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Weighted guided image filtering and haze removal in single image

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Abstract

Many applications in the fields of computational photography and image processing require smoothing techniques that can preserve edge well. The smoothing process usually decomposes an image to be filtered into two layers: a base layer formed by homogeneous regions with sharp edges and a detail layer which can be either noise. Local filtering-based edge preserving smoothing techniques suffer from halo artifacts. A weighted guided image filter (WGIF) is introduced by incorporating an edge-aware weighting into an existing guided image filter (GIF) to address the problem. The WGIF is applied for single image detail enhancement, single image haze removal, and fusion of differently exposed images. Poor visibility degrades the perceptual image quality as well as the performance of the computer vision algorithms such as surveillance, object detection, tracking and segmentation. Poor visibility in bad weather such as fog, mist and haze caused by the water droplets present in the air. Due to the presence of fog, mist and haze light scattered in the atmosphere before it reaches the camera. Fog formation is due to attenuation and airlight. Attenuation reduces the contrast and airlight increases the whiteness in the scene. Proposed algorithm uses bilateral filter for the estimation of airlight and recover scene contrast. Qualitative and quantitative analysis demonstrate that proposed algorithm performs well in comparison with prior state of the art algorithms. Proposed algorithm is independent of the density of fog and does not require user intervention. It can handle color as well as gray images. Proposed algorithm has a wide application in tracking and navigation, consumer electronics and entertainment industries. Proposed weighted guided image filter algorithm improves the quality of an image and by the use of haze removal algorithm a high quality depth map can also be obtained.

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Keywords: Image smoothing techniques;Guided image filter; Halo artifacts ; Haze removal ;Attenuation; Airlight.

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1. Introduction

Most applications in the fields of computational photography and image processing require smoothing techniques that can preserve edge well. The smoothing process usually decomposes an image to be filtered into two layers: a base layer formed by homogeneous regions with sharp edges and a detail layer which can be either noise, e.g., a random pattern with zero mean, or texture, such as a repeated pattern with regular structure. There are two types of edge-preserving image smoothing techniques. One type is global optimization based filters as in [1], [2], [4], and [8]. The optimized performance criterion consists of a data term and a regularization term. The data term measures fidelity of reconstructed image with respect to the image to be filtered while the regularization term provides the smoothness level of the reconstructed image. Even though the global optimization based filters often yield excellent quality, they have high computational cost. The other type is local filters such as bilateral filter (BF) [9], its extension in gradient domain [10], trilateral filter [11], and their accelerated versions [5], [12], [13] as well as guided image filter (GIF) [14]. Compared with the global optimization based filters, the local filters are generally simpler. However, the local filters cannot preserve sharp edges and produce halo artifacts

Proposed an edge-aware weighting is introduced and incorporated into the GIF [4] to form a weighted GIF (WGIF). In human visual perception, edges provide an effective and expressive stimulation that is vital for neural interpretation of a scene [7]. Larger weights are thus assigned to pixels at edges than pixels in flat areas. Local variance in 3 × 3 window of a pixel in a guidance image is applied to compute the edge-aware weighting. The weighting can be easily computed via the box filter in [4] for all pixels in the guidance image. The local variance of a pixel is normalized by the local variances of all pixels in the guidance image. The normalized weighting is then adopted to design the WGIF. Due to the proposed weighting, the WGIF can preserve sharp edges like the global filters. As a result, halo artifacts can be reduced/avoided and also avoids gradient reversal.

Fog formation is due to attenuation and airlight. Attenuation reduces the contrast and air light increases the whiteness in the scene. Proposed algorithm uses bilateral filter for the estimation of air light and recover scene contrast. Qualitative and quantitative analysis demonstrate that proposed algorithm performs well in comparison with prior state of the art algorithms. Proposed algorithm is independent of the density of fog and does not require user intervention. It can handle colour as well as gray images. Proposed algorithm achieves better results than other existing algorithms. Proposed algorithm does not require any user intervention and is applicable for colour as well as gray images.

2. Literature review

One type of edge-preserving smoothing techniques is based on local filtering. The BF is widely used due to its simplicity [2]. However, the BF could suffer from “gradient reversal” artifacts despite its popularity [4], and the results may exhibit undesired profiles around edges, usually observed in detail enhancement of conventional LDR images or tone mapping of HDR images. The GIF was introduced in [4] to overcome this problem. In the GIF, a guidance image G is used which could be identical to the image X to be filtered. The range similarity parameter of the BF in [5] is adaptive to the content of the image to be filtered while both the spatial similarity and the range similarity parameters of the BF in [6] are adaptive to the content of the image to be filtered. Compared with the global optimization based filters, the local filters are generally simpler. However, the local filters cannot preserve sharp edges like the global optimization based filters [1], [4]. As such, halo artifacts are usually produced by the local filters when they are adopted to smooth edges [4]. There are two major differences between the WLS filter and the GIF. 1) The GIF in [4] is based on local optimization while the WLS filter in [1] on global optimization. As such, the complexity of the GIF is O(N) for an image with N number of pixels and the WLS filter is more complicated than the GIF. 2) The value of λ is fixed in the GIF while it is adaptive to local gradients in the WLS filter.

Poor visibility in bad weather such as fog, mist and haze caused by the water droplets present in the air. These droplets are very small and steadily float in the air. Two fundamental phenomena which cause scattering are attenuation and airlight [25]. A light beam travels from a scene point through the atmosphere, gets attenuated due to the scattering by the atmospheric particles, this phenomena is called attenuation which reduces the contrast in the scene. Light coming from the source is scattered by fog and part of it also travels towards the camera and leads to the shift in color. This phenomena is called airlight. Airlight increases with the distance from the object. It is noted that fog effect is the function of the distance between camera and object. Hence removal of fog requires the estimation of depth map or airlight map. If input is only a single foggy image then estimation of depth map is an under constrained problem The irradiance received by the camera from the scene point is attenuated along the line of sight. Furthermore, the incoming light is blended with the airlight (ambient light reflected into the line of sight by atmospheric particles). The degraded images lose the contrast and color fidelity. Since the amount of scattering depends on the distances of the scene points from the camera, the degradation is spatial-variant.

3.Existing system

Existing edge-preserving smoothing techniques are summarized with the emphasis on the GIF in [4] and the WLS filter in [1].The task of edge-preserving smoothing is to decompose an image X into two parts as follows:

$$X(p) = \hat{Z}(p) + e(p), \quad (1)$$

where ˆZ is a reconstructed image formed by homogeneous regions with sharp edges, e is noise or texture, and p(= (x, y)) is a position. ˆZ and e are called base layer and detail layer, respectively. One type of edge-preserving smoothing techniques is based on local filtering. The BF is widely used due to its simplicity. However, the BF could suffer from "gradient reversal" artifacts despite its popularity [4], and the results may exhibit undesired profiles around edges, usually observed in detail enhancement of conventional LDR images or tone mapping of HDR images. The GIF was introduced in [4] to overcome this problem. In the GIF, a guidance image G is used which could be identical to the image X to be filtered. It is assumed that ˆZ is a linear transform of G in the window $\Omega_{\zeta 1}$ (p′).

$$\hat{Z}(p) = ap'G(p) + bp', \forall p \in \Omega_{\zeta 1}(p'). \quad (2)$$

where $\Omega_{\zeta 1}$ (p′) is a square window centered at the pixel p′of a radius ζ1. ap′ and bp′ are two constants in the window $\Omega_{\zeta 1}$ (p′).To determine the linear coefficients (ap′, bp′), a constraint is added to X and ˆZ as in Equation (1). The values of ap′ and bp′ are then obtained by minimizing a cost function E(ap′ , bp′) which is defined as

$$E = \sum_{p \in \Omega_{\zeta 1}(p')} (ap'G(p) + bp' - X(p))^2 + \lambda a_{p'}^2, \quad (3)$$

where λ is a regularization parameter penalizing large ap′. Besides the above local filtering based edge-preserving smoothing techniques, another type of edge-preserving smoothing techniques is based on global optimization.It is shown in the linear model that ∇ *ˆZ (p) = ap′* ∇ *G(p)*. Clearly, the smoothness of ˆZ in $\Omega_{\zeta 1}$ (p′). depends on the value of *ap*′. This implies that the data term and the regularization in the GIF are similar to those in the WLS filter in the sense that the data term measures the fidelity of ˆZ with respect to the filtered image *X* and the regularization term provides the smoothness level of ˆZ . There are two major differences between the WLS filter and the GIF. 1) The GIF in [4] is based on local optimization while the WLS filter in [1] on global optimization. As such, the complexity of the GIF is *O(N)* for an image with *N* number of pixels and the WLS filter is more complicated than the GIF. 2) The value of *λ* is fixed in the GIF while it is adaptive to local gradients in the WLS filter. Fattal proposed a method which is based on the independent component analysis (ICA) for fog removal. This method estimates the optical transmission in hazy scenes. Based on this estimation, scattered light is eliminated to increase scene visibility and recover haze from scene contrasts. Here restoration is based on the colour information, hence this method is not applicable for gray image. This method fails when there is a dense fog because dense fog is often colourless

4. Proposed System

An edge-aware weighting is introduced and incorporated into the GIF to form a weighted GIF (WGIF). And fog removal algorithm is also applied to this enhanced image. In human visual perception, edges provide an effective and expressive stimulation that is vital for neural interpretation of a scene. Larger weights are thus assigned to pixels at edges than pixels in flat areas. Due to the presence of fog, mist and haze light scattered in the atmosphere before it reaches the camera. Here onwards the word fog will be used for all fog, mist, and haze. Two fundamental phenomena which cause scattering are attenuation and airlight [19].

4.1 Weighted Guided Image Filter

In this section, an edge-aware weighting is first proposed and it is incorporated into the GIF in [4] to form the WGIF.

4.1.1. An Edge-Aware Weighting

Let *G* be a guidance image and $\sigma^2_{G,1}(p')$ be the variance of *G* in the 3 × 3 window Ω_1 (p′)., An edge-aware weighting ΓG(p′) is defined by using local variances of 3 × 3 windows of all pixels as follows.

$$\Gamma G(p') = \frac{1}{N} \sum_{p=1}^{N} \frac{\sigma^2_{G,1}(p')+\varepsilon}{\sigma^2_{G,1}(p)+\varepsilon} \tag{4}$$

Where ε is a small constant and its value is selected as $(0.001 \times L)^2$ while L is the dynamic range of the input image. All pixels in the guidance image are used in the computation of ΓG(p′). In addition, the weighting ΓG(p′) measures the importance of pixel p′ with respect to the whole guidance image. Due to the box filter, the complexity of ΓG(p′) is O(N) for an image with N pixels.The value of ΓG(p′) is usually larger than 1 if *p′* is at an edge and smaller than 1 if *p′* is in a smooth area. Clearly, larger weights are assigned to pixels at edges than those pixels in flat areas by using the weight ΓG(p′) in Equation (4). Applying this edge-aware weighting, there might be blocking artifacts in final images. To prevent possible blocking artifacts from appearing in the final image, the value of ΓG(p′) is smoothed by a Gaussian filter.

4.1.2. The Proposed Filter

Same as the GIF, the key assumption of the WGIF is a local linear model between the guidance image G and the filtering output ˆZ as in Equation (2). The model ensures that the output ˆZ has an edge only if the guidance image G has an edge. The proposed weighting ΓG(p′) in Equation (4) is incorporated into the cost function E(ap′ , bp′) in Equation (3).As such, the solution is obtained by minimizing the difference between the image to be filtered X and the filtering output ˆZ while maintaining the linear model , i.e., by minimizing a cost function E(ap′ , bp′) which is defined as

$$E = \sum_{p \in \Omega_{\zeta_1}(p')} \left[(a_{p'} G(p) + b_{p'} - X(p))^2 + \frac{\lambda}{\Gamma G(p')} a_p^2 \right] \tag{5}$$

The optimal values of ap′ and bp′ are computed as

$$a_{p'} = \frac{\mu_{G\odot X, \zeta_1}(p') - \mu_{G, \zeta_1}(p')\mu_{X, \zeta_1}(p')}{\sigma^2_{G, \zeta_1}(p') + \frac{\lambda}{\Gamma G(p')}} \tag{6}$$

$$b_{p'} = \mu_{X, \zeta_1}(p') - a_{p'}\mu_{G, \zeta_1}(p') \tag{7}$$

Where $\odot$ is the element-by-element product of two matrices. The bellow elements $\mu G\odot X,_{\zeta 1}(p'), \mu G,_{\zeta 1}(p')$and $\mu X,_{\zeta 1}(p')$ are the mean values of $G\odot X$, G and X, respectively.The final value of $\hat{}Z$ (p) is given as follows:

$$\hat{}Z(p) = \bar{a}pG(p) + \bar{b}\ p \tag{8}$$

4.2 Haze Removal Algorithm

A novel fog removal algorithm is proposed. Present article demonstrates the efficacy of bilateral filter[34] for estimating the image depth map. Here algorithm achieves better results than other existing algorithms. Proposed algorithm, requires pre and post processing steps. Histogram equalization is used as a pre processing. This pre processing increases the contrast of the image prior the fog removal and results better estimation of airlight map. Histogram stretching is used as a post processing, which increases contrast of the fog removed image which is more often a low contrast image. Transfer function of the stretching is adjusted according to the image content.

$$I_{att}(x,y) = I_0(x,y)e^{-kd(x,y)} \tag{9}$$

where, $Iatt(x, y)$ is the attenuated image intensity (gray level or RGB) at pixel (x, y) in presence of fog, $I0(x, y)$ is the image intensity in absence of fog, k is the extinction coefficient and $d(x, y)$ is the distance of the scene point from the viewer or camera.Airlight is represented as

$$A(x\,,y) = I_\alpha(1\text{-}e^{-kd(x,y)}\ ) \tag{10}$$

where $I\infty$ is the global atmospheric constant. It is also called sky intensity. According to the Koschmieder's law [19]-[20], the effect of fog on pixel intensity is represented as the summation of attenuation and airlight.

$$I(x,y) = I_{att}\ (x,y) + A(x,y) \tag{11}$$

where, $I(x, y)$ is the observed image intensity at pixel (x, y). By using (9) and (10) in (11), Koschmieder's law may be represented as

$$I(x,y) = I_0\ (x,y)\ e^{-kd(x,y)}\ +\ I_\alpha(1 - e^{-kd(x,y)}) \tag{12}$$

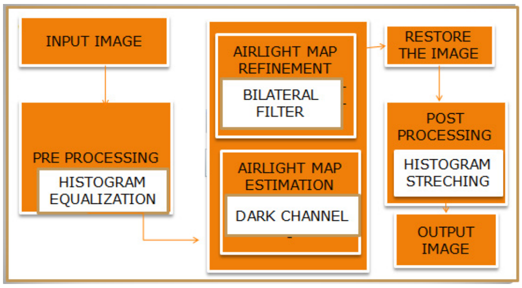


Fig.1. Block diagram of proposed haze removal algorithm

Here, for simulation original foggy image (x, y) is normalized and sky intensity $I\infty$ is set to [1, 1, 1]. To restore image $I0(x, y)$, information of airlight map A is needed. This airlight depends upon the depth of the scene. Block diagram of proposed fog removal algorithm is shown in Fig.2. In order to remove fog, first as a pre processing step, histogram equalization is performed over foggy image. This pre processing step results better estimation of airlight map. Then initial value of airlight map is estimated. Final airlight map is refined using bilateral filter. Once airlight map is obtained, image is restored. Histogram stretching of output image is performed as post processing step. This histogram stretched image is final de-foggy image.

4.2.1. Airlight Map Initialization

It is known that airlight map A is a scalar image which is always positive, hence $A > 0$. Taking minimal across each colour component in (9), we get

$$A(x,y) = \min_{c\in(r,g,b)}[(I^c\,(x,y)) - \left(1 - \frac{A(x,y)}{I_\alpha}\right)] \quad (13)$$

Dark channel is denoted as the minimum intensity across red, blue and green channels. Proposed dark channel is using temporal window i.e. minimum across R, G, and B channels at the particular pixel location instead of spatiotemporal 3D window proposed earlier. This modification reduces calculation significantly without loss of quality. Natural outdoor images are usually full of shadows and colorful objects (viz. green grass, trees, red or yellow plants and blue water surface). For fog free image, except for sky region intensity of the dark channel is low and tends to be zero .Thus

$$\min_{c\epsilon(r,g,b)}(I^c(x,y)) \geq A(x,y) > 0 \quad (14)$$

Thus initial estimation of A can be assumed as in equation 15. where β is a constant and $0 < \beta < 1$. If input image is a gray scale image then initial estimation of A can be assumed as in equation 16.

$$A(x,y) = \beta\ \min_{c\epsilon(r,g,b)}(I^c(x,y)) \quad (15)$$

$$A(x,y) = \beta I(x,y) \quad (16)$$

4.2.2. Refinement of Airlight map

Airlight map is the function of the distance between object and camera. Different object may be at different distance from camera and thus airlight should be different for different object. Also it must be smooth for an object except along the edges. Hence airlight map undergo intra-region smoothing preferentially over inter-region smoothing. The said requirements can be fulfilled by bilateral filter [28].

4.2.3. Restoration

Once airlight map (x, y) is estimated then each color component of de-foggy image $I0(x, y)$ can be restored as

$$I_{0(x,y,c)} = \frac{I(x,y,c) - A(x,y)}{\left(1 - \frac{A(x,y)}{I_\infty(c)}\right)} \quad (17)$$

where $c\ \epsilon\ (r, g, b)$. It is noted that proposed algorithm can also be applied for gray scale image.

4.2.4 Post processing

Restored image may have low contrast. Thus there is a requirement of some post processing. There can be number of choices for post processing like histogram equalization, histogram specification and histogram stretching. The main drawback with histogram equalization is that output image looks saturated. For histogram specification, there is a requirement of a reference image. Moreover, due to the large variations in image contents, a standard reference image may not serve the purpose. Thus to increase contrast, histogram stretching of restored image is performed. Transformation function is shown in Fig.4.2.2 Horizontal axis r represents input pixel value, and vertical axis s represents output pixel value. In this transformation, there are three straight line segments. The parameters specifying the contrast stretch mapping are $r1$, $s1$, $r2$, $s2$, which determine the position of the intermediate straight line segment. Modifying any of these four values modifies contrast stretching transformation.

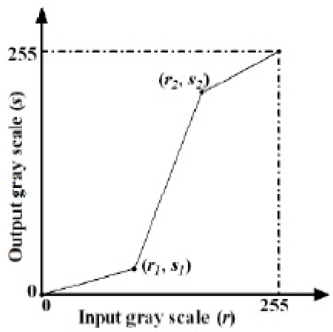


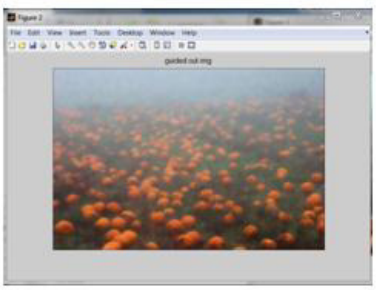
Fig. 2 Transformation function for histogram stretching

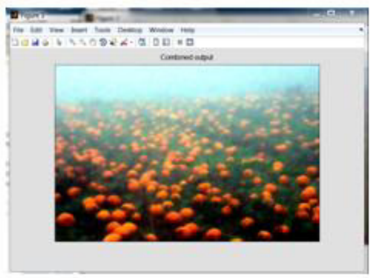
5. Conclusion

A weighted guided image filter (WGIF) is proposed here by incorporating an edge-aware weighting into the guided image filter (GIF) for smoothing and a haze removal algorithm also used for haze removal. The WGIF preserves sharp edges as well as existing global filters, and the complexity of the WGIF is *O(N)* for an image with *N* pixels which is almost the same as the GIF. Due to the simplicity of the WGIF, it has many applications in the fields of computational photography and image processing. Experimental results show that the resultant algorithms can produce images with excellent visual quality as those of global filters, and at the same time the running times of the proposed algorithms are comparable to the GIF based algorithms **.**A novel and efficient fog removal algorithm is proposed. Proposed algorithm uses bilateral filter to generate airlight map. Generated airlight map preserves edges and performs smoothing over the object region. Proposed algorithm does not require user intervention and can be applied for color and gray scale images. Results show that proposed algorithm enhances foggy image better than prior state of the art algorithms. Even in case of heavy fog, proposed algorithm performs well, as algorithm is independent of the density of fog present in the image.

Appendix

A : Input Image *B:Weighted Guided Output* *C:Smoothed Haze Removed Output*





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