# Exploration of Human-Computer Interaction System for Product Design in Virtual Reality Environment based on Computer-Aided Technology

Qiongqiong Guo[1] and Guofeng Ma[2]

[1]School of Artificial Intelligence, Zhengzhou Railway Vocational & Technical College, Zhengzhou, Henan 450052, China, guoqiongqiong4472@163.com

[2]School of Artificial Intelligence, Zhengzhou Railway Vocational & Technical College, Zhengzhou, Henan 450052, China, maguofeng@zzrvtc.edu.cn

Corresponding author: Qiongqiong Guo, guoqiongqiong4472@163.com

**Abstract.** The development and application research of quasi-realistic technology provide new auxiliary means for product design. With the help of the establishment of virtual scenes, dynamic simulation of model making process, and stereoscopic visual rendering of the environment, designers can make the most similar to the actual physical model. We carry out the conceptual design of the product in the environment, thereby getting rid of the constraints of the traditional modeling software on the expansion of the designer's thinking in the conception stage of the scheme. The development of virtual reality technology has stimulated changes and progress in related fields, and tactile feedback can effectively improve users' immersion in a virtual environment. This article combines virtual reality technology with computer-aided design, based on virtual reality graphics library and computer-aided product design software development kit to establish a product modeling system based on tactile feedback, which injects new vitality into traditional design methods. In this paper, a product design model based on virtual reality technology is established, and the discrete mass points in the grid are fitted with triangular surface products, and then the dynamic analysis of the mass point system under external force is performed, and the Euler method is used to solve the dynamics of the system. We discuss the realization mechanism of tactile feedback in virtual environment based on proxy points and analyze the hardware composition and software development tools of the tactile/graphic dual output system. We start from the convenience of operation and the functional requirements of computer-aided modeling design, based on the window menu instruction mode, use virtual reality application toolkit library functions to design and build the human-computer interaction interface of the modeling system.

**Keywords:** Virtual reality; computer aided; product design; optimization
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## 1 INTRODUCTION

Driven by the rapid development of computer technology and the demand for reform of traditional industrial design methods, computer-aided industrial design (CAID) has generally been involved in the field of industrial design. Computer-aided industrial design refers to product designers who carry out various creative activities in the field of industrial design with the support of computers and corresponding computer-aided industrial design systems, including product modeling, visual communication design, and display design [1]. General product development is divided into forward engineering and reverse engineering. Forward engineering is from conceptual design, product design drawings to the establishment of three-dimensional CAD models, while reverse engineering is to obtain three-dimensional digital models from the measured data of objects or models. For example, the car design involves complex functional products, which are difficult to directly model and not easy to control. Therefore, the general design process is to first draw the conceptual design effect diagram, and we obtain the optimal solution after evaluation; secondly, the effect diagram is refined and the evaluation is determined. Effect drawing plan makes the sludge model again, and it builds the CAD three-dimensional model of the car on the basis of this model to make the CAD structure design [2, 3]. Although this design method that combines traditional and digital models is widely used, the early drawings and physical models consume a lot of time and resources.

With the nourishment of the powerful power of computer technology, virtual reality technology has been developed day by day, and has penetrated into the research fields of various disciplines, injecting fresh blood into industries such as industrial production, entertainment, medical care, and education. CAID technology absorbs advanced research results in the field of computer graphics to serve industrial design. Its traditional pure graphics system restricts design ideas and lacks an interface for horizontal transplantation of experience. This makes the introduction of virtual reality technology to optimize the CAID system present a natural advantage. The unique interactivity, immersion and multi-directional information feedback of virtual reality technology can make up for the shortcomings of the CAID system based solely on images. The rapid development of science and technology promotes fundamental changes in people's lifestyles, and at the same time provides new materials, new methods and new ideas for product design [4]. Scientific and reasonable design and management methods can effectively reduce production costs and production cycles. With the support and encouragement of technological development, product design models are moving towards digitalization, integration, networking and intelligence. This subject is dominated by application research, based on virtual reality feedback equipment and its software development kit, combined with real-time graphics rendering technology under CAD, to achieve simultaneous graphics/tactile display, and establish a tactile product modeling system suitable for product design. We solve the unnatural connection between traditional CAD modeling methods and pointing devices and conceptual design, and discuss the transformation of traditional product development systems based on tactile feedback. And through case studies on the basic methods of constructing virtual prototypes of consumer electronic products in virtual reality environments, we discuss how to apply computer virtual reality technology to the design process of consumer electronic products, so that computers can assist the development of consumer electronic products to a greater extent, and accelerate the development process and reduce costs, design products that meet market needs. The thesis provides a new design idea for the prototype construction in the industrial design stage, and the method and process given have a certain degree of operability and practical value.

## 2 RELATED STUDIES

Computer-aided process design is the middle joint between product design and manufacturing management, and is the computer-aided design and documentation of the assembly process. From the 1990s to the present, CAD technology has realized the standardization, standardization and scale of assembly process, and has made significant progress in the aspects of intelligence, integration, and tooling. Many countries have conducted a lot of exploration and research on CAD technology, and the country has included it as a key development project of CIMS(Computer Integrated Manufacturing System) [5]. CAD is an important link in the cross-collection of information from various departments and the data source of the product information management system. The successful development of a CAD system can shorten the production cycle and free the majority of technicians from repeated and tedious labor. Many problems in CAD systems are extremely complex, and there are often no algorithms to follow. Therefore, people use artificial methods and technologies to simulate human thinking and realize "machine thinking" to solve problems that only human experts can solve. They use the company's existing process design knowledge and the empirical knowledge of process experts to create a process knowledge base, and use intelligent technology to achieve a high degree of knowledge in each process stage of process design. Boton [6] proposed production rules based on disassembly and replacement of tools and fixtures, and obtained the assembly process through graph search, and realized the automatic generation of the assembly process based on knowledge. The process design standards of the reconfigurable 3D-CAD system based on platform technology are not uniform, and general-purpose CAD cannot meet all the needs of enterprises. Using the database-based integration platform IDP and integrated development platform IDE with the system's secondary development interface, a dedicated CAD system has been developed on the existing system. The establishment of assembly process design based on the 3D model can make full use of the feature information in the model for process design. Zhang et al. [7] used model to extract 3D model data, and used OpenGL high-quality images to redraw the 3D model. Coburn et al. [8] used the product information of the model to improve the feature recognition of the model. The quality of assembly sequence planning directly affects the difficulty and accuracy of assembly operations, and plays an important role in the entire life cycle of product manufacturing. Experts and scholars at home and abroad are actively participating in the exploration of this field. Digital assembly sequence planning technology is a product of the fusion of computer-aided assembly process design and virtual reality. Roldán et al. [9] put forward the concept of virtual reality. VR technology combines simulation technology, multimedia technology, sensor technology and other disciplines. VR is a highly realistic human-computer interaction technology that can immerse people in a computer virtual environment. The natural interaction between people and the real environment is modeled through visual, auditory, tactile and other behaviors. VR technology provides a new means for assembly process training. Virtual reality-based assembly provides users with a good simulation environment. With the help of tools such as data gloves, stereo glasses, and helmets, the virtual environment is used to simulate actual operations. Digital assembly sequence planning for non-immersive desktop display: a computer or monitor screen is used as a window for users to observe the virtual environment, and it is necessary to wear stereo glasses to observe and operate three-dimensional images, which is simple and convenient. For example, Paes et al. [10] proposed the first digital assembly system to display the assembly process generated by the virtual environment on the desktop. At the same time, combining virtual reality and intelligent disassembly algorithms, the system can automatically plan the disassembly sequence. With the advancement of assembly sequence planning based on virtual reality, corresponding assembly process editing and teaching are needed. At present, there is a lack of research on combining three technologies of assembly sequence planning based on virtual reality, three-dimensional process editing and assembly teaching [11].

## 3 APPLICATION OF COMPUTER AIDED PRODUCT DESIGN SYSTEM BASED ON VIRTUAL REALITY TECHNOLOGY

### 3.1 Virtual Reality Technology Hierarchy

Virtual Reality (VR) actions such as listening, seeing, and moving in a natural environment. It is a system for experiencing the virtual world. It combines the most advanced modern information technology and human creativity. VR system can provide the advantages of real-time interactive operation, three-dimensional space and multi-channel man-machine interface.

$$X[n]=\{x,i=1,2,...,n\,|\,x(1),x(2),...,x(i),i\in N\} \tag{1}$$

In this virtual design triangle, network technology is the foundation of virtual reality technology, and a parallel structure design system is established through the network. It connects consumers, manufacturers, and designers on one platform, and also integrates design, engineering, manufacturing, and consumption into one system. Due to time and space constraints, factors such as people and equipment involved in a product from design to market entry may be different, which requires a unified digital model.

$$y(x)=n(t)/n(x)*a+n(t-1)/n(x-1)*b,a,b\in[0,1] \tag{2}$$

The multimedia computer system integrates text, image, sound, data and other media, and has the function of comprehensively processing audio, video, image, text and other types of information, including computers, televisions, video recorders, tape recorders, game consoles, and faxes. The performance of many new electronic products, such as the machine, has realized the integration of graphics and text, and the integration of audio-visual.

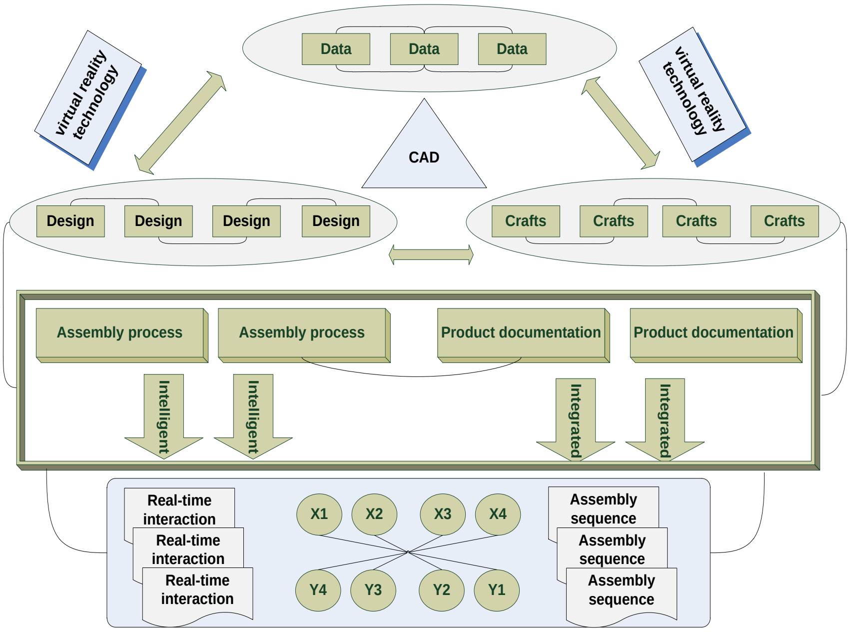


**Figure 1:** Schematic diagram of the hierarchical architecture of virtual reality technology.

Figure 1 shows a schematic diagram of the hierarchical architecture of virtual reality technology. This is also called the virtual technology triangle.

$$D(t)-\frac{\sum_{t=1}^{N}\sigma(t)*y(x)}{\sum_{t=1}^{N}\sigma(t)}=0 \tag{3}$$

The graphics system includes: geometric configuration, drawing engineering design drawings, drawing various function curves, drawing various data tables. We perform graphics transformation on the graphics display, as well as analysis, simulation, and simulation. The graphics system is the basis of CAD technology. The database is a universal, comprehensive and "data collection" that reduces data duplication.

$$f(x,t)=\begin{cases}\alpha*x(t)+(1-\alpha)*x(t-1), x>t\\ x(t)+x(t-1), x<t\end{cases} \tag{4}$$

It composes data according to the natural connection of information, that is, it stores the description between the data itself and the entity in the database, and uses various methods to combine the data to meet various needs and make the data needed for the design convenient, new data is easy to add.

$$T(x,t)=\max(\{f(x,t)\,|\,x,t\in P, f(x,t)\to f(x,0)\}) \tag{5}$$

The basic configuration of the hardware system consists of four components: computer, monitor, printer and plotter. The computer performs data processing, and the processing results are displayed on the display for the designer to judge and modify. Finally, the plotter outputs the required graphics, and the printer is used to output the results of the data processing. If necessary, it can also output the printed graphics.

$$H(x)=\begin{bmatrix} f(x,1) & 0 & 0\\ 0 & f(x,2) & 0\\ 0 & 0 & f(x,t)\end{bmatrix}*\begin{bmatrix} s(1) & 1\\ 1 & s(2)\end{bmatrix} \tag{6}$$

The computer-aided highway design system takes the environmental sections in highway planning, design and management as the main line, uses computer technology for data collection, processing and development, and completes highway design theories, methods and modeling. They mainly include: terrain data collection, digital ground model, route CAD, and system analysis, system design, system implementation and system application of the integrated system of route design based on aerial survey digital model and field survey digital model.

### 3.2 Computer-Aided Product Design and Implementation

Conceptual design has an important meaning in product design, it is a manifestation of creative thinking. The conceptual product designed using virtual reality technology is a digital virtual product (VP), but it contains the characteristics of a real product. On this digital product, we can simulate real-time operation through virtual technology, and designers can evaluate, analyze and improve it as if it were a real product. Table 1 shows the analysis of computer-aided product design data. The computer-aided process includes not only the processing and management of product data, but also the organization of the auxiliary process. The latter includes the planning of the process, as well as the supervision of content and deadlines. Product development and production development are carried out at the same time, and the target and market positioning product development of the entire process chain is pre-optimized. The computer can not only ensure that the product-related sub-tasks in the process are computer-assisted, but also need a computer-assisted system in the process organization of the overall process. At the same time, it also needs a mechanism for proper data exchange between systems.

| Process index | Type of data | Display method | Expressable information |
|---|---|---|---|
| 1 | Nvarchar() | Text | Process node |
| 2 | Number | Number | Employee ID |
| 3 | Varchar() | Figure | Process drawings |
| 4 | Varchar() | Animation | Assembly simulation |
| 5 | Nvarchar() | Tree structure | Product structure |

**Table 1:** Data analysis of computer-aided product design.

As the core part of virtual reality, graphics technology is an important part of it. How to provide true and lifelike displays and simulated reality scenes are all problems to be solved by computer graphics. The main content of computer graphics has three parts, namely three-dimensional object modeling, rendering technology and human-computer interaction technology. The most commonly used is geometric modeling, that is, the shape to be displayed is represented by a batch of geometric data and the relationship between the data, which is generally a regular shape. In computer-aided design and manufacturing, in order to connect the representation method of the shape with the engineer's habit of describing the shape and facilitate the integration of CAD/CAM, feature modeling technology has emerged in recent years, that is, the use of shape features, material features, and tolerance features. When describing a product, in order to express irregular shapes, fractal modeling, grammar-based modeling, etc. appeared.

Figure 2 shows the flow chart of computer-aided product modeling design. Since the design of industrial products involves a wide range of products and industries, the appearance and internal structure of different products vary greatly in complexity, and different companies have different requirements for design work, so sometimes design work of the procedure will be different. But in general, there is a basic design process for every product design. It is generally divided into three stages, namely "problem conceptualization, concept visualization, and design commercialization". These three stages contain different types of work, corresponding to the process of product planning, design, and mass production. The assembly process information editing connects the assembly process design and the assembly process document guidance, manages and integrates the numerous data information generated in the process design process, and then converts it into a data form that can be directly browsed and referenced by the operator. According to the process information editing, it can be divided into two types according to the data form: (1) Process information editing for two-dimensional process cards. Traditional assembly process information management is oriented to assembly process cards, integrating two-dimensional process information into process cards, such as text and two-dimensional process drawings. (2) Process information editing for 3D process. The process information involved in digital assembly technology is mainly in three-dimensional form, so that traditional two-dimensional process information editing software can no longer meet the needs of three-dimensional process information management. The core of the research on process information editing for 3D process is the management and storage of process information. After the product appearance design is initially completed, the next step is the product structure design. The industrial designer's task is to handover the work of styling design and structure design with the structural engineer, and work with the structural engineer to resolve the appearance and structure design of the product design.

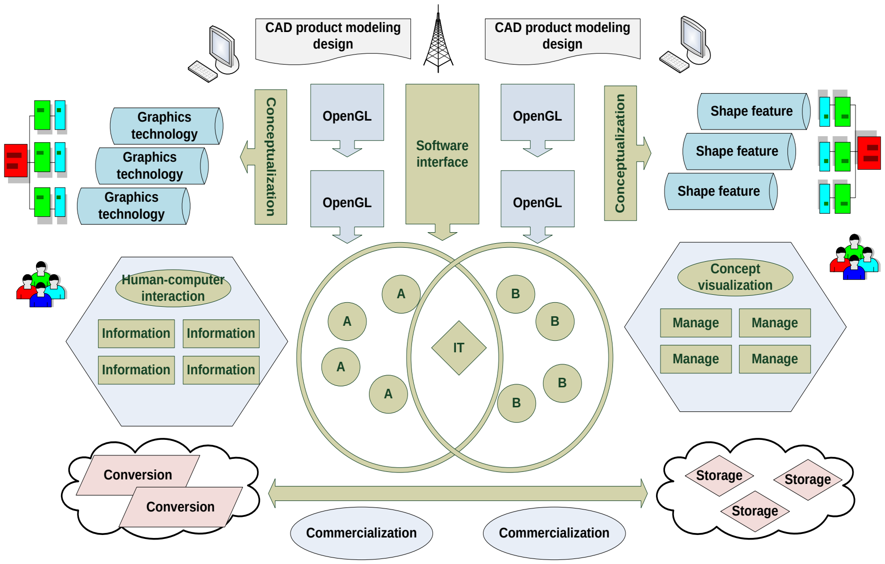


**Figure 2:** Flow chart of computer-aided product modeling design.

## 4 ANALYSIS OF RESULTS

### 4.1 Computer-Aided Design Data Processing

The process directory tree in the process editing software contains three nodes: process index, process item and process step. A process directory tree contains multiple sub-processes, a process node contains multiple process nodes, and a process node contains multiple process step nodes. OpenGL is a software interface that has nothing to do with hardware, which can be transplanted between different platforms such as windows 95, windows NT, Uninstall, Linux, MacOS, OS/2. On the basis of OpenGL, there are many advanced graphics libraries such as Open Invemor, Cosmo3D, Optimizer, etc., to adapt to different applications. Among them, Open Inventor is the most widely used. The software is an object-oriented toolkit based on OpenGL. It provides objects and methods for creating interactive 3D graphics applications, provides predefined objects and event processing modules for interaction, and is an advanced application unit for creating and editing 3D scenes. They have the ability to print objects and exchange data with other graphic formats. Figure 3 shows a histogram of computer-aided product design matching. The function of the data interface is to carry out data transmission and conversion between the virtual environment generator, input and output devices and users, and organically connect them into a whole, including technical content such as hardware matching, software and hardware joint debugging, and man-machine interface.

We design a large amount of assembly process information in the digital assembly process design system, which can be divided into the following categories: (1) Process catalog tree, auxiliary material tree, assembly resource tree and product structure tree; (2) Basic information of parts and assembly resources and assembly model; (3) Process drawings, mainly in the form of pictures; (4) Simulation video animation of assembly process of nodes; (5) Basic information and assembly site data of process nodes; (6) Basic information of the user. The above data covers various types of information such as text, numbers, tree structure, pictures, animations, 3D models, etc. The database only supports character format, text and number information can be directly written into the database, while other process information needs to be converted into characters or numbers.

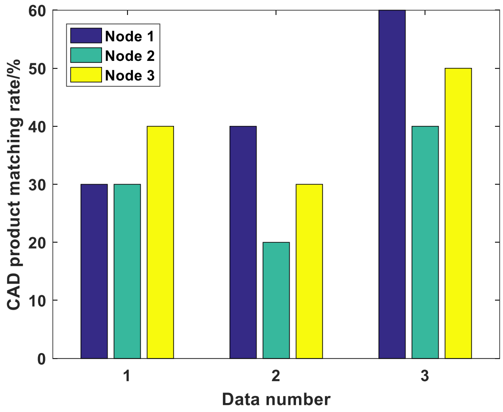


**Figure 3**: Histogram of computer aided product design matching.

Types of pictures, animations and 3D model information are written into the database in the form of relative paths or absolute paths. The software program accesses the database to read the path, finds the corresponding directory according to the path, and then retrieves the corresponding files in the directory.

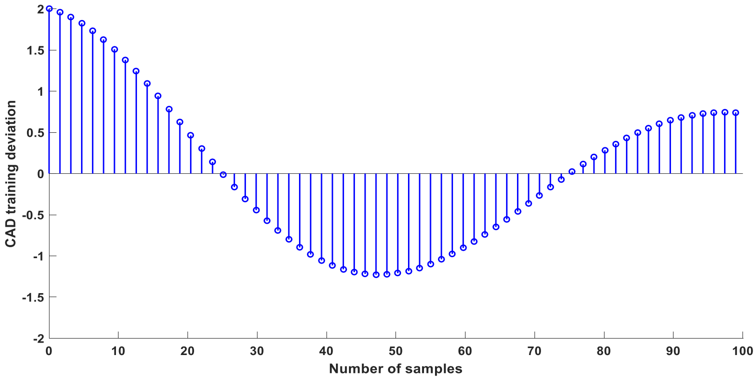


**Figure 4:** A matchstick graph of computer-aided product design training data deviation.

This part includes the determination of the number of training samples and the adjustment of error tolerance, learning rate and momentum factor. In order to prevent the occurrence of over-fitting, the number of training samples needs to be increased. The training samples are acquired by the network once, and then the sum of the variances between the samples and the target value is calculated. This value is the final sample deviation value. The purpose of this is to achieve parallelization and increase the calculation speed. Figure 4 shows the deviation matchstick chart of the computer-aided product design training data. There are 100 sets of training samples for testing. Among them, the experimental status is divided into "ready" and "testing". The former means that the product design system is ready to output designated human body data at any time, and the latter means that the product design system is in working condition. At the same time, users can customize the number of experiments performed. After reaching the specified number of times, the product design system no longer outputs data. The purpose is to prevent user fatigue from affecting the experimental experience. During the experiment, the user can suspend the experiment at any time. The computer-aided design algorithm is implemented by Matlab 2015b. The process node associated personnel assignment, process simulation animation, process drawings and process numbers, etc., correspond to the process directory tree and product structure tree. The product structure tree contains all the matching information of the corresponding process components; the process node associated process drawings and process animation information; process node related parts matching information, assembly resource information and auxiliary material information.

## 4.2 Analysis of Experimental Results

The database is the basis of digital assembly process information editing and assembly teaching. The design of the data table directly affects the function of the system. In order to facilitate data interaction and unified management, the system uses back-end database Oracle. The database information is entered by the digital assembly process editing software and displayed by the digital teaching system. Before creating a data table, we must first design the data table, put forward the required fields and data types of the table according to the actual application, and then design the structure of the table according to the characteristics of the database. Process information editing software and assembly teaching software use a unified format database, and data table design should consider multiple factors such as data type, data entry and process information display. Figure 5 shows the two-dimensional scattered point distribution of computer-aided product design nodes. Digital assembly process editing and digital teaching are based on the assembly process directory tree. The types, attributes and connections between process nodes are shown in the text.

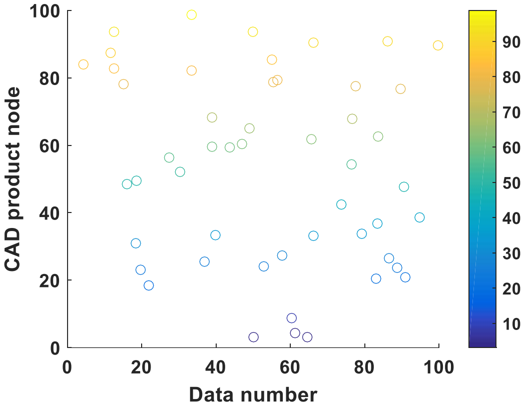


**Figure 5:** Two-dimensional scattered point distribution of computer-aided product design nodes.

The Oracle NET Framework is used as the data source. The OracleConnection object establishes a connection with the database. The DataSet is used to store the data retrieved from the database. Various SQL commands are issued to the database through the OracleCommand object, including query and update, delete and insert, the OracleDataAdapter object accesses the database through SQL commands, transfers data between the database and the DataSet object, and is used to fill and update the DataSet data set. The digital assembly process simulation is carried out in Tecnomatix, the model is imported into the system and the product catalog tree is generated based on the 3D model, and the XML file is exported. Then we carry out assembly sequence planning, generate assembly sequence tree and assembly path. Finally, the interference check is performed, and a reasonable assembly sequence is obtained through the assembly process simulation.

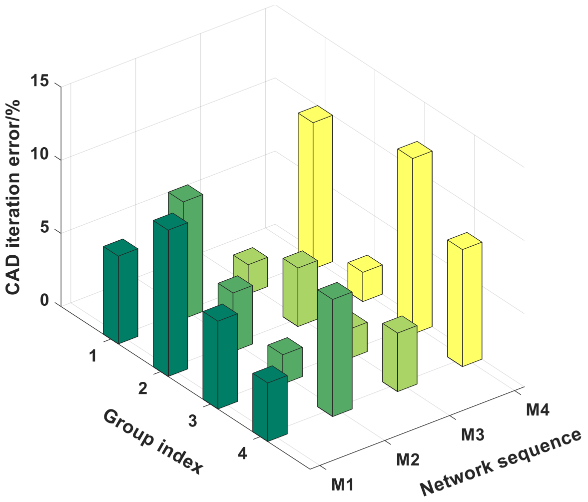


**Figure 6:** Three-dimensional histogram of iterative error of computer-aided product design sequence.

Figure 6 shows the three-dimensional histogram of the iterative error of the computer-aided product design sequence. The original data obtained in this study is in the form of 4 sets of vectors. Afterwards, scripts are written in C++ to process the original data, and these vectors are used as basic units to form a matrix {M1, M2, M3, M4}, where M is the number of times to complete a single set of actions. Then we input the matrix into the computer-aided product design system for learning. The performance of computer-aided product design system is mainly restricted by the number of hidden layer neurons, learning rate, momentum factor and number of iterations. We use guided search methods to get the best performance results for network stability. It can be seen from the figure that, compared with other networks with similar uses, the computer-aided product design system shows a better learning ability, reaching a relatively stable and relatively low mean square error of 15% at 500 iterations.

After the multi-dimensional space is transformed into 2D image display, the network still shows obvious classification and aggregation effects. The main reason for the overlap of some points in the area is that the 2D cannot fully carry all the information. Figure 7 shows a box diagram of the recognition rate of CAD products based on virtual reality technology. The correct rate of the behavior recognition algorithm reached 95.04%. When performing high-similarity action recognition, taking into account the limitations of the input samples, such a correct rate has demonstrated the excellent performance of the network. We search for the target behavior by using the Microsoft product design system equipment, then use the depth data and bone data of the product design system to obtain relevant joint information and extract the stable characteristics of the relevant data to describe the target motion. Finally, the above characteristics are based on virtual reality technology. Among them, the feature vector extraction method and virtual reality technology learning are the key to this research algorithm. Experimental results show that the algorithm can efficiently and stably recognize actions with high similarity. On the basis of improving the robustness, the average accuracy of the algorithm is above 95%.

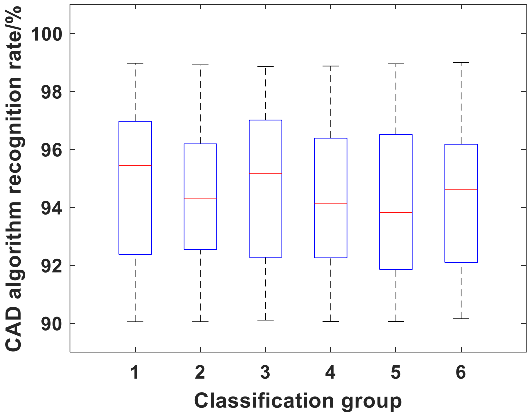


**Figure 7:** Box diagram of CAD product recognition rate based on virtual reality technology.

## 5 CONCLUSION

Digital process design technology is one of the important applications of digital assembly. Using assembly sequence planning and simulation information to edit and release assembly process information in detail can realize the operation guidance of the product assembly site. This paper develops a product assembly process design system with 3D process information as the core, simulates the product assembly process based on virtual reality technology, designs the method of editing and management of assembly process information, and develops a digital assembly teaching website to demonstrate the model. The assembly process information verifies the reliability and stability of the system through examples. This article will take consumer electronic products as an example to study the application method of virtual reality technology in the development process of consumer electronic products, discuss the strategy and implementation technology of using software to construct virtual prototypes of consumer electronic products, and how to use virtual reality technology to simulate the basic use functions of products design process. We realize the timely correction of errors in the virtual prototype of the product before the production of the physical prototype, reduce the number of production of physical prototypes and capital investment, and design consumer electronic products more efficiently, quickly and economically. Finally, the plastic deformation of the product is achieved by forcibly resetting the dynamic model of the mass point spring system while retaining the geometric state of the product after deformation, that is, manually reconstructing the equilibrium mass point spring mesh model with zero energy for the deformed product by using OpenGL graphics. The rapid programming interface constructs virtual modeling tools with modeling semantics to represent interactive operation points; and through product modeling examples based on tactile feedback to test and improve the modeling system, we discuss the positive role of the tactile modeling system in the product development process.

*Qiongqiong Guo*, https://orcid.org/0000-0002-2110-5288
*Guofeng Ma*, https://orcid.org/0000-0002-9773-1509

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