Creation of system of computer-aided design for technological objects

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Abstract. Due to the competition in the market of process equipment, its production should be flexible, retuning to various product configurations, raw materials and productivity, depending on the current market needs. This process is not possible without CAD (computer-aided design). The formation of CAD begins with planning. Synthesizing, analyzing, evaluating, converting operations, as well as visualization and decision-making operations, can be automated. Based on formal description of the design procedures, the design route in the form of an oriented graph is constructed.
The decomposition of the design process, represented by the formalized description of the design procedures, makes it possible to make an informed choice of the CAD component for the solution of the task. The object-oriented approach allows us to consider the CAD as an independent system whose properties are inherited from the components.
The first step determines the range of tasks to be performed by the system, and a set of components for their implementation. The second one is the configuration of the selected components. The interaction between the selected components is carried out using the CALS standards. The chosen CAD / CAE-oriented approach allows creating a single model, which is stored in the database of the subject area.
Each of the integration stages is implemented as a separate functional block. The transformation of the CAD model into the model of the internal representation is realized by the block of searching for the geometric parameters of the technological machine, in which the XML-model of the construction is obtained on the basis of the feature method from the theory of image recognition.
The configuration of integrated components is divided into three consecutive steps: configuring tasks, components, interfaces. The configuration of the components is realized using the theory of "soft computations" using the Mamdani fuzzy inference algorithm.

1. Introduction
Fierce competition in the market of technological equipment annually forces its manufacturers to offer advanced and new technologies designed for a wide range of products. Therefore, production must be flexible, directing towards different types of raw materials, product configurations and productivity, according to the current market needs. The complexity of technological processes does not allow us to calculate them by conventional methods without the use of automated design (CAD) systems [1, 2, 3, 5, 10].
The choice of the software component for the implementation of the design process depends on the design task, the properties of the material being processed, the design features of the process machine and the set of initial data.

2. Design route construction
Before configuring, it is necessary to determine the type of design route. The following operations can be automated: synthesizing, analyzing, evaluating, converting and making decisions.

The procedure is defined for each operation: $P = (B, E, F, K, R)$, where $B$ is the starting position, $E$ is the final position, $F$ is the set of functions that implement the procedure, $K$ is the set of components that provide the required functionality, $R$ is the distribution of the roles of the performers ($(R_{hum})$ person, $(R_{mach})$ machine).

A formal description of the design procedures, taking into account the usual signs, is given in table 1. Such interpretation will save the design path in the form of an oriented graph, where each design node corresponds to a design situation (Figure 1).

Table 1. Description of design procedures

| Design procedure          | Formal description                                                                 |
|---------------------------|-----------------------------------------------------------------------------------|
| Synthesis procedure       | $P_S = (S_{dig}^{i-1}, S_{dig}^i, F_S, K_S, \{R_{hum}, R_{mach}\})$              |
| Analyzing procedure       | $P_A = (S_{dig}^i, S_{A}^i, F_A, K_A, \{R_{mach}\})$                             |
| Evaluation procedure      | $P_E = (S_{A}^{i-1}, S_{A}^i, F_E, K_E, \{R_{hum}, R_{mach}\})$                 |
| Conversion procedure      | $P_C = (S_{dig}^i, S_{vis}, F_C, K_C, \{R_{mach}\})$                             |
| Rendering procedure       | $P_V = (S_A^i, S_{vis}, F_V, K_V, \{R_{mach}\})$                                 |
| Procedure for making project decisions | $P_D = (S_A^i, S_{dig}, F_D, K_D, \{R_{hum}, R_{mach}\})$ |

![Figure 1. The route of designing an object](image_url)

3. CAD Formation
Designing structures is an iterative process, so a similar representation of the route allows one to repeat or adjust one of the simulation steps, eliminating the need for multiple reconfiguration. For each project situation, the task is to determine the aggregate of the components of $K$ needed to implement the required functions [11].

Decomposition of the design process, represented by a formalized description of the design procedures, makes it possible to make a reasonable choice of the CAD component for the solution of...
the task. Using an object-oriented approach allows us to consider the CAD system as an independent system whose properties are inherited from the components that make up its composition.

The task of CAD constructing consists of selecting of a set of components $Z$ to solve project problems $R$ in such a way as to provide the necessary properties of $F$ in system $S$ while minimizing design time $t$. $S$ has properties $F = \{ F_i \}, i = 1, n, k \in m, S_k = \{ R_p \}, p = 1, T_k$.

$R_p$ is characterized $F_p = \{ F_{pk} \}, k = 1, K$.

$$F_k = \bigcup_{p=1}^{P} \{ F_{pk} \}; Z_k = \{ Z_{kj} \}, j = 1, J,$$

where

$S$ – system under formation;

$F$ – system property;

$R$ – CAD resource (component);

$P$ – number of subsystems;

$Z$ – system process (design task);

$n$ – number of properties;

$m$ – number of system variations;

$J$ – number of processes;

$U$ – the condition of the transition to resource $R$.

The target function of configuring the system in the case of using an additive criterion will take the following form:

$$\sum_{j=1}^{J} \left[ \frac{c_j Q_j F_j}{Q_j F_j} - v_j \frac{t_j F_j}{t_j} \right] \rightarrow \max,$$

where $F_j$ is the alternate subsystem property for solving the $j$-th design problem (controlled parameter),

where $F_j \in \bigcup_{p=1}^{P} \{ F_{jp} \}; Q_j, t_j$ – function of evaluation of qualitative and temporal characteristics;

$Q_{0j}, t_{0j}$, normalizers; $c_j, v_j$ weighting coefficients of $j$ criterion, where

Controllable parameters = \{ system properties ($F$);

combination of components ($R$). \}

To achieve the maximization condition, the controlled parameters are the resources of the system and their properties [1].

Constraints are the design task, design features, technological requirements, a set of initial data. To achieve the presented objective function, a technique for creating and configuring CAD was developed.

First step. Based on the initial design requirements, the range of tasks the system solves and the set of components for their implementation are determined. The choice of the set of components is realized according to their classification according to the design procedures as shown in Figure 2.
The set of initial data

\[ \bigcup_{p=1}^{P} \{ F_p \} \bigcup_{j=1}^{J} \{ Z_j \} \]

The set of components \( \{ R_j \} \) to automate the solution of the task \( Z_j \) for \( j \in J \).

The result is a set of properties of these systems.

The set of components for solving \( j \) task

\[ \bigcup_{j=1}^{J} \bigcup_{p=1}^{P} \{ F_{j,p} \} \]

Component matrix

| Component         | The tasks | \( Z_5 \) | \( Z_6 \) | \( Z_7 \) | \( Z_8 \) | \( Z_9 \) |
|-------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| POLYFLOW          |           |           |           |           |           |           |
| eDrawings         |           |           |           |           |           |           |
| XTRU-XPERT        |           |           |           |           |           |           |
| AutoCAD           |           |           |           |           |           |           |
| Mesh Morpher      |           |           |           |           |           |           |
| Flow Simulation   |           |           |           |           |           |           |
| DesignModeler     |           |           |           |           |           |           |
| DesignXplorer     |           |           |           |           |           |           |

Figure 2. Defining a set of components

The second step is to configure the selected components. Initially, the interaction between the selected components is realized. The interaction is carried out using the CALS standards (because the data are unified, they are easily processed independently of the systems) and implement the link between the implemented components and the system - integration components. Based on the CALS (Continuous Acquisition and Lifecycle Support) standards, the product model (XML markup) is defined. An organization in the form of XML markup does not limit the number of node properties, which makes this view universal for different data sets. The connecting link is a special module designed to transfer and transform data. Schematically, the procedure is shown in Figure 3.

Figure 3. Configuring of components

The process of transformation consists in removing some small elements of the drawing in order to obtain, for example, a wireframe or surface model, or to distinguish the characteristics necessary for modeling using a mathematical model (MM).
The chosen CAD / CAE-oriented approach allows creating a single model, which is stored in the database of the subject area. Based on this approach, the required CAE (Computer Aided Engineering) - the model from the design drawing performed in the integration components - is successively obtained.

Each of the integration stages is implemented as a separate functional block. Converting CAD (Computer Aided Design) - a model into the model of the internal representation - is realized by the block of searching for geometric parameters of the technological machine, in which, based on the sign method from the theory of pattern recognition, the XML model of the construction is obtained.

The essence of the recognition task is to establish whether the objects studied have a fixed finite set of attributes that allows them to be assigned to a certain class. One of the most common methods of recognition is a sign method.

Let there be given a set of \( M \) objects for \( \omega \). Objects are specified by values of some characteristics \( x_i, i = 1, \ldots, N \), the sets of which are the same for all objects. The totality of the characteristics of object \( \omega \) determines its description \( I(\omega) = (x_1(\omega), \ldots, x_N(\omega)) \).

On the whole set \( M \) there is a partition into a finite number of subsets (classes) \( \Omega \) :

\[
M = \bigcup_{i=1}^{m} \Omega_i
\]

The task of recognition is to compute predicates for given object \( \omega \) by its description \( I(\omega) \) and a priori (learning) information \( I_0 \) about classes: \( \Omega_i, P_i = (\omega \in \Omega_i), i = 1, \ldots, m \) each of which takes a true value when object \( \omega \) belongs to the class with number \( i \).

To describe the impossibility of object recognition, predicates \( P_i \) are replaced by quantities \( \alpha_i = \{ \omega \in \Omega_i \}, \theta(\omega \notin \Omega_i), \Delta(\text{unknown}) \} \). Thus, for the object under consideration \( \omega \) it is necessary to calculate its information vector \( \alpha(\omega) = (\alpha_1(\omega), \ldots, \alpha_m(\omega)) \), describing the belonging of the given object to each of the known classes of the domain.

The procedure that builds information vector \( \alpha(\omega) \) in this case expresses the algorithm for deciding whether to assign object \( \omega \) to a particular class.

To determine a priori information about the set of recognizable objects \( (I_0(\Omega_1), \ldots, \Omega_m)) \), it is necessary to conduct a training sample. It is a description of the proposed objects with an indication of their belonging to classes, i.e. one can define it as a collection of object descriptions:

\[
(\! I(\omega_1), \ldots, I(\omega_k)), I(\omega_1), \ldots, I(\omega_2), I(\omega_3), \ldots, I(\omega_m), \ldots, I(\omega_m)),
\]

where objects \( (\omega_1, \ldots, \omega_k) \) belong to class \( \Omega_1 \), objects \( (\omega_2, \ldots, \omega_3) \) - to class \( \Omega_2 \) and so on.

In this case, if criterion \( K(I(\omega)) \) is given that allows one to distinguish objects from one another in accordance with a certain condition, then the action of the criterion in this case is determined by the following expression:

\[
\forall i, j \! (i, j = 1, \ldots, m) \quad i \neq j \iff K(I(\omega \in \Omega_i)) \neq K(I(\omega \in \Omega_j))
\]

Thus, the training sample is a table whose rows are labeled with object names \( \omega_i \), and the columns by the names of the characteristics: \( x_j, j = 1, \ldots, N \). Elements of the table are the values of object attributes \( x_j(\omega_i) \). Following types of rules for decision-making are distinguished:

• parallel - conducting a series of tests on the entire set of identified data on the site and making decisions based on their results;
• sequential - a sequence of tests on sub-sets of identified data; the choice of the next test is determined by the results of previous tests.
Since not all components of the technological machine can be determined by one criterion, it will be necessary to perform several tests on each of the objects; therefore, the authors used a parallel type of decision making.

The system can be organized in the form of a set of parallel functions \( F=\{f_i(x_1,\ldots,x_n)\}, \) each of which evaluates the belonging of the object to the corresponding class.

In this case, the decision function selects basing on the maximum value obtained - \( g=\max(f_i) \).

The evaluation of the proximity of information vector \( a(\omega) \) to the reference characteristics of particular object \( a(\omega_i) \) is determined through the inequality:

\[
|\alpha_i(\omega_j) - \alpha_i(\omega)| \leq \varepsilon_i
\]

where \( \varepsilon_i \) - proximity threshold \( i=1,...,m \).

The configuration of integrated components can be divided into three consecutive stages: configuring tasks (defines a set of projects for a particular project situation), components, interfaces (visual display of functional elements in application windows). The configuration of the components is implemented using the theory of "soft computing", since there is no complete information on the relationships between the components. According to Mamdani's fuzzy inference algorithm, the minimax composition of fuzzy sets allows one to obtain an estimate of the correspondence of components to the required norms \([2, 4, 6, 7, 8]\).

For this, it is necessary to formulate rules of the form:

\[
x \in A \land y \in B \rightarrow z \in C,
\]

where \( x, y \) - current constraints (the problem of analysis of the design); \( z \) - the desired component of CAD; \( A, B \) - conditions for the identification of component \( C \).

Let us determine the fuzziness: \( b_A=\mu_A(x,A), b_B=\mu_B(y,B), b_C=\mu_C(z,C) \), where \( b \) is the degree of compliance of current restrictions and identification conditions \( b \in [0,1] \). Fuzzy output: \( \lambda' = \min\{\min(b_A,b_B),b_C\} \), where \( \lambda' \) - evaluation of the compliance of the rule with the imposed restrictions.

**Figure 4.** Diagram of options for use of software system
Composition: \( \lambda_\Sigma(z) = \max \left\{ \lambda'_i \right\} \), where \( I \) is the number of components \( \lambda_\Sigma(z) \) - identification characteristics of which satisfy the requirements.

The component with the highest degree of compliance is selected as a priority.

The result of this method is CAD, optimized for the solution of the task [9]. To determine the necessary characteristics of the software system, a diagram of usage options is constructed that describes the interaction of the user with the software system (SS) (Figure 4).

4. Conclusion
The developed technique for constructing an integrated environment allows organizing the interaction of CAD components based on their classification, integration and configuration. The configuration of components (third-party CAD / CAE systems, mathematical models of projected processes and user interface components) on the basis of artificial intelligence methods reduces the complexity of the design process, expands the possibilities of searching for new and improving existing designs.

References
[1] Zubkova T M 2017 Technique of automated design of technological objects using elements of artificial intelligence. STIN 11 15-20
[2] Zubkova T M, Mustyukov N A, Tokareva M A 2016 Construction of a CAD architecture for single-screw extruders using artificial intelligence elements. Software products and systems 4 176-183
[3] Kirillov N P 2013 Description of the method of combined conceptual modeling of technical systems. Tr. SPIIRAS 31 223-235
[4] Vasiliev P V, Kuzenyi V V 2011 Improving the effectiveness of scenario development in the intellectual-modeling environment Tr. SPIIRAN 19 288-297
[5] Korobeynikov A G, Fedosovsky M E, Zharinov I O, Shukalov A V, Gurjanov A V 2017 Development of conceptual modeling method to solve the tasks of computer-aided design of difficult technical complexes on the basis of category theory. International Journal of Applied Engineering Research 12-6 1114-1122
[6] Troitsky A K 2016 Two-level multiple face detection algorithm based on local feature search and structure recognition methods. International Journal of Applied Engineering Research 11-1 4640-4647
[7] Koberis I S, Shkurkin D V, Zatonskiy A V, Volodina J I, Safyanova T V 2016 Moving objects control under uncertainty. ARPN Journal of Engineering and Applied Sciences 11-5 2830-2834
[8] Molodtsov D A 2013 Soft probability of large deviations. Advances in Systems Science and Applications 13-1 53-67
[9] Shishigin D S 2016 To the choice of integration technology for application software with CAD. Proceedings of SPIIRAS 4(47) 211-224
[10] Gorbunov A A, Pripadchev A D, Bykova I S, Elagin V V 2015 Simulation Modelling For Computer Aided Design Of Secondary Aerodynamic Wing Surfaces. Advances in Systems Science and Applications 15-4 346-358
[11] Gorokhov Yu V, Timofeev V N, Belyaev S V, Kirko V I, Avdulov A A, Konstantinov I L, Gubanov I Yu, Avdulova Yu S, Koptseva N P, Ivanov A G 2017 Conform installation structural elements design methods. ARPN Journal of Engineering and Applied Sciences 12-9 2917-2922