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Single image defogging by gain gradient image filter

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Dear editor,

With the advancements in computer vision applications, the image defogging methods have received a lot of consideration. Defogging methods are extensively utilized in civil and military areas such as target detection, traffic surveillance, remote sensing. Therefore, the development of visibility restoration models has become a task of great interest and significance.

Singh and Kumar [1] have proved that the dark channel prior (DCP) is an adequate haze removal model. However, its procedure causes annoying halo and gradient reversal artifacts. Also, the existing approaches still suffer from color distortion, edge degradation, and halo artifacts issues. To overcome these problems, a fog removal technique based on modified gain coefficient filter (GCF) is implemented [2]. Also, modified restoration model (MRM) based DCP is proposed in [3] to minimize the color distortion rate. The partial differential equation-based filter has been designed to remove the fog from images in an efficient manner [4]. In [5], the transmission map obtained from DCP has been refined by designing an efficient gain coefficient-based trilateral filter (GGF). A novel integrated channel prior (ICP) is implemented in [1] to solve the sky-region problem associated with DCP. The gain intervention filter is also utilized to improve computational speed and edge preservation. The notch filter (NF) is proposed to improve the texture information of restored images [6]. However, these techniques [1–6] can be further improved by designing an efficient channel prior to deal with dense fog image.

We attempt to restore the visibility of foggy outdoor images and concurrently suppress artifacts for restoration of radiometric detail in inclement weather circumstances. The major contributions of this study are: (1) A modified restoration method with dynamic threshold has been developed to resolve the sky region problem associated with DCP. The use of dynamic threshold value also reduces the color distortion rate. (2) The gradient guided image filter has been modified by considering the improved guide image (G_d). It has an ability to overcome the issue of halo and gradient reversal artifacts problems. The gain coefficient-based gradient guided image filter is then utilized to improve the coarse estimated atmospheric veil.

Fog formation model. The fog formation model is mathematically evaluated as

$$I_m(i,j) = A_r(i,j)t(i,j) + A_l(1 - t(i,j)). \quad (1)$$

Here, I_m represents the evaluated foggy image. A_r is actual object radiance. A_l and t represent airlight and transmission map respectively. (i,j) defines the pixel coordinates of an image. The transmission map (t) depicts the light which is not sprinkled and received at satellite visual sensor.

Dark channel prior. The DCP is utilized to evaluate the airlight (A_l) and the transmission map (t) from weather degraded image. It states that at least one-color channel (i.e., red, green, or blue) has some pixels whose values are near to 0. The

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minimum pixel value in such a patch is equal to 0. For an image, dark channel prior (I^d) can be computed as follows:

$$I^d(i,j) = \min_{y\in\Psi(i,j)} \left(\min_{c\in(r,g,b)} (I_s^c(l)) \right). \quad (2)$$

Here, I_s^c is the available color channels of I_m. $\Psi(i, j)$ represents the local mask at coordinates (i,j).

Airlight estimation. The value of A_l is obtained from foggy scene, from similar segment as its dark channel image. Pixel with maximum luminance in actual image (I_m) is defined as global atmospheric light. Pixel with highest dark channel is used to evaluate airlight (A_l).

$$A_l(i,j) = I_m \left(\max_c (I_s^c) \right). \quad (3)$$

Transmission map estimation. The foggy image (I_m) is normalized by A_v to evaluate the transmission map (t). The existence of fog is an essential indication for human to observe depth is called aerial perspective. If we eliminate fog systematically, then the fog-free image may appear artificial. Therefore, we may allow some amount of fog for distant objects using a constant attribute $\beta \in [0,1]$. It can be computed as

$$t(i,j) = 1 - \beta \min_{y\in\Psi(i,j)} \left(\min_c \frac{I_s^c(y)}{A_t^c} \right). \quad (4)$$

Coarse atmospheric veil estimation. Initially, the coarse estimated atmospheric veil ($A_{\rm veil}(i,j)$) is defined as

$$A_{\rm veil}(i,j) = 1 - t(i,j). \quad (5)$$

From (4) and (5), the normalized value of $A_{\rm veil}(i,j)$ can be computed as

$$A_{\rm veil}(i,j) = \beta \min_{y\in\Psi(i,j)} \left(\min_c \frac{I_s^c(y)}{A_t^c} \right). \quad (6)$$

The estimation of atmospheric veil is done by approximation $A_{\rm veil}(i,j)$, i.e., considering the minimum operation of object $\frac{I_m(i,j)}{A_t}$, it will result in $A_{\rm veil}(i,j)$'s discontinuity even if no unexpected depth discontinuities occur. To handle halo artifacts of visibility restored image, a filtering technique is required to evaluate coarse atmospheric veil.

To improve the atmospheric veil, a gain coefficient-based gradient guided filter is proposed. From [5], $A_l^c(q) = \psi_v(1 - M_{T_m}(q))$ is set as the transmission veil. $M_c(q) = \min_c(I_c(q))$ is the minimum color channel of $I_m(q)$. As known in prior, $0 \leqslant A_v(q) \leqslant M_c(q)$, therefore, for gray image, $M_c = I_m$. By designing modified guided image filter, transmission refinement can be achieved by evaluating $T_m(q) = \sigma^2(q) - J_{\mathcal{W}}^f(|M_c - \sigma^2(q)|)$. $\sigma^2(q)$ represents σ^2 of pixel centered at position k, with its neighbors in local mask of 7×7. Therefore, atmospheric veil is rewritten as

$$A_v(q) = \max\left(\left(\min\left(T_m^f(q), M_c(q)\right)\right), 0\right). \quad (7)$$

Here $T_m \in [0,1]$. Transmission of every mask is redefined as follows:

$$\overline{M_{T_m}} = 1 - \frac{A_v}{\psi_v^c}. \quad (8)$$

The environment ψ_v^c is typically supposed to be pixel illumination with maximum luminosity in an object. But, in real time, this hypothesis frequently delivers invalid outcomes because of the occurrence of self luminous organisms. In the same way, the sky pixel values are also calculated between all local minimum corresponds to background illumination ψ_v^c.

$$\psi_v = \max_{z\in I_m} \left(\min_{z\in\mathcal{W}(q)} (F_i^c(z)) \right), \quad (9)$$

where $I_m^c(z)$ is color components of $I_m(q)$ in every mask.

Gain coefficient-based gradient guided filter has the capability to overcome gradient reversal artifacts of haze-free image. The filtering procedure is initially prepared under the guidance of image ψ_d which is obtained by applying the gain intervention filter on input image (I_m). Let $I_{\rm val}$ and $\psi_{\rm val}$ be illumination values at pixel q of minimum channel object and guided image respectively, W_r be kernel mask at j, to be depended upon bilateral filter. Gain coefficient-based gradient guided filter is then devised as

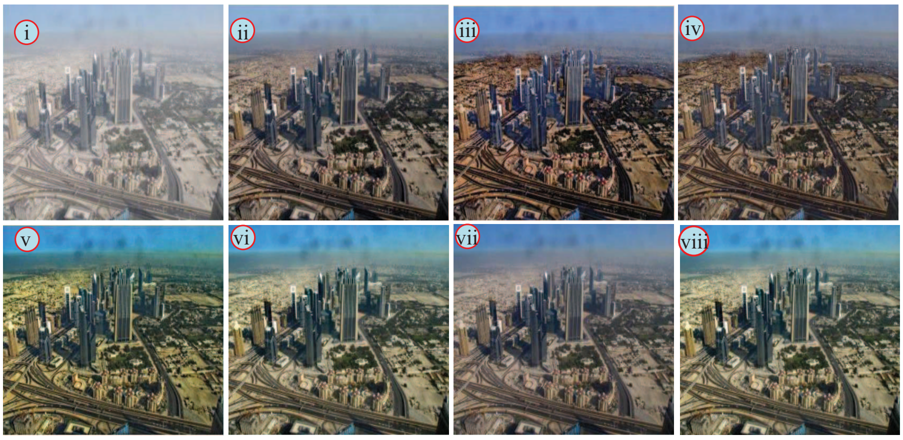
$$J_f(I_m) = \frac{\sum_{q\in k_r} M_c^{pq}(\psi_d) \times I_q \times \sigma^2(I_q, \psi_d)}{\sum_{q\in K_r} M_c^{pq}(\psi_d)}, \quad (10)$$

where kernel weights function ($M_c^{pq}(\psi_d)$) can be defined as follows:

$$M_c^{pq}(\psi_d) = \frac{1}{|n|^2} \sum_{n:(p,q)\in k_r} \left(1 + \frac{(\psi_{d_p} - \mu_n)(\psi_{d_q} - \mu_n)}{\sigma_n^2 + A_v} \right), \quad (11)$$

where μ_n and σ_n^2 denote mean and variance of ψ_d in local mask k_r, respectively. $|n|$ is total pixels in mask. When ψ_{d_p} and ψ_{d_q} are simultaneously on the similar side of an edge, the weight allocated to pixel q is maximum. When ψ_{d_p} and ψ_{d_q} are on opposite sides, a minimum weight will be allocated to pixel q.

Modified restoration model. The main objective of restoration model is to restore A_r from foggy image (I_m). Obviously, it is an ill-posed issue because only I_m is available. It has been observed that we need to specify A_l and t as input prior. The object radiance A_r is computed using A_l and t, which is given as



(a)

Image	DCP	GCF	MRM	GGF	ICP	NF	Proposed
Im1	0.94	0.86	0.72	0.71	0.65	0.52	0.54
Im2	0.66	0.70	1.19	0.97	0.83	0.56	0.51
Im3	1.10	1.02	0.92	0.93	1.15	0.69	0.68
Im4	1.07	1.17	1.00	0.80	0.93	0.73	0.71
Im5	0.98	0.83	0.93	0.96	0.86	0.79	0.76

(b)

Figure 1 (Color online) (a) Results of defogging methods for Im3: (i) input image, (ii) DCP, (iii) GCF, (iv) MRM, (v) GGF, (vi) ICP, (vii) NF and (viii) proposed method; (b) comparative analysis of perceptual fog density.

$$A_r(i,j) = \frac{I_m(i,j) - A_l}{t(i,j)} + A_l. \qquad (12)$$

The restored image (A_r) suffers from noise when transmission map (t) methods towards zero. t is constrained as the lower bound which is denoted by t_l. According to literature review, t_l is experimentally set to 0.1. Therefore, the object radiance (A_r) is computed as

$$A_r(i,j) = \frac{I_m(i,j) - A_l}{\max(\bar{t}(i,j), t_l)} + A_l. \qquad (13)$$

Performance evaluation. The performance of the proposed method is compared with seven well-known defogging methods on the five outdoor fog affected images.

Figure 1(a) shows the restored images obtained from proposed and existing defogging techniques. It is observed that the proposed method achieves a remarkable visual superiority with lesser number of halo and gradient reversal artifacts.

Quantitative analysis. The no-reference perceptual fog density assessment metric (PDF) [6] is considered to compare proposed and existing defogging techniques. Figure 1(b) demonstrates that proposed method has less PSP as compared to the competitive defogging techniques. The mean reduction in PFD by using proposed method over available methods is approximately 0.0143.

Conclusion. A novel gain coefficient-based gradient guided image filter has been designed for obtaining accurate transmission map. The proposed method has been tested on five popular outdoor images. Experimental results show that the colors of fog-free images are not distorted. The proposed method has less number of artifacts and perserves more significant edges than the existing defogging methods.

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