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Computer-Aided Design AND APPLICATIONS

Network Assisted Agricultural Product Packaging Design Based on Virtual Reality

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Abstract. With the continuous changes in the socio-economic environment, the Internet has been rapidly popularized in various fields, and online shopping has become the main way for people to shop daily, effectively improving their quality of life. As an important component of people's daily lives, agricultural products can be effectively enriched through online sales channels, enabling more people to understand agricultural products, providing convenience for them to purchase agricultural products, and creating distinctive agricultural product brands. However, currently most product packaging designs are two-dimensional, which cannot fully display the product packaging structure. Therefore, it is particularly important to adjust and improve agricultural product packaging design in a targeted manner, and to study product outer packaging design methods under virtual reality technology. In the above context, this article conducts theoretical analysis on the design of a virtual system for product packaging. The organizational structure optimization of network assisted agricultural product packaging design was carried out through virtual reality product packaging design. And analyzed and studied the main aspects involved in the implementation process of the system and corresponding software, proposed an immune algorithm for user packaging design, and conducted simulation verification.

Keywords: Network Assisted Agricultural Products; Virtual Reality; Packing Design
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1 INTRODUCTION

In the current development process, online shopping has provided many conveniences for consumers to purchase products. In the context of online sales, consumers only need to use product images to understand product information and choose their desired products. Innovative product packaging design can leave a deep impression on consumers and have a positive promoting effect on increasing sales volume. Topology optimization is a method to find the optimal solution through heuristic search of directed acyclic graph (DAG). In the design of molded pulp packaging, topology optimization can be used to find the optimal packaging structure, so that it cannot only protect products, but also have the best performance. Bahlau and Lee [1] used heuristic algorithms such as the A * algorithm to search for DAGs to find the optimal packaging structure. In the algorithm, a greedy strategy can be used to select the next operation to be performed, in order to minimize the search space as much as possible. Brenes et al. [2] proposed a virtual reality system aimed at improving the quality of data collected. The design and development of this system utilized human-computer interaction technologies such as iterative design, storyboards, and prototypes. The focus of food packaging is mainly reflected in product protection during transportation and storage. With the development of multi-purpose packaging, intelligent packaging has become an inevitable choice for multi-channel transportation. The development of modern poultry farming in the United States is ruthless. The application of new innovative technologies from breeding to processing has played a crucial role in the enormous growth of the industry. Chowdhury and Morey [3] conducted innovative product applications for intelligent packaging. The bio gas sensor has been applied to the product market by setting the internal and external environment of the package and the temperature time indicator. Drago et al.'s [4] critical and up-to-date analysis of the results in the field of product intelligent packaging research. Dewi et al. [5] conducted research on the packaging and sorting technology of agricultural fruits using CAD image processing technology. The application of a 4DOF fruit sorting robot based on color and size in packaging systems has resulted in more efficient sorting. It performs color difference recognition through HSV and saves threshold data in grayscale images. Ensure the completion time of the task. Georgakarakou et al. [6] developed high-precision green product drawings using CAD technology, which allows packaging designers to complete design tasks faster and more accurately. By using CAD for 3D modeling, packaging can more intuitively see the appearance and structure of the product, thereby better grasping design details and style. The digitized green packaging reduces errors in traditional manual drawing, allowing packaging designers to more accurately complete design tasks.

There is a certain correlation between product packaging design and corporate brand building, so it should be given sufficient attention. Consumers are attracted by packaging when choosing agricultural products. Agricultural product packaging designers closely align with the needs of the times and adjust packaging design accordingly to make agricultural products have higher added value, making consumers more enthusiastic about purchasing agricultural products, and promoting the development of agricultural product branding. The packaging of products is not only an external manifestation, but more importantly, in the entire process of agricultural product packaging design activities, it must fully focus on the comprehensive integration of design concepts and cultural connotations. Especially with the increasing maturity of people's understanding of the value and role of the entire agricultural product, optimizing the packaging design activities of agricultural products has become an important link in the transformation and development of characteristic agriculture and enhancing its added value. Idumah et al. [7] elaborated on the agricultural functionalization of composite material interface interactions and their relationship with the performance of agricultural reinforced packaging materials. Mellinas et al. [8] developed multifunctional plant polymer properties. It introduces the extraction of plant cell wall materials for pectin food packaging and their application in packaging materials. Currently, especially in light food packaging, various materials related to pectin and combinations with other biopolymers need to be used for food and beverage industry applications. Park et al. [9] used mathematical modeling to simulate the deformation behavior of materials in three-dimensional space. In the study of edge compression behavior of corrugated cardboard, corrugated cardboard can be regarded as a three-dimensional elastic body and modeled using finite element method. Plungsri et al. [10] aim to group products with designed box sizes and find the maximum number of layers that can be stacked on pallets. Its research is to propose packaging design guidelines to reduce purchasing costs, reduce storage space, and increase transportation volume. This work uses K-means clustering to group products and design new packaging box sizes. It analyzed the quantity of products on the pallet through the application of Box Compression Test (BCT) to determine the factors affecting box quality.

The full text is mainly divided into 5 chapters. Chapter 1 mainly introduces the important role of agricultural product packaging in the network era and the arrangement of paper chapters; Chapter 2 introduces the relationship between consumer behavior and product packaging, analyzes the current situation of agricultural product packaging at home and abroad, and proposes the impact of virtual reality technology on packaging design; Chapter 3 mainly designs a framework for agricultural product packaging design based on virtual reality and proposes an improved immune algorithm for packaging design; Chapter 4 mainly constructs a virtual reality based agricultural product packaging system and conducts experimental verification of the platform's usage and efficiency. Chapter 5 mainly summarizes the work of the entire text.

2 STATE OF THE ART

2.1 Product Packaging Design and Consumer Behavior

When purchasing a product, consumers typically experience a series of psychological processes within themselves. After analyzing consumer psychology, it was found that each consumer has different consumer psychology when making purchases of goods. In this context, Rodríguez et al. [11] introduced a conceptual design solution for personalized and adaptive geometric shape packaging based on digitalization of fresh food to enhance consumer loyalty and satisfaction with the product. Uzelac et al. [12] considered the role of branded agricultural products in better market pricing. The benefits of a brand are particularly important for rural and underdeveloped environments. Rural environmental issues are multifaceted, but revitalization and improved development can help strengthen the competitiveness of these areas. Visconti et al. [13] constructed a classic field of IoT, which describes the traceability development control of IoT intelligent farms. By designing the data collected in the field by wireless sensor network (WSN), a decision operating system for container processing of agricultural products in the field was developed. After testing, the system can play an important role in tracking information and storage conditions of products.

Wang et al. [14] introduced a conceptual design scheme for personalized and adaptive geometric shape packaging based on digitalization of fresh food. By analyzing consumers' demand for personalized product packaging and exploring how to use internet and artificial intelligence technology to achieve rapid and accurate production of personalized packaging. Yousefi et al. [15] constructed new materials for food quality using multifunctional sensors and applied them to intelligent packaging, among others. By monitoring the food quality of the entire food supply chain in real-time, new materials, equipment, and multifunctional sensing systems for food quality can be developed. Zhu et al. [16] analyzed the role of personalized packaging in enhancing product added value and brand image. It explores how to achieve precise production of adaptive geometric packaging through computer vision technology and automatic control technology.

2.2 The Impact of CAD Product Packaging Design

The construction frame of product design database needs to define the goal of database design. For example, support relational database and non-relational database, and realize database configuration and replacement. Data model: Establish a data model that describes concepts such as tables, columns, and data types in the database, while also considering issues such as concurrency and transaction processing. Based on the design objectives, considering business architecture, technical architecture, and other aspects. Determine the overall architecture of the system, including aspects such as database storage structure, indexing, and query optimization. Based on the data model and architecture design, carry out specific database design, including table structure, field types, and constraints. In database design, index establishment and optimization should be considered to improve query efficiency and reduce cache loss. Figure 1 shows the construction framework of a product design database.

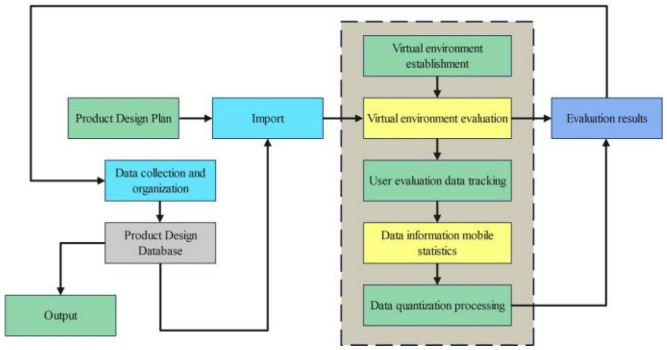

Figure 1: Database construction framework for product design system.

3 METHODOLOGY

3.1 Framework of Agricultural Product Packaging Design System Based on Virtual Reality

The preferences of agricultural product brands and their interactive effects in the e-commerce environment are a complex topic. Agricultural products have significant differences in quality and taste due to factors such as their growth environment and seasonality. Therefore, different brands of agricultural products may be favored by different consumers, and at the same time, the brand's control over the quality of agricultural products and the improvement of their taste will also affect consumers' purchasing decisions. E-commerce platforms have the advantages of convenience, speed, and price transparency, while also facing issues such as information asymmetry and fierce price competition. Therefore, when consumers choose to purchase agricultural products, they are more inclined to choose e-commerce platforms with high visibility, good reputation, and complete services.

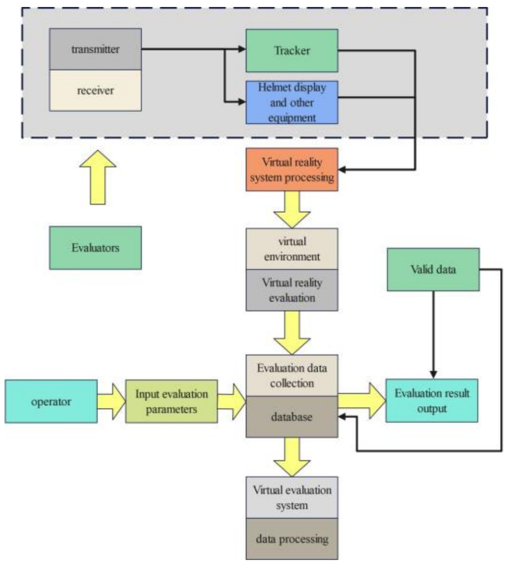

Figure 2: Schematic diagram of the VR-PDS system architecture.

Figure 2 shows a schematic diagram of the VR-PDS system architecture. The VR-PDS system architecture refers to the overall architecture of virtual reality (VR) and training management system (PDS). Including data collection and processing modules, data storage and management modules, etc., used to collect and process user data, store training data, etc. The service layer includes network connection module, data transmission module, cloud management module, etc., used to provide network connection, data transmission, and cloud management services. This architectural diagram is only a conceptual design, and the specific implementation may vary due to factors such as technology, cost, and user needs. In practical applications, the VR-PDS system architecture still needs to consider more factors, such as performance, scalability, security, and user experience.

3.2 Network Assisted Agricultural Product Packaging Design Based on Immune Algorithm

Since the mid-19th century, people's understanding of the structure and function of organisms has become increasingly profound. With the continuous deepening of research on natural biological systems and mechanisms, it has been found that applying the structure and operating mechanisms of organisms to practical production and life has significant theoretical value and significance. This discipline has had many successful cases in the field of product design. The flowchart of the improved immune algorithm is shown in Figure 3.

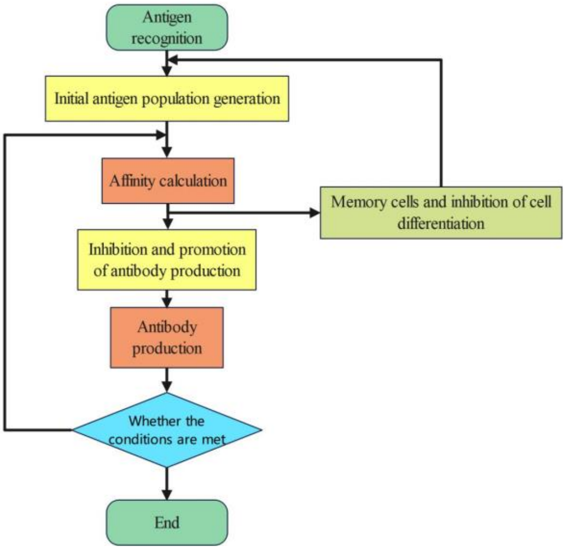

Figure 3: Flow chart of improved immune algorithm.

The population sequence Xn of the artificial immune algorithm constitutes a random sequence. Firstly, let the population size of the algorithm be N, with the approximate solution in the population being considered as a point in neighborhood S1, the approximate solution in the middle part being considered as a point in neighborhood S2, and Vi representing the variable V being in neighborhood S in the nth generation. At the same time, if the objective function to be optimized is f and the definition domain is I, then the overall optimal solution of the function f is:

$$S^* = \{x \in I \mid f(x) = \max f(x_i)\} \tag{1}$$

If all initial distributions have:

$$\lim_{n\to\infty}\sum p\{X_n^i\}=1 \tag{2}$$

Different agricultural product packaging has different colors, sizes, shapes, and artistic requirements, which belong to typical multi-objective design tasks. The number of iterations required for each coupled task set to reach convergence during the design process varies, mainly depending on factors such as the accuracy of coupling information used in upstream task design and the sensitivity of downstream tasks to this coupling information. The start time of any design task:

$$sj_i = \max\{(sj_{i-1}+d_{i-1}) \mid J_{i-1}\} \tag{3}$$

Early completion can be represented as the minimum start time for virtual completion task Jm, i.e.:

$$\min f(x) = \max\{(sj_{i-1}+d_{i-1}) \mid J_i\} \tag{4}$$

For design task planning, the main resources for design tasks are knowledge-based employees, and the duration is closely related to the difficulty of the design task itself, the selection of designers, and the skill level of personnel. For tasks with less difficulty, the difference in personnel skills has a smaller impact on the duration; For difficult tasks, designers with higher skill levels can greatly shorten the design period.

Designers with the same skill level and different skill levels need to allocate their work proportion reasonably based on the actual needs of the project during the planning process. Therefore, load balancing refers to balancing the workload of designers with the same skills and skill levels as much as possible. The optimization goal of load balancing for designers can be expressed as:

$$\min f_2(x) = \sum_{k=1}^{l}\sqrt{\sum_{s=1}^{n}\sum_{j=1}^{n}\sum_{i=2}^{m-1} x_{ij}(O_{ksj}-\overline{O_{ks}})^2 / N_{ks}} \tag{5}$$

Among Oks is the average output per unit time of all designers with skill Sk and skill level s; Nks is the number of designers with skill Sk and skill level s. Considering the randomness of design time and cost, it is necessary to simulate the task execution sequence generated during the optimization process multiple times and use four statistical indicator values to represent the execution results of the simulation. Four statistical indicators are selected as the mean, variance, range, and extreme values of time (cost), and their sum utility function (UF) is used to evaluate the quality of a task execution sequence. The sum utility function of the four statistical indicators is represented as:

$$UF = w_a \times I_a + w_v \times I_v + w_r \times I_r + w_m \times I_m \tag{6}$$

The mean Ia represents the probability distribution center of the execution time (cost) of the task sequence, which describes the overall trend of multiple simulation results. The tolerance Iv and range Ir represent the distribution and range of random time (cost) obtained from multiple simulations near their mean, respectively, representing the stability and controllability of the solution's performance. The extreme value represents the maximum time or cost of task execution, representing the worst-case time or cost spent on the task sequence. Taking into account the time and cost factors in the design process, the goals of the design process planning are defined as:

$$\min UF = w_t \times UF(TIT) + w_c \times UF(TIC) \tag{7}$$

TIT and TIC are the total iteration time and total cost in the product development process, respectively, and their calculation methods are shown in Figure 1. It should be noted that although time and cost have different measurement units, the linear sum of their utility functions can still serve as the goal of task restructuring optimization.

In the theory of the immune system, antigen reference can interact with the effector T cells and lymphoid B cells of the body itself, and through differentiation, replication, and proliferation, produce antibodies that play a role in the body's immune response to problems. In the theory of artificial immune systems, antigens represent the engineering problem to be solved, antibodies represent the global optimal solution of the corresponding problem, the affinity between antibodies and antigens represents the relative consistency between the optimal solution and the problem to be solved, the differentiation of memory cells in the system refers to the preservation of the optimal solution, the promotion and inhibition of antibodies represent the promotion of the optimal solution, and the deletion of non-optimal solutions. The Hamming distance between antibodies is:

$$D=\sqrt{\sum_{i=1,j=1}^{n}(y_i-y_j)^2}(i\neq j) \tag{8}$$

According to information theory, the information content T(α)of the jth gene by:

$$T(\alpha)=\sum_{i=1}^{n}-P_{ij}\lg P_{ij} \tag{9}$$

$$P_{ij}=\frac{\text{The number of occurrences of alleles on gene j}}{\alpha} \tag{10}$$

The immune system is composed of antibodies N with M genes. The average information entropy (quantity) of all antibody diversity is:

$$T(\alpha)=\frac{1}{M}\sum_{j=1}^{M}T_j(\alpha) \tag{11}$$

Take α= 2. According to the concept of information entropy, the affinity of any two antibodies V and W is:

$$ay_{v,w}=\frac{1}{1+H(2)} \tag{12}$$

$$c_v=\sum_{w=1}^{N}\frac{ac_{v,w}}{N} \tag{13}$$

$$ac_{v,w}=\begin{cases}1 & ay_{v,w}>Tac_1\\ 0 & else\end{cases} \tag{14}$$

4 RESULT ANALYSIS AND DISCUSSION

4.1 Construction of VR-PDS System

A software and hardware environment that can generate a three-dimensional world is the core component of a VR system. Its main function is to receive motion information related to the subject (such as head, eyes, hands, etc.), generate left and right eye views in different paths/times, and fuse them into three-dimensional stereo images. At the same time, it performs three-dimensional sound synthesis and emits feedback signals such as tactile and pressure.

Generating realistic visuals is an important task of software. Constructing polygons into visual shapes is the most commonly used method. Simple application projects can be developed from underlying functions in accordance with the OpenGL standard, while complex visual projects are best developed using specialized tool software.

In the process of product design and production, the design solutions of existing products will be stored in the enterprise database. Due to the limited total amount of databases, it is necessary to regularly layout and organize existing databases, reuse efficient design solutions, and eliminate relatively inefficient solutions. This article takes the customized product packaging design based on customer needs as an example. Firstly, based on Carnot's engineering product mapping model, it extracts user specific requirements and related importance indicators for the product. Secondly, based on AIS, customized packaging design for customer demand products can be achieved to maximize the satisfaction of customer needs.

4.2 Experimental Data and Analysis

In order to evaluate the performance of the design-based system and the satisfaction of the decision, the first party will use two sets of morphological semantic vocabulary required for packaging design (three each for simplicity, robustness, fluency, and technology, warmth, and dynamism) as the design starting point, and require each set of semantic vocabulary to produce three sets of design scheme diagrams. Designers design separately through clear semantic vocabulary constraints for design decisions, and describe the descriptive vocabulary as a design solution through personal design ideas, ultimately obtaining two sets of design solution groups Q (namely Group A and Group B). Set up Party A's team and expert group (4 design expert members) to jointly participate in 3 × Evaluate the satisfaction of two design schemes and compare them with the evaluation of the system design scheme.

As shown in Figure 4, the performance of the decision model is evaluated using the design scheme decision accuracy curve. Draw a design decision accuracy curve using the number of evolutionary iterations of the system model as the horizontal axis. In the figure, the decision-making accuracy of the model increases with the increasing number of iterations and tends to stabilize.

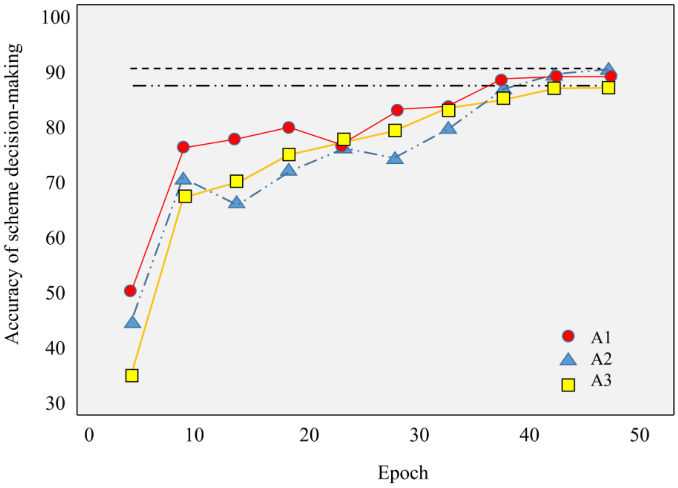

Figure 4: Comparison results of the first group of packaging schemes.

The semantic vocabulary labels of the first group of morphological design are concise, robust, and fluent. After inputting the corresponding three views of Group A design scheme as data images, observe and analyze the change curve of the decision-making accuracy of Group A design scheme by the Party A group, design expert group, and the designed system model. The expert group's design decision accuracy rates for the three design schemes were 79%, 89%, and 86%, respectively. When the number of iterations of the VR-PDS system is 50, the accuracy of design decisions for the three schemes is 86.1%, 87.5%, and 88.7%, respectively. The decision satisfaction of the decision model for A1 and A3 schemes is higher than the average decision satisfaction of the expert group.

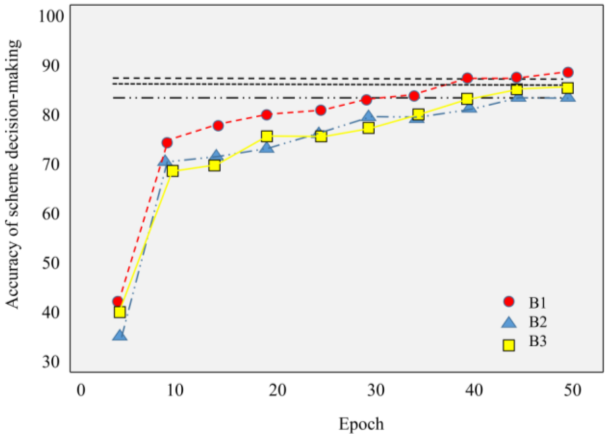

Figure 5: Comparison Results of Packaging Schemes in Group 2.

The semantic vocabulary labels for the second group of product design are technology, warmth, and dynamism. The expert group's design decision accuracy for Group B's design scheme is 85%, 86%, and 82%, respectively. When the number of iterations is 50, the design decision accuracy of the VR-PDS model for the three schemes is 84.1%, 87%, and 83%, respectively. The decision satisfaction of the decision model for B2 and B3 schemes is higher than the average decision satisfaction of the expert group. After training with the first set of data, the second group was trained again, and its model design decision accuracy increased more rapidly compared to the first group, with a relatively stable growth trend. The model performance improved with the increase of training times as shown in Figure 5.

In addition, VR-PDS, CNN, and DNN were sequentially used to learn the experimental dataset, further verifying the effectiveness of the model proposed in this paper. As shown in Figure 6, the experimental accuracy and recognition time of identifying agricultural product features, as well as the average decision satisfaction and average recall rate of decision-making data records, are compared as reference data. From the figure, it can be seen that under the same data situation, the VR-PDS system can recognize agricultural product images from different perspectives with high accuracy, thus proving the feasibility of this model in the decision-making task of agricultural product packaging design schemes.

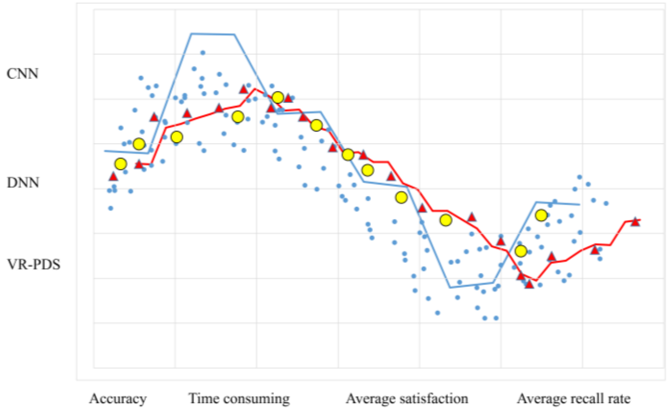

Figure 6: Comparison statistics of performance and decision satisfaction of different algorithms.

Figure 7 compares the errors of models obtained from three different sample sets, and the results show that using only DOE samples to train BPNN has the greatest error, which is a direct consequence of insufficient sample size; The error of reusing DOE samples for three times to construct training set is large, and the generalization error caused by sample distribution is the main factor; Minimum error in BPNN obtained by training three times virtual samples.

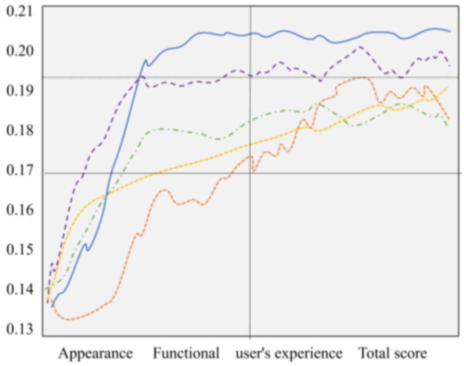

Figure 7: Modeling errors based on different datasets.

4.3 Evaluation of the Design Effect of Agricultural Product Packaging

The designed virtual reality agricultural product packaging design system relies on a virtual interactive evaluation platform, which can evaluate the product packaging. Users enter product reviews and rate the product based on their personal preferences and satisfaction. The scoring interface is implemented using system controls, and the desired functionality is achieved through collaboration with scripts. Scoring is based on 5 points, representing completely unimportant, unimportant, average, important, and very important. Randomly select 40 individuals who cover various occupational fields and are evenly distributed between the ages of 20 and 50 for evaluation, including 15 males and 25 females, for investigation. After the user evaluation is completed, click submit and the system will automatically record the evaluation data. After the evaluation is completed, you can view the evaluation results. Collect all evaluation data, and the outer packaging evaluation data of the two agricultural products are shown in Figure 8.

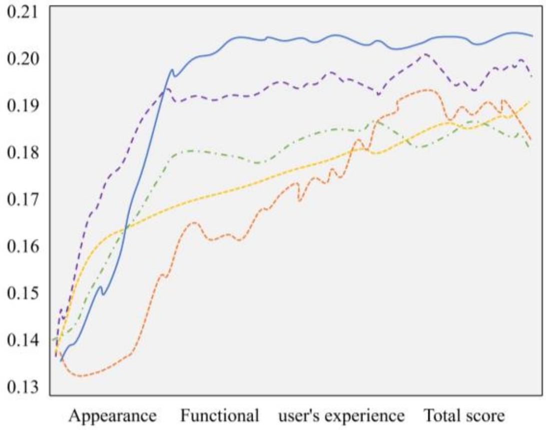

Figure 8: Comparison chart of scores from different evaluation angles.

The overall comprehensive score of Scheme 1 is 3.73 points, which fails to meet the general satisfaction level of users and needs further adjustment. Solution 1 has a poor completion rate in terms of user experience satisfaction. To improve user experience satisfaction, improvements should be made in two aspects: "easy to observe product status" and "easy to operate".

5 CONCLUSION

With the development of economy and science and technology, the competition in the agricultural product market is becoming increasingly fierce, with new processes, new materials, and new packaging coming one after another. With the rapid development of agricultural science and technology, a large number of new agricultural products have emerged. Consumers can only obtain relevant information from the packaging and appearance of various agricultural products in the market. Whether packaging can provide consumers with a strong sense of taste, arousal, and security has become a key factor in gaining market share. The packaging design of agricultural products, as an aspect of product packaging design, has certain design commonalities. Firstly, it must meet the basic needs of human life, fully consider key issues such as production and processing of agricultural products, and also fully demonstrate the unique characteristics of agricultural products. With the increasingly mature development of virtual reality technology, more and more industries are choosing to combine virtual reality technology with their own development, bringing higher profits to the industry's development. Through the application research of the combination of virtual reality technology and agricultural product packaging, it can not only accelerate the modernization transformation of agricultural product packaging in the new era, bring new development directions for agricultural product packaging design, and promote the continuous development of network assisted agricultural product packaging towards diversified design forms.

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