

Figure 2. Flow chart of clothing shape parametric design.

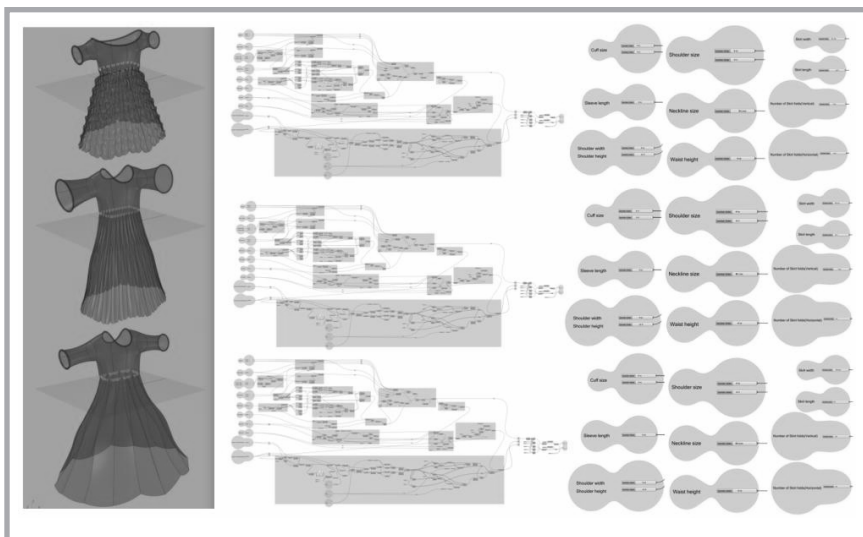


Figure 3. Clothing shapes and their corresponding Grasshopper controller groups.

tensive research of international scholars in this direction mainly focuses on algorithm technology, sensors, framework process optimisation, cooperative design, amongst others. In the field of design, more focused keywords, such as man-algorithm cooperative design, sustainable design, digital vision, serialisation design, parametric design and so on, are frequently studied. The intelligence algorithm has made some theoretical and applied breakthroughs in the field of design. Gao Feng used the deep learning algorithm to enable a computer to learn an existing chair shape and successfully generated a conceptual design sketch of 310000 chairs [1]; Qin Jingyan discussed a scheme of transforming the

common pattern picture style into a Cloisonne design pattern through Generative Adversarial Networks (GAN) with an unpaired data set [2]; Phillip Isola used the conditional confrontation network to realise the machine automatic rendering and colouring of a hand-painted clothing outline [3]; Taeksoo built a DiscoGAN to migrate the style patterns on existing bags to shoes and clothing across domains, that is, he completed the design of a series of clothing products through algorithm learning [4]; Donggeun Yoo proposed a conditional image generation model to generate regular clothing display images from photos of models wearing clothes [5]. Scholars around the world have begun to explore the appli-

cation and combination of algorithms in clothing design. But so far there has been little research on upgrading the design method of fashion design in multi links from the perspective of human algorithm collaboration. The important and difficult points of the research are the realisation possibility of human-algorithm collaborative clothing design, the specific combination method of current advanced algorithm technology in the multi links of clothing design, and the collaborative mode between multi human roles and intelligent algorithms. In this study, researchers will explore the theory and practice of intelligent algorithm participation in the design of garment products in the whole cycle and multi links so as to solve the problems existing in clothing design for a long time, such as being unable to reduce the marginal cost through economies of scale, low product development efficiency, low robustness and adjustability of the design process system, high waste of unnecessary resources, etc.

Parametric development of clothing shape

Parametric design establishes the relationship between the parametric function and design modeling through the number state algorithm [6]. Then we can adjust the product shape by changing the parameter variables. In the clothing shape design link of clothing product development, parametric design can help designers to achieve the rapid and accurate adjustment of the design result, series design and complex composite shape design, such as interference, compilation, random growth, and so on [7]. With the help of a parametric algorithm, the digitised clothing shape model can directly change into a plane structure or a sample be made by flexible 3D printing. The samples made by means of the plane structure or flexible 3D printing can be entity modified and returned to the digital platform through 3D scanning to form a closed loop. The process of clothing shape parametric development proposed in this study is shown in **Figure 2**.

Currently, the main popular parametric design platforms include 3D Max, Solid Works, Grasshopper, etc. The Grasshopper platform exists in the form of Rhino software's parametric plug-ins. Because Grasshopper provides the operation form of an analog node controller and its good storage, Grasshopper is highly suitable for designers who lack a programming back-

ground to quickly realise the establishment and adjustment of a clothing shape model. The interface of the Grasshopper platform has both logic and geometry operating systems. The logical operating system includes functions of maths and sets, while the geometry operating system includes vector, curve, surface, mesh, intersect and transform functions. In this study, we use the Grasshopper platform to practice the parametric design of clothing modelling. In the Grasshopper interface, we establish the matching relationship between the target clothing shape modeling language and the algorithm function through the logic system, as well as establish the node controller group. After that, we use the geometry system to perform real-time variable corresponding product modelling in the Rhino interface. **Figure 3** shows the clothing shape modelling and the corresponding node controller group in the Grasshopper platform.

Print pattern creation by Generative Adversarial Networks

As one of the top ten breakthrough technologies of the MIT science and Technology Review in 2018, the Generative Adversarial Network has been used as the core algorithm structure in many fields since it was proposed by Ian Goodfellow in 2014, such as super-resolution face recognition, pose simulation, image enhancement, etc. [8]. Generative Adversarial Networks can simulate human perception of the external environment and master the characteristics and structure of the research object through training. The breakthrough development of GAN enables algorithms to replace human beings in art design. We build a pattern creation model of a clothing print pattern with the core of GAN and select a Chinese splash ink pattern for design practice. Splash ink is one of the most important techniques in Chinese painting. The splash ink print pattern has a great diversity of the sense of the picture and

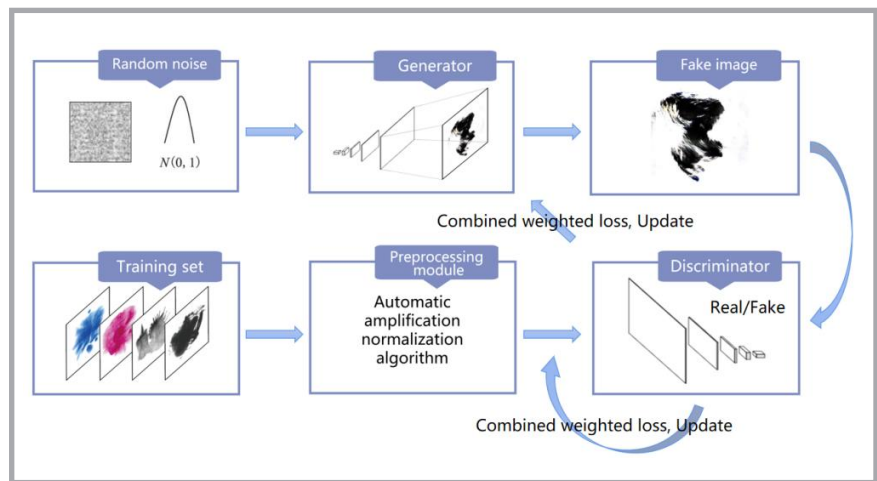


Figure 4. Design model of a splash ink print pattern based on GAN.

perception of Chinese art symbols. Different combinations of water and ink colour, together with the blank part left in the picture, together create a vivid graphic effect with a great sense of life, which is highly suitable for a variety of textile and garment materials.

In recent years, splash ink print patterns have appeared many times on international fashion products, such as the fashion cloth launched by Italian fashion brand Gabriele Colangelo in 2019, Chinese fashion brand JIESI in 2014 and the fashion cloth, bag and footwear launched by French fashion brand Louis Vuitton in 2021.

Through investigation, we analysed the artistic performance characteristics and sample status of a splash ink print pattern, and then built a model with the Python 3.6 language. Based on the core artistic expression language elements of the ink colour shade and blank layout of the splash ink pattern, we introduce the HSV model algorithm with a 0.5 combination weight into the model loss function to indicate the training process of the whole model. In view of the training difficulties, such as few samples, miscellaneous specifications, slow convergence

speed, and gradient disappearance in the process of model training, we add the self-amplification normalisation preprocessing module, the batch normalization mechanism, Leaky ReLU and other algorithm optimisation designs to the model. The final model architecture is shown in **Figure 4**.

The 361 pieces of splash ink print patterns collected by us were transformed into 821 pieces of high-quality data sets with consistent specifications after preprocessing. The data set is inputted into the model, and through about 16000 times of unsupervised training, the image generated by the algorithm is improved from full noise to a splash ink print pattern close to a human creation, as shown in **Figure 5**. After about 15 hours, the model training tends to be flat, and the loss function value is close to zero, as shown in **Figure 6**. After training, the network model can complete the design generation of 10000 splash ink print patterns in 72.12 seconds. Some of the sample patterns and model generated patterns are shown in **Table 1**. Compared with the representative original GAN model and DCGAN model, this one shows better performance in dealing with the ink splashed clothing printing pattern. IS (in-

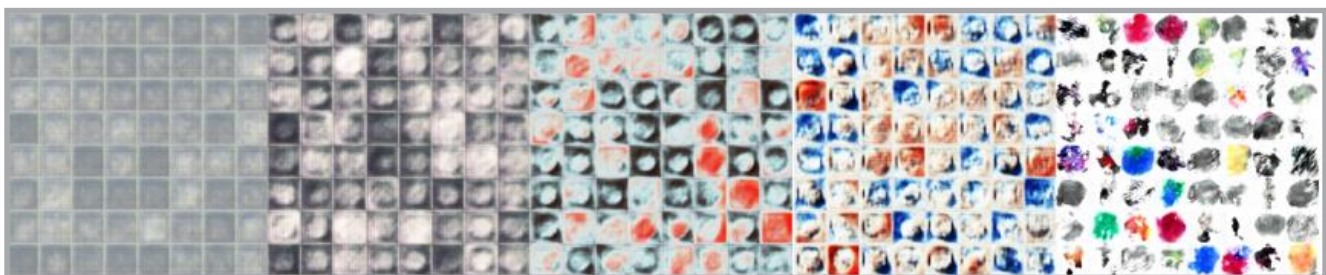


Figure 5. Output results of model training process nodes.



Figure 6. Change chart of model loss function.

Table 1. Contrast of a pattern created by a human and by an algorithm.

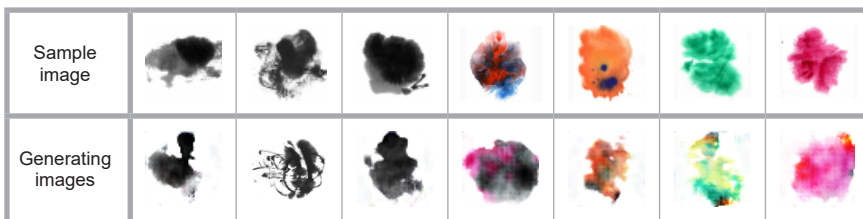


Table 2. Results of comparative experiments.

Model	Convergence time	Generation time of 10000 images	IS
Our Model	15 h	72.12 s	3.13
Original GAN	24 h	73.63 s	2.34
DCGAN	18 h	78.98 s	2.493

Table 3. Results of comparative experiments.

	Model-size	Speed (256)	Speed (512)
Gatys et al. [10]	N/A	0.07 fps	0.02 fps
Johnson et al. [11]	6.7 MB	91.7 fps	26.3 fps
Dumoulin et al. [12]	6.8 MB	88.3 fps	24.7 fps
Chen et al. [13]	574 MB	5.84 fps	0.31 fps
Huang et al. [14]	28.1 MB	37.0 fps	10.2 fps
MSG-Net	9.6 MB	92.7 fps	14. fps

ception score) is also introduced into the evaluation system as a highly recognised index for quantitative evaluation of the quality and richness of the results generated. The higher the IS value, the better the quality and richness of the pattern generated by the model. The experimental results are shown in *Table 2*.

Texture craft presentation by style transfer

Style transfer technology transfers the style of a style reference graph into a content graph by means of a convolution neural network algorithm, and generates a new image with both style expression and content information. We attempted to use the style transfer algorithm in the design and presentation of clothing texture crafts to help designers quickly obtain an effect image of a print pattern in a variety of texture crafts. After investigation, we selected six clothing pattern texture crafts: double braided twist, geometric fold weaving, pleated crepe, honeycomb washing, worn jacquard weave, and patchwork. We investigated and analysed the artistic performance characteristics and technical behaviour significance of the six kinds of clothing texture crafts, and obtained a representative image of them through collection, screening and preprocessing.

After analysis, research and experimental comparison, we finally chose the MSG-Net (multi style generative network), which better reflects the sample objects of this study, to carry out the style transfer of clothing texture technology. MSG-Net introduces a CoMatch layer to match the second-order feature statistics with the target style, and adopts a special up

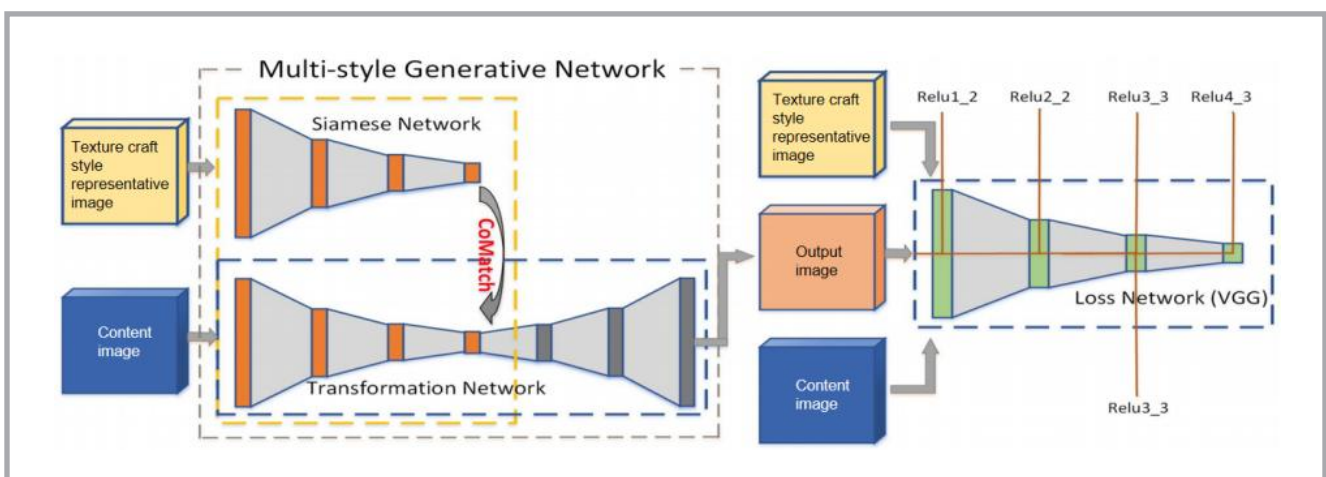


Figure 7. Network structure of MSG-N.

sampling convolution strategy to avoid chessboard artifacts caused by fractional convolution. The algorithm structure is shown in **Figure 7** [9]. Compared with the representative models proposed by other scholars, MSG-Net shows higher progressiveness in model size and speed, (as shown in **Table 3**), and has a relatively advanced performance in generating image quality and model stability [9]. We selected a splash ink pattern created by a algorithm model built in a previous article as the content image, and inputted it into the style transfer network together with representative images of the six texture styles. The algorithm uses a convolution neural network to calculate and extract the style and content data, and continuously optimises the output image under the guidance of the loss function. The final output of the migration image of the six texture styles and its corresponding style reference figure are shown in **Figure 8**.

In the man-algorithm cooperation design mode, we rendered a splash ink pattern with a double twist texture craft on the parametric series clothing shape, as shown in **Figure 9**. The design expression of the rendering effect shows that the man-algorithm cooperation design method can be well practiced to the multi links of the clothing product design.

Clothing digital vision generation by intelligent algorithm

With the technology iteration and popularisation of mobile Internet and electronic devices, the significance of product digital vision in all aspects of product development is increasing. The new generation of digital natives are more and more used to obtain product information and design ideas through various forms of digital vision [15]. Traditional clothing products cannot be used as the end of the clothing development process to meet the existing commercial structure. H5, banner and commodity information display charts, product information pictures, which can be adjusted automatically according to different specifications and requirements, and even different posters generated based on the data of each user are becoming new product carriers. This is a new challenge to the traditional visual design method of clothing products.

Before the intelligence algorithm entered the clothing design industry, the

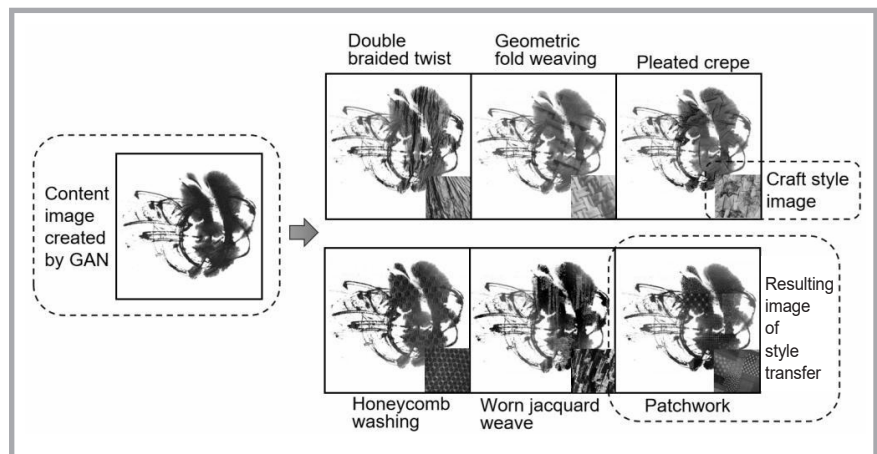


Figure 8. Style transfer effect of clothing texture crafts.



Figure 9. Effect of clothing designed by man-algorithm cooperation.

traditional fashion product vision was mostly completed manually with the help of computer vision software [16]. After receiving the clothing product image and display of semantic information, visual designers of different education background and training experience complete the clothing product vision through conception, design, communication and adjustment. Due to the low efficiency and data utilisation as well as non real-time generation, the traditional visual design methods of clothing products cannot meet the demand of the technology and the market's supply matching.

Through the introduction of intelligence algorithm thinking, we propose to build an intelligent visual generation model of clothing products, shown in **Figure 10**. The model translates the visual requirements from multiple interaction modes into computer structured language information. After information of theme style, layout and color matching, element type and quantization space is translated into codes, we can generate unlimited visual images with relatively

limited information codes. Based on the structured information code, the planner plans a 16*16 pixel visual sketch through a multi-channel sequence learning algorithm. It effectively transforms the design process into a recursive and cyclic process. The participant uses the reinforcement learning of the multi-agent system to refine and adjust the sketch. In order to ensure the controllability of the results, we use a trick to realise the combination optimisation action, which is always in the limited range set in advance. Constructors have many kinds of construction methods, such as copying, migration, creation, etc. According to the existing visual elements and visual reference state, the constructor builds the thinning adjustment image, and outputs it with the help of confrontation learning and the rendering algorithm. The evaluator uses the depth cascade regression evaluation network to quantitatively evaluate the aesthetics and effect of the input visual mapping. Finally, the evaluator completes the closed loop of the model in the form of a data log, and driver the upgrade of the algorithm online.

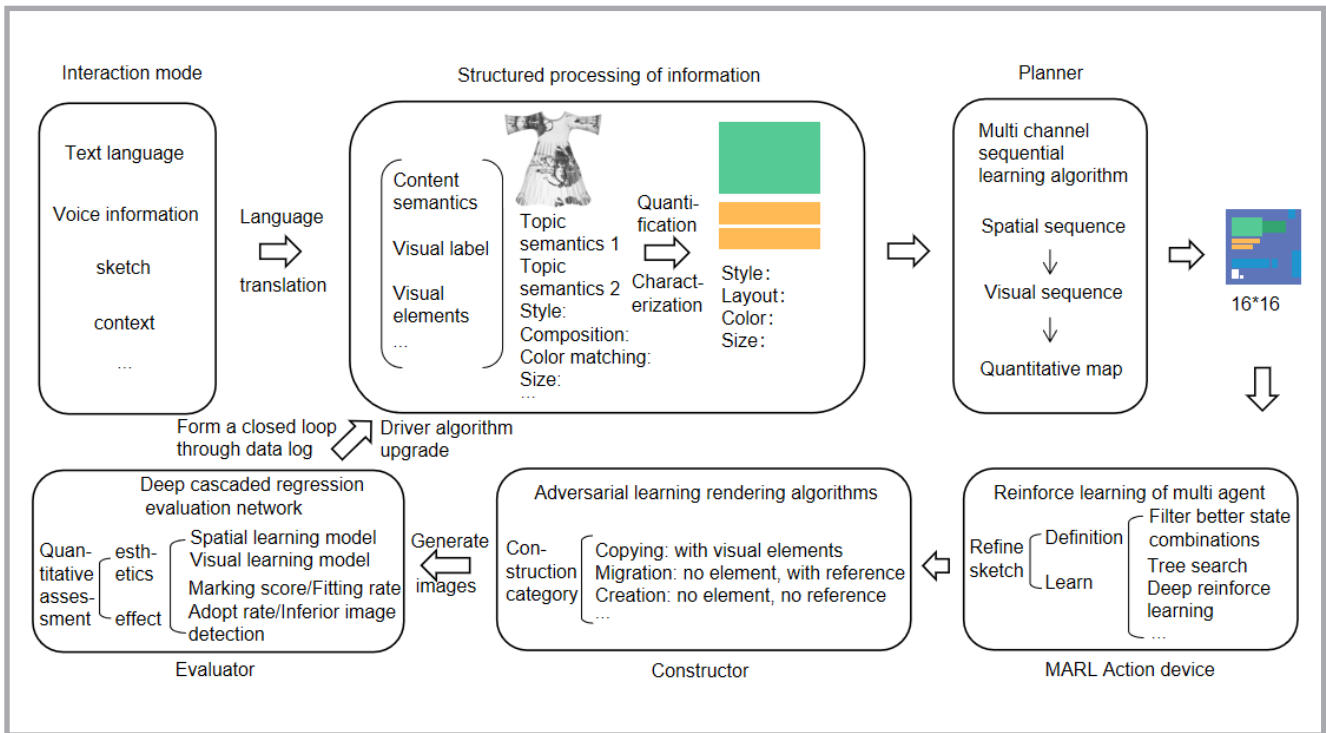


Figure 10. Structure of clothing vision generation model based on the intelligent algorithm.

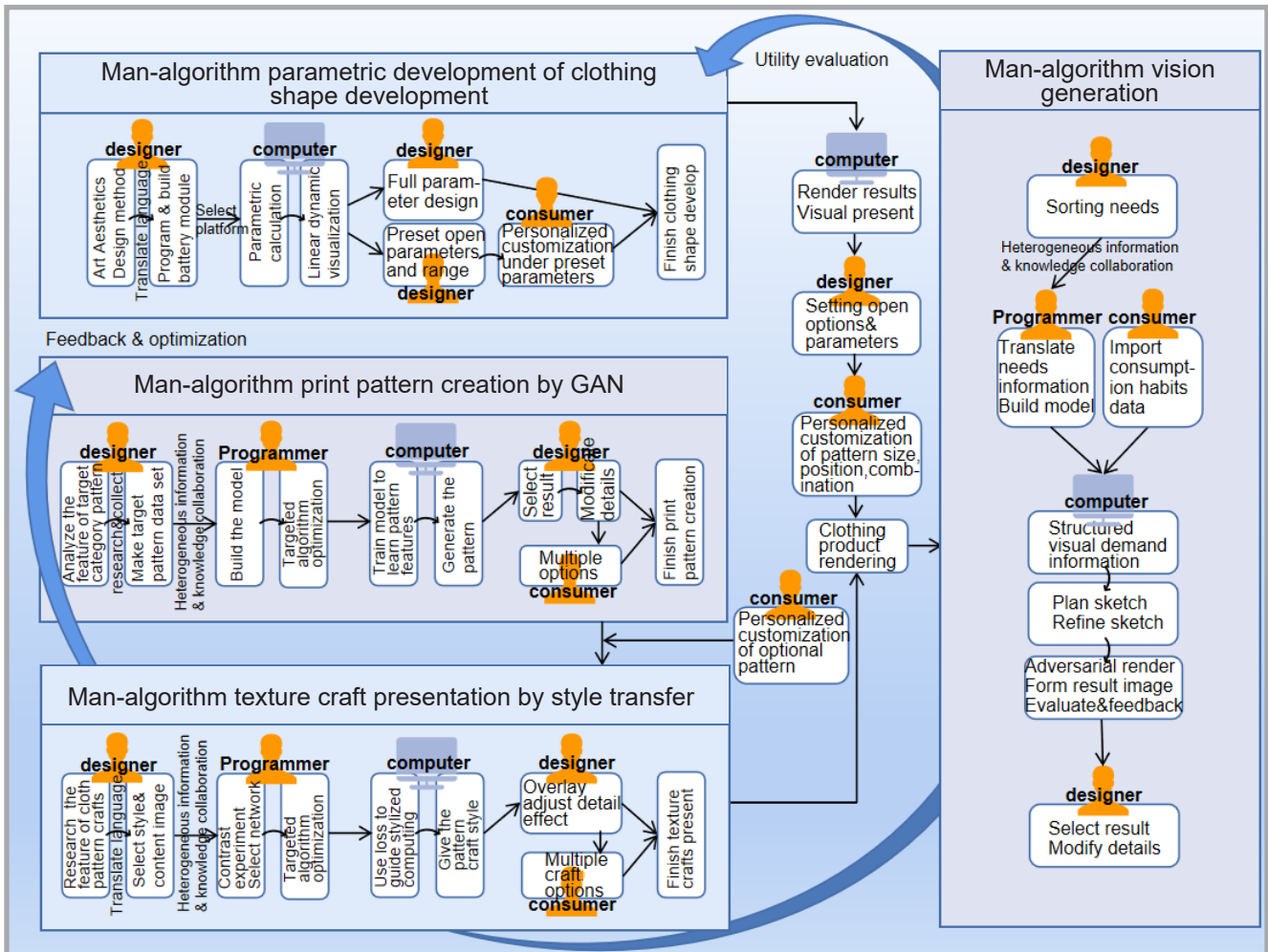


Figure 11. Man-algorithm cooperative clothing design mode.

Intelligent mode of man-algorithm cooperation in clothing design

The modular design mode is closer to the logic of the actual product development process, and it is also conducive to simplify the operation of program design, debugging and maintenance [17]. We simulate the process of clothing design, connect the four man-algorithm cooperative modules of the parametric clothing modeling design, GAN clothing pattern design, style transfer texture craft simulation and composite algorithm product visual design in sequence. Then we optimise and improve each module through the feedback of product utility evaluation to form an ecological closed-loop man-algorithm cooperative clothing design mode, as shown in *Figure 11*. Each scheme is composed of multiple types of collaboration, such as internal collaboration between different human functional roles, internal collaboration between different machine algorithm platforms, external collaboration between the single human functional role and the machine, external collaboration between internal collaboration results, and external collaboration between composite human functional roles and machines, which corresponds to different time consumption, labour cost, machine computing power requirements and the design result. The specific cooperative method, place and result state (activation pending or determined import) required by different cooperative combination paths will lead to cumulative result change. Therefore, reasonable and effective man-algorithm cooperation mode planning and real-time results visible debugging are of great significance [18].

In the clothing shape parametric development module, the designer translates the clothing aesthetic design language into logic function language, and builds the node controller group with the help of the parametric platform. The intelligent algorithm uses the platform to carry out the parametric logic calculation and corresponding dynamic geometric modelling presentation. In the other way of consumer participation, consumers can customise the clothing modelling by means of the limited parameters, and the scope is preset by designers. The real-time visualisation of the parameterised digital state is the core support of consumer personalised application. In the print pattern generation module, designers make and

arrange data sets by analysing and investigating the specified category of print patterns. Through cross domain experience collaboration, designers send information such as the artistic performance characteristics of the specified category pattern and the sample status of the dataset to the algorithm engineer. According to the above characteristics and state information, the algorithm engineer constructs the algorithm model and processes the details. After the completion of the algorithm model, the computer begins to conduct unsupervised counter learning and imitation creation for the dataset samples. The pattern created by the computer is directly determined as the print pattern after the designer's selection and adjustment, or it is determined as the print pattern after forming multiple schemes for consumers to choose. Before the print pattern is inputted into the clothing texture process stylisation module, the mode provides the input port option for consumers to customise the pattern. This step may occur before the machine creation module because consumers have specific print pattern requirements, or it may occur after consumers are not satisfied with many schemes of machine creation. The powerful computing power of the computer in image processing and real-time rendering is the core support of this customisation option. In the texture craft style transfer module, the designer collects a data set of the specified texture craft style through analysis and research. After the designer and the algorithm engineer complete the cross domain experience collaboration, the algorithm engineer establishes the network model and processes the details. Under the guidance of the loss function, the computer generates the process style pattern by gradient descent. Finally, through adjustment by the designer is performed directly or a number of programs for consumers to choose are formed to complete the style pattern design. The designer renders the clothing model and the print pattern of texture craft style to obtain a clothing effect picture, which is inputted into the visual design module as the main material of the clothing product vision. The designer organises the multi-dimensional visual requirements put forward by the product side into design requirements. The operator translates the design requirements into the programming language, builds an algorithm model, and then imports the consumption habit data of the target consumer group or individual. After completing the process of re-

quirement information structural calculation, sketch planning and sketch refinement, the computer constructs a visual result graph using confrontation rendering. The designer completes the design after screening and adjusting the details of the output visual scheme, and optimises the whole model by closed-loop feedback through utility evaluation, as shown in *Figure 11*.

Conclusions

The enabling and reform of technology to design has been happening continuously and never stopped. Although clothing design is a lagged field affected by the intelligence algorithm, because of its special creation and emotional attributes, the participation of an intelligence algorithm in design as an inevitable trend of the times has attracted more and more scholars. At present, the theoretical research and application practice of the intelligence algorithm mainly focus on the input side, such as recognition, understanding, research and so on, while on the output side, such as generation, creation, fusion and so on, there is less attention. When the intelligence algorithm is involved in the design process in a creative role like that of a human being, how to better coordinate the division of work and cooperation between different human roles and machines, so that machines can give full play to the advantages of computing power instead of human beings to deal with repetitive and timely tasks, so as to solve the supply side matching problem of design demand under the new commercial structure, is a very valuable topic.

We try to introduce an intelligence algorithm to assist designers in the multi clothing design links like the clothing shape, print pattern, texture technology and clothing product vision. It is worth noting that, different from the previous single software passive aided design scenario, in the intelligence algorithm aided design scenario built in this paper, the machine algorithm has a higher ability of active creation and judgment. In this complex work system with heterogeneous knowledge and languages, designers are no longer the only human role, algorithm engineers and even consumers are also involved. In view of this, we propose a man-algorithm cooperation clothing development cycle design mode, and carry out design practice through this mode path.

According to the results of several individual experiments and overall design practice, the innovation value of this study is mainly reflected in the following aspects: 1. Compared with the previous clothing design methods, this one greatly improves the design efficiency and modifiability of the design results, and weakens the dependence on the designer's personal ability. To a certain extent, it also reduces the unnecessary waste of resources in the process of clothing design, and improves the sustainability thereof. 2. because of the introduction of an intelligent algorithm, this research method reduces the degree of human participation in all aspects of clothing design, and is expected to realise the scale economy of clothing design through the unlimited computing power of the machine; 3. modular design and real-time visual presentation endow each link of clothing design with high modifiability, which also makes series design more convenient; 4. this method is conducive to promoting the "F2F" of clothing design, that is, the seamless connection of digital records from the initial design idea to product production and visual completion; 5. from the perspective of technology and pattern structure, this research method encourages more identities than garment practitioners, such as consumers, to participate in the process of clothing design without burden; 6. This method provides support for more innovative styles and production processes of clothing design from the technical side.



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