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Research on Knowledge Transfer-Oriented Intelligent Assistance Design Communication System for CNC Machine Tools

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Abstract. In product design, the most critical part is collaboration and communication with different stakeholders with different expertise and knowledge. Sketches and scheme drawings are the medium for design communication and interpretation among different groups of people. However, due to the different knowledge backgrounds of different groups of people, there will be understanding errors and communication barriers in design communication, slowing down the entire design cycle. To improve the efficiency of communication in design projects, this paper proposes a knowledge communication mechanism based on design knowledge research to support professional industrial design processes. Inspired by intelligent technology and generative design, an intelligent assistance design communication system architecture for CNC machine tools is constructed for knowledge transfer. We concept an intelligent design tool from the user's perspective and design a prototype for usability testing. We hope to realize design knowledge transfer and collaboration through the system, assist in completing the appearance design for CNC machine tools, and provide users with a good experience.

Keywords. Knowledge transfer, Design communication, Intelligent assisted design, CNC machine tools, Interactive design

1. Introduction

Design is essentially a process of knowledge flow, integration, competition, and evolution [1], and its core is the acquisition and application of knowledge. In the current mainstream industrial design process of CNC machine tools, the essence of the design process can be understood as the process of knowledge transfer and integration between user knowledge of the 'problem and demand carrier', designer knowledge of the 'industrial design carrier' and engineer knowledge of the 'engineering data carrier'.

The traditional industrial design method of CNC machine tools is generally a project commission system and personalized customization. The demand side expresses its design vision by proposing project requirements to the design side. In the early stage, the design side needs to conduct a lot of design research on the demanding enterprise or communicate with the demanding enterprise to make a preliminary design judgment. However, due to the knowledge and cognitive differences between the demand side and

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the design side, it is easy to cause cognitive bias and low communication effectiveness between the two sides, which in turn leads to the delay of the design process and the reduction of design efficiency.

Communication is the core of knowledge exchange between stakeholders with different technical and social backgrounds. Zhinan Zhang et al. proposed a method to systematically improve the understanding of the target object, including the composition of the object, the nature of the object, and the tools to support its related communication and promote knowledge communication and collaboration between stakeholders in the product design process by improving communication efficiency [2]. Rajaratnam Dilakshan et al. assessed how AR can be used to overcome design communication issues in the early stages of architectural projects. They believe that AR can be used for architectural design communication, and AR toolkit models can improve users ' cognitive ability of knowledge and design experience [3]. Collaboration and communication with stakeholders with different knowledge backgrounds are the most critical aspects of the design phase, and solving design communication problems is the key to improving design efficiency.

Intelligent design, as a design trend driven by artificial intelligence technology, can realize in-depth exploration, analysis, processing, and application of design data and knowledge. An intelligent assistance design communication system will become a guiding role in the process of transferring design knowledge. Therefore, analyzing, acquiring, and expressing knowledge in the process of CNC machine tool industrial design, and constructing a knowledge-assisted design communication system are the hotspots of research and application of intelligent technology in industrial design and concept design.

2. Research status of intelligent-assisted design

Intelligent design refers to the application of modern information technology, using computer simulation of human thinking activities to improve the intelligence level of computers so that computers can more and better undertake various complex tasks in the design process, and become an important auxiliary tool for designers. Fang Liu et al. argue that intelligent design or design intelligence usually refers to the introduction of artificial intelligence methods in design work, to help designers or other creators perform more efficient or more creative work. Through literature review, it is found that the intelligent design system has mainly experienced four stages of development.

2.1. System KBS is based on a knowledge database (expert system)

For example, Jiuxi Li et al. applied artificial intelligence theory and expert system technology to the field of product design, proposed a product design expert system framework structure, and realized the organization of information and materials through intelligent agent technology. According to the shape analysis method, the system realizes auxiliary innovative design [5].

2.2. Scheme creation and screening platform (vision-based)

For example, the AutoDraw sketch drawing platform generates a series of detailed images through sketch drawing.

2.3. Intelligent system that combines the designer's thinking and cognitive processes

For example, Ali AI Graphics, through inputting needs, platform generation and output, adjustment of detailed elements, and selection of design schemes, completes the design process. This process combines AI generation with the designer's thinking process and can improve the quality of design works to a certain extent.

2.4. Intelligent collaborative system for AI, designers, and engineers

For example, JD Linglong, in addition to providing a series of intelligent image generation tools, also provides development frameworks, intelligent code platforms, front-end development workstations, and design collaboration platforms.

In recent years, research on intelligent-assisted design has focused mainly on sketch drawing, visual communication design, interaction and interface design, 3D modeling, and AI art creation design. Through the use of artificial intelligence, the design process can be completed from text to image, from sketch to image, from sketch to 3D model, from 2D design diagram to 3D model diagram, and also layout retrieval and reformatting, trend analysis, and automatic generation of creative text and graphics can be realized. It can be seen that artificial intelligence technology applied in different scenarios can assist in completing users' personalized needs, help users improve the efficiency of information acquisition, and shorten the product design cycle.

3. Knowledge transfer-related research and traditional CNC machine tool industrial design process overview

3.1. Knowledge transfer-related concepts

- Explicit knowledge and tacit knowledge

Based on different acquisition channels, knowledge can be divided into explicit knowledge and implicit knowledge. The design process is mainly composed of implicit knowledge, including intangible skills, judgment, and intuition possessed by human experts, as well as designers' personal insights, inspiration, visual perception, and experience. In CNC machine tool industrial design, background research must first be conducted to understand the product itself and user needs. Then, through their knowledge system, designers use sketch and effect drawings to express design knowledge. The essence of this process is knowledge transformation and externalization. In the industrial 4.0 era, the development of artificial intelligence technology will further promote the explicit transformation and dissemination of knowledge.

- Explicit knowledge and tacit knowledge

Knowledge transfer is an activity between knowledge subjects with knowledge differences, first proposed by Titus in 1977, focusing on the economic development phenomenon brought about by knowledge production based on technology transfer [6]. Knowledge transfer is a deterministic knowledge activity that is evident in its clear goals, determined knowledge senders, receivers, and intermediaries, and mostly carried out in controlled environments and processes [7]. Some scholars summarize it as five factors, including source, information, channel, receiver, and context [8]. Traditional knowledge transfer models focus on the process of knowledge transfer, with classic models such as

Gilbert and Cordey-Hayes' five-stage model of knowledge acquisition, communication, application, acceptance, and assimilation [9].

- Knowledge visualization

In 2004, Martin J. Eppler and Remo A. Burkhard first proposed the concept of knowledge visualization, considering it as an application of knowledge representation used to improve knowledge creation and transfer between two or more people [10]. Knowledge visualization is a graphical method that can be used to build and convey complex insights, emphasizing how to promote the transmission of knowledge between people and teams.

In product design, sketches, and model effect drawings are mediums for different people to exchange and explain designs, but due to differences in knowledge backgrounds among different groups, there may be understanding errors and communication barriers in design exchanges. Effective knowledge transfer and knowledge visualization models can promote the process of integrating different knowledge and solve problems related to communication barriers in design exchanges.

3.2. Traditional CNC machine tool industrial design process overview

The traditional industrial design process is based on the design process evolved from IDEO Company in the United States and Olivetti Company in Italy [11]. It mainly includes four parts: exploration stage, development stage, iteration stage, and implementation stage.

In the exploration stage, designers collect essential information to support their design concept from a large number of information systems. For CNC machine tool industrial design, the exploration stage mainly includes background research (market, competitors, society) and user analysis (user needs, user roles), and extracts and screens the results, analyzes and converts the needs.

The development stage is the core stage of industrial design. Based on the concept formed in the first stage, develop design ideas and conduct preliminary design. In the early stage, collect design inspiration, and stimulate creative thinking through brainstorming; the design process is to express design ideas through design thinking and methods, including sketches, model diagrams, effect diagrams, scene diagrams, and necessary descriptive text.

The iteration stage mainly includes design evaluation, design decisions, and iteration optimization. Based on the preliminary design solution, select the optimal solution, improve the design solution based on user and expert opinions, and finally output the complete design product. Generally speaking, the development stage and iteration stage are carried out simultaneously, and the design process requires repeated review and optimization.

The implementation stage involves putting the design results into production, which requires the first three stages to focus on maximizing user satisfaction.

From these four stages, the traditional CNC machine tool industrial design process has several special problems: including a long product update cycle, more design solutions constrained by technology, and customization of processing methods. This determines CNC machine tool design needs more communication with engineers.

4. Knowledge system in intelligent assistance design communication

4.1. Knowledge classification in industrial design of CNC machine tools

According to the design role, the knowledge system in CNC machine tool industrial design includes designer knowledge, engineer knowledge, and user knowledge. Based on the acquisition path, the knowledge system can be classified into explicit knowledge and implicit knowledge. Based on the characteristics of CNC machine tool industrial design and combining the knowledge classification method based on roles and acquisition path, the knowledge system in CNC machine tool industrial design is further divided into usage knowledge and experiential knowledge.

- Usage knowledge

Usage knowledge refers to knowledge that is explicitly expressed and can be used directly. It includes design object knowledge and user knowledge. The design object knowledge for the CNC machine tool is the design language in exterior design, mainly including structural layout style, morphological characteristics, presentation details, overall color, material texture, processing technology, etc. The user here refers to the operators who directly use the machine tool and the workers. User knowledge includes aesthetic elements, operation methods, human-machine engineering, and other contents of CNC machine tools.

- Experiential knowledge

Experience knowledge refers to the knowledge that designers and engineers accumulate over a long period in their work, which cannot be clearly expressed. It includes problem-solving strategies, skills, and aesthetic potential of CNC machine tool designers and engineers. Problem-solving strategies and skills experience can reflect the logical thinking process of solutions, and aesthetic potential can infer mainstream solutions. Experience knowledge can be transferred and converted into useful knowledge through a conversion mechanism.

4.2. Knowledge communication mechanism

Based on the research method of structured expression of knowledge in engineering design communication [2], combined with the five factors of knowledge transfer mentioned earlier, the communication mechanism in CNC machine tool industrial design is divided into the following five parts.

- Communication node

Stakeholders in design communication, including the source and receiver. Here, it refers to designers, users, and engineers, among which users also include novice designers.

- Communication object

The information processed in the communication process, which here refers to design knowledge. To solve the communication barriers in the design process, different knowledge integration methods must be realized through different knowledge transfer ways, with a focus on expressing design knowledge in different ways.

- Communication channel

Composed of asynchronous and synchronous communication methods that connect the source and receiver, which can promote design communication. Based on the assistant system, knowledge transfer among different communication nodes in the CNC machine tool industrial design process is realized through artificial intelligence methods.

- Communication mode

The knowledge expression methods of different communication nodes. The communication modes of different nodes are as follows: designers-sketches and design diagrams; engineers-data and structure; users-emotional descriptions and scenarios.

- Communication context

Use contextualization. In the design communication process, product design thinking must be carried out in a system of people, objects, and environment throughout the product lifecycle.

As shown in Figure 1, design communication involves knowledge transfer. During the design communication process, the assistant system based on artificial intelligence technology encodes the design knowledge of different groups, and decodes and outputs it through the system. Knowledge transfer of CNC machine tool design knowledge is carried out based on the visualization of CNC machine tool design knowledge. The source of knowledge transfers design knowledge to the receiver in a visualized way and stores it in the knowledge base.

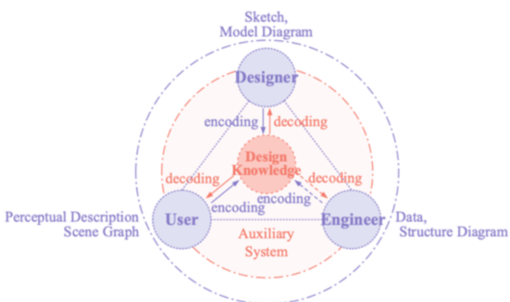


Figure 1. Knowledge communication mechanism in intelligent assisted design for CNC machine tools.

5. Construction of intelligent assisted design communication system for CNC machine tools

5.1. System architecture

Based on the research on CNC machine tool industrial design knowledge and the proposed knowledge communication mechanism, in combination with the five-stage model of knowledge transfer, a knowledge transfer-oriented intelligent assisted design system architecture is proposed, as shown in Figure 2. Group knowledge communication, knowledge application, and knowledge acceptance together, because in the intelligent assistant system, these three stages are performed at the application layer, while knowledge acquisition and knowledge assimilation are both based on the knowledge base in the data layer.

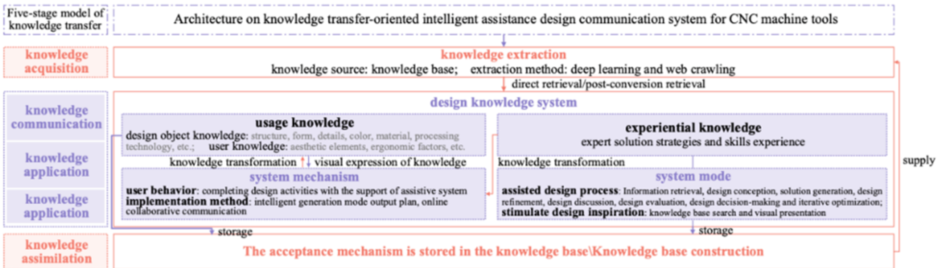


Figure 2. System architecture.

- Knowledge extraction and knowledge base construction

Knowledge extraction uses methods such as machine learning and natural language processing to extract specific information from different data, which is the foundation of building a knowledge base [12]. The CNC machine tool knowledge base can provide designers with design information to choose from and help make design decisions. The methods of knowledge extraction and knowledge base construction can refer to the research of scholars in the field, and in the system construction, the interfaces based on existing technologies are accessed.

- Research on design knowledge system

This section mainly focuses on the research of the knowledge system in intelligent assisted design for CNC machine tools. The core of the research on the design knowledge system revolves around knowledge communication and the communication mechanism. The use of knowledge in the system can be directly expressed through knowledge visualization and is divided into functional modules in the system design. Experience knowledge in the system can be transformed and materialized into usable knowledge through knowledge conversion. After acquiring, communicating, applying, and accepting design knowledge, it is stored and expanded in the knowledge base to provide for the next knowledge retrieval.

- System position

The positioning of the system operation end includes the system mechanism and system mode. The system mechanism refers to the implementation method of user behavior and the operation end, where user behavior refers to user design communication and completion of design activities supported by the system. The corresponding implementation method is to automatically generate a large number of design schemes through intelligent technology and provide a large number of design cases to assist in online collaborative communication. The system mode is the main function of the system, which is to assist designers in their industrial design activities and solve design communication problems. The system provides both assistance in the design process and a mechanism to stimulate design inspiration. The assistance process includes users' input design requirements and conducting information retrieval in the application layer, using the design modules for creative ideas and intelligent generation of design schemes, and using the communication module to conduct design evaluation and optimize the design scheme through iterative design.

5.2. Design practice and verification

- Function definition

The system aims to provide users with auxiliary design and communication functions throughout the process, including five functional modules: search, analysis, design, communication, and personal center, as shown in Figure 3. Specific functions include self-designed, auxiliary design, solution testing, data display, and providing a multi-directional communication platform.

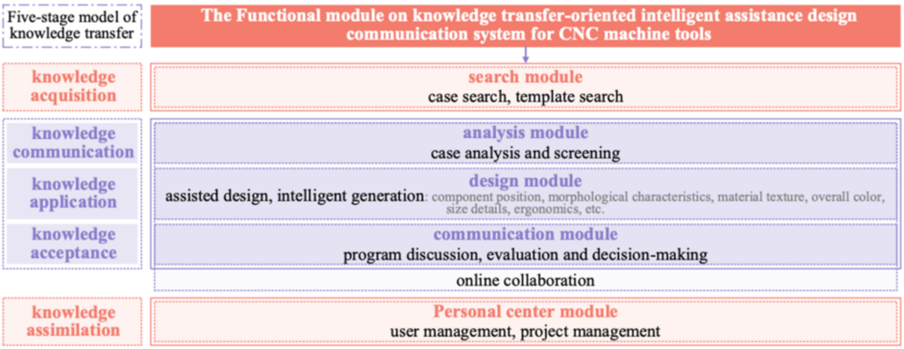


Figure 3. Function modules.

- Scheme design

The interface prototype is the external manifestation form of functional and interaction architecture. By drawing the interface prototype, abstract functional requirements can be visualized [13]. Prototype design unfolds from functional interaction flow and visual design, as shown in Figure 4. The interface prototype can be used for preliminary interaction operations. Through usability evaluation of the prototype, user satisfaction and opinions on the interface prototype can be obtained, and the prototype solution can be iteratively optimized based on the feedback results.

Figure 4. Prototype solution.

- Design practice verification

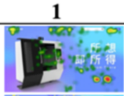
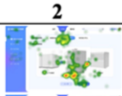
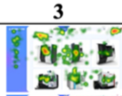
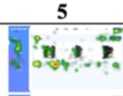
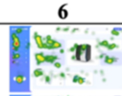
Carry out usability testing on the preliminary prototype solution, including eye-tracking experiment and 5-level Likert scale scoring. Quantitative analysis of the user's operation effectiveness and operation efficiency can be conducted using eye-tracking experiment, and qualitative analysis of user satisfaction can be conducted using the 5-level Likert scale. The two can be combined to comprehensively evaluate the usability of the system's interactive interface and functions. Content is shown in Table 1. After completing the eye-tracking test, the user is scored from 1 to 5 points from the three dimensions of usability, effect of the generated scheme, and degree of design knowledge transfer.

Table 1. Test contents

Test task	Test type	Test question
1. Find the design entrance on the homepage and enter. 2. Browse the design interface and select the content of the machine tool design module in sequence. 3. Generate a scheme and select one for optimization. 4. Browse the design optimization interface, adjust the details of the scheme, and exit. 5. Enter the user management interface and browse, enter the file exchange details, and browse.	Usability	Q1: This system is simple and easy to use. Q2: The content displayed by the system is clear. Q3: The interface of the system makes me feel comfortable.
	Effect of the generated scheme	Q4: The system can quickly output schemes. Q5: Using the system can shorten the design cycle. Q6: Quick generation can save discussion time.
	Degree of design knowledge transfer	Q7: Online collaboration can reduce communication problems. Q8: Using this system can obtain knowledge of machine design. Q9: The system can improve the reuse rate of design knowledge.

A total of 10 effective experimental data were collected. As shown in Table 2, according to the track map obtained by the eye-tracking experiment, the visual search trajectory meets expectations, no important information is missing, and the acquisition rate is relatively high. Through the heat map, it is found that the heat map distribution is concentrated, and the color contrast is obvious, with many focus points on graphic information. Among them, the layout of collaborator information in interface six interferes with the identification of main content and needs to be optimized later. The eye movement tracks and focus areas of most pages are on the main information, the function buttons and interface information are unambiguous, and the interface usability is good.

Table 2. Eye-tracking heat map and track map (partial)

Type	1	2	3	4	5	6
Heat map						
Track map						

The Cronbach's alpha reliability coefficient value of the scale is 0.838, which is relatively high. Further analysis of the scale data found that the coefficient of variation of the questions is less than 0.15, and there are no abnormal values in the test data. The results can be directly described and analyzed by averaging the results. The specific results are shown in Table 3. From the data in the table, it can be seen that the mean of the questions is all above 4 points, and the average values of the three content dimensions are 4.367, 4.267, and 4.300, which are all in the high score range. This indicates that the descriptive statements in the scale are all positive, which means that the usability and use effect of the intelligent assistance design communication system interface and function for knowledge transfer are ideal. The system can be further optimized and iterated based on this scheme.

Table 3. Data analysis of test results

Dimension	Question number	Average value	Standard deviation	Average value of dimension
Usability	Q1	4.3	0.483	4.367
	Q2	4.3	0.483	
	Q3	4.5	0.527	
Effect of the generated scheme	Q4	4.3	0.483	4.267
	Q5	4.4	0.516	
	Q6	4.1	0.568	
Degree of design knowledge transfer	Q7	4.1	0.568	4.300
	Q8	4.4	0.516	
	Q9	4.4	0.516	

6. Conclusion

This article explores the knowledge communication mechanism among designers, engineers, and users in the industrial design process of CNC machine tools from the perspective of design knowledge and knowledge transfer and proposes an intelligent assisted design communication system architecture oriented to knowledge transfer based on the design knowledge transfer process. An intelligent assistance design communication system that helps different stakeholders with different knowledge backgrounds to efficiently acquire, reuse, and transform design knowledge is constructed. The system aims to intelligently generate CNC machine tool product design schemes and provide many design cases to assist online collaborative communication. Through preliminary user testing, it can be known that the system can improve the reuse rate of design knowledge and the efficiency of design communication, and reduce the time required for early product design of CNC machine tools. This paper regards the knowledge systems of different personnel as the medium of product attributes to guide the design direction, which is of great significance for industrial design and design communication of CNC machine tools.

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