Information Technology of Robotic Prosthesis Computer-Aided Design Based on Parametric Modeling

A V Parkhomenko*, O M Gladkova, Y I Zalyubovskiy and A V Parkhomenko

National University Zaporizhzhia Polytechnic, 64, Zhukovskogo str., Zaporizhzhia, 69063, Ukraine

*Email: parhom@zntu.edu.ua

Abstract. The features of modern technologies of three-dimensional parametric modeling were investigated in this paper. It was shown that the application of tabular parameterization makes it possible to increase the efficiency of the computer-aided design of biomedical products by accelerating the development of similar components in their composition. An information technology for the computer-aided design of a robotic prosthesis prototype in the PTC Creo environment has been developed. The functionality of the virtual and physical prototypes of the robotic prosthesis was checked with the usage of digital kinematic simulation and real tests. The developed tabular parametric model makes it possible to control the mass-dimensional characteristics of the product during the development of individual prostheses, taking into account the anatomical features of a particular patient.

1. Introduction
The development of modern technologies in the field of bioengineering provides new opportunities, ranging from smart implants and prostheses to 3D printing of tissues and even organs. Earlier a person, who having lost a limb, felt significant discomfort and unnaturalness while wearing a prosthesis. Then modern prostheses have become more approximate both functionally and visually. For example, in work [1], a whole set of hand prostheses was presented, and the same testing procedure had been performed for all of them.

The investigations have shown that the most important parameters influencing the quality indicators of the prosthesis are the hand weight [2-3], the size and anatomically correct kinematics of fingers, the type of drive and the drive mechanism, the force and the speed of grip, durability, and appearance [4]. At the same time, a compromise must be found between anatomical accuracy and reliability, weight, complexity and cost of the product. Thus, there are many problems associated with the design of robotic prostheses, taking into account the individual characteristics of patients, the level of needs and activity. The complexity of parallel design of mechanical and electronic parts of the prosthesis is one of them [5]. The parameters and characteristics of the real product can be improved, and its cost can be reduced based on modern technologies of computer-aided design (CAD) and investigation of virtual prototype of the robotic prosthesis [6-7].

The goal of this work is the development of information technology of computer-aided design of a virtual prototype of the mechanical part of the robotic prosthesis based on parametric modeling.

2. Analysis of the features of a parametric modelling
Parametric modeling is used today in various fields of design, in particular in mechanical engineering and architecture [8]. However, its application in the development of prostheses and implants requires...
consideration of the specifics of the designed products and verification of the results based on comprehensive study of 3D virtual and physical prototypes.

The process of parametric modeling is based on the usage of model elements parameters and interrelations between them. Parameterization gives the opportunity to go through various design schemes in a short time (by changing the parameters or geometric relations) and avoid fundamental errors. Parametric modeling differs significantly from conventional two-dimensional drawing or three-dimensional modeling. In the case of parametric design, the developer creates a mathematical model of objects with parameters. Their change leads to changes in the configuration of the part and the mutual movement of the parts in the assembly [9].

Parameterization of 2D drawings is usually available in CAD-systems of medium and lightweight. However, the emphasis in these systems is on 3D design technology, and the possibility of two-dimensional drawings parameterizing is practically not used. Parametric CAD systems focused on two-dimensional drawings are often "truncated" versions of more advanced CAD. Three-dimensional parametric modeling is a much more efficient (but also more complex) tool than two-dimensional parametric modeling. In modern systems of medium and heavy weight, the presence of a parametric model is embedded in the ideology of CAD itself, and the parametric description of the object is the basis for the entire design process.

As studies have shown, there are different types of parameterization (Fig. 1), which have their own features, advantages and disadvantages.

![Figure 1. Classification of parameterization types](image)

Tabular parameterization is based on the creation of a table of parameters for typical parts. The development of a new instance of the part is carried out by selection from the table of standard sizes. The possibilities of tabular parameterization are limited because it is usually impossible to set arbitrary new values of parameters and geometric relations. However, tabular parametrization is widely used in all parametric CAD-systems as it can significantly simplify and speed up the creation of libraries of standard and typical parts, as well as their use in the design process [9]. That is why tabular parameterization can be recommended for use in the automated design of prostheses and implants to take into account various standard sizes, depending on the individual anatomical characteristics of patients.

3. Information technology of parametric modelling

According to research [10], PTC Creo is one of eight the best parametric modeling software in the world. The system has powerful functionality and provides an intelligent design environment. That is why this system was chosen for parametric modeling of a robotic hand prosthesis. The main stages of the developed information technology are the following.

1. Creation a structural diagram of a designed product based on the principles of hierarchy and decomposition (Fig. 2).

2. Analysis of the design features of the components of the product and identification of features (notches, channels, etc.) to ensure kinematic properties.
3. Design of individual parts (fingers) using tabular parameterization. Table 1 contains the following parameters: F_HEIGHT - finger height; F_WIDTH - finger width; F_LENGHT - finger length; F_F_HEIGHT - height of the main part of the finger; F_WIDTH_END - width of the terminal phalanx; SMALL_F - length of the terminal phalanx of the finger; F - length of the main phalanx of the finger.

![Figure 2. Structural diagram of a designed product](image)

The parameters F_HEIGHT, F_WIDTH, F_LENGHT are entered by the designer independently, based on the dimensions of the required finger. The parameters F_F_HEIGHT, F_WIDTH_END, SMALL_F, F are calculated using simplified expressions that were obtained based on the anatomy of an average person's finger: 

- \( F_F_HEIGHT = F_HEIGHT - 9 \);
- \( F_WIDTH_END = F_WIDTH - 1 \text{mm} \);
- \( SMALL_F = (F_HEIGHT / 3) \times 4 \);
- \( F = (F_LENGHT - (SMALL_F + 2 \text{mm})) / 2 \),

where 2 mm is the sum of the distances between three phalanges and 2 is the number of phalanges.

4. Building and rendering of the final assembly (Fig. 3a). Checking the functionality of the product with digital kinematic simulation tools.

5. Generation of files for printing the components of the product on a 3D printer.

6. 3D printing, assembling and testing the physical prototype (Fig. 3b).

| Parameter     | Index finger, mm | Middle finger, mm | Ring finger, mm | Small finger, mm | Thumb, mm |
|---------------|------------------|-------------------|-----------------|-----------------|---------|
| F_HEIGHT      | 13,2             | 14,1              | 13,2            | 12              | 16      |
| F_WIDTH       | 14               | 15                | 14              | 13              | 18      |
| F_LENGHT      | 71,6             | 77,8              | 71,6            | 56,7            | 80      |
| F_F_HEIGHT    | 4,2              | 5,1               | 4,2             | 3               | 7       |
| F_WIDTH_END   | 13               | 14                | 13              | 12              | 17      |
| SMALL_F       | 17,6             | 18,8              | 17,6            | 16              | 21,333  |
| F             | 26               | 28,5              | 26              | 19,35           | 28,333  |
Conclusions

The usage of prototyping technologies in computer-aided design of robotic prostheses opens ways to further improvement of their shape, weight and size characteristics and control algorithms. Creation and research of a virtual prototype of a designed product allows to identify errors at the early stages of project creation and, accordingly, reduce the development time and costs for revision; to explore more alternatives and ways of project realization; to perform prototype investigations, which are sometimes impossible in real conditions on a full-scale model; to perform fewer physical experiments that require significant time and material costs.

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