Multi-Sensor Information Fusion Technology in the Product Design Using Back Propagation Network

Qingnan Ji[1] ⓘD, Jinxia Wang[2] ⓘD, Lu Liu[3] ⓘD and Juan Du[4] ⓘD

[1]Department of Art and Design, Shaanxi Fashion Engineering University, Xi'an 710000, China, n240321@126.com.cn
[2]Department of Art and Design, Shaanxi Fashion Engineering University, Xi'an 710000, China, W15202422172@126.com
[3]Department of Art and Design, Shaanxi Fashion Engineering University, Xi'an 710000, China, l826591@126.com
[4]Department of Sports, Chongqing Jiaotong University, Chongqing 400074, China, dujuan@stu.hunau.edu.cn

Corresponding author: Juan Du, dujuan@stu.hunau.edu.cn

Abstract. Computer aided design has been widely used in various industries. The information level based on multi-sensor has required more complete expression and analysis. At the same time, compared with the past, today's focus of product design education has shifted from printing to digital design, from teaching to practice and market. This paper presents the research and application of multi-sensor information fusion technology in product design teaching. The basic probability distribution of D-S evidence theory is usually obtained through subjective experience, which leads to the problem of low credibility of decision-making. This paper proposes to use BP (Back Propagation) network to obtain the basic probability distribution. The results show that the recognition rate of BP is 90.71%, and that of genetic algorithm is only 82.26%. The number of training steps of BP is less than half of that of GA, so based on the data in this paper, BP's target recognition effect is better than GA's. The practical application shows that the application of MIF technology in product design teaching has effectively improved the teaching efficiency, enriched the teaching process, increased the interest and interactivity of teaching activities, and promoted the communication between teachers and students. This paper analyzes the types of fusion technologies under different sensor technology analysis, and explores the practical application of different technology algorithms.

Keywords: multi-sensor information fusion; product design; computer-aided; practical teaching; bp network
DOI: https://doi.org/10.14733/cadaps.2023.S10.181-191

1 INTRODUCTION

People have higher and higher requirements for industrial design. The emergence of computer technology undoubtedly provides a huge development space for China's manufacturing industry. There are many deficiencies in traditional industrial design. With the computer technology, the development requirements of industrial design are becoming higher and higher, and it is beginning to move towards diversification, scientization and personalization. The engineering design research of Yoo et al. [1] has carried out supervision and analysis of different industry projects under the assistance of computers. In the conceptual design stage, this study proposes a CAD/CAE framework based on deep learning. The development and progress of electronic information technology has promoted the application of computer aid in industrial design industry. The design quality of industrial products has been fully improved, which has greatly met the needs of customers. At the same time, from the perspective of environmental protection and appearance, the product performance level is superior. Therefore, in practical design, the designer should formulate a more reasonable production plan. Deeply analyze the current development trend of computer-aided industrial design, so as to realize more rational application of technical data and save costs. This paper mainly studies the development and trend of computer-aided industrial design. Mountstephens and Teo [2] believe the system is analyzed according to the main objectives of the system, the generation method, the design stage concerned. Han et al. [3] proposed a method to find key function modules in 3D CAD assembly model of complex machinery. Product design in teaching websites is a two-dimensional art, which is based on the principle of effective communication of teaching information, network and multimedia technology, integrates teaching spirit and aesthetic value, and realizes the coordination, comprehensiveness, integrity and systematicness of the integration of teaching information and visual elements. Ramnath et al. [4] built an independent thread that can be created in a computer program to process the input, output and processing of digital signals. This thread can use the high-speed computing ability of the computer to realize high-speed digital signal processing and improve the efficiency and speed of data processing. Its precision is high, and digital thread can realize high-precision digital signal processing. For the processing of audio, video and other fields, the accuracy and clarity of the signal can be guaranteed. At the same time, it has strong reliability: digital thread can realize the input, output and processing of digital signals through program control. This avoids the influence of human factors and improves the reliability of signal processing [5].

The variables of the differential equation are rewritten as node values composed of derivatives or variables. The selected interpolation function points are used to form a linear expression, and then the weighted residual method and variational principle are used to solve the differential equation. Computer aided technology has made great contributions in the production of industrial products, virtual users begin to communicate and design from multiple perspectives. Product design takes the expression and dissemination of information as the research object, and takes the accurate expression and efficient dissemination of information as the purpose, and carries out visual design and processing of information to meet the needs of people's information dissemination. The goal and direction of talent training in higher vocational colleges need to be clear. At the same time, we should abandon the traditional teaching methods and turn to the cultivation of innovative talents, emphasizing the importance of practical skills in today's design teaching.

2 RELATED WORK

With the popularization of computer technology, more and more people begin to attach importance to the efficiency and results of design. Under the current industrial design situation, the industry should strengthen the importance of CAD/CAM and CAID technology, and continue to improve and optimize in practice. However, based on the development situation of computer-aided industrial design in China, there are still some deficiencies and defects. For this reason, it is necessary to carry out the integration and analysis of industrial design data with CAID technology and establish

a database with artificial intelligence. Fully involve the whole process of man-machine, modeling, sales and management, and service to create an integrated product design and application system. Further strengthen the feedback of the design results by the computer-aided industrial design system. Ensure the continuous optimization of design products, and then directly or indirectly drive the efficient development of industrial design. The most direct method of image fusion is to average or weighted average the source image. Average operation improves the signal-to-noise ratio of the fused image, but weakens the contrast of the image, especially for the useful signal that only appears in one image. Wang et al. fused visible and infrared images by spatial adaptive nonlinear processing method. The original image is first divided into high-pass and low-pass parts. Lalegani et al [6] compared the fill patterns and fill densities generated by CAD and FDM. CAD software is used to design mesh. Garc í a et al. [7] designed a new CAD software tool, which may pave the way for the next generation of engineering design. Zhou et al. [8] has developed a kind of emotional virtual situation simulation software. Using computer technology, it can achieve efficient and accurate monitoring and analysis of emotional state, avoiding the subjectivity and error of traditional manual monitoring methods. The software layout is real-time, and computer-aided design emotional monitoring can achieve real-time monitoring and analysis. It can help researchers grasp the emotional state of the subjects in a timely manner and provide more accurate data for subsequent analysis and processing. Emotional monitoring can process a large amount of data. Through the analysis of a large amount of data, we can find the rules and trends of emotional changes.

3   RESEARCH METHOD

3.1   Characteristics and System of Practical Teaching of Computer-Aided Product Design

The level of modern product design of computer-aided design has been continuously improved and the application scope has been expanded. To some extent, it also promotes the development and progress of product design. In the era of information explosion with multidisciplinary integration, computer technology has become the best way for people to meet the requirements of information acquisition. Computer aided design plays an important role. Therefore, we should actively adapt to the development of the situation and promote the diversification and intelligence of product design. The transformation of the whole society to visual culture means a series of cultural changes. With the emergence of visual culture transformation, society has entered an unprecedented era of popular culture. In the sense of cultural model, "visual culture" provides us with an opportunity to build a fairer and more inclusive cultural environment. For product design education, it is an inevitable task to pay attention to the aesthetic phenomenon in daily life, which will inevitably lead to the transformation of product design education paradigm and the expansion of its connotation and scope. Product design education can select some content to organize and improve, make it become a new teaching content, and build a new product design teaching system. Therefore, in the education of product design, it is necessary to add new professional courses such as public art education and comprehensive art expression language, closely connect with the reality of contemporary society, and cultivate practical talents required by the society, so as to quickly adapt to the changes brought by the visual turn. The entrepreneurship studio is an incubation base to support industrial development and graduate entrepreneurship, and also a teaching demonstration base for entrepreneurship education. As shown in Figure 1.

In the process of designing experiments and discussions, teachers can gain knowledge, effectively control the teaching process, and make full preparations before teaching. They should make detailed plans for the details of teaching, such as the decomposition of color and light, the harmony of three primary colors, the psychological feelings of colors, etc., and draw conclusions by scientific experiments. Under the guidance of teachers, students participate in every link of business negotiation, material evaluation, market research, design and production, so that

students' professional quality and professional ability can be cultivated in real life. Professional theoretical knowledge is mastered by teachers and students in the process of communication.

Figure 1: Schematic diagram of production-teaching combination level, studio types and participating students.

The college should build a skill teaching system based on practical teaching, organically combine classroom theoretical teaching with practical skill training, and focus on cultivating students' professional practical operation ability. Therefore, the reform of the teaching system should reasonably construct the practical teaching system of the college according to its own characteristics. A reasonable training plan should be time-sharing, interconnected, and form a strong systematic experimental and practical teaching system, so as to ensure that students' practical ability and comprehensive quality can develop harmoniously while learning theoretical knowledge.

3.2 The Application and Realization of MIF Technology in Product Design Teaching

Information fusion is to make full use of multi-sensor information in different time and space. When some sensors can't be used or interfered or a certain target is not covered, there will always be some sensors that can provide information, so that the system can run continuously without interference, weaken faults and increase the detection probability.

Evidence theory has great advantages in integrating basic probability assignment, but it is difficult to acquire its own basic probability assignment, while neural network is just easier to acquire basic probability assignment. Therefore, we can use neural network to get the relative input values and basic probability assignments of various categories through training, and then use evidence theory to make fusion judgment. The specific block diagram is shown in Figure 2.

In evidence theory, basic probability assignment function, trust function and truth-like function are commonly used to describe and deal with the uncertainty of information. The recognition framework is defined as a complete set of mutually incompatible events, that is, the result is a set of all possible values, usually defined as U, then the function $m : 2^{U} \rightarrow [0,1]$ satisfies the following conditions:

$$m(\phi) = 0 \tag{3.1}$$

The trust function $BEL(A)$ indicates the degree of trust in proposition A, which is defined as:

$$BEL(A) = \sum_{B \subset A} mB \tag{3.2}$$

It represents the sum of probability measures of all subsets of A, that is, the total reliability of A.
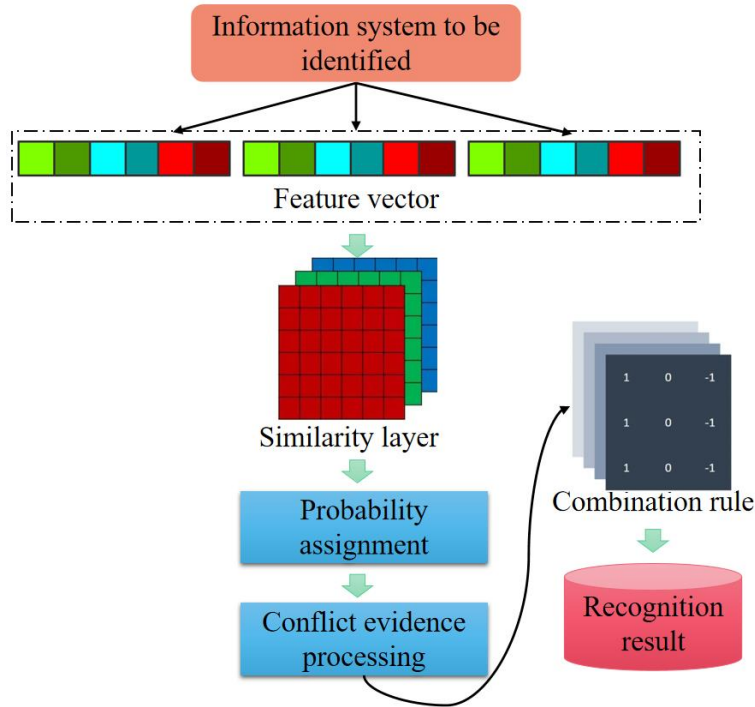

Figure 2: Block diagram of recognizer based on neural network and evidence theory.

The paradox of the D-S evidence synthesis formula is that it takes the same important attitude to integrate the evidences involved in the synthesis, and the distance between evidences can be used to measure the similarity among the evidences in the system. Similarity coefficient can be used to measure the similarity between evidences. The larger the value, the higher the similarity. The degree of support between evidences is:

$$Sup(m_i) = \sum_{j=1}^{n} d_{ij} \qquad (i, j = 1, 2, \cdots, n) \tag{3.3}$$

$Sup(m_i)$ indicates the degree to which evidence E_i is supported by other evidence. When a certain piece of evidence is very similar to other pieces of evidence, it is considered that the degree of mutual support between them is higher. By normalizing the support degree of evidence E_i, the credibility value of evidence E_i can be obtained.

The credibility of m_i is:

$$Crd(m_i) = \frac{Sup(m_i)}{\sum_{i=1}^{n} Sup(m_i)} \qquad (i, j = 1, 2, \cdots, n) \tag{3.4}$$

Bayesian optimal estimation gives the optimal solution of nonlinear function filtering. According to Bayesian theory, the estimation of system state can be obtained by approximating the nonlinear probability density function of the system. Consider the following nonlinear discrete stochastic systems:

$$x_{k+1} = f(x_k, k) + w_k \tag{3.5}$$

$$z_{k+1} = h(x_{k+1}, k) + v_{k+1} \tag{3.6}$$

$x_k \in R^n, z_k \in R^m$ represents the state vector and observation $f(\cdot)$ represents the state function of the system, and $h(\cdot)$ represents the observation function of the system.

In the reasoning process of D-S evidence theory, it is assumed that the weights of each evidence are equal. Now, the Euclidean distance between evidence E_i and evidence set E is defined:

$$S_i = \frac{1}{n} \sum_{j=1}^{n} d(m_i, m_j) \, S_i \in [0,1] \tag{3.7}$$

S_i is an index to measure the conflict degree of evidence E_i, which reflects the difference between this evidence and other evidence. When S_i is small, E_i is consistent with other evidences, and the conflict degree is low. On the contrary, when S_i is large, it means that E_i is quite different from other evidences, which have great differences and conflicts.

4   RESULT ANALYSIS

Aided product design is similar to CAD modeling, and computer aided modeling design can comprehensively and intuitively display the characteristics of industrial design products. Generally, industrial product modeling design mainly involves sketch design and free-form surface design, which is also the main research field of computer-aided modeling design. In reality, product modeling directly affects people's perception of products, and even affects the sales of products. Therefore, modeling design has always been a concern in the field of industrial design. However, before the formal production of product modeling, it involves many links such as sketch design. Using sketch design can effectively fill the gap between industrial design and computer-aided design. For computer-aided modeling design, human-computer interaction and sketch reconstruction are the most important technical means, which are related to the simulation of the designer's hand-drawing process by the design system. As the name implies, free-form surface design is the implementation of free-form surface design for product shape. When implementing the design work, it is necessary to apply the surface features reasonably. This work involves basic surfaces, serial graphics and mobile features. It can be said that sketch design and free-form surface design are important factors that affect the market prospects of products. Therefore, these two designs are also the focus of research in the field of computer-aided industrial design. Now, two commonly used algorithms of neural network: BP and GA are used for target recognition respectively, and the simulation results are compared. In this paper, there are 150 groups of classified samples, of which 90 groups are used as training data and 60 groups are used as test data. Two algorithms are used to simulate.

Both neural network algorithms adjust the weight matrix according to the training vector until the input and output of the training vector are basically met. The test results of both are shown in Figure 3 and Figure 4, respectively.
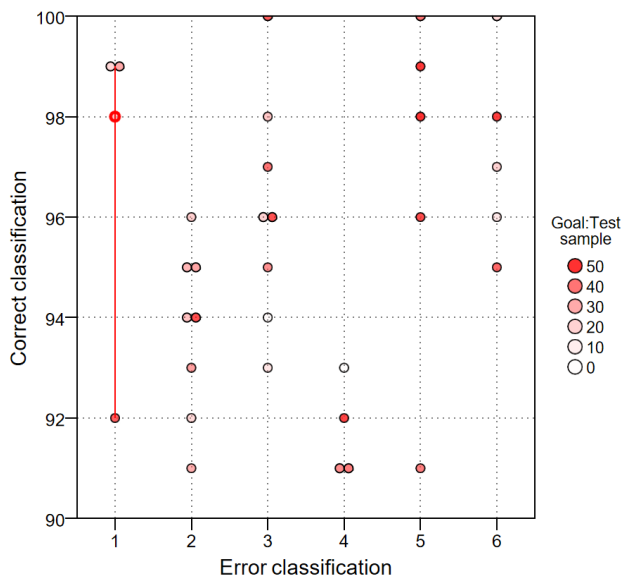
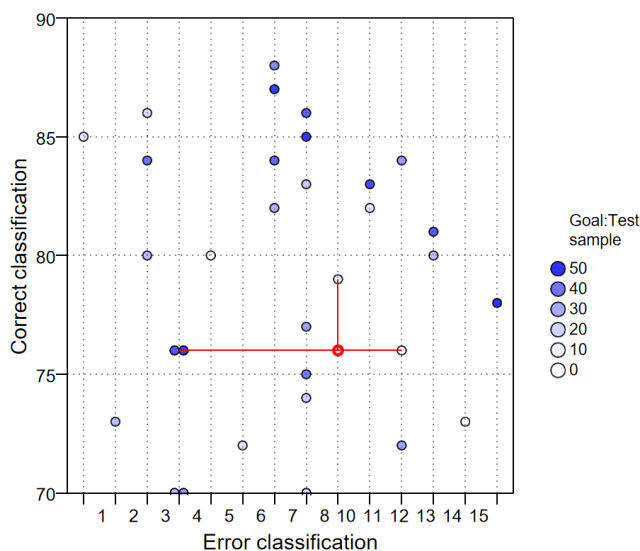**Figure 3**: Classification of BP test samples.

Figure 4: Classification of test samples based on GA.

As can be seen from the above four figures, the recognition rate of BP is 90.71%, that of GA is only 82.26%, and the number of training steps of BP is less than half that of GA. Therefore, the effect of target recognition with BP is better than that of GA based on the data in this paper.

According to the above experimental steps, after GA optimizes one of the subnets, the variation chart of fitness and evolutionary algebra is shown in Figure 5: the dotted line indicates the variation of population mean, and the solid line indicates the maximum fitness, that is, the variation trend solved.
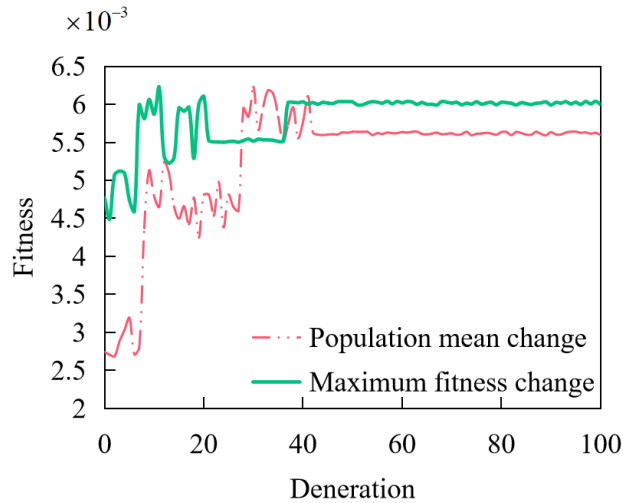
Figure 5: Algebraic variation diagram of fitness and evolution.

From the simulation results in Table 1, the method in this paper is obviously superior to the other two methods. Compared with BP network training algorithm, it is easy to fall into local extremum due to the randomness of weight selection, which affects the performance of the network.

Weight factor	Algorithm in this paper	GA	BP
0.1	90.948%	83.729%	86.887%
0.2	91.331%	83.742%	87.189%
0.3	90.974%	83.735%	87.192%
0.4	91.287%	83.754%	87.119%
0.5	90.821%	84.119%	86.607%
0.6	91.317%	84.153%	86.824%

Table 1: Effective recognition rate of different information fusion algorithms.

In this paper, GA's powerful global search ability is used to optimize the structure of neural network in advance, which relieves the worries of local extremum.

In the existing research, for the nonlinear state estimation problem with state delay, scholars mostly study the one-step or two-step state delay problem. RMSE (Root mean square error) is selected as the comparison criterion of filtering algorithm performance. In order to verify the efficiency of the proposed algorithm, a nonlinear function with one-step and two-step delay states is taken as a numerical simulation example. The simulation results are shown in Figure 6 and Figure 7.

From the estimation results, it can be seen that when the measurement noise is small, the GA estimation error curve jumps, which is because the linearization error of the state posterior estimation becomes larger, which makes the Jacobian matrix for calculating nonlinear functions stagnate. However, both GA and BP algorithms have different degree of jump phenomenon, especially in the figure, these two algorithms have not entered a stable state, which is due to the state delay of the system, which leads to the decrease of the estimation accuracy and numerical stability of the standard algorithm. Simulation shows that the improved algorithm has similar numerical stability to GA algorithm, but the former has stronger robustness, higher estimation accuracy and wider applicability than the latter. The performance of this algorithm is better than that of GA algorithm because of different approximation forms of nonlinear Gaussian integral.
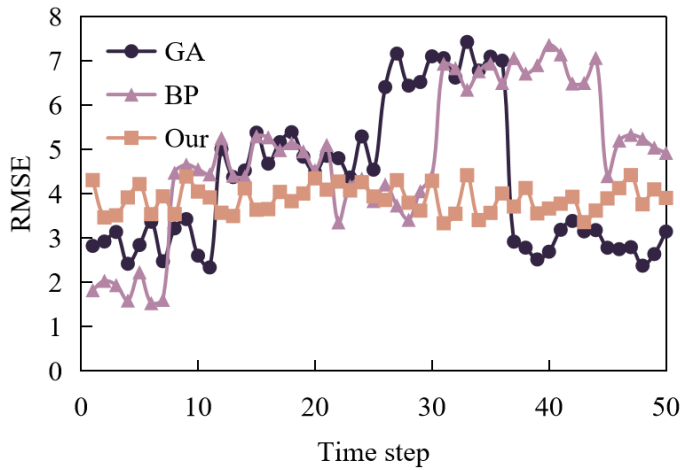
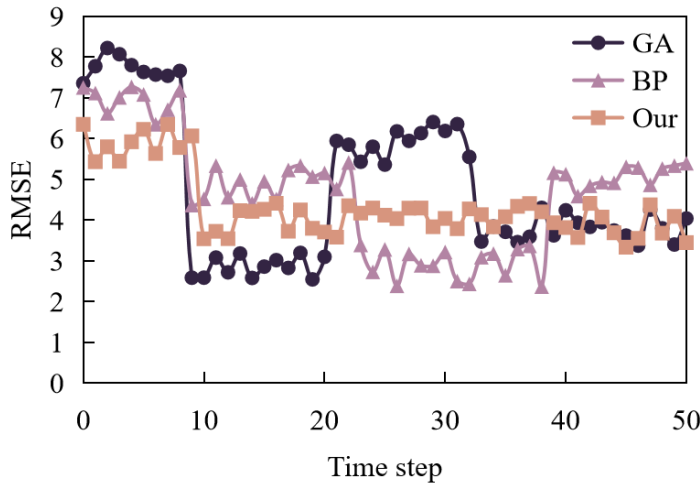**Figure 6**: RMSE of state x_1 under $R=8$ condition.

Figure 7: RMSE of state x_2 under $R=10$ condition.

Spatial frequency is a quantity that reflects the degree of spatial variation of an image, and is used to characterize the quality of image compression. Select 48×48 image blocks from the image and blur them with Gaussian functions with different blur radii. The spatial frequency, visibility and edge features of these image blocks are shown in Table 2, from which it can be seen that the values of the three features become smaller and smaller as the image blocks become blurred.

Image sequence number	Spatial frequency	Visibility	Edge feature
1	13.554	0.0073	211
2	12.665	0.0073	211
3	8.473	0.0072	208
4	7.814	0.007	198
5	6.596	0.0067	180

Table 2: Feature quantity corresponding to image block.

A similar experiment was carried out on the image blocks selected from the image, and the corresponding three eigenvalues are listed in Table 3. It can be seen that the clearer the image blocks, the larger the corresponding eigenvalues.

Image sequence number	Spatial frequency	Visibility	Edge feature
1	15.814	0.0092	256
2	13.993	0.0089	252
3	10.912	0.0082	248
4	9.112	0.0082	243
5	8.841	0.0075	237

Table 3: Image block feature quantity.

From the above two experimental results, it can be found that the three features used can reflect the clarity of the image block, and multi-focus image fusion is to get a clear image from two images with different focuses, so the above three features can be used to achieve this purpose.

5 CONCLUSION

Computer aided design product appearance monitoring can display the emotional state in the form of charts, curves, etc., which can help researchers understand the change process of product state more intuitively. Then, this will inevitably affect education, and the first is product design education characterized by computer-aided design. This paper studies the application of MIF technology in product design teaching, fully understands the concept of innovative thinking and art professional knowledge, and combines the experience gained in personal practice to achieve effective results. The recognition rate of BP is 90.71%, the recognition rate of GA is only 82.26%, and the number of training steps of BP is less than half of that of GA. Therefore, based on the data in this paper, the target recognition effect of BP is better than that of GA. Only by combining practical teaching can we cultivate product design talents who are in line with social development, have strong innovative thinking ability, strong practical ability and keen market insight.

Qingnan Ji, https://orcid.org/0000-0001-7410-0352
Jinxia Wang, https://orcid.org/0000-0003-1222-6990
Lu Liu, https://orcid.org/0000-0001-9348-6254
Juan Du, https://orcid.org/0000-0002-3701-601X

REFERENCES

[1] Yoo, S.; Lee, S.; Kim, S.; Hwang, K. H.; Park, J.-H.; Kang, N.: Integrating deep learning into CAD/CAE system: generative design and evaluation of 3D conceptual wheel, Structural and multidisciplinary optimization, 64(4), 2021, 2725-2747. https://doi.org/10.1007/s00158-021-02953-9
[2] Mountstephens, J.; Teo, J.: Progress and challenges in generative product design: A review of systems, Computers, 9(4), 2020, 80. https://doi.org/10.3390/computers9040080
[3] Han, Z.; Tian, C.; Zhou, Z.; Yuan, Q.: Discovery of key function module in complex mechanical 3D CAD assembly model for design reuse, Assembly Automation, 42(1), 2022, 54-66. https://doi.org/10.1108/AA-06-2021-0073
[4] Ramnath, S.; Haghighi, P.; Venkiteswaran, A.; Shah, J.-J.: Interoperability of CAD geometry and product manufacturing information for computer integrated manufacturing, International Journal of Computer Integrated Manufacturing, 33(2), 2020, 116-132. https://doi.org/10.1080/0951192X.2020.1718760

[5]   Pessôa, M.-V.-P.; Becker, J.-M.-J.: Smart design engineering: a literature review of the impact of the 4th industrial revolution on product design and development, Research in engineering design, 31(2), 2020, 175-195. https://doi.org/10.1007/s00163-020-00330-z

[6]   Lalegani, D.-M.; Ariffin, M.-K.-A.-M.; Serjouei, A.; Zolfagharian, A.; Hatami, S.; Bodaghi, M.: Influence of infill patterns generated by CAD and FDM 3D printer on surface roughness and tensile strength properties, Applied Sciences, 11(16), 2021, 7272. https://doi.org/10.3390/app11167272

[7]   García, A.-P.-A.; Pérez, D.-L.; Luviano, C.-D.; Solano, N.-J.-J.; Martínez, G.-E.; Callejas, C.-M.: PFDA-FMEA, an integrated method improving FMEA assessment in product design, Applied Sciences, 11(4), 2021, 1406. https://doi.org/10.1007/978-3-031-25182-5_21

[8]   Zhou, J.; Phadnis, V.; Olechowski, A.: Analysis of designer emotions in collaborative and traditional computer-aided design, Journal of Mechanical Design, 143(2), 2021, 021401. https://doi.org/10.1115/1.4047685

[9]   Barreto, J.-C.-L.; Cardoso, A.; Lamounier, J.-E.-A.; Silva, P.-C.; Silva, A.-C.: Designing virtual reality environments through an authoring system based on CAD floor plans: A methodology and case study applied to electric power substations for supervision, Energies, 14(21), 2021, 7435. https://doi.org/10.3390/en14217435

[10] špelic, I.: The current status on 3D scanning and CAD/CAM applications in textile research, International Journal of Clothing Science and Technology, 32(6), 2020, 891-907. https://doi.org/10.1108/IJCST-07-2018-0094