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NK-CDS: A Creative Design System for Museum Art Derivatives

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ABSTRACT At present, designing museum art derivatives attracts more and more attention. Experts in the field often use hand painting or image editing software to process images. This is time-consuming work and requires professional knowledge for design. In order to address this problem, by exploiting the advanced computer simulation and image processing techniques, we develop a novel museum art derivative design system, named NK-CDS. This system consists of element operation and element application modules. Given a cultural relic image, the user extracts the interest region in the image, then processes the appearance of the element by denoising, sharpening, etc. Finally, with the application interface, the user can flexibly map the processed elements to any location of a lifestyle model. This system is intuitive and easy to operate, which can improve the design efficiency of museum derivatives and inspire ideas for creative culture product design.

INDEX TERMS Computer simulation, element processing, element application, museum derivatives design.

I. INTRODUCTION

As a non-profit cultural institution, the development of the museum has been hit by the market economy to a certain extent. The museum has gradually changed from the traditional cultural institutions with the core function of collections to the service-oriented organizations with the core function of servicing of the masses. During the transition, the museum is constantly innovating the content of its artistic services [1]. Museum derivatives with the cultural resources have become a significant part of the artistic services provided by museums and perform the function of social education. Museum derivatives break the place-restriction of museum collections, so that visitors can take the museum home and receive cultural education in daily life, which has become an extension of the education function of the museum [2], [3]. Museum derivatives are the symbols of museum mobility. Only by strengthening the design ability of museum derivatives and making them possess cultural, educational and product characteristics can they provide better cultural services for the public.

The product of museum derivatives has developed rapidly, and the quantity and sale amount of the products is growing rapidly. However, the design of derivatives is relatively slow, and the products usually suffer from lack of creativity, highly homogenous, and feeble sense of time. Even some museums have no creative derivatives, only fill in the blank with the replicas of cultural relics and tourist souvenirs, which cannot meet the needs of the artistic communication of the museum and the consumer's aesthetic needs. There has been much work on the methods of museum derivative product design [4]–[6]. However, most of these methods ignore the problem in software operation and design difficulty.

Museum derivative designers usually use existing image processing tools, such as Photoshop and KeyShot. These tools are difficult to use for non-professionals. Therefore, it is of practical significance to develop an intuitive and simple museum derivatives design system based on computer simulation. With the development of computers, the application of computer technology in museums has become a trend [7]–[9]. Users can process cultural relic images through image processing techniques [10], [11] to extract the elements they need. Here, elements refer to some typical cultural elements in cultural relic images, such as the rabbit in the Cui Bai's double happiness picture. Therefore, we develop a creative design system for museum art derivative named as NK-CDS that is convenient for non-professionals. In this system, we optimize the edge extraction algorithm to highlight the cultural texture features and select the suitable mapping method. As an easy-to-use integrated design tool,

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NK-CDS can help non-professionals complete their design ideas, as well as provide inspiration to professionals in the manuscript design.

II. RELATED WORK

Design is the core of museum art derivatives. For non-professionals, the design of museum derivatives is complex. To provide better cultural services for the public, we need to simplify the design process of museum derivatives so that they have cultural characteristics, education features and product features [12]–[14]. Hsu *et al.* [5] built a design process for cultural creative product, including analysis, design and application. Attribute analysis and design of cultural products are main components of this framework. Lin *et al.* [6] suggested that cross-cultural design would be the key point of design evaluation. Their work focused on the analysis of cultural connotation, operational interface and the application scenarios. Chen [4] proposed a new method on cultural creative design by interpreting the lyrics of Chinese poems. Some systems make full use of a large amount of heritage information and apply it to cultural design and image processing [15], [16]. However, people rarely think about cultural product design in terms of the software and operation, so we consider the whole design process by combining software usage situation and popular design framework, mainly involves the following three aspects:

(1) Element extraction: Element extraction is the selection of typical cultural elements in the cultural relic image. In the actual design process of museum derivatives, the features of museum cultural are not sufficiently dug and lack representative cultural elements [13]. To some extent, this results in homogeneity of museum derivatives. In the design process of museum derivatives, the extraction of the image elements of the cultural relic image is very important. Designers generally paint element images by hand. This is a very time-consuming work, which is also difficult for people who do not have a basis of painting. However, this can be solved by computer simulation. By adopting the geometric element extraction method [17], the designer can directly extract the element of the image they want. Previously, geometric elements were extracted by sketching the edges of objects. The researchers proposed a gradient method based on pixel gray values [18], such as the Roberts operator, Sobel operator, Prewitt operator, LOG operator, and Canny operator [19]. The gradient method can be used to extract relatively accurate object edges. The appearance of the gradient method makes a great contribution to the extraction of geometric element edges, but the gradient method does not consider the noise caused by the sensor. With the development of computer processing capabilities, the method of graph cut [20] is used for geometric element extraction. The graph cut method marks the background information of the global pattern and calculates the global minimum energy segmentation to obtain the front background separation result. The graph cut method has achieved good results but suffers from large computational overhead. In order to optimize the computational efficiency of the graph cut method, researchers improved it, such as graph-based image segmentation [21], and hypergraph segmentation [22]. These methods are based on the local color information of the pixel to get the local minimum energy segmentation. Since only the differences among the local pixels are considered, the processing speed of this kind of method is faster.

(2) Element process: Element process is at the core of design process. During the process, designers use modern expression methods to design traditional cultural elements, retaining its traditional features and modern sense. Designers usually draw by hand or utilize Photoshop, Adobe Illustrator, etc. to design two-dimensional graphics product. It is difficult for non-professionals to operate these tools. Cultural relics pattern has some unique characteristics, therefore we need to further process the elemental images after extracting the cultural relics elements. The element extraction divides the image into many small pieces and the element process needs to improve the image block merging method so as to make the extracted elements more accurate. Duarte *et al.* [23] modified the traditional region adjacency graph into graph that are not related to region adjacency. They still merged the intersected blocks together by color. Valiente *et al.* [24] had classified and merged the blocks by considering the symmetry, similarity and attraction, but failed to give an error control that easily controls symmetry and attractiveness. Shih and Cheng [25] replaced the blocks in the over-segmented image with seed points. The attributes of the seed points are related to the algorithm. The algorithm combines the difference measurement between seed points with the size limit of the block. When these tasks are combined for blocks of over-segmented images in the geometric element extraction process, only the differences in the color space of the blocks are often considered. Some of them take into account some geometric properties of the blocks (such as size, boundary, and geometric center) and most of them do not involve blocks. Therefore, this paper considers the relationship between blocks in the element image, so that the element image can be more accurate.

(3) Element application: Element application is to map an element image onto a 3D model with texture mapping strategy. Texture mapping is to cover a pre-defined texture or image to the surface of a 3D object through a mapping algorithm, and to establish a one-to-one correspondence between texture and space object. Niem and Broszio [26] grouped the adjacent triangles describing the surface of the 3D model to homogenous surface regions which are textured with a common image followed by a local texture filtering at the region boundaries. Niem and Wingbermuhle [27] bound texture information to a single surface triangle, the clipped rectangular image part containing the projected triangle was defined as texture map. Yemez and Schmitt [28] developed a texture mapping strategy based on surface particles to adequately address photography related problems. Andrade *et al.* [17] calculated each RGB pixel value in the final texture map through the weighted sum of all the RGB pixels values that have the same coordinates on the partial

texture maps to join the partial texture maps. For UV unwrap, Sheffer *et al.* [29] improved the ABF (Angle Based surviving) method. ABF methods were time-consuming and error-prone for large grids. Sheffer *et al.* [29] proposed an efficient extension ABF method to overcome these disadvantages. The common products of museum derivatives include office supplies, household products, ornaments, toys, apparel, food, etc. It is obvious that many aspects of museum derivatives design require computer to assist in the design. Three-dimensional models of cultural relics are studied, including modeling methods and information maintenance [30]–[32]. However, the existing design system is relatively decentralized and there is no complete design system specifically for museum art derivatives. Moreover, the existing design tools are complex and time-consuming, which hinders the usage of non-professionals. In contrast, we propose an intuitive museum art derivative design system based on computer simulation, which users can design product without learning detailed knowledge.

III. RESEARCH AIM

In order to promote the development of designing museum art derivatives, we propose an efficient and easy-to-use cultural product design system, which consists of two parts: element operation and element application. From the point of software usage, the users can extract the element from the cultural relic image and process with artistic styles. Then these elements are pasted to the three-dimensional living model to complete the final creation. Non-professionals can use the system to quickly design various style of the products, and professionals can use the system to perform pre-design and effect preview work. Compared with the current design mode, our system can effectively generate basic element images, and complete the material and cultural creation design through user interaction, which is characterized by integrity, ease of operation and practicality.

IV. SYSTEM AND DETAILS

The system consists of different types of element operations including element exaction, element processing, and element application in product models. Given a cultural relic image, users can extract their favorite elements from the image. Cultural element processing is a finer processing step of selected elements, including image denoising, image sharpening, color edit, etc. The element application module aims to map the processed elements to a three-dimensional model by dragging, zooming, and other user interactions. The system also includes a database to preserve the information of the design and product step. Fig. 1 shows the overall framework of the system.

A good museum derivative design system needs to ensure that even the first-time users can carry out complete art design by themselves, which puts forward high requirements for the ease of use of the software. First of all, users can extract materials from cultural relics, to ensure that users can extract specific patterns according to their own ideas and can process

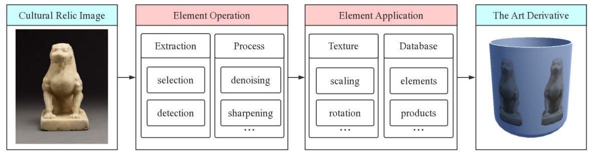


FIGURE 1. **The overview of the proposed museum derivatives design system. These two color sections show how to use traditional cultural relic images to design an art derivative. The element operation is to exact the features and process original image. The element application is to decorate the prepared models with the processing images.**

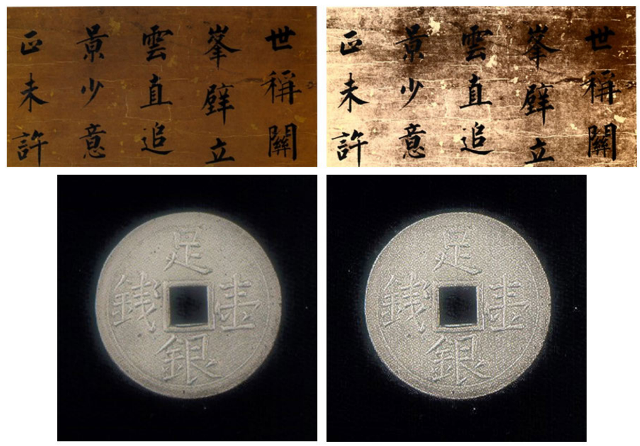


FIGURE 2. **Image processing results. The right top image shows the contract change of a deep color image. The right bottom image shows the image sharpening results for a blurred image.**

materials through cutting, scaling, rotation and other basic functions, as well as stylization, edge detection and other artistic functions. In the three-dimensional design stage, users can also apply the material to the appropriate position by scaling, rotating and other functions, and can modify it at any time. After the completion of mapping, we set the function of loading and saving to facilitate the user's secondary processing, and we can keep the effect of the work through the function of taking photos to facilitate the display on the website.

NK-CDS is proposed for the creation of museum derivatives, so the quality of the images used in our system is good by default. The cultural relic images can usually be obtained from famous museum websites and cultural communication community. However, there may still be problems such as illumination and blurred image (as shown in Fig. 2), and users have different standards for image quality. We provide image preprocessing operation to solve the above problems before processing source images. This step is provided to the user for selective use.

A. ELEMENT OPERATION

We summarize all operations form cultural images to texture elements as element operations, including element exaction and element process. We need to extract the cultural elements of cultural relic images by image segmentation techniques.

Here, we improve the watershed algorithm to extract the cultural elements. The watershed algorithm [33] is a mathematical morphology segmentation method that has been widely used for image segmentation. However, this method has strong dependence on edges and is susceptible to over-segmentation due to interference factors such as image noise, grayscale texture, etc. We hardly make sure the quality of cultural relic images and there are many noise points in these images. Therefore, we improved this method specified for element extraction. The target image is filtered firstly. Then, the color image preprocessing and the watershed segmentation are implemented by the gradient calculation method based on image information entropy. Finally, we merge the divided regions. The tools in NK-CDS will also help users to adjust the elements flexibly in different areas.

(a) (b) (c) (d)

FIGURE 3. Comparison with the existing methods. (a) shows the original image, in which the black box represents the area of interest marked by the user. The right part lists three results by the GrabCut (b), watershed (c) and our optimized method (d).

1) ELEMENT EXACTION

According to the principle of the watershed algorithm, $M_1, M_2, \cdots, M_r$ represent small areas of the image to be segmented. $C(M_i)$ represents the watershed associated with the minimum region M_i. The terms of *min* and *max* represent the minimum and maximum values of the gradient, respectively. It is assumed that the overflow process is increased by a single gray value, and n represents the increased value of the overflow (i.e., the depth of the overflow at the nth step). $T[n]$ represents a set of all points x satisfying $f(x) < n. f(x)$ is a gradient image signal. For a given watershed, there will be varying degrees of overflow (and may not occur) at step n. Assuming that in the very small region M_i at the nth step, an overflow occurs, so that $C_n(M_i)$ is a part of the watershed associated with the very small region M_i. That is, at the overflow depth n, the area formed by the horizontal plane formed in the watershed $C(M_i)$, $C_n(M_i)$ is a binary image, which can be expressed as:

$$C_n(M_i) = C(M_i) \cap T[n] \tag{1}$$

If the gray value of the minimum area M is n, then at the $(n + 1)$th step, the overflow portion of the watershed is exactly the same as the minimum area, that is, $C(M) = M$. $C[n]$ represents the sum of the overflow parts in the nth step, and then $C[\max +1]$ is the sum of all the watersheds. At the beginning of the algorithm, $C[\min +1] = T[\min +1]$.

The definition of overflow is recursive. Assuming $C[n-1]$ has been established, from Equation 1, $C[n]$ is a subset of $T[n]$, $C[n-1]$ is a subset of $C[n]$ and $C[n-1]$ is a subset of $T[n]$. If D is a connected component of $T[n]$, there are three possibilities:

(1) $D \cap C[n-1]$ is empty;

(2) $D \cap C[n-1]$ is non-empty and contains a connected component of $C[n-1]$;

(3) $D \cap C[n-1]$ is non-empty and contains a plurality of connected components of $C[n-1]$.

Case 1 will occur when the increased overflow reaches a new minimal area. For case 2, D will be within a small watershed. For case 3, D must contain some parts of watershed $C_{n-1}(M_i)$ that constitutes $C[n-1]$. Therefore, a dam must be built in D to prevent the overflow from spilling over in a separate basin. The dam is the skeleton of $C[n-1]$ geodetic impact zone within $T[n]$ (watershed line). When $C[n-1]$ forms $C[n]$, $C_{n-1}(M_i)$ in each part of the basin grows into its geodetic impact area within $T[n]$.

After splitting, we merge the regions. The basic idea of the area merging algorithm is as follows: (1) choose a very small area as a seed area; (2) combine the regions adjacent to the seed region and close to the gray level mean, and set it as the new seed region for the region with a large difference in gray mean values; (3) iteratively update the seed area, and then obtain the ideal combination result, so that the over-segmentation problem will be reduced.

We used Chinese traditional cultural relic as the example to compare our algorithm with the GrabCut and watershed methods. Fig. 3 shows a comparison of our algorithm with the existing methods. We extracted an element from china image of cultural relic. Fig. 3(a) represents the area where users are interest in. Fig. 3(b) shows the result of the GrabCut method. Fig. 3(c) shows the result image by watershed method without other processing. As can be seen from Fig. 3(b) and 3(c), some unnecessary elements are also extracted. In contrast, our algorithm successfully extracted the desired element of original image (see Fig. 3(d)). It can be seen that the segmentation results of the improved algorithm are more accurate and clean. Under the premise of ensuring the segmentation effect, the influence of noise can be well suppressed.

2) ELEMENT PROCESS

To make the extracted element consistent with user needs, we should further perform element processing, such as element denoising, element sharpening, etc. Next, we take denoising and sharpening algorithms as examples to introduce the element processing in detail.

Element denoising: The conventional median filter [34] works well when the density of the noise is not very serious. When the probability of noise occurrence is high, the effect of conventional median filtering is not very good. The adaptive filter can not only filter out the salt and pepper noise with higher probability, but can also better protect the details of the image, which is not possible with the conventional median filter [35]. Noise detection is a critical step. We divide the image of size $M \times N$ into S sub-blocks, and the $k(k = 0, 1, \cdots, S-1)$ sub-blocks are denoted as B_k. The gray value of the pixel to be detected (i, j) in the sub-block is $f(i, j)$, and a detection window of 3×3 size is formed centering on the point. The set of gray values of all pixels in the window is

$$A_{i,j} = \{f(i+s, j+t)|(i,j) \in B_k, s, t \in [-1, 1]\} \tag{2}$$

The maximum and minimum values of the gray value in set $A_{i,j}$ are $Max(i, j)$ and $Min(i, j)$, respectively. The gray values that are not equal to $Max(i, j)$ and $Min(i, j)$ in $A_{i,j}$ form a set $C_{i,j}$, and the average value $T(i, j)$ of all gray values in the set is obtained. If the difference between $f(i, j)$ and $T(i, j)$ is greater than the detection threshold T_d, $f(i, j)$ is equal to a value in $Max(i, j)$ and $Min(i, j)$, then (i, j) is used as a noise point, and is marked with $y_{i,j} = 1$. Otherwise, (i, j) is used as a non-noise point, marked with $y_{i,j} = 0$.

$$\begin{aligned} f(i,j) &= Max(i,j) \cup f(i,j) \\ &= Min(i,j)) \cap (|f(i,j) - T(i,j)| \geq T_d) \end{aligned} \tag{3}$$

Element sharpening: The Laplace operator is an edge point detection operator independent of edge direction. Its response to isolated pixels is stronger than that of edges or lines, so the image needs to be smoothed before image sharpening using this operator [36]. Given a continuous function of two variables $L(x, y)$, the Laplace operation is defined as

$$\nabla^2 L = \frac{\partial^2 L}{\partial x^2} + \frac{\partial^2 L}{\partial y^2} \tag{4}$$

For a digital image, the Laplace operator can be simplified as

$$\begin{aligned} G(i,j) = 4L(i,j) - L(i+1,j) - L(i-1,j) \\ - L(i,j+1) - L(i,j-1) \end{aligned} \tag{5}$$

The above equation can also be expressed as convolution, that is

$$G(i,j) = \sum_{r=-k}^{k} \sum_{s=-l}^{l} L(i-r, j-s)H(r,s) \tag{6}$$

In this equation, $i, j = 0, 1, 2, \cdots, N-1$, $k = 1$, $l = 1$. $H(r, s)$ can be expressed as

$$H_1 = \begin{bmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{bmatrix} \tag{7}$$

Fig. 4 shows the final result of the element image after three types of processes (denoising, sharpening and color editing). Fig. 4(b) shows the results after image denoising, which is smoother than Fig. 4(a). Fig. 4(c) are the results after image sharpening. The edges in Fig. 4(c) are clearer and the color is brighter. Fig. 4(d) shows the results after color editing. After changing the color, the element image looks more vivid and suitable for mapping to a 3D model.

Lots of researches have been done on processing color and detail features of the image [37]–[39]. One thing to note is that there is no algorithm suitable for all types of cultural relics. The effect of the colorful china is more vivid than that of the handwriting in color editing. Instead, the sharpening algorithm does well on some blurry images of calligraphy works. We provide the basic process method and user can compare with different styles of the extracted element. By optimizing the processing of the classical algorithm, the system hopes to obtain the effect desired by the user as much as possible. This effect is not the final result, and the built-in tools will encourage users to design more times, to achieve the desired effect of the relic image element. This also reflects the flexibility and freedom of our system in terms of material extraction.

FIGURE 4. Results of element process for an image. (a) is the input image. (b)-(d) show the results of denoising (b), sharpening (c), and color edit (d), respectively.

B. ELEMENT APPLICATION

Generally, users simply map texture onto the two-dimensional image of the designed object to complete the design of cultural relics derivatives. Some of them rely on the existing software for processing design. The problem is that the existing software is not targeted for the design of cultural relic derivatives, and most functions are never used by users and are relatively professional. In order to solve this problem so that non-majors can also complete the museum derivative design easily, the element application module is proposed which can ensure that users can design freely directly on the three-dimensional model, and set up relevant functions for the needs of derivative design of cultural relics, which not only meets the practicality but also ensures the ease of use.

When using computer simulation technology to design products, we must first consider the authenticity of texture mapping effect. In order to make this system have a more realistic effect and a better user experience, the mapping must have the characteristics of tight fitting, small distortion, without image distortion and so on. For the process of mapping two-dimensional pictures to three-dimensional models, it is realized by mapping in the field of computer graphics. Mapping methods such as projection mapping can only map the image to the model surface, but because of the shape of the model itself, the texture will appear serious deformation on the model surface. Therefore, this paper chooses the UV mapping method as the 3D mapping method, so as to ensure the one-to-one correspondence between the material and the

FIGURE 5. The prepared daily necessities model in our element application tool including cup, umbrella, clothes, etc.

pixel points on the model surface. It is also very important to ensure that every edge of the model is marked when do UV unwrap.

The museum derivatives design aims to carry out the appropriate UV unwrap of the 3D model of daily necessities, and then use texture mapping to put the decal operation into effect. In order to meet the needs of practical application, it is necessary to conduct the decal framework on each surface of the model individually. On the other hand, the UV unwrap of each surface of the model is required.

Our system provides seven categories of models, covering most of the commodity models to meet user needs (see Fig. 5). The user can directly control the angle of view of the three-dimensional model to be designed, and adjust the distance to perform partial or overall design. The processed artifact texture element is stored in a specific folder for the user to select. The selected texture element can be directly mapped to the 3D model according to the cursor position. Our system also allows the user to customize texture size and angle to meet design needs. Museum derivatives that are designed or under design can be saved at any time in order to preserve the progress. By loading, the user can also perform secondary processing on the semi-finished products.

Furthermore, from the user's point of view, we consider all kinds of situations that may occur when applying texture. When the user has extracted the appropriate texture in the element extraction program and has processed the relevant texture, the size of image element extracted by users is random, and when mapping the texture element for the first time, the wrong size of texture can make the process difficult. Therefore, we set a fixed parameter to ensure that whatever the size of the element extracted by the user is, it will be converted to an appropriate size by equal scaling during mapping. Because the 3D commodity model is essentially a polyhedron, common texture mapping algorithms often produce texture distortion, truncation or wrong coverage when processing its edges. In order to solve the problem of edge error mapping, our method is designed as follows: firstly, the edge position of 3D object is identified by stitches in the 2D grid after UV unwrap, and the texture pixels on and around it are smoothed to make them as natural as possible. Since we use UV mapping method, when a two-dimensional

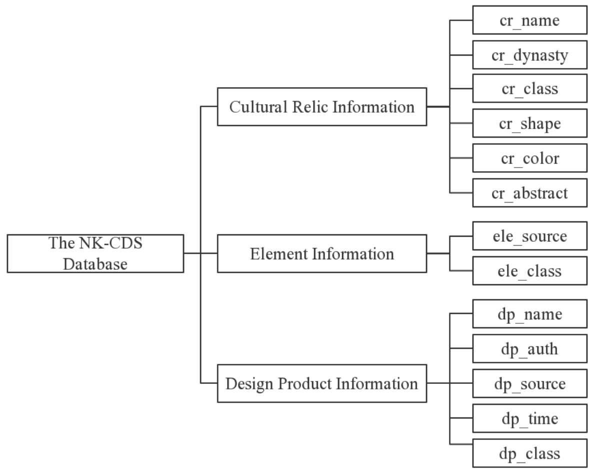


FIGURE 6. Illustration of the database structure. It consists of three parts, cultural relic information, element information and design product information. The cultural relic part includes name, dynasty, type, shape, color and brief. The element part includes the source image and its type. The design product part includes name, author, inspiration, create-time and type.

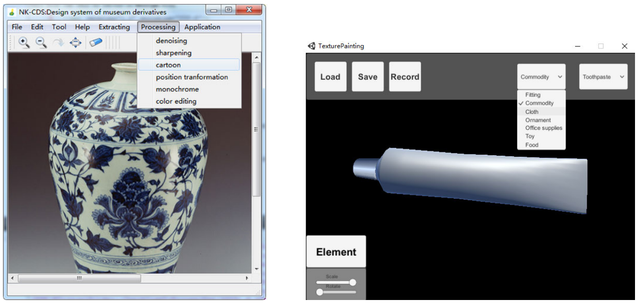
texture is mapped to multiple adjacent surfaces of a three-dimensional object, the effect of folding and twisting similar to the real object map can be achieved.

In the design process of museum derivatives, it is often necessary to apply the same element for many times and arrange or overlap the elements. In order to make the operation process more convenient, users can complete the texture with the mouse and then apply the same element again. In addition, if the texture element used is a vector image, each texture will not affect the effect due to contour occlusion, and users can overlap the texture according to their preferences, which meets the requirements of artistic design. In addition, the solution to these problems is mainly attributed to the reasonable UV unwrap and the selection of UV mapping algorithm. With these features we offer, users can easily complete most of the museum's derivatives design work.

In the final step of the application, we provide a database to store various types of files produced by the design, and one of the benefits of this is that the data are centrally managed rather than scattered around. The structure of the database is shown in Fig. 6. Users can upload images and submit related information they want to save. By saving these design materials, designers do not have to process the same material, but simply query and download existing element editing results. If not satisfied, the designer can perform a new round of creation.

V. RESULTS AND DISCUSSION

By combining the above modules of element operation and element application, we have realized a lightweight, simple and easy-to-use system, NK-CDS, for the non-professional users in museum derivatives design. This system uses OpenCV and QT for programming which is appropriate for non-professionals. At the same time, an object-oriented



(a) (b)

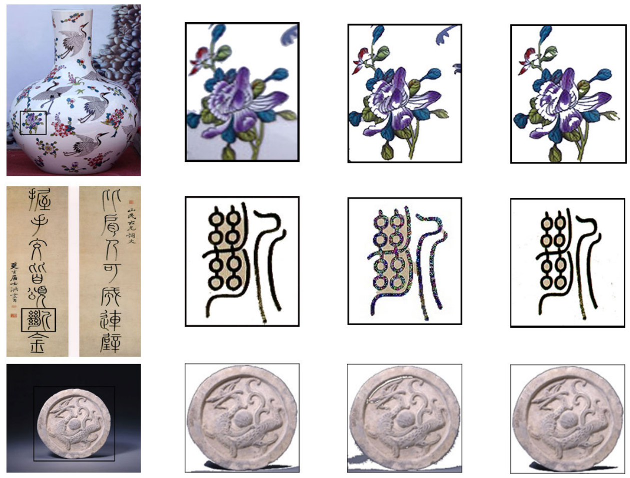
FIGURE 7. User interfaces of our system. (a) is the main interface of the design system and shows a drop-down box after clicking the "Processing" button. (b) is the model selection interface after clicking "application", which is a middle process.

development program is written in C++ language, so as to write the theoretical structure and research results into the window software, which is convenient for designers interaction. In addition, we use MySQL technology to complete the related work of database. The main system interface is shown in Fig. 7(a), which includes the menu bar, toolbar and image window. The function of the menu bar is to provide basic file edit and to guide the user to use the software. The toolbar is used to adjust the parameters of element operation. The user can view original images and process effects in the image window.

A. EVALUATION ON ELEMENT OPERATOR

We compared our algorithm with the GrabCut method and the watershed method. Figure 8 compares our results with those generated by other methods. There are more than ten classes of cultural relic including porcelain, jade, stone, paper, metal, and bamboo statue, etc. Depending on the actual situation, users usually use objects with distinct contours and rich textures, such as porcelain, calligraphy and painting, carvings, etc. We use these three categories of representative artifacts for experimental comparison. We chose some typical cultural relic to compare with the above algorithms. The results by our proposed algorithm are more clean, simple and accurate than those by the GrabCut method and the watershed method. All the results extract the zone of interest successfully and our results show fewer noisy points which ignores the final effect presented on the daily life models.

We adapt popular methods on image processing and provided different types of stylization. We set the slider bar for each feature so that the user can control the result of the material processing well. For example, the gray slider bar provides a range of 0-255 variations. The color-adjusted slider provides a range of regular color changes. Figure 9 shows the results of the element image processed in several ways. As can be seen from Figure 9(c), the element image is distorted, which can be changed with parameter adjustment. Figure 9(d) is the result of element mono-chromatization. The overall color of the element image becomes one. Figure 9(e) is the result of local



(a) (b) (c) (d)

FIGURE 8. Comparison among results produced by different methods mentioned in Fig. 3. (a) is the original image, (b) is result of the GrabCut method, (c) is result of the watershed method and (d) is our result.

(a) (b) (c) (d) (e) (f)

FIGURE 9. The processing results of the element image by different processing types. (a) is the original element image, (b) is the result of horizontal flipping, (c) is the result of perspective mapping, (d) is the result by mono-chromatization, (e) is the result by local color editing, and (f) is result of cartoon stylization.

color editing. We can change the color of the element image through local color editing. Figure 9(f) is the result of cartoon stylization of elements. Users can keep trying to find the best result as they desire in different processing steps.

We pursued a quick and simple method to attain the result that is acceptable by the user. Users usually show interest in some complete structures, such as a flower and a crane, since some small pixels in the region can be ignored. So the improved algorithm can make more clean and specific results. However, for some cultural relics which consist of tiny patterns, the algorithm in this paper may suffer from some problems, and it is also an aspect that needs to be improved in the future. On the other hand, in these algorithms, we did not use the method of deep learning but focused on the traditional method.

FIGURE 10. The results of elements used in different models. Each element image has been applied in three different models. The design model selection is flexible and rich.

FIGURE 11. The result of different elements used in one model. Each model has been applied in different kinds of elements. The design element selection is also flexible and rich.

B. EVALUATION ON ELEMENT APPLICATION

In this paper, we chose an appropriate texture mapping method for the feature of cultural relic images and considered common problems in the usage of design such as boundary and scaling. A design product will be done after the combination step of element and model. Users can reuse elements in different types of models and reuse different elements in the same model. There are hundreds of ideas can be realized in NK-CDS. Figure 10 and Figure 11 demonstrate the final results by different combinations.

The system provides seven types of daily life models, and the user create elements what they desire. The users can keep trying to modify their works. The model is fixed and only has several classes, more variety of models may arise more ideas in museum derivatives design. Currently, the user can not adjust the parameters such as color and illumination in our provided models. It is worth considering how to edit the models easily the same as images.

C. EVALUATION ON SYSTEM USAGE

At present, the popular designing model is the combination of application software and technical skill. The image software such as PhotoShop is used for image processing, while the KeyShot software is mainly served for 3D processing. But there is no targeted design software or other open source software, this paper combines PhotoShop and KeyShot software as a set of design systems, as a comparison object of our system. Table 1 comprehensively analyzed the advantages and disadvantages in terms of the data source, operator difficulty, software experience and other aspects.

The main purpose of this museum's derivatives design system is to simplify the complex operating procedures of existing software, and to provide a design tool that can be used easily for first time users. The system is required as a useful aid, so it should also have considerable practicality. In order to verify the effectiveness of the NK-CDS system and the truth of the comparative analysis in Table 1, we conducted the following experiment to verify these items from the user's perspective. Survey objects consist of two groups. The first group consisted of 60 students and teachers from the department of Archeology. The design of museum derivatives was also one of their coursework. They will use both traditional methods and our system to conduct museum derivative design to examine the practicality and ease of use of the system. At the same time, there are a group of 60 students and teachers from other colleges. They have never used professional software such as Photoshop and Keyshot before. They will also try to use traditional software and our system to design museum derivatives to investigate the system's ease of use.

In the first survey, the Archeology majors and teachers first used traditional image processing software Photoshop and 3D rendering software Keyshot to conduct derivatives product design, and then used the system of this paper. According to the subjective experiment, each method is scored on the practicability and ease of operation. In these surveys, we give scores from 0 to 10 points. The results are shown in Fig. 12. The results show that, in terms of practicality, the scores of the two methods are close, although the utility of using existing software is slightly higher. But in terms of ease of use, our system achieved a better score, indicating that our system is indeed more convenient to operate, and this result is obtained on the premise that survey users have mastered the traditional tools.

Since the second group of respondents did not use traditional software and did not use this system, the use of software without pre-learning could lead to a more objective assessment of the ease of use of the system. The students evaluated both methods with five levels, which respectively represent very easy, easy, normal, hard, very hard. The results are shown in the Fig. 13. It can be seen that the advantage of this system in terms of ease of operation is highlighted in this group of surveys. Even students who have not previously studied software use can perform basic museum derivative design operations.

The above is a survey of the practicability and ease of use of the museum's derivatives design system. The results showed that our system has some advantages. Then, we also investigated the satisfaction of users with the final results of the

TABLE 1. A qualitative comparison table of different design modes. The table shows the characteristics of the four design modes in five aspects.

Compared item	Photoshop	Keyshot	PS + KeyShot	NK-CDS
Interface	friendly	friendly	complex	simple
Function	image	graphic	overall	customized
Design Difficulty	need experience	need experience	hard	easy
Result	2D	3D	more details	more ideas
Aim user	professionals	professionals	professionals	non-professionals

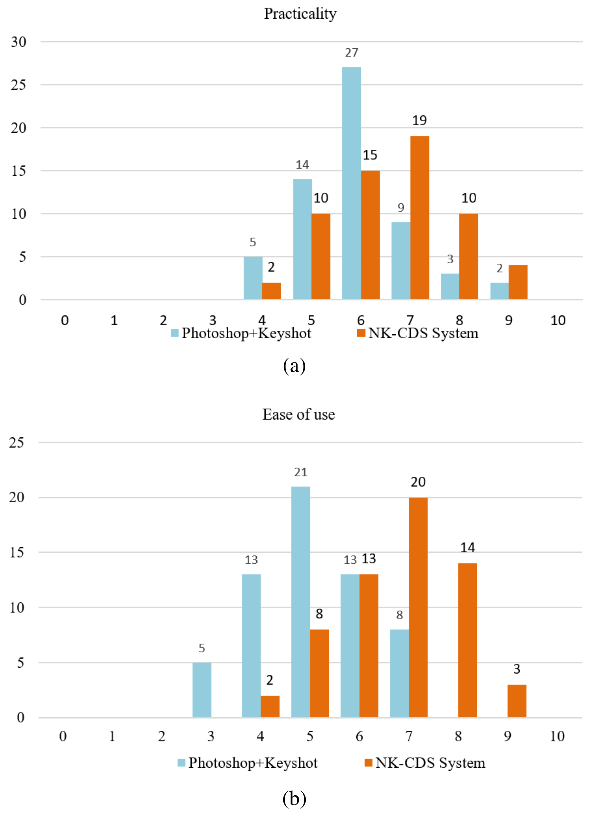


FIGURE 12. The user's vote on system practicality (a) and ease-of-use (b).

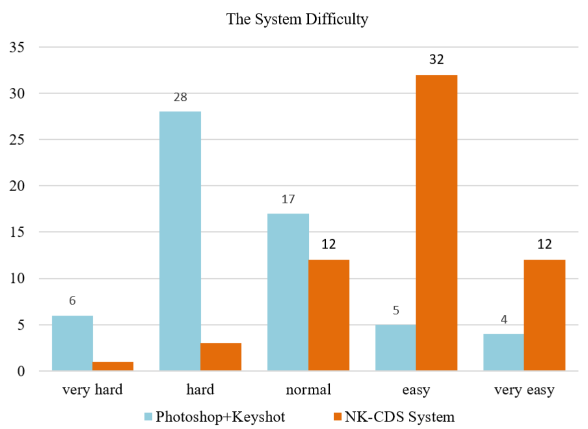


FIGURE 13. The non-professional students' scoring of the difficulty of these two systems.

design works. This part is mainly to investigate whether the users' final design meets their previous expectations and the needs of the museum's derivatives design. In this part, we set

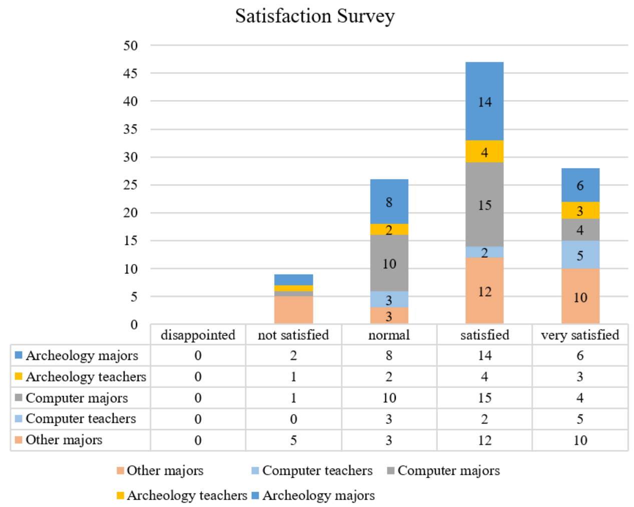


FIGURE 14. The results of satisfaction assessments of system-generated results for students of different majors.

up five satisfaction levels (very satisfied, satisfied, normal, not satisfied, disappointed) and investigated 40 archeology majors and teachers and 40 computer majors and teachers and 30 other majors. The final result is shown in Figure 14. This part of user survey showed that whether the archeology majors or other majors, the final design is satisfactory, which demonstrates that the proposed system has a good design effect and easy to operate, which can meet the needs of museum's derivatives design.

As an aided design software for non-professionals and students, NK-CDS has the features of simple interface, specific function and short design cycle. NK-CDS only provides necessary functions to users and avoids interference from other functions. The use of our system, in museums or schools, can help visitors and learners to understand the design process of cultural relic products and complete their own works, thus promoting the development of museum art derivates. Owing to the simplicity of operation, non-professionals can adjust their works repeatly in every short creative cycle, and professionals can pre-design and use the model to simulate the final effect.

VI. CONCLUSION AND FUTURE WORK

This paper demonstrated how digital image processing techniques could greatly impact museum art derivatives applications. In this paper, we proposed a complete set of museum derivatives design system based on computer simulation. Our purpose is to develop a design system that can integrate and replace existing professional image processing software and 3D rendering tools on the market. In response to the unique needs of museum cultural materials, we combined various methods of image processing and texture mapping, and improved algorithms for cultural relic features. Then we designed a set of procedures such as extracting elements from cultural relic pictures, performing element processing, and finally applying the processed 2D elements to 3D models. This system does not require users to have professional image processing skills, greatly saving the user's creation time. However, our method still has one limitation. For the image of cultural relics with very vague outline, it is difficult to extract elements, and some details will be lost. Therefore, in the future, we will further optimize the method of element extraction.

Currently, our system mainly considered the realization of museum derivative design on computer and display on web page, so at this stage, we did not transform the final effect into entity by 3D printing. However, as the final 3D model has a great visual effect and authenticity, we believe that 3D printing in the later stage is feasible and will be used as the follow-up work [40].

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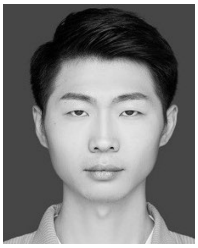

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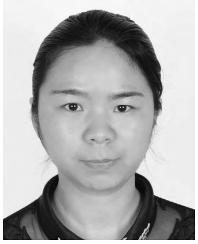

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