Bilateral Filtering for Gray and Color Images

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***Abstract*— Usually, filters that removes noise from the images, blur entire image, including the edges of the objects. New pixel values are selected based on the neighbors, taking into account the variable weight of the blur. The bilateral filter smooths out the image in similar way to a Gaussian filter, but it does not affect the edges. This is due to the variability of the blur coefficient, which depends not only on the distance of pixels adjacent to the central pixel but also on the value of the local gradient - blur is stronger in more homogeneous areas, and weaker in regions of significant edges. This approach is uncomplicated, local and noniterative. Bilateral filtering blend colors or gray levels based on their photometric correlation and geometric similarity, and goes for near values over distant values in range and domain.**

I. INTRODUCTION

Image filtering is one of the core digital signal processing methods. Filtration is a mathematical operation on the pixels of the source image that results in a new, transformed image. Filtering is referred as contextual transformation, because in order to determine new pixel value of the target image, information from multiple pixels of the source image is needed. Filtration is usually used as a method of extracting a series of information from the original image for further processing. Such information can be: edge position, object corner positions, etc. Another filtering application is noise removal (median filter and others) or image blur (averaging, Gaussian filters).

Filtration can be carried out in both spatial and frequency domain. Spatial filtration is achieved using convolution operations. In the frequency domain, the equivalent of convolution is the operation of multiplying image and filter transforms. The assumption of slow spatial changes fails at the edges, which are consequently blurred by low-pass filtering. Much effort has been devoted to reducing this undesirable effect. It is possible to avoid blurring edges, when averaging smooth regions?

In this paper, we came up with noniterative solution for preserving edge blurring, which is simple and non-linear. This solution is bilateral filter. The name comes from that this filter depends on two parameters that indicate contrast and size. Bilateral filter occurs in applications such as Adobe Photoshop, GNU Image Manipulation Program (GIMP) and GREYC's Magic for Image Computing (G'MIC).

There are a lot other edge-preserving smoothing filters such as anisotropic diffusion and edge avoiding wavelets. So why should we focus on this type of filtering above the others. Bilateral filter has certain number of advantages that explain its success:

- Simple composition: every pixel is retrieved by the average value of its neighbors. This is really important aspect because it make a lot easier to achieve intuition about filter behavior. It allows to adapt and implement specific requirements much faster.
- Filter is built upon two main parameters that express contrast and size of the features.
- It is possible to use filter in d in a non-iterative manner. Effects are not cumulative over iterations. Thanks to that parameters are easy to set.

This article is organized as follows. Section 1 is introduction that's briefly present concept of bilateral filtering. Section 2 describe Gaussian filter, and mathematical description of bilateral filtering as an evolution of Gaussian filter. Section 3 presents recent applications in which bilateral filtering can be used. Section 4 focus on tests and results of implemented bilateral filter. Section 5 presents final say on the algorithm and conclusion of whole paper.

II. APPLICATIONS

This section focus on some recent, new and update applications in which the filter has significant meaning:

- Denoising is precursor, main purpose of bilateral filtering, in which a wide range of scientific fields it is used. It includes restoration of movies, tracking systems, imaging for medical purposes and more.
- Texture and Illumination Separation: One of the usage of bilateral filtering is decomposition picture into small/large-scale features and textures. It adjust tonal distribution by editing every fragment separately.
- Data Fusion: By using bilateral filtering we can decompose couple input images into several different components and recreate them in form of single output image, that obtain some visual properties from the input pictures.
- 3D Fairing: bilateral filtering can be adapted in 3D point clouds and meshes by blurring noises away in big fields but keeping all sharp edges and corners in the same time.

1. DENOISING

First main target of bilateral filtering was denoising of images. After some time it became popular in computer graphics, due to the ability of preserving edges, and easy way to set parameters and understand logic behind it. Bilateral filtering is a standard in most of denoising tools. It occurs in applications such as Adobe Photoshop, GNU Image Manipulation Program and GREYC's Magic for Image Computing. In contrast to simple Gaussian filter, that blurs pictures not concerning edges and visual structures, it preserves the object sharp contours. Thanks to that it can be used as an easy way to achieve decomposition of image into cartoon-like pictures.

Fig 1. Input and out of bilateral filtering with parameters set to create cartoon-like pictures.

2. TEXTURE AND ILLUMINATION SEPARATION

One of the usage of bilateral filtering is decomposition picture into small/large-scale features and textures. It adjust tonal distribution by editing every fragment separately. Bilateral filtering is especially effective as a tool for contrasting enhancement or reduction. By usage of adequately large range of parameters, filter is able to removes variations thanks to reflectance texture, preserving discontinuities stemming from changes in illumination or geometry.

3. DATA FUSION

By using bilateral filtering we can decompose couple input images into several different components and recreate them in form of single output image, that obtain some visual properties from the input pictures. Bilateral filtering can be used in techniques to produce successfully pictures in lo low-light conditions. It can be made thanks to combining no-flash and flash pictures or photographs.

4. 3D FAIRING

Bilateral filtering can be adapted in 3D point clouds and meshes by blurring noises away in big fields but keeping all sharp edges and corners in the same time. So Bilateral filtering can be extends to meshes. But with 3D Fairing comes new problem: we need to conclude all three xyz coordinates. Also not like pixel intensity, z coordinate is not a function of other coordinates. In order to smooth a meshes, algorithm assume that is locally flat.

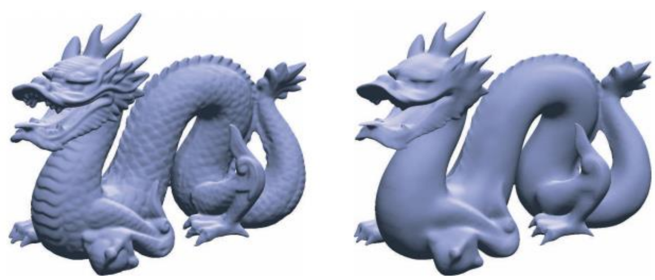


Fig 2. Bilateral filtering adapted to smooth 3D meshes.

III. BILATERAL FILTER

1. GAUSSIAN FILTER

To understand the bilateral filter a grasp on the Gaussian filter is required. It estimates at each position a local average of intensities and corresponds to low-pass filtering. So it smooths every pixel at an average of every neighbor pixel in a defined range. The Gaussian filter is declared by a below equation:

$$GB[I]_{\mathbf{p}} = \sum_{\mathbf{q}\in\mathcal{S}} G_{\sigma}(\|\mathbf{p}-\mathbf{q}\|)\, I_{\mathbf{q}},$$

Where G_σ is a Gaussian kernel defined as:

$$G_{\sigma}(x) = \frac{1}{2\pi\,\sigma^2}\ \exp\left(-\frac{x^2}{2\,\sigma^2}\right).$$

So, Gaussian filter is a weighted average of the level of the nearby pixels with a weight diminishing with the spatial distance to the position p. This separation is characterized by $G_\sigma(\|p - q\|)$, where σ is a parameter characterizing the extension of the area.

However there is a problem with using only this filter. It averages every pixel, so edges also gets smoothed, so in addition to cancelling the noise in areas where we want it, we get blurred edges which is definitely not the desired result. So in order to preserve the edges the range Gaussian filter is added to original spatial Gaussian equation.

2. BILATERAL FILTER

Part of the bilateral filter uses Gaussian convolution but in order to preserve the edges, it takes into account also the difference between the intensity of the neighbor pixels. The idea of bilateral filtering is that two pixels are similar to each other not only if they occupy nearby spatial locations but also if they have little difference in brightness.

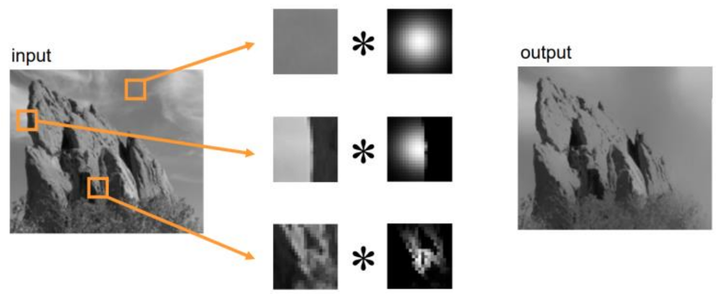
The bilateral filter is defines as:

$$BF[I]_{\mathbf{p}} = \frac{1}{W_{\mathbf{p}}} \sum_{\mathbf{q}\in\mathcal{S}} G_{\sigma_s}(\|\mathbf{p}-\mathbf{q}\|)\, G_{\sigma_r}(I_{\mathbf{p}} - I_{\mathbf{q}})\, I_{\mathbf{q}}$$

Where ther fist part is a normalization factor defined as:

$$W_{\mathbf{p}} = \sum_{\mathbf{q}\in\mathcal{S}} G_{\sigma_s}(\|\mathbf{p}-\mathbf{q}\|)\, G_{\sigma_r}(I_{\mathbf{p}} - I_{\mathbf{q}})$$

Parameters σ_s and σ_r are the measures of the amount of filtering for the image I. Equation above is a normalized weighted average, where $G\sigma_s$ is a spatial Gaussian that decreases the importance of distant pixels, $G\sigma_r$ a range Gaussian which decreases the importance of pixels q with an intensity value different from Ip. Note that the term range refers to pixels intensity, in opposition to space which refers to pixel distance from another.



The kernel shape depends on the image content.

As can be seen on above picture, the product of spatial and range factors creates a kernel that does not averages the intesity of pixels across the edges, while edges are considered to be where we can observe high differences in brightness across neighborhood.

3. PARAMETERS

The bilateral filter is restricted by two parameters: σ_s and σ_r.

• As the range parameter σ_r rises, the bilateral filter goes closer to Gaussian blur because the range Gaussian is flatter i.e., almost a constant across the intensity interval covered by the picture.

• Increasing the spatial factor σs smooths bigger features.

An important feature of bilateral filtering is that the parameters are multiplied, so as soon as one of the weight is close to 0, no smoothing happen. As an example, a large spatial Gaussian joined with narrow range Gaussian results in a limited smoothing although the filter has large spatial result. The range weight demands a strict preservation of the edges.

For filtering color images the same method as in grayscale images is used, only the operation is repeated three times. Every time for different channel of the image, because color images are three dimensional matrices, where the third dimension have size of three and contains intensity of each RGB color.

IV. FILTER IN PRACTICE

One of the important issues in real life usage of the filter is choosing the right parameters. It hugely depends on the application but few guidelines can be specified:

-space parameter should be proportional to image size, for example 2% of image diagonal

-range parameter should be proportional to edge amplitude, for example mean or median of image gradient

1. BILATERAL FILTER ON GRAYSCALE IMAGES

The filter was tested for different parameters values for a grayscale image. The result can be seen on a picture below. As can be observed, bigger the parameters values, more blurry the image.

2. BILATERAL FILTER ON COLOR IMAGES

With color images, different complication arises from the fact that between any two colors there are other, often different colors. For example, between blue and red there are various shades of pink and purple. Disturbing color bands may be produced when smoothing across color borders. The filtered image does not just look blurred, it also exhibits odd, colored aura around objects.

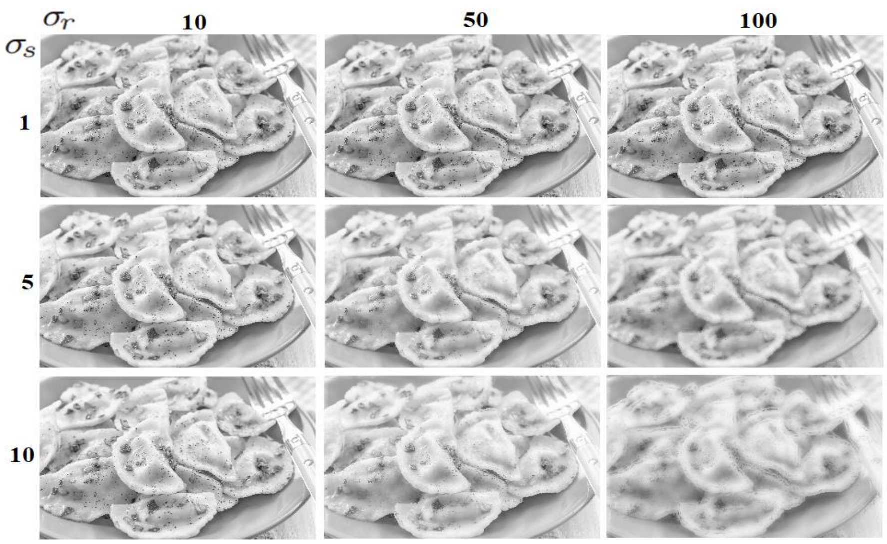


Figure 3. Tests for grayscale image

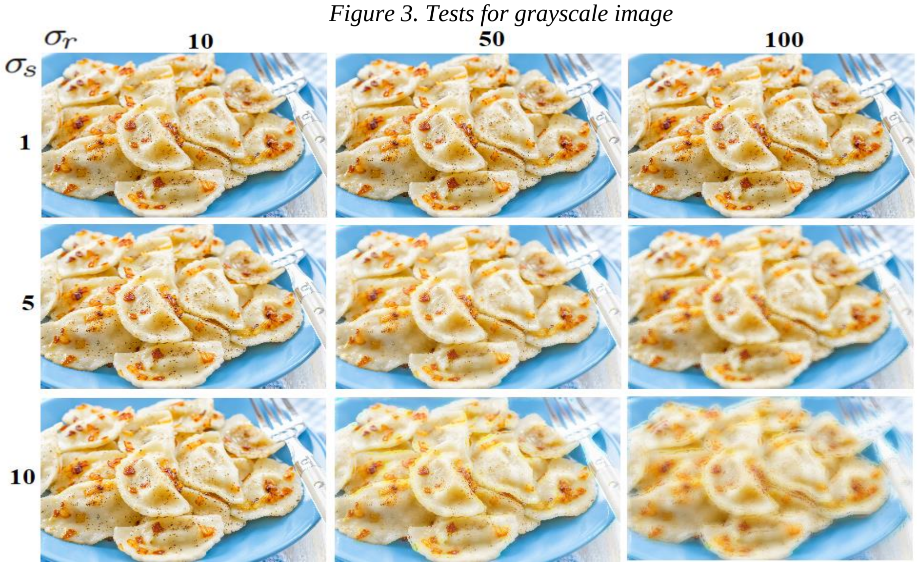


Figure 4. Tests for color image

V. Conclusion

Filters that removes noise from the images, blur entire image, including the edges of the objects. New pixel values are selected based on the neighbors, taking into account the variable weight of the blur. The bilateral filter smooths out the image in similar way to a Gaussian filter, but it does not affect the edges. Bilateral filtering noniterative solution for preserving edge blurring, which is simple and non-linear. It’s used in many various areas such as denosing pictures, 3D fairing, and even have a use in medicine. Bilateral filtering nowadays is mostly used in two-scale decomposition, but fully multiscale approaches deserve more investigation.

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