Methods and algorithms of development of a CAD system to design automated process control systems in the transport sector

D I Sachkov¹, A V Dimov¹, R U Upyr¹

¹Irkutsk State Transport University, Irkutsk, Russia

E-mail: leninb@yandex.ru

Abstract. The article considers questions of creation of an intelligent CAD (Computer-Aided Design) system to design APCS (Automated Process Control System) in the transport sector. The CAD system should represent a graphic 2D engine adapted for the solution of problems of design of APCS, surrounded with an information support cloud in the form of a set of relational databases of the engineering information necessary for effective and error-free work of the APCS designers. Programs of processing information that appears on drawings, schemes and tables of the APCS projects on the basis of the algorithms adopted in this subject domain should become an essential part of information support. A CAD system should be equipped with artificial intelligence programs for processing and sorting of external information and search of mistakes in the project.

1. Introduction.

The main direction of the innovation development of the Russian industry is to universally develop and implement computerized APCS (Automated Process Control Systems), as well as to replace old analogue monitoring and control systems (MCS) with digital APCS. At the same time, human participation in process flows is minimized (the proverbial “human factor” is eliminated), the volume of automatic regulation of the process flow expands and its quality improves, providing reliable protection of equipment from all kinds of accidents, simplifying the analysis of emergency situations, improving the personnel labor quality, etc. The APCS is required to be pre-designed.

This article discusses an intelligent CAD (Computer Aided Design) system for the designing of automated process control systems. The basis of this CAD is a cloud of information support in the form of a set of relational databases of engineering information necessary for the efficient and error-free operation of the designers of the automated process control system. An essential part of the information support should be the programs of processing information that appears on the drawings, diagrams and tables of the APCS projects. They contain a general part, applicable to all types of drawings, and an individual component, applicable only to drawings, diagrams and tables of a particular type.

As practice shows, the need to develop information assurance to support CAD systems is extremely high. The available graphic programs, such as AutoCAD, AutoCAD-electrical, Compass, CAD-Alpha, E-Plan, and others do not fully satisfy the needs of designers, as they solve only some part of the APCS design tasks and leave too much manual work as a consequence.
2. Distinctive features of the design of APCS
The design of automated process control systems is different from the design of machines, mechanisms, buildings and structures:

1. The graphic part of the APCS project consists mainly of a set of flat (2D) drawings and diagrams with its specific set of graphic elements connected by lines and arrows of various types.
2. Quite a number of alphanumeric designations - by orders of magnitude more than in the schemes of machines and mechanisms, buildings and structures - are plotted to the drawings.
3. The project of the automated process control system has a tabular part, the amount of which exceeds 50% of the total number of project volumes. The information contained in the tabular part is complexly connected with that which is put on the drawings.

This article discusses the development of intelligent CAD for the automated process control system. A CAD system like this should contain a project management program, a 2D drawing program, a relational database, a generator of output forms and a significant amount of information management and processing programs.

The methodological aspects of developing a database to support CAD for the automated process control system, as well as the specific content of the CAD information support are elaborated in [1,2,3,4]. It is shown that, conceptually, works in the field of databases for CAD systems have a direct link to the problem of artificial intelligence and have not been implemented earlier [5, 6].

3. An approach based on engineering information databases
The result of the work is a new type of CAD systems for the APCS design. The graphic engine of such a CAD system is immersed in a cloud of engineering information databases arising in a specific APCS project and accumulated from various projects. Work with the CAD is performed in a general purpose program through a special interface. Engineering information in such a CAD system is processed using "artificial intelligence" technologies, i.e. special well-considered design algorithms that implement a modular or object-oriented approach to the format ion of the APCS structure.

An intelligent CAD for designing automated process control systems will make it possible to:

1. Reduce the time to design systems of APCS class by three or four times.
2. Reduce the number of engineering and technical personnel engaged in the APCS design in design organizations.
3. Reduce the time spent on the APCS project adjustment, project checking and finding errors up to 10 times.
4. Minimize the number of errors in the APCS project arising due to the "human factor".
5. Semiautomatically sort and place in the database external engineering and economic information with minimal involvement of the designer’s brain costs.
6. Automatically find and correct errors in numerous codings and markings of signals, equipment, cable cores, terminal arrangements, etc.
7. To give hints to the designer during the collection of primary information and block possible errors.
8. Automatically generate output design forms, complex and bulky cable schedules, cable records, tables of connections of cable cores to terminal arrangements, etc.
9. Automatically generate a field information database for broadcasting to a SCADA system.

The developed CAD system contains several software modules: AutoCAD module, general purpose C++ program module, Access database module, Word module, AutoCAD interaction module (VBA, VB.NET macros). We purposefully chose the AutoCAD-14 module for implementation, since it has a powerful and well-developed graphics system. Naturally, the entire graphic service of AutoCAD-14 will be available to the user.

A CAD system for automated process control systems must be intelligent. CAD for APCS belongs to the category of "intelligent support" for computer systems. Its development includes: system-wide solutions, information support, mathematical support, programming support, organizational support.
In the “System-wide solutions” section, the general CAD system software architecture, the general-purpose program architecture, and the AutoCAD add-in architecture are developed.

The information support of CAD system includes the development of: common interfaces, specialized interfaces, information structure of the database, structure of reference information.

The mathematical support may contain (a) a description of the mathematical and logical formulas used by the program, (b) an algorithmic part that describes the logic of the operation of various software modules. In the case of CAD system, the algorithmic part is very extensive. Without the development of algorithmic support, the CAD programming support cannot be written. In the section of “algorithmic support” a set of algorithms is developed, on the basis of which the CAD system works. It includes the following algorithms:

1. construction of project document identifiers, technological installation paths, field devices for the automated process control system, electric signals for field devices, and other APCS elements;
2. operation of AutoCAD built-in windows intended for the construction of paths, the application of field devices to circuits, the construction of electrical circuits;
3. automatic formation of frames and stamps for documents; algorithms for the formation of special tables for schematic electrical diagrams and processing of these tables;
4. processing of electrical circuits necessary to switch to the external wiring diagrams; distribution algorithms for field devices in control cabinets, intermediate terminals and controllers (automation cabinets);
5. automatic generation of project documents of the second group (list of field devices, list of signals of hardware and software complex, cable schedules);
6. formation of reference catalogs;
7. other algorithms.

It is advisable to select the AutoCAD design system as the CAD graphics engine. This system has a powerful 2D graphics editor with advanced service. On the other hand, AutoCAD is essentially an advanced development environment, which makes it easy to write your own services and connect to a standard field. In the third, almost all design institutes and industrial enterprises leading innovative activity have the AutoCAD system.

The standard CAD system database contains the parameters of graphic elements, notes to them, text data for stamps (not always). Additional products (see, for example, AutoCAD-Electrical) reflect domestic designations, terminology and standards. With that, there are practically no products on the market that implement the distribution of devices and circuits for some units, cabinets, boxes and other similar devices. All this results in the absence of effective means of automatic control and taking into consideration the embedding structures and communication of units. Thus, the problem of supplementing the standard parameters of AutoCAD elements with a description of their location and switching with the infrastructure of the structure is considered relevant.

Description of additional parameters can be similarly performed and effectively implemented in relational databases. In these conditions, the standard SQL query language can be used to solve various table formation problems. AutoCAD provides ample opportunities to access tabular data [8], including those placed in databases [9].

Using SQL allows one to implement various queries to design data in a database management system (DBMS). One can use a variety of data formats to select a DBMS. MS Access DBMS is selected to implement this project. It provides the processing of the required data volumes for a large project of automated process control systems (within the limits of 1000 field devices). This DBMS is widely distributed and is part of the standard office software. The stem-forming technology provides storage of tabular data and running queries to them, and also allows the database to be included in the project as an additional, free file, avoiding the need to manage and maintain the SQL server.

As a result, in the work on the basis of the technology of additional databases the following labor-intensive non-standard tasks of automatic electrical design can be implemented within the framework of a modular (object) approach: Construction of tables for distribution of field devices over APCS cabinets; Construction of tables for distribution of field devices over the APCS subsystems;
Construction of tables for connecting cables to cabinets; Construction of cable project schedules for the system installation; Construction of a cable record; Construction of project specifications; Construction of the project register; Construction of lists of project field devices and their signals; Generation of engineering tables in the drawings; Providing reference tables.

Each of these technologies has its own advantages and disadvantages. Using Object-ARX allows one to write the most efficient and small-footprint code. However, in programs in C++, one have to do manually a lot of things that are automated in higher level languages. As a result, the speed of development and especially debugging may fall unnecessarily. It makes sense to use this technology when resource-heavy calculations are expected, such as 3D modeling and non-standard analysis and data processing. In our case, this need arises when writing a general-purpose program. At that, one can use simpler approaches when interacting with AutoCAD.

Auto-LISP is the oldest mechanism for expanding the capabilities of AutoCAD [14], but this technology has not been actively developed lately. In particular, it is not very convenient to develop forms and other user interface mechanisms by using Auto-LISP. It is also hard enough to find qualified developers with knowledge of the LISP language, which can increase development and support costs.

The Visual Basic for Applications (VBA) technology is widely used to automate AutoCAD after Microsoft began using the same environment in its Microsoft Office suite. It compares favorably with Object-ARX by automatic memory management, user-friendly user interface creation and database access. The disadvantages of this technology are the lowest software code efficiency, as well as the recent trend of development of this environment, slowed down by both Autodesk and Microsoft [16].

The .NET technology, on the contrary, is actively developing. With virtually every version of Windows, new versions of the .NET Framework are released, while maintaining compatibility with previous versions. The convenience of creating a user interface and database access has only increased compared to VBA. The unique advantage of this environment is that the same program (the compiled code, not the source code) can be run on both 32-bit and 64-bit versions of AutoCAD [16]. The speed of the programs on .NET occupies an intermediate position between VBA and C++. Considering the fact that it is the user interface and the work with the database that are critical in our task, the choice of .NET seems to be the most reasonable. This technology, unlike the others described, allows the developer to choose among several programming languages. The most common are VB.NET and C#, there are also less common options: F#, IronPython, IronRuby and others, but choosing them is worthwhile in rather specific cases. VB.NET and C# are almost equivalent in all characteristics, so one can leave the choice between them to the discretion of the developers.

One of the important technical issues that needed to be resolved to accomplish the task, is a method of permanent storage of information.

It is advisable to store the main body of information about the paths, devices, etc. in the database in terms of ease of access. However, it is required to associate this information with the elements of the drawing. Two options are possible:

1. Links to the drawing objects are kept in the database.
2. The AutoCAD document stores information that allows one to link drawing objects and records to the database.

Drawing objects can be uniquely defined by an identifier — a 64-bit integer. To implement the first option, it would be enough to store identifiers of related objects in the database. However, there is a possibility that the user will edit the drawing without downloading our extensions. At the same time, he may, inadvertently as well, perform actions that change the identifiers of objects — for example, cut out a fragment of a drawing and paste it onto another page.

In this regard, the second option seems to be more reliable: the drawing stores information about which element of the drawing corresponds to which record in the database. AutoCAD presents two mechanisms for storing this kind of information: XCODE and XRECORD. XCODE is an older mechanism that is not recommended for use in new projects due to limitations on the amount of stored data [17]. Working with XRECORD entries is somewhat more complicated than with XDATA, but safer due to the absence of the above limitations. Additionally, in the XRECORD record it is possible to
duplicate the main part of the information stored in the database. This will be the key to preventing unnecessary access to the database while working with the drawing.

Report generation is an important task for software developers. There is both specialized software for performing design and report generation tasks, as well as utilities, and libraries included in other software and systems (for example, in the DBMS). Examples of such generators are: Crystal Reports; Fast Report; Gen Rep; List and Labels; Active Reports; Stimul soft Reports.

The presented generators have powerful capabilities, in particular: a large amount of different data drivers; access to sources of heterogeneous data; xml support; visual report designer; experts and masters; drawing diagrams and schematics; custom templates; powerful formula language; export to various formats; customizable report viewers and more.

One of the main tasks of information systems is to promptly present information necessary for decision-making. At the same time, the structure of modern database management systems, on which information systems are based, is focused primarily on compact, secure and consistent storage of information, rather than on optimizing arbitrary sampling and data presentation. The main problem is not storing information, but providing it to the end user in the form of a report in the necessary context.

A special module - a report generator - is responsible for presenting user-friendly information in information systems. The report generator is a module (or a separate program) that allows one to present information in a readable structured form, in other words, to make information from the data (document, report, table), which can be printed or saved in various electronic formats.

Taken together, all of the above disadvantages resulted in the decision to develop our own generator, designed to create reports of the information system for the automated process control system. Reports are created in the form of MSWord documents in accordance with the assigned technical requirements: requirement on the formation of the project title page; requirement on the formation of a statement of the project; requirement on the formation of a list of paths; requirement on the formation of the list of equipment; requirement on the formation of lists of signals.

The generator is based on Microsoft Visual Studio, Visual Basic.NET. ADO Net technology is used for data connection. Connection to various databases is possible. Due to the fact that the APCS uses the Microsoft Access database, all queries are created statically “inside” the generator. The creation of two versions is envisaged: as an embedded library and as a separate software product.

4. Conclusion
This paper considers some issues of developing an intelligent CAD system to design an automated process control system in the transport sector. At the moment, there is no CAD system that satisfies the needs of designers in all respects. The main problem is the lack of advanced intelligent support to form the APCS project. Above, there are main problems that arise when creating a CAD system like this. These include: development of relational databases of project information, development of mathematical algorithms for designing automated process control systems, additional specific service to the graphic engine of CAD, IT technologies of generating report forms using databases, developing a general-purpose control program. These issues are addressed in the article.

Further promising scientific developments include:
- the study of various options for the technical structures of the APCS and their formalization necessary for the best use of IT technologies, such as relational databases, a modular or object-oriented approach in the APCS design;
- the analysis and further development of optimal algorithms for generating APCS design structures;
- development of problems of artificial intelligence to search for and prevent errors of designers.

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