Design of Digital Repair System for Damaged Cultural Relic Image in the Professional Training of Restoration

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Abstract. In the traditional cultural relic image digital repair system, there are obvious color aberrations and structural deviations between the restored part and the surrounding part, which weakens the visual connectivity of the restored result. In view of this, this research designs a digital repair system of damaged cultural relics image in professional training of restoration. In the hardware of the system, an integrated fast spherical camera is designed, and the transformation between image and pixel coordinate system is expressed by homogeneous coordinate system according to its parameters. In the system software, the damaged areas of cultural relics images are segmented and marked first, and the optimization algorithm of texture synthesis and restoration based on samples is designed. The experimental test results show that the system in this paper can ensure the use of the known information of the original image to the greatest extent, and make the repair result more reasonable on the basis of the minimum modification of the original image, so as to achieve the effect of professional practical training of repair.

Keywords: Restoration professional training · Cultural relic restoration · Image digital inpainting · Image region segmentation

1 Introduction

With the rapid development of science and technology and the continuous improvement of social system, people's quality of life is also improving. It is accompanied by people's demand for high-quality spiritual life, of which cultural life is a very important part [1, 2]. People are more and more interested in understanding the cultural history of their own country and the world, which leads to the emergence of various types of museums.

As there are currently a large number of unearthed cultural relics in a severely damaged state, the number of cultural relics restoration workers is far from enough to cope with the large number of damaged cultural relics restoration work. There are many problems in the artificial restoration of damaged ancient cultural relics, including slow restoration, consuming a lot of manpower and material resources, and easy to cause secondary damage to ancient cultural relics. Therefore, people eagerly hope that there

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will be a system that can automatically complete the restoration of damaged images, so that the restoration workers can be freed from the processing of a large number of digital images, and at the same time, it can also ensure that the damaged ancient cultural relics can be repaired as soon as possible. And show it in front of the world [3, 4].

For this reason, cultural relic image digital repair system is applied in related cultural relic restoration profession. However, due to the operational deficiencies in the process of algorithm optimization in the traditional system, there will be obvious color difference and structural deviation between the repaired part and the surrounding part, which will weaken the visual connectivity of the repaired result. In order to solve this problem, this paper designs a new digital repair system of damaged cultural relics image in professional training of restoration. In this paper, an integrated fast spherical camera is designed in the hardware environment of the system. According to its parameters, the transformation between image and pixel coordinate system is expressed by using homogeneous coordinate system, and the camera is calibrated. In the software environment, an optimization algorithm of texture synthesis and restoration based on samples was designed on the basis of segmenting and marking the damaged areas of cultural relics images.

2 Design of Digital Repair System for Damaged Cultural Relic Images in Repair Professional Training

2.1 Hardware Design

In the hardware design, the main function is to identify the cultural relic image, complete the image information collection and transmission. The collection of cultural relic information image mainly depends on the camera. In this paper, the e588/G3 integrated fast spherical camera is selected. 128 preset positions are built in the camera. According to the above preset positions, the automatic timing activation function can be used to complete the omni-directional detection and automatic scanning of cultural relics [5, 6]. In addition, the camera needs to be calibrated to ensure that the image obtained by the camera is true and accurate. Firstly, the coordinate system of the vision system is established. The representation of several collected digital images in PC is an array of $P(M \times N)$. There are single pixels in the array. After the image is collected, the pixel coordinate system (U, V) can be obtained. On the actual CCD sensitive surface, the transformation between image coordinate system and pixel coordinate system can be expressed by homogeneous coordinates:

$$\begin{bmatrix} u \\ v \\ l \end{bmatrix} = \begin{bmatrix} \frac{1}{d_u} & s & u_0 \\ 0 & \frac{1}{d_v} & v_0 \\ 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} x' \\ y' \\ l \end{bmatrix} \tag{1}$$

In the formula, d_u represents the pixel pitch in the U direction, and s represents the tilt factor, which is mainly caused by the fact that the plane coordinate axes are not orthogonal to each other during the imaging process of the camera. $\begin{bmatrix} u \\ v \\ l \end{bmatrix}$ represents the coordinates of the pixel coordinate system, and $\begin{bmatrix} x' \\ y' \\ l \end{bmatrix}$ represents the coordinates of the image coordinate system. d_v represents the pixel pitch in the V direction. The schematic diagram of the conversion between the pixel coordinate system and the image coordinate system is shown in Fig. 1.

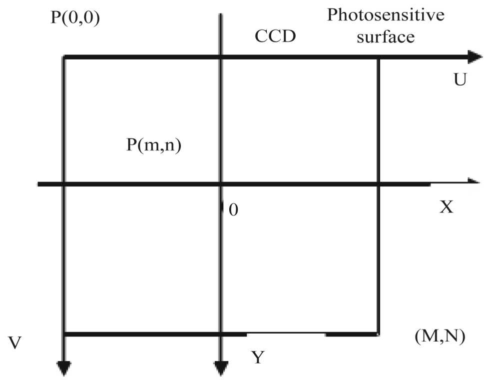

Fig. 1. Schematic diagram of pixel coordinate system and image coordinate system

In Fig. 1, the camera optical axis of image coordinate system (x, y) is perpendicular to the coordinate plane, the coordinate origin is the intersection point of the optical axis and the coordinate plane, and the coordinate axis direction is the row and column direction of the image. In the process of imaging, the camera uses the pinhole perspective model. The imaging is linear, also known as perspective projection. The related scale relationship is as follows:

$$\begin{cases} x' = \dfrac{fx}{z} \\ y' = \dfrac{fy}{z} \end{cases} \tag{2}$$

Written in the form of formula (1) as a homogeneous coordinate relationship, it can be expressed as:

$$z * \begin{bmatrix} x' \\ y' \\ l \end{bmatrix} = \begin{bmatrix} f\ 0\ 0\ 0 \\ 0\ f\ 0\ 0 \\ 0\ 0\ f\ 0 \end{bmatrix} \times \begin{bmatrix} x \\ y \\ z \\ l \end{bmatrix} \tag{3}$$

The above formula can describe the equation in the process of projecting the camera coordinate system onto the image plane. Based on the above calculations, the internal and external parameter models of the camera can be calculated, and the actual situation of the cultural relics corresponding to each pixel in the image coordinate system can be easily estimated through linear mapping. So far, the hardware design of the system is completed.

2.2 Segmentation and Marking of Damaged Area in Cultural Relic Image

In 1981, Bezdek and others first proposed the traditional fuzzy C-means (FCM) algorithm, that is, clustering method based on objective function. Taking $X=\{x_1, x_2, ...x_n\}$ as the sample set, c as the number of cluster centers, $V = \{v_1, v_2, ...v_n\}$ as the cluster center. Euclidean distance as the similarity measure of clustering, and adding membership function u_{ik} to the objective function, the objective function of clustering can be expressed as follows:

$$J_1 = \sum_{i=1}^{c}\sum_{k=1}^{n} u_{ik} \|x_k - v_i\|^2 \tag{4}$$

In the formula, when the value of J_1 is the smallest, the data set can be divided, x_k represents the k-th sample in the sample set, v_i represents the ith cluster center, and n represents the weighting function to control the degree of blur. u_{ik} represents the membership degree of the i th sample to the k th cluster center, and satisfies the following constraints:

$$\sum_{k=1}^{c} u_{ik} = 1 \tag{5}$$

In the formula, u_{ik} is a number between 0 and 1. The clustering criterion based on the fuzzy c clustering algorithm is to make the objective function the smallest value under the condition of meeting the constraints [7–9]. At present, iterative methods are commonly used to find the approximate minimum value of $J_1(U, V)$ to solve this type of optimization problem.

Taking the damaged area of the cultural relic image as the foreground and the non damaged area as the background, the FCM algorithm is used to segment the mural, and the spatial feature information of pixels is introduced to avoid the influence of noise on the segmentation effect. Since a color image can be represented by a three-dimensional vector on a two-dimensional grid point, each grid point represents a pixel [10–12]. The coordinates of grid points, that is, pixel coordinates, can represent the spatial distribution of the image. In the segmentation process, R, G, B and three color components in RGB space model are used to represent the color feature vector $x_i^o = (r_i, g_i, b_i)$ of the mural, and the pair $x_i^s = (x_{i1}, x_{i2})\ i = 1, 2, ..., N$ is used to represent the pixel coordinates. Therefore, a five dimensional vector is used to represent the mural image as the input feature vector based on FCM algorithm. Then the mural image is shown as follows:

$$X = \left(x_i^o, x_i^s\right)\ i = 1, 2, ..., N \tag{6}$$

In the formula, N represents the number of pixels. The color features of cultural relic images include the brightness and chromaticity information of cultural relic images, which can be obtained by color histogram. The steps for segmenting and labeling the damaged areas in the image are as follows:

Step (1): determine the number of clusters $c, (2 \le c \le n)$ and set the iteration threshold value $\varepsilon > 0$;

Step (2): initialize membership matrix $U = [u_k(i,j)]$ and cluster center $V = [v_1, v_2, ..., v_c]$ with random numbers between [0,1];

Step (3): Input the feature vector and calculate c cluster centers;

Step (4): Calculate the objective function and then calculate the difference with the last value function. If the difference is less than the preset threshold ε, the algorithm is completed, the membership matrix and cluster center are obtained, and the membership matrix is updated:

$$u_{ik} = \frac{1}{\sum_{k=1}^{c} \left(\frac{d_{ij}}{d_{kj}}\right)^{\frac{2}{m-1}}} \tag{7}$$

The image is segmented according to the classification matrix and clustering center. Mark the broken area in the original image as white.

2.3 Sample Based Texture Synthesis and Repair Optimization Algorithm

The sample-based texture synthesis image restoration algorithm has a better effect when repairing an image with a relatively large area to be repaired. The algorithm is mainly to randomly select a pixel on the boundary of the repair area of the image to be repaired in the repair process, and take a fixed pixel block at the center of the pixel as a matching sample block. The size of the sample block can be selected arbitrarily, such as 9×9. Then search and match the entire image area from the area to be repaired, find the texture block most similar to the sample block as the optimal matching block, and finally fill the center pixel of the optimal matching block into the sample block area. The repair diagram is shown in Fig. 2.

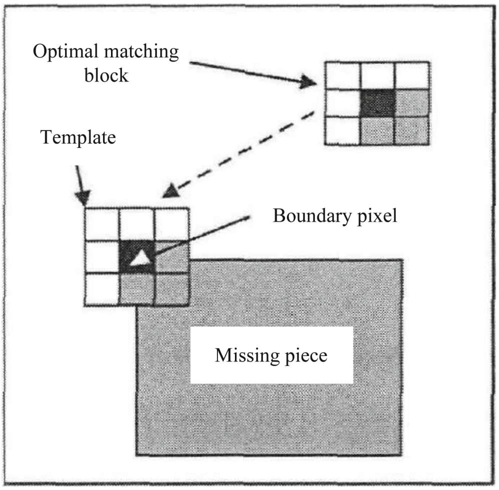

Fig. 2. Schematic diagram of sample-based texture synthesis image restoration

As shown in Fig. 2, the template sample block is a texture block with the same size centered on a pixel on the boundary of the region to be repaired. When matching the template sample block, search and match the white area in the image to find the optimal matching block. After matching, the center pixel value of the optimal matching block is updated to the center pixel of the template [12–14]. This algorithm is mainly through the calculation of the priority of the pixel to be repaired and the matching texture block and pixel value update three steps for texture synthesis to complete the region to be repaired in the repaired image.

3 System Performance Test

3.1 Build a Test Platform

In order to verify the system performance designed in this paper, a test platform is built in the process of system performance test. According to the number of cameras selected according to different cultural relic models, several cameras, image acquisition card, computer, auxiliary light source, experimental bench and other corresponding parts are selected. The final restoration results are output by the computer display screen. The core structure of the hardware part is 15 fourth-generation processor, 1050T1 graphics computer and Daheng DH-SV1421FC camera. The hardware components of the system are shown in Fig. 3.

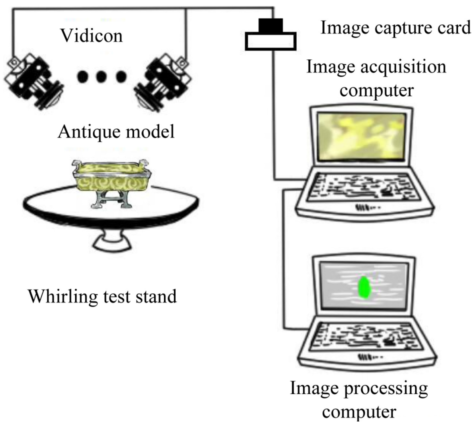

Fig. 3. Structure diagram of experimental system design

In the image acquisition process, the camera is used to shoot the damaged cultural relic model, and the image information of the real model is saved to the computer through the camera's dedicated image acquisition card to form digital information. Then judge the damaged area of the image or the missing area of the image information according to the requirements, and prepare for the later image repair and reproduction. The specific steps of the experiment are as follows:

Step (1): through multiple cameras (the number of cameras selected according to different cultural relic models), image acquisition card, computer, auxiliary light source, experimental bench and other corresponding parts, the final repair results are output by the computer display screen. The damaged cultural relic model is photographed by the camera, and the image information of the real model is saved to the computer by the special image acquisition card of the camera to form digital information. After the restoration of the damaged area, the image is ready for restoration according to the requirements of the image.

Step (2): use the existing digital image restoration algorithm program to achieve the restoration of the texture and structure information of ancient objects.

Step (3): analyze the repair results, find the shortcomings, and improve the algorithm.

The experimental flow chart is shown in Fig. 4.

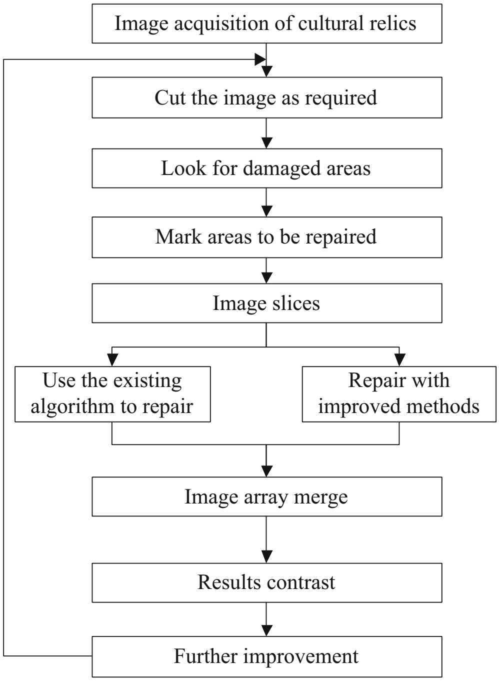

Fig. 4. Experimental process design

For the first part of the image acquisition process of the overall experimental process, the current plan is to use a monocular camera multi-angle shooting method, that is, to fix the camera position unchanged, and operate the experimental platform on which the cultural relic model is placed to make it rotate at a uniform speed. After the camera is fixed, the camera must be calibrated before proceeding with the operation of the experimental platform. Use linear transformation method to calibrate the camera: establish a set of basic linear constraint equations to express the relationship between the camera and the coordinate system of the space where the three-dimensional model is located, and use the least square method to solve the linear equation. In the process of image acquisition and preprocessing of the 3D cultural relic model, the surface texture and structure information of the 3D cultural relic model is stored by replacing the three-dimensional image with a two-dimensional image, realizing the process of "from 3D to 2D". After the overall restoration process is over, image stitching technology is used to "paste" the two-dimensional texture image on the surface of the three-dimensional cultural relic. The key steps of image stitching include two aspects of technology, namely image registration and image fusion. Figure 5 was repaired according to the above experimental method.

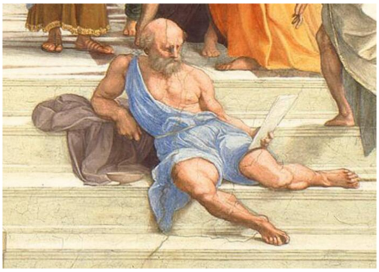

Fig. 5. Picture to be repaired

The original two systems and the system in this paper are used to repair the above figure, and the repair results are analyzed and compared.

3.2 Performance Test Results and Analysis

The test result is shown in Fig. 6.

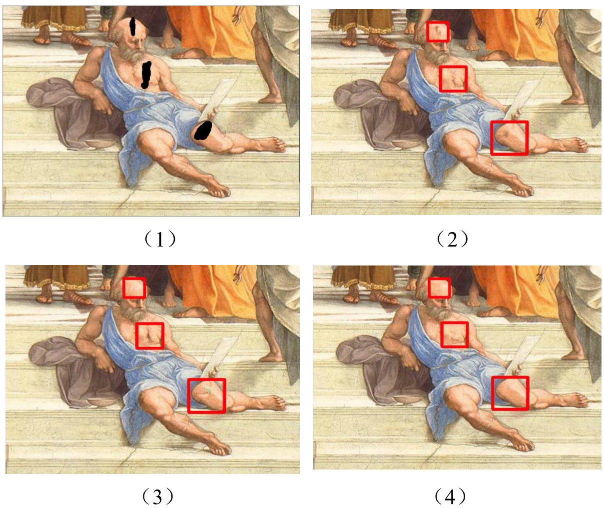

Fig. 6. Comparison of repair results

In Fig. 6, Fig. 6 (1) represents the cracked part of the marked human body; Fig. 6 (2) represents the repair result when the repair factor of the original system is 0.5; Fig. 6 (3) represents the repair result when the repair factor of the original system is 0.7; and Fig. 6 (4) represents the repair result of the present system.

In the experiment, the marked parts are respectively the head, chest and legs of the characters. These areas are the more seriously damaged parts, and there are great differences in the repair results after various methods. In the experimental results of the original system, we can see that the head, chest and legs of the characters have different degrees of unreasonable extension, resulting in obvious visual irrationality in the local part. There will be obvious color difference and structural deviation between the repaired part and the surrounding part. The visual connectivity of the repaired results in this paper is significantly enhanced.

The images repaired by different methods were compared with the original image for structural similarity detection, and at the same time, local structural similarity detection was performed on the repaired key area, namely the marked area. The repair results of each method and the original image structure similarity detection results are shown in the Table 1 shown.

Table 1. Experimental results SSIM value comparison

System approach	R channel	G channel	B channel	Grayscale
Original image	99.29%	99.29%	99.19%	99.26%
The original system repair factor is 0.5	99.35%	99.37%	99.27%	99.33%
The original system repair factor is 0.7	99.35%	99.37%	99.25%	99.32%
Text system	99.51%	99.55%	99.46%	99.51%

At present, the result evaluation of image restoration is usually based on the judgment of human eyes, with the connectivity of human eyes as the main judgment principle. By comparing the experimental results of different systems, it can be seen that: Compared with the repair results of the original system under different repair factors, the repair results of the cracks on the head, chest, legs, ground and steps of the characters in this system are more in line with the connectivity of human vision, which greatly improves the seam effect and unreasonable extension of the image. At the same time, the structural similarity value between the restoration result of the system in this paper and the original image is higher. The above results indicate that the repair system designed in this paper can ensure the use of the known information of the original image to the greatest extent and make the repair results more reasonable on the basis of the minimum changes to the original image.

4 Conclusion

Image restoration technology is an essential key technology in the restoration of damaged cultural relics, and the technology has important applications in many fields, such as photo restoration, film and game special effects production, the underlying application of mobile phone image software, etc. Due to the unreasonable algorithm optimization process in the traditional cultural relic image digital repair system, there will be obvious color difference and structure deviation between the repaired part and the surrounding part, which weakens the visual connectivity of the restored result. In order to solve this problem, this paper designs a digital repair system for damaged cultural relics image in professional training of restoration. This system has advantages in many aspects, which can make the restoration result more reasonable with the least modification to the original image. But at the same time, the system also has some shortcomings, such as long computing time, low timeliness, in the future research process, it needs to be improved and strengthened.

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2. "The Education Department of Tibet Autonomous Region'Building a National Team and Key Laboratory of Computer and Tibetan Information Technology' (Zang Jiao Cai Zhi [2018] No. 81)".

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