A Seamless Image Editing Technique Using Color Information

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Abstract - *This paper suggests a Poisson equation based method for editing color images. In Poisson image editing, a guided vector field is first obtained by using source and target images, within a selected region. The guided vector is then used in creating the output image. Most of the existing techniques perform image editing without considering color information. However, image structure cannot be generated properly without utilizing color information in some cases, and therefore acceptable results cannot be created. Unlike those methods, the proposed study uses color information in image editing and the generated results by the method seem to be in acceptable specifications.*

Keywords: Poisson Equation, Guided Interpolation, Color Image Editing, Color Image Gradient, Seamless and Mixed Seamless Cloning, Texture Flattening.

1 Introduction

Image editing operation is related with global changes such as image correction, filtering, colorization or local changes in a selected region where the altering operations take place. One example of this is the commercial or artistic photomontages that consider the local changes. Along with the technologic improvement in this research topic, quite number of software has been developed for photo editing such as Adobe Photoshop. But, professional experience is required to be able to use these kinds of software skillfully and editing photos using the software takes a long time. Additionally, the edited image regions may include some visible corruptions.

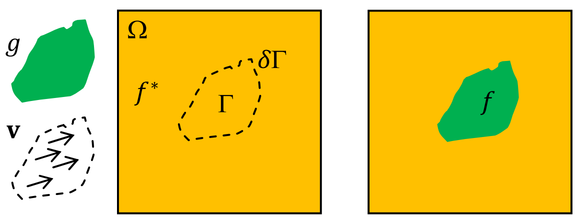
In recent years, the image editing methods based on The Poisson equation have been frequently employed [1-6]. An image editing method was presented by Perez *et al*. based on the Poisson equation with Dirichlet boundary conditions [1]. But, using this method, color inconsistencies occurred in edited image regions. An image matting approach using the Poisson equation is suggested by Sun *et al.* [2]. However, due to a long processing time, the method is not practically usable. Chuan *et al.* improved the method presented by Perez *et al.* to overcome the color inconsistency problem [3]. But the experiments show that the improved method is still very complex. Leventhal *et al.* suggested an alpha interpolation technique to remove brightly colored artifacts caused by mixed seamless cloning in the result [4]. Jia *et al.* presented an image editing method, called drag-and-drop pasting, which computes an optimized boundary condition automatically by employing a new objective function [5]. But this study compares the developed method not with mixed seamless cloning but with only seamless cloning method proposed in [1]. Georgiev suggested a new method that is invariant to relighting and handles seamlessly illumination change, including adaptation and perceptual correctness of the results [6]. The method processes the image by considering its texture information. However, all of the above methods are complex and may cause some artifacts due to independent implementation of methods on each color channel.

We suggested an image editing method based on the Poisson equation, which utilizes color information. The proposed method successfully edits the image in a seamless manner.

2 Image Editing

Let $\mathbf{f}: \Omega \rightarrow \mathbb{R}^n$ and $f: \Omega \rightarrow \mathbb{R}$ be color image $(n = 3)$ and grayscale image, respectively, and they are defined on domain of $\Omega \rightarrow \mathbb{R}^2$. Also let $f_i: \Omega \rightarrow \mathbb{R}$ represent the image channel i of $(1 \leq i \leq n)$: $\forall \mathbf{p} = (x, y) \in \Omega$. The method is explained in detail in the following sections.

Poisson image editing is basically the process of generating a new result image f based on the source image g and target image f^*. In this method, guided vector field $\mathbf{v}$ is first created using the images g and f^*. Then, the method tries to generate the image f by using Dirichlet boundary conditions so that the gradient of f is closest in the L_2-norm to $\mathbf{v}$ over the region Γ, given $f = f^*$ over $\delta\Gamma$. Therefore the edited image region includes the features of both images g and f^* and matches the rest of the image (Figure 1).



(a) (b)

Figure 1. Source, target images and guided vector field (a), and result image edited by the Poisson equation method (b).

A basic approach for interpolation process is to minimize the variation of image f over region Γ by estimation of gradient norm $\|\nabla f\|$:

$$\inf_{f:\Gamma\to\mathbb{R}} E(f) = \iint_{\Gamma} \|\nabla f\|^2 \, d\Gamma \, , f|_{\delta\Gamma} = f^*|_{\delta\Gamma} \tag{1}$$

As defined in (Eq. 2), the *image gradient* denoted by ∇f is the derivation of *scalar* (*grayscale) image* f with respect to its spatial coordinates $\mathbf{p} = (x, y)$:

$$\nabla f = \left(f_x, f_y\right)^T = \left(\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}\right)^T \tag{2}$$

In order to represent magnitudes of the scalar image f and its maximum variation directions, a vector $\nabla f: \Gamma \to \mathbb{R}^2$ is created. Scalar and pointwise measure of the image variations are given by the *gradient norm* $\|\nabla f\|$, which is used in image analysis in many cases:

$$\|\nabla f\| = \sqrt{f_x^2 + f_y^2} \tag{3}$$

Here, f_x and f_y are first derivatives of the image f on x and y directions, respectively. These are calculated by Taylor's Formula as follows:

$$\begin{aligned} f(x+1, y) &= f(x, y) + f_x(x, y) + \mathcal{O}(1) \\ f(x, y+1) &= f(x, y) + f_y(x, y) + \mathcal{O}(1) \end{aligned} \tag{4}$$

Eq. (5) is reached if Eq. (4) is solved using forward finite differences method:

$$\begin{aligned} f_x(x, y) &= f(x+1, y) - f(x, y) \\ f_y(x, y) &= f(x, y+1) - f(x, y) \end{aligned} \tag{5}$$

Finding the function f minimizing the functional $E(f)$ is not an easy task. Necessary condition is given by the *Euler-Lagrange equations*, which must be confirmed by f to reach a minimum of $E(f)$:

$$\frac{\partial E}{\partial f} = \frac{\partial F}{\partial f} - \frac{\partial}{\partial x}\frac{\partial F}{\partial f_x} - \frac{\partial}{\partial y}\frac{\partial F}{\partial f_y} = 0, f|_{\delta\Gamma} = f^*|_{\delta\Gamma} \tag{6}$$

where $F = \|\nabla f\|^2 = f_x^2 + f_y^2$.

The calculation of $\frac{\partial}{\partial x}\frac{\partial F}{\partial f_x}$ and $\frac{\partial}{\partial y}\frac{\partial F}{\partial f_y}$ according to the standard differentiation rules is shown below:

$$\begin{aligned} &\frac{\partial F}{\partial f_x} = \frac{\partial}{\partial f_x}\left[\left(\sqrt{f_x^2 + f_y^2}\right)^2\right] = 2f_x \\ &\frac{\partial}{\partial x}\frac{\partial F}{\partial f_x} = \frac{\partial}{\partial x}(2f_x) = 2f_{xx} \\ &\text{and} \\ &\frac{\partial}{\partial y}\frac{\partial F}{\partial f_y} = 2f_{yy} \end{aligned} \tag{7}$$

Accordingly, $-2\left(f_{xx}+f_{yy}\right)$ is found as a solution to Eq. (5). Constant 2 may be removed from the equation for simplicity. So, $-\left(f_{xx}+f_{yy}\right)$ is reached.

A classic iterative method called *gradient descent* is employed to solve Partial Differential Equation (PDE) in Eq. (1). As a matter of fact, Eq. (1) can be seen as the gradient of the functional $E(f)$. A local minimizer f_{min} of $E(f)$ can be found by starting from f_0 and then following the opposite direction of the gradient:

$$\begin{cases} f_{(t=0)} = f_{initial} \\ \dfrac{\partial f}{\partial t} \quad = -\left(\dfrac{\partial F}{\partial f} - \dfrac{d}{dx}\dfrac{\partial F}{\partial f_x} - \dfrac{d}{dy}\dfrac{\partial F}{\partial f_y}\right) \end{cases} \tag{8}$$

Solving the equation:

$$\frac{\partial f}{\partial t} = f_{xx} + f_{yy} = \Delta f, f|_{\delta\Gamma} = f^*|_{\delta\Gamma} \tag{9}$$

is found. Here, Δ is the Laplace operator, and Taylor's Formula is used in finding second derivatives f_{xx} and f_{yy} as follows:

$$\begin{aligned} f(x+1, y) &= f(x, y) + f_x(x, y) + \frac{f_{xx}(x, y)}{2} + \mathcal{O}(1) \\ f(x-1, y) &= f(x, y) - f_x(x, y) + \frac{f_{xx}(x, y)}{2} + \mathcal{O}(1) \end{aligned} \tag{10}$$

Consequently Eq. (11) is derived from Eq. (10) by summation. Here, f_{yy} is calculated similarly.

$$\begin{aligned} f_{xx} &= f(x+1, y) + f(x-1, y) - 2f(x, y) \\ f_{yy} &= f(x, y+1) + f(x, y-1) - 2f(x, y) \end{aligned} \tag{11}$$

Eq. (9) is called a *diffusion* or *heat equation*.

Basically, Eq. (9) at a particular time t gives the convolution of $f_{initial}$ with a *normalized 2D Gaussian kernel* G_σ of variance $\sigma = \sqrt{2t}$: $f_{initial} * G_\sigma$ means the *linear* smoothing where $G_\sigma = \frac{1}{2\pi\sigma^2}\exp\left(-\frac{x^2+y^2}{2\sigma^2}\right)$ [7].

As seen above clearly, during the PDE evaluation, the image is blurred gradually in an *isotropic way*. Here, isotropic smoothing acts as a *low-pass filter* suppressing high frequencies in the image f. Unfortunately, since image edges and noise are both high frequency signals, the edges are quickly blurred and may be lost by this operation. Therefore interpolation operation based on a guided vector field could generate a better result [1].

Thus, a function minimizing the difference between the gradient ∇f of the image f and the guided vector field $\mathbf{v}$ over region Γ should be found. The equation given below can be used for the operation:

$$\inf_{f:\Gamma\to\mathbb{R}} E(f) = \iint_{\Gamma} \|\nabla f - \mathbf{v}\|^2 \, d\Gamma, f|_{\delta\Gamma} = f^*|_{\delta\Gamma} \tag{12}$$

The result below is found when the above equation is solved by Poisson equation based on Dirichlet boundary conditions:

$$\Delta f = \operatorname{div}\mathbf{v}, f|_{\delta\Gamma} = f^*|_{\delta\Gamma} \tag{13}$$

Here, $\operatorname{div}\mathbf{v} = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}$ is the divergence of $\mathbf{v} = (u, v)$. This is a fundamental equation used in image editing.

The guided vector field $\mathbf{v}$ can be directly obtained from the source image g. In this case, the interpolation operation is conducted considering the equation as follows:

$$\mathbf{v} = \nabla g \tag{14}$$

If the Eq. (9) is reorganized accordingly, Eq. (12) is obtained for seamless cloning:

$$\Delta f = \Delta g, f|_{\delta\Gamma} = f^*|_{\delta\Gamma} \tag{15}$$

At each point of region Γ, if stronger variations on any of source image g or target image f^* is to remain the same, the following vector field can be used for mixed seamless cloning:

$$\forall \mathbf{p} \in \Gamma, \mathbf{v}(\mathbf{p}) = \begin{cases} \nabla f^*(\mathbf{p}) & \text{if } \|\nabla f^*(\mathbf{p})\| > \|\nabla g(\mathbf{p})\|, \\ \nabla g(\mathbf{p}) & \text{otherwise} \end{cases} \tag{16}$$

The guided vector field can be defined as follows to arrange local illumination change in any region of the image:

$$\mathbf{v} = \alpha^{\beta}\|\nabla f^*\|\nabla f^* \tag{17}$$

with $\alpha = 0.2$ times average gradient norm of f^* over Γ and $\beta = 0.2$.

Texture flattening on the image is performed by applying Eq. (18).

$$\forall \mathbf{p} \in \Gamma, \mathbf{v}(\mathbf{p}) = M(\mathbf{p})\nabla f^*(\mathbf{p}) \tag{18}$$

where M is a binary mask obtained by using an edge detection method.

3 The Proposed Method

The method studied in [1] utilizes each color channel of the color image in Poisson Equation independently. However, the exact geometric structure of the image may sometimes not be obtained if the color information is not considered. Consequently the image structure may inaccurately diffuse to the target region. Figure 2 depicts the lightness channel component of the test image in CIE-Lab color base. Examining the image carefully, it is seen that the lightness channel of the image was not able to be obtained properly. In this case, as can be seen in Figure 3.a clearly, insufficient results may be obtained when the image is edited based on gradient information of the channel. Therefore, image editing should be done by considering the effects of color channels on each other.

(a) (b)

Figure 2. Color image (a) and the lightness channel L of the image in CIE-Lab color base (b).

On the other hand, the image gradient can be calculated considering the color information [7] as follows:

$$\forall \mathbf{p} \in \Gamma,\ \mathbf{G}(\mathbf{p}) = \sum_{i=1}^{n} \nabla f_i \nabla f_i^T \quad \text{where } \nabla f_i = \begin{pmatrix} \frac{\partial f_i}{\partial x} \\ \frac{\partial f_i}{\partial y} \end{pmatrix} \tag{19}$$

$\mathbf{G}$ is defined as the following for color images $\mathbf{f} = (R, G, B)$:

$$\mathbf{G} = \begin{pmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{pmatrix} = \begin{pmatrix} R_x^2 + G_x^2 + B_x^2 & R_xR_y + G_xG_y + B_xB_y \\ R_yR_x + G_yG_x + B_yB_x & R_y^2 + G_y^2 + B_y^2 \end{pmatrix} \tag{20}$$

The positive eigenvalues $\lambda^{+/-}$ and the orthogonal eigenvectors $\theta^{+/-}$ of $\mathbf{G}$ are formulized as follows:

$$\lambda^{+/-} = \frac{g_{11} + g_{22} \pm \sqrt{\Delta}}{2} \tag{21}$$

and

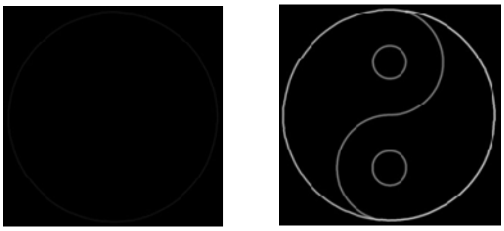
$$\theta^{+/-} = \begin{pmatrix} 2g_{12} \\ g_{22} - g_{11} \pm \sqrt{\Delta} \end{pmatrix} \tag{22}$$

where $\Delta = (g_{11} - g_{22})^2 + 4g_{12}^2$.

More consistent geometry is obtained provided that $\mathbf{G}_\sigma = \mathbf{G} * G_\sigma$ is smoothed by Gaussian filter. Here, $\mathbf{G}_\sigma$ is a good estimator of the local geometry of $\mathbf{f}$ at point $\mathbf{p}$, and its spectral elements give the vector-valued variations (by the eigenvalues λ^-, λ^+ of $\mathbf{G}_\sigma$) at the same time and the orientations (edges) of the local image structures (by the eigenvectors $\theta^- \perp \theta^+$ of $\mathbf{G}_\sigma$).

The *gradient norm* $\|\nabla \mathbf{f}\|$ of color image is easy to compute as follows since it perceives image structures successfully [7] (See Figure 3.b):

$$\|\nabla \mathbf{f}\| = \sqrt{\lambda^+ + \lambda^-} = \sqrt{\sum_{i=1}^{n} \|\nabla f_i\|^2} \tag{23}$$



(a) (b)

Figure 3. Gradient norms calculated based on only lightness channel *L* of the image in CIE-Lab color base (a) and color information (b).

As a result, Eq. (15-18) can be rewritten as below by taking color information into account. Seamless cloning, mixed seamless cloning, arrangement of local illumination changes and texture flattening are stated in the following Eq. (24-27) respectively.

$$\Delta f_i = \Delta g_i, f_i|_{\delta\Gamma} = f_i^*|_{\delta\Gamma} \tag{24}$$

$$\mathbf{v_i} = \begin{cases} \nabla f_i^* & \text{if } \|\nabla \mathbf{f}^*\| > \|\nabla \mathbf{g}\|, \\ \nabla g_i & \text{otherwise} \end{cases} \tag{25}$$

$$\mathbf{v_i} = \alpha^{\beta} \|\nabla \mathbf{f}^*\| \nabla f_i^* \tag{26}$$

$$\mathbf{v_i} = \mathbf{M} \nabla f_i^* \tag{27}$$

where $\mathbf{M}$ is the binary image obtained using $\|\nabla \mathbf{f}^*\|$.

4 Experimental Results

The proposed method is compared with the approaches suggested in [1] and [5] by utilizing seamless and mixed seamless image editing methods, arrangement of local lightness variation method, and texture flatting approach. The methods are tested on color images containing RGB color channels. The test images for visual results of the techniques are given in Figure 4-7. The proposed editing operation is performed on only the selected region marked by user.

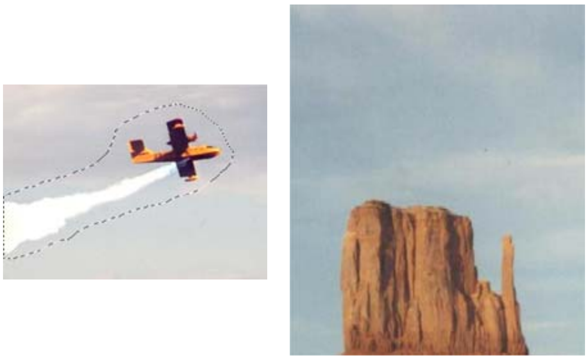
The test results of seamless and mixed seamless cloning suggested in [1] and by our proposed method are given in Figure 8. Both of two approaches of seamless editing method cause blurring on some parts of edited region of target image. However, mixed seamless editing method does not cause any blurriness on the result image. As can be seen in Figure 8.d, there is almost no color inconsistency on the result image generated by the proposed method since the color information is used in editing the image. This situation can be clearly observed on variation of color of fume in the result image.

The test results for seamless cloning proposed in [5] and mixed seamless cloning in our study are given in Figure 9. The former method performs very complex operations to find an optimized boundary condition. Unlike this method our proposed method is very simple and it is as effective as the former one.

The results obtained by applying local lightness arrangement methods are given in Figure 10. As can be observed in Figures 10.a-b, both the method proposed in [1] and our proposed method produced acceptable result in terms of the visual quality.

The results of texture flattening methods are given in Figure 11. It is seen that our method properly flattened the selected region on the test image.

The methods were implemented in Microsoft Visual C++ 2005 by employing *CImg Library* [8]. The program was run on a PC with Pentium 2.20 GHz processor and 2 GB RAM. The average required time changes according to selected regions for image editing. The processing time for the mixed seamless method shown in Figure 8.d is 14 minutes for 5000 iterations.



(a) (b)

Figure 4. Test images used in seamless and mixed seamless cloning methods: source image and selected region on it (a) and target image (b).

(a) (b)

Figure 5. Test images used in mixed seamless cloning methods: source image and selected region on it (a) and target image (b).

Figure 6. Test image used in arranging local lightness variation methods.

Figure 7. Test image used in texture flattening approaches.

(a)

(b)

(c)

(d)

Figure 8. Result images produced using seamless and mixed seamless cloning methods proposed in [1] (a), (c), and in this study (c), (d).

(a)

(b)

Figure 9. Result images produced using seamless cloning methods proposed in [5] (a), and mixed seamless cloning in this study (b).

(a)

(b)

Figure 10. The results of local lightness variation arrangement methods suggested by [1] (a) and our method (b).


(a)


(b)


(c)


(d)

Figure 11. Test results of texture flattening approaches. Gradient norm of image in Figure 7 calculated by proposed method (a), binary mask calculated from the gradient norm (b), the result produced by [1] (c), and the result produced by our method (d).

5 Conclusion

In this study, a method is proposed for editing color images by effectively using color information. In this method, gradient information is utilized by considering the effects of color channels on each other. This consideration minimizes the color inconsistency and thus the selected region in source image is copied to the target image in a seamless manner.

One future task that could improve the result of this method could be performing the editing operation by considering geometry and texture components of images.

6 References

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