A Qualitative Classification of Various Enhancement Restoration and Filtering Techniques for Dense Fog Removal from Images

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Abstract— Aerosol Particles such as Fog haze and smoke reduces contrast level of the image that affects the visual quality of the image and hence is a main reason for road accidents. Airlight and Attenuation phenomena are responsible for affecting visual quality and visibility level of an image in the field of computer vision. For improving the visibility level of an image and reducing fog and noise various image enhancement methods are used, followed by the subsequent restoration methods. The main aim of this paper is to review state-of-art image enhancement and restoration methods for improving the quality and visibility level of an image to provide a clear, fog-free image even in bad weather condition. The review work includes the classification of various approaches or methods that could be selected for introducing enhancement and restoration of images. It could then serve as the base to start with new research work by upcoming researchers.

Key words: Fog, Enhancement, Restoration, Filters

I. Introduction

Images of outdoor scenes captured in bad weather suffer from poor contrast. Optically, poor visibility in digital images is due to the substantial presence of atmospheric particles which absorb and scatter light between the digital camera and the captured object. Image degradation can cause problems for many systems which must operate under a wide range of weather conditions.

These aerosol particles include Fog, haze, mist and smoke.

Haze constituted of aerosol (small particles suspended in gas)

Its main sources are volcanic ashes, foliage exudation, combustion products, sea salt. Haze particles are larger than air molecules but smaller than fog droplets and produce a distinctive gray or bluish hue and affects visibility. It extends to altitudes of several Kms.

Fog is haze, associated with an increase in relative humidity of an air. Here size of water droplets increases. Haze can turn into fog (transition state: *mist*).It reduces visibility more than haze and extends to altitudes of few hundred meters.

Figure 1[10]

Condition	Particle Type	Radius Micrometer
Air	Molecule	10^{-2}
Haze	Aerosol	$10^{-2.1}$
Fog	Water Droplet	10^{-10}
Cloud	Water Droplet	10^{-10}
Rain	Water Droplet	10^{2} - 10^{4}

Table 1: Aerosol Particles

A. *Effect of Fog:*

In field of computer, effect of fog/haze that's vision visual quality and visibility level of an image is caused by:-

1) *Attenuation[6]:*

The light beam coming from a scene point gets attenuated because of scattering by atmospheric particles, called attenuation that decreases the contrast of the scene. Fog particles add into 3D GIS (Geographic information system)

2) *Airlight[6]:*

The light coming from a source is scattered toward camera and give on to the shift in color, its called airlight. The fog effect is the function of the distance between scene point and viewer or camera. Hence, removal of fog requires the estimation of airlight map.

From the atmospheric point of view, weather conditions differ mainly in the types and sizes of the particles present in the space as shown in Table no.

Fog degrades the perceptual image quality, thus the efficacy of computer vision algorithms based on small features or high frequencies. Removal of fog from images as a preprocessing increases the accuracy of these computer vision algorithms. This review work aims to study different methods for reducing fog effect and recover scene contrast.

For improving the visibility level 4 major steps are used:-

- Step 1. Acquisition process of foggy images.
- Step 2. Estimation process (estimate scattering phenomena, visibility level).
- Step 3. Enhancement process (improves visibility level, reduce fog or noise level).
- Step 4. Restoration process (restore enhanced image).

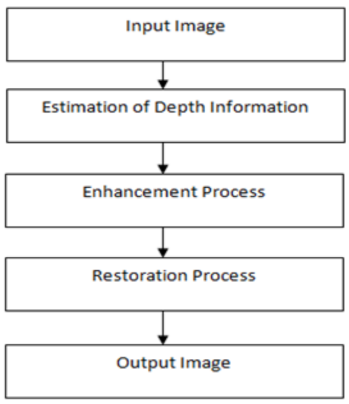


Fig. 1: visual quality and visibility level of an image

II. Haze removal techniques

Numerous haze removal techniques have been proposed to improve visibility in hazy images. These techniques are based on one of the below models:

A. Types of Models:

1) Atmospheric Scattering Light Model:

Uses specific scattering models such as Rayleigh scattering and does rely on the knowledge of illumination directions.

2) Physics based Model:

Uses Polarisation Technique; rely on fact that usually the natural illuminating light scattered by atmospheric particles airlight is partially polarized.

3) Optical based Model:

Could work well only in restricted situations. It is sufficient only on clear days, with weak light scattering mainly due to air molecules, when the Sun is 90° to the viewing direction.

B. Haze Removal Techniques:

The techniques based on above models are categorized as:

(1) Multiple image approach,
(2) Additional information approaches (single image + depth map),
(3) Single image approach

1) Multiple Image Approach:

They require special equipment (polarizers) or same scene under different weather conditions. Also, they don't necessarily produce better results than single-images approaches. Here, 2+ images of the same scene are taken:

– Under different weather conditions [3], or
– With different polarization filters [2]

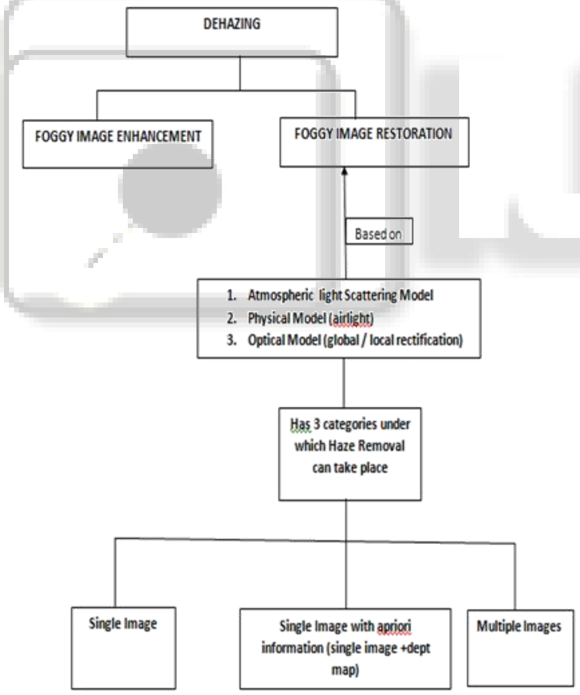


Fig. 2: Dehazing Algorithm categories

a) Under different weather conditions [3]:



Fig. 3: Foggy Image Fig. 4: Normal Image Fig. 5: Dehazed image

b) With different polarization filters [2]:

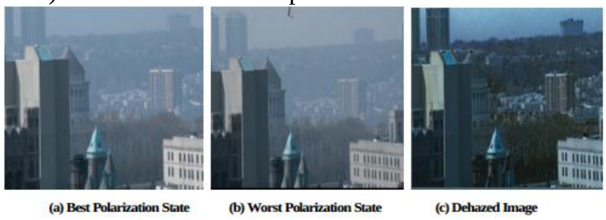


Fig. 6: different polarization filters

2) Single image + depth map:


Fig. 7: Dehazed Image Fig. 8: Foggy Image

3) Single Image Approach [5]:


Fig. 9: Dehazed Image Fig. 10: Foggy Image

III. VISIBILITY RESTORATION TECHNIQUES

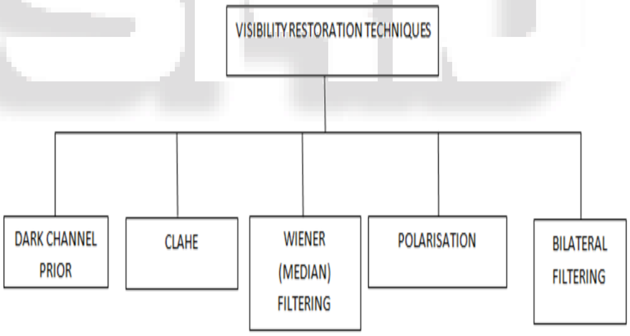


Fig. 11: Visibility Restoration Techniques

A. Depth Estimation Method (Dark Channel Prior) [5]:

Dark channel prior is an effective image prior. It was proposed to expel cloudiness from a single image, where the key perception is that most local patches in outside fog free pictures hold a few pixels whose intensity is low in no less than one shade channel. In light of this former with the fog optical model, one can specifically assess the thickness of the dimness and restore a great fog free picture.

1) Statistical Assumption:

"In most of the non-sky patches, at least one color channel has very low intensity at some pixels. In other words, the minimum intensity in such a patch should have a very low value".

The 1st assumption is used to estimate *airlight*;
The 2nd assumption is used to estimate the *transmission*

Dark Channel: $J^{dark}(\mathbf{x}) = \min_{c \in \{r,g,b\}} \left(\min_{\mathbf{y} \in \Omega(\mathbf{x})} (J^c(\mathbf{y})) \right)$

He shows that the **transmission** can be estimated by calculating:

$$\tilde{t}(\mathbf{x}) = 1 - \min_c \left(\min_{\mathbf{y} \in \Omega(\mathbf{x})} \left(\frac{I^c(\mathbf{y})}{A^c} \right) \right)$$

- It is based on single image approach.
- Airlight is estimated by picking up the pixels of the image corresponding to the 0.1% brightest pixels in the dark channel, and then choosing the one with maximum intensity.

To refine the estimation of depth information, these algorithms use some assumptions or prior knowledge. Removal of fog requires the estimation of image depth information.

The main origins of blur objects, being out of focus, shadows casted by objects, or objects having a physical surface that is perceived as blur. An object out of Focus will produce a blur because it is too far away from the focal plane. This already hints to distance or depth. The amount of blur that is in a part of such an image increases with depth. Therefore, if we can estimate the amount of blur, we can estimate the relative depth.

B. CLAHE[18]:

Step 1: The original image should be divided into sub-images which are continuous and non-overlapping. The size of each sub-image is M×N.
Step 2: The histograms of the sub-images are calculated.
Step 3: The histograms of the sub-images are clipped.

The number of pixels in the sub-image is equally distributed to each gray level. Then the average number of pixels in each gray level is given as

$$N_{avg} = (N_{SI-XP} * N_{SI-XP}) / N_{graylevel}$$

- where SI the average number of pixels, GRAYLEVEL is the number of the gray levels in the sub-image, XP is the number of pixels in the x dimension of the sub-image,YP is the number of pixels in the y dimension of the sub-image

C. Polarization based Method[2]:

Usually the natural illuminating light is scattered by atmospheric particles air light is partially polarized. Optical filtering alone cannot remove the haze effects, except in restricted situations. Our method, however, stems from physics-based analysis that works under a wide range of atmospheric and viewing conditions, even if the polarization is low.

The approach does not rely on specific scattering models such as Rayleigh scattering and does not rely on the knowledge of illumination directions.

It can be used with as few as two images taken through a polarizer at different orientations. As a byproduct, the method yields a range map of the scene, which enables scene rendering as if imaged from different viewpoints. It also yields information about the atmospheric particles.

D. Bilateral filter[18]:

A Bilateral Filter is a filter based on Gaussian blur but preserves edges. The Gaussian blur uses the same Gaussian kernel for every pixel of the image. The kernel is used for averaging the pixels on weight.

The Bilateral Filter changes the kernel to conserve edges. This preserves sharp edges by systematically looping through each pixel and adjusting weights to the adjacent pixels accordingly.

By penalizing the pixels with high difference in intensity they affect the smoothing process less leading to maintaining strong edges within an image.

Intuitively this can be seen as smoothing over pixels while excluding pixels whose intensity differs significantly.

E. Median filter [8]:

The Median Filter is another type of filter for smoothening and reducing noise from an image while preserving strong edges. It is a simple filter that uses the median to obtain its result.

It replaces the value of a pixel by the median of the values of surrounding pixels up to a defined range. In the case of noise this works because the median is unaffected by the outlying values from the noise as long as there is not too much noise. It even preserves edges, however thin lines on a plain background will not be preserved.

F. Markov Random Fields [18]:

Also known as a Markov Network a Markov Random Field (MRF) is an undirected graphical model that specifies factorization and a set of conditional independence relations in probabilistic. Each node in the observed layer is only connected to its corresponding latent variable, while the latent variables are also connected to their neighboring latent variables. The model is factorized based on cliques which are sets of mutual connected nodes. Due to the factorization on cliques the complexity only increases slightly when a set of nodes is added to the model.

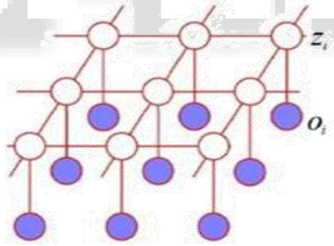


Fig. 12: Representation of a Markov Random Field

In the model two types of cliques are encountered, the first clique is in the form of zi,oi, where zi is a latent variable and oi an observed node. This clique describes a correlation between the two variables and can be controlled by an energy function that should give a small value for correct values of zi with respect to o. The collection of these cliques is known as the data term. The other type of clique is in the form of zi,zj, where zj is a neighboring node of zi.

Similar to the previous clique a smaller energy value is assigned when the two nodes are more similar. This constrains the smoothness and is therefore known as the smoothness term or prior term.

Algorithm	Description	Disadvantage
Markov Random Field	Incorporates the prior that neighboring pixels should have similar transmission	Tends to produce over enhancement images in practice.

	values	
Bilateral Filter	A Bilateral Filter is a filter based on Gaussian blur but preserves edges.	Defogging result is not so good when there are discontinuities in the depth of scene. The haze among gaps cannot be removed.
Median Filter	It is a simple filter that uses the median to obtain its result	Thin lines on a plain background will not be preserved.
Polarization Based Method	Polarization based methods remove the haze effect through two or more images taken with different degrees of polarization.	Requires multiple images. So, the requirement met with real-time applications of images. Eg. changing scenes, or image taken from a static old database
Depth estimation method	Depth at various locations in an image is estimated then fog is removed from the image	The algorithm is complex and the processing speed is slow. Edges are not preserved.

Table 2: Comparison between Existing systems[18]

IV. FILTERING TECHNIQUES

Enhancement techniques could be applied in 2 domains namely:

A. *Spatial Domain Enhancement methods:*

Spatial Domain techniques are performed to the image plane itself and they are based on direct manipulation of pixels in an image. The operation can be formulated as g(x,y)=T[f(x,y)]

Where, g is the output; f is the input and T is the operation on f defined over some neighbourhood of (x,y).

Spatial Domain: g(x,y)=f(x,y) X h(x,y)

According to the operations on the image pixels, it can be further divided into 2 categories:

B. *Point Operations and Spatial Operations:*

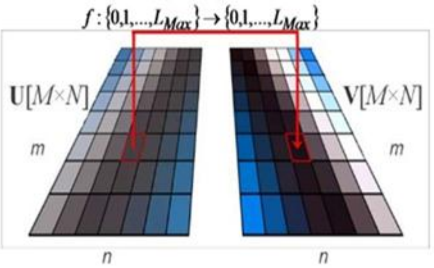
1) *A Point Operations [21]:*

Zero memory operations where a given grey level where u∊[0,L] is mapped into a grey level v∊[0,L] according to a transformation.

v(m,n)=f[u(m,n)]

$$v(m,n)=f(u(m,n)), \forall m=0,1,\ldots,M-1; n=0,1,\ldots,N-1;$$

$$f:\{0,1,\ldots,L_{Max}\}\rightarrow\{0,1,\ldots,L_{Max}\}$$



a) Contrast Stretching[21]:

The idea behind contrast stretching is to increase the dynamic range of grey levels in the image being processed. Low Contrast Images occur often due to:-

– Poor lightening conditions
– Small dynamic range of image sensors

b) Gray Level[21]:

There are several ways of doing this technique but most of them are variations of two basic themes:

– Display high value for all grey levels in the range of interest and the low gray level values for rest of the gray values which produces binary image.
– Brightening the desired range of gray levels but preserving the background and the gray level tonalities in the image.

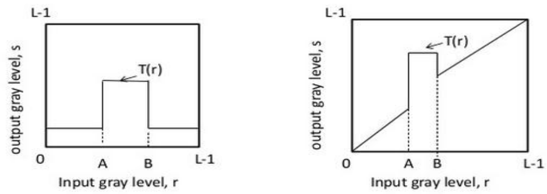


Fig. 13: Gary Level

c) Bit Plane Slicing:

Focus is on highlighting the contribution made to total image appearance by specific bits. Higher order bits (top 4) contain the majority of visually significant data. Other bit planes contribute to more subtle details in the image.

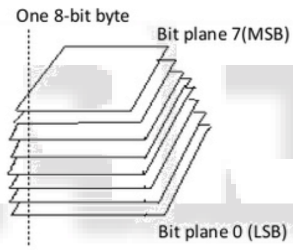


Fig. 14: Bit Plane representation off an 8 bit image

d) Histogram Processing[21]:

The histogram of a digital image with gray levels in the range (0,L-1) is a discrete function h(r_k)= n_k,where r_k is the kth gray level and $n_k$is number of pixels in the image having gray level r_k.

Histogram is normalized by dividing each of its values by total number of pixels in the image denoted by 'n'. Thus normalized histogram is given by P(r_k)= n_k/n, where k=0,….L-1

2) *Image Subtraction[21]:*

The difference between two images f(x,y) and h(x,y) is expressed as-

g(x, y) = f(x, y) - h(x, y)

The key usefulness of subtraction is the enhancement of differences between images. Difference is taken between corresponding pixels of 'f' and 'h'.

3) *Image Averaging[21]:*

The purpose of image averaging is noise removal. Consider a noise image g(x, y) formed by the addition of noise n(x,y) to an original image f(x, y); i. e

g(x, y) = f(x, y) +n(x, y)

If noise satisfies the constraint then averaged image is given by –

$$\bar{g}(x,y)=1/k* \sum_{i=1}^{k} g_i(x,y)$$

Then it follows that

$$E\{\bar{g}(x,y)\}=f(x,y)$$

i.e it is the expected averaged image approaches to the original image as the number of noisy images used in the averaging process increases.

4) Spatial Filtering [23]:

It is performed on local neighborhoods of input pixels. Image is convolved with FIR (finite impulse response filter) called spatial Mask.

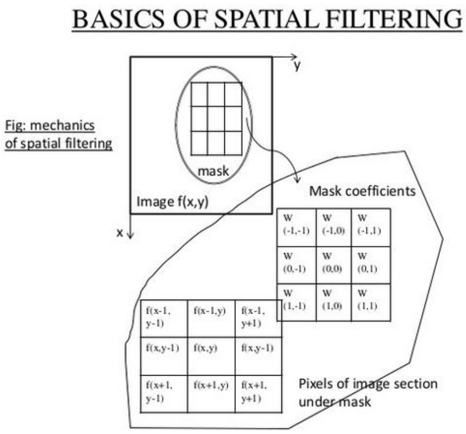


Fig. 15: Basics of spatial filtering

a) Low Pass Filter[21]:

Each pixel is replaced by weighted average of its neighboring pixels that is,

$$v(m, n)=\sum\sum_{(k,l)\epsilon W}^{n} a(k,l)y(m-k,n-l)$$

Where, y(m, n) and v(m, n) are input and output images respectively. W is suitably chosen window and a(k, l) are filter weights.

A common class of spatial averaging filters has all equal weights.

$$v(m, n)=\frac{1}{N} * \sum\sum_{(k,l)\epsilon W}^{n} y(m-k,n-l)$$

It is used for noise smoothing, low pass filtering and subsampling of images.

b) High Pass Filter[21]:

It can be implemented by subtracting low pass filter output from its input. High pass filters are useful in extracting edges and in sharpening images.

c) Median Filtering [23]:

In median filtering, input pixel is replaced by the median of the pixels contained in a window around a pixel

v(m, n) = median {y(m-k ,n-l),(k ,l) ϵ W}

The algorithm requires arranging the pixels in an increasing or decreasing order and picking the middle value. For odd window size is commonly used as[3*3 or 5*5 or 7*7]

For even window size, the average of two middle values is taken.

Median filter is a Nonlinear filter and performs very well on images containing binary noise poorly when the noise is Gaussian.

C. Frequency Domain Enhancement Methods[20]:

These methods enhance the image f(x,y) by convoluting the image with a linear, position invariant operator. The 2D convolution is performed in Frequency Domain with DFT

Frequency Domain: G(w1,w2) = F(w1,w2)H(w1,w2)

It is further classified as:-

- Low pass filter
- High pass filter
- Pseudo color filter
- Homomorphing filter

1) Low Pass Filtering[22]:

a) Ideal low pass Filter [22]:

It cuts off high frequency components at a distance greater than a certain distance from origin (cut off frequency)

$$H(u,v)=1, \text{ if } D(u,v) <= D_0$$
$$=0, \text{ if } D(u,v) > D_0$$

b) Butterworth Low Pass Filter[22]:

Here, transfer function does not have sharp discontinuity establishing cut off between passed and filtered frequencies, The cut off frequency D_0 defines point at which H(u,v)=0.5

$$H(u,v)=1/(1+[\frac{D(u,v)}{D_0}]^{2n})$$

c) Gaussian Low Pass Filter:

Here, transfer function is smooth like Butterworth Filter. It concludes that Gaussian in frequency domain is Gaussian in spatial domain. No ringing artifacts are produced.

$$H(u,v)=e^{-D^2(u,v)/2D_0^2}$$

2) High Pass Filtering:

a) Ideal high pass Filter:

It cuts off high frequency components at a distance greater than a certain distance from origin (cut off frequency)

$$H(u,v)=1, \text{ if } D(u,v) >= D_0$$
$$=0, \text{ if } D(u,v) < D_0$$

b) Butterworth high Pass Filter:

Here, transfer function does not have sharp discontinuity establishing cut off between passed and filtered frequencies, The cut off frequency D_0 defines point at which H(u,v)=0.5

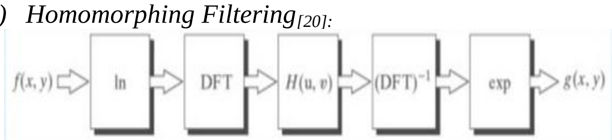
$$H(u,v)=1/(1+[\frac{D(u,v)}{D_0}]^{2n})$$

3) Pseudocolor Filtering[21]:

In this techniques a set of images are mapped into a color image where different features are represented by different colors. It also exploits pseudorandom mapping of gray levels into RGB co-ordinates for any image display system.

The pseudocolor mappings are non-unique and extensive interactive trials may be required to determine an acceptable mapping for displaying a given set of data.

4) Homomorphing Filtering[20]:



It involves simultaneous dynamic range compression (reduce illumination variation) and contrast enhancement (increase reflectance variation). Illumination Variation is characterized by slow spatial variations (low spatial frequencies). Reflectance Variation is characterized by abrupt spatial variations (high frequency variations).It can be accomplished using a high frequency emphasis filter in log space –

DC gain of 0.5(reduce illumination variation)

High frequency gain of 2(increase reflectance variations)

Output of homomorphic filter:

$$g(x,y)=\sqrt{i(x,y)}*(r(x,y))^2$$

V. CONCLUSION

This paper describes the classification of various approaches or methods that could be selected for introducing enhancement and restoration of images in an hazy environment. The comparative study could make researchers use the best possible techniques for worthy fog free output image with least noise, negligible block artifacts, improved contrast and preserved edges.

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