quantities determined by means of parametric identification.

It should be emphasized that the process of identifying several (generally) observable deviations is a key component of the control process and, hence, the process of control-based conversion and its corresponding special case – the measurement process. This is one more illustration to the thesis from [1] about tight fundamental relationship between many informational processes.

It is practically important that the identification can be applied: (i) when actual input signals are replaced with the reference ones (the so-called reference signals method), (ii) for reference increments of participating active and passive quantities without cutting off actual inputs (test methods [3]), and also (iii) for real signals only (passive identification). It is also important that functional

transformations both in simulation and in identification can be implemented either in analog or in digital form – it is only necessary to agree the form of I/O quantities representation for participating processes.

If we further continue the differentiation of the methods of control-based transformation accuracy improvement, the ways to organize the deviations elimination process have to be considered. For feedforward control based on influencing quantities measurement, the variety of opportunities is determined by the variety of impacts combinations in time and space with respect to each influencing quantity, but each impact is implemented by applying a correction subject to full information about the corresponding deviation. For feedback control based on controllable quantities deviations, which unlike the deviations of influencing quantities reflect the effectiveness of the impacts applied, we can introduce the control also using partial information about the deviations Δ ($|\Delta| \leq \varepsilon$, $\text{sign}|\Delta|$, etc.). Possible variants were detected above with reference to a simple case of implementing the transformation process. The above considerations can be repeated here for the case of transformation accuracy improvement by means of feedback control of controllable converter's parameters. The obtained information about the deviation is used either for applying an additive or a multiplicative correction or for self-tuning implemented with any of the aforementioned balancing methods.

The way of deductive revelation of qualitatively different methods discussed above can be further extended in view of other features also ensuing from logically clear generic capabilities of process organization in time and space, application of iterations, combination of “pure” variants, etc.

The place of each transformation or transformation accuracy improvement method in deductive hierarchical classifications that can be built using the above techniques determines the method's features, merits and drawbacks. Unfortunately, we have no room here to illustrate this statement as well as to present any more or less complete classifications. But these were not maid the paper's aim.

V. Conclusions

It looks rational to single out the knowledge related to quantities transformation process and to consider it as a single whole. This process defined as a process of physical realization of the desirable relationship between physical quantities is one of the fundamentals of measurement, control, monitoring, communication, and many other processes. The knowledge related to its organization and technical implementation comprise and exhaust the knowledge related to sensors and transducers. Though the quantities transformation task is generally solved for the quantities of specific physical nature, and its implementation is to be based on a specific technology, we can single out from the set of the related knowledge an extensive block of nontrivial generic knowledge independent on specific physical nature or technology. This is called structural knowledge. The generic methods for solving basic tightly interrelated “internal” tasks of quantities transformation, such as establishing causal relationships between quantities and improving transformation accuracy, can be related to structural knowledge first of all. The paper has outlined and illustrated a simple and logically clear way for deductive derivation of possible variants of these methods from some more generic principles and mechanisms starting from the upper levels of consideration. It is based on the understanding of a transformation process as a process of establishing a causal relationship between specific type of events. As far as one of the two possible ways of transformation implementation includes the control process, the corresponding possible variants of transformation methods (and their properties) are in many respects determined by possible variants of control organization, which differ first of all, in the characteristics of the information employed and the impacts applied. In future work, it is intended to continue the research in this direction. The results presented above are open for discussion.

Reference

- [1]. V. Kneller. Measurement, control and other processes: to the problem of knowledge systematization. *Proc. XVII IMEKO World Congress*, June 22-27, 2003, Dubrovnik, Croatia, pp. 1119-1124.
- [2]. В.Ю. Кнеллер, Ю.Р. Агамалов. А.А. Десова. *Автоматические измерители комплексных величин с координированным уравновешиванием*. Энергия, Москва, 1975.
- [3]. Э.М. Бромберг, К.Л. Куликовский. *Тестовые методы повышения точности измерений*. Энергия, Москва, 1978.