

Review Of Digital Image Inpainting Algorithms

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Abstract- Image Inpainting algorithms repair damaged regions of an image so that the image appears normal and the image looks complete and natural after the inpainting process. Since an important part of the scientific and cultural heritage of the modern times has been stored in the form of film and photo archive, Image Inpainting is very important and emerging field of research. Image Inpainting was manually done by painters for removing defect from old paintings and photographs. Filling the missing information from an image using surrounding information is the basic work of inpainting algorithms. In this paper we have studied and reviewed different algorithms implemented in the past for performing Image Inpainting. We have classified some algorithms for Image Inpainting.

Keywords – Partial Differential Equation (PDE). Texture, exemplar.

I. INTRODUCTION

Digital image inpainting deals with filling in missing pixels of an image. Its applications include removing scratches in old photos, removing text or logos, repairing damaged areas in unreliably transmitted images, image zooming, removing undesired objects from an image, and creating artistic effects. It is also one of the important research fields in computer graphics, computer vision and image processing. Inpainting operation itself is not new technique. This operation has been done manually from several decades by experts to modify painting or repair damaged area in a painting. From the time when digital media is widely used, this operation was also brought into digital operation by experts.

The algorithms for filling in missing data can be broadly categorized into the following groups:

1. Partial Differential Equation (PDE) based algorithms.
2. Texture based algorithms.
3. Exemplar and search based algorithms
4. Hybrid both texture and structure

In this paper an extensive survey of previous work related to digital inpainting techniques will be presented. The survey includes scientific techniques used mainly in the research environment. Despite the significant differences between the existent techniques, in the authors manage to draw the main directions that each method must follow. Accordingly, [9] the four steps that make up the underlying methodology of any inpainting algorithm are given as:

1. "The global picture determines how to fill in the gap, the purpose of inpainting being to restore the unity of the work.
2. The structure of the area surrounding the hole is continued into the gap, contour lines are drawn via the prolongation of those arriving at the boundary of the inpainting domain
3. The different regions inside the inpainting domain, as defined by the contour lines, are filled with color, matching those of the boundary of the region to be inpainted;
4. The small details are painted (e.g. little white spots on an otherwise uniformly blue sky): in other words, *texture* is added."

The rest of the paper is organized as follows. PDE based algorithms explained in section II. Texture based algorithms are presented in section III, Exemplar and search based algorithms are discussed in section IV. Hybrid both texture and structure based algorithms are presented in section V, Concluding remarks and future work are given in section VI

II PDE BASED ALGORITHMS.

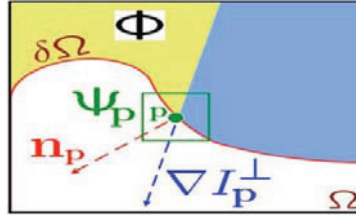


Figure 1

Before presenting the inpainting methods falling under this category, a short definition of a Partial Differential Equation (PDE) will be given. A differential equation contains one or more variables, relating the values of the function itself and its derivatives of various orders. Consequently, a PDE is a differential equation that uses partial derivatives – that is a derivative with respect to one variable, with all other variables held constant.

The fundamentals of image inpainting can be explained by figure 1. Let Ω stand for the region to be inpainted, and $\delta\Omega$ for its boundary. In representing the image, the patch is Ψ_p , n_p is the normal to the contour $\delta\Omega$ of the target region Ω and $\Delta I_p^\perp$ is the isophotes (direction and intensity) at point p . A Partial Differential Equation (PDE) based iterative algorithm proposed by Marcelo Bertalmio [1] paved the way for modern digital image inpainting. Inspired by manual inpainting concepts, this method tries to actually translate the four rules used in manual inpainting into a mathematical and algorithmic language. This paper proposes an algorithm, which is an iterative process propagating linear structures (edges) of the surrounding area called Isophotes, into the hole region denoted by Ω . This diffusion process is defined by the following equation.

$$I^{n+1}(i, j) = I^n(i, j) + \Delta t \cdot I_t^n(i, j), \forall (i, j) \in \Omega \quad (1)$$

where n is the iteration time, (i, j) are pixel co-ordinates, Δt is the rate of the change of inpainting, $I_t^n(i, j)$ is the update factor on the image $I^n(i, j)$. The update factor in the above equation, is a smoothed image obtained by applying a Laplacian operator in the direction perpendicular to the gradient in an iterative fashion. The PDE form of this process is expressed as

$$I_t = \nabla(\Delta I) \cdot \nabla^\perp I \quad (2)$$

Where ΔI is the isophotes direction and (ΔI) is the Laplacian smoothness operation on the gradient.

The CPU time required for inpainting depends on the size of the region to be inpainted. In all the color examples presented in [1], the inpainting process was completed in less than 5 minutes (for the three color planes), using non-optimized C++ code running on a Pentium II PC (128Mb RAM, 300MHz) under Linux.



Figure 2: (a) Damaged Image (b) Inpainted Image

In paper [8] the algorithm is implemented by using total variation in wavelet domain which reconstructs the structural component of the image. Thus this method comes under PDE algorithm. Working in the wavelet domain, instead of the pixel domain, changes the nature of the inpainting problem, since damages to wavelet coefficients can create correlated damage patterns in the pixel domain. This paper proposes variation model, which combines the total variation (TV) minimization technique with wavelet representations. The associated Euler-Lagrange equations lead to nonlinear partial differential equations (PDE's) in the wavelet domain, and proper numerical algorithms and schemes are designed to handle their computation. The proposed models can have elective and automatic control

over geometric features of the inpainted images including sharp edges, even in the presence of substantial loss of wavelet coefficients, including in the low frequencies.

III TEXTURE BASED ALGORITHMS.

In texture based algorithms, holes are filled by sampling and copying neighboring pixels. Main difference between different texture based algorithms is how they maintain continuity between hole's pixel and original image pixels. In [2] the inpainting algorithm is implemented by using median filters which reconstructs the texture of the image by filling in holes. The damaged region in an image is selected manually by the user. The proposed algorithm in [2] is as follows after determining damaged regions, the algorithm considers one pixel thick boundary of the missed region. For each missed pixel on the boundary, known pixels in different directions are selected. The median value in each direction is determined, and finally, the damaged pixel value is considered to be the median of these medians. Once, all of damaged boundary pixels are reconstructed, the algorithm has finished its first iteration. In next iteration, the new boundary is first calculated. Then in a similar manner, the boundary pixels are reconstructed. The method needs several iterations for an image to complete the edges. The qualitative results obtained by paper [2] are shown in figure 3



Figure 3. (a) Damaged Image
(b) Inpainted Image

In [3] an inpainting technique is proposed that uses the pyramids to restore the damaged regions in digital images. Let I be an image of size $M \times N$. Let Ω be the region in the image to restore. The basic technique used is to reduce the given image up to the levels where all the pixels in region Ω are eliminated or a certain percentage of those pixels is eliminated. Assume there are L levels. Now we replace the values of damaged pixels in pyramid at level $L-1$ from the extended version of pyramid. Similarly, damaged pixels in pyramid $L-2$ are replaced from the extended version of pyramid $L-1$ and so on. At each level the damaged pixels values are computed from the extended pyramid at its previous level. In general, damaged pixel values in pyramid are computed from the extended pyramid at level $L-1$. The proposed algorithm works in two steps: Pyramid Generation and Restoration.

Paper [4] proposes inpainting algorithms supporting completely different level of details and characteristics of still pictures. The methodology is known as the multi-resolution and multi-layer inpainting methodology that reconstructs the damaged part of the image. The aim is to develop effective rule to revive broken areas of still image, with high PSNR values. If the image is seriously broken, it's not realistic to extrapolate neighboring pixels. Instead, global information should be used. Thus, a multi-resolution strategy has to be thought-about. The algorithm proposed in paper [4] is as follows. Let DIB be a damaged image block. This block is subdivided into n by n image

blocks. There are three adjustable thresholds used: α is a threshold of variance of pixel colors, and β_1 and β_2 are the thresholds of percentages. For an image block containing $i \times j$ pixels, variance can be calculated as

$$\bar{x} = \frac{\sum_{\forall i} \sum_{\forall j} x_{ij}}{i \times j}, \quad var = \frac{\sqrt{\sum_{\forall i} \sum_{\forall j} (x_{ij} - \bar{x})^2}}{i \times j - 1} \quad (3)$$

The threshold α sets the criterion of whether a multi-resolution inpainting is required. The recursive algorithm iterates through each of the IBs in a DIB. If the color variance of IB is below the threshold α , there is not much difference of pixels in IB. No subdivision is required that is there is no need of looking at the next level of details. Thus, the algorithm further divides IB into several pixel blocks (i.e., PBs). If the percentage of damaged pixels in a PB is too high the mean color of PB is used. Note that, the computation of mean colors does not take damaged pixels into the account. If the percentage is low, neighbor pixels are used for inpainting. Finally, if the color variance of IB is not below the threshold α , the algorithm is called recursively to handle the next level of details. The results obtained by paper[4] is shown in figure4

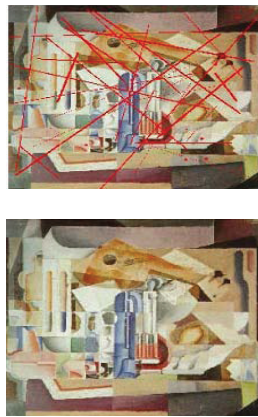


Figure 4. (a) Damaged Image (b) Inpainted Image

This paper [5] compares four different inpainting algorithms, including linear interpolation, texture synthesis, edge inward expansion and radial basis function. The paper proposes a revised inpainting algorithm. The main idea is that the damaged image may be divided into different blocks and each block has corresponding characteristics. Then our adaptive matching algorithm will automatically select appropriate method to do inpainting to each block and get optimal inpainting result. Experiments show the adaptive algorithm can do image inpainting more effectively and

efficiently. Linear interpolation is a simple way to do image inpainting for reconstructing the texture component. As BMP images are stored from bottom to up, it is necessary to start searching from the bottom for inpainting. If a sequence of pixel values equal to 255 is encountered in the image then, it means the point is broken and needs repair. We use templates to store the texture information around the pixel to be repaired. Through the template, pixel closest to the texture of the damage point in the target image was found. Then use the pixel to repair the damage.





Figure 5(a) Original image (b) Adaptive matching algorithm

IV EXEMPLAR AND SEARCH BASED INPAINTING

In [6], the exemplar-based inpainting technique is used image patches are selected from the same image to reconstruct the missing regions. The aim is to preserve the local consistency of the inpainted region by exploring the relationship between a set of candidate inpainting patches and the neighborhood of the missing region. The optimal patches are recovered by maximizing the local consistency with respect to the neighborhood candidates and the inpainting region boundary pixels. In order to choose the best matching patch a confidence term is calculated and maximized.

V HYBRID BOTH TEXTURE AND STRUCTURE

In paper [7] a decomposition method is used to obtain two components of the image, namely structure and texture. Reconstruction of each component is performed separately. The missing information in the structure component is reconstructed using a structure inpainting algorithm, while the texture component is repaired by a texture synthesis technique. To obtain the inpainted image, the two reconstructed components are composed together. Taking advantage of both the structure inpainting methods and texture synthesis techniques, an effective image reconstruction method is used.

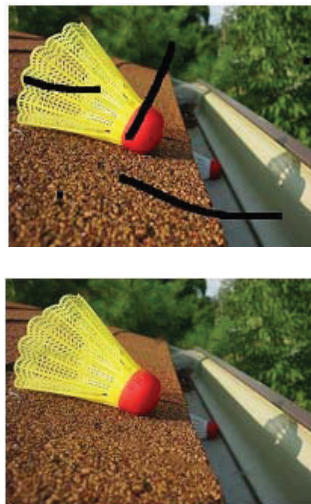


Figure 6. (a) Damaged Image
(b) Inpainted Image

VI CONCLUSION AND FUTURE WORK

Image inpainting is recently very important research area in the field of image processing. Research work is carried out in the different areas (classification as listed in the above sections) of image inpainting. Signal to noise ratio and time required for inpainting are considered as important parameters for performance comparison. The performance of different techniques is compared based on the area to be inpainted. Most of the algorithms work well for small scratch regions or small regions to be inpainted. In future we would like to implement algorithms reviewed in this paper would like to compare their performances. We would like to improve those algorithms and would like to propose a new inpainting algorithm for inpainting large regions.

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