Intelligent Integrated System for Computer-Aided Design and Complex Technical Objects' Training

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Abstract. This paper is focused on the generalized structure, mathematical and software of the complex system of design and training that is based on author's models and methods. The system includes a block of training and block of recommendations. The domain model consists of the scheme level, presentation level and practical level, and is based on the ontology of objects of the problem area. Experiments on teaching student showed an increase in the average level of skill of trainees.

Keywords: Computer-aided design · Intelligent · Training

1 Introduction

The paper presents the author's methods and techniques of workflow processing and complex technical objects' design and using. We deal with two classes of complex technical objects: complex automated systems (CAS) and complex mechanical products (CMP).

The key problem of CAS' design and development is to create a successful project. According to the Standish Group data, only 40% of software projects are successful projects (i.e., the projects completed in duly time and budget, with all the specified features and functions) today. And the especially significant role in achievement of the CAS development's success is given to the diagrammatic models in visual forms of business process artifacts, particularly at the concept phase of CAS design. For this purpose, the visual languages (UML, IDEF, ER, DFD, eEPC, SDL, BPMN, etc.) were developed, and they are widely used in practice. Such models' use sufficiently increases an effectiveness of the design process and a quality of the design solutions, through the unification of interaction language of the CAS development participants, the strict documentation of the project-architectural, functional solutions, and the formal control of diagram notation correctness.

In recent years the large industrial companies and enterprises actively use distributed dynamic flows of designing and manufacturing activities. For example, according to [1], the first generation of statistical management systems of product lifecycle and project workflow can no longer meet the requirements of many companies. The approach and automated tools of the first generation of project workflow standardization have already exhausted its resources, and, as a result, there are poorly

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formalized processes (often containing semantic errors) increasing the growth of expenses for their development and improvement.

However, in theory and practice of corporate use of diagrammatic models there are no effective methods and tools for monitoring diagrammatic representations of dynamic distributed workflows of CAS, that results in the serious design errors.

Thus, the analysis, monitoring and processing of distributed dynamic workflows in CASs' design and operation, presented via their diagrammatic models, is an important scientific and technical task.

In frames of creating and interpreting of training flows in automated training systems, the world practice is currently dominated by an adaptive approach associated with the formation of individual learning paths. A formation of the custom-oriented (designed for a specific employer) competences, based, in particular, on the development of the employer's experience and best practices, is nowadays a key task of implementing the software engineer's training. Even such a concept as the World of Work has appeared. However, the modern training systems do not take into account the unique features of project activities' training, there is no integration of such systems with CAD software packages and project repositories, and the project activities of designers are not assessed. Formation of the necessary competences and recommendations for a designer will improve an efficiency of his/her work. And an important element of the modern training systems is a virtual environment (within the project's context) in a form of training systems, virtual worlds, including virtual work places, work stations, workshops, and enterprises in total. However, the task of trainee's action assessment is not automated in these environments (as usual, the experts manually make an expert analysis of trainees' action reports or an expert visual real-time analysis). That is why a development of the approach that allows the experts to evaluate automatically their trainees' actions in virtual environments and to generate recommendations, including the same for enhancing their skills, has a great fundamental and practical significance.

Thus, the goals of this research work are: to extend the class of diagnostic errors within the process of CAS design and operation - through the development and implementation of methods and tools for analysis and control of dynamic diagrammatic workflows' models, as well as to improve the designers' competences - through the development and implementation of methods, models and tools for the analysis of project solutions and the formation of personally-oriented training on basis of a uniform intelligent project repository.

The paper has the following structure. In the Sect. 2, the general structure of a complex system is discussed. In the Sect. 3, methods of distributed diagrammatic workflows' analysis and control at CAS's design are described. The Sect. 4 deals with personified training software for CAS and CMP designers, as well as the method of actions' analysis and recommendations' formation for CMP designers. Findings and further directions of the research are presented in the conclusion.

2 The Generalized Structure of an End-to-End System of Design Automation and Training of Difficult Technical Objects

The system's structure is presented in Fig. 1.

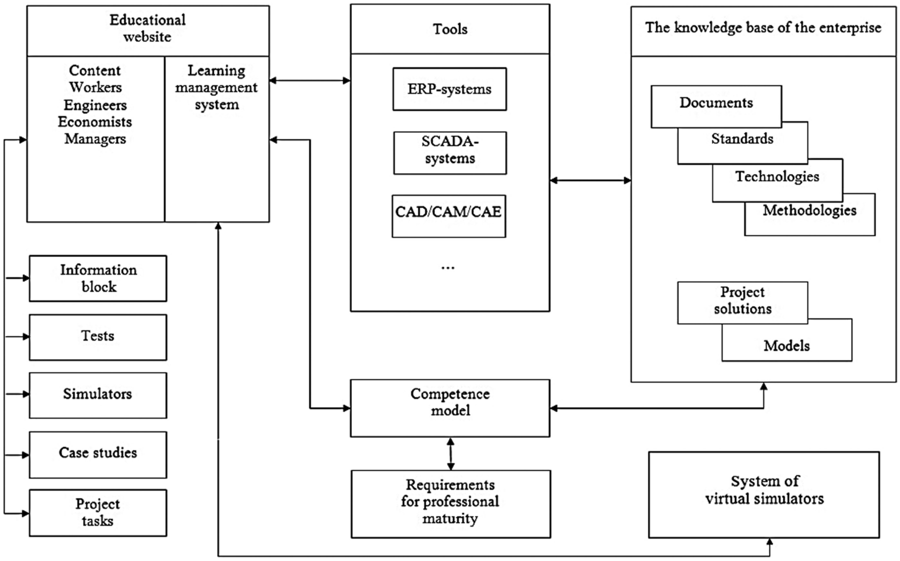

Fig. 1. The structure of the intelligent training environment.

The project part of the system is represented by a computer-aided design system and an electronic workflow system, and the training part is represented by a training portal.

The data storage in the system is based on the data bus development (unified service-oriented framework) that connects the tools for developing / designing artifacts of the enterprise's design and production process and an intelligent repository built on a dynamic ontological model and physical database (Fig. 2).

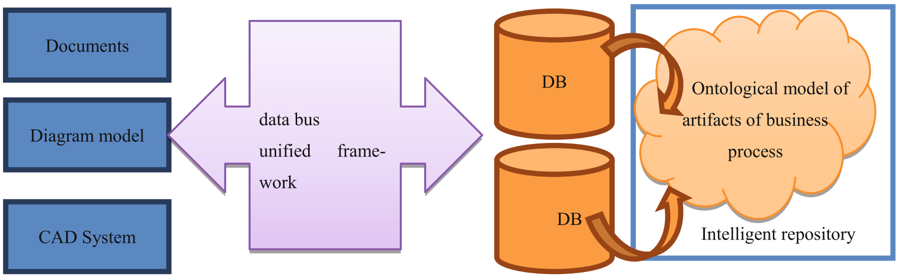

Fig. 2. Database organization.

The distributed workflows are characterized by the diverse usage of visual language facilities (for example, the scheme in Fig. 3).

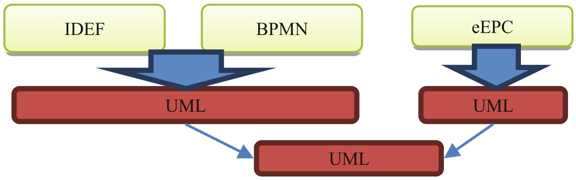

Fig. 3. The example of a distributed workflow's scheme.

At the same time the task of such schemes' analysis is connected with topological control including complex diagrams (for example, in the UML language) and with control of semantic approval. The above-mentioned problems are offered to be solved via the author's device of the multi-level syntactic oriented RVM grammars [11].

The generalized structure of the automated training system (ATS) is presented in Fig. 4. Let us consider the ATS components.

1. The training block is organized to train (materials' selection, testing, training scenario's development). The subject domain stores a set of training materials and links between them. The test and task's base contains both tests for assessing trainee's knowledge-level and practical tasks for assessing skills. The trainee's profile stores the information concerned with the level of trainee's current competences, test results, etc. A training path is built on tests based on data analysis of a trainee's profile and subject domain information. A training scenario is the sequence of trainee's training materials and tests' selection. Monitoring is a set of tests for assessing new knowledge the trainees gained from learning materials.
2. The recommendation block is responsible for recommendation development and trainee's skill-level diagnostics. The operation's generator tracks trainee's operations and codes them for the further analysis. The state's generator forms a project's state on the basis of operations. The project's state stores a history of project's states throughout the work in a CAD. The facts box is a base of facts received from a set of operations and project's states. The rules' generator fills rules for the expert system (ES) by the certain algorithms. Expert is an expert in CAD who fills the rule's base in the ES. ES is a tool for recommendation's selection based on facts and rules. The recommendations box stores recommendations for a trainee. The recommendations' analysis is a user's profile correction on the basis of the provided recommendations.

Training process is based on the following steps.

1. A trainee takes a test, the results of which is the basis for current training scenario formation with data from subject domain base, test and task base, and trainee's profile.

2. The work in CAD gives the operations' generator an opportunity to process user's operations, and this information is the basis for the facts' formation for the ES.
3. The ES creates recommendations based on laid down rules and received facts and provides trainees with them.
4. The trainee's profile is corrected based on performed actions and recommendations.
5. After trainee's profile correction a new training scenario is formed.

The domain model is based on the ontology and consists of three levels: the scheme level, presentation level and practical level.

The scheme level describes the domain knowledge structure and relations among the knowledge units. At this stage the order of studying the elements is determined.

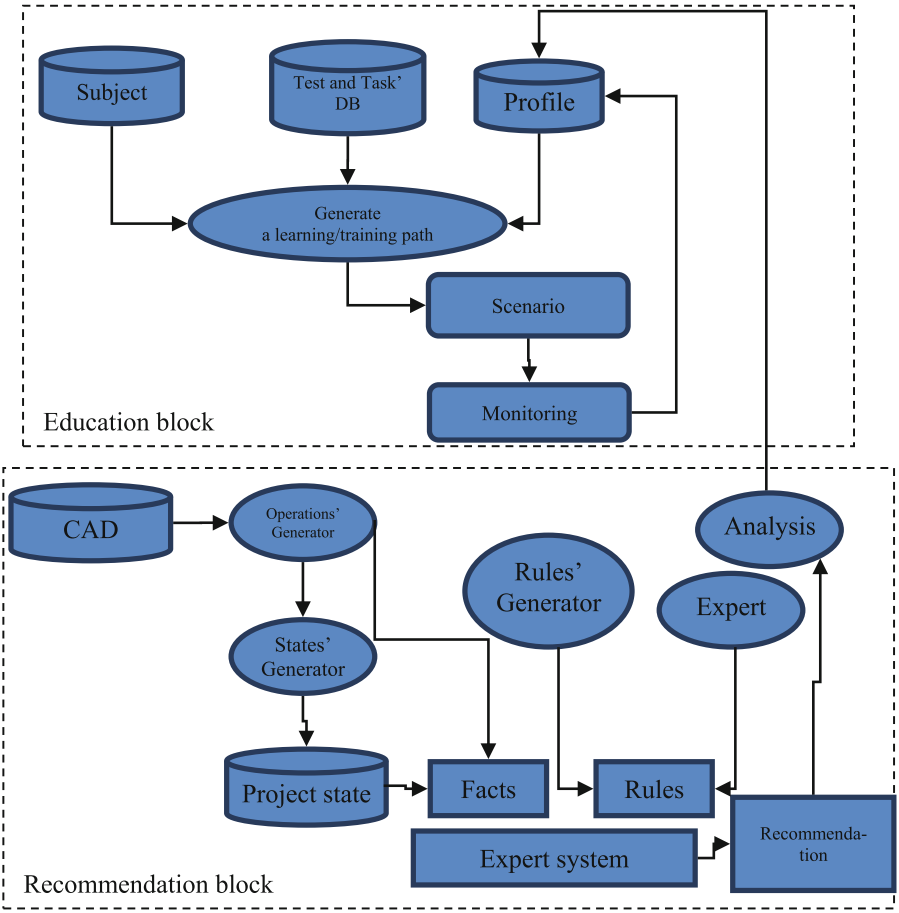

Fig. 4. A diagram of an educational system.

The presentation level is a set of training materials and reference books given as hypertext. The reference books are additional materials presented as hyperlinks for optional review. There are three types of supplementary training materials: reference books, glossary, and similar training materials.

The practical level is a level for designer's skill testing: the ability to perform design activities based on the acquired knowledge of automated design and design practice. This level is represented by a set of project solutions.

In subject domain there are the following classes:

- knowledge atoms;
- terms/concepts are the atoms grouped by any principle;
- training materials are the materials for studying. One of the types of training materials can be reference books.
- training purposes group atoms that should be studied;
- competences group the atoms that are included into this competence. Competences are a subclass of training purposes.

The domain model is given as:

$$O = (PSL, T, R, F, Ax), \tag{1}$$

where $PSL = \{psl_i | i = 1..x\}$ is a set of project solutions, T is the terms of the applied domain, which the ontology describes. A set of terms is defined as:

$$T = \{C, In\}, \tag{2}$$

where $C = \{A, P, D, GOAL, COMP\}$ is a set of ontology classes (A is knowledge atoms, P is terms/concepts, D is training materials, GOAL is the training objectives, COMP is competences). The class «training material» has a slot «is a Reference» with «true» or «false» values, In is a set of objects of ontology classes.

R is a set of relations between ontology objects:

$$R = \left\{R_{learn}, R_{part}, R_{next}\right\}, \tag{3}$$

where R_{learn} is the binary relation «is_studied_in» which has the semantics «connected_to» and connects the objects of the ontology classes («Atom», «Concept») to the objects of the «Training Material» class, R_{part} is the binary relation «is_a_part_of» that has the semantics «part_of» and connects the objects of the ontology classes («Atom», «Concept») to the objects of the «Concept», «Purpose of Learning» classes, R_{next} is the binary relation «is_trained_after», which has the semantics «after_of» and connects the objects of the ontology classes («Atom», «Concept») to objects of the «Concept» and «Atom» classes.

A set of interpretive functions is defined as:

$$F = \left\{Fatom_{op}, Fpsl_a, Fedu, Fdefine, Fsimilar, T\right\}, \tag{4}$$

where $Fatom_{op} : A \rightarrow \{Operation\}$ is a function of the «Atom» class object mapping into a set of project solution operations, $Fpsl\_a : PSL \rightarrow \{A\}$ is a function of the project solution mapping into a set of the «Atom» class objects, $Fedu : \{A\} \rightarrow \{D\}$ is a function for constructing an ordered set of training materials for studying certain knowledge atoms, $Fdefine : P \rightarrow \{D\}$ is a function of finding training materials that describe a certain concept, $Fsimilar : D \rightarrow \{D\}$ is a function of finding the most similar training materials, $T : D \rightarrow Q+$ is the didactic material complexity.

A set of axioms is defined as:

$$Ax = \{AxAHP, AxAHL, AxAHD, AxPAfP, AxPAfA, AxAAfP\}, \quad (5)$$

where AxAHP is «atoms are part of the terms/concepts» , if the atom Y is related to the concept of X, which is related to the concept of Z, then the atom Y is related to the concept of Z as Semantic Web Rule Language (SWRL): Term/Concept(?x) ∧ Atom(?y) ∧ Term/Concept(?z) ∧ be_a part of (?y, ?x) ∧ is_a part of (?y, ?z) → be_a_part of (?y, ?z).

AxAHL is «atoms are related to training purposes» , if the atom Y is related to the concept of X, which is related to the training purpose of Z, then the atom Y is related to the training purpose of Z as SWRL: Term/Concept(?x) ∧ Atom(?y) ∧ the_training_objective (?z) ∧ be_a_part of (?y, ?x) ∧ be_a_part of (?y, ?z) → be_a_ part of (?y, ?z).

AxAHD is «atoms are related to training materials» , if the atom Y is related to the concept of X, which is studied in the training material Z, then the atom Y is studied in the training material Z as SWRL: Term/Concept(?x) ∧ Atom(?y) ∧ Training Material(?z) ∧ be_a_part of (?y, ?x) ∧ be_ studied_in(?y, ?z) → be_ studied_in (?y, ?z).

AxPAfP is «atoms are studied after atoms» , if the atom Y is related to the concept of X, which is studied after the concept of Z, and the atom C is related to Z, then the atom Y is studied after C as SWRL: Atom(?y) ∧ Term/Concept(?x) ∧ Term/Concept(?z) ∧ Atom(?c) ∧ be_ a_part_of (?y, ?x) ∧ be_a_part_of (?c, ?z) ∧ be_ studied_after(?x, ?z) → be studied after(?y, ?c).

AxPAfA is «concepts are studied after atoms» , if the atom Y is related to the concept of X, which is studied after the atom C, then the atom Y is studied after C as SWRL: Atom(?y) ∧ Term/Concept(?x) ∧ Atom(?c) ∧ is a part_of (?y, ?x) ∧ be_ studied_after(?x, ?c) → be_studied_after(?y, ?c).

AxAAfP is «atoms are studied after concepts» , if the atom Y is studied after the concept of X and the atom C is related to X, then the atom Y is studied after C as SWRL: Atom(?y) ∧ Term/Concept(?x) ∧ Atom(?c) ∧ is a part_of (?c, ?x) ∧ be_studied_after(?y, ?x) → be_studied_after(?y, ?c).

Mathematical basis and representation of domain models, a trainee, test design tasks are given in [12–17].

3 Experiment

The experiment in training was performed among 160 students of the Ulyanovsk State Technical University. In order to assess the initial skills' level, these students passed a pre-test, as a result of which two groups of 80 and 80 students were organized. Their average skill's level was 0.5. The groups were trained on the materials of CAD KOMPAS-3D [15]. The first group was trained based on a linear scenario; the second group was trained in accordance with an adaptive scenario. After training, the task was to build an assembly «Pump cover» of 471 elements. The experiment's results are shown in Table 1. When applying the adaptive training scenario, the average level of students' skills is 20% higher compared with the linear training scenario due to the more detailed training. This resulted to 17% increase in time required for preparation.

Table 1. Comparison of linear and adaptive learning scenarios.

	The average level of skills before training	Average time of training, hours	The average level of skills after training	Average time of creation of assembly, hours	The general spent time, hours
Linear script	0,5	1,65	0,745	2,8	4,5
Adaptive script	0,5	2	0,9	1,9	3,9
Prize		**−17%**	**20%**	**50%**	**20%**

4 Realization

The training block was built according to the classical three-tier architecture: a client, an application server and a database server. Java Platform, Standard Edition technology is used as a development platform. This technology supports built-in client-server applications (RMI and ISOAP technologies). MySQL is used as the database server. The system is scalable, allows for functionality expansion by adding components (plugins). Plugins allow client and server's components to be extended by providing a client and server API. In order to implement the client-server technology at Java SE, the technology of Web Services is chosen. The SOAP protocol is used to exchange messages between Web services. The recommendation block is built on .NET Framework. As an example, the computer-aided design system called KOMPAS-3D V16 was chosen. In order to process events, it is used the Automation technology that is implemented as a library at C#.

5 Conclusion and Future Work

A generalized structure of an integrated design and training system for a large design and manufacturing enterprise is proposed. This system is based on the intelligent repository of design and production artifacts. Methods for the analysis and control of distributed workflows, represented by diagrammatic models in various visual languages, are proposed.

We have developed ATS that uses a new ontological domain model and method for forming an individual training scenario. The method for recommendation formation is developed on basis of the proposed modules. A trainee's profile is corrected based on designer's work tasks performance, which allowing improve the effectiveness of practical training.

The main quantitative positive indicator of this research work is 20–25% increase of designer's productivity. Further research directions are the development of temporal RV-grammars that take into account the dynamic and temporal nature of the development of project workflows; the study of this finite-state grammars class; development of a universal expert system for forming recommendations for designers.

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