Specific aspects of evaluation of control systems similarity

V F Evtushenko[1], V N Burkov[2], L P Myshlyaev[3] and G V Makarov[3]

[1]Siberian State Industrial University, 42 Kirova Street, Novokuznetsk, 654007, Russia
[2]Institute of Control Sciences of the Russian Academy of Sciences, 65 Profsoyuznaya Street, Moscow, 117997, Russia
[3]R&D Center of Control Systems LLC, 42 Kirova Street, Novokuznetsk, 654007, Russia

E-mail: evtushenko_vf@sibsiu.ru

Abstract. The paper discusses the problem of estimating the similarity of two or more control systems. In accordance with the statements made earlier it is indicated that such management systems should be characterized by a strict or approximate equality of the values of targeted indicators (criteria) of control effectiveness. Two main variants of procedures for estimating the control systems similarity are proposed. The first is based on the direct evaluation of the targeted indicators of control performance, the second – on the use of the so-called similarity relations, describing the conditions the fulfillment of which is valid for such systems. The procedures for evaluating the control systems similarity with the help of special *similarity relations* are associated with considerably less expenses. However, they are formed for a relatively narrow class of automatic control systems and are basically special cases of similarity, which requires further research in this direction.

1. Introduction

One of the primary and important tasks for development of the traditional theory of similarity [1] for control systems is the problem of estimating the similarity of two or more systems. Its solution is based on the axiomatics of similarity of control systems, stated in the form of *Statements*, according to which such control systems should be characterized by a strict or approximate equality of values of the targets (criteria) of control effectiveness. The formula expression for this statement for the j-th and l-th control systems can be written in the form [2]

$$\left\| q_j^n\{(t-T),t\} - q_l^n\{(t-T),t\} \right\| \le \delta q_{jl}^{n*};\ j \ne l;\ j = \overline{1,J};\quad l = \overline{1,L}, \tag{1}$$

where $\|\ \|$ − the measure of proximity; $q_j^n\{(t-T),t\}$ and $q_l^n\{(t-T),t\}$ − the normalized targeted values of the performance efficiency in the specified time interval T, respectively, of the j-th and l-th control systems; δq_{jl}^{n*} − the value determined by the maximum permissible (predetermined) threshold of the proximity of indicators $q_j^n\{(t-T),t\}$ and $q_l^n\{(t-T),t\}$, under which the effectiveness of these systems is considered to be the same; J and L are the number of control systems.

The strict equality of indicators values q_j^n and q_l^n corresponds to the functioning of control systems in the absence of influence on their behavior of uncontrolled disturbances. While the approximate equality of indicators values, represented, in particular, in the form of inequality (1), reflects the functioning of control systems under uncertainty. The numerical value of the acceptable threshold δq_{jl}^{n*} depends on the specific values of the level of uncertainty, its characteristics and methods of their estimation [3, 4]. We shall note here that preliminary studies of dynamic properties and conditions for the functioning of full-scale control objects and their operating physical models [5, 6] have made it possible to conclude that almost all of them are subject to the influence of uncontrolled disturbances.

2. Research methods

Two variants of procedures for evaluating the control systems similarity can be distinguished. The first is the direct use of the relation (1), the practical realization of which requires a reliable estimation, and in the case of a non-stationary control object – continuous or periodic tracking of the values of the target indicators of control systems efficiency and their subsequent comparison with the corresponding value δq_{jl}^{n*}. It is also possible to estimate the control systems similarity by the method of correlated processes [7], by calculating and subsequently analyzing the correlation moments between the values of the performance indicators of the two control systems.

The second version of the procedure for estimating the control systems similarity is based on the use of the so-called *similarity relations* [5] describing the conditions that are valid for such systems. They represent a linear or nonlinear combination of known characteristics of the actions properties, objects and control parts of systems, such as statistical and fractal time series, parameters of dynamic characteristics of the transformation channels for these effects of objects and control algorithms. *Similarity relations* can be obtained, in particular, by analytical methods or by using numerical simulation and search optimization methods. The statement of the problem, the solution scheme, conditions for the effective application of these methods are given in [5]).

3. Application of methods

Practical application of the first variant requires the following basic operations:

- normalizing of the values of targeted indicators q_j^n and q_l^n in order to bring them into a single coordinate scale of change. Here we can use the known normalization operation [8] by means of the difference relation obtained at a given interval of time *T* of efficiency indicator of the system under consideration and its minimum possible value to the difference of the maximum $q_j^{\max}$ and minimum $q_j^{\min}$ possible values, i.e.

$$q_j^n\{(t-T),t\} = \frac{q_j\{(t-T),t\} - q_j^{\min}}{q_j^{\max} - q_j^{\min}}, \tag{2}$$

where $q\{(t-T),t\}$ – the current value of the targeted criterion in the time interval *T*; $q_j^{\min}$ and $q_j^{\max}$ – accordingly, the minimum and maximum possible values of the targeted criteria for the functioning of the *j*-th control system;

- coordination of input, output effects and state variables of the *j*-th and *l*-th control systems. The control objects of these systems can operate at different coordinate and time scales. Therefore, to ensure a single coordinate-time space for the operation of both control systems, it is necessary to reconcile the trajectories of changes in the input, output actions and state variables of their control objects [9].

Such coordination can be provided, in particular, by converting the values of the input $V_j(t)$, output $Y_j(t)$ effects and the state variables of the $S_j(t)$ *j*-th control object represented in the form

$Z_j(t)=\{V_j(t); Y_j(t);\ S_j(t)\}$, by means of the scaling function $F_M^Z\{\cdot\}$ to the scale of the changes in the values of the output actions of the *l*-*th* control object $Z_{jl}(t)$

$$Z_{jl}(t)=F_M^Z\{Z_j(t)\} \tag{3}$$

The values obtained as a result of the value transformation (3) $Z_{jl}(t)$ change in the same range of values and time scale as the values $Z_j(t)$ of the *j*-th control object. The execution of operations using relations (2) and (3) is a necessary condition for the realization of the first variant of the similarity estimation, regardless of the determination method of specific values for target indicators of the functioning control systems;

- determination of the target indicators values of the effectiveness of control systems, estimation of which can be performed by processing full-scale, model or full-scale and model [10] data, including recurrent procedures.

4. Classification of methods for similarity evaluation

The results of experience generalization concerning the evaluation and study of the control systems similarity [1, 2, 4, 5, 7] made it possible to form a finite set of methods for estimating the similarity of control systems (Figure 1), the differences between them for the first variant are determined by possible ways of estimating the values of their performance indicators.

The first version of the procedure for assessing the control system similarity, based on the direct use of targeted indicators of their efficient performance using the relation (1), is more universal from the point of view of its practical application. It can be used to estimate the similarity of almost any control systems having different structures and functioning in different conditions, if the values of the targets are evaluated on a finite time interval with the use of full-scale, model, full-scale and model data. However, in order to obtain adequate estimation results, it is necessary to have a large number of arrays with a large volume of reliable data computation of which is very time consuming. In addition, obtainment of reliable data in the existing control systems is associated with considerable difficulties and cannot always be realized.

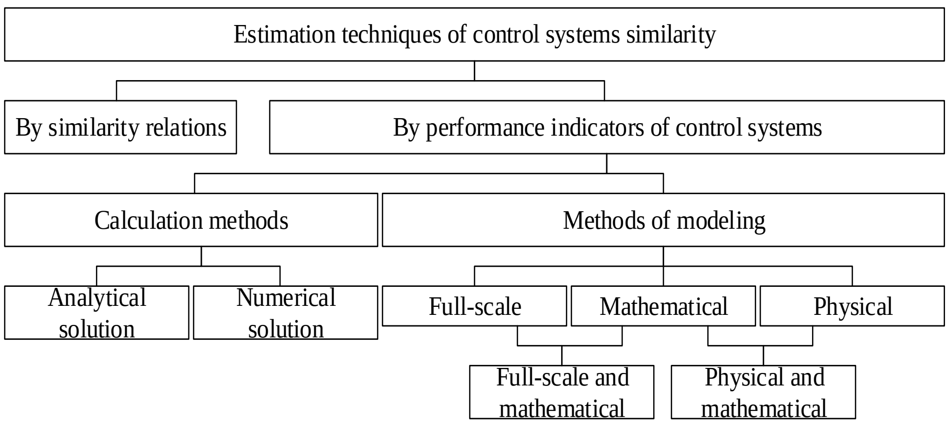

Figure 1. Classification of methods for evaluating the similarity of control systems.

The most preferable from the point of view of the cost of realization are the calculation methods for evaluating the control systems similarity, to which refer such methods that help to obtain an analytical solution of mathematical equations with an output to the target indicator of the functioning control systems. To implement the calculation method the initial information should be presented in the form of mathematical models of the channels for converting input effects and the effects themselves, including uncontrolled ones with fairly strict limitations on their structures and the range of parameters. It is possible to obtain a solution of the integral equation with an subintegral function comprising irrationality in the denominator only in very rare cases [3], in which on the area of effective application of the calculation method substantial limitations are imposed associated mainly with the structure and the range of variation of the values of model parameters transforming the channels of control objects, their input effects, control algorithms etc. Usually these restrictions are also very rarely implemented in practice. Area of the calculation methods can be somewhat extended in the cases when such numerical solution of integral equations is associated with a lower cost compared to the cost for the realization of the modelling methods of control systems.

The second version of the procedure for estimating the similarity of control systems, based on special *similarity relations* requires considerably less computing and time costs, and from this point of view it is more preferable. However, it, as well as analytical methods, is essentially limited in practical application. Such relationships are obtained only for a small class of control systems. In particular, they include control systems of positioning action with typical laws of regulation, the similarity relations for which and the scope of their application are given in [5].

5. Conclusions

The procedures for estimating the control systems similarity, based directly on the relation (1) are applicable for virtually any control systems of the same or similar structures. However, they require significant costs and time for reliable determination of the targeted indicators of their performance efficiency.

The procedures for evaluating the control systems similarity with the help of special *similarity relations* are associated with considerably less expenses. However, they are designed for a relatively narrow class of automatic control systems which requires further research in this direction.

Acknowledgments

The work was supported by the RFBR grant, project No. 15-07-01972

References

[1] Venikov V A 1976 *Theory of Similarity and Modeling* (Moscow: Higher School) p 479
[2] Myshlyaev L P et al 2012 *Steel in Translation* **42(12)** 823–4
[3] Rotach V Ya 1973 *Calculation of the Dynamics of Industrial Automatic Control Systems* (Moscow: Energia) p 439
[4] Barkovsky V V et al 1969 (Moscow: Mechanical Engineering) p 385
[5] Evtushenko V F et al 2016 *IOP Conference Series: Earth and Environmental Science* **45** 012010
[6] Tsiryapkina A V et al 2015 *Steel in Translation* **45 (12)** 943–8
[7] Pugachev V N 1973 *Combined Methods for Determining Probabilistic Characteristics* (Moscow: Sov. Radio) p 256
[8] Rykov A S 1999 *Methods of System Analysis: Optimization* (Moscow: Economika) p 255
[9] Krasovskii A A 1979 *Avtomatika i Telemekhanika* p 156–62
[10] Avdeev V P 1979 *Ferrous Metallurgy* **6** 131–4