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PECULIARITIES OF DESIGN SOFTWARE ARCHITECTURE OF ADAPTIVE INFORMATION PROCESSING, MODELING AND CONTROL SYSTEMS

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The article proposes an approach to developing the architecture of a service-oriented information processing system, modeling and process control. The system, which is being developed, is a tool for identifying, predicting and controlling discrete-continuous processes. Its mathematical apparatus is based on nonparametric algorithms of identification and control. The software architecture includes the following main modules: the module for processing data, modeling and forecasting output process variables and the process control module. The first module includes data preprocessing algorithms: normalization, centering and analysis of outliers and omissions. The modeling module is an algorithm for research and recovery dependencies between process variables, process identification using nonparametric estimation of the regression function from observations. The last module is an implementation of nonparametric dual control algorithms. Control devices built on the basis of these algorithms perform functions of both object control and its study.

The article discusses the application of architectural solutions based on two proven approaches in the field of software development: the composite approach and the service- oriented approach.. The main principles of composite architecture as a set of software systems with many characteristics that perform a specific task and service-oriented architecture as a modular approach to software development are described. The advantages of the applied composite service-oriented architecture over other variants of software architecture for control systems are shown, in particular, monolithic software architecture is compared with composite service-oriented architecture. This means that a researcher can use a single operation, which is a logically isolated, repeated task related to the production process of the enterprise. At the same time, it is necessary to ensure positive results when integrating with existing software products of enterprises which greatly complicates and requires the development of new components, as well as support for the "inherited" parts of the system.

Keywords: service-oriented architecture, software development, design of process control systems.

ОСОБЕННОСТИ ОРГАНИЗАЦИИ ПРОГРАММНОЙ АРХИТЕКТУРЫ АДАПТИВНЫХ СИСТЕМ ОБРАБОТКИ ИНФОРМАЦИИ, МОДЕЛИРОВАНИЯ И УПРАВЛЕНИЯ

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В статье предложен подход к разработке архитектуры сервис-ориентированной системы обработки информации, моделирования и управления технологическими процессами. Разрабатываемая система представляет собой инструментарий для идентификации, прогнозирования и управления дискретно-непрерывными процессами, математический аппарат которой основан на непараметрических алгоритмах идентификации и управления. Программная архитектура состоит из нескольких основных модулей: модуль обработки данных, моделирования и прогноза выходных переменных процесса, модуль управления технологическим процессом. Первый модуль включает в себя алгоритмы предобработки данных: нормализация, центрирование и анализ выбросов и пропусков. Модуль моделирования представлен алгоритмическим функционалом для исследования *и восстановления зависимостей между переменными процесса, идентификации процесса с использованием непараметрической оценки функции регрессии по наблюдениям. Последний модуль – это реализация непараметрических алгоритмов дуального управления. Управляющие устройства, построенные на основании данных алгоритмов, выполняют функции как управления объектом, так и его изучения.*

В статье обсуждаются вопросы применения архитектурных решений, основанных на двух зарекомендовавших себя в области разработки программного обеспечения подходах – композитном и сервис-ориентированном. Описываются основные принципы композитной архитектуры как набора программных систем с множеством характеристик, которые выполняют определенную задачу, и сервис-ориентированной архитектуры как модульного подхода к разработке программного обеспечения. Показаны преимущества примененной композитной сервис-ориентированной архитектуры перед другими вариантами архитектур программного обеспечения для систем управления, в частности, в работе сравнивается монолитная программная архитектура с композитной сервис-ориентированной архитектурой. Выбранное архитектурное решение предоставляет возможность выстроить систему из набора независимых модулей, каждый из которых реализует отдельную операцию, которая является логически обособленной, повторяющейся задачей, являющейся составной частью производственного процесса предприятия. Использование описанного в работе подхода позволило достичь положительных результатов при интеграции с существующими программными продуктами предприятий, значительно сократить сложность и стоимость разработки новых компонентов, а также поддержки «унаследованных» частей системы.

Ключевые слова: сервис-ориентированная архитектура, разработка программного обеспечения, проектирование систем управления технологическими процессами.

Introduction. Today, to solve a complex of tasks related to the management and modeling of complex technological processes in various industries, the aerospace industry in particular, software and algorithmic tools are used to provide identification and process control functions. One example of this type of tool is adaptive process control systems, the operation of which is carried out using nonparametric theory [1–5]. The use of nonparametric identification and control algorithms allows modeling, forecasting, and process maintaining within the framework of technological regulations in conditions of priori information lack, when the parametric structure of the model of the process under study remains unknown from priori information [6–9]. This situation is quite common in the development of computer control systems, since in most cases a researcher has to work with poorly studied processes for which it is not possible to reasonably choose the parametric structure of the model. At the same time a number of requirements are imposed on the developed control system, which include: data synchronization from various control points; the ability to work with heterogeneous data (the system independently converts the data into a single format); the possibility of both autonomous operation of the control system and correction of the control actions of the system by an expert technologist; security by encrypting and backing up data. Thus, the main task of this study is to develop and design the architecture for software and algorithmic support that allows optimal operation of the system.

Functional diagram of the system. The information processing, modeling and control system is a set of subsystems which includes the following modules shown in fig. 1.

Process variables are monitored over a time interval Δt. The input and output of the process are represented by measurements forming a sample of the $\{u_i, x_i\}, i = \overline{1,s}$ form, where s is the sample size, u_i, x_i are the measurements of the object input and output at a time t_i. This sample is contained in the “Enterprise database” block. The data processing module imports data of various formats, converts data into a single format with which the system works. Also, this module implements data preprocessing algorithms: normalization, centering, analysis of omissions in the observation sample. The result of the module operation is an internal database of the system, which contains the converted data in a single format.

The process identification module implements the following nonparametric identification algorithms [10].

In this paper, we consider the classes of control processes that can be described by equations of the form:

$$x_t = F\left(x_{t-1}, \ldots, x_{t-k}, u_t, \xi_t\right). \quad (1)$$

Here F – unknown functional; k – order of the difference equation that is bounded $k \le k_{\max}$; u_t – input variable of the object; x_t – output variable of the object; index t – discrete time; $\xi(t)$ – vector accidental hindrance.

Let us introduce the following designations:

$$z_t = \left(z_1, \ldots, z_{k+1}\right) = \left(x_{t-1}, \ldots, x_{t-k}, u_t\right), \quad (2)$$

then

$$x_t = F\left(z_t\right). \quad (3)$$

Taking into account redesignations (2), the model of the technological process under consideration can be reduced to the model of the dynamic system in discrete time, when not only variables u_t enter the input of the latter but also $x_{t-1}, x_{t-2}, \ldots, x_{t-k}$ and so on.

Under these conditions the following nonparametric estimation of the regression function based on observational data $\{x_i, u_i, i = \overline{1,s}\}$ [11] can be used as a nonparametric model of the object:

$$x_s^t = \frac{\sum_{i=1}^{s} x_i \cdot \Phi\left(\frac{u_s - u_i}{c_s^u}\right) \prod_{j=1}^{k} \Phi\left(\frac{x_{s-j} - x_{i-j}}{c_s^{x[j]}}\right)}{\sum_{i=1}^{s} \Phi\left(\frac{u_s - u_i}{c_s^u}\right) \prod_{j=1}^{k} \Phi\left(\frac{x_{s-j} - x_{i-j}}{c_s^{x[j]}}\right)}, \quad (4)$$

where $\Phi(\cdot)$ – bell-shaped function, $c_s^u, c_s^{x[j]}$ – core blur coefficients that are found in the presence of a training sample from the task of minimizing the object output and model output correspondence index based on the sliding exam method, when the nonparametric model (4) excludes the q-e observation of the variable presented for the exam by index i:

$$R(c_s^{\boldsymbol{u}}, c_s^{x[1]}, ..., c_s^{x[k]}) = \\ = \sum_{q=1}^{s} \left(x_s(\boldsymbol{u}_q, x_{q-1}, ..., x_{q-k}) - x_q \right)^2 = \min_{c_s^{\boldsymbol{u}}, c_s^{x[1]}, ..., c_s^{x[k]}}, q \neq i, \quad (5)$$

where the index i appears in the nonparametric model (4). The non – gradient method of multidimensional optimization, the Nelder-Mead method, is implemented as an optimization algorithm, since this method is effective at a low calculation speed of the minimized function. To select the initial vertices of the deformable polyhedron, a range of possible values of the nuclear function blur coefficients $c_s \in [0.01, 4]$ was specified, from which an $n + k + 1$ point was arbitrarily selected, where n is the number of input variables, k is the order of the difference equation, which form a simplex of $n + k$-dimensional space .

The process control module implements the following control scheme (fig. 2).

The nonparametric dual control algorithm has the form [12]:

$$u_{s+1} = u_s^* + \Delta u_{s+1}, \quad (6)$$

where u_s^* – component that accumulates information about the object of research, and $\Delta u_{s+1} = \varepsilon(x_{s+1}^* - x_s)$ – "learning" search steps.

The dualism of algorithm (6) is as follows. At the first control steps the main role in the formation of control actions is played by the summand Δu_{s+1} from formula (6).

But during the accumulation of information about the object the role of the summand u_s^* increases.

In this case, the following expression can be taken as a summand u_s^* from equation (6):

$$u_s^* = \frac{\sum_{i=1}^{s} u_i \cdot \Phi\left(\frac{x_{s+1}^* - x_i}{c_s}\right) \prod_{j=1}^{k} \Phi\left(\frac{x_{s-j} - x_{i-j}}{c_s}\right)}{\sum_{i=1}^{s} \Phi\left(\frac{x_{s+1}^* - x_i}{c_s}\right) \prod_{j=1}^{k} \Phi\left(\frac{x_{s-j} - x_{i-j}}{c_s}\right)}. \quad (7)$$

The process control algorithm is constructed as follows.

Based on the rule for selecting significant variables, the order of the differential equation of the dynamic process model k is determined, which is later used for calculating control actions in (7) where only those variables that were selected by the algorithm are present.

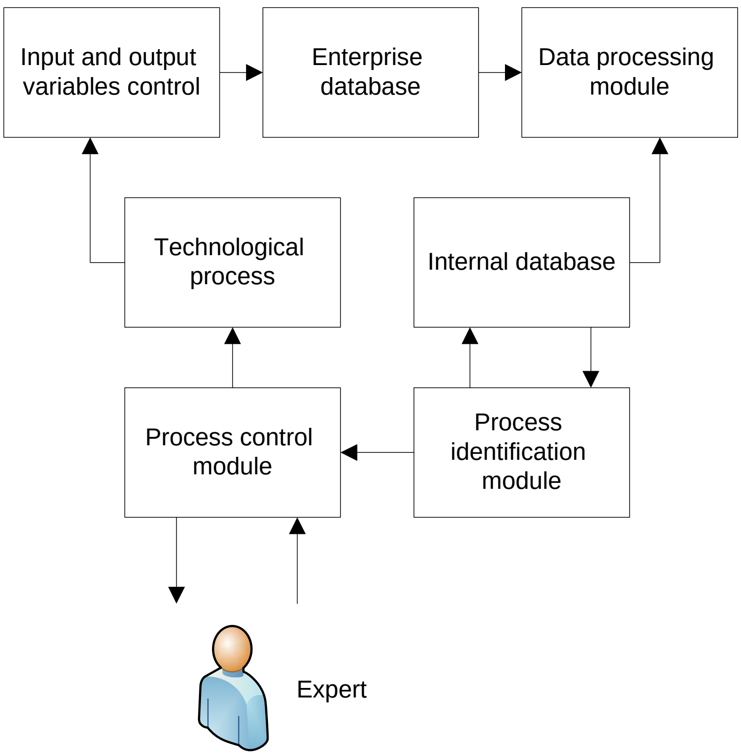

Fig. 1. Functional scheme of the developed adaptive information system for data processing, modeling and control

Рис. 1. Функциональная схема работы разрабатываемой адаптивной системы обработки информации, моделирования и управления

The quality of control is assessed by two characteristics:

1. Control time t_p – the time from the start of control to the moment when the output value differs from the task no more than a certain set value *α*. Usually: α= $0{,}05y_{уст.}$

2. A relative control error *Wp* equal to the total deviation of the actual output of the process from the setting effect during the entire time of regulation in relation to the setting effect, expressed in relative values, in %

$$W_P = \frac{\frac{1}{s}\sum_{i=1}^{s}\left|x_i - x_i^*\right|}{x^*}.$$

The calculated values of control actions u_{s+1} are available for correction by an expert technologist. Thus, the developed system is a tool that includes the following main modules : the data processing module, modeling and forecasting of output process variables, and the process control module.

Software architecture of the system. When designing the software architecture, we took into account the fact that each of the modules can be easily replaced with a new implementation in case of changes in the technological process, as well as be supplemented with new ones when expanding the system's functionality.

Fig. 3 shows an example of the same system built on two different architectures. The classic version of the system is a single monolithic application within which you can identify a number of closely related subsystems built around specific large business processes. Although the architecture of such system is a three-layer architecture, its high connectivity significantly complicates the maintenance and implementation of new functionality in such system. In addition, the implementation of a new business process leads to the development of a new subsystem, most of the source code duplicates the code of existing subsystems.

The selection of basic elements from the system as well as the division of business processes into atomic operations and their transfer to a set of services that are independent of the implementation of other components of the system, allow us to build a more flexible system based on composite architecture. At the same time, the access to data is carried out through a single interface, and any subsystem can easily access services. Moreover, such separation of the system allows to divide the system into several parts with less effort: a data server, a service server, client applications.

Our architectural solution is based on two proven architectural approaches in the field of software development: composite and service-oriented. Composite architecture is a set of software systems with multiple characteristics that perform a specific task developed in the established order and based on a common set of basic tools. At the same time, integration and testing operations replace design and coding operations.

Service-oriented architecture is a modular approach to software development based on the use of distributed, loosely coupled interchangeable components equipped with standardized interfaces for interaction over standardized protocols.

The main difference and advantage of composite architecture over SOA is that the composite architecture provides flexibility on all layers (levels) of the application, while SOA provides flexibility only on one layer – the application layer (business logic) [13]. Since the composite architecture is essentially a further development of the service-oriented architecture and, accordingly, has all the advantages of the service-oriented approach in the software development. Composite applications are usually a further development of an already developed group of individual applications, from which basic sets of components and containers are allocated for their further integration with each other.

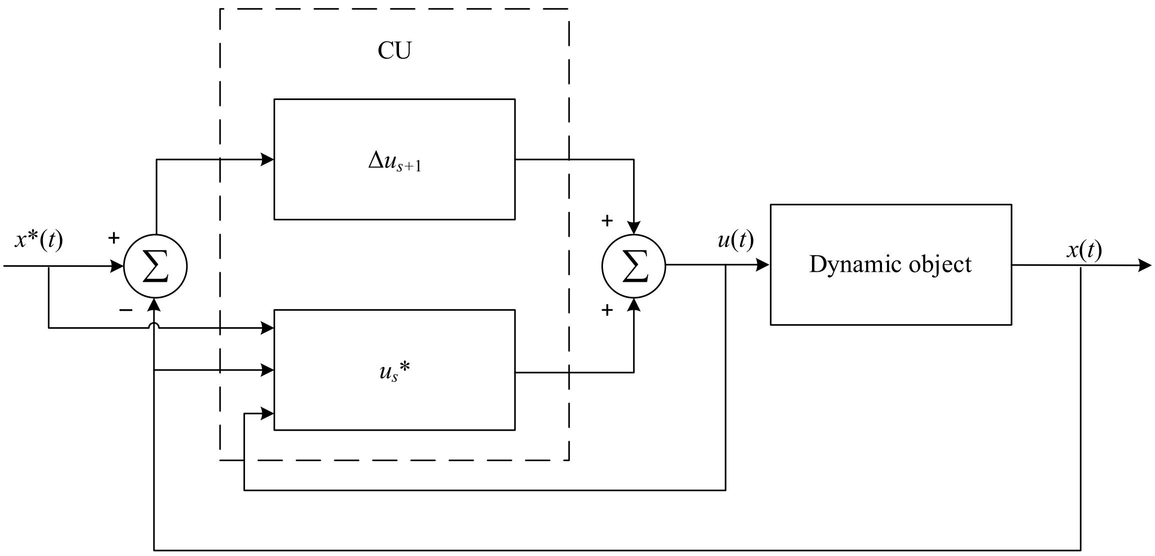

Fig. 2. Scheme of dual control of a dynamic object

Рис. 2. Схема дуального управления динамическим объектом

Fig. 3. Architecture Comparison

Рис. 3. Сравнение архитектур

Currently, the idea of building service-oriented applications based on composite architecture is widely used in various areas of software development and is the subject of study in many research centers. One of the largest organizations is Software Engineering Institute (SEI) [14].

At the moment, the Institute is a recognized international leader in the study of building composite service-oriented applications. Composite service-oriented architecture is an approach to designing software systems to organize existing software products so that disparate sets of complex, distributed systems and applications can be turned into a network of integrated, simple, and flexible resources.

Based on SEI's methodological recommendations, we designed and applied a hybrid architectural approach and thus obtained a composite service-oriented software system, which is a set of services, service components, and data access components that can be designed and deployed in a single application [15]. Interaction between services and various components is carried out by exchanging messages.

In our service-oriented composite architecture service components, which are the building blocks of our software system modules, play an important role. Each component is placed in a specific service container. Messages are sent to service containers and then redirected to the corresponding service components within them. In addition, service containers can interact with each other. For example, a message intended for a process is first sent to the container of that process, and then the service container processes the received information and redirects the messages to the corresponding service components within itself. Service components in the developed hybrid architecture solve the following tasks:

– describe and implement domain operations;
– define the rules of operations;
– transmit messages between system components.

The services themselves provide interaction between the composite application and its consumers. Communication with the service is performed using the specified protocols (for example, SOAP/HTTP). Data access components are used to retrieve and modify data based on messages sent from service components. The links describe how information is exchanged between services and service components, between different service components, or between service components and data access components.

The applied composite service-oriented architecture makes it possible to build a system from a set of independent modules, each of which implements a separate operation, which is a logically separate, repetitive task that is an integral part of the enterprise's production process. Moreover, services can be implemented independently of programming languages and other technical features of the implementation, which makes it possible to use different technologies.

Also, services can be written independently of other services in the system, you only need to know the interface of the services used, that is, the services will be loosely connected. The use of the architectural approach described in this paper also allowed us to achieve positive results when integrating with existing enterprise software products, significantly reducing the complexity and cost of developing new components, as well as supporting ”inherited“ parts of the system.

Conclusion. The work is devoted to the integrated development of the system designed for data preprocessing, modeling and control of multidimensional discrete-continuous processes. The core of the system is nonparametric algorithms. Two basic algorithms are presented for modeling the process of unknown structure and control under conditions of incomplete data about the object. The developed system architecture is flexible – the replacement of key modules does not have irreversible consequences during the functioning of the system as a whole.

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