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Control systems for complex technological facilities with the accumulation of experience in the development of control actions

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Annotation. The complex task of man-machine control of weakly formalized technological units and complexes, which are characterized by a wide variety of conditions, multidimensionality, non-stationarity, uncertainty, multivariate products, is considered. The insufficient effectiveness of the model approach to creating control systems for such objects is shown. Alternative approaches based on the concept of best practices are considered. The well-known best practice procedures using typical representative situations and the model cycle method are presented. A new (precedent) method for the selection and implementation of control actions with the participation of an operator-technologist is proposed. A precedent cycle for selecting controls and a functional diagram of the control system have been developed. An information model of the precedent is formed on the example of steelmaking control in an oxygen converter. The advantages of the precedent method compared with the method of representative situations are determined.

1. Introduction

The problem of automated control of weakly formalizable technological objects (WFTOs), which include many technological units and human-technical complexes of various industries, today cannot be recognized as effectively solved on the basis of the traditional (model) approach. The essence of the latter consists in the identification of the control object, that is, in the construction of a mathematical model of control channels and influence channels of the controlled disturbing influences of the object, and in the case of human-technical complexes, in the construction of regulatory models and the synthesis on their basis of algorithms (mechanisms) for the generation and implementation of control actions.

The lack of effectiveness of the model approach to the creation of automated control systems of WFTO is due to: the intensity, complexity, multiplicity and unsteadiness of internal processes; incompleteness and errors of control of numerous parameters; multi-mode operation, multivariance of products; the variability of the characteristics of the object during operation. The listed properties and features of WFTO, in combination with the lack of effectiveness in managing them, prompt us to look for other approaches to making control decisions. For example, it is useful to turn to the modification and algorithmization of the concept of “best practices” that is widely known and used in organizing people's activities, as applied to the management practices of WFTO [1, 2]. In the field of control of technological units and complexes of ferrous metallurgy units in this direction, two research directions can be distinguished: [3, 4, 5], [6,7]. This report briefly analyzes the traditional (model) approach to the construction of automatic control systems [8, 9], [10], [11, 12], gives a description of the two above full-scale development models that specify the best practices for managing WFTO in metallurgy and, more the author's approach to the algorithmization of accumulation of experience in the control of WFTO based on the precedent method is presented in detail [13, 14, 15].

2. The traditional model approach to the construction of automatic process control systems

A distinctive feature of the classical method of synthesis of a feedback control algorithm is the use of a mathematical model of the object's channels, as well as the influence model of the reduced uncontrolled disturbance. In a simple case, the structure of the algorithm is selected from among the typical ones (P, I, PI, PID, etc.), and its settings are determined on the basis of empirical formulas or by solving the optimization problem by the criterion of the minimum variance of control errors, Figure 1, [8, 9].

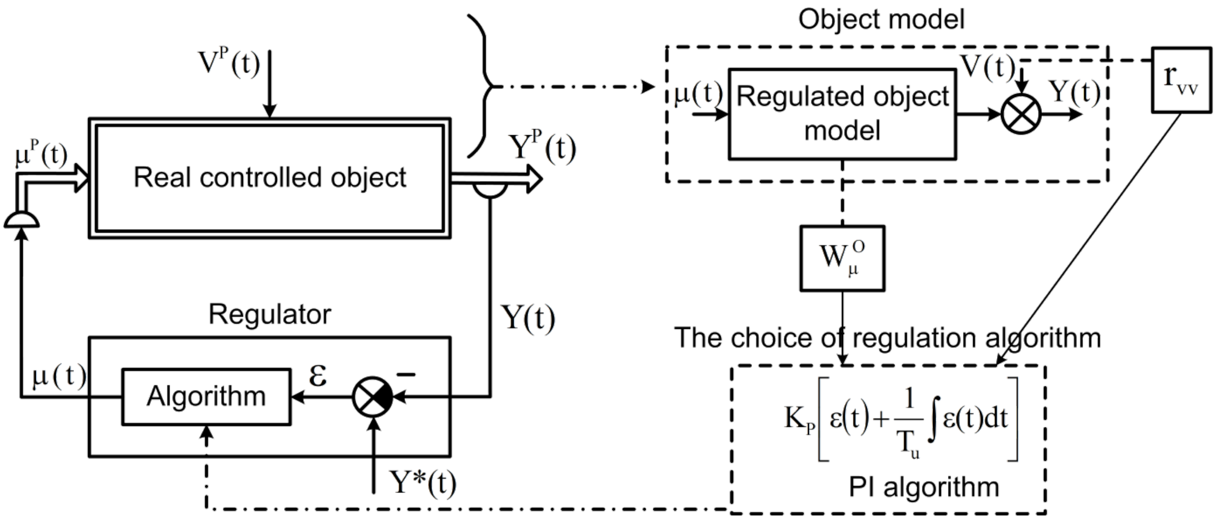

Figure 1. The classical scheme of selection of the regulation algorithm.

Designations: $Y^P(t), \mu^P(t), V^P(t)$ - real output action, control action, uncontrolled disturbing influences of the object at the moment $\mathbf{t}$; $Y(t), Y^*(t)$, $\mu(t)$ - measured and set output, as well as the control action of the object at the moment $\mathbf{t}$; $V(t)$ - equivalent disturbance reduced to the output of the object; r_{vv}, W_μ^O - autocorrelation function and object operator; K_P, T_u - tuning parameters of the PI algorithm.

The original development of SibSIU Professor V.P. Avdeev and his colleagues is PPR - a predictably-predictable regulator, [10], the structure of the algorithm of which explicitly includes a model of a control channel, Figure 2.

Designations: $U^\partial, Y^\partial, \omega^\partial, \varphi_O^\partial, \varphi_\tau^\partial$ - actual control, output, disturbing influences, as well as the operator of the control channel and the operator of delay; Y, U_τ^B, U^Π - output variable, restored ideal control action, predicted control action; $\varphi_O^M, \varphi_\tau^M$ - model operators of the control and delay channel; $\left[\varphi_O^M\right]^{-1}$ - reverse operator of the control channel model; f^Π - prediction operator; , - the symbol of the actuator and the measuring information sensor.

The main operations of PPR are: estimation of the deviation of the controlled variable from the task, retrospective restoration of the ideal control action (using the inverse model of the control channel), correction of the control taking into account the delay operator, extrapolation of the time series of ideal control actions, implementation of the extrapolated control action.

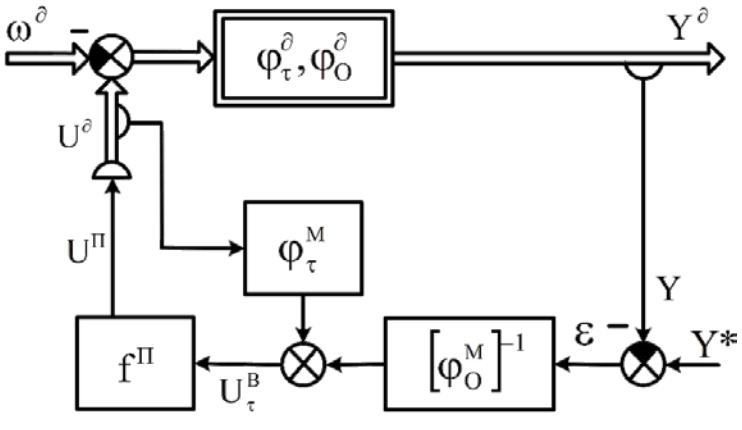

Figure 2. The structure of a simplified PPR (without disturbance compensator and corrective circuit).

The so-called Advanced Process Control (APC) systems are considered more efficient in relation to typical systems and more complex, that is, systems for the advanced control of multidimensional technological objects, the main component of which is the predictive object model and predictive control algorithms (Model Predictive Control - MPC) , [11,12]. They are widely used in oil refining, chemical, pulp and paper and other enterprises in the world. A control system diagram with a predictive model is shown in Figure 3. With respect to the PID controllers, MPCs give an effect in these enterprises in the range of 0.5-5.0 million dollars per installation per year, [12]. The control action selection algorithm uses numerical optimization to find controls U^{H} on the control horizon using forecasts Y^{H} for the dynamic memory interval of the object.

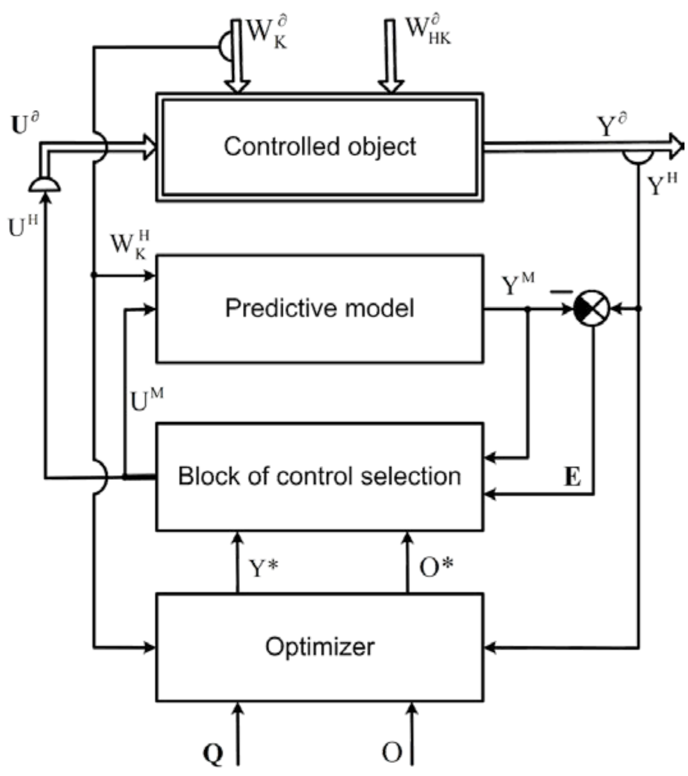

Figure 3. The structure of the control system with a predictive model.

Designations: $U^{\partial}, Y^{\partial}, W_{K}^{\partial}, W_{HK}^{\partial}$ - actual control, output, as well as controlled and uncontrolled disturbing influences (disturbances) of the control object; U^{H}, Y^{H}, W_{K}^{H} - full-scale control signals, output signals of the object and signals of controlled disturbances; U^{M}, Y^{M} - model control signals and output signals of the object; Y^{*}, O^{*} - set values of the output effects of the object and restrictions on the controls; Q, O - objective functions and limitations of the optimizer.

The considered effective structures of automatic control systems for technological objects are characterized by implicit [8, 9] or explicit [10, 11, 12] using a functional or essential model of the control object, which is adequate for a long time or can be updated in a timely manner (with a significant change in the properties of the object) with using the identification subsystem integrated into the control system. Such systems are ineffective for poorly (poorly) formalizable objects, for example, coke oven complexes, blast furnaces, oxygen steelmaking converters and arc steelmaking furnaces. It is advisable for them to create control systems based not on the model, but on the full-scale and (or) full-scale approaches, [16].

3. Characterization of known methods and control systems WFTO with control experience

3.1. Set-based forecasting and control

In [3, 4, 5], it was proposed to accumulate and use the experience of forecasting and decision making in control systems in the form of a set of typical representative situations (TRS). At the same time, TRS is understood as an interconnected set: structure, information display of an object, external and internal conditions of its functioning, parameters of control channels and controlled external influences, implementations of the given disturbing influences, control performance criteria.

The final set of TRS is considered as a full-scale model based on which control decisions and (or) forecasts are made. For example, more than 50 TRS are used in the predictive control system of the coke-chemical production of a metallurgical plant, [5].

The procedure for selecting controls based on TRS includes the following main actions: collecting data on the current situation in the control system; recognition of the class to which the current situation relates; adoption of an effective control action (or forecast) recommended for the selected class of situations; correction of the recommended impact (forecast), taking into account the differences in the characteristics of the current situation from the characteristics of a typical representative of the class, the implementation of the formed control action. The introduction of the TRS method is presented in detail in [5], which is a clear example of the effective control of WFTO.

3.2. Control of the unit of cyclic action on exemplary cycles

In [6, 7], a concrete example of the application of the control method for model cycles, namely, control of steel melting in an oxygen converter for model melts, is considered. All swimming trunks became divided into classes depending on their input (initial) and output (final) variables. The classification of steel melts involves the use of the following elements: the content of silicon, manganese, phosphorus, sulfur in molten iron; temperature and mass of molten iron; the content of carbon, phosphorus, sulfur in steel; steel temperature; basicity of slag, minute consumption of blast; position of the purge lance. The range of values each of these variables is divided into several (up to 5) subranges. Such a partition corresponds to no more than 65 classes. If the input and predetermined output values of the variables of the forthcoming melting coincide with one of the previously produced exemplary (effective) melts, information on the parameters of which is stored in the database, then the values of the control actions for the forthcoming melting are taken to be the same as in the found model melting.

This method is basically similar to the method of making control decisions on typical representative situations, TRS. But it does not imply the operational adjustment of the controls using the recalculation model (the model of the object in “small”), and is an example of a full-scale approach to the control of WFTO, which includes the process of steelmaking in the converter.

4. A case-based method for the accumulation and use of decision-making experience in the man-machine control system of WFTO

The essence of the case-based decision-making method is widely known and clearly displayed by the so-called CBR-cycle of case-based decision-making, [13, 14]. At the same time, the algorithmic foundations of a precedent approach to making control decisions in automated (man-machine) process control systems are still at the initial stage of their development [15, 16, 17].

First of all, it is necessary to modify the CBR decision-making cycle, considering it as a cycle of generating control actions based on information about the situation in the control system (about external influences, parameters of the state of the unit, output actions, past and current controls, control goals and limitations). Figure 4 shows such a modified cycle of generating control actions on the basis of precedents (the case-control cycle - CPU).

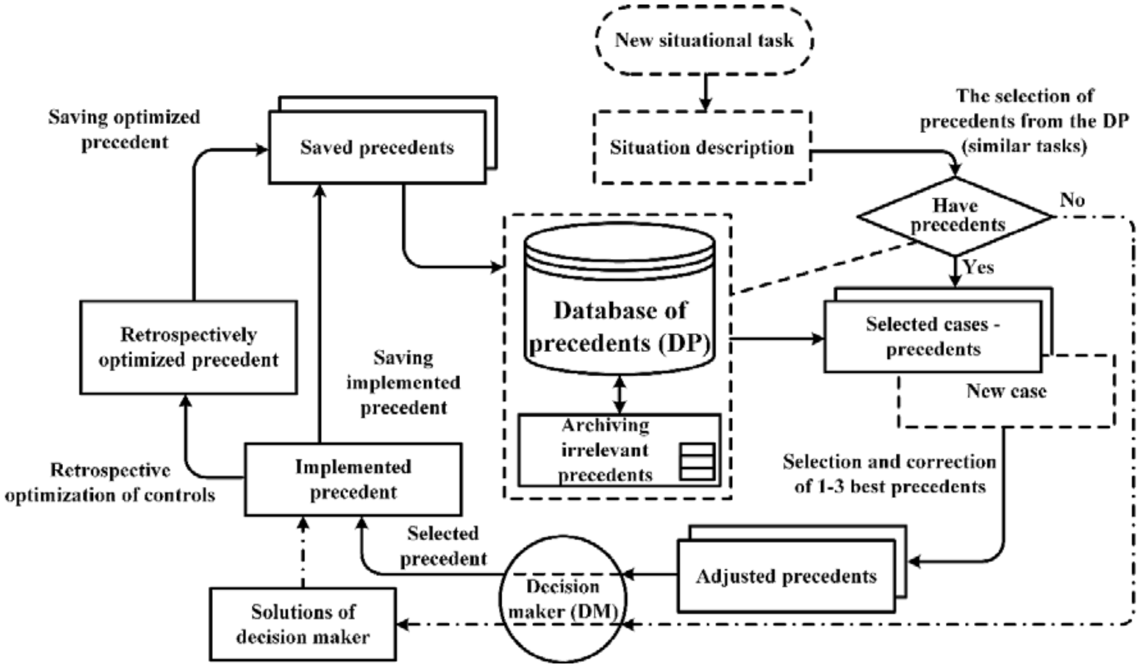

Figure 4. Modified cycle for the development and implementation of control decisions in the control system of WFTO.

Actual tasks related to the modified CBR cycle (CPU) are: the development of a functional diagram of the control system of WFTO; building a precedent information model, choosing the best (optimal) precedent from the set of relevant, at the moment, precedents and others. For example, the development of a control program for the forthcoming steelmaking in an oxygen converter, including the number and times of delivering charge materials, graphs of the flow rate of the blast and the position of the purge form, mass and rhythm of the supply of slag-forming materials, melt temperature, developed: general scheme of the control system, figure 5; information model structure of precedent, figure 6.

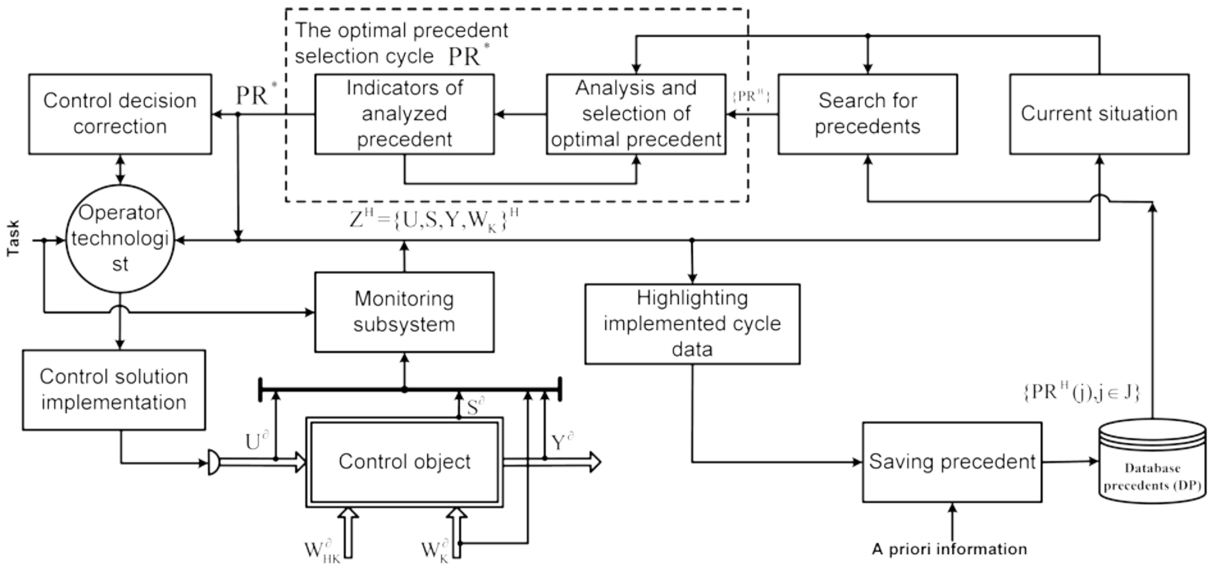

Figure 5. Scheme of the control process WFTO cyclic action.

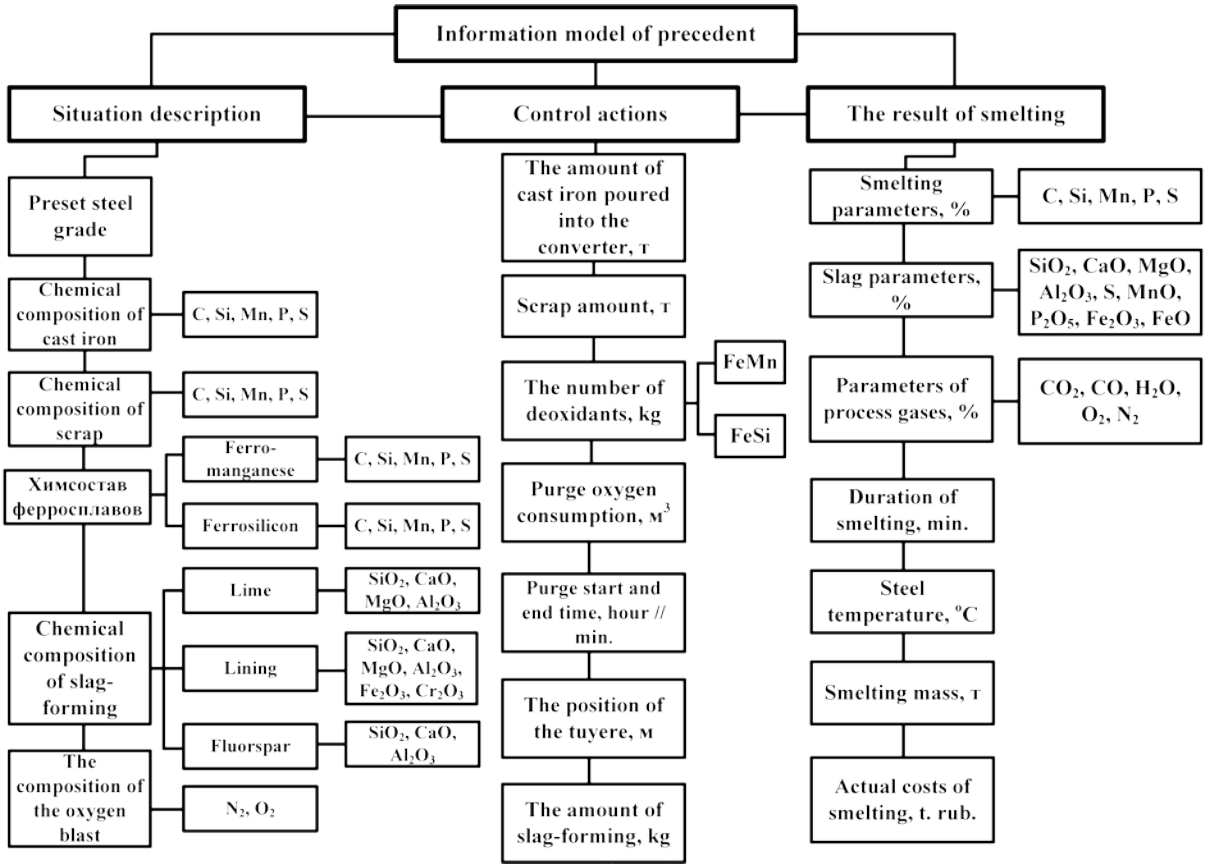

Figure 6. The structure of the precedent information model (for the synthesis of the control program for the upcoming steel melting in the converter).

5. Conclusion

An important issue with respect to decision-making by the use-case method is the identification of the similarities and differences of this method with respect to the TRS method and its special case – the model of model cycles. First of all, it should be noted that all three methods under consideration (TRS method, model cycle method, precedent method) belong to the same class of control decision-making methods. Namely, to the class of methods characterized by the accumulation and subsequent use of data on earlier implemented effective (as well as ineffective) controls, briefly to the class of methods with accumulated control experience (ACE methods).

The main differences between the TRS method and the TRS method are:

1) Different basic concepts: type representative (TRS), precedent.

A type representative is a characteristic, regularly occurring, typical object, process, situation, implementation of a measuring signal, a decision-making task.

A precedent is any specific decision-making case, process, event, situation that has taken place (implemented) in the past, similar to the upcoming decision-making case, process, event, event.

2) Different concepts of making control decisions (on the basis of TRS and on the basis of precedents).

To develop a control decision on the basis of TRS, it is necessary to form a set of typical situations and corresponding effective solutions, from which a decision is made for the current situation in the control system, after assigning it to a TRS.

In order to develop a decision based on precedents, it is necessary to create and update online many specific cases of decision-making (base of precedents), from among which a choice is made (and correction, if necessary) of the forthcoming decision that is as close as possible, by initial conditions, to the precedent optimal at the moment.

3) The power of many TRS in control systems of complex objects is always much (by orders of magnitude) less than the power of many precedents. Accordingly, the TRS method does not meet the principle of necessary diversity of U.R. Ashby in relation to WFTO, which are characterized by a very high variety.

4) Decision-making methodology based on precedents use new (with respect to decision-making based on TRS) tools, such as:

- domain ontology;
- theory of structural mapping;
- methods for constructing an information model of precedents;
- fuzzy precedent classification rules;
- methods for selecting optimal precedents;
- methods for assessing the relevance and archiving of actual precedents in real time.

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