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Research on new energy vehicle styling bionic design based on imagery coupling

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SUMMARY: *Driven by the rapid development of China's new energy vehicle industry and consumer upgrading, this paper focuses on the innovation of new energy vehicle front face design. Aiming at the problems of discrete biometric feature extraction and insufficient coupling with user cognitive experience in the current biomimetic design, a multidisciplinary coupled biomimetic design method is proposed by integrating the theory of perceptual dynamics, perceptual engineering and topological analysis. First, a model of user visual cognitive process is constructed based on the theory of perceptual dynamics, which provides support for understanding the relationship between front face appearance and user experience. Second, data crawling, text mining and factor analysis, combined with cosine similarity screening, are utilized to construct a representative sample library of new energy vehicle front faces and biomorphic forms. Next, topological analysis and hierarchical analysis are applied to resolve the feature layers and contours of biological and automobile front faces, and Harris Hawk Optimization Algorithm is introduced to optimize the design parameters of (HHO), which is combined with the evaluation of target imagery and eye-movement experiments to verify the effectiveness of the scheme. Finally, based on the secondary development of Grasshopper platform, the coupled bionic design system of new energy vehicle front face driven by user's imagery is constructed to realize the generation of diversified solutions under the parameter constraints, which provides innovative design paths for the front face of new energy vehicles with biometrics, aesthetic expressiveness, and user's cognition, and assists the enterprises in differentiating themselves from the competition.*

KEYWORDS: *Imagery-coupled bionics; New energy vehicles; Topology theory; Cosine similarity; Harris Hawk optimization algorithm (HHO)*

1 Preface

With the growing awareness of environmental protection and the shortage of new energy sources, new energy vehicles have received widespread attention as a green and sustainable mode of travel and are rapidly integrating into the market to become an important driver of change in the transportation sector. However, the design and manufacturing of new energy vehicles still face many challenges, one of which is how to maintain their unique design aesthetics while pursuing high efficiency and performance. At present, the development of fuel

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cell vehicles is of special strategic significance for improving China's energy structure, promoting low-carbon transformation in the transportation sector, and enhancing the international competitiveness and technological innovation of key industries. Because of this, in the programmatic documents such as “Made in China 2025”, the Chinese government has put forward a clear development plan for fuel cell vehicles and their related technologies, and the degree of importance has been increasing [1].

Traditional automobile design is often limited to the optimization of mechanical structural shapes and engineering parameters, and lacks an in-depth exploration of human perception and natural world forms. Therefore, adopting the method of bionic design to return automobiles to nature can increase the emotional communication and affinity with users and satisfy their spiritual needs [2]. Bionic design, as an interdisciplinary field of study, explores the complex structures, functions and behaviors of living organisms that have developed during the evolutionary process. By drawing on the morphological features and functional mechanisms of nature, it can provide new ideas and methods for the styling design of new energy vehicles. Automotive styling design, as the main body of interpreting the visual style of automobiles, is an important medium for consumers to perceive and experience cultural design. Bionic design has always had a strong attraction to the development of automobile styling [3]. Many scholars have explored product styling design methods with bionic theory.

Bauerheimer et al [4] to grain sudden box puffer as bionic object design underwater fishing robot pressure-resistant cabin, fishing robot feature height as a variable modeling, and the rotary body compared with the fluid simulation modeling analysis; Xu Yongsheng et al [5] to the great white shark and high-speed train coupling bionic design as an example, in order to enhance the degree of coupling of the product bionic modeling and the natural biological prototypes, will be the application of the coupling of the bionic in the product modeling design process to enhance the efficiency of product bionic design and the natural biological prototypes, so as to improve the product bionic design. In order to enhance the efficiency and accuracy of product biomimetic design; Gao Xiaoqin et al [6] clearly define the product and biological structure, use the Delphi method and fuzzy evaluation method to quantify the biomimicry, accurately match the product components and biological imagery, and realize the high efficiency of biomimicry; Ren Luquan et al [7] elucidate the concept of biocoupling and biomimicry, and reveal the coupling mechanism between biological modeling, structure, and materials, and the relationship of functional synergy; Mei Ye et al [8] investigate the relationship of the cat's paw gait silent and strong gripping, and the coupled biomimetic design. Mei Ye et al [9] explored the cat's paw gait mute strong grip mechanism, experimental analysis of the grounding characteristics of the paw pad, and then use the cat's paw biological function to achieve the mechanism to guide the tire tread structure coupled biomimetic design; Guo et al [10] proposed a quantitative analysis based on genetic algorithms on the product styling biomimetic process. Sun Yuxin et al [11] developed a novel adaptive feature-driven method by providing a reasonable initial layout for feature-driven optimization of heat dissipation structure with the help of tree branching structure hierarchical growth technique of bionic topology optimization method; Luo Shijian et al [12] constructed the mapping relationship between product family shape genes and consumer preference, and optimized the innovative automotive shape design gene network model of SUV side profile genes by using genetic algorithm; Zhou Xuan et al [13] quantified the cognitive distance between forest drones and bionic organisms through a parametric topological property analysis method.

In summary, the above scholars have mainly researched in biomimetic design, coupled bionics, topology theory and its application in design, etc. However, there are still the following problems in the research on combining perceptual imagery with biomimetic design as well as optimizing the design through intelligent algorithms: (1) Insufficient theoretical research on the combination of perceptual imagery and biomimetic design and the lack of systematic methodological support; (2) Intelligent algorithms in bionic design is still in its infancy, lacking mature optimization models and algorithms; (3) there are fewer empirical studies on the combination of imagery and bionic design in the existing research, and there is a lack of verification of actual cases.

To address the above problems, this paper, based on the theory of bionics, starts from the fit point of biological forms and product modeling, and applies topological analysis and hierarchical analysis to effectively solve the complexity problem in the process of matching and integrating imagery and bionic design. Through these methods, the key feature parts of biological and new energy vehicles are identified and extracted, and the HHO algorithm is used as the core optimization tool to develop and build a bionic fusion design system. The system aims to improve the accuracy and innovation of the design, and then provide theoretical support and practical solutions for new energy vehicle styling design.

2 Research framework

Based on the new energy vehicle imagery coupled bionic design system, the whole will be divided into three modules: constructing the biological product and target imagery library, feature contour fusion scheme library construction, system construction and model construction, the research ideas and processes are shown in Figure 1:

(1) Construct biological, product and target imagery library. The initial sample library is constructed from the collected new energy vehicle images by crawling the online automobile platform images using octopus technology. Meanwhile, the review texts of new energy vehicles are deeply analyzed using Word2Vec model and SPSS dimensionality reduction to extract the word vector model and finally obtain the target imagery vocabulary. Meanwhile, the initial biosample library is obtained by abstracting and simplifying in the biosample database, and the target biosample library is obtained by semantic splitting method. Finally, the target imagery vocabulary is used to screen biological representative samples and automobile representative samples by using cosine similarity for biology and products respectively and questionnaire survey.

(2) Feature profile fusion scheme library construction. In order to screen biological prototypes with high coupling degree, by comparing and analyzing the biological sample library with the features of new energy vehicles, we adopt biological topology and automobile hierarchical analysis model to sort the important feature parts of the biological and automobile, and realize the extraction and fitting of the feature contour, so as to generate the feature fusion scheme set of new energy vehicles and biomimetic biological prototypes.

(3) System construction and model building. 80% of the schemes from the fusion scheme set were selected for imagery word scoring, and a parametric bionic design model was constructed using the Harris Hawk Optimization (HHO) algorithm. The remaining 20% of the solutions are used for model validation, and the system construction is finally completed, realizing the biomimetic fusion from biometric features to the design of new energy vehicles, and providing an innovative solution for the styling design of new energy vehicles.

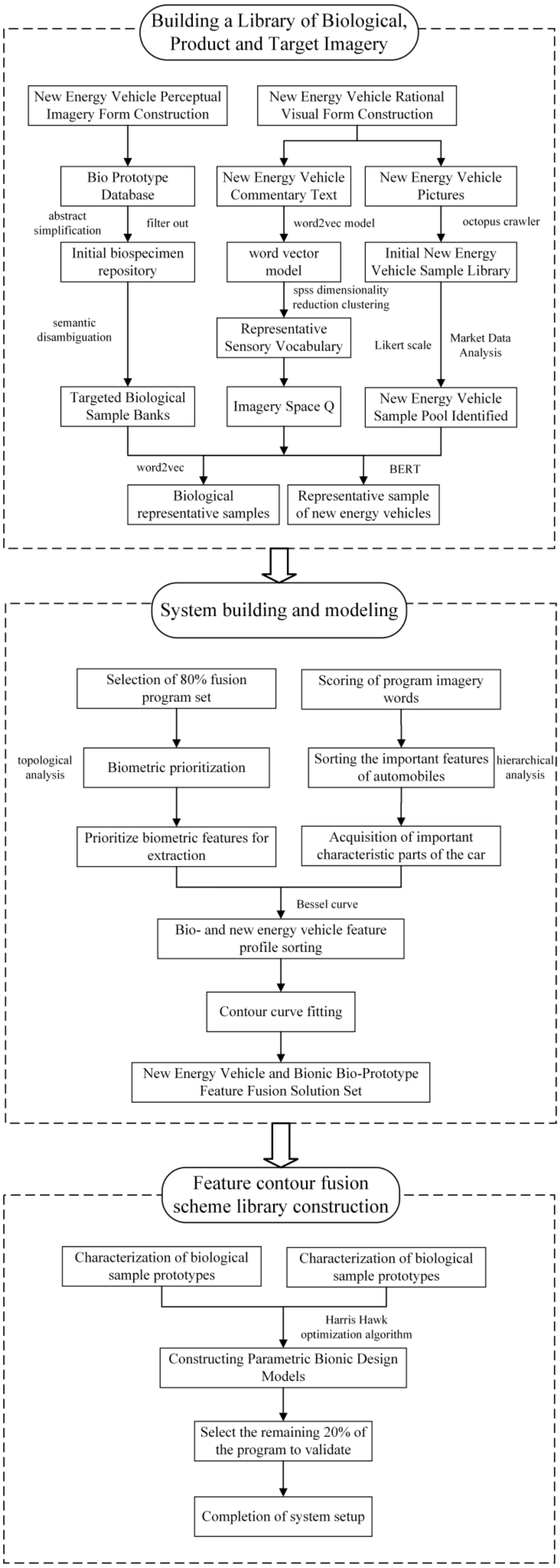


Figure 1: Research idea and process

3 New Energy Vehicle Imagery Bionic Research Experiments

3.1 Construction of Rational Visual Imagery Forms

3.1.1 New Energy Vehicle Target Imagery Acquisition

140 new energy vehicle imagery words were collected through diversified channels, such as online questionnaires and feedback from online shopping malls, and 12 pairs of representative new energy vehicle imagery vocabulary pairs were screened out using questionnaires and expert scoring methods. The semantic difference scale was designed based on the 12 pairs of imagery words, and a total of 84 valid questionnaires were collected. Among them, the questionnaire for each sample semantic scoring set by the indicated (on behalf of the first sample, on behalf of the first imagery words, on behalf of the first questionnaire), expressed as the mean value of the semantic score of the corresponding imagery words; by the following formula (1), formula (2) to calculate the sample in the imagery words of the mean and the standard deviation, so as to effectively reflect each sample of the scores for each imagery word dispersion, that is, the more uniform the credibility of the evaluation of the respondents is the higher the degree of credibility. This process uses SPSS software to calculate the mean value of each sample's perceptual imagery scores, and some of the results are shown in Table 1. Meanwhile, in order to ensure that the data are more accurate, principal component analysis is used to streamline the factor dimensions, and according to the Layda criterion (3), i.e., formula (3), outliers are eliminated to realize the data dimensionality reduction, so as to obtain the variance interpretation graph and the principal component matrix, and some of the results are shown in Table 2 and Table 3.

Table 1: (a) Mean values of imagery perception evaluation (partial)

brochure	progressive-conservative	Sharp - Kind	Square - Rounded	Dynamic - Static	distinctive - common	compact - loose
1	3.62	3.94	4.06	3.71	3.53	3.38
2	3.24	3.56	3.97	3.41	3.68	3.38
3	2.76	3.59	4	2.79	3.56	3.5
…	…	…	…	…	…	…
84	3.38	3.65	3.12	4.06	3.15	3.97

Table 1: (b) Continued table of mean values of imagery perception evaluation (partial)

brochure	Lightweight - bulky	Technological - traditional	Safe - dangerous	Flexible - clumsy	Expensive - cheap	Fluid - stagnant
1	3.09	3.06	2.65	2.82	2.94	3
2	2.91	3.06	2.44	2.94	2.76	3.03
3	2.94	2.82	2.71	2.88	3.47	2.82
…	…	…	…	…	…	…
84	4.26	3.76	3.32	4.32	3.59	3.88

$$C_{ij} = \frac{1}{k}\sum_{k=1}^{k} C_{ijk} \tag{1}$$

$$\sigma = \sqrt{\sum_{k=1}^{k}[(C_{ij} - C_{ijk})^2 \div (k-1)]} \tag{2}$$

$$v_i = |C_{ij} - C_{ijk}| > 3\sigma \quad (3)$$

Table 2: Factor Analysis Load Matrix Machine Variance Contributions

ingredient	Initial eigenvalue			Extract the sum of the squares of the loads			Rotational load sum of squares		
	total	Percentage of variance	Cumulative %	total	Percentage of variance	Cumulative %	total	Percentage of variance	Cumulative %
1	7.4	61.7	61	7.4	61	61	4	36	98
2	2.1	17.3	79	2.0	17	79	3	29	49
3	0.7	6.1	85	0.7	6	85	1	13	79
4	0.5	3.9	89	0.4	3	89	1	9	89

Table 3: Factor principal component analysis matrix

	ingredient			
imagery vocabulary	1	2	3	4
Safe - Dangerous	0.844	0.356	0.262	0.091
Unique - Ordinary	0.890	0.135	0.151	0.317
Sophisticated - Clumsy	0.190	-0.224	0.093	0.933
Dynamic - Static	0.752	0.486	0.153	0.123
Sharp - Kind	0.936	0.012	0.211	0.013
Compact - Loose	0.526	0.536	0.412	-0.078
Light - Bulky	0.076	0.893	0.131	-0.229
Technological - traditional	0.700	0.579	0.249	0.031
Advanced - conservative	0.312	0.357	0.822	0.181
Square - rounded	0.243	0.869	0.240	-0.176
Expensive - cheap	0.622	0.397	0.601	-0.032
Fluid - stagnant	0.305	0.838	0.258	0.058

After applying principal component analysis to reduce the dimensionality of the data in Table 2, it can be seen that the eigenvalues of the four factors are greater than 1, and the cumulative contribution rate of variance is 89.057%, which satisfies the generalization of the main information. Therefore, combining the high loading coefficient factors, the final set of new energy vehicle style imagery is determined as sharp, advanced, light and delicate.

3.1.2 New Energy Vehicle Sample Collection and Screening

By applying the Octopus crawler tool to collect in the automobile 4S stores, automobile home and other commercial platforms, a total of 108 samples of new energy vehicles available for sale in the market were obtained to establish a product sample library. Based on the automobile target imagery space combined with the SD questionnaire, 25 representative new energy vehicle samples were finally selected by the expert panel after comprehensive evaluation and refinement, and some of the new energy vehicle samples are shown in Table 4.

Table 4: Sample of some new energy vehicles

serial number	Brochure 1	Brochure 2	Brochure 3	Brochure 4	Brochure 5
Brochure					
serial number	Brochure 6	Brochure 7	Brochure 8	Brochure 9	Brochure 10
Brochure					
serial number	Brochure 11	Brochure 12	Brochure 13	…	Brochure 25
Brochure				…	

3.1.3 Representative Sample Acquisition for New Energy Vehicles

Based on 25 car samples, the BERT (Bidirectional Encoder Representations from Transformers) model is used to extract the representative semantic vocabulary of each car separately. BERT is a pre-trained language model based on the Transformer architecture, and it learns the semantic and syntactic information of words through a large amount of textual corpus. BERT is a pre-trained language model based on the Transformer architecture, which learns the semantic and syntactic information of words from a large amount of text corpus. After processing, a vector representation reflecting the features of the car can be obtained, and the representative semantic vocabulary can be extracted from it.

In this process, the obtained semantic vocabulary vectors and the target imagery vectors are used to calculate the cosine similarity, which serves as a measure of similarity between the samples, and evaluates the proximity between the two in terms of distance and direction based on the cosine of the vector angle, thus effectively capturing the distance between the sample imagery [13]. This method can effectively capture the distance between sample imagery and thus assess the similarity between them. Eventually, the new energy vehicle samples with the closest distance to the target imagery can be selected from them, and the calculation formula is shown in Equation (4), and some of the calculation results are shown in Table 5.

$$\mathrm{d} = \cos(\theta) = \frac{\alpha\cdot\beta}{\|\alpha\|\cdot\|\beta\|} = \frac{\sum_{i=1}^{n}\alpha_i\times\beta_i}{\sqrt{\sum_{i=1}^{n}(\alpha_i)^2}\times\sqrt{\sum_{i=1}^{n}(\beta_i)^2}} \tag{4}$$

where α denotes the feature vector of the bionic object, β representation of target imagery word vectors, d denotes the similarity distance between the feature vector of the bionic object and the target imagery word.

Table 5: Cosine similarity analysis of new energy vehicles and target imagery words (partial)

Cosine similarity	Sharp	Advanced	Lightweight	Sophisticated
BMW i3	0.33568	0.36596	0.32294	0.32869
Gaohe HiPhi	0.46204	0.47657	041929	0.41322
BYD Song	0.29151	0.35804	0.46150	0.34804
Zero Run T03	0.38285	0.37329	0.64969	0.44081
Ola Good Cat	0.32892	0.28383	0.38441	0.46633
Xiaomi su7	0.65006	0.63715	0.67763	0.62929
Mercedes EQE	0.24302	0.36408	0.27527	0.41181
...	…	…	…	…
pandamini	0.21337	0.18946	0.50981	0.28921

The analysis of the cosine similarity values shows that Xiaomi SU7 new energy car takes relatively higher values in these four imagery words. This means that Xiaomi SU7 new energy vehicle is characterized by outstanding performance in the four aspects of sharp, advanced, lightweight and exquisite, and has a higher degree of fit with the target imagery words. Therefore, Xiaomi SU7 new energy vehicle was finally selected as the representative sample.

3.2 Construction of Perceptual Visual Imagery Forms

3.2.1 Establishment of biological research sample library

Bionic design is a high-quality bridge connecting nature and product design, in order to determine the bionic prototype [14], biological samples are collected in platforms such as Biodata (iNaturalist), gray scale and contour processing through PS software, biological samples with significant bionic morphology and easy to be integrated with the automobile are selected, and some of the samples are shown in Figure 2.

Figure 2: Selected biological samples

3.2.2 Selection of target organism prototypes

In order to screen the target organisms called a total of 18 automobile designers and professionals to vote, from the results of the discussion and the questionnaire screening results can be seen, the preliminary selection of seagulls, antelopes, jaguars, catfish, sailfish, sharks, eagles, rainbows 8 organisms for the mimicry of the object, and the results of this are shown in Table 6.

Table 6: Summary of votes for bionic organisms (partial)

Name of creature	Number of votes	Name	Number of votes	Name	Number of votes
Snake	12	Horses	3	Lion	9
Eagle	15	Mice	5	Cheetah	12
...	…	...	…	...	…
Whale	4	Foxes	2	Antelope	15

3.2.3 Cosine Similarity to Quantify Imagery Cognitive Coupling

The target imagery vocabulary of new energy vehicles is obtained in chapter 2.1.1, in order to evaluate the match between the bionic object and the target imagery words, the Word2Vec model is used to take the target imagery words as the input, and the corresponding numerical vectors are output to compute the cosine similarity between the feature vectors of the bionic object and the vectors of the target imagery words, and the results of the computation are shown in Table 7.

Table 7: Cosine similarity analysis of biological and target imagery words

Cosine similarity	Sharp	Advanced	Lightweight	Sophisticated
Antelope	0.30451	0.28314	0.35395	0.33153
Cougar	0.18843	0.15323	0.29747	0.18873
Eagle	0.22021	0.08096	0.25302	0.14141
Catfish	0.16859	0.13037	0.11488	0.15967
Seagulls	0.10503	0.11751	0.25170	0.19945
Sailfish	0.13451	0.17217	0.20728	0.20964
Sharks	0.23495	0.19429	0.21867	0.20031
Rainbows	0.18530	0.12718	0.25876	0.21625

3.3 Topological structure analysis method

3.3.1 Establishing the bionic object feature topology

Topological structure analysis method is a biomimetic modeling feature analysis method established by taking topological properties as the theoretical basis and applying the stability of topological properties in modeling recognition [15]. The topological property defines the topological relationship, and a tree structure is used to characterize the bionic features into five levels, see Figure 3.

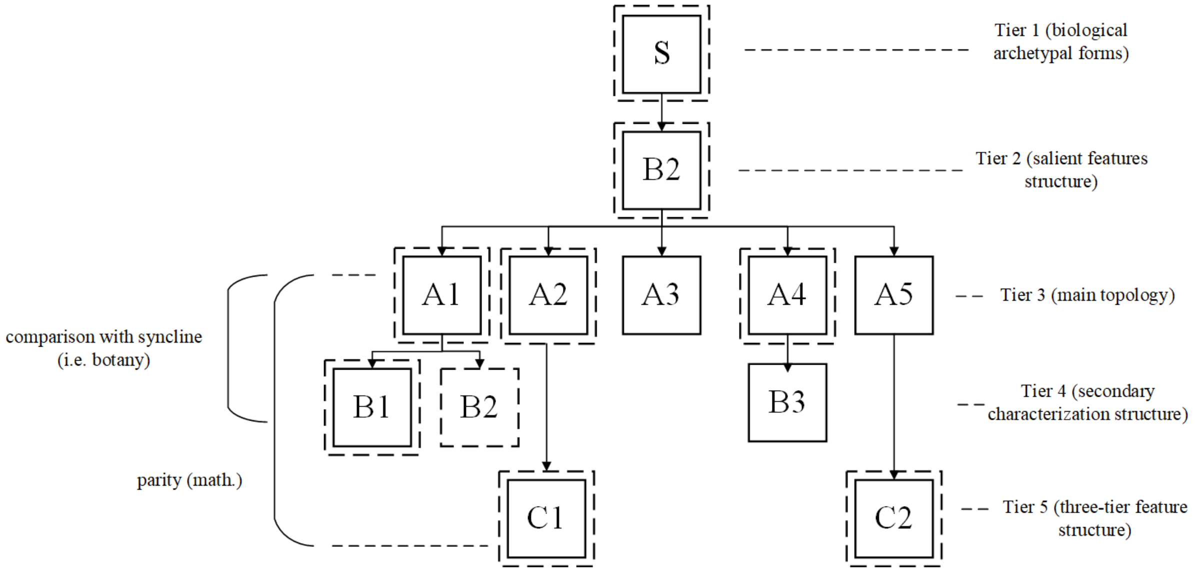


Figure 3: Topology of bionic object features

The first level is the biological prototype; the second level is the salient features of the biological prototype; the third level is the main topological structure; the fourth level is the features that have different characteristics in comparison with the benchmark of the same class; and the fifth level is the structure that distinguishes the benchmark organisms of the same family with the third level as a whole.

3.3.2 Biological Feature Elements and Optimized Design Cognitive Structures

Distinguish between significant feature elements and non-significant features by topological weights, significant features refer to features that are easy to establish consensus with users, and non-significant features are general topologies [16]. Calculate the biometric structure line through the feature topological weights, the topological weights calculation formula is shown in Equation (5):

$$S(ip,mq)=\sum_{k=m}^{J} Ik\times\lambda\times Mk(ip,mq)$$
$$Ik=2^{k-1};\lambda=\frac{1}{(2^{\Delta k})}; \tag{5}$$
$$\left(i,m,j\in Ni\le m\le ji,m,j\le Q,Q\text{is the highest number of floors}\right)$$

where, i refers to the p layer in which; m refers to the q layer in which; k represents the layer; $s_{(ip,mq)}$ refers to the total topological value from layer i to layer j with mq; $Mk(ip,mq)$ refers to the ip; mq refers to the topological weight in the k layer; Ik refers to the k layer index in the first layer; λ refers to the attenuation coefficient; ΔK refers to the number of ip layers with mq the intervals (when calculating the topological weights, the bottom layer is the first layer. Using the method of topological weights analysis, it is possible to precisely define the critical hierarchical order of the biometric elements in the overall cognitive architecture of the organism, and thus optimize the cognitive structure in the design.

3.4 Harris Hawk Optimization Algorithm (HHO)

The HHO algorithm is a new meta-heuristic algorithm proposed by Heidari et al. in 2019, which has the advantages of fewer parameters to be tuned, simple and easy-to-implement principle, and strong local search ability, and it is widely used in the fields of numerical engineering optimization, image recognition, and optimal design of electric power grids, etc [17].

The algorithm is divided into three processes: in the global exploration phase, members of the Harris hawk population are scattered over a wide area, and two complementary global search strategies are implemented based on different random probabilities r; in the exploration and exploitation conversion phase, the algorithm adopts the energy of prey escape to dynamically select the exploration behaviors or the exploitation behaviors for hunting; and in the local exploitation phase, the phase adopts four encircling strategies to mimic the hunting behaviors of the Harris hawk. hunting behavior.

The HHO algorithm achieves the optimization of complex problems by simulating the hunting behavior of the Harris Hawk. In the bionic design, the HHO algorithm can effectively find the optimal parameter values and provide stronger support for the bionic design, the specific steps of the algorithm are shown below and the flow is shown in Fig. 4:

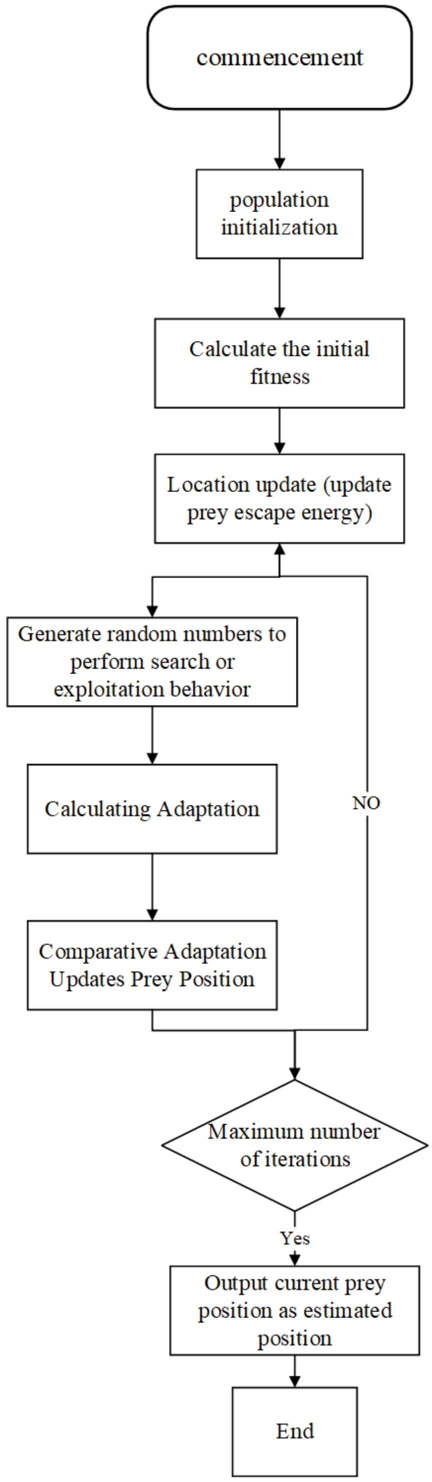


Figure 4: Flowchart of HHO algorithm

(1) Initialize the population
(2) Calculate initial fitness
(3) Update position and adjust prey escape energy
(4) Perform exploration or exploitation behavior based on generated random numbers
(5) Calculate the fitness of the new location
(6) Compare the updated prey positions and retain the new position if the fitness improves
(7) Iterate until the maximum number of iterations is reached

(8) Output the final prey position as the optimization result

After many iterations, the HHO algorithm is able to effectively search in the complex design parameter space, gradually approaching and eventually finding the best design solution. Through its optimization searching ability, it can provide innovative and practical optimal design solutions for the field of new energy vehicles.

4 Imagery Coupled Bionic Design System Establishment and Verification

4.1 Establishment of Key Styling Parts of New Energy Vehicles

Based on the application of expert guidance and the styling analysis of new energy vehicles, the key styling parts of new energy vehicles are obtained by using the hierarchical analysis method (AHP) [18], so as to construct the hierarchical analysis model for new energy vehicles, which is shown in Figure 5.

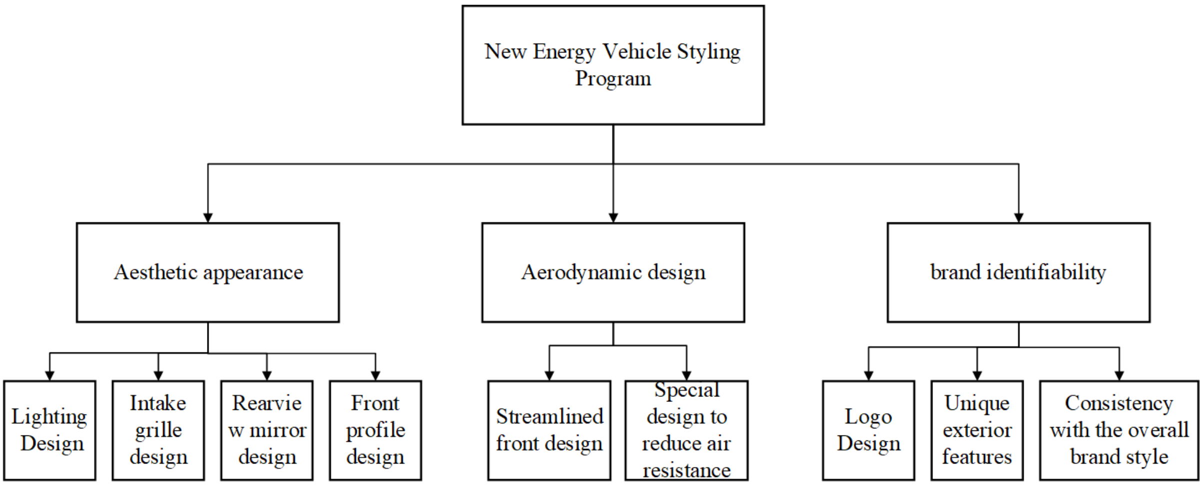


Figure 5: Hierarchical analysis model for new energy vehicles

Based on the analysis model in Figure 5, construct the hierarchical judgment matrix of each level of indicators of new energy vehicles, evaluate each level of evaluation indicators based on the scale value of two-by-two comparison, and get the weight value of evaluation indicators of the key styling parts of new energy vehicles, and take the top four automobile parts in accordance with the index variables as the fusion part, and the top four of its weight ordering are shown in Table 8.

Table 8: Ranking of weights of key parts of new energy vehicles (partial)

Indicator Variables	weights	arrange in order
Lamp design (C1)	0.3172	1
Grille design (C2)	0.1514	2
Mirror design (C3)	0.1098	3
Front profile design (C5)	0.1057	4
…	…	…

4.2 Cognitive analysis of biological samples' features and acquisition of topological weights

According to the third section of the imagery coupling degree ranking to get the highest coupling degree of the creature is the antelope. According to the topological hierarchy analysis method, we draw a topological map of antelope features: the first level is the overall morphology of the antelope; the second level is the salient features of the antelope; since the antelope belongs to the class of mammalians, the third level is the main topological structure of the class of mammalians; the fourth level is the secondary feature structure of the antelope, and compared with the mammalian organism, the jaguar, we found that there are differences between the antelope in terms of the morphology of the eyes, the mouth, the ears, the nose, and the overall facial outline and the jaguar; the fifth level is the overall local features. The fifth level is the overall local features, because there is no subdivision so there are only four levels, antelope feature topology is shown in Figure 6.

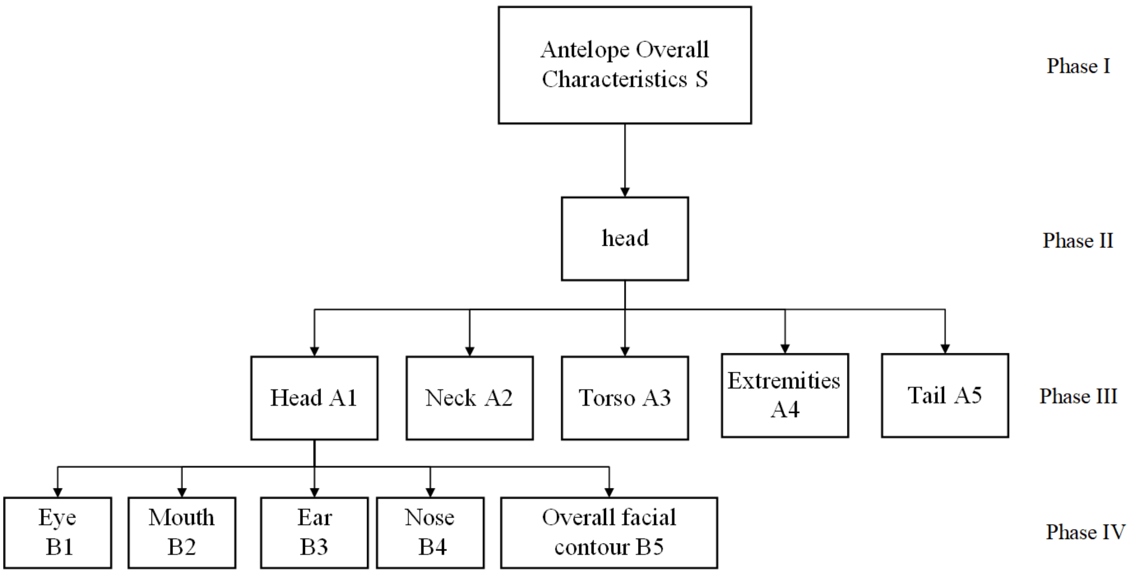


Figure 6: Topology of antelope features

Combined with the feature topology map, the topological weights of the antelope facial features are calculated according to Equation (5), and the feature topological weights are shown in Table 9.

Table 9: Topological weights of antelope facial features

Feature nodes	Nose	Mouth	Ears	eye and horn	facial contour
Eyes	12	12	12	20	9
Nose	20	16	14	12	11
Mouth	16	20	12	12	11
Ears	14	12	20	12	11
Facial profile	11	11	11	9	20
Feature relations	Eyes and horns, mouth, etc*	Eyes and horns, ears, etc*	Eyes and horns - facial contours, etc.*	Eyes & Horns-Nose,etc	Nose-Mouth
Topological weights	73	71	69	65	62

In order to obtain the topological weights of the features of the nodes of the antelope's face more intuitively, the morphological features of the antelope are simplified and labeled with their topological nodes, so as to calculate the topological weights of the nodes, as shown in Fig. 7a and 7b for the simplification process of modeling, and as shown in Fig. 7c for the feature nodes, and Table 11 shows the topological weights of the antelope's facial nodes.

Given that one of the significant features of the antelope is its unique horn, in the subsequent bionic design process, the overall form of the antelope's horn and eyes is used as a bionic prototype to match with the headlight of the new energy vehicle in order to realize the innovative application of bionic design. Combined with the analysis of topological weights in Table 9 and Table 10, it can be seen that the topological weights of the antelope's facial features are ordered from largest to smallest as four parts: the eyes and horns, the mouth, the ears, and the facial contour.

a b c

Figure 7: Morphological feature simplification and node topology weights

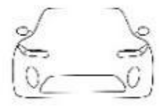
Table 10: Node topology weights

characteristic node	Eyes and corners	Nose	Mouth	Ears	Facial contours
	1	2	3	4	5
Topological weights	65	73	71	69	62
Sum of weights	209		131		

4.3 Bionic Fusion Program Construction

In order to find the optimal design scheme, the four fusion parts of new energy vehicles and bionic creatures are adjusted using parametric design methods, different new energy vehicle fusion schemes are obtained by adjusting the parameter values in Rhino, and the bionic fusion schemes are quantitatively scored using a scoring method based on the user's perceptual imagery words, and initially 47 bionic fusion schemes are obtained, and some of the schemes are shown in Table 11.

Table 11: Demonstration of bionic fusion part of the program

Program No.	Sharp	Advanced	Lightweight	Sophisticated Programs	Showcase
1	3.95	4.02	4.23	4.04	
2	3.46	3.64	3.48	3.45	
..	…	…	…	…	…
47	4.21	4.2	3.95	4.27	

4.4 Construction and Application of Imagery-Coupled Bionic Design System

4.4.1 Biomimetic Matching of Styling Characteristics of Biological and New Energy Vehicles

Relying on the PyQt5 framework and the Grasshopper platform, an imagery-coupled bionic design system is built. In the biomimetic matching interface, the designer first uploads a new energy vehicle profile sample through the imagery evaluation interface, and then invites users to rate the vehicle sample profile in the imagery evaluation interface. Using the cosine similarity calculation, the system filters out from the bio-profile library the bio-profile that most closely matches the uploaded imagery of the new energy vehicle profile, see Figure 8.

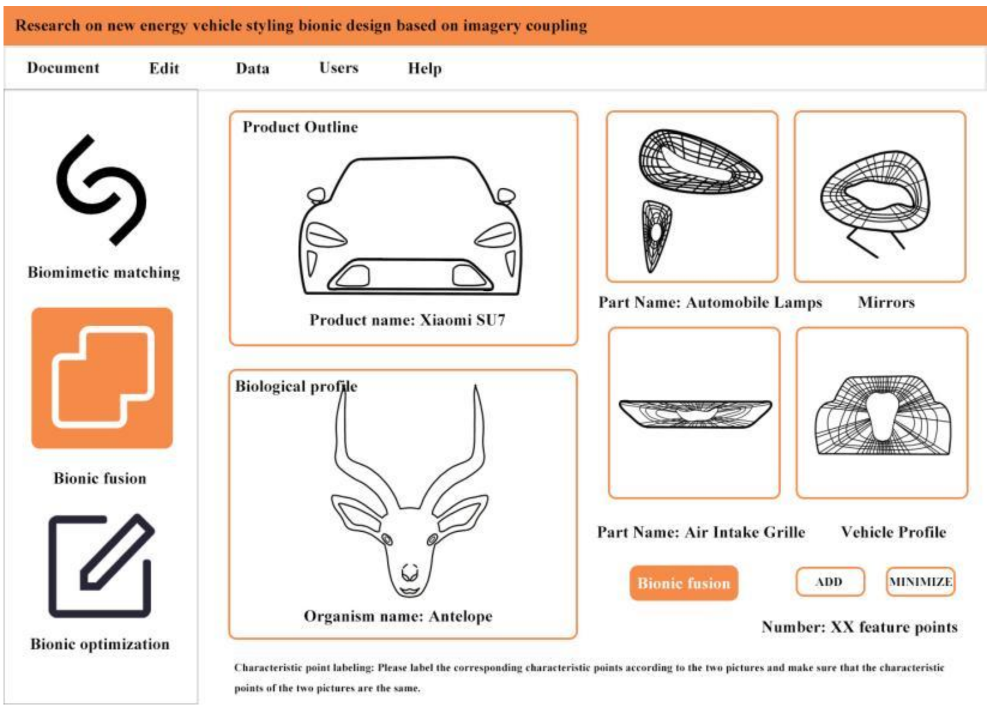


Figure 8: Interface of bionic matching system based on new energy vehicle

4.4.2 Integration of Biological Features and New Energy Vehicle Contour Styling

After determining the bionic object (e.g., antelope), by annotating and adjusting the number and position of feature points, the system applies the curve fusion method to show the fusion effect of multiple parts to save the scheme in the right interface, and constructs the bionic fusion scheme dataset in order to optimize the bionic design of the new energy vehicle, see Fig. 9.

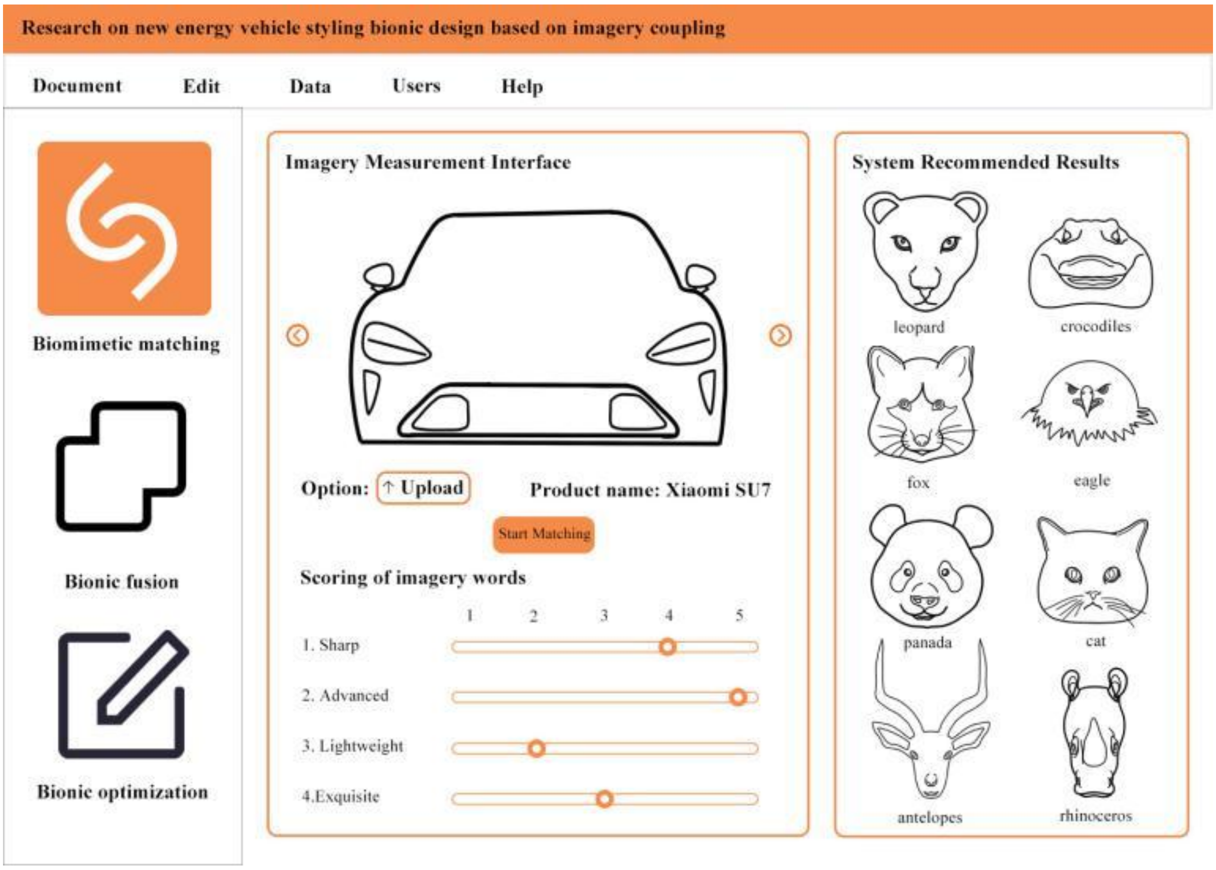


Figure 9: Interface of bionic fusion system for new energy vehicles

4.4.3 Construction of the fusion scheme dataset

In the evaluation and optimization process of the bionic fusion scheme, 80% of the fusion schemes are selected for training, and the designer first quantitatively scores the schemes to ensure the accuracy of the evaluation. The scoring scheme is uploaded to the iterative optimization module, the relevant parameters and scores are input, and the HHO algorithm is used to carry out iterative optimization to find the optimal parameters, so as to construct the parametric bionic design model.

From the results of 18 rounds of iterations of this experiment, it can be seen that after 10 rounds of the generated scheme scores are stable and located in the majority of more than 4.5 points, and after 16 rounds, the maximum, minimum and average values of the four scheme scores in each round are closer to each other, and the scheme iterations are smooth and reliable, and the optimal scheme is finally obtained in 17 rounds, with a scheme score of 4.893, and the six parameters of the bionic fusion are: 0.98214, 0.67836, 0.62973, 0.57545, 0.53579, 0.64826, see Fig. 10.Finally, the optimal parameter set is outputted to select the scheme that best meets the design goals and designer's needs, see Fig. 11.

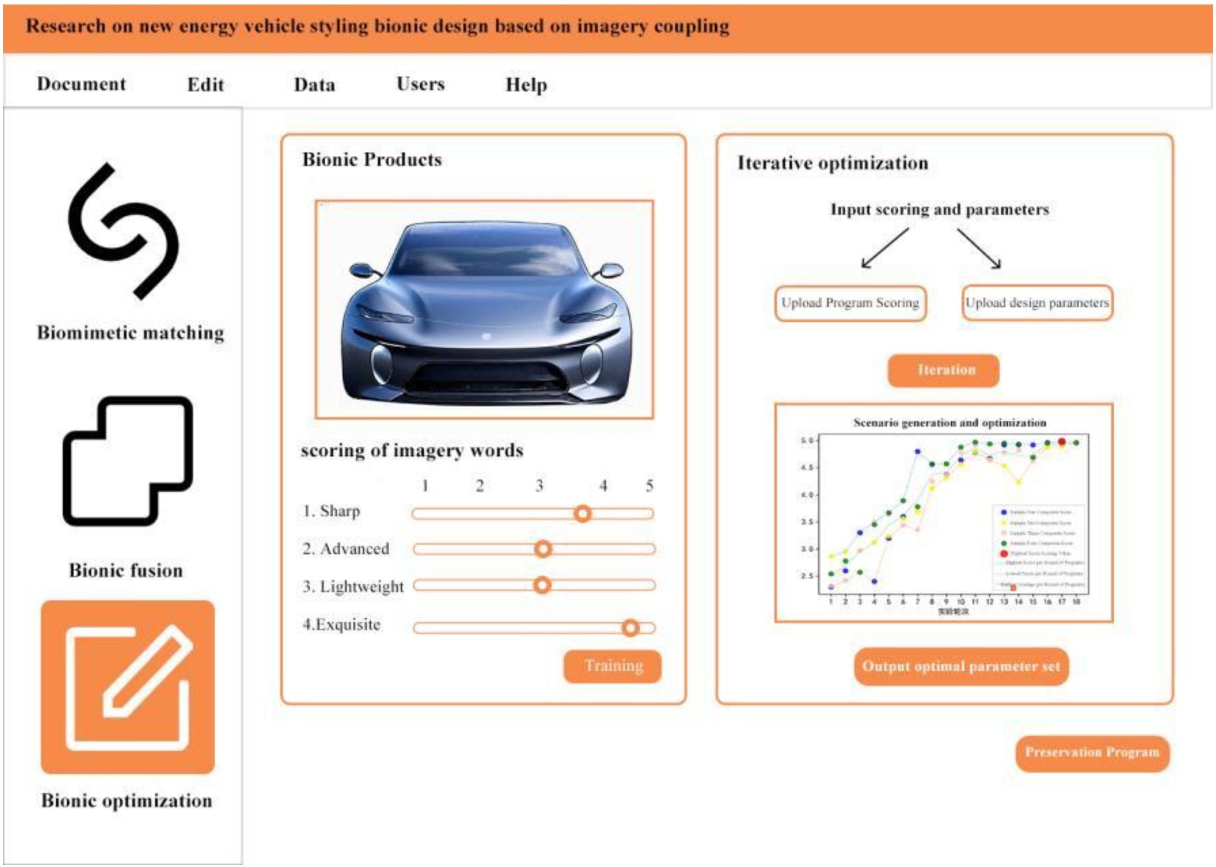


Figure 10: Scenario generation iteration and optimization

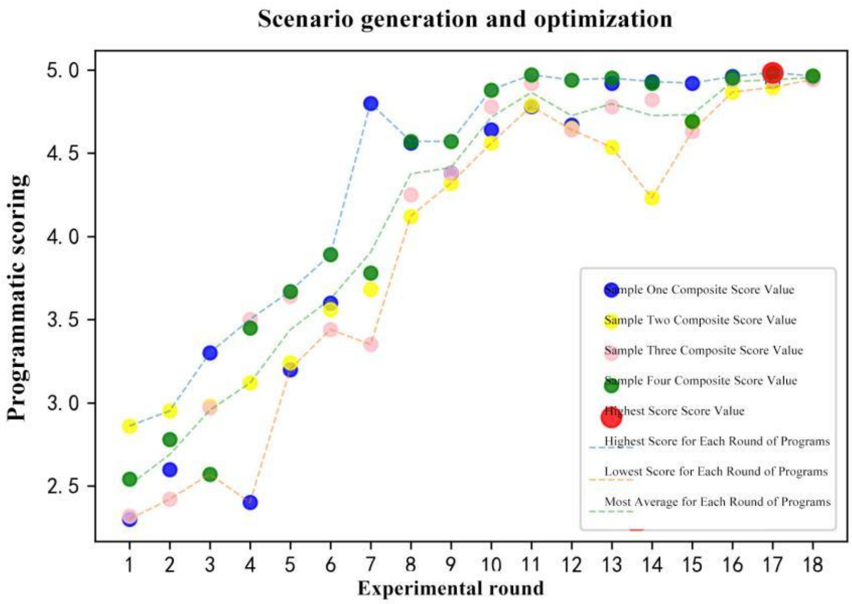


Figure 11: Interface of bionic evaluation system for new energy vehicles

4.5 Imagery coupled bionic design system validation

In order to verify the effectiveness of the model, the remaining 20% of the fusion program set is selected for validation, the effectiveness of the program is verified by using the R^2 evaluation of fit, and the value of its index is close to 1.0 indicating a good fit, and the evaluation indexes and results are shown in Table 12.

Table 12: Evaluation indicators and results

Support vector machine regression model	Indicator name	metric
	R^2	0.9870
	Mean square error	0.3751
	Interpretable variance value	1.0000
	Mean absolute error	0.4897

By comparing the real and predicted values of the fusion scheme in the model, it is proved that the model improves the prediction accuracy and reliability, reduces the subjectivity and randomness of the parameter selection, and can provide more reliable results in practical applications, see Fig. 12.

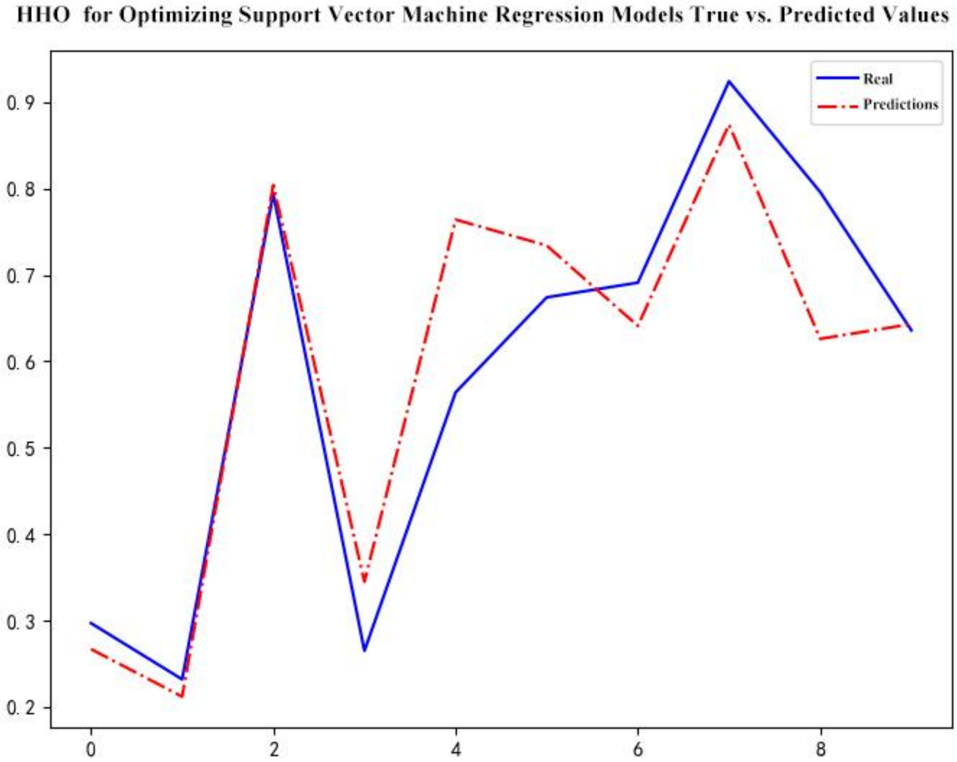


Figure 12: Plot of true vs. predicted values for the HHO model

In order to test the effectiveness of the system, inheritance metricization is introduced to compare the old and new schemes. Table 13 shows the evaluation results of the new scheme, which verifies the effectiveness and usefulness of the model in optimizing the bionic design.

Table 13: New program evaluation results

Programs	Sharp	Advanced	Lightweight	Sophisticated	degree of inheritance
Original Programs	3.98	4.2	4.02	4.43	
New Programs	4.71	4.86	4.57	4.57	4.67

5 Conclusion

In this paper, in order to significantly improve the integration efficiency between product imagery and bionic design, topology principle is introduced to calculate the similarity between design elements, and combined with HHO optimization algorithm for training and optimization. On this basis, we build an imagery-coupled bionic design system, which can significantly enhance the innovation and accuracy of the design. The system contains three parts of functions, namely, “imagery-bionic matching, imagery-bionic fusion, and program optimization and evaluation”, and through the bionic design case of “Antelope - New Energy Vehicle”, the system can significantly enhance the efficiency of the integration between product imagery and bionic design. The feasibility of the system design is verified through the bionic design case of “Antelope - New Energy Vehicle”, and the main conclusions are as follows:

(1) Imagery and bionic sample library construction and analysis: through collecting new energy vehicle user comments and online data, a vocabulary library of new energy vehicle imagery is established, and at the same time, a biological data platform is used to screen out bionic biological samples that meet the design requirements. Combined with Word2Vec model and topological analysis, the study quantifies the similarity between imagery and biomorphology, and extracts relevant features to provide theoretical basis for the subsequent bionic design.

(2) Construction and optimization of bionic design model: On this basis, Harris Hawk Optimization Algorithm (HHO) is used to optimize the parameters and integrate the biological features with the styling features of the new energy vehicle. After many iterations of optimization, by the 17th iteration, the bionic design model has become stable.

(3) Construction and validation of bionic design system: Based on PyQt5 framework and Grasshopper platform, the research constructs a design system that integrates imagery bionic matching, fusion, optimization and evaluation. The system verifies its effectiveness through real cases, and the experimental results show that the system can efficiently generate the optimal design solution that meets the target imagery, and has high accuracy and reliability in practical applications.

This paper integrates industrial design and computer technology to realize the fusion bionics that integrates biological features and styling features of new energy vehicles, which provides reference for design intelligence. In future research, the system will be further optimized, and attempts will also be made to improve the existing fusion algorithms and explore new algorithms to meet more complex design challenges.

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