Computer-Aided Industrial Design in the Context of Intelligent Manufacturing

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Abstract. The vigorous rise of the intelligent manufacturing industry and the profound transformation of industrial digitization are reshaping the global manufacturing landscape at an unprecedented speed, leading to the explosive growth of market forces. In this wave of transformation, big data and computer-related auxiliary technologies have become hot topics widely discussed in academia and industry as the core driving force. In the vast field of industrial design and manufacturing, the deep application of big data lies in its ability to extract hidden value, predict trends, and assist decision-making from massive, complex, and heterogeneous data. Firstly, the development process of data in an intelligent manufacturing environment is explored from a literature review perspective, and the future development direction is analyzed from the perspective of data information characteristics. Combined with big data management technology, the information management model related to industrial design is constructed, and a new idea is put forward for industrial product design and production. Build a visual interface for industrial design big data to facilitate enterprises in analyzing and managing industrial data effectively. Finally, the paper expounds on the diversified advantages of CAID in computer-aided industrial design, analyzes the current situation of human-computer interaction in computer-aided industrial design for the purpose of improving the effectiveness of computer-aided industrial design, and proposes the development direction of collaborative work in industrial design. A distributed environment is proposed and established to lay the foundation for a computer-aided collaborative industrial design system. Network communication, collaborative control, and other operations are realized in the collaborative industrial design environment. The research results show that big data management under the background of intelligent manufacturing can establish a collaborative industrial design model.

Keywords: Intelligent Manufacturing; Big Data Management; Computer-Aided Industrial Design; Work Together; Scheme Optimization
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1 INTRODUCTION

With the development of industrial automation and information, the field of intelligent manufacturing has been rapidly improved. The Internet of Things is perfectly integrated with industrial manufacturing, which enables the data generated by various parts of the industrial manufacturing field, such as scheme design, procurement, and production, to be collected and utilized [1]. With the expansion of the scale of industrial enterprises and the transformation of enterprise informatization, the data scale faced by the industry continues to expand, and the manufacturing industry has begun to enter the era of intelligent big data [2]. The first to propose the concept of intelligent manufacturing is a well-known company in the United States, which believes that data has penetrated into every industry and become an important factor in managing information. People's mining and application of data predict new productivity growth [3]. They also found in their data analysis that innovative, competitive, and productive enterprises are more in need of data and computer systems. At the same time, new industrial design models occupy an important part of the market [4]. In the context of intelligent manufacturing, if industrial design products want to improve their own advantages and competitiveness, they must first improve from the designer; the designer must not only make certain changes in professional skills and ideas but also complete innovation and application from the use of tools.

As a course of design science, industrial design, in a broad sense, involves many industries. From the perspective of production, the mode of modern industrial mass production is the most basic feature of industrial design, which determines both the process of the industrial sector and the information management mode in industrial design [5]. A scientific design process can not only ensure the production time but also improve the efficiency of the team, coordinate the production relations of various units, and improve the interaction between products and users [6]. With the constant demand for innovation in the field of intelligent manufacturing and industrial design, breakthrough data processing technologies and computer-aided tools are critical to the success of this industry in the market. In industrial design management, the effective allocation of resources is one of the key factors determining the success or failure of a project. Big data management technology can help enterprises identify bottlenecks and redundant links in design and accurately evaluate the resource requirements and contributions of each link. Based on this, enterprises can allocate resources such as funds, manpower, and technology more reasonably, ensuring that resources are tilted toward high-value and high-efficiency design tasks. This precise resource allocation strategy not only improves resource utilization efficiency but also reduces unnecessary waste, further enhancing the competitiveness and sustainable development capability of the enterprise. In the context of data, industrial design products should strengthen the degree of integration with users. The user's sense of experience with industrial design content has also become an important criterion for testing the success of manufactured products. The application of big data management technology can not only excavate the linear relationship between users and enterprises but also sort out the information to better grasp the real-time changes in the evaluation and quality of industrial design products [7]. The application of big data management technology has also brought innovative opportunities for business models to enterprises. By delving deeper into user data, enterprises can discover new market demands and potential user groups, thereby developing products or services that better meet market needs. At the same time, big data can also help enterprises achieve personalized customization and precision marketing, improve user satisfaction and loyalty, and expand revenue sources. For example, customized design services based on user data analysis and value-added services based on data insights have become new profit growth points for enterprises. In the rapidly changing market environment, enterprises face many uncertainties and risks. Big data management technology can provide comprehensive risk warning and assessment capabilities for enterprises, helping them to timely identify and respond to potential market risks, technological risks, supply chain risks, etc. By laying out and adjusting strategies in advance, enterprises can effectively reduce the losses caused by risks, ensuring the stable operation and sustainable development of the enterprise [8].

With the rapid development of intelligent manufacturing technology, big data has become a key factor driving production optimization, decision support, and product innovation. In this context, the deep integration of CPPS and big data management enables the system to respond in real time to market changes, dynamically adjust production plans, achieve refined management of the production process, and optimize resource allocation. Computer-aided industrial design (CAID), as an important means of modern industrial design, greatly improves the efficiency and quality of product design through digital tools and methods [9]. Big data management not only involves the collection, storage, and processing of data, but also emphasizes the deep mining and analysis of data to reveal hidden patterns, predict future trends, and guide production practices accordingly. Specifically, big data provides CAID with rich design materials and market feedback, enabling design teams to iterate and innovate products based on real-world data. In the context of intelligent manufacturing, the synergy between CAID and big data management is particularly significant [10]. By analyzing market demand, user behaviour, and other data through big data, CPPS can accurately predict future product trends, guide CAID in customized design, and meet diversified market demands. Big data management can monitor product quality in real time, and detect and solve problems in a timely manner. CAID fundamentally enhances the reliability and durability of its products through design improvements. Meanwhile, CAID's precise modelling and simulation capabilities provide a reliable physical model foundation for the validation and application of big data, accelerating the transformation process from data insights to product implementation. Combining real-time sensor network collected production data, big data analysis can identify production bottlenecks and optimize production processes. CAID verifies the improvement plan through simulation to ensure the effective implementation of optimization measures.

2 CURRENT SITUATION OF BIG DATA MANAGEMENT AND COMPUTER-AIDED INDUSTRIAL DESIGN

Generally speaking, before the industrial design of a product, Pal [11] conducts a user positioning analysis to understand the potential benefits that the product may bring. Therefore, utilizing big data management technology to collect and analyze relevant information is crucial for industrial manufacturing and industrial design. To a certain extent, it can help industrial design enterprises obtain valuable information, such as product purchase feedback, and then summarize and classify the information, providing reliable references for subsequent product design. The development of big data has led to fierce competition in the industrial design market under the background of intelligent manufacturing. To enhance market competitiveness, enterprises must fully utilize big data technology to optimize industrial design in the form of data. In the context of intelligent manufacturing, big data management technology will also make industrial design increasingly service-oriented and personalized. Sun et al. [12] shifted from simple design functionality to more intelligent service design. Industrial design is also based on the non-material aspect, which not only integrates design into the product development stage but also enhances the competitiveness of enterprises in the modern market. According to the statistical report on network development released by the Internet Information Center in 2024, people rely on the Internet and are good at using the Internet to obtain relevant information. The gradual improvement of the internet has also led to the innovative development of industrial design in the context of intelligent manufacturing. Big data management brings optimization to the target industrial design process by breaking through innovative data processing models.

Computer-aided technology is an important means of using computer-related graphics processing software to assist industrial designers in product design. In the design process, Tsang and Lee [13] need to use computers to process various graphics and data, adjust product data, compare and analyze, and ultimately determine the best solution. Both digital text and graphics can be stored in computer-aided systems and retrieved in a short amount of time. Compared to traditional manual drawing methods, the design process is more simplified. Meanwhile, computer-aided technology can also edit the required solutions and perform various operations such as copying, shrinking, translating, and rotating. Computer-aided industrial design technology is a new auxiliary capability developed on the basis of computer-aided technology. Wan et al. [14] have become a popular application method in industrial design under the background of intelligent manufacturing, combining numerical control machining, rapid prototyping, and mould production. Traditional computer-aided industrial design systems have some problems, such as unstable theoretical foundations, lack of innovative features, and insufficient intelligence. Therefore, modern industrial design systems need to innovate with the help of big data technology. The computer-aided industrial design technology management system not only enables employees to communicate with clients on the management platform but also enhances the enthusiasm and creativity of designers, greatly improving the coordination and interactivity in industrial design.

In the wave of intelligent manufacturing, big data management has injected powerful analytical capabilities into CAD/CAM systems. The collaboration between big data management and CAID enables CAD/CAM systems to respond more flexibly to market changes and accelerate product innovation cycles. Meanwhile, CAID serves as a bridge connecting design and market, utilizing big data feedback to continuously iterate product design, ensuring that products meet technical requirements and market expectations. Through the MR graphical user interface (GUI), Zhang et al. [15] directly inspected, modified, and validated designs in interwoven virtual and real environments. The introduction of mixed reality (MR) technology provides a more intuitive and efficient way for collaboration between CAD/CAM and big data management. More importantly, MR technology enables engineers to interact with component holograms through simple gestures, greatly simplifying the operation process and improving work efficiency. This immersive experience not only enhances the intuitiveness of the design process but also strengthens the communication and collaboration skills among engineers. By collecting, processing, and analyzing massive production data, enterprises can accurately grasp market demand, predict production trends, and guide the design and optimization of CAD/CAM systems based on this. This framework enables the centralized management and sharing of data through a cloud platform, ensuring that engineers from different departments and companies can access the latest data in real-time and achieve seamless collaboration. At the same time, the introduction of MR GUI enables engineers to design and manufacture work anytime, anywhere through mobile applications or universal design tools, greatly improving the flexibility and convenience of work.

3 RESEARCH ON THE COLLABORATION BETWEEN BIG DATA MANAGEMENT AND COMPUTER-AIDED INDUSTRIAL DESIGN UNDER THE BACKGROUND OF INTELLIGENT MANUFACTURING

3.1 Research on Information Systems and Visual Industrial Design Based on Big Data Management Under the Background of Intelligent Manufacturing

Before the application of big data technology is mature, the past industrial design often relies on the understanding of the industry, especially the design team's own knowledge system and the experience of the management, to determine the direction of product design. As a result, early big data technology appeared less frequently in the field of industrial design and manufacturing. With the popularization and expansion of computer-aided and intelligent technology, big data management, big data analysis, and other technologies have developed rapidly with the help of the network level and also promoted the green and digital evolution of the intelligent manufacturing field. From the perspective of data structure, big data mainly includes three types: structured, semi-structured, and unstructured. We use data charts to show the differences and connections between traditional data and big data technologies, as shown in Table 1:

Project	*Traditional data*	*Big data*
Data volume	TB	TB ~PB

	1.0	10.0~100.0
Data growth	Single time	sustain
	20%	60%~100%
diversify	structured data	semi-structured
		unstructured
	abstract	abstract
Usage scenario	report forms	Data mining and analysis
User acceptance level	12.8	88.9

Table 1: The differences and connections between traditional data and big data technologies.

As can be seen from Table 1, in terms of the gap in data volume, the maximum data capacity of traditional data is in the TB range. Big data is from terabytes to petabytes. From the point of view of data increment, the continuous production of big data keeps the data volume above 60%. From the perspective of diversification and comparison, traditional data adopts structured data, while big data adopts semi-structured and unstructured data. Finally, from the perspective of usage scenario analysis, tool application, scope, and user acceptance, big data technology has great advantages. As an important branch of big data technology, big data management can complete the processing and storage of information on the basis of databases, distributed file systems, and other tools. We illustrate the development process of data management technology in the form of a chart, as shown in Figure 1.

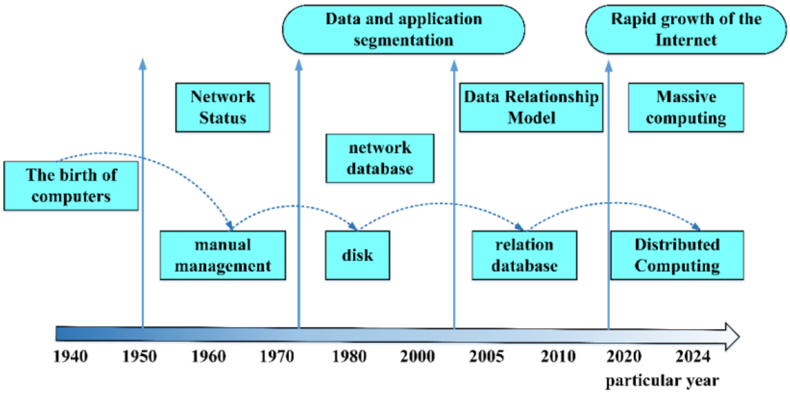

Figure 1: The development history of data management technology.

As can be seen from Figure 1, big data management technology can be traced back to the 1940s; first, from the birth of the computer, the emergence of manual management and disk let big data management quickly into the form of network model. Many companies use network databases to come up with data relational models to separate data from applications. Subsequently, the establishment of relational databases has made data management technology develop faster and faster and has now become an important information processing technology in many application fields, such as project industrial manufacturing. Based on the above survey of big data management technology, we also analyze the application times of this technology in the four fields of industrial design, architectural design, machinery manufacturing, and automobile design so as to explore the characteristics and advantages of big data management.

This is followed by architectural design and automobile design. It can be seen that the application of big data management in the design industry can provide designers with reliable information references and improve the applicability of design schemes. In the information age, the development of intelligent manufacturing and industrial design continues to accelerate. We use big data management technology to build intelligent manufacturing information systems in order to store relevant data content and reasonable application. Data management function is a general concept that should include real-time data processing, collection, sorting, storage, traceability and analysis, and other branches. In short, the intelligent manufacturing and information management functions of big data need to cover the whole process of data application. To this end, we will show the design structure of the big data management system, as shown in Figure 2:

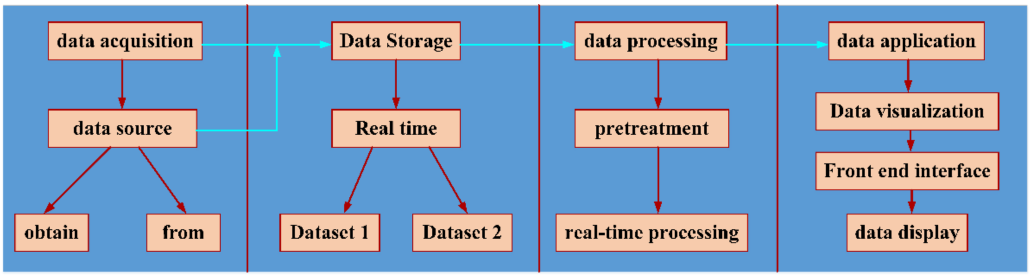

Figure 2: Design structure of big data management system.

As can be seen from Figure 2, the structure of the big data management system is divided into four modules: data acquisition, data storage, data processing and data application. In data collection, it is necessary to obtain and trace the data source, analyze the real-time data add it to the data storage, and establish different data storage sets to ensure the normal operation of subsequent data processing. The data processing module is also divided into preprocessing and real-time processing. In order to make the big data management system more in line with the needs of industrial design under the background of intelligent manufacturing, we focus on industrial design products as the main object in data information analysis. Relevant design sketches and elements are extracted and added to the data control as key features. In order to ensure that the industrial design link under intelligent manufacturing can be covered by big data, we also add a big data management system to all production line operations. Whether it is device parameters, running status, or management content, data information can be generated in a timely manner and is collected and stored. Due to the large amount of data involved in industrial design, we elaborate on each link in big data management. Firstly, in the information extraction module of big data management, the deep learning of the big data network is added, and the data acquisition function is automatically generated by training parameters and threshold values. The optimal data selection calculation formula is as follows:

$$Q(s,a_1) \leftarrow Q(s,s)_0 + b[r + y \max O(s,a)] \tag{1}$$

$$Q = \; l,2,3,\ldots,k_m \tag{2}$$

In the actual parameters, the direction of information acquisition is adjusted according to the current state of the big data management system so that the data management content is more suitable for the industrial design and manufacturing industry. In order to further improve the performance of data acquisition, we should predict the unknown state of the data according to the current state in each iteration:

$$\pi(s) = \arg\max Q(s,a)_1 \tag{3}$$

In the formula, s Represents the current state factor. Add the same data to the same data module to get the maximum sum data set:

$$a_{t+1} = \arg\max L(u,n)_Q \tag{4}$$

$$a = \sum_{i=1}^{n} Q(s_t, a_{t+1}) \min \tag{5}$$

Observe the execution actions of the data information to determine whether the information collection content meets the requirements. Considering the energy consumption in industrial design, we also need to take into account the energy consumption of the system when dealing with nonlinear problems in the generation of data management systems. Linear regression algorithm is used to improve the processing efficiency of the model:

$$D = \ (x_i, y_i) \mid lx \in R \tag{6}$$

$$D_w = \ Y \in R, [-1,1] \max Q(a,s) \tag{7}$$

Next, we also need to calculate and optimize the error of data analysis in big data management:

$$wc - b = [u / l_a] \tag{8}$$

The formula, b represents the error variable. The main effect of error variables is that they interfere with the system's decision to manage big data. Therefore, we need to clear the error data further. The classification algorithm is used to reduce the generation of error probability:

$$\arg\min \frac{1}{2} \| W \|^2 \tag{9}$$

$$s.t.y(wx - b) > 1, i = 1, \ldots, n \tag{10}$$

In order to improve the generalization ability of big data management, we also need to define the target as a data set with multiple characteristics in data storage so as to meet the standards and scope requirements of data storage:

$$L(W,B,A) = \frac{1}{2} \| w \|^2 - A[Y(WX + B) - 1] \tag{11}$$

The optimized storage formula is obtained:

$$l = \max a \sum_{k}^{i=1} n - \frac{1}{2} a_{ij} \tag{12}$$

The greater the storage time of the big data management system, the greater the energy consumption of the system application, and we further reduce the storage time of big data management:

$$\sum_{i=1}^{n} a_i y_i = 0 \tag{13}$$

Although the data processing process includes pre-processing and real-time processing, the results of data cleaning will be uniformly stored in the database. In order to determine that certain data samples meet the needs of industrial design in the context of intelligent manufacturing, we add a supervised learning model to improve the feedback efficiency of the system:

$$\arg\min \sum_{i=1}^{k} \sum_{x} \| x - y \|^2 \tag{14}$$

$$d = [uv + b] \frac{1}{2} \ln_a \tag{15}$$

Through the above formula, we completed the construction of a big data management system. In the follow-up research, it is also necessary to explore the optimization brought by computer-aided industrial design technology for the collaborative work of industrial design and intelligent manufacturing.

3.2 Research on Collaborative Work in Computer-Aided Industrial Design Under the Background of Intelligent Manufacturing

Industrial design is a specialized study of industrial products in the human-machine environment to seek the optimal design of the subject. It combines products and designers and seeks new design methods to meet the needs of more people. Computer-aided process design software is a kind of technical work based on computer systems. Computer-aided industrial design work is also divided into different stages in the process of work needs to conduct a comprehensive analysis of the content and results of the previous paragraph to find out the loopholes. Then, the optimized mature technology is applied to the production line to improve the efficiency and quality of the work. At present, computer-aided industrial design technology is widely used, and in the background of intelligent manufacturing, virtual simulation, inspection, evaluation, and other work have been completed. We present intelligent manufacturing designs generated using computer-aided industrial design:

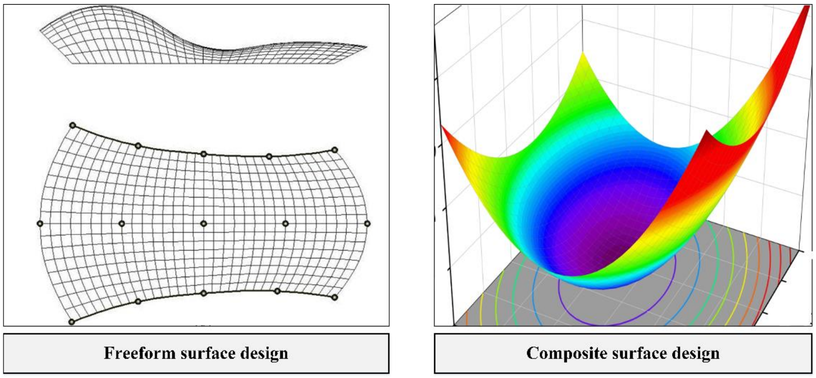

Figure 3: Intelligent manufacturing design drawings generated by computer-aided industrial design.

As can be seen from Figure 3, we show two kinds of drawings for free-form surface design and composite surface design. The complexity of the drawings fully reflects the advantages of computer-aided industrial design technology. By analyzing the networked manufacturing environment under the background of intelligent manufacturing, we propose a collaborative work optimization based on computer-aided industrial design. Collaborative work can be oriented to designers and users, with two-way objects as the main body, to solve the appearance design and functional requirements of products jointly. At the same time, a collaborative evaluation system is established to judge whether the product design quality meets the standard. The collaborative application model of computer-aided industrial design is built as shown in Figure 4.

As can be seen from Figure 4, in the collaborative model of computer-aided industrial design, the user layer is the consumer-facing audience group, and the system application layer needs to complete the integrated processing of networked manufacturing data. Realize resource sharing, collaborative design information management, product industrial design optimization and evaluation, product customization, supply chain management, big data management, and so on. The application tool involved at the technical level is computer-aided industrial technology. By means of virtual modelling, data processing, and model building, information in the basic database is extracted to construct standard industrial design requirements.

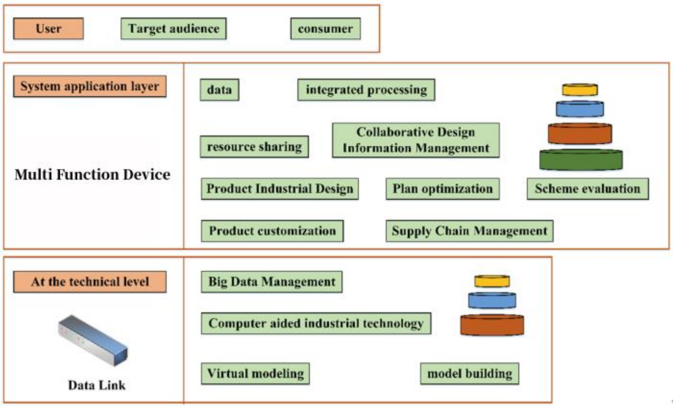

Figure 4: Building a collaborative application model for computer-aided industrial design.

Considering the complex information resources contained in the industrial design process, we also need to refer to actual cases and the current situation of the market in collaborative work.

4 BASED ON THE RESEARCH RESULTS OF COLLABORATIVE WORK BETWEEN BIG DATA MANAGEMENT AND COMPUTER-AIDED INDUSTRIAL DESIGN UNDER THE BACKGROUND OF INTELLIGENT MANUFACTURING

4.1 Analysis of Research Results of Information System and Visual Industrial Design Based on Big Data Management Under the Background of Intelligent Manufacturing

Under the background of intelligent manufacturing, the field of industrial design, whether it is production or product research and development, needs to use more information and data. Among these data, semi-structured data and unstructured data bring new challenges to information management. In order to improve the audience and quality of products in intelligent manufacturing industrial design, it is necessary to make full use of data information and show the superiority of big data technology. For information systems in a big data environment, the data management function is a complex function, including data collection, data processing, and data analysis. Whether designing products from parameters, devices, operating states, or data modeling, big data management is needed as a basic support. We use big data management technology to analyze the industrial design process in the context of intelligent manufacturing and build relevant information management systems and data visualization functions to improve the practicality of data. It emphasizes the intelligent control and early warning of data so that the big data management system acts as an assistant and supervisor in the production link. First, we use the visual construction of big data management to elaborate the relevant data involved in industrial design, as shown in Figure 5.

As can be seen from Figure 5, in the visual interface, we describe the content of data information related to industrial design. Industrial big data is mainly based on internal business data, and it needs to face the problems of rapid generation of large data and low-value density in data management. The internal business of industrial design also needs to carry out product demand design, material purchase, production, and subsequent sales, as well as build a relevant big data management visualization system, which can see the relevant factors affecting the quality of industrial design in detail. In order to further verify the reliability of big data management technology, we compared the changes in the validity of industrial design-related data before and after adopting big data management, as shown in Figure 6.

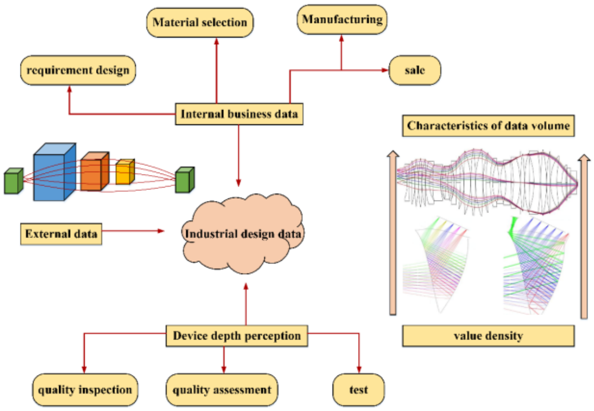

Figure 5: Related data involved in visual industrial design.

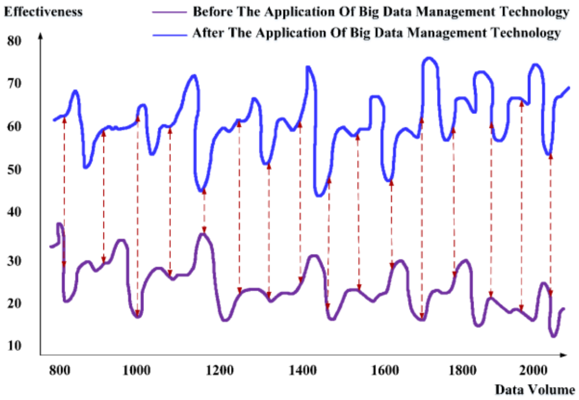

Figure 6: Changes in the effectiveness of industrial design-related data before and after adopting big data management.

As can be seen from Figure 6, before the adoption of big data management technology, data information related to industrial design was less effective in practical applications and could not provide help for industrial design and production in an intelligent manufacturing environment. After the optimization of big data management technology, the actual data information has a high reference value.

4.2 Analysis of Collaborative Work Research Results Based on Computer-Aided Industrial Design Under the Background of Intelligent Manufacturing

After more than 20 years of exploration, computer-aided technology can complete parametric and variable design optimization and provide reliable help for product modeling. At the same time, under the background of intelligent manufacturing, computer-aided industrial design technology can also design the product appearance of the free surface, using surface characteristics and freedom data adjustment, forming complex design drawings. From the perspective of the development trend of industrial design, only by improving the development ability of products can we occupy a place in the market competition. Achieve high-end, personalized demand customization, so that products and users are closely connected. Traditional product design is single, function has become the weakest link. The development of diversified complex products can become the core competitiveness of enterprises. Therefore, computer-supported collaborative process design has become the main direction to improve the quality of product design and diversified development. It emphasizes the use of group work in the process of industrial design, combined with computer-aided industrial design technology, to change the disconnection between design and production, design and management in the traditional industry to varying degrees. We compared the generation quality of design schemes in collaborative working environments before and after adopting computer-aided industrial design optimization.

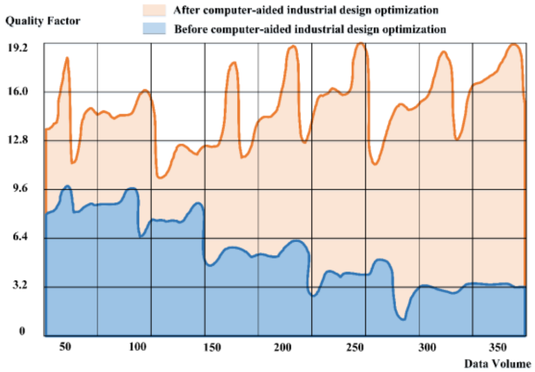

Figure 7: The quality of design scheme generation in a collaborative work environment before and after computer-aided industrial design optimization.

As can be seen from Figure 7, due to the need for multiple design activities in the collaborative work environment, a large amount of data is generated. The quality of design schemes generated by traditional collaborative work is lower, while the quality of design schemes generated by computer-aided industrial design software is higher, which can deal with big data problems in multi-dimensional environments, and at the same time can make products show better colour and human-machine interaction. Since collaborative work in industrial design involves the integration of multiple departments and links, certain errors are likely to occur in the process of data exchange. We compared the changes in the information error rate of collaborative work before and after the optimization of computer-aided industrial design technology, as shown in Figure 8.

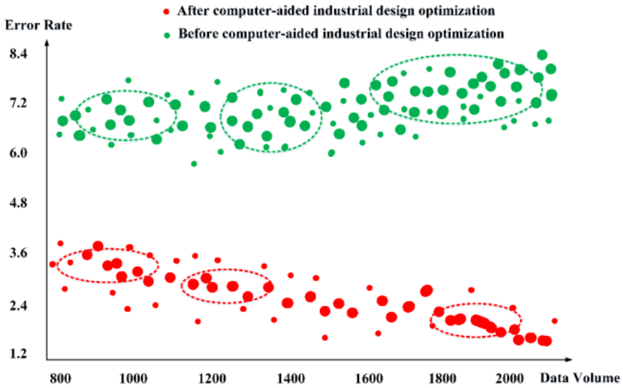

Figure 8: Changes in collaborative work information error rate before and after optimization of computer-aided industrial design technology.

As can be seen from FIG. 8, the information error rate of collaborative work has decreased significantly after the optimization of computer-aided industrial design technology. This further shows that the basis for collaborative behaviour, control information, and completion of information management under the background of intelligent manufacturing is to reduce the error coefficient of data interaction, so as to achieve multi-level and multi-group collaboration model support. The accuracy of control information is crucial for the stable operation of intelligent manufacturing systems. In the intelligent manufacturing environment, control information is like instructions from the nervous system, guiding the operation of production equipment and the flow of materials. The optimized CAID technology ensures the accuracy of control information by reducing the error coefficient in data exchange, avoiding production delays, resource waste, and even safety accidents caused by information errors. This is not only a manifestation of technological progress, but also a powerful guarantee for the safety, reliability, and sustainability of intelligent manufacturing.

5 CONCLUSIONS

With the increasing popularity of intelligent manufacturing, the industrial manufacturing industry with big data and computer assistance has also undergone new changes. More and more researchers have begun to pay attention to how to use big data and computer-aided software to improve the quality of industrial design products. On this basis, we also use big data management and computer-aided technology to optimize industrial design in the context of intelligent manufacturing. Firstly, the scope of intelligent manufacturing and industrial design in the big data environment is analyzed. Based on data collection, data management and data analysis, the overall structure and selected technology of industrial design are studied, and the big data management information system under the background of intelligent manufacturing is built. The system can process the data related to industrial design, and store it, complete the tracing and analysis training functions. Designers can use big data management systems to realize data visualization and intelligent control. Computer-based optimization of industrial design collaborative work. Complete the creation of multiple functions such as collaborative information management and collaborative product design. The results show that big data management and computer-aided technology can optimize industrial design and work together to improve the quality of industrial design products with reliable information support in the context of intelligent manufacturing.

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