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Review on Raindrop Detection and Removal in Weather Degraded Images

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***Abstract* - Bad weather conditions lead the robustness of most surveillance and driver assistance system. Therefore this paper attempts to review the type of bad weather in a perspective of computer vision and image processing and some recent effort on raindrop detection and removal techniques which has been successfully designed and developed to enhance the image degraded by the bad weather.**

I. INTRODUCTION

Research in the area of image processing and computer vision began almost 60 years ago. The main typical problem in both areas are [1] image compression, enhancement of low quality image, performing recognition of object from image and visualization of image which offer a wider spectrum of potential problem in many domains such as military, medical, agriculture and industrial requirements [2].

This main aim of this paper is to give an overview the definition of bad weather in computer vision perspective and types of bad weather can be identified from the image. In more focused the research will go depth on removing raindrop on a car windshield that can improve the visibility of driver assistance system.

Prior to discuss the bad weather, we give some description of image enhancement which particularly involve in removing noise as well as enhance the image. Image enhancement is the process of treating an image to increase the quality whether the contrast is low or is it noisy or is it blurred that suit for particular applications such as surveillance monitoring and driver assistance system [1]. The term of image enhancement was firstly discussed by Huang (1969) [3] which described parameter of image enhancement consists of 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.

Researchers begin to explore image enhancement when a digital image quality always degraded by noise, blurring, incorrect color balance and poor quality [4] 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 use optimized techniques for smoothing and finally iv) image sharpening technique is applied to produce the improved quality images. The challenge in image enhancement is a subjective evaluation, this could be due to the fact that, image enhancement is a problem oriented matter, thus, successful applications depend on the judgment of the viewer [5]. This is to note that; image enhancement has been used in many domains such as underwater vision [6], biomedical images [7], and outdoor vision (surveillance, terrain classification, and autonomous navigation) [8].

II. BAD WEATHER

Recent studies on a vision in a bad weather begin at the late 90s. The goal of the study is to towards weather free vision by involving much techniques on image enhancement [9, 10]. Another challenging problem in image enhancement is removing noise from images taken from outdoor scene which always contain quality degradation due to different weather environment effect such as haze, fog, snow, and rain [10]. 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 [11].

Weather conditions can be discretely distinguished based on the types and size of the particles and their concentration in space [10] as illustrated in Table 1. The presence of the considerable number of atmospheric particles with significant size and distributions in the participating media [12].

TABLE I.
WEATHER CONDITION AND ASSOCIATED PARTICLE TYPES

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

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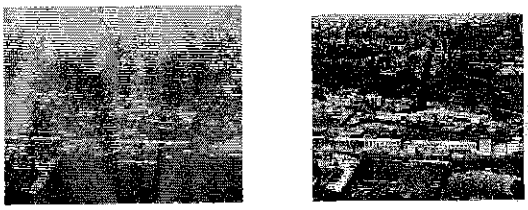
Rain	Water drop	10^2-10^4	10^{-2}-10^{-5}

A. Haze

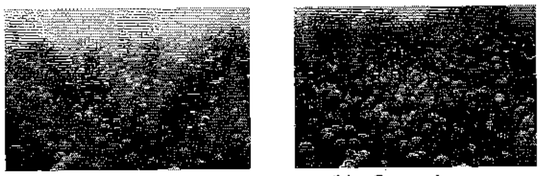
Haze refer a particle in the air constitute of aerosol which is a disperse system of small particles suspended in gas. It is a set of atmospheric effect that reduce image contrast [13]. In order to improve the visibility of vision system, haze need to be removed. Numerous researchers are working on improving visibility from a single image by removing haze [14-16]. The figure below shows example of haze removal using technique Dark Channel Prior [14].



(a) Input image (b) Output image
Figure 1. Haze removal results using Dark Channel Prior

B. Fog

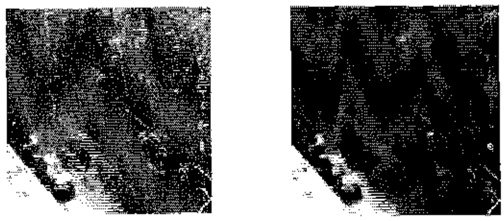
Fog can be described as a small water droplet near ground level that is sufficiently dense to reduce horizontal visibility to less than 1000 meters. Hence, fog and certain types of haze have similar origins and an increase in humidity is sufficient to turn haze into fog [10]. A lot of research has been done in solving fog [17, 18]. Most of techniques applicable for haze also can be used in removing fog. As similar to haze, fog reduces the contrast of the image taken from the vision system thus impaired the visibility. Figure below show example of fog removal using moving mask [19].



(a) Input image (b) Output image
Figure 2. Fog removal results using moving mask

C. Rain

The 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 [20]. Many researchers have been made at resolving static weather problems like haze [21-25] and fog [21, 22, 26, 27]. It is highlighted that the effect of rain on vision system is rarely explored [28]. One of the latest researches on removing rain is introduced by Kang et. al [28] using Morphological Component Decomposition. Below is an example of rain removal using Morphological Component Decomposition technique.



(a) Input image (b) Output image
Figure 3. Rain removal results using Morphological Component Decomposition

In the perspective of dynamic weather conditions such as snow and rain, it can be classified into rain/snow streak [28] or rain/snow drops on a car windshield [11, 29]. Rain streak (Fig. 3(a)) is a particle of rain falling from sky to the ground. However, raindrop considers a water droplet on a car windshield which can distort the view especially during driving. Depending on the speed, raindrop fly upwards as the speed increase and flow downward as the speed is slowing down [30]. Some clear windshield, the water droplets is clear in a spherical form but occasionally on a dirty windshield, water droplet not in a spherical form thus make the view become blurred, in this circumstance known as unfocused raindrops (Nashashibi, de Charrette et al., 2010). The overall picture of the bad weather image vision is classified as in Fig. 4.

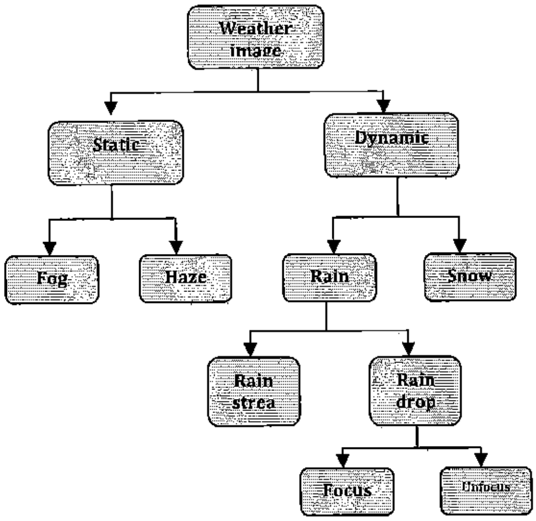


Figure 4. Bad Weather classification

III. RAINDROP DETECTION AND REMOVAL

In the previous section we have discussed the bad weather effect on image which consists of static such as haze and fog and dynamic such as rain and snow. This section discusses another perspective on removing noise in weather degraded image but in more specific focus on raindrop. To avoid the misunderstanding, raindrop in this perspective will focus on the water drop on a vehicle windshield. The raindrop falling on earth we consider as rain streak. This area is getting concern nowadays due to improve the robustness of driver

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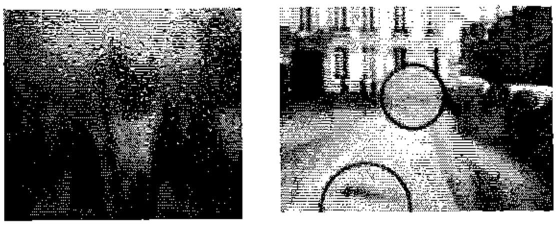
assistance systems as the current existing system work properly in a clear weather. Current manual and some auto-wiping systems on some commercial car are controlled by "rain sensor". However, the target region for detection covered is small, so it does not reflect the changes in the visibility from the driver's viewpoint. In addition, Nashashibi et. al. defined raindrop fall on car windshield can be divided into two types focused raindrops and unfocused raindrops [31](Fig. 5).



(a) Focused raindrop (b) Unfocused raindrop

Figure 5. Raindrop fall on a car windshield

Focused raindrops can be seen in a spherical form on windshield (Fig. 5(a)) and unfocused raindrops (Fig. 5(b)) are vice versa which cause blurring view. Both types of raindrop offers challenging task in terms of detecting and removing the raindrop. Table 2 listed recent a raindrop detection and removal algorithms.

TABLE II.
Existing raindrops detection and removal model

	Author	Detection Algorithm	Removal Techniques	Year	Type
1	Qi Wu et. al[32]	Visual Salient Features	Image inpaiting	2012	Focus
2	Sugimoto et. al [33]	Improved RIGSEC		2012	Focus
3	Roser et. al [34]	Bezier Curves		2011	Focus
4	Nomoto et. al [35]	Epipolar Geometry	Spatiotemporal Patches	2011	Focus
5	Ching-Lin Yang [36]	Intersection operation	Template matching & Morphological operation & Image inpainting	2011	Focus
6	Nashashibi et. al. [31]	Intensity variation & contour verifications	Spatial & temporal correlation	2010	Unfocus
7	Schwarxlmuller et. al. [37]	Support Vector Machine	Cellular Neural Network	2010	Focus
8	Roser & Geiger [38]	Improved RIGSEC	Improved RIGSEC	2009	Focus
9	Halimeh & Roser [11]	RIGSEC	RIGSEC	2009	Focus
10	Yamashita et. al. [39]	Template matching	Image inpainting	2008	Focus
11	Miyahara et. al [40]	Principle Component Analysis (eigendrops)		2007	Focus
12	Kurihata et. al [41]	Time-series		2007	Focus

As the research on raindrop detection begin at late 90s, the work is inspired from Narasimhan and Nayar [8] which developed scattering model to detect rain and snow. The main challenges in detection and removal of raindrop on a car windshield is to design the algorithm with less computation cost and it can be operated in real-time with minimum human interaction.

The early models for detection of raindrop proposed by Miyahara [40] [41] which used raindrop templates known as eigendrop to detect raindrop from image taken from in-vehicle camera. Results of detections are quite promising on a clear sky and provide inconsistency on a complex background of an image.

Yamashita et. al. [42] developed several methods of detecting and removing raindrop from images. The method detect noisy regions using different images and replace the effected image parts with image from second camera by assuming to see a distant scene. Yamashita et. al further proposed a spatio-temporal approach to detect adherent noise by image sequence analysis.

In addition, Halimeh and Roser [43] proposed the geometric-photometric model to detect and remove raindrop on a car windshield. These approaches use well defined laboratory setting and not consider the fact that raindrop appear blurred when they are not in the scene focus of the camera. Moreover, the proposed model utilized high computational time and out-of-focus thus causes blurring. Nevertheless, Roser and Gieger [38] improved the model in [11] realistic out-of-focus blur and validate the model in real-world environment. The model developed by [38] still disregard to cover all shapes of raindrop in which the real raindrop comes in a various shapes.

Other techniques that can be used to detect raindrop is using Cellular Neural Network to detect the raindrop in a real-time environment and Support Vector Machine to classify the detected raindrops [37]. The proposed system can be executed in real-time however the main limitation, it only focuses on a large raindrop. Too small raindrops will be neglected. In addition, the shortcoming of the proposed model is the limitation of memory due to the large size of templates.

In contrast with [37] which only detect large raindrops and ignoring the small one, the presented by [36] cover large obvious raindrop and also raindrop around the corner including the trails. In addition, the techniques use two algorithms to detect raindrops in a lane scene or a building scene using both Hough transform and Sobel operator. However, the work not design in a real-time environment thus requires human interaction the process the images.

On the contrary from [11] and [38] which not cover for all raindrop shapes, Roser el. al. [34] proposed novel raindrop shape model based on cubic Bezier curves. The model provides a physically interpretable parameter set of low dimensionality. The model can be incorporated into existing raindrop detection frameworks.

All discussion above is considered on focused raindrops which can easily view in a spherical form. However, Nashashibi et. al. [31] proposed the unprecedented work to detect the unfocused raindrops in spherical deform that causing blur to the windshield. The algorithm does not require specific device or focus to be set on the windshield.

However, the techniques are a first prototype and suffer from some lacks in terms to define some ground truth and same methodology should be re-defined to enable measurement of performance can be done precisely.

In conjunction with raindrop detection on the car windshield, Nomoto et. al. (Kyohei Nomoto, Fumihiko Sakaue et al., 2011) claims that raindrops on side mirror and windows impaired driver's view, thus they proposed to remove these raindrops on a virtual way using epipolar geometry image in-painting since the window and mirrors are taken by cameras.

IV. RAINDROP CHARACTERISTICS

Rain is a collection of randomly distributed water droplets from sky which consists of different shapes and sizes that move at high velocities [20]. Raindrops appear in a different shape and sizes due to two reasons. First are the initial differences in particle size and different rates of coalescences. Both reasons reflect the appearance of raindrop on a car windshield. The characteristics of raindrops are [37]:

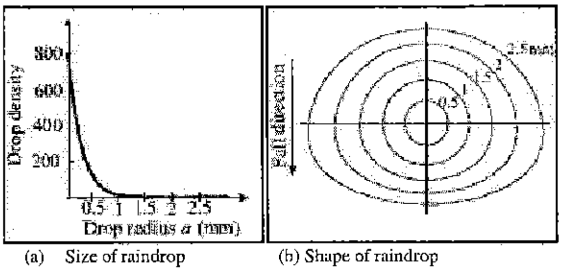
- Edges that feature an outline of a raindrop
- Blurry edges
- Refraction of light
- Consists of dark and bright region
- Appears in circular form on windshield
- Texture varies since the background varies
- Causes blurring

A. Size of a Raindrop

The physical properties of rain have been extensively explored in atmospheric sciences and transportation. The size of a raindrop typically varies from 0.1 mm to 3.5 mm. The density of drops decreases exponentially with the drop size. The common distribution of raindrop size is a Marshall-Palmer distribution given as [44]

$$N(a) = 8\times10^{6} e^{-8200*h^{-0.21}a} \;........(1)$$

where h is the rain rate in mm/hr, a is the radius of the drop in meters and $N(a)$ is the number of raindrops per unit volume that contain sizes within the interval *(a, a+da)*. Fig. 6(a) illustrates the Marshall-Palmer distributions.



(a) Size of raindrop (b) Shape of raindrop

Figure 6. Properties of raindrop

B. Shape of raindrop

The shape of a drop can be expressed as a function of its size. Smaller raindrops are generally spherical in shape while larger drops resemble oblate spheroids. Figure 6(b) illustrates the raindrop size distribution and shapes. The sphere shape of raindrop can be mathematically defined based on Beard and Chuang [45]

$$r(q) = a\left(1 + \sum_{n=1}^{10} c^{n} \cos(nq)\right) .....(2)$$

where,

a is a radius of the undistorted sphere
$c_1 \ldots c_{10}$, coefficients radius of the drop
θ, polar angle of elevation

C. Velocity of a Raindrop

During a normal rainfall, most of the drops are less than 1 mm in size. Hence, most raindrops are spherical. Therefore, this approximation in size is used to model the raindrops. As a drop falls through the atmosphere, it reaches a constant terminal velocity. The terminal velocity v of a drop is also related to its size a and is given by

$$v = 9.40(1 - e^{-3,4510^{3}a^{1.31}}) \;..........(3)$$

where a is in meters and v is in meters/s.

The individual raindrops are distributed randomly in 3D space. This distribution is usually assumed to be uniform. Moreover, it can be assumed that the statistical properties of the distribution remain constant over time. These assumptions are applicable in most computer vision scenarios.

The spatial and temporal intensity fluctuations in images produced by rain depending on several factors such as drop distribution and velocities, environment illumination and background scene, and the intrinsic parameters of the camera. In order to model the appearance of rain, firstly, the correlation model that captures the dynamics of rain based on the distribution and velocities of raindrops is developed. Then followed by develop the physics- based motion blur model that describes the brightness produced by streaks of rain.

V. PROCESS FLOW

Processing time varying image sequences to preserve or enhance the visibility of important parts of the image, which degraded by moderate raindrops effect can be done using an algorithm which is capable to manipulate raindrops visual properties in order to eliminate its effects. This section describes the process of removing the raindrop on a windshield. It consists of three main phases which are input image with region affected (raindrop), processing which involves another three sub process i) detection of raindrop ii) removing the raindrop and iii) smoothing and color balancing (Figure 5).

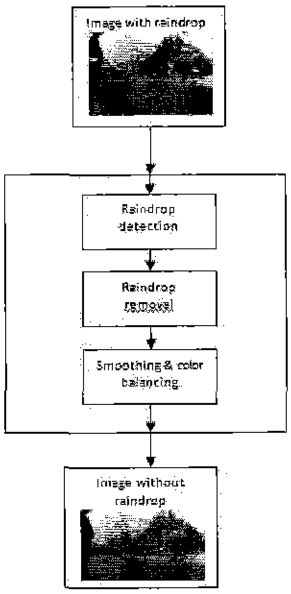


Figure 5. Raindrop detection and removal

Figure 5 illustrates the general steps which consists of 3 sub phases i) raindrop detection ii) raindrop removal and iii) smoothing and color balancing. Image with raindrop will be input and fit into the three sub process than output is an image with raindrop removed.

A. Raindrop detection

In this phase, the steps are based on the following characteristics of raindrop:

1. A raindrop usually appears on an image with spherical form.
2. The illumination of a raindrop is higher than its surrounding area.
3. Raindrop shape is closing similar to an ellipse.
4. When a raindrop is obvious, the change of the gradient around the boundary is more apparent.

B. Raindrop removal

Once the raindrop regions are detected, it will be removed in this phase. Raindrop can be removed based on two steps. First is the patch location of raindrop from the previous frame. Second is the replacement of raindrop area.

VI. Conclusion

This article briefly describes preliminary study of the research fields in image processing and computer vision, more specific on image enhancement for weather degraded image. The main aim is to develop an algorithm to enhance image that can efficiently remove (raindrop) on a car windshield within real-time processing. Recent studies indicate the research in removing raindrop are less investigated in literature thus this will open a room for advancement to explore.

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