Digital Twin Driven Bionic Shape Design Path Construction Research

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Abstract. Bionic shape design is an important means of industrial design, in order to effectively improve the efficiency of morphology bionic design, to solve the design process there are information barriers, bionic structure extraction difficulties, can not be verified in a timely manner iteration and other issues, and the digital twin unique big data, virtual and real intermingling of the key technologies for the morphology bionic design provides a new means of solving the problem. This thesis proposes a digital twin-based morphological bionic design idea, aiming to introduce digital twin technology into morphological bionic design to solve the problems in the development process of bionic design. The conclusion proves the feasibility of applying digital twin technology to the morphological bionic design process. Digital twin-enabled bionic shape design promotes the study of the theory and methodology of bionic design, and provides new ideas and possibilities for bionic design for future intelligent cross-innovation design.

Keywords: Bionic shape design; Digital twins; Interdisciplinary; Bionic design; Product design.

1 Introduction

With the continuous development of industrial big data, cloud computing, AIGC and other technologies, digital twins have been maturely applied in many fields, and industrial design will certainly develop in the direction of digitalisation and intelligence. Bionic shape design is an important innovative design method for industrial design and an important interdisciplinary design tool.

However, the traditional bionic shape design method can no longer support the innovative design in the new situation. There are three status quo problems in the current bionic design process: difficulty in obtaining prototypes of bionic organisms, single extraction of multi-behavioural feature structures, and difficulty in implementing bionic design solutions.

In order to solve the problems in the bionic design process, this thesis provides an innovative design idea. The advantages of digital twin technology-assisted morphological bionic design are elaborated in detail. This thesis can help designers improve

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their work efficiency, provide reference for the theory and method of bionic design, and advance the research of bionic design.

2 Literature review

2.1 Digital twin

The idea of the digital twin was first introduced in Professor Grieves' Product life cycle management (PLM) course at the University of Michigan in 2003, but at that time the idea had not been developed into a systematic body of theory. NASA formally defined the digital twin in 2010: "A simulation model of a system or vehicle that integrates multiple physical quantities, scales, and probabilities." Digital twin is the use of digital methods to establish a simulation virtual model of physical entities, through the mobilisation of virtual data, simulating the behaviour state of physical entities in real environments, and tracking the full life-cycle process of a product in real time by means of virtual-reality mingling, real-time mapping, and iterative optimisation [1], which plays a connecting role as a bridge and a link between the physical space and the virtual space, with the aim of providing more real-time, efficient, and intelligent services as a goal.

Since the concept of digital twin was put forward in 2010, it has been widely applied in many fields such as aerospace, medical rehabilitation, intelligent manufacturing, etc., and scholars at home and abroad have defined it from different fields respectively. The author selected the research about the product design field to do the relevant description, Tao Fei proposed the digital twin five-dimensional model to meet the new requirements of modern applications based on solving the bottleneck problems existing in the traditional digital twin 3D model research, and conducted research on the application of digital twin in the product design process, as well as an in-depth study on the digital twin-based product design framework and its specific applications [2-5]. Sherry Li etc. intervened digital twin technology into product CMF design and proposed a new service support model for designers to provide innovative design decisions [6]. Li Hao etc. proposed a new idea of design-manufacturing co-development based on digital twins, and studied the key technologies, application cases and scenarios [7]. As a new technical concept with high value, digital twin has been increasingly applied in the field of product design. The descriptions of the above related studies all provide the theoretical foundation and scientific basis for this paper's innovative research on bionic shape design theory based on digital twin technology [8].

2.2 Bionic shape design

Bionic design is an important method in the industrial field and one of the design paths for industrial design innovation. Bionic design is a design method based on the principle of bionics, which extracts the structure and completes the product innovation according to the design requirements after in-depth research on the morphology, structure, behaviour and colour of natural objects. Bionic design includes structure bionic, colour bionic, texture bionic, imagery bionic and morphology bionic, of which the most commonly used is morphology bionic design. Morphological bionic design is an innovative design method that breaks through the existing product forms by directly imitating and extracting the external forms of living organisms in nature, and then re-innovating and designing the extracted forms through artistic processing techniques. For example, a gull-wing car (Figure 1) is designed by simulating the shape of seagull's wings in the open state and the principle of dynamic behaviour of swinging wings. The doors of this model have been changed from the traditional push-out and push-forward type to open and close type in both directions, which not only facilitates passengers to enter and exit, but also forms a new gull-shaped car. Morphological bionic design from nature, further exploration of the relationship between man and nature, so that the product has an impact on the visual image and aesthetic characteristics, to provide users with more emotional value of product design.

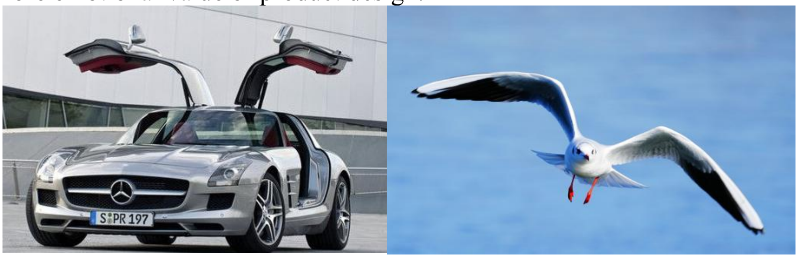

Fig. 1. Gull-winged car.

The traditional bionic shape design refers to the designer's bionic design based on the design principles and methods of industrial design by making individual judgement on the morphology of organisms and microorganisms in nature as well as existing bionic products [9]. Obviously, the quality of bionic product design is determined by the designer's own artistic background, professionalism, and depth of understanding of organisms and their own products. The results of product form design can vary greatly between different designers, increasing the uncertainty of the design.

2.3 Research gaps

Morphological bionic design is mainly composed of three stages (Figure 2). The first stage of bionics target selection - designers analyse and compare the biological prototypes according to the design requirements to select suitable bionics targets after defining the design objectives; the second stage of morphological features extraction and transformation - extract the target form and abstract the innovative design on the basis of the user's perception and the study of sufficient morphological features information; the third stage of evaluation and optimization - the effectiveness evaluation needs to be based on the final design results. Phase 2: Morphological feature extraction and transformation - on the basis of clear user perception and sufficient information on morphological features of the bionic prototype, the target form is extracted, the structure is simplified, and the innovative design is abstracted; Phase 3: Evaluation and optimisation - validity assessment is needed to control the final design results, verify the scientific validity and accuracy of the design results, as well as the return rate of the target production. In this whole design process there are still design knowledge access is small and one-sided, bionic object understanding is not comprehensive, the target features are not extracted accurately and other defective problems, affecting the design efficiency, increasing the cost of time and economic consumption, is not conducive to the development of bionic design.

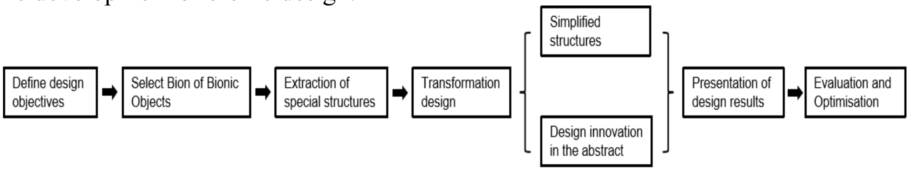

Fig. 2. Design Bionics Process.

2.3.1 Difficulty in obtaining bionic object prototypes.

The selection of inspiring biological prototypes as the source of inspiration for design bionics is the first step of morphological design bionics, and the selection of bionics object prototypes directly determines the feasibility of the design scheme and the validity of the design results. Currently, the selection of bionics prototypes mainly relies on the designers' accumulation of design knowledge and subjective experience, and the designers usually determine the bionics objects based on their existing knowledge and experience by reading biological publications, searching keywords on the Internet, or consulting with relevant experts, etc. Such a subjective judgement of the process of acquiring the bionics objects is accidental and blind, which results in the lack of comprehensiveness in the bionics information of prototypes acquired. Therefore, the difficulty of obtaining information across fields, the "knowledge gap" in the design process, and the difficulty of obtaining effective bionics prototypes have become one of the difficulties in the design of bionic shape.

2.3.2 Multi-behaviour feature structure extraction single.

The morphological features of a product are related to the user's perception of the product, and accurate feature extraction allows users to recognise the form and function of the product at a glance, so the accurate extraction of bionics features and the simplification of key structures is a key step in the bionic shape design. The traditional biometric feature extraction method is that after determining the bionic prototype object, the designer scans the surface of a single static organism to form a surface to simplify it into a structural line, conducts cognition and research on it, and then finally carries out a purposeful product morphology biomimicry design according to the design elements such as product positioning and user population. In the traditional extraction process, designers only study a single behaviour or a single state of the organism, ignoring the multi-behaviour dynamic bionic study of the organism.

Organisms in nature are able to change their shapes, movements and colour to adapt to complex environments as their living environments change. For example, mudskipper can swim underwater, survive on beaches by their hard pectoral fins, and sometimes climb on the roots of trees. Current biological structure extraction methods are qualitative rather than quantitative, and bionics with reference to only a single behaviour of a creature lacks comprehensiveness and scientificity. Therefore, the extraction of multi-behaviour dynamic feature structures of bionics objects is the second difficulty in bionic shape design.

2.3.3 Bionic design solutions are difficult to implement.

Bionic products are realized by imitating the natural biological structure, behaviour laws or movement patterns and other forms, but the current bionic products (such as mechanism design, movement modelling, etc.) have weak consistency with the natural biological prototypes, and their design results do not meet the expectations of the user population, in which the morphological structural reasoning link has become one of the shackles for the products to achieve a more lifelike bionic performance. The reason for this is that, on one hand, the designers do not have a precise grasp of the target population and market research, on the other hand, the designers do not have enough knowledge and research on the structure and mechanism of living organisms, and on the other hand, the bionic reasoning process of the product relies very much on the previous experience of the designers or the team, and there is a lack of effective computer-assisted bionic design reasoning methods and a lack of comprehensiveness in the design process.

Currently, deep learning-based multi-domain analogical reasoning and inference methods have achieved certain breakthroughs, providing potential research possibilities for achieving cross-domain structural reasoning to generate new design solutions. Therefore, the study of cross-domain intelligent assisted computing technology from bionics prototypes in the biological field to the generation of innovative design bionics solutions is of great theoretical and practical significance to promote the development and application of design bionics in the manufacturing field.

3 Discussion

In recent years, with the implementation of Germany's "Manufacturing 4.0", the U.S. "Industrial Internet", China's "Manufacturing 2025" and other corresponding advanced manufacturing development strategy, intelligent manufacturing has become a new trend and goal of global development. become the new trend and goal of global development. As the first echelon of intelligent manufacturing, industrial design is the key to realising "Made in China 2025", and how to synergize the development of design and information technology. The industrial design mode will inevitably develop in the direction of digitalisation and intelligence. Computer-aided product design is also gradually conforming to this development trend, for example, designers have begun to use Grasshopper parametric computing to create simple morphology bionic design. Therefore, the intelligent cross-innovation application of cross-disciplinary bionic shape design is a major trend.

At present, the research application of digital twin in bionic design is relatively small, and its related literature is mainly concentrated in the fields of product design, automobile aircraft machine tools, production workshop, etc. The research on digital twin at home and abroad has developed mature key technologies and breakthroughs in theoretical research and practical application research, which can provide solid theoretical foundations and scientific basis for the theoretical innovation research in this paper. In this paper, digital twin technology is used as a technical means to solve problems, and it is intervened in the process of bionic shape design, and with the help of its core ideas and technical means such as big data, combination of reality and reality, real-time simulation and so on, it puts forward three problem-solving research ideas to provide a new method way to achieve the rapid acquisition of cross-domain bioinformation and optimisation of the design [10].

3.1 Big Data-Driven Acquisition of Bionic Prototypes

Digital twin is mainly composed of three elements, physical space, virtual space, and data transmission connecting the two spaces [11]. Among them, big data is one of the key technologies supporting digital twin, and it is also the source and driving force for accurately acquiring the bionic target. The data of digital twin is more comprehensive, which not only relies on expert knowledge, but also can collect data from all systems in real time. To address the problem that it is more difficult to obtain information across domains for bionic object prototypes, firstly, the massive data about bionic design goals can be mined in the Internet, and then the industry knowledge of related biological fields is continuously extracted through crawlers and other big data processing technologies to obtain multi-source, comprehensive, reliable and accurate information data, and the designers obtain the value behind the data by digitally analysing the information so as to select the best fit for the The designers digitally analyse this information to obtain the value behind the data, so as to select the most suitable bionic object prototype for the design requirements.

In the process of selecting bionic object prototypes in bionic shape design, digital twins provide designers with an auxiliary platform to quickly and accurately obtain biological prototypes that fit the design goals, and the selected bionic targets are more scientific and comprehensive, which reduces the time spent on collecting information in the early stages, and reduces the probability of product rework and the complexity of the design.

3.2 Standard model library to build bionic dynamic morphology

In digital twin, physical space and virtual space are not two static and isolated existences, but real-time interaction, flow feedback and mutual integration. In bionic shape design, accurate extraction of the main structural features of the bionic object is a key step in linking the bionic product to the consumer, traditional bionic shape design can only be based on the designer's subjective experience to extract the static behaviour features of the organisms, which is unscientific and incomplete. However, the dynamic behaviour model of bionic organisms can be built in the simulation evolution platform of digital twin virtual space through scanning, and designers can extract and simplify the bionic prototypes in an all-round way by manipulating the simulation model in the virtual space, and the simulation model in the virtual space replaces the entity modelling in the physical space, and completes the real mapping of the physical entity in the virtual space, which greatly reduces the trial-and-error rate and production cost of bionic products, improves the cooperation between designers and intelligent designers, and increases the cost of production, and increases the cost of designers and intelligent designers. production costs, and improves the co-design efficiency of designers and intelligent innovation.

The digital twin is capable of storing massive amounts of physical bionic models, virtual bionic models, and behaviour histories of all data within the design system, so in the bionic design process, designers can store their extracted biometric morphology models in accordance with the functional structure (e.g., bird's nest structure, helical structure, armour-wing structure, etc.) in the bio-morphology model library. In addition, in order to greatly reduce the designer's workload, the morphological feature groups in the model library are standardised and normalised, so that these product morphological models can achieve the effect of reusability, improve the utilisation rate of the morphological models, and achieve the purpose of reducing the cost of product design.

3.3 Virtual-real interaction realizes design closed loop

Digital twins are currently most maturely used in manufacturing systems, where they can iteratively optimise activities throughout the product cyclical, and in the virtual space of the digital twin, various design activities throughout the product cyclical can be simulated, inspected, optimised and verified [12-13]. Product validation is crucial to ensure the feasibility and effectiveness of product design, and product validation techniques in digital twins can significantly reduce the cost of inefficient physical validation. Bionic product design results need to be evaluated by iterative simulation verification to ensure that the product prototype achieves the desired results.

Due to the lack of real-time feedback data and usage scenarios, traditional bionic product design validation can only be effectively evaluated when the product is produced in small batches, which prolongs the production cycle of the bionic product and increases the cost of time and money. However, the digital twin exists throughout the cyclical of the physical bionic product design, storing and recording all the real-time simulation data of the product, so it can be quickly verified and redesigned, which greatly improves the design efficiency. The digital twin is a real mapping of the physical product, through the real-time transmission of feedback data, open and transparent communication between the user and the designer, detailed analysis of user feedback and the problems that occurred in the previous generation of products, to further guide the improvement of iterative products, to achieve the implementation of the design plan and product iteration optimisation of the design of the closed loop.

4 Conclusion

This paper proposes a study of bionic morphology design ideas based on digital twins. Firstly, it points out the problems existing in the traditional morphological bionic design process; secondly, based on the study of domestic and international digital twin product design application fields, it puts forward the innovative design ideas of digital twin morphological bionic design.

The advantages of morphological bionic design are described in detail by introducing digital twin technology to assist design. The paper proposes three design ideas: 1 big data-driven acquisition of bionic prototypes, 2 standard model library empowering bionic dynamic morphology construction, and 3 virtual-real interaction to achieve closed-loop design, which solve the problems of traditional bionic design, such as the difficulty of acquiring cross-domain knowledge, inaccuracy of dynamic feature extraction, and inconsistency between bionic models and design results.

At present, the theory and method of bionic shape design based on digital twin is still in the primary research stage. The design ideas proposed in this thesis provide theoretical and methodological references for the cross-innovative design of bionic shape design, and the digital twin-driven bionic shape design application model will be further created and improved in the future.

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