DOI 10.1007/s10527-015-9526-6
Biomedical Engineering, Vol. 49, No. 3, September, 2015, pp. 182-187. Translated from Meditsinskaya Tekhnika, Vol. 49, No. 3, May-Jun., 2015, pp. 41-45.
Original article submitted March 27, 2015.

Classification and Structure of Systems of Computer-Aided Design for Biomedical Engineering

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This article suggests discriminating biological computer-aided design (CAD) systems as a separate class, proposes considering medical CAD systems as a new class of application systems, suggests classification of biological and medical CAD, and describes features of the composition and structure of medical CAD.

Introduction

In recent years, the need to establish medical information systems (MIS) for different purposes has been declared at various levels of the Russian healthcare system. The concept of creating a unified state information system in the health sector was developed. In general, current health information systems already provide certain practical result of their introduction and include a large number of experimental and well-researched decisions with long-term experience of work in terms of national healthcare [1-3].

A survey of the MIS market shows that there is a sufficient number of successful products, some of which implement the technology of computer-aided design of medical facilities and processes. The most relevant of the considered systems are the DentCAD system (Delcam, UK) used in dentistry, the AccuShape system used for plastic surgery of skull defects, and other products of the American company MedCAD [4, 5]. Another known program is TinkerCell, enabling modeling networks of molecular-biological interactions of cell "parts" available in the database, and observing their dynamics; this CAD system is labeled as oriented on biology application [6].

At the same time, the existing CAD systems (including those of medical purpose) implement the principles and techniques of designing technical objects. This situation leads to a narrowing of the actual scope of the CAD technology when addressing health problems.

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In accordance with this, this article proposes the concept and theoretical basis of biological CAD systems different from engineering CAD systems by the type of designed objects, methods, and models of activity of the main users of the system (including models of clinical thinking of a medical doctor), and principles of automation of work with designed objects. Also, features of a medical CAD system are described that should include a narrow class of computer systems – surgery support systems or CAS-technology (Computer Assisted/Aided Surgery) that are being increasingly used in world medical practice. In addition, using the well-known classification of medical technology proposed in [1], the proposed biological CAD could be considered as a new object belonging to the class of systems for automation of biomedical research and demanding independent investigation.

Classification of Biological and Medical CAD Systems

CAD classification by type of the designed object, according to GOST 23501.108-85 [7], considers objects and processes of machine building and tool making, objects and processes of building, software tools, and organizational systems. CAD systems of objects and processes of other types are distinguished into the section "Other". We proposed to expand the classification by biological area. Thus, it would be possible to distinguish the class of "Biological object CAD" and class "Biological process CAD".

Classification of biological object CAD by variety of designed objects should be performed in accordance with sections of biology or the kingdoms of living organisms.

The simplest division for the convenience of the development and application of biological object CAD systems is their conventional division into medical, the main object of which is human, and veterinary, the main object of which are animals.

Classification of biological process CAD by variety of design processes should be performed in accordance with an accepted allocation of functional subsystems and processes in biology.

Thus, a system approach to the following conceptual point of view on biological CAD is proposed (Fig. 1).

The concept of biological CAD is proposed to allocate and separately consider the class of medical CAD. They may be technical, biological, or biotech (mixed) depending on their application and main object of design. Therefore, it is proposed to distinguish the following methods of using CAD systems:

– engineering CAD in design of technical objects and processes (traditional approach);

– engineering CAD in design of medical facilities and processes in biomedical engineering and bioindustry (current trends);

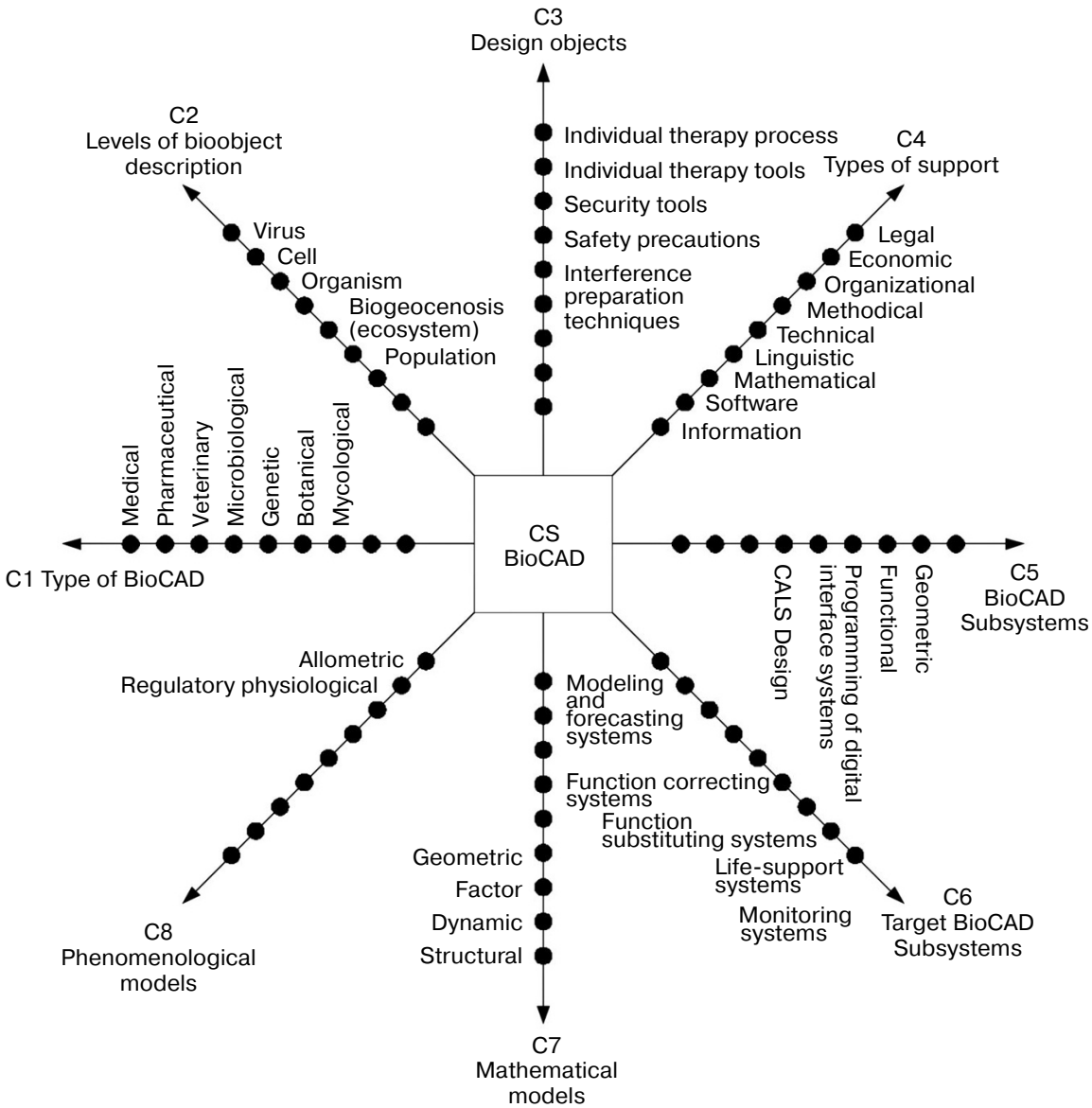

Fig. 1. Coordinate system of BioCAD.

– biological CAD in predicting human health (near future medicine);

– biological CAD to correct genetic defects in humans and animals (medicine of the future);

– biological CAD in the design of technical objects in bionics (near future technology).

When considering the proper medical CAD as a narrower class, it is also possible to highlight anatomical CAD, which is related to biological object CAD, and physiological and psychological CAD related to biological process CAD.

A distinctive feature of medical CAD, offered by the authors, is creation and use of mechanisms and models providing a high degree of unification and standardization of descriptions of objects and processes in the human body and the consequent wide range of their applications. Figure 2 shows a diagram of possible application of a medical CAD depending on the user's role.

Compositional and Structural Features of Medical CAD

Medical CAD consists of various elements, which are presented in Fig. 3.

The structure of medical CAD, as well as of any technical CAD, contains the following types of support: technical, mathematical, software, methodical, organizational, legal, ergonomic, information, and linguistic.

Technical support is a set of connected and interoperable technical devices (computers, peripheral devices, network equipment, communication lines, measuring tools) [5].

Unlike traditional CAD systems, technical support for medical CAD should include specialized medical equipment, such as life support equipment, therapeutic equipment, medical monitors, diagnostic equipment, surgical equipment, medical laboratory equipment, transportation equipment, equipment for calling medical staff, and disinfection and sterilization equipment.

It should be noted that medical monitors and medical diagnostic and laboratory equipment essentially provides information about the patient and using it directly for modeling of the organism, corresponding to CAD-technologies in the international practice of CAD. In turn, data conversion and generation of control programs for life support equipment and medical and surgical equipment (e.g. robot surgeon) in medical CAD can be considered as an analog of engineering CAM systems. The range of these systems can form a closed system under the control of a specialist and solve a wide range of medical problems of surgery, intensive care, and rehabilitation.

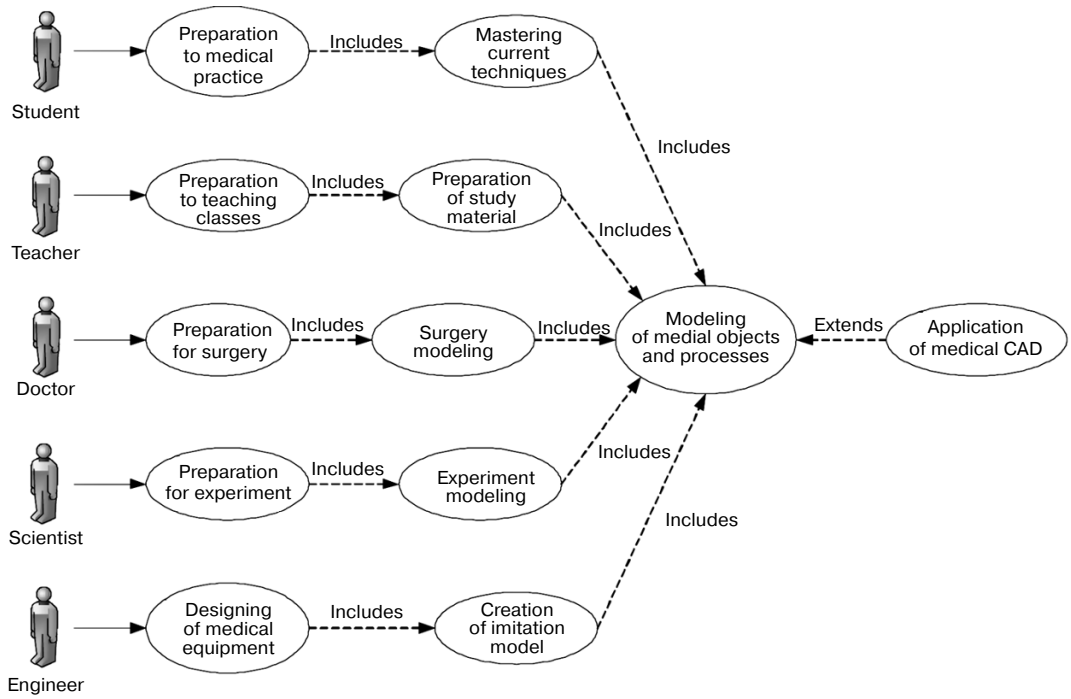

Fig. 2. Application of medical CAD.

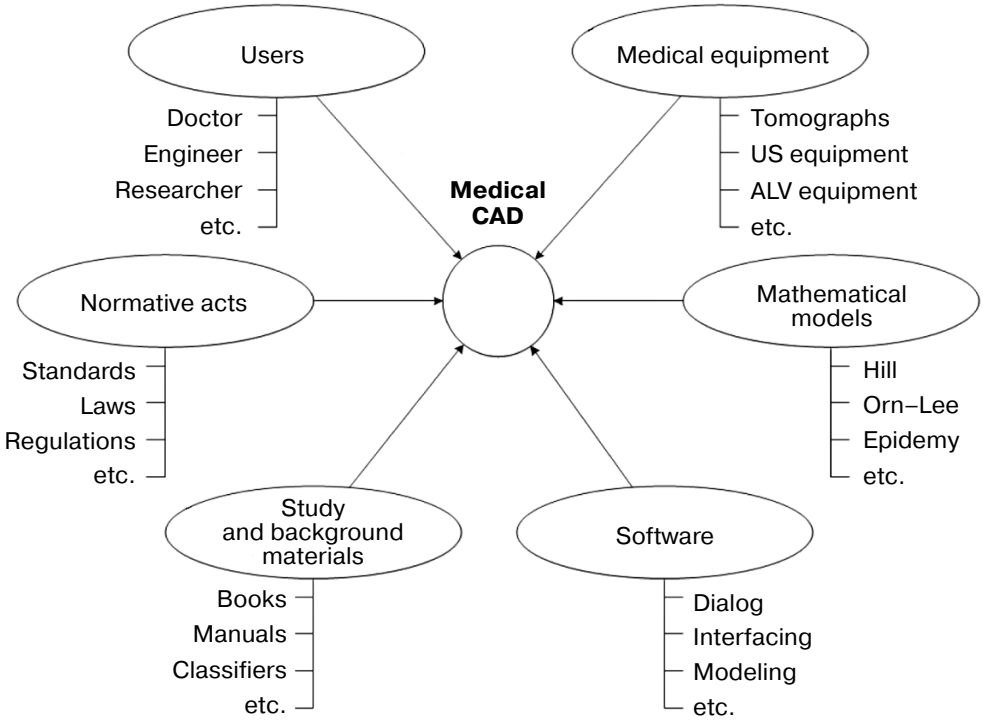

Fig. 3. Example of medical CAD.

Thus, it is essential to ensure standardization of hardware and software interfaces of interaction of medical equipment and medical information systems.

Mathematical support of traditional CAD includes methods of mathematical modeling of objects and processes of design, mathematical models of objects and processes of design, and algorithms for solving problems of the design process [8].

Medical CAD, as well as engineering CAD, must include a unit of classical mathematics and mathematical tool for creation and management of three-dimensional graphics (spatial modeling). The difference in mathematical support between medical and engineering CAD software is the availability of specialized mathematical models of medical facilities and processes, such as the model of patient dynamics depending on the therapeutic effects, Orn–Lee model, Bellman model of optimal injection doses of potent drugs, model of image synthesis in tomography, etc., depending on the purpose of the medical CAD and of the design object. A common feature of most of the models used in the description of biological objects is their assignment to the class of "soft" [8].

Due to the complexity of biological objects in the mathematical support of medical CAD, structural mathematical models can prevail over functional in the initial stage of CAD application.

Information support of engineering CAD is defined as the collection of information needed to complete the design. It consists of a description of the standard design procedures, standard design solutions, components and their models, and rules and regulations of the design [9].

In contrast, information support of medical CAD consists of descriptions of the anatomical structure of the human body, its functional characteristics and pathologies and their treatment, etc. In this regard, this type of information support of medical CAD includes contents of anatomical atlases, various medical reference books, encyclopedias, and other sources of medical knowledge.

Linguistic support includes a set of languages used in CAD for representation of projected objects, processes, and design tools, as well as for designer–computer interaction and communication between the technical tools of CAD. It includes terms, definitions, rules for the formalization of natural language, and methods for compression and decompression [9].

A feature of linguistic support of medical CAD is that it enables formation of logical connection between professional thesaurus of medical workers with descrip-

tions and software implementation of design tools of the medical CAD.

Methodical support is a description of functioning of CAD technology, methods of selection, and application by users of technological methods to produce concrete results. It includes the theory of processes occurring in the designed objects, methods of analysis, synthesis of systems and their components, and various design techniques [9].

Methodical support of medical CAD is based on the technology of therapeutic process, clinical thinking of the physician, as well as models of processes in biological objects, which are significantly different from the processes in technical objects.

Organizational support is a set of documents that define the structure of the project organization, communication between departments, organizational structure and system of automation, activity within functioning system, and presentation of the design results [9].

In contrast to engineering CAD, organizational support in medical CAD should include a medical basis for the organization of the treatment process, job descriptions for physicians, operating rules for equipment connected to CAD, etc.

Ergonomic support integrates interrelated requirements aimed at coordination of psychological, psychophysiological, and anthropometric characteristics, and possibilities of human with technical characteristics of automation systems and parameters of working environment in the workplace [9].

Ergonomic requirements for medical CAD are of specific nature associated with the conditions and characteristics of medical activity. An example of ergonomic medical CAD can be voice control system of geometric spatial models that would enable direct use of the simulation results by a physician during surgery. This can also include using a stylus as an analog to a surgical scalpel during training on a computer simulator.

Legal support is formed by a set of regulations, orders, and instructions defining the legal status of development and functioning of the system [10].

TABLE 1. Examples of Suitable "Element – Type of CAD Support"

Types of support \ Elements	Three-dimensional anatomy atlas	Geometric solver	Mathematical package	GOSTs (CAD, DICOM, HL7)	Laws	MRI equipment	US equipment	X-ray equipment	Physician	Researcher	Engineer	Programmer	Database	Database Control System	Manual	Classifier
Technical						+	+	+								
Software	+	+	+										+	+		
Information	+			+	+								+	+	+	+
Linguistic									+	+	+	+				
Mathematical		+	+													
Methodical				+	+				+	+	+	+				
Organizational				+	+				+	+	+	+				
Ergonomic						+	+	+	+	+	+	+				
Legal				+	+				+	+	+	+				

This type of support of medical CAD has special significance because of the specific duties and responsibilities of medical personnel. The results of the user's work with medical CAD can be used in life support equipment or equipment for invasive procedures. Therefore, for the widespread use of high-grade medical CAD, it is necessary to identify and legislatively establish legal status of the system, the rules, and the results of its work, etc.

Software support of engineering CAD serves for direct implementation of project procedures and contains application packages designed to serve at certain stages of the design or for solutions of groups of similar problems at different stages.

Software support in medical CAD implements other types of support in the form of software and differs from engineering CAD by a suite of software applications. An example of such a program is an anatomical geometric solver.

Different elements can be included into several types of support of medical CAD (Table 1).

Conclusion

The proposed concept of both general and medical biological CAD systems as a professional-oriented product enables implementation of a complex formalized approach to the creation and implementation of such CAD systems. In turn, the use of medical CAD aims to improve the efficiency of health care organizations and medical industry companies. The process of solution standardization in the field of medical CAD enables faster and cheaper development of more advanced medical information systems for the study of the human body under normal and pathological conditions, as well for prediction, diagnosis, and treating various diseases.

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