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Image Reproduction Based on Texture Image Extension with Traced Drawing for Heavy Damaged Mural Painting

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Abstract

Not only geometric information but also optical information is needed to reproduce ruins using three-dimensional realistic computer graphics as they were when those were founded. In order to give a model a sense of reality, it is common to carry out the texture mapping of the photographed image. However such information can not be acquired from either weathered or partially destroyed ruins. While there are various conventional techniques for image restoration, which can overcome in the case of small missing and cracks, it is difficult to restore such a heavy damaged mural painting well when there is no information from the periphery.

In this paper, we propose an image reproduction of a heavy damaged mural painting using a texture information extracted from another mural painting which has actually been restored by conservators and a traced drawing which the specialist guessed and drew. The restored image was used same pigment inks. Based on texture information from the restored image and a segmented traced drawing, we produce a restored image by applying the texture extension to each segment.

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Keywords: Image inpainting; Image restoration; Extending texture; Poisson image editing; Traced drawing;

1. Introduction

This research has been performed as a part of the digital archives project for the ruins of Teotihuacan in Mexico[1]. By three-dimensional (3D) realistic computer graphics (CG), we have tried to reproduce the ruins as they were when those were founded. The ruins of Teotihuacan are the greatest religion city states in Mexico built around the B.C. 2nd century and are located about 50 km northeast of Mexico City. Because the academic investigation and the administrative excavation in circumference area have been continued, the archaeological data such as city construction, daily life, religion, social organization, trade and chronology have been increasing now. However, since the character has never been discovered, there are many unclear points, for example, a main ethnos, a language spoken and a political mechanism. Moreover, it is difficult to dig into deep geological formation in

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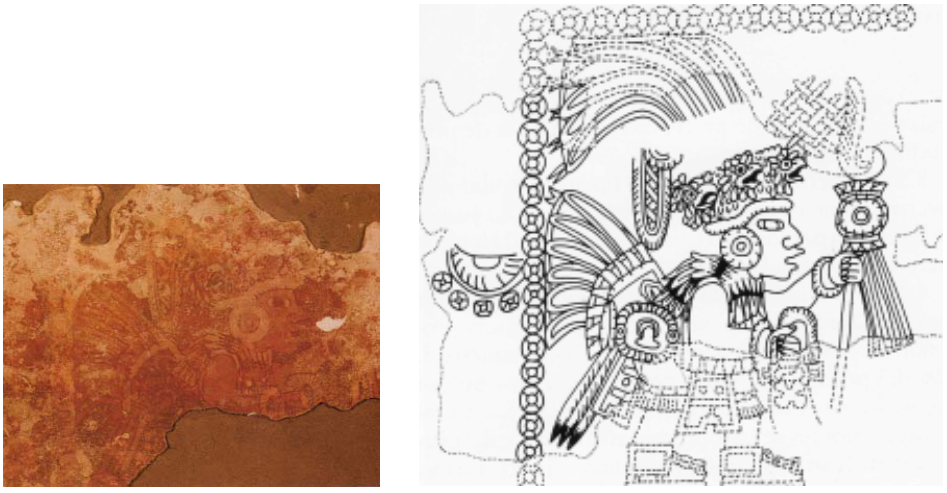
order to conserve the existing condition of the artifacts. Therefore, the material about a city formative period is very scant and the mechanism of city genesis has poorly been understood.

The mural paintings were drawn on various places in the ruins of Teotihuacan, such as apartment dwellings, Avenue of the Dead, Palace of the Jaguars, and Palace of Quetzalpapalotl, and so on. Humans, eagles, pumas, jaguars, wolfs and geometric patterns were drawn on the discovered mural paintings, so it has been surmised that the animals were drawn by choice. These were a symbol of a battle or the human sacrificial victim. For acquiring new inference and knowledge, restoration and observation of all mural paintings have been anticipated eagerly.

Not only geometric information but also optical information is needed to reproduce ruins using CG. About geometric information, we can use data of the 3D computer aided design system (CAD) for ruins [1], which Sugiyama and others created from the measured data on the ground. About optical information, it is common to carry out the texture mapping of the photographed image in order to give a model a sense of reality. However, all the ruins including the Pyramid of the moon etc. have been weathered by passage of time or destroyed by Spanish people's invasion. So, most present artifacts are the archaeological replicas.

It was discovered that the wall surfaces were coated by the plaster when the ruins have been founded. But the plaster of current wall surfaces has been removed completely, and inner stone blocks have been bared. It is difficult to acquire the texture information of that time directly from there anymore. And, the mural paintings in ruins are missing or cracked in some parts for the same reason. Therefore, when the texture mapping is carried out with pictures of current wall surface, it is not a restoration of artifacts at that time. That is, it is necessary to restore the image of mural painting of those days for the texture mapping. There, in this paper, we propose a technique to reproduce an image of a mural painting in those days from damaged one, and use it as a texture of wall surfaces for 3D CG.

Various methods for image inpainting have ever been studied. However, only small cracks and chips are restorable by such a conventional method. While, it is difficult to restore well since the necessary information cannot be obtained from a source image when the greater part of the human body is lost as shown in Fig.1(a).



(a) (b)

Fig. 1. (a) Heavy damaged mural painting; (b) Traced drawing.

For example, the methods which consider the continuity of the intensity [2][3][4] was often used in early stages of the image restoration study. These methods can produce an excellent result for images such as a photograph with scratches and telops. However, a sensitive texture to restore can not be expressed in case of a large amount of area, and the output image will be an indistinct picture.

And, the Back Projection for Lost Pixels (BPLP) method [5] was based on the autocorrelation of an image such as a landscape which has fractal features. This method creates eigenspace from only one image with missing parts. However, the image must have the autocorrelation such as an existence of a similar feature area to a missing part.

In addition, an image inpainting method [6] which combined the restoration technique and the texture synthesis was proposed. Moreover, there is a method [7] which fills the missing part in a mask image given the gradation and composes a similar texture within the image. These techniques compound from the boundary to inside of the missing part sequentially, it is no longer changed once the pixel value was composed. Therefore, while the restoration is completed in a short time, the quality of a generated image greatly depends on the order of composition. And there is a problem that the discontinuity often happens for a complex texture pattern.

In this paper, we propose a new approach of reproducing a mural painting to solve that problem, where previous methods can not be applied. The key ideas are a utilization of a line drawing in black and white which the specialist guessed and drew such as Fig.1(b) (hereinafter called traced drawing) and the texture expansion based on a sample texture colored by the same pigment. It is expressed as a line drawing by a specialist what kind of patterns the greatly missing part in a heavy damaged mural painting were originally . We try to reproduce an image of a heavy damaged mural painting using the traced drawing and the sample texture information which is extracted from another mural painting already restored.

There are the restored mural paintings which has actually been restored using same pigment ink by conservators . Concretely, based on texture information from the restored image and a segmented traced drawing, we restore image from deficits and deterioration by applying the texture expanding [8] to each segment. It is a condition that there is a traced drawing corresponding to the mural painting whose a most area of a face or a body of an animal have been lost. Furthermore, a region to be restored shall be manually determined in the damaged mural painting.

2. Previous work : Texture expansion

2.1. Image Quilting

As a way to enlarge a small image while keeping the image features, Image Quilting (IQ)[9] is well known. Small patches, which are appropriately sampled from the input image, can be sewn side by side to synthesize a large image. IQ lays texture patches out in a line (tiling), the combination of the patches is restrained by similarity of the overlap area of them. Then, the pixel selection (quilting) is applied in a duplicated region in order to reduce unnatural connection of overlap areas.

First of all, we select a patch P_f as subpart of a source image $\mathbf{I}$, then search the similar patch set Φ_{P_g} from $\mathbf{I}$. The intensity difference d between P_g and P_f in overlap region O must be less than error tolerance $d_{\max}$. Each patch area P_g is randomly selected from Φ_{P_g} to prevent the texture from failing into some regular patterns. P_g must be similar to the neighboring patch of P_f, which is previously chosen, to be able to connect smoothly. P_g is decided like equation (1).

$$\Phi_{P_g} = \left\{ P_g \mid d(O_f, O_g) < d_{\max},\ P_g \subset \mathbf{I} \right\} \tag{1}$$

where, let O_f and O_g be each overlap regions in P_f and P_g. The error distance d and maximum tolerance error $d_{\max}$ between the patches used in searching a similar patch are calculated as shown in the equation(2) and (3).

$$d(O_f, O_g) = \frac{1}{m} \sqrt{\sum_{u,v} \left\{ O_f(u,v) - O_g(u,v) \right\}^2} \tag{2}$$

$$d_{\max} = \frac{1}{m} \sqrt{\sum_{u,v} \left\{ \epsilon O_f(u,v) \right\}^2} \tag{3}$$

where, let m be the number of overlap region pixels, (u, v) be the pixel coordinate value in a patch, and ϵ be an error acceptable value to decide $d_{\max}$ manually.

Next, as shown in Fig.2, the least cost path in the overlapping area of the neighboring patch is calculated, the patches are connected by sewing along the path, and some discontinuity is reduced. The surface of error e is generated using equation(4) in overlap region O_f between P_f and P_g, and energy E based on e is computed.

$$e(u,v) = \left\{ O_f(u,v) - O_g(u,v) \right\}^2 \tag{4}$$

$$E(u,v) = e(u,v) + \min\{E(u-1,v-1), E(u-1,v), E(u-1,v+1)\} \tag{5}$$

A path with the smallest energy is followed based on E obtained at all the pixel coordinates in O_f. It is considered as the least cost path. Finally, pixels are adopted so that both patches may be sewn up according to the least cost path. Although equation (5) is an energy function in case of overlap region O_f and O_g connected horizontally, the energy is similarly calculated in case that two patches are connected perpendicularly. And the least cost path is obtained in the same way.

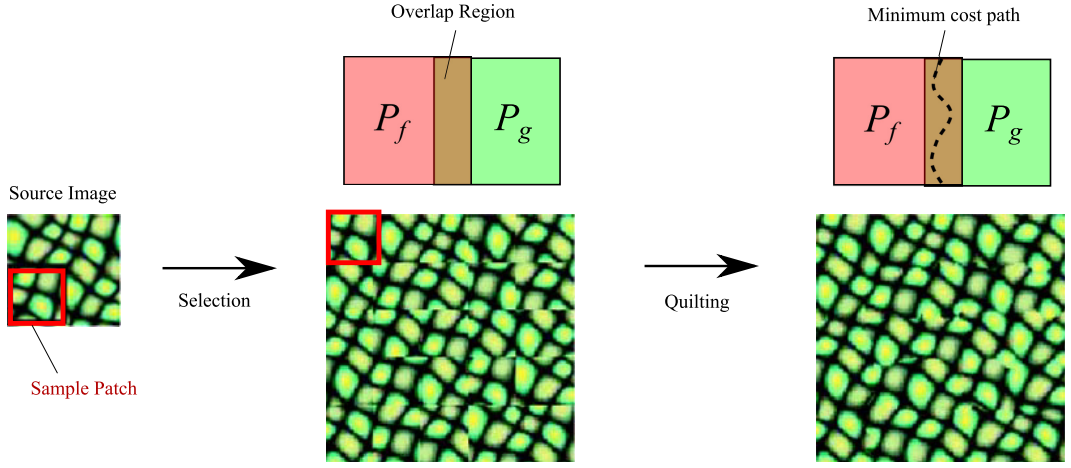


Fig. 2. Image Quilting

After that, repeating this process from "searching of candidate patches" to "removing discontinuities", the texture expansion is performed. The least-cost path in an overlapping area of the neighboring patch is calculated, the patches are connected by sewing along the path, and some artifacts are reduced. A potential, which unnatural edges between neighboring patches occur, still remains in this approach.

2.2. Poisson Image Editing

Poisson Image Editing (PIE)[10] is a famous technique to composite images seamlessly by solving the Poisson equation with Dirichlet boundary conditions. This technique clips an arbitrary particular area from the source image in order to compound in the specified location within a target image. Then it creates a Poisson equation from the Laplacian of the source image. And it generates an image by solving the poisson equation which consists of Dirichlet boundary conditions which let the pixel value of the target image be a boundary value. But, if just tiled images are used for texture mappings, a repetitive and regular pattern would be occurred.

2.3. Application of PIE to the sewing processing of IQ

We shall describe about a way to generate a large texture image seamlessly without changing the texture feature of the input image by using PIE to sew up the overlapping area of IQ. Below are the steps of that algorithm[8].

At First, we randomly select an initial patch P_f from an input image $\mathbf{I}$. Then, select multi-candidate patches Φ_{P_g} similar to P_f from $\mathbf{I}$, and randomly choose P_g satisfying equation (1) from among the candidates Φ_{P_g}. Next, Target image of overlapping area O_f is achieved by equation (6)

$$O_f(u,v) = \frac{1}{|N_f(u,v)|} \sum_{(u',v')\in N_f(u,v)} \left\{ O_f(u',v') + O_g(u,v) - O_g(u',v') \right\} \tag{6}$$

where, let $O_f(u,v)$ be an intensity of a pixel (u,v) in the target image O_f, $O_g(u,v)$ be an intensity of pixel (u,v) in the overlapping area O_g, $N_f(u,v)$ be a set of neighboring pixels to (u,v). $O_g(u,v)$ is used as initial state of

Algorithm 1 Texture Extension

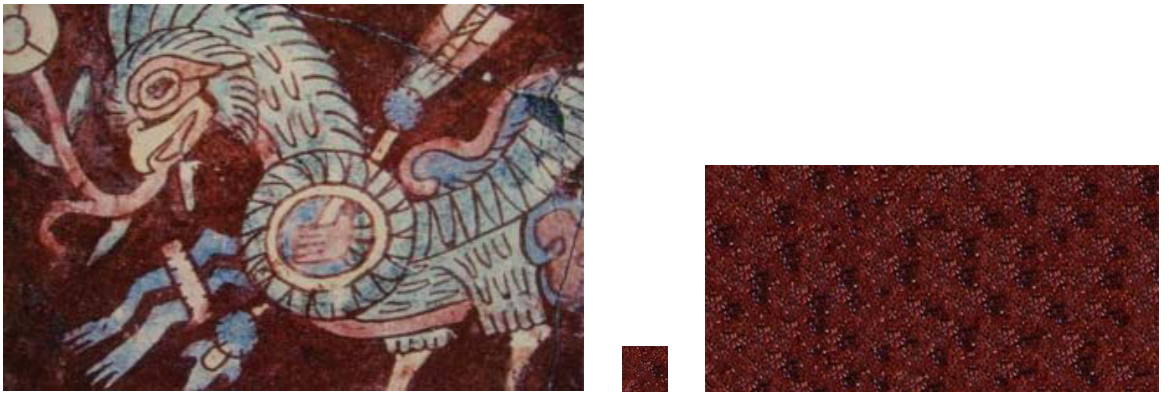
1: Randomly select an initial patch P_g from an input image I.
2: Select multi-candidate patches $\Phi_{P_g} = \left\{P_g \mid d(O_f - O_g) \leq d_{\max}, P_g \subset \mathbf{I}\right\}$
3: **while** ΔO_f not converged **do**
4: $$O_f = \frac{1}{|\mathbf{N}_f(u,v)|} \sum_{(u',v') \in \mathbf{N}_f(u,v)} \left\{O_f(u',v') + O_g(u,v) - O_g(u',v')\right\}$$
5: $$\Delta O_f = \sum_{(u,v)} \left|O_f(u,v)^i - O_f(u,v)^{i-1}\right|$$
6: **end while**

$O_f(u,v)$. Repeat until the change of pixel values ΔO_f of equation (7) become in sufficiently small. Then the optimal $O_f(u,v)$ is determined.

$$\Delta O_f = \sum_{(u,v)} \left|O_f(u,v)^i - O_f(u,v)^{i-1}\right| \tag{7}$$

where, let $O_f(u,v)^i$ be the intensity value $O_f(u,v)$ at the i-th iteration. By repeating the above process, the texture image can be expanded to any size. And, the texture image has various complex patterns, even as unnatural connection between neighboring patches can be reduced.

The example which created the texture expansion from a mural painting image is shown in Fig.3. Fig.3(b) is one of the extracted small areas from the mural painting in Fig.3(a). They were the basis for the image of Fig.3(c). The size of the source image, a patch, the overlap width and an output image were 64[pixel], 30[pixel], 6[pixel],and 12822[pixel] in that order.



(a) (b) (c)

Fig. 3. (a) Mural painting of a bird with a shield and a spear; (b) Sample patch; (c) A part of output image.

3. Image Reproduction Using Traced Drawing

We shall describe about the image reproduction of a heavy damaged mural painting whose a most area of the face or the body of an animal have been lost when the traced drawing is existence. At that time, composition, an arranged method [8], which applies PIE for the sawing of IQ method, is used in order to realize seamless texture. The traced drawings, which are presented by specialists, are published in a literature [12]. The outline of image reproduction of a damaged mural painting is shown in Fig.4. A reproduction algorithm is roughly divided into "the segmentation of a traced drawing" and "texture composition in each segment."

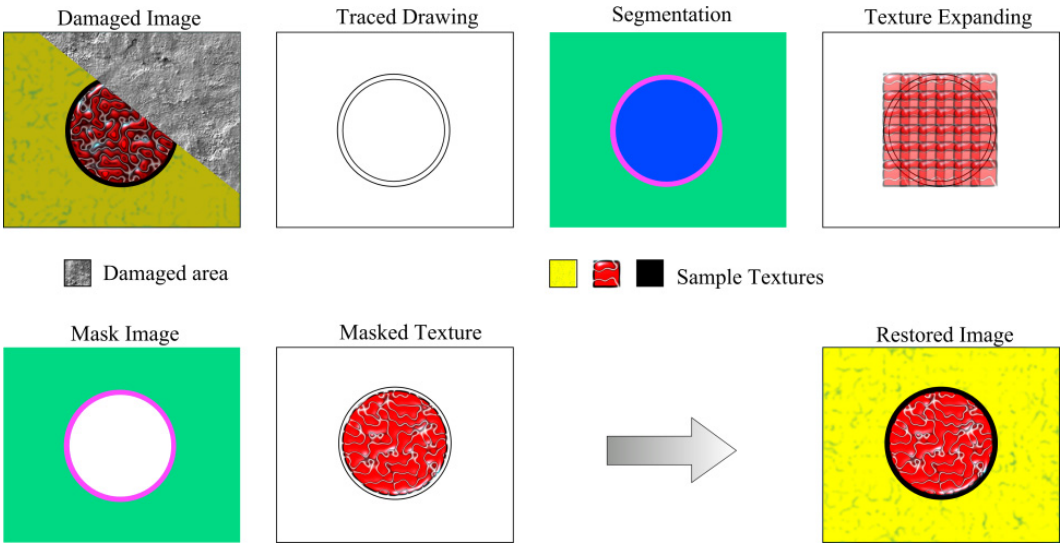


Fig. 4. Image reproduction process

Algorithm 2 Image Reproduction Method Using Traced Drawing

1: Segmentation of a traced image to super pixels
2: Generation of sample textures
3: Create mask image for each segment
4: Apply texture composition in each segment

First, the efficient graph-based image segmentation [11] is used for the region segmentation of a traced drawing. This technique sets up an edge weight between pixels, and performs the region segmentation from relation of this edge.

Secondly, the texture images for all color pigment, which are used in the mural painting, are created as sample textures according to the previous method [8]. There is enough componential analysis about pigments to investigate where they are and what they are [12]. Based on the result of that analysis, sample textures are created by extraction from mural paintings which have actually been restored by conservators.

Thirdly, a mask is created for every segment after changing a region into a fitting rectangle from the four peak coordinates of the right-and-left sides and top-and-bottom sides. Finally, the texture expansion is applied for every mask. As shown in Algorithm 1, an initial patch is chosen, and it begins from the upper left of the target region. And the extension processing is performed by extracting each patch from a sample texture at random. After that, the image pixels are repainting for every mask by the textures expansion. Through the above processing, we can complete the image reproduction of the whole mural painting including all missing parts.

4. Experimental Result for Real Mural Painting

A mural painting image was actually reproduced from a heavy damaged mural painting image using restored one and a traced drawing. The damaged image and its traced drawing are shown in Fig.5(a), (b). The head and the limbs of the jaguar are absent as shown in this figure. The texture of such a missing part cannot be restored by the conventional technique. Moreover, the surface has been weathered and the color has faded severely (especially black). And fine cracks and abrasions are everywhere.

Next, the result applied the region segmentation is shown in Fig.6(a). The number of segments is 120 pieces in all. The pigment of each part used for restoration obeyed the information described in the literature [12], and the sample textures were obtained from pictures of other painting images actually repaired by renovators. The reproduced mural painting image is shown in Fig.6(b).

(a) (b)

Fig. 5. (a) Damaged image; (b) Traced drawing.

We can confirm that the image with the new visual information, which does not exist in the original mural painting, was generated. However, by judging subjectively, there is some place where the textures are not unified. Because there was no correspondence of photographing conditions of restored images from which sample textures are extracted, or no correspondence of the resolutions (DPI) of all images to be used for the image reproduction. The actual restored image of the mural painting has been photographed with a different resolution from the source image. So, the image resolution of every sample texture is inequable. It causes the difference of quality subjectively. It is necessary to adjust the resolution of every sample texture to suit the picture of an actual mural painting.

And, the sample texture is extracted from the picture taken in the National Museum of Anthropology and the Murals Museum. Because the condition of the light depends on museums or show spaces at which mural paintings were located, there is a possibility that a difference of quality could be occurred. The shadow and shading in the picture should be removed in advance.

5. Conclusion

In this study, we proposed the technique to reproduce a texture image from a heavy damaged mural painting image. To bring this about, we applied the region segmentation to a traced drawing where the specialist guessed and drew about a missing part of the damaged image, and applied the texture extension to each segment using images of actually restored mural paintings. Although the grand truth of the texture information does not exist for the missing part of the mural painting, we reproduced in conformity with the literature which indicates a traced drawing and the pigments for the actual mural painting.

By applying this technique to many shrines, houses, ruins and remains, we expect the digital archives to be conducted furthermore. Digital archives and resulting appearance by very realistic CG are greatly useful for not only a significance such as preservation of the documentary information but also the investigation research future. Moreover, the distribution of restored visual information to the world through a computer network could help understand religious perspective of ancient Mesoamerican indigenous people more deeply and correctly. And it could develop further research and education. As mentioned above, the meaning of the digital archives by 3D CG is great. It is expected that the result of this research will be harnessed.

Future works are an examination of the way of quantitive valuation about restored images of mural paintings and an automatic determination of the sample texture used for every segment. It is important to check the effectiveness of the proposed method by getting specialists to evaluate the generated images from now on.

(a) (b)

Fig. 6. (a) Region segmentation; (b) Reproduction result.

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