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Secondary Development of CAD Software for the Construction of Mechanical Product Design System

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Abstract. To meet the needs of different stages of product generalized design process, presents a CAD software secondary development method for the construction of mechanical product design system. Firstly, a freehand drawing board based on CAD geometric modeling platform is used to draw three-view sketches. Then, feature information was extracted from the freehand three-view sketch and the three-view projection from CAD models in the model library, and 2.5D spherical harmonic descriptor was used to represent the feature information of the sketch. Finally, Euclidean distance was used to calculate the distance between graphic feature vectors obtained by spherical harmonic transformation, so as to realize the similarity evaluation between models, and the algorithm was verified in the agricultural machinery and equipment model base. The experimental results show that the feature extraction time and feature comparison time of the proposed algorithm are only 0.471s, while the processing time of the other two algorithms are 0.937 and 0.826 respectively. The product designed by this system has better retrieval performance, and the retrieval results can better reflect the user's retrieval intention. It can save design time and improve production efficiency of products, and has high practical application value.

Keywords: Product design; Spherical harmonic descriptor; CAD.
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1 INTRODUCTION

3D CAD models have been widely applied in the field of mechanical design and manufacturing, resulting in a large number of product models containing rich information [1]. In the context of mechanical engineering, 3D CAD modeling is the process of developing accurate specifications and comprehensive drawings to aid in the design, construction, and manufacture of mechanical products and their components [2, 3]. Mechanical design professionals may employ 3D CAD modeling to create three-dimensional images that are nearly as lifelike as the physical products they represent. This relatively new method is extensively used in a wide range of industries, including shipbuilding, vehicle manufacturing, architectural design, and the fabrication of nearly any complex mechanical product [4, 5]. 3D CAD modeling approaches have gained popularity in the mechanical engineering community throughout the world due to their excellent ability to allow reuse of different design data throughout the production life cycle [6, 7]. How to effectively browse and retrieve these models, so as to maximize the design reuse of this resource information, so as to reduce the design cost and shorten the product development cycle, has become a research hot topic in the manufacturing industry [8]. Manufacturing has evolved throughout time, from human-centered processes to machine-reliant assembly lines to the fully automated operations that are becoming more prevalent [9, 10]. And the industry is always evolving. Indeed, several trends are converging to change production, and these developments are referred to together as "Industry 4.0" [11, 12]. We have the Industrial Internet of Things (IIoT), which collects data from networked devices in manufacturing and industrial settings and then uses it to optimize the production process. Sensors are an excellent example of linked IIoT devices [13, 14].

Now days, Augmented reality is a design experience in which computer-generated input is used to augment features of the user's physical environment. Designers provide real-time inputs in digital content such as music, video, images, GPS overlays, and more. The advantages of using virtual reality in CAD are evident. To begin, virtual reality allows customers to view their works in 3D. It also enables students to see how their design would seem when compared to other virtual products of the same size. e to changes in the user's environment, most commonly movement For the retrieval system, how to design the interactive way of query input, so as to express the user's query intention conveniently and quickly, is an important subject of the 3D CAD model retrieval technology. 3D model retrieval systems in general field mostly adopt query interface in the form of instance submission, but this method is not applicable to engineering design [15]. The most inventive way for obtaining 3D content is to use methods to add descriptive language to 3D content files, including the content data file, link text, and web page title, because then relevant 3D material may be located using text retrieval. Because manually marking 3D data is inefficient, scholars have investigated ways to automate the process and give a standardized method for providing text descriptions for 3D material.

In the initial stage of design, designers are more used to drawing two-dimensional sketches to record their design inspiration. Therefore, for CAD model retrieval system, the retrieval input method based on sketch is an indispensable part [16]. As a result of continual improvements in the fields of 3D modeling and digital archiving, the amount of data preserved digitally has expanded. As a result, several retrieval mechanisms have been developed based on the type of data stored in these databases. However, searching for 3D models is more challenging than looking for text or images [17, 18]. Because of the presence of holes, volumetric properties, sharp edges, and other features that distinguish CAD, recovering 3D Engineering/CAD models or mechanical components is significantly more challenging [19, 20]. At the same time, this approach is more conducive to improving the efficiency of design reuse because it conforms to the design habits of designers.

Moreover, IoT-enabled CAD models enable the collection of real-time data from several sources into a single file. This enables designers and engineers to realistically and precisely assess how real-world data influences their design. When Augmented Reality (AR) is added to the mix, the entire process improves even further. IoT may also be used to monitor machine activity in

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order to discover, avoid, and minimize errors. At the stage of product conceptual design, designers usually only have some original and fragmentary models in their minds that simply reflect the design intention. They usually express their design ideas by freehand sketches, and then urgently push 3D CAD models of products according to the design intention of designers [21].

3D CAD allows designers to develop and change every detail of a product, part, or assembly in real time. Other aspects of product engineering, such as simulation testing, drawing design drafting, manufacturing, data management, computer produced animations, and others, are simplified and automated with 3D CAD software [22, 23]. Therefore, the research on similarity design push method of sketch-based product 3D CAD model has become an important way to realize rapid response in product conceptual design stage, so as to help designers find abundant model cases similar to conceptual model and inspire design thinking through reference. Query input is the first step of the retrieval process. How the computer understands the submitted 2D sketch will directly affect the accuracy and accuracy of the retrieval results. The input 2d sketch is used for 3D reconstruction, but this method is limited to simple 3D model reconstruction.

Nowadays, there are several methods for converting a 2D graphic into a 3D model. Unsurprisingly, digital solutions such as computer-aided design (CAD) and drawing software are the most used. However, the design medium is not as black and white as you may think. Many people blend traditional and digital methodologies, drawing out iterations on paper and then developing them online. The conversion technique varies based on the particular of the 3D image or model you want to create. At the same time, due to the lack of depth information of two-dimensional images, some important geometric features are often lost in the reconstructed models. Compared with the method of 3D reconstruction directly based on sketches, the method of extracting shape features based on sketch representation information and converting them into corresponding shape descriptors for similarity comparison can obtain the similarity differences between different views more conveniently and has higher practicability. Han, Z. et al obtained rapid CAD assembly model by using product conceptual design stage to carry out model reuse in product conceptual design stage. Aims to find semanteme-based assembly retrieval based on functional function correlation analysis and structural function correlation analysis and functional semantic annotation of mechanical CAD assembly model. A method of structural function correlation analysis and functional semantic annotation for design/method/method CAD assembly model is proposed.

Firstly, the product knowledge model is constructed based on ontology, including design knowledge and functional knowledge. Then, the CAD assembly model is represented by a partial attribute adjacency graph and divided into several functional areas. The assembly area and flow activity area were defined for structural functional correlation analysis of CAD assembly models. At the same time, the extraction process of assembly area and flow area is given in detail. In addition, structural function correlation analysis and functional semantic annotation are realized by considering the overall assembly structure and the shape structure of assembly part in CAD assembly model. Then, a structure-function relationship model is established based on the polychromatic group, which is used to express the polychromatic set of functional structure, assembly parts and functional semantics. It is found that the correlation between structure and function is analyzed effectively, marking the functional semantics corresponding to structure in CAD assembly models. In addition, the relationship between functional structure, assembly parts and functional semantics can be explicitly and formally described [24].

Many companies have begun to employ cloud-based CAD software. This saves money by removing the need for a large IT team or a lot of on-site technology. Security has been a cause of concern; however advances in cloud technology have resulted in significant advancements in its security. Additive manufacturing is a one-of-a-kind process for producing objects by combining tiny layers of material. It can help you save money by using less material and allowing you to employ atypical shapes, such as a lattice structure instead of a solid framework. On the basis of this research, proposes a CAD software secondary development for the construction of mechanical product design system. By extracting the shape features of the three-view sketch of the product

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model at the initial stage of design, the 2d graphics are mapped to spherical graphics and the spherical harmonic descriptors are used to measure the similarity in the product model database. Explore the three-dimensional CAD model most consistent with the intention of the product conceptual design stage, speed up the transformation of conceptual design and detailed design, and then reference, inspire and expand the design thinking, and form the final design scheme.

The above-mentioned section is the introduction to the paper. The section 2 covers the research methodology. The results analysis has been done in the section 3. Finally, section 4 concludes the paper.

2 RESEARCH METHODS

2.1 CAD Model Retrieval Based on 2D Sketch

2.1.1 Algorithm Overview

Before retrieving the CAD model with 2D sketch, it is necessary to obtain the three views of the CAD model in the model library, and then extract the shape features of the three views and store the feature vectors into the model library. During retrieval, the corresponding shape features are extracted from the three views of the sketch submitted by users, and similarity matching calculation is carried out with the model shape features previously stored in the model library. Finally, the retrieval results are output according to the size of the similarity value. The whole process is shown in Figure 1. The three views were initially extracted from the cad model. The shape is designed from there and data base is created. This system's product has superior retrieval performance, and the retrieval results are more likely to represent the user's retrieval purpose.

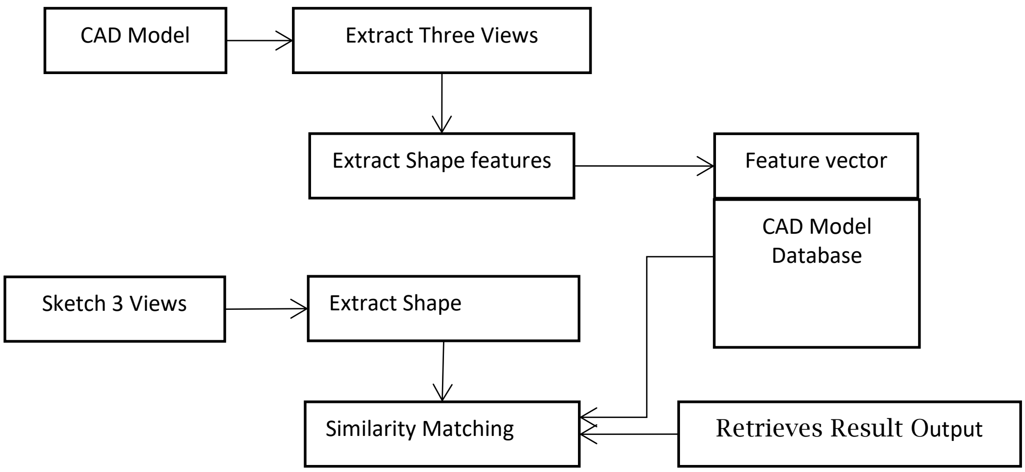

Figure 1: CAD model retrieval process based on sketch.

2.2 Feature Extraction based on Fourier Descriptors

The basic idea of Fourier shape descriptor is to use the Fourier transform of exterior contour as its shape feature description. For the contour of a two-dimensional view, it needs to be transformed into a one-dimensional representation before Fourier transform. At present, curvature function, centroid distance function and complex coordinate function are commonly used to represent external contour shapes [25]. Generally speaking, the effect of centroid distance function is better than other methods, so chooses centroid distance as the shape representation of outer contour.

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The centroid distance is defined as the distance between a view's outer contour boundary point and its centroid. The steps for generating Fourier descriptors of the outer contours of the three views are as follows:

2.2.1 Normalization

It includes the following steps:

- Subdivide the contour map using Canny operator;
- Point set $\{p(x_i, y_i) | i = 0,1 \cdots N-1\}$ is obtained by tracking the outer contour, where N is the total number of pixels on the contour;
- Calculate its geometric center $x_c = \frac{1}{N+1}\sum_{i=0}^{N} x_i, y_c = \frac{1}{N+1}\sum_{i=0}^{N} y_i$;
- Transform the view to a new coordinate system with (x_c, y_c) as the origin.

2.2.2 Calculation of centroid distance

Since the view coordinate system has been normalized in the preprocessing process, the centroid distance of the three-view contour graph can be directly calculated as shown in Formula (2.1):

$$r(i) = \sqrt{(x_i - x_c)^2 + (y_i - y_c)^2} \, (i = 0,1,\cdots, N-1) \quad (2.1)$$

2.2.3 Carry out Fourier transform for centroid distance

Since $r(i)$ is a set composed of N discrete points, the discrete Fourier transform formula is used, as shown in Formula (2.2):

$$R(k) = \sum_{i=0}^{N-1} r(t) e^{-j2\pi \frac{k}{N} t} \, (k = 0,1,\cdots, N-1) \quad (2.2)$$

Generating Fourier descriptors: Its description vector is shown in Formula (2.3):

$$f = \left[\frac{R_1}{R_0}, \frac{R_2}{R_0}, \cdots, \frac{R_{N/2}}{R_0} \right] \quad (2.3)$$

Where, the purpose of R_k divided by R_0 is to normalize the parameters to ensure the scale invariance of the shape. The purpose of taking the absolute value is to keep the scale invariance of the shape. The above Fourier description vector F is the shape feature vector of the outline outside the three views. By measuring the distance between feature vectors of Fourier descriptors, similarity evaluation between two trisomic contours can be realized. In this paper, the most common Euclidean distance is used to calculate the distance between feature vectors.

2.3 Feature Information Extraction of Sketch Based on Spherical Harmonic Descriptors

2.3.1 2.3.1 Extraction of spherical harmonic descriptors

Obtain rotation invariants of freehand sketches, 2B Chebyshev data points were sampled on a spherical function with bandwidth B using a fast spherical harmonic transforms. The extraction steps of spherical harmonic descriptors of freehand sketch D are as follows:

1. Data point sampling on sketch D: 2B rays are extracted from the center of the minimum enveloping Box of sketch D, and the intersection point between the rays and sketch D is: $p_i = f(\theta_i, d_i)$. The position of the sampling point in 3D space is calculated as shown in Formula (3.4):

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$$\begin{cases} \theta_i = (i+0.5)\frac{\pi}{B} \\ \varphi_i = \arctan\frac{d_i}{r} \end{cases} (i = 0,1,2,\cdots,2B-1) \tag{3.4}$$

2. The Chebyshev point position of sampling point (θ_i, φ_i) is calculated as shown in Formula (3.5):

$$\begin{cases} i = i \\ j = \frac{2B\varphi_i}{\pi} - 0.5 \end{cases} (i、j = 0,1,2,\cdots,2B-1) \tag{3.5}$$

Then graph D can be represented by Chebyshev point position (I, j), as shown in Formula (3.6) :

$$D = \{d_i = f(i,j) | i、j = 0,1,2,\cdots,2B-1\} \tag{3.6}$$

3. Normalization processing: In general, different graphs have different sizes. If two graphs have the same shape but different sizes, then $\{d_i\}$ is different. Therefore, the graph needs to be normalized. The normalization of graph D is generally to normalize the long or short sides of the minimum bounding box of graph D. The normalization factor is the bounding sphere radius R, and its normalization formula is shown in Formula (3.7):

$$\begin{cases} S = \frac{V}{r} \\ D = \{d_i S = f(i,j) | i、j = 0,1,2,\cdots,2B-1\} \end{cases} \tag{3.7}$$

Where V is a predefined constant

4. Fast spherical harmonic transformation: The method in this paper is used to carry out fast spherical harmonic transformation to obtain the rotation invariant descriptor of graph D. For each frequency, a corresponding rotation invariant is obtained. This method can avoid the instability caused by one-to-many and shape disturbance, and thus obtain the rotation invariant descriptor of graph D, which has good robustness [26]. Bandwidth B determines the density of sampling points. When B is small, much details will be lost. However, when B is large, the description of graph D is more accurate, but it takes a lot of time. Therefore, it needs to be weighed. When the bandwidth B is 64, the precision is 0.005, which can meet the requirement of graph retrieval.

More intuitively and image described, the method to extract the spherical harmonic descriptor, build the spherical harmonic descriptor histogram, as shown in figure 2, figure 2 and figure 2 b are two similar graphics, the graphics of spherical descriptor histogram are similar in shape, and two graphics spherical harmonic descriptor of the biggest component with the smallest size is more close. However, the similarity between figures 2A, 2B and 2C is relatively small, and the shape similarity of the corresponding spherical harmonic descriptor histogram is very low. As can be seen from the maximum components of spherical harmonic descriptors, the maximum components of figure 2A and figure 2B are close to 1.2, while the maximum components of figure 2C are close to 1.1. The proposed method has good discrimination.

2.3.2 Similarity measurement

By using spherical harmonic transformation to obtain the feature vectors of graphs, the problem of similarity comparison between graphs is transformed into the distance measurement between feature vectors. Euclidean distance was used to calculate the distance between feature vectors. Assuming that the feature vectors of the two models F and G are respectively

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$f_{SH} = \left(\left|f_0\right|, \left|f_1\right|, \cdots, \left|f_B\right|\right)$、$g_{SH} = \left(\left|g_0\right|, \left|g_1\right|, \cdots, \left|g_B\right|\right)$, the similarity distance between the two models is shown in Formula (3.8):

$$D\left(f_{SH}, g_{SH}\right) = \sqrt{\sum_{i=0}^{B}\left(\left|f_l\right| - \left|g_l\right|\right)^2} \tag{3.8}$$

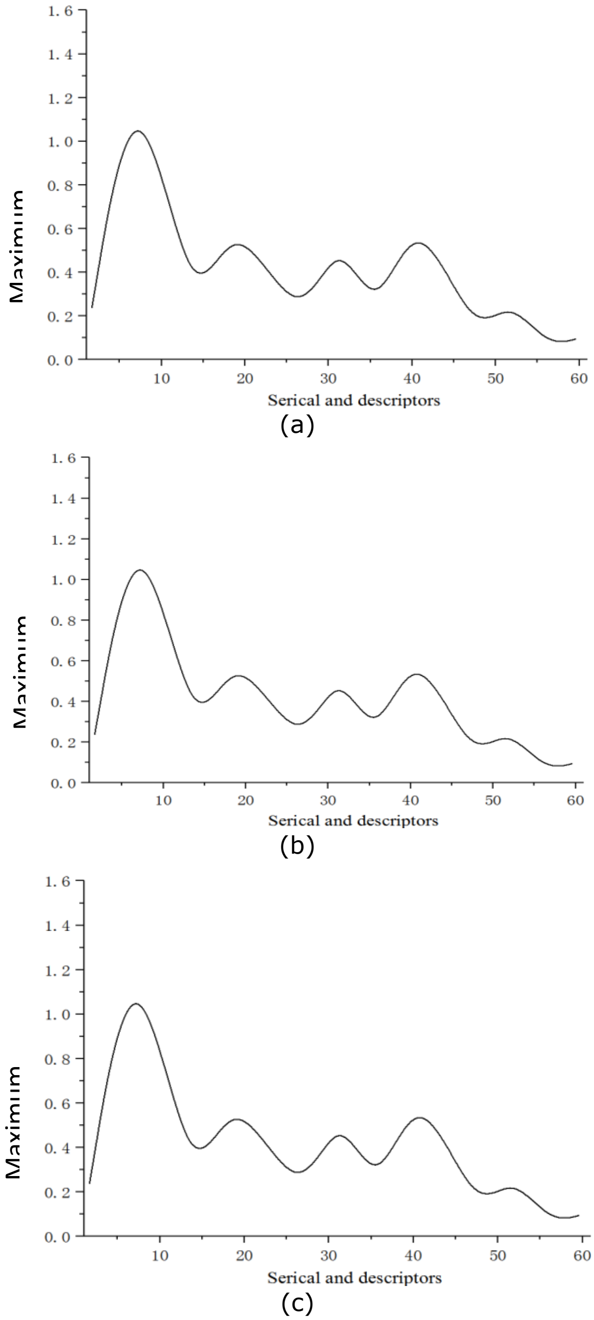

Figure 2: Comparison of spherical harmonic descriptors of different graphs in (a), (b) and (c).

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3 RESULT ANALYSIS

3.1 Algorithm Performance Test and Evaluation

In the prototype system, the sketch-based retrieval function allows users to draw three views of the target model on the 2D sketching interface provided by the system, and then expand the retrieval based on the query conditions. This function can help users quickly visualize the query intention, which is suitable for the product concept design stage when the user's query objective is relatively vague. Fully compare the performance of the algorithm, statistical tests were carried out on the CAD models in ESB model base and agricultural machinery model base respectively, and the precision-recall (PR) curve was obtained. As can be seen from the curve in figure 3, the retrieval performance of the proposed algorithm is significantly better than the other two methods.

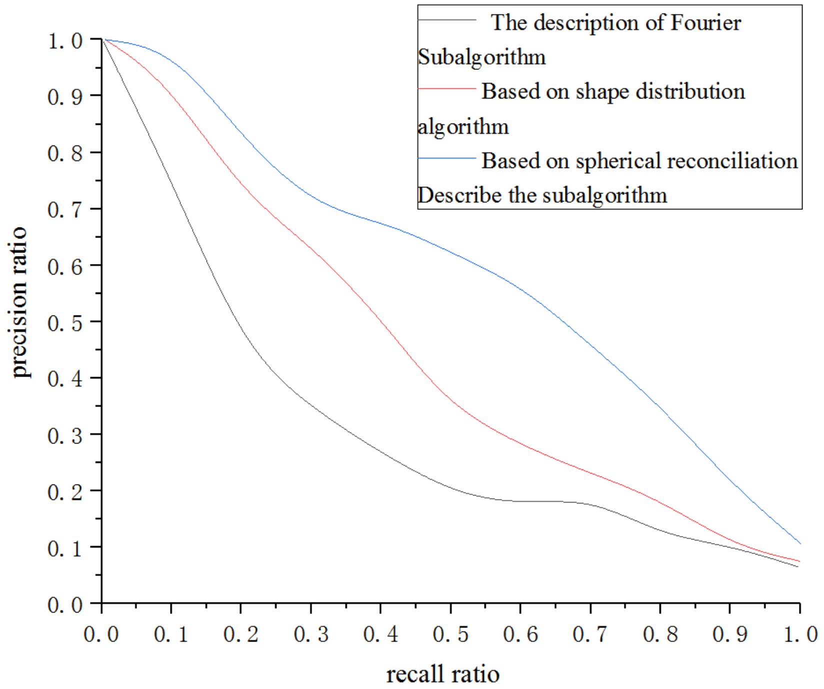

Figure 3: Recall accuracy curve.

The CPU used for algorithm verification is intelpentium 4CPU3.06ghz and memory is 4GB. Table 1 statistics the average processing time of the three algorithms for a single model. The feature extraction time and feature comparison time of the algorithm are only 0.471s, while the processing time of the other two algorithms are 0.937 and 0.826 respectively. It can be seen that the efficiency of the proposed algorithm is higher than the other two algorithms. From the table it is clear that, the proposed algorithm as minimum execution time which offers better efficiency. This algorithm inspires and expands the design thinking, and form the final design scheme.

Arithmetic	*Based on Spherical Harmonic Descriptor Algorithm*	*Based on Shape Distribution Algorithm*	*Fourier Description the Child Algorithm*
Time	0.471	0.937	0.826

Table 1: Comparison of execution time of single model algorithms.

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3.2 Product Model Push Instance Based on Freehand Sketch

3.2.1 Conceptual design of variable speed box

The chassis gearbox of crawler combined harvester is mainly composed of box body, shaft parts, gears, bearings and keys. In the process of gearbox design, first according to the harvester power, speed and other design requirements to get the gearbox design parameters, and calculate the required gear, shaft and other parts, at the same time combined with the harvester chassis transmission system layout scheme planning the space position of such parts; Then the gearbox box is designed according to its spatial position requirements [27]. Among them, the shaft parts are simple in structure, gear, bearings and keys are generally standard parts, do not need to be designed separately, and the gearbox box shape is complex and irregular, there is the phenomenon of repeated design. If designers need to design a gearbox, due to the complex shape of the gearbox box, in product conceptual design, designers are used to drawing three-sight sketches according to the size and spatial position of the designed parts of the gearbox to express their ideas. According to the results of product conceptual design push in the model database of agricultural machinery equipment, it can be found that the proposed method can be used to retrieve five parts with high similarity between three sketches in the model database of agricultural machinery equipment. The method in this paper can push the similarity design resources to designers by drawing the gearbox box sketch, and realize the rapid response of product concept design.

3.2.2 Detailed design of L-shaped joint shell

Hill and mountain tractor steering mechanism is mainly composed of driving shaft, driving shaft sleeve, L-shaped joint housing, driven shaft, driven shaft side cover, gear, bearing and keys. Among them, shaft parts are simple in structure, gear, bearings and keys are generally standard parts, do not need to be designed separately; The shape of shell parts such as driving sleeve, L-shaped joint shell and driven shaft side cover is complex, and there is the phenomenon of repeated design. The following takes the l-shaped joint housing of steering mechanism of hill-mountain tractor chassis as an example to verify the application of detailed product design. In the conceptual design stage, the designer usually designs the parts size and space position according to the L-shaped joint of steering mechanism, and obtains the simple design model of l-shaped joint shell. And express the initial design intention of the product through hand-drawn sketches; Designers draw sketches of product concept design by hand in the system sketch drawing interface. At this point, rich similarity design references can be obtained through conceptual design push method of 3D CAD model of products based on sketches [28]. By analyzing and comparing the pushed model, the model most similar to the shape, structure and function of l-shaped joint housing of steering mechanism was selected manually for reuse in the next stage of design.

In the preliminary design stage of the product, rich overall reusable design achievements are required. The similar product push model obtained from the conceptual design can be submitted directly, and more similar models can be found in the product model base by using PDM system. Then combined with the mountain tractor chassis transmission system layout scheme planning and steering mechanism L joint has been designed parts of the size and space position, the best of the best, through reference to inspire design thinking, complete the preliminary design of the product. In the detailed design stage of the product, a great deal of design reuse is to mine the design features and typical structures of the retrieved results of the preliminary design of the product in the model base based on the internal characteristics and typical structures of the components in a more detailed view, and quickly generate the current detailed design through a series of revisions or variations.

3.2.3 Generalized design of gearbox box

In the hilly mountain tractor chassis gearbox box design process can be clearly understood, designers according to the gearbox has designed parts (shaft parts, gears, bearings and keys, etc.), consider its size and space position, determine the design intention of gearbox box; Then,

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according to the manufacturing requirements, the gearbox box is refined into three components, and recursive design is carried out; Then from the initial rough hand-drawn sketches, through the understanding of product requirements and design factors, the gradual refinement of each component, in turn to achieve the gearbox box product conceptual design, preliminary design and detailed design of the top-down generalized design; At this point, the final design is completed. The detailed design results of the GEARBOX assembly CAD model can be easily assembled by the detailed model of each component in the CAD system.

4 CONCLUSIONS

In view of the product design process, puts forward a kind of mechanical product design system build CAD software secondary development method, this method can provide convenience for designers in the conceptual design phase, flexible way of query, help them using simple hand-drawn sketches for meet the demand of design reuse of 3D CAD models. Thereby expanding design reference, enlightenment and thinking, and form the final design scheme, for designers in the initial stage of the design of rapid use of the existing resource information to provide a new means of support. The experimental findings reveal that the proposed algorithm's feature extraction and feature comparison times are just 0.471s, whereas the processing times of the other two techniques are 0.937 and 0.826, respectively. In the future, one can work on Generative Create, which eliminates the need to develop something and then test it against all potential materials, processes, and other elements. Instead, submit your design and apply criteria based on cost and supply, then watch as it generates ideal alternatives.

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