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Image Cloning Research Challenges

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Abstract: ***Seamless cloning of a source image patch into a target image is an important and useful image editing operation, which has received considerable research attention in recent years. This operation is typically carried out by solving a Poisson equation with different boundary conditions, which smoothly interpolates the discrepancies between the boundary of the source patch and the target across the entire cloned area. In this paper, different approaches like alpha matting, gradient domain, mean value coordinates are introduced. In gradient domain methods obtain the final cloning result in the cloned region by solving a Poisson equation, which eventually solves a large sparse linear system. The results of gradient domain methods are seamless and match well with the destination image on the overall appearance. In coordinate-based approach, where rather than solving a large linear system to perform the aforementioned interpolation, the value of the interpolant at each interior pixel is given by a weighted combination of values along the boundary. Style-aware image cloning allows users to seamlessly insert any photorealistic or artificial objects into an artwork to create a new image that shares the same artistic style with the original artwork. Extensive experimental results demonstrate the effectiveness of these methods***.

Keywords ***Image editing, image gradient, mean value coordinates, Poisson equation, seamless cloning.***

I. INTRODUCTION

Image compositing is widely applied in image and video editing tasks, which may be effectively accomplished by alpha blending and gradient domain methods. Alpha blending is the process of combining an image with a background to create the appearance of partial transparency. The accurate alpha matte is necessary in order to achieve good composite results. Instead, gradient domain methods obtain the final cloning result in the cloned region by solving a Poisson equation, which eventually solves a large sparse linear system. The results of gradient domain methods are seamless and match well with the destination image on the overall appearance.

Solving large linear systems is usually expensive. Recently, a novel seamless cloning approach that used mean value coordinates to achieve similar results to that of Poisson image cloning. The main advantages of coordinates-based approaches are easy to implement, fast to compute in parallel, and unnecessary to solve a large linear system. However, users often need to draw the boundary of the cloned regions carefully when applying the Poisson method and the coordinates based method in order to achieve satisfactory results.

Alpha blending may preserve original color of the source patch, but its result does not match well with the destination image on the luma when the luma between the source and destination images is significantly different. Although the gradient domain cloning method usually matches well on the overall appearance, it produces the smudging and discoloration artifacts when the texture near the boundary between the source patch and the destination patch is not sufficiently similar.

To clone a given object, two factors should be considered. First, the pixels in the source image, which do not belong to the object region, should not contribute to the final result. Only those pixels within the object region should be processed. Second, the compositing should be as natural as possible. Besides the seamless boundary, the luma of the composite image should match well with that of the destination image, and its chroma should be as similar as possible to that of the source image in most cases. Alpha matting can extract objects accurately with their color preserved, while the gradient domain method can produce results with seamless boundary.

According to above analysis, methods used for image cloning purpose are described as:

(i) Alpha matting Matting It is one of the key techniques in many image editing applications. Various matting techniques have been proposed to efficiently extract foreground objects from images. Image matting techniques can be classified into color sampling-based and affinities-based. Color sampling-based methods define nearby known foreground and background pixels as samples and then use them to estimate alpha values of unknown pixels. These methods work well when the input image contains smooth regions and the trimap is well-defined. Affinities based methods use local image statistics by defining

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various affinities between neighboring pixels in a small window. For complex images, affinities-based methods are more robust than color sampling-based methods. However, sometimes small errors of the matte values could be accumulated to produce bigger errors because of the propagation feature in affinities-based methods. Thus, some optimization methods, which combine sampling methods and affinities together, are introduced for more accurate and robust matting results. Moreover, learning based, segmentation-based, fast large kernel, and shared sampling methods were introduced to obtain higher matting quality[3].

(ii) Gradient domain image cloning Over the past few years, researchers have made significant advances in image cloning using gradient domain methods. Poisson image editing method introduced to seamless cloning images by solving a Poisson equation in the gradient domain. Further this method is improved by optimizing the blending boundary. A method to remove boundary smudging artifact by a blending mask is introduced. An error-tolerant approach that was robust to inaccuracies and could prevent color bleeding without changing the boundary location. A hybrid image compositing method combine improved Poisson blending and alpha blending. An image composition method is introduced that faithfully preserves the color of regions specified by user manual markup. Gradient domain techniques is extended by reconstructing images from a much larger set of filter outputs and integrated harmonization into the composite result. Several fast optimized solvers for gradient domain methods were proposed in past several years[4].

(iii) Coordinates-based image cloning As a standard interpolation technique, coordinates solve a boundary-value interpolation problem and can be used to interpolate discrete scalar or vector fields. Coordinates are used to solve the transfinite interpolation problem in image cloning. Similar Poisson image cloning results using mean value coordinates is obtained instead of solving an expensive Poisson equation. The idea is to interpolate interior pixels by a weighted combination, i.e., coordinates, of values along the boundary. Improved coordinate-based image cloning algorithm provided a modified sampling algorithm to deal with concave regions that were problematic in coordinates for instant image cloning. Recently, several methods that combine mean value coordinates with matting techniques have been proposed like, A content-aware image cloning method using a weight function combining the alpha matting technique with the Poisson method, An optimized mean value cloning method to eliminate artifacts in seamless video cloning, Harmonic cloning which used harmonic coordinates instead of mean value coordinates for image cloning, An image cloning algorithm which took the prevailing illumination effect into account in the destination image. They constructed a reference image based on the global illumination of the destination image and then diffused the reference image into the cloned patch. All above mentioned coordinates-based methods deal with the region cloning [5].

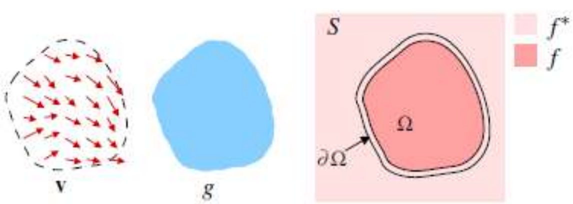

Figure 1 Guided interpolation notations[1]

2. Poisson solution to guided interpolation

In this section, we detail image interpolation using a guidance vector field. As it is enough to solve the interpolation problem for each color component separately, we consider only scalar image functions. Figure 1 illustrates the notations: let *S*, a closed subset of R^2, be the image definition domain, and let W be a closed subset of *S* with boundary $\partial\Omega$. Let f^* be a known scalar function defined over S minus the interior of Ω and let f be an unknown scalar function defined over the interior of Ω. Finally, let **v** be a vector field defined over Ω.

The simplest interpolant *f* of *f** over W is the membrane interpolant defined as the solution of the minimization problem:

$$min \iint_{\Omega} |\nabla f|^2 \quad and \quad f|_{\partial\Omega} = f^*|_{\partial\Omega} \qquad (1)$$

where $\nabla = [\partial/\partial x, \partial/\partial y]$ is the gradient operator. The minimizer must satisfy the associated Euler-Lagrange equation

$$\Delta f = 0 \; over \; \Omega with \; f|_{\partial\Omega} = f^*|_{\partial\Omega} \qquad (2)$$

Where $\nabla = [\partial^2/\partial^2 x, \partial^2/\partial^2 y]$ is the Laplacian operator. Equation 2 is a Laplace equation with Dirichlet boundary conditions. For image editing applications, this simple method produces an unsatisfactory, blurred interpolant, and this can be overcome in a variety of ways. One is to use a more complex differential equation as in the "inpainting" technique. The route proposed here is to modify the problem by introducing further constraints in the form of a guidance field as explained below.

A guidance field is a vector field **v** used in an extended version of the minimization problem (1) above:

$$min \iint_{\Omega} |\nabla f - v|^2 \quad and \quad f|_{\partial\Omega} = f^*|_{\partial\Omega} \qquad (3)$$

whose solution is the unique solution of the following Poisson equation with Dirichlet boundary conditions :

$$\Delta f = div\ v\ over\ \Omega with\ f|_{\partial\Omega} = f^*|_{\partial\Omega} \qquad (4)$$

where $div\ v = \partial u/\partial x, \partial v/\partial y$ is the divergence of v = (u; v). This is the fundamental machinery of Poisson editing of color images: three Poisson equations of the form (4) are solved independently in the three color channels of the chosen color space. All the results reported in this paper were obtained in the RGB color space, but similar results were obtained in CIE-Lab for instance.

When the guidance field **v** is conservative, i.e., it is the gradient of some function g, a helpful alternative way of understanding what Poisson interpolation does is to define the correction function $\tilde{f}$ on Ω such that $f = g + \tilde{f}$. The Poisson equation (4) then becomes the following Laplace equation with boundary conditions:

$$\Delta\tilde{f} = 0\ over\ \Omega with\ f|_{\partial\Omega} = (f^* - g)|_{\partial\Omega} \qquad (5)$$

Therefore, inside Ω, the additive correction $\tilde{f}$ is a membrane interpolant of the mismatch $(\tilde{f} - g)$ between the source and the destination along the boundary ∂Ω. This particular instance of guided interpolation is used for seamless cloning[1].

3. Environment-Sensitive cloning in images

Let $S \subset R^2$,$T \subset R^2$ and $R \subset R^2$ be the domains of source, target and reference images. The intensities of these images are denoted by g: S→R, f: T → R and ξ : R→R, respectively. Let $\Omega \subset R^2$ be the region to be cloned with the boundary ∂Ω.

3.1 Global feature extraction

In general, the appearance of an object in the scene is mainly determined by the illumination conditions. However, regarding a single image, there are no simple methods to extract and represent the illumination features. When we observe a single image carefully, a lot of cues in it can tell us its illumination features (e.g. the position of the sun can be indicated by the shadows on the ground or the shading on vertical objects, and the appearance of the existing objects in the scene can also tell us the illumination conditions). With this in mind, we make use of these cues in a single image to extract the illumination features of the target scene by human interactions, and create a reference image ξ to represent the extracted features, which can then be easily diffused into the cloned patch by gradient-based method. As shown in Fig. 2(a), the light direction is marked by a white arrow, which indicates that the right part of ξ should be brighter, while the left part is darker. The size of ξ is the same as the boundary box of the cloned patch.

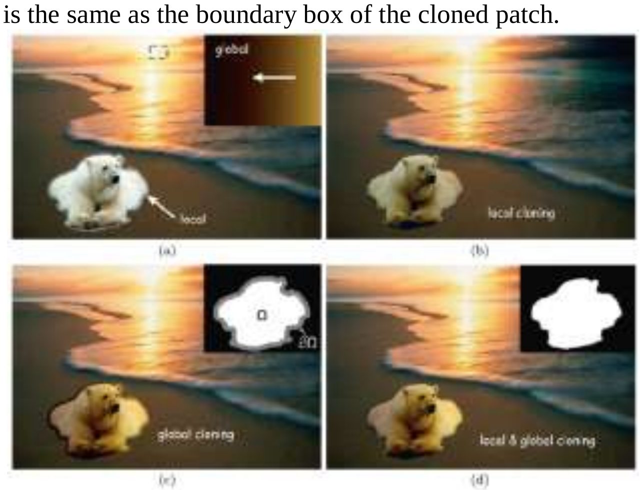

Figure 2 An example of Environment-Sensitive image cloning [2]

We focus on constructing the reference image ξ when there is a prevailing illumination from a certain direction in the target scene. The construction of ξ is in LAB color space which separates the lightness L and color component A&B effectively. The lightness L can be set as shown in Fig. 3, after simple interactions, the lightness distribution of the reference image can be expressed by

$$\xi_L(w,h) = \left(\frac{dis(w,h,N)}{d_M}\right)^{\tau} * V_M \qquad (6)$$

2.14

where N is a line perpendicular to the direction of red arrow, and the position of N is indicated in Fig. . V_M is the maximum lightness, and dis(w,h,N) is the distance of pixel (w,h) to N, while d_M is the distance from the farthest pixel of ξ to N. τ is used to control the illumination changes in ξ. See Fig. 3 for the distance definition in details.

Next, we consider the color style of the reference image. We first transform the target image from RGB to LAB color space, and then select a region in the target image which represents the color style of the target scene. As shown in Fig. 2(a), we select a region in the sunset with a rectangle, and then compute the mean values of color component $Mean_A$ and $Mean_B$ in it. For all pixels in the reference image, their A&B components are set to $Mean_A$ and $Mean_B$, respectively.

After calculating the lightness L and color components A&B, the reference image ξ is constructed in LAB which is then converted to the RGB color space. The top-right corner of Fig. 2(a) is an example of reference image constructed by our method, which characterizes the global feature of the target scene.

3.2 Approach of Environment-Sensitive image cloning

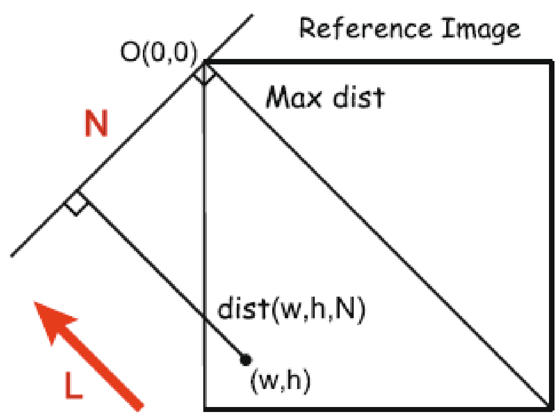

Figure 3 Distance definition for creating a reference image[2]

Our cloning approach combines the local and global features of the target scene. As shown in Fig. 2(a), the global feature is represented by a reference image ξ, while the local feature refers to the pixels' color on the cloning boundary of target image.

Since the essence of gradient-based cloning is to construct a harmonic interpolant *R(x)* which diffuses the discrepancies on the boundary of the source and target image into the cloned patch, the final result can be simply expressed as,

$$f(x) = g(x) + R(x) \quad (7)$$

When the global feature is diffused into the cloning area by constructing a harmonic interpolant $r_1(x)$, as shown in Fig. 2(c), the cloned patch appears to be consistent with the target scene. However, the visible seam exists near the cloning boundary. To remove the seam, the local feature should be taken into account by constructing a harmonic interpolant $r_2(x)$ to diffuse the discrepancies on the cloning boundary of target and source images. See Fig. 2(b), the cloned patch is pasted into the target scene seamlessly while ignoring the global illumination feature.

The unsatisfactory results above arise because the global and local features are considered separately. We believe that these features should collaborate to yield satisfactory results. Thus, we construct a new interpolant R(x) which is a linear combination of the interpolant used in global and local diffusion. For important region of the cloned patch whose appearance should be changed to match the target scene, a larger factor should be given to the global interpolant. While for region near the cloning boundary, the visible seam should be smoothly diffused, so that the local interpolant is given a larger factor. Thus, it is natural to express the factor by alpha matte $\alpha : S \rightarrow [0, 1]$. α represents the extent to which a pixel's color is influenced by the local and global features of the scene. Thus the interpolant R(x) can be expressed by

$$R(x) = \alpha(x) r_1 + \big(1 - \alpha(x)\big) r_2(x) \quad (8)$$

Where $r_1(x)$ and $r_2(x)$ are the interpolants of global and local diffusion, respectively. As shown in Fig. 2(d), when the interpolants are constructed by (8), the source patch can be pasted into the target scene seamlessly and naturally.

3.3 Implementation of Environment-Sensitive image cloning

Unlike the previous cloning approaches, we do not have to specify the region to be cloned by drawing a boundary. Since we have to create a trimap for calculating alpha matte of the source image, the cloning boundary $\partial\Omega$ can be given by the outer boundary of trimap, as shown in Fig. 2(c). As the traditional gradient cloning involves solving a PDE, which is time and memory consuming, we prefer to employ Mean-Value Coordinates (MVC) to approximate a harmonic membrane without solving a large linear system. Given the cloning boundary (the points are ordered counter clockwise) ∂Ω = (P0, P1, . . . , Pn−1,P0), Pi ∈ R2. The MVC of a point x ∈ R2 inside the region Ω are given by

$$\lambda_i(x) = \frac{w_i}{\sum_{i=0}^{n-1} w_i} \quad i = 0, \dots, n-1 \qquad (9)$$

$$\text{Where, } w_i = \frac{\tan\left(\frac{\alpha_{i-1}}{2}\right) + \tan\left(\frac{\alpha_i}{2}\right)}{||p_i - x||} \qquad (10)$$

α_i is the angle $\angle P_i x P_{i+1}$.

After calculating the MVC of the points in Ω, the discrepancies on the boundary of source and target image can be smoothly diffused into the entire region Ω by constructing a harmonic interpolant. Guided by MVC, the harmonic interpolants r1(x), r2(x) can be expressed as

$$r_1(x) = \sum_{i=0}^{n-1} \lambda_i(\xi(P_i) - g(P_i)) \qquad (11)$$

$$r_2(x) = \sum_{i=0}^{n-1} \lambda_i(f^*(P_i) - g(P_i)) \qquad (12)$$

As the cloning boundary does not change in the diffusion process of global and local features, the mean-value coordinates *λi(x)* can be shared by *r1(x)* and *r2(x)*, which takes *∂Ω = (P0,P1, . . . , Pn−1,P0),Pi* ∈ R2 as the boundary. 2.20

After MVC has been introduced into (7) and (8), the final cloning result can be expressed by

$$f(x) = g(x) + \sum_{i=0}^{n-1} \lambda_i(\xi(P_i) - g(P_i)) + \sum_{i=0}^{n-1} \lambda_i(f^*(P_i) - g(P_i)) \qquad 2.19$$

Equation (13) is not only an implementation of our Environment-Sensitive cloning, but a general model for image cloning. Note that the color discrepancies on the cloning boundary is expressed by $(\alpha\xi + (1 - \alpha)f^* - g)$, which means that the target boundary condition is determined by both the reference image ξ and target image f^*- α is used to control the target boundary condition in the following way: the interpolants of pixels with higher α value will be mainly determined by the reference image ξ . While for pixels with lower α value, their interpolants are influenced by the target image f^*. Thus, the global feature will be diffused into the important part of the cloned patch, while the unimportant part (e.g. the region near the cloning boundary) will blend with the target image seamlessly.[6]

3.4 MVC cloning with hybrid boundary

The pixels classified near the cloning boundary into two types: M_1 consists of pixels where texture and color between the source and target are consistent, and M_2 refers to the inconsistent boundary. In M_1, direct Poisson Blending is used by solving a Poisson equation with a Dirichlet boundary, while in M_2, the Poisson equation is solved with a Neumann boundary. Thus, the cloning result is calculated by solving a Poisson equation with hybrid boundary, as shown in (14).

$$\Delta f' = div\ v\ over\ \Omega, with$$
$$f'|M_1 = f'\ and\ \nabla f'|M_2 = \nabla f_f^s \qquad (14)$$

In the previous sections, we assume that the boundary of source patch and target image are consistent, thus the MVC-based method can be applied directly in image cloning. However, when their boundaries are inconsistent, direct MVC-based approach will cause smudging and discoloration artifacts, see column (c) of Fig. 2. The Poisson blending with hybrid boundary involves solving a large linear system, which is memory and time consuming. Thus, we propose an interpolation method based on MVC with hybrid boundary to improve the efficiency. For the boundary in M_2, their first derivatives are known while their values are unknown. First, we set their values to b x_1, x_2, x_3… Then, we calculate the MVC interpolation of the points n_1,n_2,n_3, . . . which is on in the neighbor of M_2, see column (a) of Fig. 2 for details. Thus, the values of n_1,n_2,n_3,.. are a linear combination of x_1, x_2, x_3..

Next, a linear system can be figured out according to the Neumann boundary in M_2, see 2.26.

$$x_i - \sum_{p \in M_1} w_i(p)\Big(f'(p) - g(p)\Big) - \sum_{q \in M_1} w_i(q)\Big(x_q - g(q)\Big) = 0 \qquad (15)$$

where wi(p) and wi(q) are the MVC interpolation weights for neighboring points n_1,n_2,n_3, . . . of xi in M_1 and M_2. This non-sparse linear system is small in size, which could be solved very fast by LU factorization. After calculating the values x_1, x_2, x_3, . . . on the boundary in M_2, direct MVC is applied to get the final result. See column (d) of Fig. 2 for MVC-based cloning results with hybrid boundary, the results show that our method can produce more natural results than previous gradient-based methods, such as MVC, content-aware image cloning. In addition, the time and memory costs are largely reduced compared with solving a large linear system in Poisson blending, which makes the cloning with hybrid boundary possible for practical use, e.g. image editing and video cloning[2].

CONCLUSION

In this paper various methods of Image cloning are explored and discussed. Poisson image editing is used which is based on gradient domain method. It smoothly interpolate the discrepancies between the boundary of source patch and target image to the entire cloned area; it involves solving a large sparse linear system which is time and memory consuming. To overcome this, Mean value coordinates based method is used which effectively guarantee seamless boundaries between the cloned objects and the target image, but when the styles between the interiors and exteriors of an object are quite different, unnatural compositions may arise.

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