Application of Computer Aided Modeling Design in the Expression Techniques of Sculpture Art Space

Shengneng Guo[1] and Bei Wang[2]

[1] School of Art and Design, Anhui University of Technology, Maanshan 243032, China,
guoshengneng@126.com
[2] School of Plastic Arts, Hebei Academy of Fine Arts, Shijiazhuang 050700, China,
lingduzhijia@163.com

Corresponding author: Shengneng Guo, guoshengneng@126.com

Abstract. With the rapid development of computer graphics and image technology and three-dimensional modeling, great progress has also been made in the field of three-dimensional digital sculpture art. Digital sculpture art is generated through computer-aided modeling, which overcomes the shortcomings of traditional manual sculpture art, which is low in production efficiency and difficult to modify the product, and is easy to save. This article is dedicated to the study of non-contact depth-of-field-based three-dimensional measurement methods to recover the three-dimensional shape from the focused image (depth from focus), which is characterized by using an ordinary microscope to shoot a series of images with different focus depths to calculate the three-dimensional object. Without increasing the hardware cost, the shape can obtain the approximate three-dimensional shape through the analysis and processing of the digital image, which has the advantages of simple hardware, non-contact and measurable sub-microscopic objects. According to the actual measurement requirements, the hardware frame part was designed, a complete prototype was assembled, and the software system for stepping motor control and image data acquisition was compiled. On the basis of comparing the current main computer-aided modeling methods, starting from the analysis of traditional hand-sculpted modeling methods, in view of the actual characteristics of conceptual design and artistic modeling design, a sculpture method modeling idea based on Polygon modeling is proposed, and specific details are given. The modeling steps and the evaluation method of reasonable wiring are verified by examples through the modeling realization process of folk crafts. Practical application has proved that the computer sculpture modeling method has strong practicability for the 3D software modeling concept of artistic design, can fully follow the designer's conception and design, and is easier to be understood and understood by the modeling designer for creative design.

1   INTRODUCTION

The wide application of various computer design software in today's landscape sculpture design has brought us brand-new creative methods and art forms. Therefore, studying landscape sculpture is helpful to guide people's understanding of urban culture [1]. The computer-based landscape sculpture inherits the original rules of landscape sculpture creation, and at the same time breaks through the limitations of traditional landscape sculpture. For the design of landscape sculpture sketches, due to the participation of computers, its original difficulty in copying becomes ease of reproduction, the original static sculpture becomes a dynamic sculpture, the original silent sculpture becomes an acousto-optic sculpture, etc. [2]. With the rapid development of computer vision and 3D modeling, digital sculpture has become a research hotspot due to its editability, time-saving, labor-saving and material-saving advantages. Especially in recent years, with the increasing maturity of 3D printing technology, people's demand for personalized customization of sculpture products has increased sharply. Therefore, it is of great practical significance to study a fast 3D digital sculpture generation method [3]. These low-cost, high-efficiency, convenient and quick operation modes have opened up a new path for the development of landscape sculpture.

This article mainly discusses the current status of 3D shape measurement based on depth of field, the existing problems, the improvement of algorithms, the realization of simulation, and the design and realization of software and hardware measurement systems. The software of the electric control, image acquisition and simulation system are designed using the c++ builder programming tool, and the software of the three-dimensional shape measurement is realized using matlab. In the three-dimensional subspace, the creation of the boundary Julia set based on the time escape algorithm is realized through the establishment of grid lattice and boundary search, which reduces the complexity of computer simulation. The research on the quaternion Julia set includes analyzing and summarizing the structural characteristics of the Julia set, pointing out that the use of structural symmetry can speed up the rendering of the Julia set, designing and implementing an image depth simulation system, and verifying the optics through comparison with actual images and the correctness of the model. The simulation system improves the efficiency of problem analysis and problem solving. This paper studies a method of 3D digital concave sculpture art generation based on image feature enhancement. This method first extracts the characteristic lines of the image through threshold detection, and then uses unsharp mask technology (USM) and local information enhancement technology to enhance the image to obtain a smooth and clear sculptural artistic effect image

2   RELATED STUDIES

The generation of sculpture art based on 3D model is a key technology in the field of digital sculpture art. In the early days, Wen [4] generated a height field based on the geometric properties of sculpture art craftsmanship and its relationship with classical computer graphics perspective transformation, and then realized the generation of sculpture art through a linear compression method with a compression rate inversely proportional to the height and developed a digital sculpture art modeling system for the first time. This method has a good effect on the generation of high sculpture art. However, for shallow sculpture art, three-dimensional geometric linear compression will produce ambiguity, and when the geometric structure is complex, this realization often loses details. In recent years, in response to the problem that detailed information is not easy to retain, domestic and foreign researchers have proposed many sculpture art generation techniques based on 3D models. The main idea is to use existing 3D models to achieve sculpture art through various compression techniques and detail enhancement techniques. According to the different compression technology and detail enhancement technology used, the

artistic effect of the sculpture produced is also different. Zhu and Zhang [5] use linear compression in the high-degree domain or gradient domain, and maintain detailed information through information enhancement methods. In view of the shortcomings of linear compression, many researchers have proposed nonlinear compression functions, such as logarithmic function, tangent function, and nonlinear compression function with threshold, and combined with various information enhancement methods to achieve good preservation of the surface details of sculpture art. In addition, Fisher et al. [6] use an adaptive compression function for compression, while Furuta et al. [7] use a piecewise function for compression, using a piecewise tangent function, and Du and Yu [8] use linear compression for low frequencies. For high frequency, it uses nonlinear compression. Although these methods maintain detailed information to a certain extent, most of the methods need to solve the Poisson equation, which requires a large amount of calculation and requires the use of GPU acceleration technology to improve the efficiency of sculpture art generation.

In recent years, many researchers have begun to study the generation of concave sculptures based on the characteristics of concave sculptures. Lin [9] proposed a concave sculpture art generation algorithm based on a three-dimensional model. The valley points that need to be carved, the contour based on the current line of sight and the model boundary are used as feature points, and the expansion and erosion techniques in image processing are used to perform the feature points. The optimization of the collection, and finally the overall sculpture art and the characteristic area are given different heights to compress to obtain the concave sculpture art effect. Li et al. [10] extract the characteristic lines from the 3D model to obtain the 2D characteristic line drawing. By smoothing the 3D model and directly applying image processing methods to the characteristic line drawing, the detailed information is preserved and enhanced. The processed lines are engraved into a background plane gets concave sculpture art. On this basis, some researchers have transformed the three-dimensional model into a three-layer input, using geometric information and visual cues to assist the generation of sculpture art, and optimize the effect of sculpture art by minimizing the weighted energy function to make the generated concave sculpture art more natural, it can well reflect the shape change between the lines, but the optimization process of this method is computationally expensive [11]. Some scholars mainly cut, link and smooth the extracted characteristic lines, convert the messy lines into smooth lines, and smoothly transition of the height field based on Lambertian shadows, and use continuous pitting to generate the engraving path. At the same time, there are also studies that divide the sculpture generation into two levels for processing separately, both of which are processed separately for the low-frequency and high-frequency components of the rubbing image, and finally the two parts are superimposed to restore the three-dimensional sculpture of the portrait, while using the three-dimensional depth of the computer

3 CONSTRUCTION OF SCULPTURE ART SPACE MODEL BASED ON COMPUTER AIDED MODELING DESIGN

3.1 Computer-Aided Spatial Hierarchy

Computer-aided technology is a technology that uses the unique computing functions of computers and high-efficiency graphics processing capabilities to assist knowledge workers in engineering and product design and analysis to achieve ideal goals or achieve innovative results. In this article, the characteristic lines are based on the original two-dimensional image. Similar to other edge detection algorithms, thresholds are needed to adjust the quality of characteristic lines. Firstly, by adjusting the Z-axis position of the microscope, obtain the sequence images of the microscopic sample, so that the entire sequence covers all the z-axis direction information of the object in the microscope, and each image has a clear and blurred area; then the depth information is restored through focus analysis. The depth from focus method combined with the Z-axis automatic control microscope hardware platform can achieve the effect that the optical hardware cannot achieve.

Therefore, this paper uses threshold detection to extract characteristic lines from the original image. The general idea is to compare the pixel values of the current detection point with its neighboring 8 neighboring points. As shown in Figure 1, the center point is the current detection point, and the point pointed by the arrow is its 8-neighborhood point.
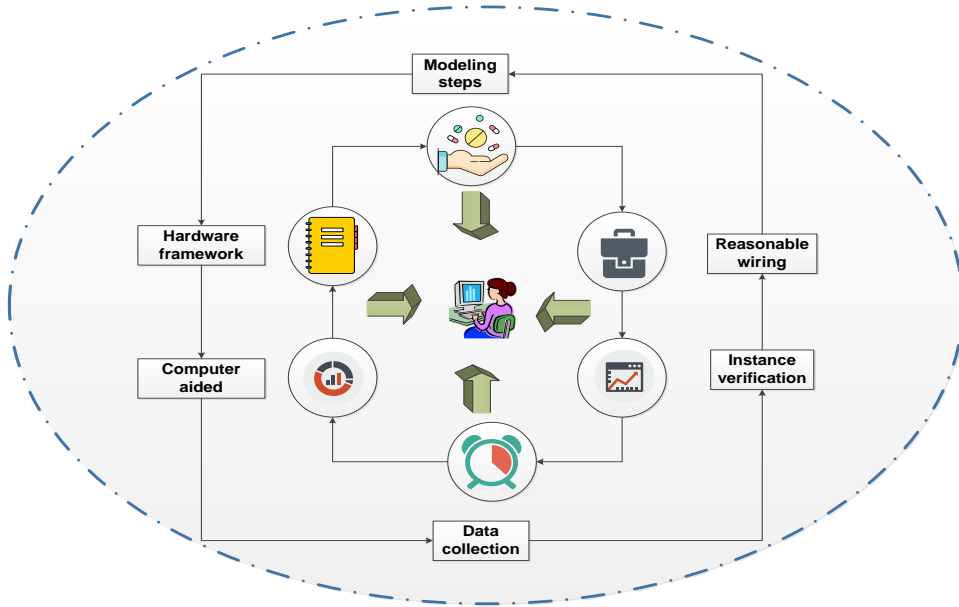

Figure 1: Computer-aided spatial hierarchical distribution.

Since the height obtained by the maximum method is discrete, the resolution is limited by the number of image layers received, and the resolution is very low when the number of images is small. For this reason, someone proposed a Gaussian interpolation fitting method to improve the measurement resolution. The focus evaluation value of each point is taken as the Gaussian function of the number of layers, so that the vertex value of the Gaussian function can be fitted, and the height information of the layer is combined with the number of sub-layers corresponding to the vertices to obtain the height at that point, which improved high resolution.

$$1/r + 1/t = 1/f \tag{1}$$

The specific steps of the threshold detection algorithm for feature line extraction are as follows: first, the input RGB image is converted into a gray-scale image I(i, j) through the weighted sum method, where i represents the row of the image matrix and j represents the column of the image matrix. At this time, the pixel value range in the image matrix is [0, 255]. In order to easily determine the difference range between pixel values and detect the target point, this paper introduces a linear transformation S, as shown in equation (2-3), the pixel value is transformed to the range by multiplying the constant m by the sin function [0, m] between.

$$u(x) = x(r,t) \cdot f(r,t) \tag{2}$$

$$v(x) = x(r',t') \cdot f(r',t') \tag{3}$$

Then, set the threshold to t. We scan the image row by row and column by row, compare the pixel value of the current detection point with the pixel value of its 8 neighborhoods, if the absolute value of the difference is greater than t, then set the current detection point as black (pixel value 0)

---

as a feature of the point on the line. Otherwise, the detection point is not a point on the characteristic line and is set to white (the pixel value is 255).

$$g(i, j) = \frac{f(i, j) \cdot u}{2\pi t} \tag{4}$$

$$h(x) = \frac{g_1(i, j)}{g_2(i, j)} = e^{-\pi u(t_2 - t_1)} \tag{5}$$

The curvature of the curve refers to the rotation rate of the tangent direction angle of a certain point on the curve to the arc length. The curvature of the curve corresponds to the degree of curvature. The greater the curvature is, the greater the degree of curvature of the curve is. Generally, a curve with a large degree of curvature gives people a sharper and sharper visual effect. From the characteristic lines obtained from it, it is not difficult to see that the lines at the facial features of the sculpture art space model tend to be more curved, that is, have a greater curvature.

3.2 Modeling Design Gradient Algorithm

In order to meet the needs of modeling design based on dynamic sculptures, the application of affine transformation in IFS is studied, that is, how to construct a new iterative function system from a given attractor and target change, so as to realize the simulation of deformation modeling and the change process of modeling motion. Therefore, this method can be used in the design of composite scenes and "moving" shapes. Let P be the point on the characteristic line of the sculpture art space model. Figure 2 is an example of the model gradient algorithm flow. It can be clearly seen that the greater the degree of curvature of the line, the greater the width, and vice versa. In the process of constructing three-dimensional modeling, firstly, according to the collage modeling method, design multiple 3D-IFS, and realize the full understanding of the characteristics of this type of fractal shape through multi-angle views. Taking the plane fern leaf as an example, according to the attractor's continuous dependence on the parameters, small changes in parameters only lead to the characteristics of small changes in the geometric shape of the attractor, combined with different natural environment designs to generate a more realistic three-dimensional fractal model.
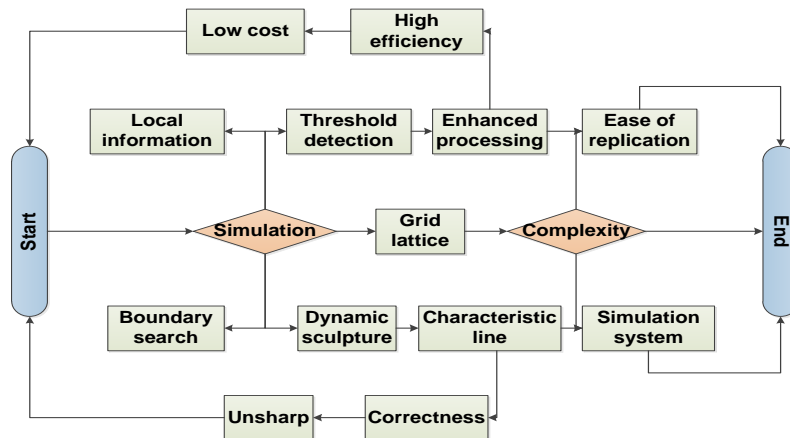

Figure 2: Modeling design gradient algorithm flow.

The threshold value plays a vital role in the quality of the characteristic line drawing. When t is small, the extracted characteristic lines contain more detailed information. As t keeps increasing, the detailed information contained in the characteristic line graph keeps decreasing, and the

breakpoints are in the line increase, but at the same time, the line becomes thinner and the noise decreases. Therefore, a proper threshold can make the feature line map retain more details and fewer breakpoints as much as possible. Through a large number of experiments, it is found that when the threshold range is between 0.25 and 3.0, the effect of the characteristic line map obtained is relatively good.

$$w = \sum (t - t^2) * c(i, j) \tag{7}$$

Generally speaking, focused images have more obvious gray changes than unfocused images, so gray changes can be used as a basis for evaluating the degree of focus. A sharply focused image should have more gray changes. When the defocus is not clear, the gray scale change will be less, so the focus degree of the image can be measured by the average degree of gray scale change (that is, the gray scale variance).

$$m = \sqrt{(w / (2 * pi^2 * (\exp(t) - 1)))} \tag{8}$$

$$n = \sqrt{(w' / (2 * pi^2 * (1 - \exp(t'))))} \tag{9}$$

We take the picture as an example to show the feature line graphs under three different thresholds. When the threshold is set to 0.25, the feature line graph contains a lot of detailed information and also contains a lot of noise points; when the threshold is set to 3.0, although the feature of the noise points in the line graph are greatly reduced, but at the same time a lot of detailed information is lost; when the threshold is set to 1.1, the characteristic line graph obtained is relatively good, which contains relatively more detailed information and avoids a lot of noise point.

3.3 Optimization of Spatial Model Parameters

According to the characteristics of plant morphology that the branch position is determined by the bifurcation angle and the azimuth angle, this paper proposes an improved three-dimensional L system modeling method and computer algorithm. When determining the branch and bifurcation, that is, the orientation rule, the azimuth vector and the growth vector determines the branching direction. In the graphics algorithm, for the change of specific eigenvectors, for a given rotation axis and rotation angle, the Euler quaternion is used to describe and establish a rotation transformation matrix to achieve arbitrary rotation between the two types of vectors.

The triangular mesh model is generated by the combination of region division and direct triangulation of space. On this basis, a continuous composite triangular interpolation surface model of the overall first-order geometry (G1) is constructed, and the STL solid model is obtained by the degenerate approximation method. It is imported into the rapid prototyping system as a data interface file, and the fractal object is processed by the light-curing three-dimensional modeling method. Generally, when performing coloring operations on an object, it is necessary to perform backside culling and hidden surface removal processing. It is generally used to perform this operation through the Z-buffeting technology. After eliminating the hidden surface through Z-buffeting technology, the hidden part on the back of the object will not be displayed. Z-Buffer is used to identify the vertical depth value of each pixel in the 3D environment, which is the coordinate data of the Z axis. In summary, the Z-Buffer value plays an important role in model drawing and other links. Therefore, in order to improve the smoothness of the concave sculpture art base grid on the basis of maintaining the high level of the sculpture art space model, and make it maintain the excessive coherence and aesthetics of each part, in this article, the sculpture art space concave sculpture art base grid is used. The depth value is proportional to the Z-Buffer value of the read sculpture art space 3D model. The sculpture art space model is appropriately compressed to obtain the concave sculpture art base grid.
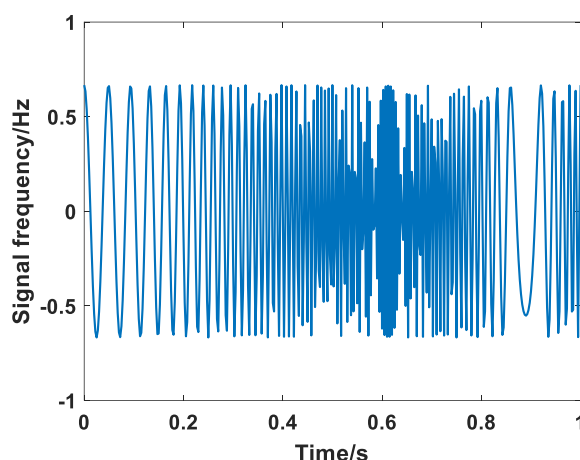
Figure 3: Computer-aided image denoising spectrum.

Since the smoothed image is the low frequency part of the original image, in order to get the high frequency part, the low frequency image needs to be subtracted from the original image. Then the high frequency part is multiplied by a constant factor, and then superimposed with the original image to get the sharpened image. Figure 3 shows the response curve of image signal frequency versus time. After using the USM algorithm to sharpen the enhanced image, the image boundary becomes sharper and more prominent, but the image quality obtained at this time is still inferior, so we use local information enhancement processing to get better results. Since the pixel value of the point on the characteristic line is 0, in this process, the point set with the pixel value of 0 is used as the domain to process the original image and scan the original image line by line. If there is a certain difference between the current detection point and its neighboring points, we modify the points on the characteristic lines.

4 APPLICATION AND ANALYSIS OF SCULPTURE ART SPACE MODEL BASED ON COMPUTER-AIDED MODELING DESIGN

4.1 Computer-Aided Modeling Design Simulation

Image sharpening is an image enhancement algorithm that uses various mathematical methods and transformations to improve the contrast and sharpness of the image, thereby highlighting the objects in the image. The operator and the area are both too small to use 3x3, and the result is obtained. We can see that the results of the Laplacian of the addition and correction are better than those of other operators, and the error results also show that in these calculations, the result of the Laplacian of the addition and correction has the smallest error. First, the image is binarized to distinguish the foreground and background, and then the distance transformation is used to realize the height change of the sculpture art surface, and then the height is compressed to a certain range through gray-scale mapping, so that it is more in line with the height characteristics of realistic concave sculpture art.

Experiments have obtained a concave sculpture art model with a good sense of reality. On this basis, the generation of hollow sculpture art is realized by deleting the background plane. In this step, the neighborhood average method is used, which recalculates the pixel value of the current detection point as the weighted average of the point and its neighborhood points. Computer-aided control of the height difference between the sculpture art space and the sculpture plane. When it increases, the error rate of the sculpture art space will increase and will gradually rise above the carving plane.
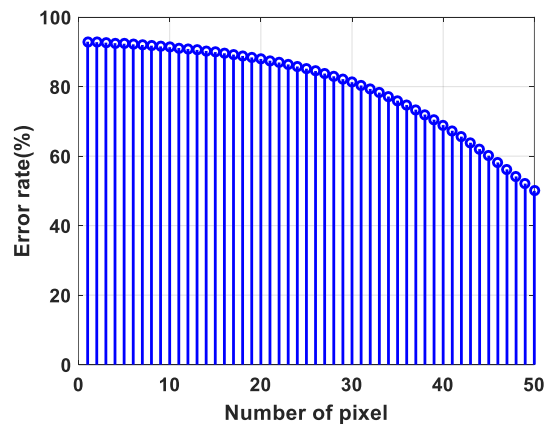
Figure 4: Statistical distribution of image pixel error rate under the model.

The sculpture art space with added illumination information generated by the method of this paper has enhanced the facial features and contour information. The engraved lines depicting the sculpture art space have different carving widths and depths, making the sculpture art space concave sculpture art more powerful. Figure 4 shows the distribution of the error rate matchsticks of different pixels in the image. The sense of hierarchy and three-dimensionality better highlight the overall shape of the object, portray the five senses of the object, and have a better visual effect. The sculpture art space concave sculpture art generated by the algorithm of this paper can clearly express the features of the five sense organs and expression forms. The depth value of the point on the line in the depth map corresponds to the gray value. When the depth is 0, the gray value is 0. The greater the depth value is, the greater the gray value is. The maximum depth value corresponds to the gray value 255. It can be seen that the greater the width of the characteristic line, the greater the change in the depth value. When the pixel points change, the points on the carving line have a relatively large angle between the normal directions, so the width of the model feature line and the depth of the sculpture have obvious changes. When the number of pixels increases, the error rate will decrease accordingly.

4.2 Sculpture Image Collection and Filtering

In this algorithm, the generation of the concave sculpture art base grid and the concave sculpture art depth image is to process each pixel in turn, so the time complexity of the algorithm is O(n). On the basis of completing the basic structure analysis of the modeling object, first establish a general model framework. In this paper, through 30 experiments, the time to generate the line depth image and the final sculpture art space concave sculpture art is calculated and averaged. The average time of the algorithm in this paper to generate the line depth image is 0.22s, and the average total of the sculpture art space concave sculpture art is generated. The algorithm is carried out in the object space. Using the light transmission algorithm to detect the visibility of lines will consume a lot of time and is related to the number of triangle meshes in the model. When the number of triangles exceeds 150,000, concave sculpture art will be generated. The time will reach more than 9s. Compared with the algorithm, the algorithm in this paper saves a lot of time.

In this paper, the difference operation is used to obtain the visual concave sculpture art effect, and a linear spatial filter function is used to realize the difference operation. The principle is convolution. Figure 5 shows the test scoring ladder diagram of different sample points under the computer-aided model. However, for most images, the part with a low model test score is usually the main part, that is, the image is built on low-frequency components.
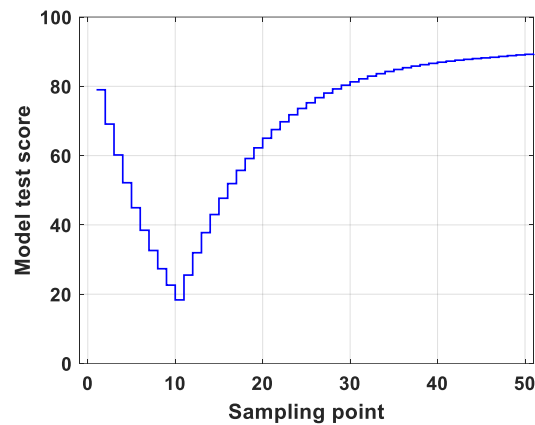
Figure 5: The dependence curve of the model test score with the number of sample points.

Therefore, after the difference operation, the pixel value of the image is usually very small, or even 0, which results in the entire image being close to black. For the nearby areas with high model test scores, due to the lack of image detail information, they are affected by high-frequency diffusion pollution, which makes the information overwhelmed and leads to height calculation errors; the high-frequency area of the model test score itself suffers relatively little interference in the height calculation. The calculation accuracy is high. Therefore, a method for obtaining key points is proposed to judge the high-frequency areas of the model test score, and take the high-frequency areas as the key points. On the layer with the maximum value of the model test score in the high-frequency region, the model test score has the smallest high-frequency diffusion, and the nearby low-frequency region of the model test score is located in the layer where the key points are determined. We use keypoint data to perform fitting interpolation to reduce measurement errors in the low-frequency region of the model test score.

In order to get a better visual effect, a through component is added on this basis, that is, a pixel constant is added to ensure that the image is at a gray level with a better visual effect. Figure 6 shows the color distribution of the two-dimensional matrix after the algorithm has extracted the feature points of the image. First, in the design process, it can be assumed that the nuclei of the image samples are points, which are evenly arranged and distributed in the space. Then, because the size of each unit is different, it can be considered that the distance between the sample feature points is different, so the points in the space are adjusted to a random distribution.
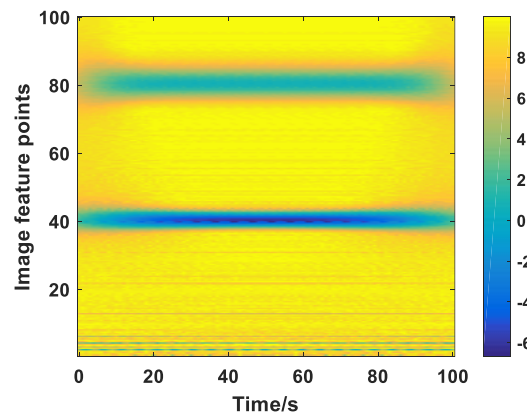

Figure 6: Two-dimensional distribution of feature points extracted from sculpture images.

4.3   Example Application and Analysis

In order to better compare the results of the algorithm in this paper, the algorithm in this paper does not consider the light and the sculpture art space generated by the light in this algorithm. The concave sculpture art is selected as 100 students who have not been in contact with this experiment. The test results are statistically checked, and the average value is taken after removing the first and second 5% of the score. It can be seen that the scores of concave sculpture art generated by the algorithm in this paper are generally higher than those of the concave sculpture art generated by the algorithm, which has a greater advantage compared with the algorithm. At the same time, compared with the concave sculpture art of the sculpture art space without adding light information, the concave sculpture art generated under the influence of adding light to the concave sculpture art line in the method in this paper has more visual aesthetics, and the score is generally higher.
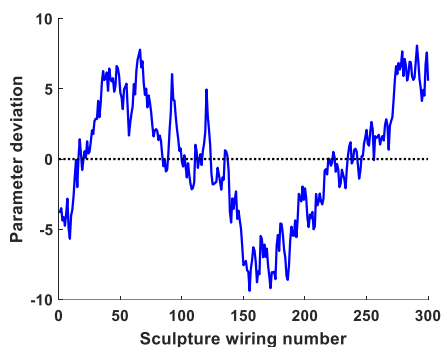

Figure 7: Deviation curve of wiring point of sculpture image.

In the two-dimensional matrix of parameter statistics, the X axis represents the edge (IE) of the model wiring point, and its unit distance [0,1] is divided into four ratios: 0, 1 / 3, 2/3 and 1.0. As the wiring value increases, the parameter deviation in the model also increases. The Y-axis represents the detailed information (ID) of the model. Accordingly, [0,1] is divided into four scales: 0, 1 / 3, 2 / 3, and 1.0. In RGB mode, each RGB component can use values between 0 (black) and 255 (white). For example, bright red uses an R value of 246, an O value of 20, and a B value of 50. When all three component values are equal, a shade of gray is produced. When the value of all components is 255, the result is pure white; otherwise, the result is pure white. When the value is 0, the result is pure black. Figure 7 shows the statistical distribution curve of different sculpture feature points. It can be seen that in the parameter deviation evaluation matrix, it is divided into units of equal wiring size, which are used to represent several different situations that may occur during the modeling process to control the number of wiring points that constitute the details of the points. Different parameter adjustment strategies are proposed to achieve the optimization of the control number of wiring points, so as to achieve the smallest amount of model data under the premise of ensuring the accuracy of the model, and achieve the goal of the best detail control effect.

In order to realize the measurement of the three-dimensional shape, a series of focused images of different node positions must be scanned and photographed, and the probability distribution density of the three-dimensional shape must be determined according to the photographed node position parameters. Figure 8 shows the histogram of the probability distribution density of different image nodes.
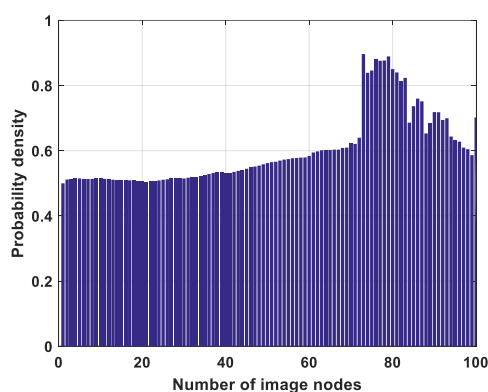
Figure 8: Histogram of the probability density distribution of image nodes.

The existence of the linear relationship of the probability distribution density, coupled with the characteristic that the sculpture stepper motor has only periodic error and no cumulative error, makes it very convenient to use the stepper motor in the field of speed and position control of the node. We use a four-phase four-beat stepper motor with a node angle of 0.90/1.80. Generally, the accuracy of a sculpture stepping motor is 3-5% of the nodal angle.

5   CONCLUSION

This paper studies the fractal-based image generation method, and enriches the diversity of concave sculpture art models by enriching the diversity of images. Fractal images have high artistic quality, and different fractal rules can generate different fractal images. Using fractal images as input images generated by concave sculpture art can enrich the diversity of concave sculpture art. This paper generates classic fractal patterns based on the iterative rules of fractals, uses Bezier curves to achieve fractal images with smooth lines, and then combines the existing artistic patterns to generate more complex and beautiful patterns, and use these as input images. This paper compares the commonly used three-dimensional shape measurement algorithms based on depth of field, analyzes their shortcomings, and proposes an algorithm based on key points for the high-frequency diffusion problem. From the experimental results, the algorithm effectively improves the measurement accuracy. This paper proposes and implements a three-dimensional shape measurement algorithm based on depth of field for color images, which is used to measure the three-dimensional shape of color images and achieve good results. The concave sculpture art lines are more in line with the cognition of sculpture art space. And the lines are more complete and smoother, which can better reflect the important feature details of the sculpture art space, and the method of this article adds illumination information, so that the width and depth of different concave sculpture art lines change when the light direction changes.

Shengneng Guo, https://orcid.org/0000-0002-3294-2890
Bei Wang, https://orcid.org/0000-0001-7214-7317

REFERENCES

[1]   Zheng, J.-M.; Chan, K.-W.; Gibson, I.: Desktop virtual reality interface for computer aided conceptual design using geometric techniques, Journal of Engineering Design, 12(4), 2020, 309-329.   https://doi.org/10.1080/09544820110085931

[2] Sun, W.; Lal, P.: Recent development on computer aided tissue engineering—a review, Computer methods and programs in biomedicine, 67(2), 2020, 85-103. https://doi.org/10.1016/S0169-2607(01)00116-X

[3] Wannarumon, S.: Reviews of computer-aided technologies for jewelry design and casting, Naresuan University Engineering Journal, 6(1), 2019, 45-56. https://doi.org/10.14456/nuej.2011.8

[4] Wen, T.-Y.: The Application of Computer Aided Design in Art Design, Journal of Hangzhou Institute of Electronic Technology, 3, 2020, 46-49. https://doi.org/10.1016/j.ijid.2020.11.191

[5] Zhu, M.-J.; Zhang, W.-K.: Art design education in the digital age, Machine Learning and Cybernetics, 4, 2020, 1768-1770. https://doi.org/10.1016/S2215-0366(21)00084-5

[6] Fisher, R.-N.; Masters, R.-J.; Preusser, R.: Computer-Aided Sculpture: Visual and Technical Considerations, Leonardo, 18(3), 2019, 133-143. https://doi.org/10.1016/j.cscm.2017.03.004

[7] Furuta, Y.; Mitani, J.; Igarashi, T.: Kinetic art design system comprising rigid body simulation, Computer-Aided Design and Applications, 7(4), 2019, 533-546. https://doi.org/10.3722/cadaps.2010.533-546

[8] Du, H.-M.; Yu, S.-H.: Study on the sculpture method modeling of folk handicraft, Computer-Aided Industrial Design and Conceptual Design, 20, 2019, 702-705. https://doi.org/10.1016/j.envsci.2020.06.024

[9] Lin, P.: The digitized technology and the design thought expression searches discusses, Computer-Aided Industrial Design and Conceptual Design, 20, 2020, 509-512. https://doi.org/10.1016/j.arabjc.2017.05.011

[10] Li, L.; Liu, F.; Peng, C.-H.: Computer-aided 3D human modeling for portrait-based product development using point-and curve-based deformation, Computer-Aided Design, 45(2), 2019, 134-143. https://doi.org/10.1016/j.cad.2012.08.007

[11] Pasko, A.; Savchenko, V.; Sourin, A.: Synthetic carving using implicit surface primitives, Computer-Aided Design, 33(5), 2020, 379-388. https://doi.org/10.1016/S0010-4485(00)00129-9