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Guided Filter for Grayscale, RGB and HSV color space

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Abstract: ***Guided filter is derived from a local linear model and in guided filter filtering output is computed by referring guidance image, which can be input image itself or different image. The Guided filter can be used as edge preserving smoothing and gradient preserving operator, it shows better result near edges. My work is focused on implementing guided filter algorithm, which is 2D algorithm. This algorithm is applicable to gray-scale image and color images like RGB and HSV by separating each color channel. The experiments show that the guided filter is effective in computer vision and graphics applications as well as edge preserving smoothing, detail enhancement, denoising, etc.***

Keywords - *Guided filter, Edge preserving, Guidance image, RGB(Red, Green, Blue), HSV(*Hue, Saturation, Value)

1.Introduction

In image processing and computer vision filtering is one of the most fundamental operation to perform image enhancement, restoration, denoising, matting/feathering [6] etc. Filtering is the process in which predefined neighbourhood values of input image at a specific location gives filtered output at the same location. The examples of Linear translation invariant (LTI) filter are Mean, Gaussian, Sobel, Laplacian filters [1]. These are used in sharpening, feature extraction, image restoration etc. In spatial domain LTI filters are used. In spatial domain nonlinear spatial filters such as median filters are also proved to be efficient. In computer vision, there are several pre-existing color models for describing the specification of the colors such as RGB and HSV. Here we uses RGB(Red, Green, Blue) and HSV(hue, saturation, value) -based color model since, a color guidance image can better preserve the edges that are not distinguishable in gray-scale image. The color guidance image is also essential in detail enhancement, flash/no-flash denoising, etc.

Edge preserving filters such as Bilateral Filter [2] and Guided Filter[5]. Both these techniques use content of guidance image. In Bilateral filter unwanted gradient reversal artifacts are present, so improved technique is guided filter. Based on bilateral filter, joint bilateral filter is developed in [4] in flash/no-flash denoising. Weighted Least Square (WLS) filter [8], it is also edge preserving smoothing operator, which is well suited for multi-scale detail extraction. WLS based decomposition yields a result without any visible halos, while fine local contrasts. WLS based filter is robust and versatile and may be used in many applications such as to construct edge preserving multi-scale image decomposition, detail enhancement and contrast manipulation.

In this paper we introduced Guided filter [5]. Filter output is local linear transform of guidance image which can be input image itself or another different image. This filter not only has good edge preserving smoothing property but also improved gradient reversal artifacts. Guided filter can be used beyond smoothing with the help of guidance image, it can make filtering output more structured and less smoothen than the input image. The applications of guided filter are smoothing, enhancement, flash/no-flash denoising, feathering etc. The execution time of guided filter is 52.87 ms on performing gray scale filtering. It is one of the fastest edge preserving filter.

2. Related Work

Edge preserving property is important feature of filtering process. The filters like average filters provide the smoothing including edges of the image too. Some edge preserving filters are given as follows:

2.1Bilateral Filter

The bilateral filter [2] is perhaps simplest and non-iterative approach to preserve edges. It is widely used in noise reduction [3]. The technique used to preserve edges during smoothing is to compute median rather than computing mean. This filter is effective for noise removal and feature extraction. But it has been observed that it may have gradient reversal artifacts in detail enhancement [5]. Artifacts results from the pixels around the edges that have an unstable Gaussian weighted sum. The reason behind it is that when pixel on an edge has few similar pixels around it, the weighted average becomes unstable. The result is that the smoothed output is not consistent with the input at the edges. So detail enhancement like operations which requires the consistency of input signal and output signal has to be performed with better gradient preserving filter

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2.2 Median Filter

The median filter [1] is one of the popular edge aware filter, which can be considered as local histogram filter. The median is statistical concept which means the center value of provided list. The particular pixel is replaced with the median magnitude. A common technique for preserving edges during smoothing is to compute the median in the filters support, rather than mean. Example of this approach is [7]. Median filter is very effective in removing paper and salt noise or impulse noise. It is used for noise reduction, while preserving edges more effectively as compared to a linear smoothing filter. But practically it is used only for small size filters due to its slowness. Median filter is having disadvantage like computational complexity.

2.3 Joint Bilateral Filter

Based on bilateral filter, joint bilateral filter is developed in [4] in flash/no-flash denoising. In joint bilateral filter the flash image contains a much better estimate of the true high frequency information than the ambient image, based on this basis bilateral filter is modified. Still it may fail in flash shadows because they only appear in the flash image. At the edges of such regions joint bilateral filter may under-blur the ambient image, similarly inside these regions, it may over-blur the ambient image. This problem is solved by detecting flash shadows, then back to the basic bilateral filtering. The limitation of joint bilateral filter is that it is non-linear and therefore a straightforward implementation requires performing the convolution in the spatial domain. This can be very slow for large variance.

2.4 Weighted Least Square (WLS) Filter

Weighted Least Square (WLS) filter [8], it is also edge preserving smoothing operator, which is well suited for multi-scale detail extraction. Edge preserving smoothing may be viewed as a compromise between two possible contradictory goals. Given an input image g, we seek new image u, which, on the one hand, is as close as possible to g, and at the same time , is as smooth as possible everywhere, except across significant gradients in g. WLS based decomposition yields a results without any visible halos, while fine local contrasts. WLS based operator is robust and versatile and may be used in many applications such as to construct edge preserving multi-scale image decomposition, detail enhancement and contrast manipulation.

3. The Idea of Guided Image Filter

Brief idea of guided filter is in [5]. Given I be the guidance image, p be an input image and q be an output image which define guided filter. The output image q of guided filter is a local linear transformation of guidance image I. Let I be the any pixel, q_i be output pixel which is linear transform of guidance image I in ω_k window center at pixel k.

$$qi = a_k Ii + b_k , \forall_i \in \omega_k \quad (1)$$

Where, (a_k, b_k) are assumed to be constant in ω_k.The cost function in window ω_k is defined to calculate linear coefficients as follows:

$$E(a_k,b_k) = \sum_{i\in\omega_k} ((a_k Ii + b_k - pi)^2 + a_k^2)) \quad (2)$$

where, ε is a regularization parameter to prevent a_k from becoming too large, also to measure accuracy of edge detection. The output image has edge only if edge is present in guidance image I.

The solution of a_k and b_k:

$$a_k = \frac{\frac{1}{|\omega|} \sum_{i\in\omega_k} (I_i p_i - \mu_k \bar{p}_k)}{\sigma_k^2 + \varepsilon} \quad (3)$$

$$b_k = \bar{p}_k - a_k \mu_k \quad (4)$$

where, μ_k and σ_k^2 are the mean and variance of I in ω_k, $|\omega|$ is the number of pixels in ω_k, p_k is the mean of p in ω_k . After getting the values of linear coefficients a_k and b_k the filtering output is defined as

$$q_i = a_k I_i + b_k, \forall_i \in \omega_k \quad (5)$$

But for different windows we are getting different values, so averaging of qi is needed for all possible windows in the image.

$$q_i = \frac{1}{|\omega|} \sum_{k|i\epsilon\omega_k} (a_k I_i + b_k) \quad (6)$$

above equation can be written as

$$q_i = \bar{a}_i I_i + \bar{b}_i \quad (7)$$

where, $\bar{a}_i$ and $\bar{b}_i$ are the average of coefficients for all windows overlapping i. The averaging process can make gradient of q smaller than gradient of guidance image I near strong edges. Therefore, most of abrupt changes in I are still conserved.

The guided filter also can be applied to colour images. In case input image is coloured, the filter should be applied to each channel separately.

3.1 Algorithm : Guided Filter

1. First read filtering inputs ie guidance image I, input image p.
2. Specify the local window radius r and regularization parameter ε.
3. Applying averaging filter (f_{mean}) on guidance and input image and find correlation (corr) as follows
   mean_I = f_{mean}(I)
   mean_p = f_{mean}(p)
   corr_I = f_{mean}(I.*I)
   corr_Ip = f_{mean}(I.*p)
4. Compute variance (var)
   var_I = corr_I – mean_I.*mean_I
5. Compute the covariance (cov)
   cov_Ip = corr_Ip – mean_I.*mean_p
6. Compute the linear coefficients a and b
   a = cov_Ip ./ (var_I + ε)
   b = mean_p – a .* mean_I
7. Compute mean of linear coefficients a and b
   mean_a = f_{mean}(a)
   mean_b = f_{mean}(b)
8. Calculate output q ie filtered image
   q = mean_a .* I + mean_b

In this algorithm f_{mean} is the mean filter with a window radius r. Mean filter is a kind of box filter. Mean filtering is a simple, intuitive and easy to implemented method of smoothing image ie reducing the amount of intensity variation between one pixel and the next.

According to the algorithm first specify the input image p, guidance image I, window radius r, regularisation parameter ε.

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Now apply box filter to calculate mean of input image and guidance image. Box filter is a type of average filter, in which patch-wise operation is performed. As per window radius r and patch-wise operation, we have to calculate cumulative sum and differences over X-axis and Y-axis. Next compute the covariance and variance of input and guidance image according to the equations given in the algorithm. Follow the steps given in the algorithm and compute the output.

4 Experiments with Grayscale image

4.1 Edge preserving filtering

Here guided filter is applied on grayscale image where input image p and guidance image I should be identical. Fig 1, Shows an example of guided filter with various sets of parameters. We can observe that guided filter behaves as an edge preserving smoothing operator in fig1.

Edge preserving smoothing property is explained as follows:

If input image p and guidance image I are identical then a_k becomes, $a_k = \sigma_k^2 / (\sigma_k^2 + \varepsilon)$ in equation 3. And $bk = (1 - a_k)\ \mu k$. Therefore if $\varepsilon = 0$, then $ak = 1$ and $bk = 0$ and if $\varepsilon > 0$, then two cases arises.

1. High variance (σ_k^2): If I changes abruptly in ωk ie $\sigma_k^2 >> \varepsilon$, then $a_k \approx 1$ and $b_k \approx 0$.
2. Flat patch: If I is constant in ωk ie $\sigma_k^2 << \varepsilon$, then $a_k \approx 0$ and $b_k \approx \mu_k$.

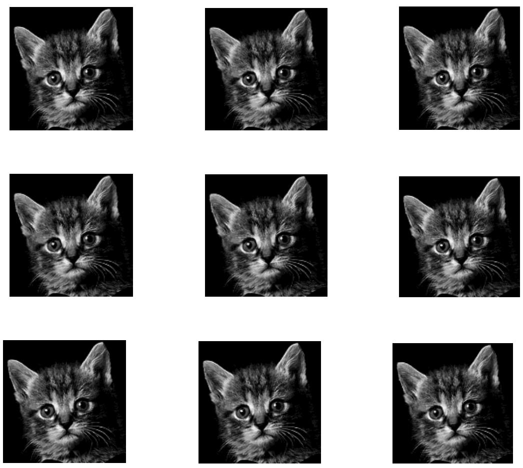
By averaging a_k and b_k and combined in equation 6. We get output q. If a pixel is in high variance region then its value is unchanged ($a \approx 1$, $b \approx 0$, $q \approx p$) and if a pixel is in flat region its value becomes average of the pixels nearby ($a \approx 0$, $b \approx \mu$, $q \approx \mu$). The patches with variance (σ^2) much smaller than ε are smoothen, where as those with variance much large than ε re preserved.

The table “PSNR” shows the quantitative results of guided filter.

Table.1 “PSNR” (dB)

	r = 2	r = 4	r = 8
ε=0.1^2	40.26	41.09	42.60
ε=0.2^2	29.42	30.10	31.40
ε=0.4^2	20.52	20.95	22.00

Input Image



r=2

r=4

r=8

$\varepsilon = 0.1^2$ $\varepsilon = 0.2^2$ $\varepsilon = 0.4^2$

Figure1. Edge preserving filtering results using the guided filter. The table “PSNR” shows the quantitative guided filter results.

5 Experiments with RGB color space

A color guidance image can better preserve the edges that are not distinguishable in grayscale image. The color guidance image is also essential detail enhancement, matting/feathering applications. The local linear model is also applicable to RGB color space. The filter should be applied to each channel separately.

5.1 Detail enhancement

Guided filter avoids the gradient reversal artifacts that may appeared in detail enhancement. A brief introduction to detail enhancement is as follows:

Given input signal p, its edge preserving smoothed output is base layer q. the difference between input signal and base layer is the detail layer $d = p - q$. It is magnified to boost details. The enhanced signal is combination of boosted detail layer and base layer. An elaborate description of this method can be found in [5].

Here we use patch-wise linear model. In case of guidance image is identical to input image ie ($I \equiv p$), its guarantee that there are no gradient reversal. In this case equation (7), gives $a_k = \sigma_k^2 / (\sigma_k^2 + \varepsilon) < 1$ and b_k is constant, so we have $\partial_x q = a_k \partial_x p$ and the detail layer gradient $\partial_x d = \partial_x p - \partial_x q = (1 - a_k)\ \partial_x p$, that means $\partial_x d$ and $\partial_x p$ are always in the same direction. When we use the overlapping model instead of linear model, we have

$\partial_x q = \bar{a}\partial_x p + p\partial_x \bar{a} + \partial_x \bar{b}$. Because $\bar{a}$ and $\bar{b}$ are low pass filter, we obtain $\partial_x q \approx a\partial_x p$. So we do not observe the gradient reversal artifacts. Fig 2 shows the results for detail enhancement.

(a) RGB Input Image (b) Guided Filter on RGB

Figure 2. Detail Enhancement. The parameters are r=16, $\varepsilon = 0.1^2$ for guided filter and detail layer is boosted x 5.

5.2 Flash/no-flash denoising

In [4], it is proposed to denoise a no-flash image under the guidance of its flash image. Reducing noising in photographic images has been a long-standing problem in image processing and computer vision. One common solution to apply an edge preserving filter to the image such as Guided filter [5], Bilateral filter [2]. We apply guided filter to each RGB color channel separately with the same parameters ie window radius r and regularization ε, so that the noise is averaged away but details are preserved. If parameters are not properly adjusted or set, guided filter tends to either over-blur (lose details) or under-blur (fail to denoise) the image in some regions. So by proper adjusting parameter values we can obtain the better results. Fig 3 shows the results for flash/no-flash denoising. In this example also gradient reversal arifacts are avoided.

(a) Guidance I (b) Filter Input p (c) Guided Filter

Figure 3. Flash/no-flash denoising. The parameters are r=8, $\varepsilon = 0.2^2$ for guided filter.

6 Experiments with HSV color space

In HSV [1] color space we separate luma or intensity from chroma or color information. This is useful in many applications, such as, if we want to work on only intensity component and leave color components alone at that time performing on HSV color space is very useful. The color information is usually much more noisy than HSV information. We can usually get better information from a HSV color space. The HSV color model can be considered as a different view of the RGB cube. Hence the values of HSV can be considered as a transformation from RGB using geometric methods. The diagonal of the RGB cube from black (the origin) to white corresponds to the V axis of the hex cone in the HSV model. For any set of RGB values, V is equal to the maximum value in this set. The HSV point corresponding to the set of RGB values lies on the hexagonal cross section at value V. The parameter S is then determined as the relative distance of this point from the V axis. The values of RGB are defined in the range [0, 1], the same value range as HSV. The value H is the ratio converted from 0 to 360 degree. Fig 4 shows the results of detail enhancement on HSV color space. Comparing with RGB color space, these results are also good, edges are preserved and gradient reversal artifacts are avoided.

(a) RGB Input Image (b) Guided Filter on HSV

Figure 4. Detail Enhancement. Result after conversion to HSV, detail enhancement on and conversion back to RGB.

7 Conclusion

In this paper, we have presented a filter which is applicable in computer vision and graphics. Guided filter is edge preserving smoothing and gradient preserving filter. The parameters used for guided filtering algorithm in our illustrative examples were to some extent arbitrary. In fact, just as parameters depend on image properties and on the intended results, so do those of guided filter. Given a specific applications, techniques for design of filter and parameter values are possible. It is more effective as compared to other existing approaches. It is one of the fastest edge preserving filter. It is applicable on RGB and HSV color space, for detail enhancement.

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