Image Contrast Enhancement for Outdoor Machine Vision Applications

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***Abstract*—Outdoor machine vision is getting a concern nowadays. Ranging from surveillance and monitoring system to automotive system such as driver assistance system require vision application or artificial eye to keep monitoring the situations. However, most of these applications works very well during clear weather and degrade during bad weather due to the atmospheric particles mitigate the quality of vision system. This paper discuss the state of the art of image enhancement techniques used to adjust the contrast of an outdoor image degrade by fog, haze, and rain. A brief overview of bad weather will be discussed and several recent techniques on removing fog, haze and rain are discussed.**

Keywords-bad weather, rain, fog, haze, machine vision, image enhancement

I. INTRODUCTION

Image processing and computer vision are the two fields that considered as one due to it complementary each other. Computer vision is a field that constructing a machine can see in a sense of designing artificial system that obtains information from images meanwhile image processing is a method to process the image either taken from camera or video sequences. Image processing can be defined as a process of extracting information from images and among the technique that computer vision used to achieve its goal. This field can be viewed as multi-discipline area from human vision, signal processing, computer sciences and pattern recognition (Figure 1).

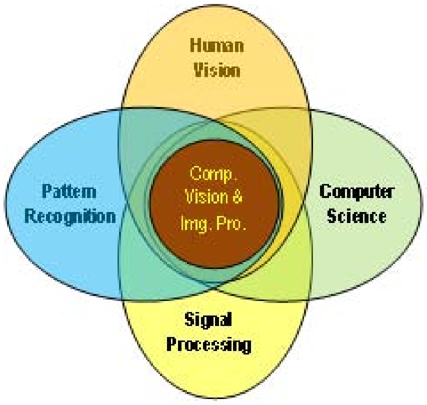

Figure 1. Image processing and computer vision field

Literature indicated [1] that Image processing and computer vision has been explored and investigated [2] nearly 80 years and image enhancement has been explored for almost 60 years ago. The first computer vision pioneer is Lawrence Gilman Robert (Larry Roberts) who received his PhD in Machine Perception in three dimensional solids in 1961 [3]. Typical problem or challenges in computer vision can be broadly classified into four categories [4] i) Compression ii) Enhancement iii) Recognition and iv) Visualization which offer a wider spectrum of potential problem in many domains such as military, medical, agriculture and industrial requirements [5].

This paper is organized as follows, section II describe the bad weather classifications and some recent work has been done. A generic model for removing weather effects are described in section III. Image enhancement techniques and noise removal are explain in section IV and V and this paper conclude in section VI.

II. TOWARD WEATHER FREE VISION

Recent studies on a vision in a bad weather begin at the late 90s. The goal of the study is towards weather free vision which utilized much techniques on image enhancement [6, 7].

Bad weather conditions can be divided into two types, i) static or steady conditions such as fog and haze and ii) dynamic conditions such as rain and snow [8, 9] (Fig 2).

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Many researchers have been made at resolving static weather problems like fog [10-13] and haze [14-16]. Problem such as fog and haze have been investigated most in literature, many attempts to solve the fog and haze due to certainly easiest since due to very small size of the particles in the air.

In the perspective of dynamic weather conditions such as snow and rain, the size and velocity of the streak are different compared to the haze and fog. Some techniques in solving haze fog may solve some problem on rain or snow if the size of the particle is small. The bigger the size of the streak may lead to other techniques and statistical characteristics may apply. Detail information regarding bad weather is discussed in next section.

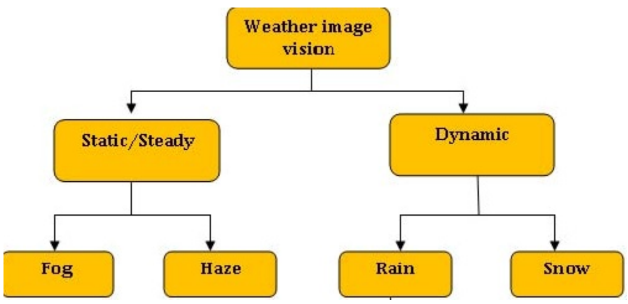

Figure 2. Bad weather classification

Most outdoor vision applications such as surveillance, autonomous navigation and terrain classification require robust detection of image features. Atmospheric conditions induced by suspended particles with significant size and distribution (Table 1) [6] in the participating media such as fog, haze and rain, severely degrade the scene appearance [17] due to contrast and color of image are drastically degraded.

TABLE 1. WEATHER CONDITION AND ASSOCIATED PARTICLE TYPES, SIZE AND CONCERTRATION

Condition	Particle Type	Radius (µm)	Concentration(cm^{-3})
Air	Molecule	10^{-4}	10^{19}
Haze	Aerosol	10^{-2}-1	10^{3}-10
Fog	Water droplet	1-10	100-10
Cloud	Water droplet	1-10	300-10
Rain	Water drop	10^{2}-10^{4}	10^{-2}-10^{-5}

In order to make vision system more reliable, there is a need to restore the original scene from a single image effected with bad weather. Unfortunately, the effects of bad weather increase exponentially with the distances of a scene point from the sensor thus removing these effects are a challenging task [18]. This is due to the inherent vagueness that arises in the image construction process.

Recently, there has been a significant interest in the image processing and computer vision communities in solving issues related to image processing under bad weather conditions. The trend of research is tabulated in Table 2.

TABLE 2. RECENT RESEARCH IN BAD WEATHER

Method	Enhancement	Year	Type of weather
Physic model [19]	Color	2001	Haze
Bilinear Interpolation HE [20]	Contrast	2010	Fog
Artificial Bee Colony Optimization[21]	Contrast	2012	Haze
Guidance Image Method[22]	Contour	2012	Rain and Snow
Kalman Filter [23]	Color	2008	Rain
HVS-CLAHE [24]	Contrast	2010	Fog and Rain
Color Ellipsoid [25]	Color	2013	Fog
Morphological Component Analysis [26]	Contrast	2012	Rain
Wavelet Fusion[27]	Color	2009	Haze
Gradient domain [28]	Contrast	2012	Haze

III. REMOVING WEATHER EFFECTS

There has been significant interest in computer vision methods for removing weathering effects such as fog and haze from images. An well-designed modeling of the effects of weather conditions was proposed by Narasimhan and Nayar [18, 29] – physical model.

It explains how light, colors, and contrast reflect on weather conditions. In [18], Narasimhan and Nayar presented two physics-based models (attenuation and airlight) that can be used for contrast restoration in images containing uniformly bad weather. The attenuation model describes the get attenuated as it travels from a point on the scene to the observer, and the airlight model measure how a column of atmosphere acts as a light source by reflecting environmental illumination towards observer.

These models provide a way of quantifying the decay in contrast of images with poor visibility conditions due to weather effects. In [29], Narasimhan and Nayar use the physical models for removing weather effects such as fog and haze from a single image of a scene without precise knowledge of the weather, and with minimal user input. Similarly, in [30] Narasimhan and Nayar present models for extracting the 3D structure of a scene occluded by bad weather.

In the work presented in Shwartz et al. [31] approach the problem of blindly recovering the parameters needed for separating airlight from other measurements.

Many algorithms have been proposed to improve the visibility of images taken in bad weather for the last two decades. They can be grouped into two classes: conventional image enhancement algorithms and recovery algorithms based on the image degradation model.

Conventional image enhancement algorithms, such as histogram specification [32], retinex [33] and contrast modification [34], have been widely used in computer vision and image processing. These algorithms work well when all the objects in an image have similar distances from the camera, such as an aerial image directly taken from up to down. However, their application is limited without considering the spatial variance of the degradation. Other algorithms are based on the degradation model.

IV. IMAGE ENHANCEMENT

Leaping into image enhancement is one of branch of image processing and computer vision. The main aim of the image enhancement is to increase the quality of image that suit for particular applications due to its contrast is low or is it noisy or is it blurred [4]. Image enhancement was firstly discussed by [35] which briefly reviewed image enhancement techniques such as contrast enhancement, crispening, noise removal and inverse filtering on a theoretical basis and compared with the hardware availability such as digital computers, optical set-ups and special electro-optical devices to perform the mathematical operations.

Prior to perform image enhancement, we need to know the types of images. Image can broadly classified into two groups [36]:

i) Image with sufficient signal-to-noise ratio
ii) Image without signal-to-noise ratio

Image in the first category typically having a good level of brightness and contrast and conversely the second category of image tend to be dark with insufficient brightness and contrast. Image in second category also tend to be images that need to be enhanced using most image enhancement methods.

Research in image enhancement begin when a digital image quality always degraded by noise, blurring, incorrect color balance and poor quality[37] which taken through image quality devices such as cameras, scanner, and video recorder. Thus, to improve the poor quality of images, several general steps in image enhancement are required. The step involves i) color balancing method or color correction to adjust the color of the image using color models ii) contrast enhancement to adjust the brightness and light illumination iii) noise removal in order to used optimized techniques for smoothing and finally iv) image sharpening technique is applied to produced the improved quality images. The challenge in image enhancement is subjective evaluation, this could be due to the fact that, image enhancement is a problem oriented matter, thus, the successful applications are really depends on the judgment of the viewer [38]. This is to note that; image enhancement has been used in many domains such as underwater vision [39], biomedical images [40], and outdoor vision (surveillance, terrain classification, and autonomous navigation) [18].

Image enhancement techniques can be further divided into two groups. i) Non-model based and ii) model-based methods [41].

A. Non-model based methods

Non-model based method used the information in the image for further processing. The popular methods utilized model-based methods are histogram equalization [42], retinex algorithm [43, 44] and wavelet based methods [45].

Histogram equalization fall into two types i) global histogram equalization and local histogram equalization (also refer as an adaptive histogram equalizations. Comparing with both type of histogram, global histogram equalization is the popular due to its effectiveness and simplicity. Although the method is effective, occasionally contrast loss happen, the method does not take the local information of the image into account. Conversely, local histogram equalization [46] is used to resolved the drawbacks in [47].

Retinex algorithm is an image enhancement algorithm that is used to balance the what the human see and the machine vision by adjusting brightness, contrast and sharpness of an image [48] as well as the color constancy [49]. Theory of retinex has been introduced by Edward Land in 1986. Retinex algorithm is divided into three groups such as i) Single-scale retinex (SSR) ii) Multi-scale retinex (MSR) and iii) Multi-scale retinex with colour restoration (MSRCR) [43]. Retinex algorithm produced better results only for color images [50] however it cannot be a reason as a major drawback of the algorithm. The algorithm perform well in a real time environment and this is the reason why the algorithm is suitable for most outdoor vision applications such as driver assistant system and autonomous robot navigation [51].

Wavelet-based method also known as wavelet transform is an efficient tool to extract relevant information of an image that allows multi resolution analysis of an image. This method received an attention in the field of image processing due to its ability in adapting to human visual characteristics. It is most powerful and widely used tool in the field of image processing. It divides the signal into number of segments; each corresponds to a different frequency band [52]. The work presented by [45] has made comparison of results of wavelet transform with weighted average arithmetic (WAA) and Laplacian pyramid transform (LPT). The results from observation indicate that wavelet transform performs better performance than WAA and LPT.

(a) Original image (b) SSR output (c) MSR output
Figure 3. Results from Retinex algorithms [43]

B. Model based mathods

Model based methods utilize physical models which use the pattern of image degradation. Most model based method yields a better results but it requires extra information about the imaging equipment and environment [41]. This method also has been used in treating image with poor weather conditions such as haze, fog and rain. Different weather condition lead to complex visual effects of spatial and temporal domain in image [26], thus many researchers use separate techniques in removing fog, haze and rain.

i) Removing fog

Fog can be described as a small water droplet near ground level that is sufficiently dense to reduce horizontal visibility to less than 1000 meters. Hence, fog and certain types of haze have similar origins and an increase in humidity is sufficient to turn haze into fog [6].

Several work has been done on performing image enhancement algorithm to remove fog based on moving mask [47], dark channel prior [53] and color ellipsoid framework [25].

(a) Input image (b) Output image
Figure 2. Image enhancement algorithm to remove fog based on moving mask [47]

Fig. 2 illustrate an example of removing fog by moving mask method. Fig. 2(a) is an input image with fog and Fig. 2(b) is an output image produced by the method.

However, the work presented by Desai et. al. [54] defined fog degraded image is a mathematically ill-posed problem and proposed fuzzy logic based algorithm to solve the problem in removing fog. Another work on removing fog presented by [53] which proposed dark channel prior with an iterative algorithm. Example of removing fog using dark channel prior is illustrated in Fig. 3

(a) Input image (b) Output image
Figure 3. Removing fog using dark channel prior [53]

ii) Removing haze

Haze refer a particle in the air constitute of aerosol which is a disperse system of small particles suspended in gas. It is a set of atmospheric effect that reduce image contrast [55]. In order to improve the visibility of vision system, haze need to be removed. Recent work presented by [56] proposed a simple and effective technique for contrast enhancement to improve the visibility of an image affected by haze. The main strength of the algorithm is does not require user interaction thus it suitable for real time application especially for driver assistance system and autonomous robot navigation.

Meanwhile, the dark channel prior [53] can be used in removing haze. The algorithm is capable to estimate the thickness of the haze particles and recover haze image effectively. The technique produce a larger saturation values for specific environment thus an iterative algorithm is proposed the color distortion effected by high saturation.

iii) Removing rain

Rain can be defined as a process by which cloud droplets turn into rain is a complex one thus it has complex visual effects due to small size, high velocity and spatial distributions [8]. Many researchers have been made at resolving static weather problems like haze and fog [10-14, 57]. It is highlighted that removing the effect of rain on vision system is rarely explored [26].

Since the visual effects of rain are complex, which have a small size, high velocity and spatial distribution [8], recent work presented by [58] proposed a method to detect rain or snow streaks and reduce or increase the effect of it. The complexity of rain or snow streak lead to the utilization of statistical characteristic to effectively perform to produce a better result. However, a very high computation employs cause the high computing power resources is required.

Other work presented by [26] proposed a framework to remove rain by formulating rain removal as an image decomposition problem based on morphological component analysis. The advantage of the algorithm used is without the need of using temporal or motion information for rain streak detection. This is suitable for most outdoor machine vision applications. However, the algorithm has a limitation due to computational complexity and visual quality thus it can be further improved by enhancing the sparse coding, dictionary learning, and dictionary partitioning processes. Example of sample image using morphological component analysis is illustrated in Fig. 4.

(a) Input image

(b) Output image

Figure 4. Removing rain using morphological component analysis [26]

III. NOISE REMOVAL

Most of the practical machine vision application requires image for processing. Since the application is used to treat image in order to improve the visibility by enhancing the contrast and color adjustment. Prior the image to be processed by the image processing algorithm, it is required to apply image noise removal algorithms before the image is fit in the system.

Generally, image denoising methods can be broadly classified into three classes i) Spatial domain methods attempt to utilize the correlations, which exist in most natural images [59] ii) transform domain methods which transform image patches are represented by the orthonormal basis (e.g., wavelets [60], curvelets [61], contourlets [62], and bandelets [63]) with a series of coefficients and iii) dictionary learning based methods perform denoising by learning a large group of patches from an image dataset such that each patch in the estimated image can be expressed as a linear combination of only few patches from this redundant dictionary. The classification of image de-noising method is illustrated in Fig. 5.

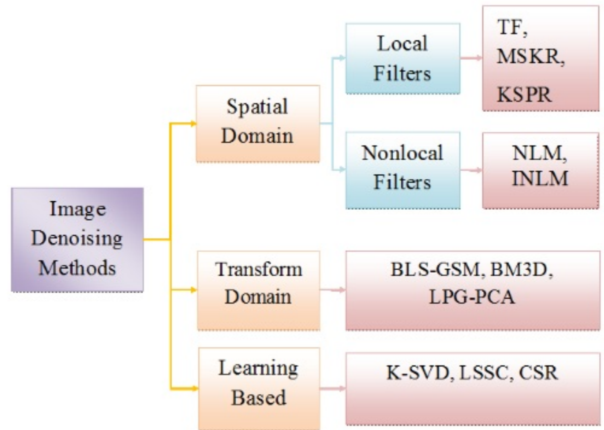

Figure 5. Image denoising methods

V. CONCLUSION

Outdoor image degradation due to bad weather condition is considered as a major problem in most vision based applications. The main aim of this field is to ensure that most vision-based application can be always "weather free" or robust to weather thus it can always produce a better results and reduce any unprecedented situations such as road accident (for driver assistant system), inaccurate decision (for autonomous vehicle or robot navigation).

Image enhancement methods are broadly classified into two classes such as model based and non-model based methods. Non-model based use the information in the image for processing and model based use extra information about the imaging equipment and environment.

Image de-noising methods usually used prior the image to be fitted in image processing algorithms. It can be classified into three classes such as spatial domain methods, transform methods and learning based methods.

All factors such as the type of weather, image enhancement techniques and image de-noising techniques are required to be analyzed prior designing machine vision applications.

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