UDC 681.5

J. MAMMADOV

Sumgait State University, Sumgait, Azerbaijan, e-mail: *cavan62@mail.ru.*

I. ALIYEV

Azerbaijan State Oil Industrial University, Baku, Azerbaijan, e-mail: *aliyevilqar674@mail.ru.*

G. HUSEYNOVA

Sumgait State University, Sumgait, Azerbaijan, e-mail: *ramiz_hu@mail.ru.*

G. ORUJOVA

Sumgait State University, Sumgait, Azerbaijan, e-mail: *orucovagulsen1975@mail.ru.*

ALGORITHMIC SUPPORT FOR THE MANAGEMENT OF THE COMPUTER-AIDED DESIGN OF FLEXIBLE MANUFACTURE SYSTEM AND ITS EQUIPMENT

Abstract. The authors propose a structure of the computer-aided design management system (CADMS) for the development of an integrated computer-aided design system for a flexible manufacture system (FMS), which provides high performance, flexibility, versatility, and accuracy of project procedures within a single system interface. The algorithmic support is developed for the management of the computer-aided design process of FMS for the implementation of the integrated computer-aided design process. An algorithm is proposed for the experimental analysis of design procedures of creating complex graphical data of mechatronic parts of an industrial robot and generating a database of calculated parameters and graphic elements.

Keywords: flexible manufacture system, computer-aided design management system, 2- and 3-dimensional graphical elements, generalized drawing.

INTRODUCTION

Flexible manufacture systems (FMS) which belong to different industries, are technical systems that produce a complex, diverse range of products. In order to provide automation procedures with flexible, fast and efficient principles in the system-technical design stages of FMS, it is necessary to create interfaces with operational functions, local and global networks, computer graphics, multimedia, intelligent systems. However, by analyzing the existing design systems for development of FMS [1–3], it was determined that there are no such systems that include multi-purpose software design functions. In this regard, the task of the article is to develop a complex automated design system for high-performance, flexible, versatile and accurate operations of project procedures performed in stages within a single system interface.

As it is known, computed design procedures of FMS are formed from the following important operations [4, 5]:

— search, analysis, intuitive selection of prototype project data;

— structuring the database management system of selected similar projects;

— selection of a model project option according to special criteria and its improvement;

— carrying out design, functional, technological and economic reports of the sketch project and development of 2D, 3D drawings;

— preparation, approval and application of working documents on the basis of sketch project;

— development of a working model of the project and its application in production.

The above design operations are executed on the standard stages of FMS (technical task, technical proposal, engineering drafting, working project, computer experiments, simulation and others) [6] what demand great time on working out, having many specialists,

using algorithmically, mathematical calculations and accurately assessment exercises parameters of the finale projects. At that also it is needed using of different the CAD software for constructor, mathematical calculation, database creation and management, information searching, making logical solution and other design computing procedures [7].

As one can see from analysis of the date problem [8–10] it is necessary to develop the intellectual, flexible, universal way like using one software system with design operations and procedures by means of some menu at the standard design stages from the design management interface. Thus the aim of this paper is to create the algorithmically support for automation of FMS design procedures with using standard stages of designing on the basis of flexible and intelligence management interface.

From the aim of this paper were defined the following tasks:

1. It is needed to propose the common block-scheme of by staging design at one interface with executive of intelligence procedures of FMS designing;

2. It is needed to develop the algorithm of FMS designing by staging to form technical task, proposal, constructor drafting, animation, simulation and application at the proposal program structure of computing design management system of FMS;

3. It is needed to create designing materials with constructor drafting, information searching and forming database of active elements (on basis industrial robot, its gripper, sensors and others elements) of FMS.
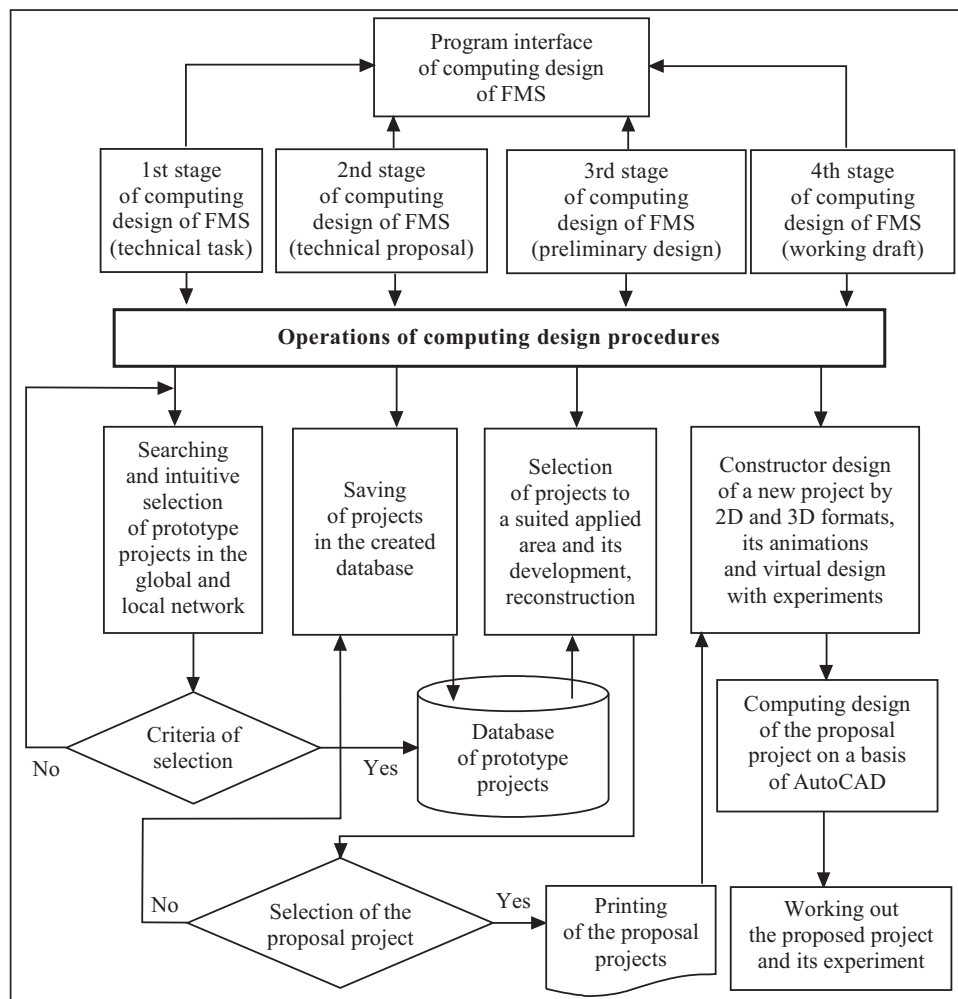

Fig. 1. Program structure of computing design management system of FMS

CREATION OF BLOCK-SCHEME OF THE COMPUTING DESIGN MANAGEMENT SYSTEM OF THE FMS

Based on the above-mentioned project operations and support tools (data and knowledge base, software modules of mathematical models, design and technological design), the structure of the general software of the computing design management system (CDMS) of the FMS is proffered (Fig. 1). To control the automated design of the FMS, the software interface of the control panel of the system is set up in accordance with the design stages. Automation of the process of working with the logical sequence of design procedures and their operations at standard stages for different areas of application is provided [11, 12].

Based on the terms of reference, prototype projects are selected, stored in the created database, the most effective project is proposed for the field of application, its improvement and reconstruction is carried out. At that CDMS provides the process of design reports, 2D, 3D, animation, virtual design, computer experiments and calculation of economic efficiency of the proposed project.

ALGORITHMIC SUPPORT FOR THE MANAGEMENT OF COMPUTING DESIGN PROCESS OF FMS

At the technical task stage of the automated design of the FMS, the subsystem of the "Terms of Reference" procedure is activated. Based on the initial data of the "Terms of Reference" software procedure, the search, intuitive selection and structuring of similar project options (SPO^i) in the global network system according to the priority of similarity is performed. The basis of this procedure is the initial data of the project (IDP) (project scope (PS), project name (PN) and project purpose (PP)) can be written as follows [13]:

First similarity priority (FSP):

FSP1: IF $\forall$ IDP $\in \{PS_i\}$, THEN $SPO^1 \& SPO^2 \& \dots \& SPO^n$;

FSP2: IF $\forall$ IDP $\in \{PN_i\}$, THEN $SPO^1 \& SPO^2 \& \dots \& SPO^m$;

FSP3: IF $\forall$ IDP $\in \{PP_i\}$, THEN $SPO^1 \& SPO^2 \& \dots \& SPO^k$.

At this stage, the technical parameters of the selected project options (constructive dimensions (CD), type of material (TM), working principle (WP)) are checked.

Second similarity priority (SSP):

SSP4: IF $\forall$ IDP $\in \{PN_i : CD_1, CD_2, \dots, CD_n\}$, THEN $SPO^1 \& SPO^2 \& \dots \& SPO^n$;

SSP5: IF $\forall$ IDP $\in \{PN_i : TM_1, TM_2, \dots, TM_m\}$, THEN $SPO^1 \& SPO^2 \& \dots \& SPO^m$;

SSP6: IF $\forall$ IDP $\{PN_i : WP_1, WP_2, \dots, WP_k\}$, THEN $SPO^1 \& SPO^2 \& \dots \& SPO^k$.

In the second phase of CDMS, the main engineering parameters of the project proposal, which is cost-effective, equipped with new information and computer technology, are studied, checked and economic evaluation is carried out. At this stage, preference is given to the project option, which is equipped with progressive automation systems and works on the principle of artificial intelligence.

Equipped with operating system and database management system software, the base subsystem includes technical parameters of active elements, 2-dimensional engineering drawings, algorithmic reports of kinematic and dynamic parameters of active elements. Management operations of the library of standard active elements are provided in the menus of data collection, structuring, editing, search in the form of queries to the database and selection menu commands [14].

Procedures for selection of the standard elements of the proposed project and processing of non-standard parts and relevant operations are carried out for the

effective formation of the database of the technical proposal stage. Design of non-standard elements is provided in AutoCAD 2D, 3D system. The technical parameters of the non-standard project are determined by means of mathematical methods providing an interface with MathLab for geometric modeling, functional and kinematic study of the selected structure. Non-standard elements and their technical parameters are stored in the database management system. This subsystem uses menu commands that allow computing animation of non-standard elements to be performed.

At the stage of technical proposal, after the selection and design of standard and non-standard elements, the assembly of these elements, i.e., the process of constructive combination is performed. Due to this, at this stage the project menu operation of the project is activated. Depending on the requirements and principles of construction of automated design tools, the basis for the development of the layout scheme of the project object at the stage of system technical design is the selection and construction of layout schemes of the structure, creation and storage, archiving and extracting graphic descriptions of the project; issues such as mathematical, algorithmic and software tool development.

Project procedures such as coordinating algorithmic and software subsystems, geometric modeling and design reports, search and selection of ready-made layout schemes are used in the construction of the layout of the proposed project object.

Within the development of non-standard elements of the proposed project object, functional, technological and structural research is required. In this regard, for designing, searching and selection, the software subsystem, the database subsystem, the graphics software system, and also the modules of processed information software, graphics software packages are used. Issues related to the development of the architecture of automated design tools, automated design subsystems of the layout scheme and non-standard elements are the basic tools for the development of the project management system. The internal interface of the computing design architecture allows selecting the active elements of the project object from the database, using the layout scheme and management system of database and their 2-, 3-dimensional image, animation data [15].

To ensure the mutual exchange of electronic documents in the corporate network of the designer, and also for carry out designing, the internal interface of the computing design system is used. Interfaces with other special programs are also implemented in the generalized menu bar. These procedures make it possible to use the work panels, fields, and program commands of various systems during project development. For example, a set of subsystems of special software for designing, mathematical, informational and intellectual purposes is used to solve individual design problems, depending on the characteristics of the projected object.

The functional relationships of the majority of application software packages used within the internal interface of the automated design architecture are described by the following logical formula:

$$\forall M_{p\_ij} \in (\exists M_{os} \in \{M_{p\_os\_i}\}) \bigcup \left\{ \begin{array}{c} M_{pk\_ij} \\ M_{pm\_ij} \\ M_{pi\_ij} \\ M_{ppy\_ij} \\ M_{ppv\_ij} \end{array} \right\}, \qquad (1)$$

where $M_{p\_os\_i} \in \{M_{p\_os\_1}, M_{p\_os\_2}, \ldots, M_{p\_os\_n}\}$ is a set of general-purpose programs that provide the functional operation of the operating system; n — number of the program operation like configuration, dispatch, service and others in

accordance with the operating system functions; M_{pk_ij} is a set of AutoCAD-based design programs; M_{pm_ij} is MathCAD, a set of mathematical programs based on MatLab; M_{pi_ij} is a set of information-based programs in Microsoft Access; M_{ppy_ij} is a set of programs created on the basis of Delphi or C ++; M_{ppv_ij} is a set of programs that provide search and selection of project information.

The hardware subsystem ensures flexible, reliable and productive operation of CDMS special software packages, intelligent software systems, algorithmic reports, and also accurate modeling results.

The block of construction, configuration, creation of functional-technological schemes of technical systems, which are considered to be the basic subsystem of CDMS, covers the following areas:

— library of ready-made configuration schemes;

— database reflecting technical indicators, functional-technological characteristics and positions of active elements;

— database query block. In the architecture of computing design, the design and selection of the layout scheme is provided through a special file menu.

Microsoft Access and AutoCAD, T-FLEX CAD 2D, 3D, Concept Draw Professional systems databases and graphic representations are used to store, search, select, add new data and perform correction procedures in the standard active elements memory database. This subsystem is considered open. To make it work, a special menu block is used to edit, search and select the project.

Mathematical and algorithmic methods and models, software and information, AutoCAD, T-FLEXCAD 2D, 3D, MathCAD and Delphi systems are used to ensure the operation of the subsystem of non-standard elements and automation schemes.

The CDMS software subsystem, which is the basic subsystem of the overall structure, includes AutoCAD, T-FLEXCAD computer graphics, Delphi, C++ programming systems, multimedia and office software tools. In CAD systems, mechatron standard and non-standard elements, design projects are developed in 2- and 3-dimensional coordinate systems in 1–3 projection format. General appearance drawings of different types of layout schemes are constructed from standard elements selected on the basis of codes, types and technical specifications included in the specification. Top-view architectural features are constructed in one projection. Images of non-standard circular structures are constructed in two projections. Complex structures of the technical system are constructed in three projections, and also their axonometry is additionally constructed.

Algorithm for development of the structure of software menu procedures for the creation of 2- and 3-dimensional graphic representations of the technical system is based on the interface of CDMS. To ensure effective implementation of designing works, procedures for drawing sketch documents through a computer graphics system should be automated. In this regard, the structure of drawing and animation of 2-, 3-dimensional images is proposed to automate the graphical mode procedures of the design process (Fig. 2).

For the designer, the process of designing a technical system within the software interface of automated design is one of the important stages. Therefore, at this stage, along with all the mechanical reports of the project object, its design appearance and materials must be selected what are substantiated and accurately described.

Graphical programming procedures of computing design architecture consist of the stages of drawing with 2-, 3-dimensional images and animation operations. The design section selected in the control panel of the automated design architecture is formed from the following menu procedures:

1. Activation of AutoCAD system and proper naming of the drawing object.

2. Drawing a generalized drawing of the project object. Depending on the field of application, a 2-dimensional coordinate system is selected for the drawing of the
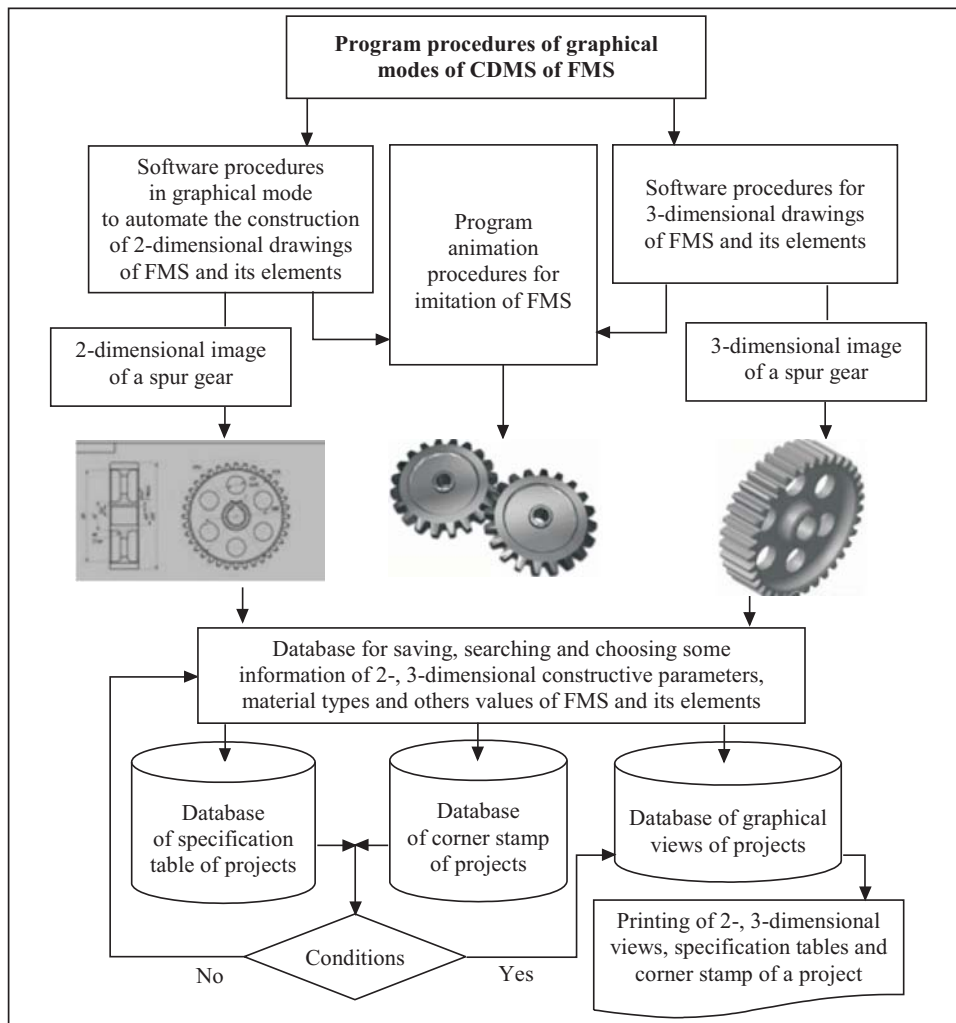
Fig. 2. Structure of graphical mode software procedures of the design process

proposed project object, and boundary lines, corner stamp in A1 format are drawn and the appropriate drawing scale is determined.

3 The prototype selected at the stage of technical proposal of the project object is placed in the working drawing area of the 2-dimensional generalized descriptive system of the project, on which changes of geometric shape, size, material type of construction.

4. Depending on the degree of complexity, the 2-dimensional generalized description provides additional views so that the process of preparing the project object can be carried out more accurately.

5. Depending on the actual dimensions of the project object, the main dimensions of the image are set according to the standard scale dimensions, and a serial number is assigned to each mechanical or electronic part.

6. A specification table is constructed according to the serial numbers of the project object. According to the names of the included parts, their quantity and material are stored in memory.

7. The data included in the corner stamp of the project include the name of the designer, information about the head, time of approval, name of the project, specially encrypted code, field of application and other standard information.

8. Based on the numerical, textual data formed in paragraphs 6 and 7, and graphical data based on the descriptions in paragraphs 3 and 4, the project design's database management system (PDDMS) is established. PDDMS procedures consist of graphic editing operations in the field of search, selection and shooting in the system according to the names of the descriptions of the mechanical or electronic parts of the project, their size, area of application on the basis of surveys.

PDDMS software procedures provide search, selection, and drawing functions for the 2- and 3-dimensional design process with logical operations. The main user-constructor builds the editing operations on the proposed project object with the query–search–selection–editing logic scheme with PDDMS. For example, the construction of a generalized project object begins with its conditional division into mechanical and electronic parts. Standard and non-standard elements of the project object are selected from separate databases (mechanical database and electronic database) of mechanical and electronic parts of PDDMS, shown in the example of the 2-dimensional drawing of the industrial robot (IR) (Fig. 3). The basis of the standard elements are mechanical or electronic means provided by the state standard. For the group of non-standard elements, mechanical or electronic parts made of newly constructed material, which differ from the traditional geometric shape and dimensions, are applied in the project (IR hand in Fig. 3).

Procedures for the selection of standard elements and the development of non-standard elements are carried out in accordance with different areas of application. For example, the mechanical (technological equipment, machines) and electronics (automated control systems, their elements) parts of a complex process automated production plant are selected on the basis of a request from the mechanical and electronic parts from the database, respectively. By analogy, the mechanical and control electronics parts of an industrial robot are selected and the generalized design is placed in the required coordinate positions.

The Generalized Project Database (GPDB) is formed from the separate databases of PDDMS. In addition, the kinematic schemes, structure, technological and functional schemes of the project are stored in the GPDB.

A generalized drawing of IR is formed on the basis of combining standard elements selected from the database of mechanical and electronic parts of PDDMS. In this case, to perform the merge logic operation, the Zadeh operator is used [16]:

$$\mu_{A \cup B} = MAX(\mu_A, \mu_B). \qquad (2)$$

Process of choising mechanical parts of IR from the mechanical database (MDB) is executed as follows:

$$\text{MDB} \rightarrow \text{IR body } (B); \text{ IR hand } (H); \text{ IR gripper } (G).$$

By means of $\mu_{B \cup H \cup G} = MAX(\mu_B, \mu_H, \mu_G)$ operator, IR frontal view is created.

The selection of the electronic parts of the IR from the electron database (EDB) and its addition to the frontal view of the IR is described by the following productions:

EDB $\rightarrow$ IR control block (CB) & IR sensor (S);

$\forall$ IR sensor $(S_i) \in \{$IR body (B), IR hand (H), IR gripper $(G)\}$;

IR body $(B) \rightarrow S_\alpha$ & S_h (where S_α — sensor of rotation on Z coordinate & S_h — sensor for moving up);

IR hand $(H) \rightarrow S_\varphi$ & S_l (where S_φ — sensor of rotation on Y and X coordinates & S_h — forward and backward motion sensor);

IR gripper $(G) \rightarrow S_{mi}$ (where S_{mi} — sensor of closing and opening).

By means of above written logical expression and $\mu_{M \cup E} = MAX(\mu_M, \mu_E)$ operator, the IR control parts are added to the IR frontal view.

Based on the frontal view of the created 2-dimensional IR, the top view is drawn. AutoCAD software commands are used to draw the most commonly used circle and rectangular geometric shapes. Performing this design procedure is required to maintain
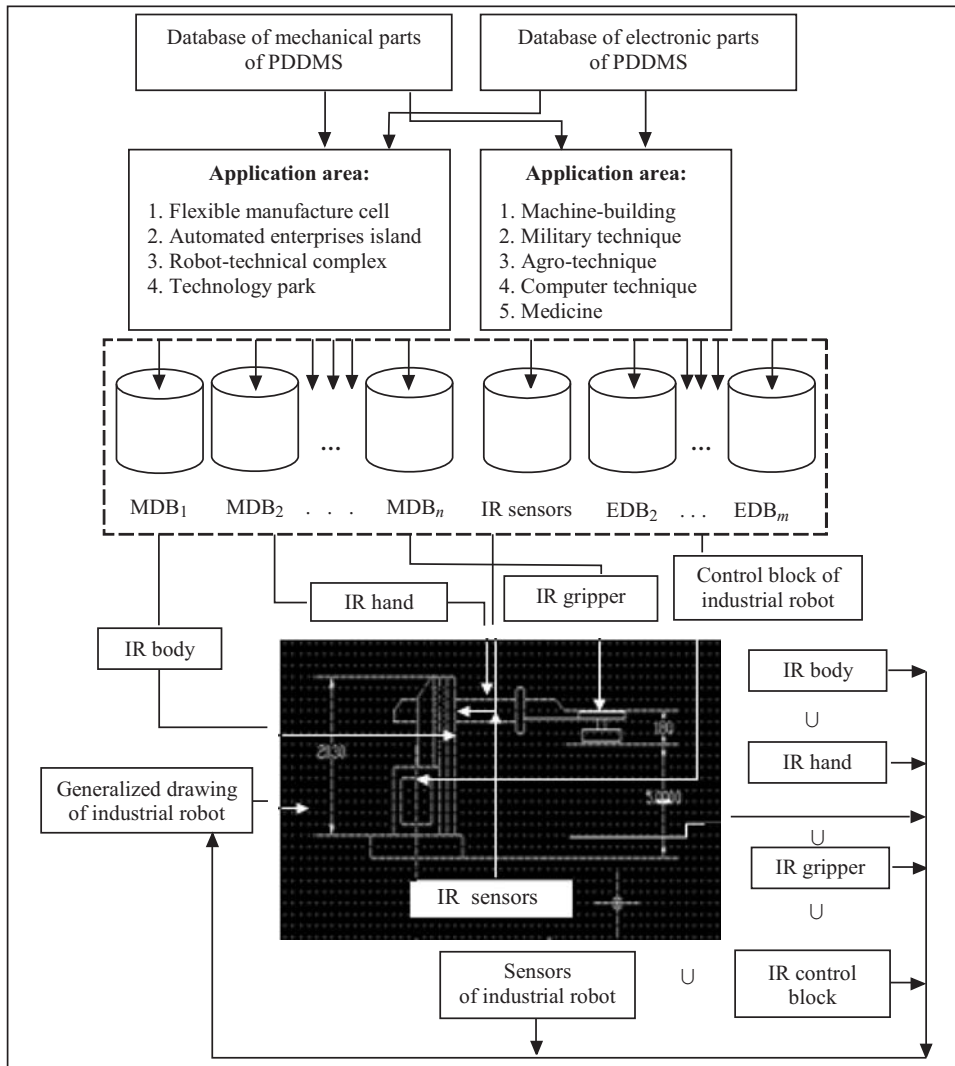
Fig. 3. The scheme of creation of the generalized drawing of IR on the basis of mechanical and electronic parts selected from PDDMS
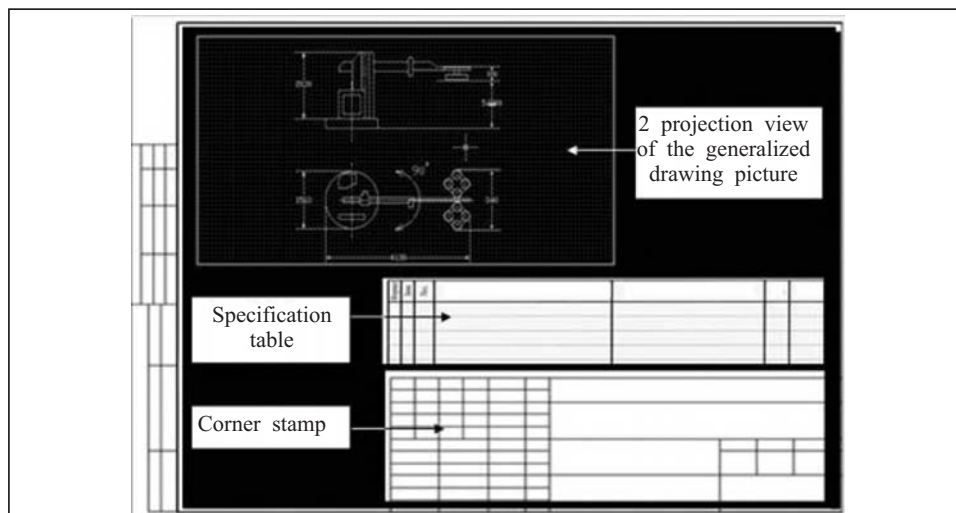

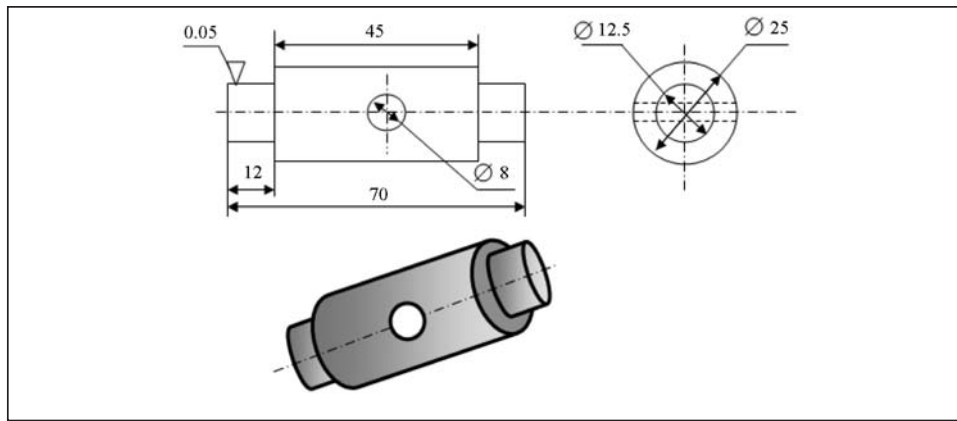*Fig. 4.* The generalized visual view of IR and its constructive database

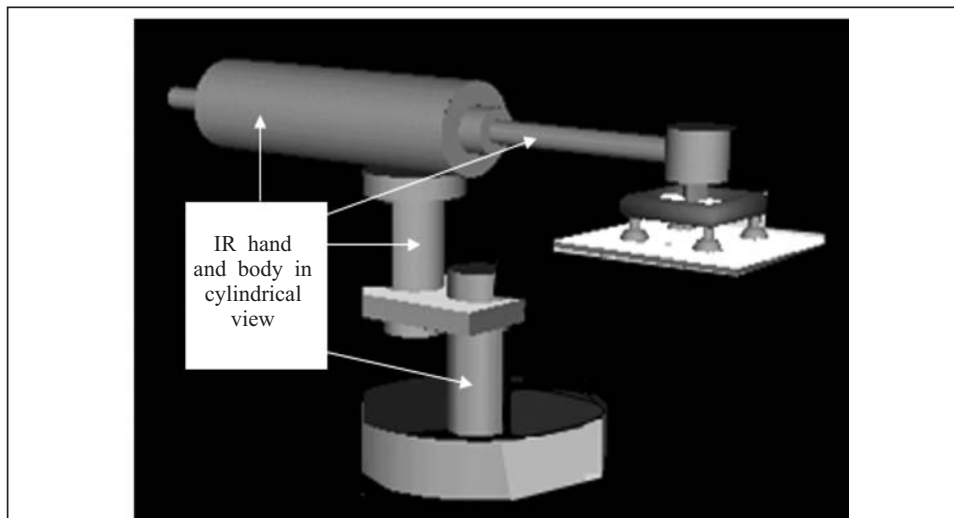*Fig. 5.* Cylindrical geometric figure of the arm part of the IR

Fig. 6. 3D axonometric view of IR formed from 3-dimensional geometric figures

symmetry with the frontal view. The broken lines are directed to the second projection area. The broken lines intersecting the central axis of the top view define the top-view boundary dimensions of the IR arm, handle, body, and control unit. Other intersecting geometric figures are placed in the drawing area of the top symmetricaly. As a result of drawing the second projection (Fig. 4) in the form of a specification table and a corner stamp, its information support is added to the generalized line obtained.

Based on the geometric dimensions of the project object in a 2-dimensional generalized view, its 3-dimensional axonometric description is developed. In the 3-dimensional image, the mechanical parts of the IR — body, arm (Fig. 5), hand, and electronics — control unit, sensors, actuators are generally formed in the form of rectangular prisms, cylinders and cones (Fig. 6).

CONCLUSIONS

1. We developed the structure of the menu procedures of the intelligent software interface to ensure the complex automation of the design process of FMS.

2. We proposed the structure of software menu procedures for the creation of 2- and 3-dimensional graphical representations of the technical system in CDMS.

3. We proffered the scheme of creation of the generalized drawing of technical system (on an example of an industrial robot) on the basis of mechanical and electronic parts selected from PDDMS.

REFERENCES

1. Jefferson T.G., Benardos P., Ratchev S. Reconfigurable assembly system design methodology: A wing assembly case study. *SAE International Journal of Materials and Manufacturing.* 2015. Vol. 9, N 1. P. 31–39.

2. Tolio T., Sacco M., Terkaj W., Urgo M. Virtual factory: an integrated framework for manufacturing systems design and analysis. *Procedia CIRP.* 2013. Vol. 7. P. 25–30.

3. Terkaj W., Tolio T., Valente A. Designing manufacturing flexibility in dynamic production contexts. In: Design of Flexible Production Systems. Tolio T. (Ed.). Berlin; Heidelberg: Springer-Verlag, 2009. P. 1–18. https://doi.org/10.1007/978-3-540-85414-2_1.

4. Terkaj W., Tolio T., Valente A. Design of focused flexibility manufacturing systems (FFMSs). In: Design of Flexible Production Systems. Tolio T. (Ed.). Berlin; Heidelberg: Springer-Verlag, 2009. P. 137–190.

5. Cantamessa M., Fichera S., Grieco A., Perrone G., Tolio T. Methodologies and tools to design production systems with focused flexibility. *Proc. 4th International Conference on Digital Enterprise Technology* (19–21 September 2007, Bath, UK). Bath, 2007. P. 627–636.

6. Colosimo B.M., Poggi A., Tolio T. The tooling system configuration in a new manufacturing system architecture. *Int J. Prod. Res.* 2002. Vol. 40, Iss. 15. P. 3779–3790.

7. Contini P., Tolio T. Computer-aided set-up planning for machining centers configuration. *Int J. Prod. Res.* 2004. Vol. 42, Iss. 17. P. 3473–3491.

8. Matta A., Semeraro Q., Tolio T. Configuration of AMSs — Stochastic models for performance evaluation of Automated Manufacturing Systems. In: Design Advanced Manufacturing Systems: Models for Capacity Planning in Advanced Manufacturing Systems. Matta A., Semeraro Q. (Eds). Dordrecht: Springer, 2005. P. 125–189.

9. Tolio T., Valente A. An approach to design the flexibility degree in flexible manufacturing system. *Proc. Flex Autom & Intell Manuf. Conf.* (25–27 June, 2006), Limerick, Ireland. Limerick, 2006. P. 1229–1236.

10. Colledani M., Gyulai D., Monostori L., Urgo M., Unglert J., Van Houten F. Design and management of reconfigurable assembly lines in the automotive industry. *CIRP Annals.* 2016. Vol. 65, Iss. 1. P. 441–446. http://dx.doi.org/10.1016/j.cirp.2016.04.123.

11. Mammadov J.F., Huseynov A.H. Algorithmic and computer-aided design software for the layout scheme of a flexible production system. *Information Technologies in Design and Production.* 2011. N 1. P. 49–52. (In Russian).

12. Mammadov J.F., Tagiyeva T.A., Akhmedova S.M., Aliyeva A. Interface for intelligence computing design and option of technical systems. *Intelligent Control and Automation.* 2015. Vol. 6, N 4. P. 289–294.

13. Marikovskaya M.P. Automation informative of intelligence system for design of technological equipment: Thesis: 05.25.05. Tambov, 2008. P. 34–41. (In Russian). URL: https://www.dissercat.com/content/avtomatizirovannaya-informatsionnaya-intellektualnaya-sistema-dlya-proektirovaniya-tekhnolog.

14. Новосельский В.Б. Метод автоматизации проектирования распределенной реляционной базы данных. *Программные продукты и системы.* 2008. №3. С. 45–48. URL: http://swsys.ru/index.php?page=article&id=1578.

15. Мамедов Дж.Ф. Разработка структуры интерфейса программного обеспечения комплексного автоматизированного проектирования технических систем. *Вестник компьютерных и информационных технологий.* 2013. № 5 (107). С. 18–21.

16. Zadeh L. From computing with numbers to computing with words — from manipulation of measurements to manipulation of perceptions. *International Journal of Applied Math. and Computer Science.* 2002. Vol. 12, N 3. P. 307–324.

Дж. Мамедов, І. Алієв, Г. Гусейнова, Г. Оруджова

АЛГОРИТМІЧНЕ ЗАБЕЗПЕЧЕННЯ ДЛЯ КЕРУВАННЯ АВТОМАТИЗОВАНИМ ПРОЄКТУВАННЯМ ГНУЧКИХ ВИРОБНИЧИХ СИСТЕМ ТА ЇХНЬОГО ОБЛАДНАННЯ

Анотація. Запропоновано структуру системи керування автоматизованим проєктуванням для розроблення комплексної системи автоматизованого проєктування гнучкої виробничої системи, що забезпечує високу продуктивність, гнучкість, універсальність і точність виконання проєктних процедур у межах єдиного системного інтерфейсу. Розроблено алгоритмічне забезпечення керування автоматизованим процесом проєктування гнучкої виробничої системи для реалізації процесу комплексного автоматизованого проєктування. Запропоновано алгоритм для експериментального дослідження проєктних процедур зі створення складних графічних даних мехатронних частин промислового робота та формування бази розрахункових даних і графічних елементів.

Ключові слова: гнучка виробнича система, система керування автоматизованим проєктуванням, елементи 2- і 3-вимірної графіки, узагальнене креслення.