Digital Inpainting with SPH Method

Fernando Alves Mazzini, Fabiano Petronetto do Carmo
IMPA/UFES

Introduction

Digital inpainting consists in reconstructing damaged parts of an image in order to restore its original aspect. This paper presents an algorithm based on SPH method for digital inpainting, named as Gather - Smoothed Particle Image Reconstruction (G-SPIR). It uses a radial interpolation provided by SPH method to fill damaged pixels in the target image.

- *Contribution.* Our method combines the neighbor gather algorithm with a definition of the area element geometrically in a simple and efficient algorithm able to reconstruct lost or deteriorated large parts of images, in contrast with the denoising SPH method, the SPIR algorithm [2].

The method

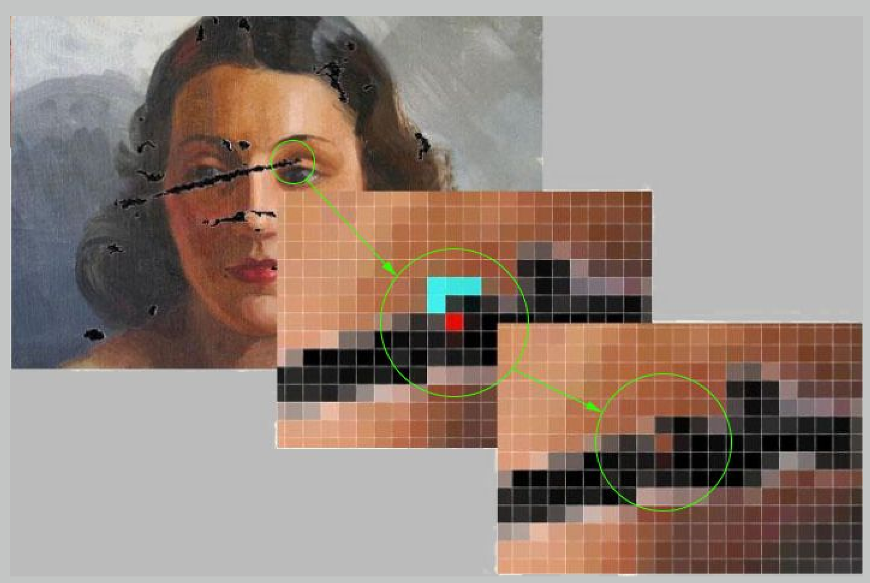
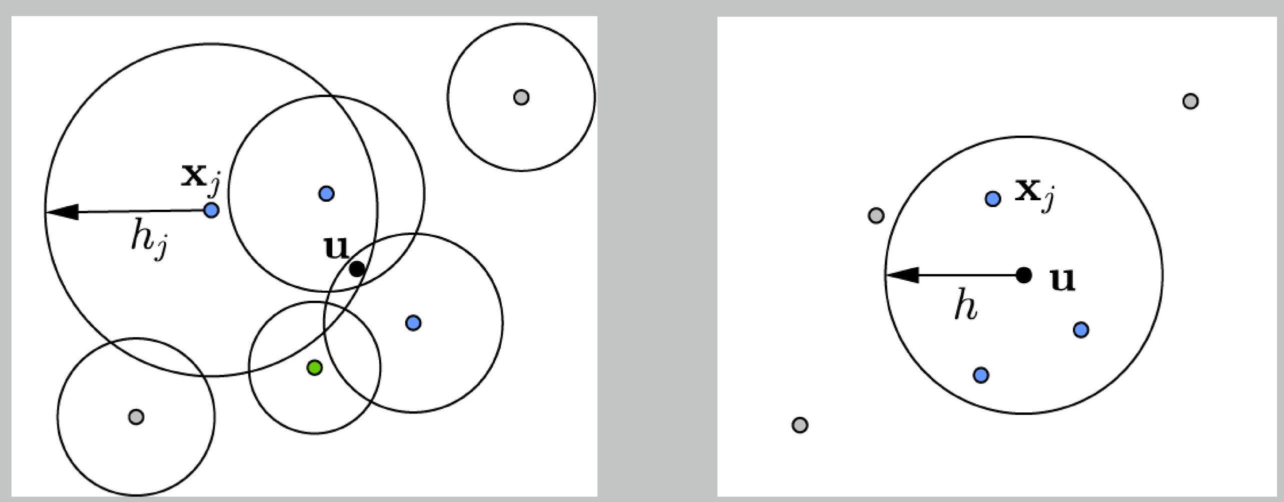


Figure 1: G-SPIR method: the inpainting steps.

Our proposed method consists in applying the SPH method in the digital inpainting context, using a gather approach in the particle approximation step. This choice led to results close to the ones obtained with the known textbook methods. Given a degraded image, the user supplies a mask that specifies the regions (Ω) to be restored and a number $k \in \mathbb{N}$ of NNP (nearest neighboring particles - used in the particle approximation step). For each damaged pixel in Ω (red), the algorithm searches for the k NNP (blue) using the gather approach, and the SPH assigns a color to the pixel based on the nearest neighbors color interpolation. The whole process is schematized in figure 1.



(a) Scatter aproach (b) Gather aproach

Figure 2: Note that the third nearest particle (green) was not classified as NNP (blue) in scatter approach (a). In gather approach (b) the NNP (blue) are the k nearest particles.

Implementation

In the algorithm presented in this text, the G-SPIR, the image to be restored

$$I : [1, a] \times [1, b] \subset \mathbb{N}^2 \to [0, 255] \subset \mathbb{N}, \quad (1)$$

will be discretized in a set of particles $\{p_1, p_2, \cdots, p_n\}$ with $n = a \cdot b$ where each particle p_k represents the pixel coordinate $(i_k, j_k) \in [1, a] \times [1, b]$ and the color $I_k = I(i_k, j_k)$ stored in this pixel. Besides, the inpainting domain Ω is set from an image

$$M : [1, a] \times [1, b] \subset \mathbb{N}^2 \to [0, 255] \subset \mathbb{N}, \quad (2)$$

for which is assigned a zero value only for inpainting pixels. That is,

$$p_k \in \Omega \iff M(i_k, j_k) = 0.$$

A particle $p_k \in \Omega$ is restored from the equation

$$I_k = \sum_{j \in N_k} I_j W_{kj} V_j, \quad (3)$$

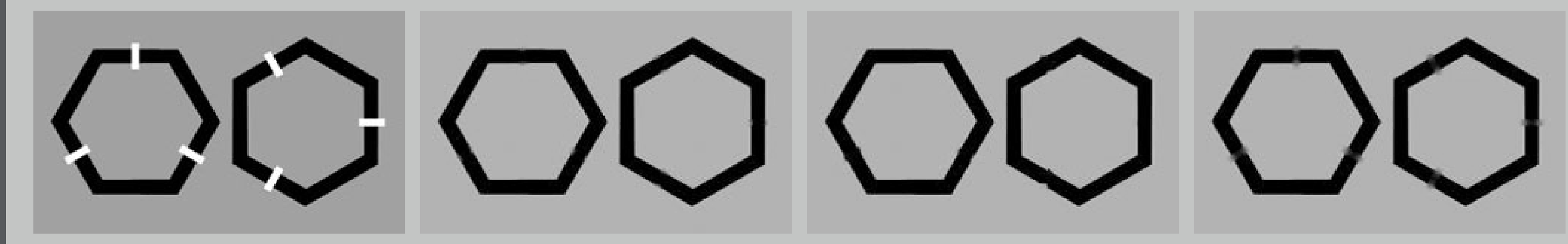
where the sum runs through all neighbor particles of p_k, denoted as N_k, $W_{kj} = W_h(r_{kj})$ with r_{kj} given by the distance between particles p_k and p_j, and V_j is the area element of the particle p_j.
The k NNP spotting should be done before performing any computation with the SPH method. Given a particle p_i, since algorithm has determinate (by the gather approach) the N_i, set of k nearest neighbors outside Ω, the smoothing length h_i is given by

$$h_i = \alpha \max\{d_{ij};\ j \in N_i\},$$

where d_{ij} is the euclidean distance between particles p_i and p_j, and α is a scaling parameter of the support radius wich avoids that contribution of distant neighbors particles of particle p_i be almost zero. The discrete area element V_j of particle p_j is given by $V_j = 1/n$.

Results and comparisons

For comparison purposes, figures 3 and 4 also shows the results obtained from the BSCB algorithm [1] and Fast algorithm [3].



(a) Original image (b) G-SPIR (c) BSCB (d) Fast

Figure 3: Reconnection of high-contrast edges. ($\#\Omega = \mathbf{1153}$)

(a) Original image (b) G-SPIR (c) BSCB (d) Fast

Figure 4: Restoration of a degraded image. ($\#\Omega = \mathbf{5126}$)

(a) Original image (b) G-SPIR (c) Original image (d) G-SPIR

Figure 5: (a) and (b): ($\#\Omega = \mathbf{6626}$) Text-over-image removal; (c) and (d): Object-over-image removal ($\#\Omega = \mathbf{6158}$).

To measure the **quality of the reconstruction**, we used the mean-square error (MSE) of the reconstructed region Ω.

Method	Elapsed time	MSE
G-SPIR	0.328967s	0.9215
BSCB	605.114918s	10.1264
Fast	1.122744s	0.8210

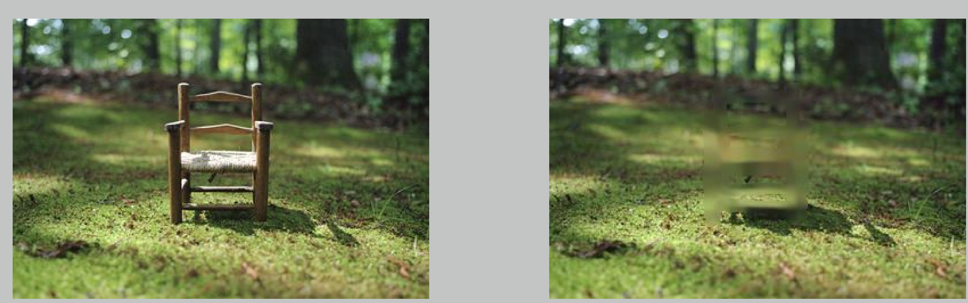
Table 1: Results for inpainting of figure 3.

Method	Elapsed time	(MSE)r	(MSE)g	(MSE)b
G-SPIR	1.532321s	101.5443	99.1971	95.3361
BSCB	450.534370s	122.1317	121.1348	110.4484
Fast	7.738811s	101.3142	99.5933	94.8378

Table 2: Results for inpainting of figure 4.

Concluding remarks

The results obtained with the G-SPIR algorithm are close, in their majority, to the ones obtained with representative inpainting (BSCB and Fast). In general, G-SPIR inpainting time was slightly faster than the Fast algorithm. However, like other inpainting algorithm previously mentioned, it was not able to transport texture to the inpainting domain when filling a large area.



(a) (b)

Figure 6: G-SPIR does not reproduce texture.

- For future studies we are concerned to make an well done quantitative evaluation of the quality of inpainting through metrics currently used by the image processing community.

References

[1] Marcelo Bertalmio, Guillermo Sapiro, Vincent Caselles, and Coloma Ballester.
Image inpainting.
In *Proceedings of the 27th annual conference on Computer graphics and interactive techniques*, pages 417–424. ACM Press/Addison-Wesley Publishing Co., 2000.

[2] G Di Blasi, E Francomano, A Tortorici, and E Toscano.
A smoothed particle image reconstruction method.
Calcolo: a quarterly on numerical analysis and theory of computation, 48(1):61–74, 2011.

[3] Manuel M Oliveira, Brian Bowen, Richard McKenna, and Yu-Sung Chang.
Fast digital image inpainting.
In *Appeared in the Proceedings of the International Conference on Visualization, Imaging and Image Processing (VIIP 2001), Marbella, Spain*, pages 106–107, 2001.

falvesmazzini@gmail.com, fbipetro@gmail.com