Advanced Image Analysis

Bilateral Filtering

Submitted By

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***Introduction*—Filtering is the fundamental process in computer vision. The main aim of filtering is smoothing image to reduce noise. There are many filters like Mean (average), Median and Gaussian filters etc. But there are some limitations for this type of filters for example when we apply mean filter for an image the resultant image will be blurred, it is able to remove simple noise and no details are preserved, Gaussian filter is better when compare to mean filter it gives same output as mean filter but it is able to preserve details for small sigma values. Median filter also has limitation like it cannot preserve all the details of the image, but it is good in removing strong noise present in the image. In order to preserve the edges filter is required to smooth regions and not to filter edges.**

In order to achieve required resultant image we need to smooth regions and not edges so, using both range and domain of the image. This filtering technique is called as Bilateral Filtering. The idea of the Bilateral Filtering algorithm is smoothing the image as usual in the domain and not smoothing when pixels are not similar i.e. preserving edges.

In the report next sections are explaining the algorithm idea, implementation, results, and experiments. Finally end up with the conclusion.

I. BILATERAL FILTERING

The idea of implementing Bilateral filtering is to smooth as usual in the domain of the image like Gaussian and do not smooth when pixels are not similar which preserves edges. This has some properties like convolution filter, smooth image but preserve edges and it operates both range and domain of the image.
This is a non-iterative scheme for edge preserving smoothing that is non-iterative and simple. The idea of bilateral filtering is to do in the range of an image that traditional filter do in its domain. Two pixels can be close to one another, that is occupied nearby spatial location, or they can be similar to one another, that is, have nearby values, possibly in a perceptually meaningful fashion. Closeness of the pixels refers to vicinity in the domain, similarly to vicinity in the range. In the domain filtering, and enforces closeness by weighting pixel values with coefficients that fall off with distance. On the other hand range filtering, which averages image values with weights that decay with dissimilarity. In this range filters are non linear because their weights depend on image intensity or color.
First low pass domain filter applied to image f(x) gives an output image like this.

$$J = \frac{1}{k_s} \sum_{p \in \Omega} f\,(p - s)\; I_p$$

$$k = \sum_{p \in \Omega} f\,(p - s)$$

f(p-s) measures the geometric distance between *p* & *s*.
Range filter is defined as

$$J = \frac{1}{k_s} \sum_{p \in \Omega} g\,(I_p - I_s)\; I_p$$

$$k = \sum_{p \in \Omega} g\,(I_p - I_s)$$

s coordinate of center pixel, *p* coordinate of current pixel, set of all pixels in local neighbor pixels.*Js* is resulting pixel intensity. *Is*,*Ip* intensities of *p* & *s*.*g(Ip-Is)* measures photometric similarity between *Ip* & *Is*.
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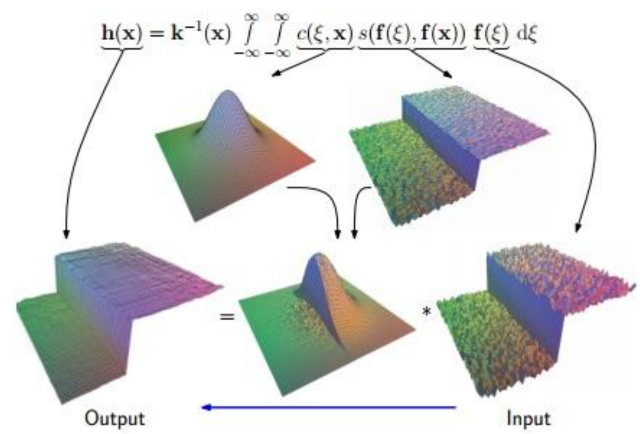
Combining both range and domain filter is described as follows with normalization. The combination of these filters refers to bilateral filtering.

$$J_s = \frac{1}{k_s} \sum_{p \in \Omega} f\,(p - s)\, g\,(I_p - I_s)\; I_p$$

$$k_s = \sum_{p \in \Omega} f\,(p - s)\, g\,(I_p - I_s)$$

The big picture of applying the bilateral filtering is shown below.



When bilateral filter is centered, when the pixel is on the bright side of the boundary, similarity function ‘s’ assumes values close to one for pixels on the same side, and close to zero for pixels on the dark side. The normalization term K(x) ensures that the weights for all the pixels add up to one. As a result filter will replace bright pixel at the center of the average bright pixel and essentially ignores the dark pixels. Conversely, when the filter is centered on dark pixel, the bright pixel is ignored instead. The out of the image is filtered with preserving edges. In this domain filter is responsible for filtering achieved at the boundaries and range filter is responsible for preserving edges at the same time.

II. IMPLEMENTATION

The code is implemented on Matlab. Firstly code is implemented on grayscale images and later for color images. The implementation steps were explained in brief.
Firstly taking the input image and computing the domain filter within the domain of the window side using formulae

$$f\,(p-s) = e^{-\frac{d(p-s)^2}{2\sigma_d^2}}$$

$$d\,(p-s) = \|p-s\| = \sqrt{p^2+s^2}$$

After adjusting the window size computing the range filter.

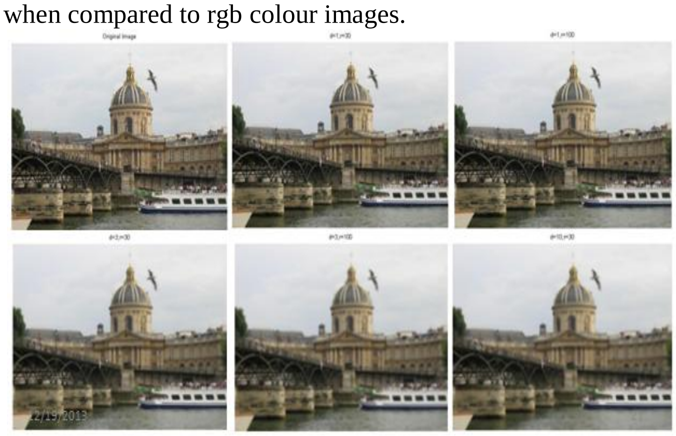
$$g\,(I_p - I_s) = e^{-\frac{\delta(I_p-I_s)^2}{2\sigma_r^2}}$$

$$\delta\,(I_p - I_s) = \|I_p - I_s\|$$

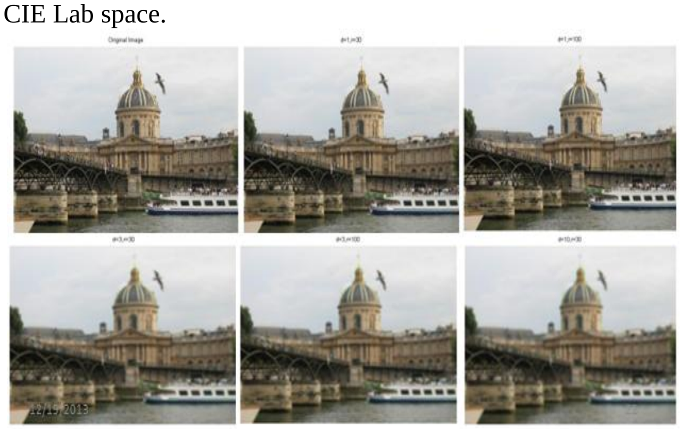
By taking the product of the range and domain filter gives good output with preserving edges. The depicted figure shows the output of for the gray scale images with different range and sigma parameter.

In the above result we can see that we can preserve edges but larger the domain value will blur the image.
For color sequence on each channel the results are not good as expected. When bilateral filter is applied for each channel the results are not that much effective because the intensity profile on each band is different & different contrast. Separate smoothing perturbs the balance of smoothing, and unexpected color combinations. The computation time is also more when compared to other because we are applying only bilateral filter for each channel so computational time is more.

In the last image we can see for high domain (=10) the image is blurred we are unable to preserve the edges.
When transformed to CIE Lab space it gives good output when compared to rgb colour images.



By using CIR Lab color space, only perceptually similar colors are averaged together, and only perceptually important edges are preserved.
I tried with HSV color space as well it gives same result as the CIE Lab space.



When i add white Gaussian noise to the image it is able to preserve edges the smoothing of image depends on domain parameter.

There are many applications of bilateral filtering

- De-noising
- Picture simplification
- Contrast reduction
- Mesh smoothing and many more

III. Conclusion

Bilateral filtering is best for preserving more information (edges).

CIE Lab color space gives better output than bilateral filter applied on each channel. Parameters of the domain filter depends on image properties.

Details are lost with large range values but edges are preserved at all ranges scales that are below the maximum image intensity value.

It is hard to analyze bilateral filtering because of non linear nature.

IV. REFERENCE

- Bilateral filtering for Gray and Color Images by C.Tomasi & R.Manduchi
- Course Slides
- www.google.com