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Sustainability assessment and improvement of generative AI in industrial product appearance design

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Abstract. As the consumer market continues to expand, relatively homogeneous approaches to industrial product appearance design can no longer meet consumers' changing needs. This study aims to examine the sustainability assessment and improvement of generative AI in industrial product appearance design, with the goal of adapting to evolving consumer demands while promoting continuous innovation. An analysis of the requirements for industrial product appearance design shows that the application of generative AI offers significant advantages. It can not only reduce production costs but also enhance the market appeal of products. Under these conditions, the application of generative AI in industrial product appearance design is becoming increasingly widespread and demonstrates promising prospects for future development.

Keywords: generative AI, industrial product appearance design, sustainability assessment, improvement

1. Introduction

As AI continues to be applied across an expanding range of fields, generative AI has found applications in various industries, and industrial product appearance design is no exception. Traditional industrial product appearance design processes have often been driven primarily by designers' ideas. However, in a rapidly evolving market characterized by constant innovation, this approach can no longer adequately respond to changing consumer needs. The emergence of generative AI has therefore created new opportunities for the development of industrial product appearance design. Through machine learning and big data analysis, generative AI can rapidly process vast amounts of information and provide designers with accurate and efficient design solutions. It can not only emulate and learn designers' creative styles but also intelligently predict and adjust designs based on market trends and consumer preferences. As a result, industrial product appearance design can become substantially more efficient while aligning more closely with market conditions and consumer needs. At present, global market competition is becoming increasingly intense, while consumers are placing growing demands on product appearance and industrial product appearance design. How to respond rapidly to market changes and consumer needs while ensuring both aesthetic appeal and practicality has become an urgent issue in the field of industrial product appearance design. The emergence of generative AI provides new possibilities for addressing this challenge.

2. Sustainability assessment of generative AI in industrial product appearance design

2.1. Technical principles and methods of generative AI for image and speech processing

2.1.1. Principles and methods of image processing technology

Image processing is one of the most widely used applications of generative AI, primarily drawing on deep learning and computer vision. Deep learning models, such as Convolutional Neural Networks (CNNs), can extract the required information from raw images through specialized layer-by-layer convolution and pooling operations [1]. In industrial product appearance design, AI-based image processing technology is mainly applied in the following areas. First, image recognition enables the effective identification of text, images, and other visual information related to product appearance through the use of pretrained models. Second, image generation allows technologies such as Generative Adversarial Networks (GANs) to produce targeted appearance images according to specified requirements. Third, image optimization improves image quality by automatically adjusting parameters such as color, brightness, and contrast. In the process of industrial product appearance design, designers can make use of the image recognition and design optimization capabilities of generative AI to obtain powerful technical support and assistance.

2.1.2. Principles and methods of speech processing technology

Speech processing technology mainly involves two aspects: speech recognition and speech synthesis. The first is speech recognition, which converts speech signals into textual information through the use of acoustic and language models. In the process of industrial product appearance design, this technology can be used to identify and analyze audio labels or audio guides associated with product packaging [2]. The second is speech synthesis, which converts textual information into speech signals. In industrial product appearance design, it can be used to generate audio labels or voice advertisements, thereby enhancing interaction with consumers. AI systems have powerful natural language processing capabilities. By combining natural language processing technology with social media, online forums, and user reviews, designers can extract user feedback on products. For example, AI can identify users' sentiments, such as positive and negative evaluations, analyze areas of concern, such as functional and performance requirements, and identify potential problems.

2.2. Applications of generative AI in industrial product appearance design

Intelligent recognition is one of the most direct applications of generative AI in industrial product appearance design. Through deep learning models, AI can automatically identify patterns, colors, text, and other visual elements on product packaging. This information can subsequently be used for design optimization and personalized customization.

Automated optimization is a core application of generative AI in industrial product appearance design. Based on deep learning and optimization algorithms, AI can automatically adjust various elements of industrial product appearance design, including colors, shapes, and fonts, to achieve optimal design outcomes [3]. Such automated optimization can substantially improve design efficiency while reducing the need for manual intervention.

Personalized customization represents one of the most innovative applications of generative AI in industrial product appearance design. By collecting and analyzing consumer data and behavioral patterns, AI can predict consumers' preferences and needs and accordingly develop distinctive industrial product appearance design solutions tailored to individual consumers. This form of personalized customization can not only improve consumer satisfaction and loyalty but also create differentiation and competitive advantages for brands.

3. Improvement strategies for generative AI in industrial product appearance design

3.1. Automated control and data analysis

Generative AI has powerful data analysis capabilities. With its accurate and efficient data analysis and evaluation functions, designers can obtain more comprehensive parameter information and decision-making support throughout the industrial product appearance design process. During the design stage, designers can use generative AI to monitor the design, manufacturing, and testing processes of industrial products in real time. They can also adjust design and production parameters according to changes in the data, thereby ensuring greater stability throughout the design process. Such data mining and pattern recognition capabilities can help designers better understand user needs and market trends and provide targeted guidance for industrial product appearance design. During the industrial product appearance design process, automated control and data analysis capabilities are also continuously improved and optimized [4]. With the development of artificial intelligence technology, generative AI can assist engineers in carrying out complex design tasks. For example, it can provide automated design services for component design and CAD modeling, reducing designers' workloads, minimizing human errors, and improving design consistency and accuracy. During the simulation and testing stage of industrial product appearance design, generative AI can work with sensors and other equipment to monitor product performance and operation. During subsequent design planning, designers can also use generative AI to collect various types of data generated throughout the design process, such as design parameters and simulation results. These data can help designers identify the strengths, weaknesses, and potential risks of design solutions, thereby providing a basis for further design improvement and optimization. For example, with the rapid development of the smart home market, consumers' demand for intelligent and personalized household appliances has continued to increase. To meet market demand, a well-known home appliance manufacturer introduced generative AI throughout the entire process of industrial product appearance design, manufacturing, and testing, with the aim of improving design efficiency and quality and better satisfying user needs. During the component design and CAD modeling stages, the manufacturer used AI algorithms to automatically generate preliminary design solutions. By learning from historical design data and user preferences, the AI system could quickly generate preliminary designs that met specified requirements, providing designers with a wide range of creative ideas. Designers then further optimized and adjusted the AI-generated designs. At the same time, the AI system analyzed design parameters and simulation results in real time, providing designers with accurate data and a basis for decision-making. During the industrial product appearance design process, the AI system used sensors and other equipment to monitor product performance and operation in real time. For example, in the design of the refrigeration system of a smart refrigerator, the AI system could continuously monitor parameters such as the internal temperature and humidity of the refrigerator and automatically adjust the operating status of the refrigeration system according to changes in these parameters, thereby ensuring stable and reliable performance. The AI system also analyzed user feedback, market data, and other information to identify potential problems and areas for improvement in industrial product appearance design. For example, after analyzing user feedback on their experience with a smart refrigerator, the AI system found that users were relatively dissatisfied with the internal layout and storage capacity. Based on this finding, designers redesigned the internal layout, increased storage capacity and convenience, and improved the overall user experience. During the simulation and testing stage of industrial product appearance design, the AI system combined sensors and other equipment to monitor product performance and simulate actual usage scenarios. It could predict product performance under different conditions and automatically adjust design parameters to optimize product performance. For example, during

the design of the air ducts of a smart air conditioner, simulation testing conducted by the AI system revealed that certain air-duct configurations generated excessive noise. Designers therefore optimized the air-duct design, reduced noise levels, and improved the product's quiet operation.

3.2. Natural language processing and user needs

AI systems have powerful natural language processing capabilities. Designers can use Natural Language Processing (NLP) technology in combination with social media, online forums, and user reviews to extract user feedback on products. For example, NLP can identify users' sentiments, such as positive and negative evaluations, analyze areas of concern, such as functional and performance requirements, and identify potential problems. NLP technology can provide an in-depth understanding of users' language and identify their actual intentions. For example, by analyzing users' search queries, it can determine whether users are looking for products with specific functions or have particular performance requirements. This technology can help enterprises analyze users' language patterns, interests, and preferences when conducting personalized product design and optimization, enabling them to provide more precise products and services [5]. Natural language processing technology can also support product function design. By incorporating user reviews and feedback, designers can further improve industrial product appearance design and enhance the user experience. Designers need to make flexible and effective use of natural language processing technology and, with the support of AI systems, develop corresponding user big-data models to analyze changes in user needs and potential expectations, thereby improving and optimizing industrial product appearance design. For example, after analyzing user reviews, an NLP system found that many users were satisfied with the color adjustment function of a smart lighting system but suggested improving the accuracy of voice recognition. The NLP system not only identified the content of users' feedback but also gained a deeper understanding of their language and actual intentions. When users searched for products on the company's official website, the NLP system analyzed their search queries to determine whether they were looking for products with specific functions or had particular performance requirements. The NLP system further analyzed users' language patterns, interests, and preferences and provided the enterprise with valuable user-profile information. These data helped the enterprise more accurately identify the needs and preferences of its target users and provided strong support for personalized industrial product appearance design. Based on user feedback and the analytical results generated by the NLP system, designers further optimized product functions. For example, in response to users' concerns about the accuracy of voice recognition, designers improved the voice-recognition algorithm of the smart lighting system, thereby increasing recognition accuracy. At the same time, based on functional requirements identified from user feedback, designers added practical features such as scheduled switching and scene modes to the smart lighting system, further enhancing the user experience.

3.3. Image recognition and design optimization

In the process of industrial product appearance design, designers can leverage the image recognition and design optimization capabilities of generative AI to obtain substantial technical support. AI-based image recognition technology enables designers to rapidly analyze usage scenarios and key elements associated with a product, such as spatial layout and color combinations. This helps designers consider the actual usage requirements of products from the early stages of industrial product appearance design, thereby improving design accuracy. Image recognition technology can also be used to identify detailed elements of products, such as lines, textures, and patterns. Analyzing these details can help designers improve functional design and refine specific product features, thereby enhancing overall design quality and the user experience. In addition, image recognition technology can provide more effective access to user feedback on products. By combining

user feedback with image recognition results, designers can iteratively improve and optimize products. Furthermore, during specific design stages, designers can combine image recognition technology with automated design tools to automate and optimize the industrial product appearance design process, thereby improving design efficiency, reducing design costs, and shortening time to market. For example, during the aforementioned smart refrigerator design process, designers used AI-based image recognition technology to identify and analyze the kitchen layouts of target user groups, including key elements such as kitchen size, shape, and lighting conditions. This enabled designers to gain a deeper understanding of users' actual needs and develop smart refrigerators that were better suited to their kitchen environments. Designers also used image recognition technology to analyze popular color combinations in the market, ensuring that the product's appearance was both fashionable and practical. For the texture design of the refrigerator door, designers used image recognition technology to analyze various texture styles and ultimately selected a design that was both aesthetically pleasing and easy to clean. For the internal layout of the refrigerator, designers used image recognition technology to identify the items users commonly stored and their storage habits. Based on these findings, they optimized the layouts of the refrigeration, freezing, and fresh-keeping compartments, thereby improving the convenience and practicality of the product. The company also used AI-based image recognition technology to collect user feedback by analyzing photographs taken by users during product use and their accompanying comments. This enabled designers to promptly identify shortcomings in the industrial product appearance design and carry out product iterations and optimization based on the feedback. For example, regarding the refrigerator noise issue, designers used image recognition technology to identify the source of the noise and implemented targeted improvements. During specific design stages, designers combined image recognition technology with automated design tools to automate and optimize the design process. After images of users' kitchen spaces were uploaded, the automated design tools could rapidly generate refrigerator design solutions that met users' needs, thereby improving design efficiency.

3.4. Simulation testing and predictive maintenance

Designers can use generative AI to obtain support for simulation testing and predictive maintenance during the industrial product appearance design stage. Specifically, generative AI can conduct extensive virtual testing at the early stage of industrial product appearance design and simulate product performance and behavior under various operating conditions. This helps designers identify potential problems during the design stage, reduce the number of subsequent modifications and iterations, and improve design accuracy and efficiency [6]. Traditional physical testing requires substantial amounts of time, effort, and human resources. By contrast, AI systems can conduct simulation testing in virtual environments and obtain various types of product performance data without the need to manufacture physical prototypes, thereby reducing testing costs. The simulation capabilities of generative AI can also reproduce product behavior under various extreme conditions within simulation systems, allowing designers to evaluate product performance and reliability while further reducing the costs associated with reliability testing. Furthermore, generative AI can analyze the actual operating conditions of previous-generation products, including failure rates and customer complaints, together with other relevant information. From a structural engineering perspective, it can identify deficiencies and shortcomings in industrial product appearance design and predict potential failures that may occur in next-generation products. Designers can then implement corresponding design improvements and optimizations in advance to minimize the likelihood of equipment failures. In addition, during the planning stage of industrial product appearance design, designers can use simulation and predictive analysis to evaluate potential resource consumption and environmental pollution arising during subsequent production. Based on these assessments, they can formulate appropriate design and production control plans, such as improving equipment and product

design parameters and optimizing manufacturing processes, thereby reducing resource consumption during mass production.

Although generative AI can play a significant role in industrial product appearance design planning, designers should apply it selectively and maintain precise control throughout the design process. Specifically, generative AI is only an auxiliary tool. Although it can assist designers in improving industrial product appearance design, its use may also introduce certain forms of interference and influence. For example, generative AI relies heavily on large-scale datasets. If the data lack timeliness, the quality of the resulting design may be affected. During industrial product appearance design planning, significant changes in product requirements may occur. Under such circumstances, directly using information from previous-generation products for AI-based predictive analysis may not produce optimal design outcomes. Therefore, designers need to ensure data quality and use reliable, up-to-date data as the basis for design optimization. At the same time, greater attention should be paid to human-centered design elements, and industrial product appearance design should not rely entirely on artificial intelligence. In addition, the application of generative AI in industrial product appearance design may involve a range of ethical issues. Designers need to conduct in-depth analysis during the planning and design process and develop appropriate ethical decision-making strategies to avoid creating products that conflict with prevailing social values. As generative AI continues to evolve, designers should continuously update and optimize its application throughout industrial product appearance design planning to maximize the quality and effectiveness of design outcomes.

4. Conclusion

In industrial product appearance design, designers should use generative AI to establish a comprehensive design process and leverage the intelligent decision-making and analytical capabilities of AI systems to obtain strong data support. In this way, the overall quality and efficiency of industrial product appearance design can be improved. In the future, further research should be conducted into the application of generative AI to product design, thereby promoting the continued development of generative AI and making a greater contribution to the advancement of China's industrial product appearance design industry.

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