Detection and Removal of Rain from Video Using Predominant Direction of Gabor Filters

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Abstract

In this paper, we examine the visual effects of rain on the imaging system and present a new method for detection and removal of rain in a video sequences. In the proposed algorithm, to separate the moving foreground from the background in image sequences that are the frames of video with scenes recorded from the raindrops moving, a background subtraction technique is used. Then, rain streaks are detected using predominant direction of Gabor filters which contains maximum energy. To achieve this goal, the rainy image is partitioned to multiple sub images. Then, all directions of Gabor filter banks are applied to each sub image and the direction which maximizes the energy of the filtered sub image is selected as the predominant direction of that region. At the end, the rainy pixels diagnosed in per frame are replaced with non-rainy pixels background of other frames. As a result, we reconstruct a new video in which the rain streaks have been removed. According to the certain limitations and existence of textures variation during time, the proposed method is not sensitive to these changes and operates properly. Simulation results show that the proposed method can detect and locate the rain place as well.

Keywords: Inpainting; Background Subtraction; Removal of Rain; Gabor Filters; Rain Detection.

1. Introduction

In indoor environment, video is recorded ideally because of artificial lighting. But in outdoor environment, it is important to remove weather effect because natural environment have diverse noise such as steady disturbances (fog and mist) and dynamic (rain and snow). To improve image quality, we need some methods to remove them. The rain in the foreground is an unwanted component of the background. The rain has distribution of droplets that falling at high speeds. Each drop with refraction and reflection of the environment causes extreme changes in the intensity of an image. Moreover, the intensity of rain appears as blurred movement and therefore it dependent on the background intensity.

Rain detection in images is one of the most challenging problems in computer vision. Recent years due to advances in computer graphics tools, much research has been done in this field and several methods have been designed that aim to determine the location and range of rain streaks in video and image and of course removal of them to improve the quality.

At first, removing the effects of bad weather was developed by Nayar and Garg in which the constant weather, water or smoke, were considered very small floating particles in the air. Using the dispersion model, the color of pictures achieved good results. In the dynamic weather, they developed rain physical properties where the rain area is detected by using properties of pixels in the certain time intervals. To reduce rain effect they used the false positives and correlated in space and time [1].

Zhang proposed a method which includes both temporal and chromatic properties of the rain on the video. In temporal properties, a pixel is not always impressed by rain in video and the color properties that contain change of value by R, G and B, in the rainy pixels are almost identical. K-Means clustering was used to divide the background and rain; however this method is not suitable for real-time processing [2].

Garg and Nayar proposed another method by adjusting camera parameters such as camera exposure time, diaphragm, etc. which remove the rain for the period of video recording, but this method cannot be applied to heavy rainfall and vague moves [3].

Shen and Xue detected and removed the rain by using the definition of the character of light field and motion field. In this case, the intensity of each pixel of the current frame is compared with the intensity of pixel of same frame in space neighborhoods and intensity of pixel of another frame in temporal neighborhoods. Also, using the motion field, distinction between the rain streak and other moving objects are created. So, using data of only three frames identified the rain, and for removal of the pixels in the detected rain area, an anisotropic diffusion smoothing method was proposed as a temporal-spatial filter [4].

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In the research of Barnum and Narasimhan that was based on the combination of the modeling of realistic streaks and knowledge of dynamic weather, unlike previous works which were seek to detect rain pixels or individual pieces, this method was dealing to rain and snow as a general phenomenon. In order to determine the influence of the rain and snow in the video, it was developed a general model in frequency space [5].

Other work was performed by Hi Lee and Joo Park in which by using the recursive data processing and using the Kalman filter, they estimate the intensity of each pixel and by comparing the intensities, detect rain streaks [6]. Further work in this field was done by Bossu, Hautière and Tarel, at that, a system based on computer vision is presented which detects the presence of rain or snow. To separate the foreground from the background in image sequences, a classical Gaussian Mixture Model is used. The foreground model serves to detect rain and snow, since these are dynamic weather phenomena. Selection rules based on photometry and size are proposed in order to select the potential rain streaks. Then a Histogram of Orientations of rain or snow Streaks (HOS), estimated by the method of geometric moments, is computed and it is assumed to follow a model of Gaussian uniform mixture [7].

Due to the random spatial distribution and fast motion of rain, removal of rain in video is a more difficult problem, Geng and Qi Submitted a background subtraction based on sample model to remove the rain. They analyze the properties of rain and establish the sample model with values randomly taken in the spatial neighborhood of each pixel on the first frame so better to classify detected rain by background subtraction. In addition, the movement of objects will cause the corresponding color pixel brightness values to change significantly. The H component of the HSI color space was applied to reduce the impact of moving objects on rain removal. Experimental results show that this method not only can eliminate a good rain compared with existing methods, but also have faster processing speed [8].
The other method is using the properties of the image. Detection and removal of rain requires discrimination of the rain and non-rain pixels. Accuracy of the algorithm depends upon this discrimination. This is done by Tripathi and Mukhopadhyay, where the merits and demerits of the algorithms are discussed that motivate the further research. A rain removal algorithm has a wide application in tracking and navigation, consumer electronics and entertainment industries [9].

A method based on the framework of a single image based on the proper technique for formulating rain removal remove rain as a problem of image analysis based on morphological component analysis of expression has been proposed by Li-Wei Kang ‹Chia-Wen Lin and Yu-Hsiang Fu. Rather than the direct application of conventional image analysis techniques, in the proposed method the first two parts of the image using a bilateral filter decays to low-frequency and high-frequency (HF). At that time, performing dictionary learning and sparse coding portion of the HF portion of the "rain component" and "component without Rain" is resolved. As a result, the rainy part of the image can be removed successfully, while preserving the most image detail [10].

The next algorithm, which is highly efficient and simple and has been proposed by A.K. Tripathi and Mukhopadhyay for detection and removal of rain from video sequence, is used for the spatial and temporal properties. Fortunately, the spatial and temporal properties of the pixel are involved to separate the non-rainy and rainy pixels. Therefore, the proposed algorithm, may be involved fewer consecutive frames to reduce the buffer size and Latency which significantly reduces the complexity and run-time. This new algorithm is not supposed to operate as well for different shape, size and speed of raindrops. The proposed method reduces the buffer size and therefore the cost of the system, the delay and energy consumption slows down, significantly. For performance evaluation, as well as to avoid errors and misdiagnosis, a new metric is introduced in the temporal and spatial variation [11].
In the work of Xudong Zhao and Peng Liu which is used for both static and dynamic scenes, K-means classification algorithm is used to identify and detect rain. Then, the rain histograms removal is performed [12]. There are other methods in which the median filter is applied to each pixel. Of course, precision of this method is very low.

In the rest of paper, in section (2), we pay attention to express a variety of weather conditions and physical characteristics of raindrops. In section (3), we provide the proposed method in which the original video frames or subtracted frames are extracted at first and then to detect the rainy pixels, dominant direction of Gabor filters are used. Finally, image completion method is employed to remove the effect of rainy pixels. In Section (4), implementation results are obtained and discussion is performed. Conclusion is performed in Section (5).

2. Types of Weather Conditions and Physical Characteristics of Raindrops

Outdoor vision systems are used for various purposes such as surveillance and navigation.

2-1- Types of weathering

In order to develop a vision system that can be used under all weather conditions, it is essential to get the visual impacts of different climate models and develop algorithms to remove them. Weather conditions can be broadly classified into Fixed (fog, mist, smoke, cloud) and Moving or dynamic (rain, snow, hail). In the case of steady weather, droplets are too small (1–10 μm) to be individually detected by a camera. The intensity produced at a pixel is due to the collective effect of a large number of droplets within the pixel's solid angle (see Fig. 1(a)). Therefore, volumetric scattering models such as attenuation and air light can be used to effectively describe the appearance of steady weather.

In this paper, we will focus on the problem of rain. Rain includes the distribution of a large number of drops with different sizes that are falling at high speed. Each droplet behaves like a transparent sphere that performs reflection and refraction of light from the environment into the camera. Thus, Rain drops are the sample of the rain and they have all of rain's features, but we worked on the drops to have simple examine and consider the more details.

The result of drops falling at high speed is the light intensity fluctuations at different times in images and movies. In addition to the limited time exposure of camera, the changes in light intensity caused by the movement of rain causes the context to be ambiguous. Thus, the visual effects of rain are the combined effects of rain and metering dynamic environment. Rain has been widely studied in the fields of atmospheric science, remote sensing and communication signals. However, the effect of rain on camera to view a scene in the natural environment is very different and sometimes remains unknown.

2-2- Physical Characteristics

Shape of a Raindrop. A raindrop experiences rapid shape distortions as it goes down, a phenomenon often referred to as oscillations. For most vision tasks, the effects of oscillations are insignificant and for this reason, a raindrop can be assumed to have a fixed shape often referred to as an *equilibrium* shape. The equilibrium shape of a drop depends on its size. Smaller drops are usually spherical in shape. However, as the size of the drop increases, it tends towards an oblate spheroid shape.

Velocity of a Raindrop. As a raindrop falls, it attains a constant speed, called the terminal speed (Manning, 1993). Gunn and Kinzer (1949) present an empirical study of the terminal velocities of falling raindrops for different drop sizes. Their observations show that the terminal speed (*v)* of a raindrop can be expressed as a function of its radius.

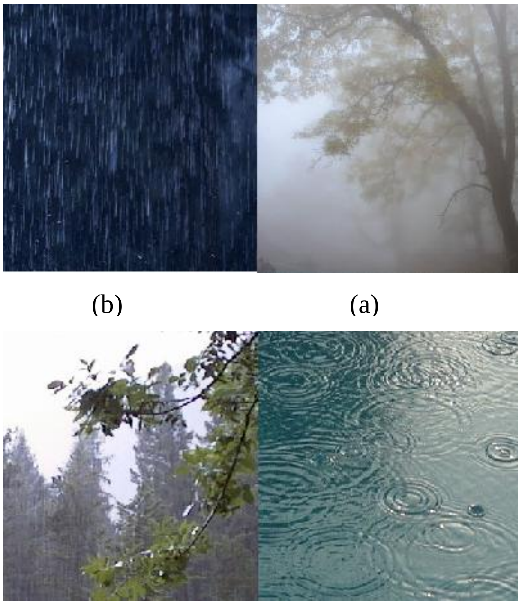

Fig 1: The different climatic conditions. Image (a) is foggy scenes pixel intensity caused by tiny flakes fog and haze are too many of them. Figure (b) shows an image of the scene taken on a rainy day and the strands are observed due to the motion of individual droplets. Blue waves in the image (c) is seen to represent the rain with variable tissue with time. Figure (d) the picture is Rain with scenes with complex motion.

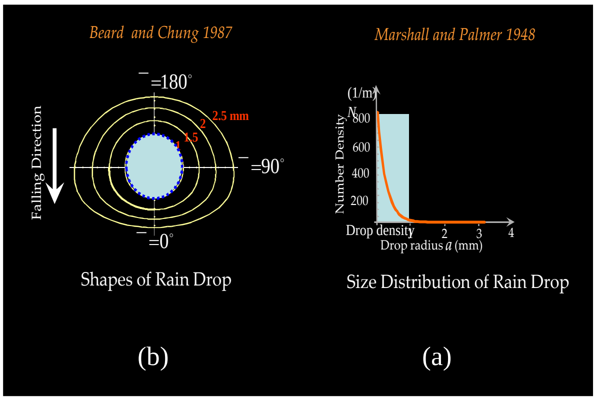

Fig 2: Distribution Marshall - Palmer count raindrops, as a function of their size. Figure (a) Note that the density drops exponentially with the size of the rain falls. Image (b) is the shape of raindrops of different sizes (0.5 to 2.5 mm). Due to the drop in flat form (an oblate spheroid shape) are falling [15].

Raindrops line. As we explained in the previous paragraphs, assuming the small amount of distortion and considering the constant speed of falling raindrops, the raindrops can fall in constant line with fix direction. With these assumptions, we use some approaches to detect streaks of rain drops in a certain direction.

Raindrop size. Raindrops turn to show a wide distribution of sizes. A typical ***distribution*** process used for the rain drop size distribution of the Marshall - Palmer [15].

2-3- Physical properties of rain

Rain is a collection of water droplets of different shapes and sizes with randomly distributed that move at high speeds. The physical properties of rain have been widely studied in atmospheric sciences. Here, we summarize these properties in brief and make observations that are relevant to our goal of modeling the appearance of rain. The size of a raindrop typically varies from 0.1mm to 3.5 mm. The distribution of drop sizes in rain is given by the Marshall-Palmer distribution. Figure 2(a) shows the distribution for a typical rainfall. Note that the density of drops decreases exponentially with the drop size. The shape of a drop can be expressed as a function of its size. Figure 2(b) shows the shapes of raindrops of various sizes.

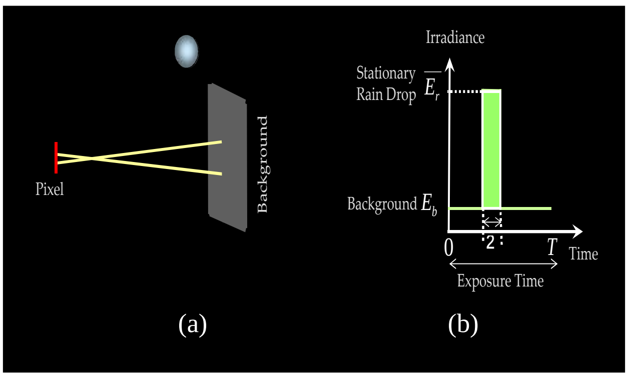

Fig 3: Changes in pixel intensity due to rain drops falling. (a) it is seen that the average pixel intensity because of the rain and because of the background scene. It should be noted that the energy drop is greater than the background energy. (b) is also shown that in $2 \leq 1.18\ ms$ less than the camera exposure time (T) is a drop of rain on the pixels of the image [1].

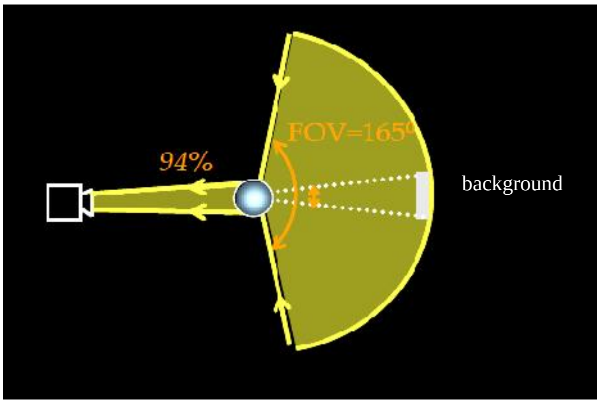

Fig 4: Lighting and visibility drops. Represents the field of view is approximately 165 degrees of raindrops.

Smaller raindrops are generally spherical in shape while larger drops are similar to oblate spheroids. In a typical rainfall, most of the drops are less than 1mm in size, as seen in Figure 2(a). Therefore, most raindrops are spherical and we will use this approximation in our work.

As a drop falls through the atmosphere, it reaches a constant terminal speed. The terminal speed v of a drop is also related to its size and is given by:

$$V = 200\sqrt{a} \quad (1)$$

Raindrops are distributed randomly in 3D space. This distribution is generally 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. Complexity of spatial and temporal fluctuations in rainfall recorded image depends on several factors:

- drop distribution and its speed
- Ambient lighting and background scene
- The intrinsic parameters of the camera

The changes in intensity of all pixels along a streak line, has a linear relationship with the intensity of the background light occluded by the streak. So, there is a limit for parameter τ. The maximum value of τ is about 1.18*ms* that is much lower than the camera exposure time (T=30*ms*). Time τ is the time that a raindrop projected on the intended pixel. As illustrated in Fig. (3-b), in the time interval zero to τ and τ to T, there is no change in light intensity since in these time intervals the drop has not reached to the pixel or has passed from the pixel. Therefore, the light intensity raindrops are much more than the intensity of background and during the drop passing from background we face with drastic changes in intensity.

2-4- Brightness of a stationary raindrop

Raindrops act similar to lenses refracting and reflecting environment radiances towards the camera. Detailed geometric and photometric models for the refraction through and reflection from a spherical raindrop have been developed. These models show that raindrops have a large field of view of approximately 165◦ (see Figure 4) and the incident light that is refracted towards the camera is weaken by only 6%.

3. Proposed Method

The proposed algorithm has several sections of which the most important ones are rain detection and removal. In the following, different stages of the proposed method are presented. To increase the quality of rainy clip, texture synthesis theory can be used because rain has regular and integrated tissue despite the integrated stripes which it has in a special direction. One of the tools which can be used for extracting features is use of Gabor filter which detects the oriented lines well and our goal is to identify the rain stripes which have individual directions. However, we have used a special kind of detection to get better result and achieve more successful detection and better removal and restoration. In our method, direction has not been directly introduced to Gabor filters. However, in each window with small dimensions (each sub image) the dominant direction is found. Using Gabor filter with dominant direction, accuracy of detection increases and rain stripes are better detected. Process of filling the lost zones of image by preserving statistical characteristics and integration in the entire image is called image completion. In other words, this process completes an imperfect image which has lost zones such that final results can be visually acceptable. In addition, image completion process should fulfill the following specifications:

- It should be able to complete complex natural images.
- It should be implemented on the large lost zones.
- All of the steps should be done automatically without human involvement.
- Image completion process should be able to solve texture synthesis problem.

Considering the mentioned reasons, image completion is a very challenging and considerable problem. Of course, image completion is applied in many fields such as graphic application, edition, restoration of film and photo. In recent years, many studies have been conducted on image completion.

3-1- Conversion of video to frames

In this stage, we select a video with complex textures which has been recorded from rain scene as input and divide them into their related frames. The selected video has many frames some of which are shown in Figure 5.

3-2- Rain detection

Considering structure of rain stripes which are usually placed in one direction and have a texture like structure, we use set of Gabor filters for detecting them. Gabor filter is used as a linear filter for extracting features from images. One of these features is extraction of directional lines which we consider here. In addition, optimal localization properties are observed in both amplitude and frequency spaces. As a result, it is a suitable method for dividing textures, detecting goal, analyzing document, detecting edge, identifying retina and representing image. Gabor filter $h(x, y)$ can be considered as a sinuous signal in special frequency and direction which has been modulated with a Gaussian push based on Eq (2).

$$h(x,y) = s(x,y)g(x,y) \quad (2)$$

In this equation, s is a complex sinuous function and g is a two-dimensional Gaussian function:

$$s(x,y) = e^{-j2\pi(u_0 x + v_0 y)} \quad (3)$$

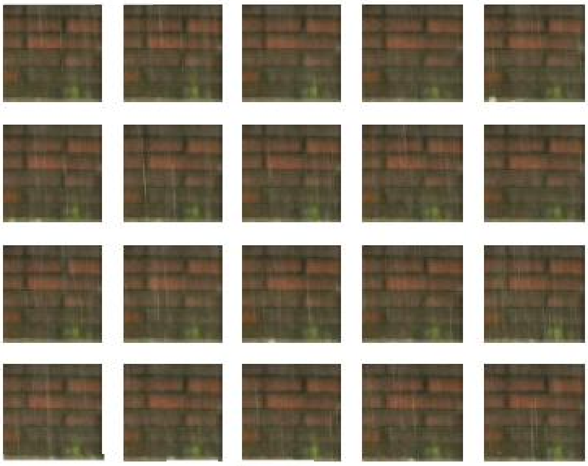

Fig 5: Some video frames for rainy scene

$$g(x,y) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{1}{2}\left(\frac{x^2}{\sigma_x^2}+\frac{y^2}{\sigma_y^2}\right)} \quad (4)$$

As a result, Gabor filter impulse response is defined with the following equation:

$$h(x,y) = e^{-\frac{1}{2}\left(\frac{x^2}{\sigma_x^2}+\frac{y^2}{\sigma_y^2}\right)} . e^{-j2\pi(u_0 x + v_0 y)} \quad (5)$$

Frequency response of Gabor filter is obtained from:

$$H(u,v) = G(u-u_0, v-v_0) \quad (6)$$

Where,

$$G(u,v) = 2\pi\sigma_x\sigma_y e^{-2\pi^2(u^2\sigma_x^2+v^2\sigma_y^2)} \quad (7)$$

In Figure (6) shows frequency response of Gabor Filter for given angles. Gabor filter has strong response in a direction where variety is in the direction of the same angle. In this case, simple smoothing action which follows a special threshold is sufficient for segmenting image into four zones relating to lines in four directions (see Figure 7). We obtain the all components of image which their energy is centralized in (u_0, v_0) by passing image through a Gabor filter with the defined parameters $(u_0, v_0, \sigma_x, \sigma_y)$. Spatial response of Gabor filter is shown in Figure (8) for some different angles and frequencies. [13]. In Gabor filters bank, a similar set of continuous and interrelated family is produced by changing delay and rotation angle. In rain detection application, rain lines are identified by introducing special direction to filter and mentioning the related mathematical relations with acceptable accuracy. Of course, a threshold limit is defined for increasing accuracy to express Gabor filter and its different values change accuracy of result. In this case, using the higher threshold limit, the more rain stripes are detected.

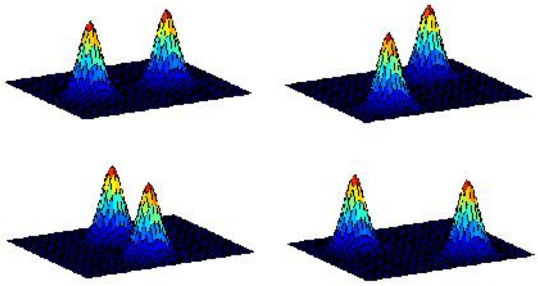

Fig 6: Diagram of frequency response of Gabor filter for different values of u0 ‹v0 relating to four directions of 0, 45, 90, 135.

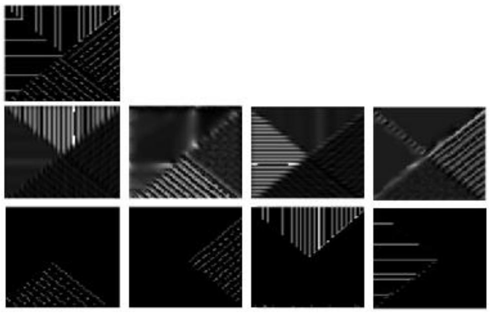

Fig 7: Output of Gabor filter in four directions when input of an image contains lines in similar frequencies but in different angles [16].

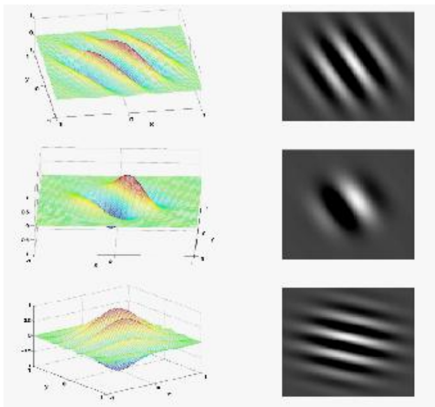

Fig 8: An example of the performance of Gabor filters with different frequencies and directions. Left: Three-dimensional graph of the Gabor filter Right: Gabor filter with intensity image [13].

This result is desirable in terms of high detection accuracy but it decreases accuracy of removal which is explained later. Therefore, we cannot consider its value very high. Figure 8 shows example of Gabor filter performance with different frequencies and directions. The first column is three-dimensional representation and the second column is diagram of its amplitude in gray level of image [13].

Since, rain stripes suddenly collapse and may be exposed to turbulences such as wind and changes from a frame to another frame for collapse, we should add a stage before applying the Gabor filter which intelligently detects direction of rain stripes in each desirable filter considering

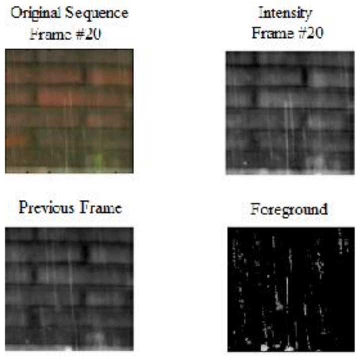

Fig 9: Separating foreground from background considering the previous and next frames. In this image which relates to frame 20 of the main video, mobile foreground is separated from fixed background considering place of mobile components in the previous and next frames.

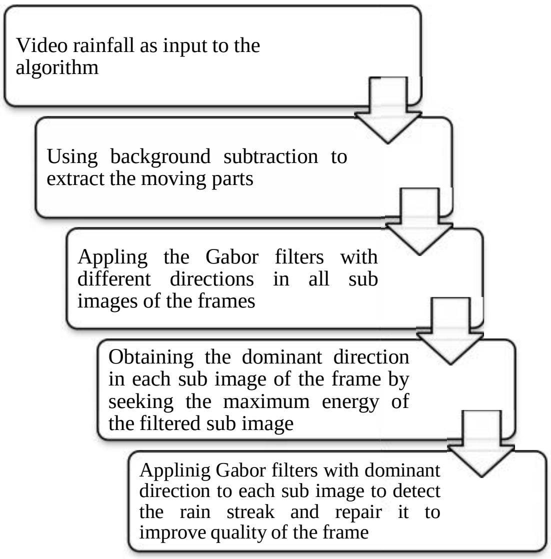

Fig 10: Flowchart of the proposed algorithm for rain detection and removal with dominant direction of Gabor filters.

The previous frame (Fig 9). For this task, we should go forward based on flowchart of Fig (10). It means that we first receive main video which has rain drops as input and then detect background of the moving components of the image which are the rain stripes using subtraction and the result of this section is binary image which indicates moving components. Now, we should identify the pixels which are rainy pixel candidates by inspecting features of rain drops and their sizes to reduce range of selection and finally increase speed of calculations.

Now, we obtain maximum energy by calculating dominant direction of Gabor filter on these rainy pixels through which direction of fully rainy pixels is detected. Using these directions detected in the stage of Gabor filter with dominant direction which is different for each frame, Gabor filter is applied at this time not with unique fix direction but with adaptively detected dominant directions and detection stage is performed. Therefore, we increase accuracy of detection as most as possible and receive more acceptable result by adaptive filtering. Estimation of the dominant direction of Gabor filter is performed by applying Gabor filter defined in Equation (8) to the sub-image I_{in} using Equation (9).

$$g(x,y,f_r,\theta) = e^{-\frac{(x^2+y^2)}{2\sigma^2}} \cos\left(2\pi f_r (x\cos\theta + y\sin\theta)\right) \quad (8)$$

$$I_{out}(x,y,f_r,\theta) = \iint I_{in}(p,q)\, g(x-p, y-q, f_r, \theta)\, dp\, dq \quad (9)$$

Therefore, dominant direction of Gabor filter is defined as the maximum argument θ in the energy of the filtered sub-imageI_{out}:

$$\theta_{dominant} = argmax_\theta \left(\sum_{x=1}^{M} \sum_{y=1}^{N} \left(I_{out}(x,y,f_r,\theta)\right)^2\right) \quad (10)$$

3-3- Rain removal

The method which is applied for removing the effect of rain is the video repair method. This method is applied for repairing the destroyed parts of photo and video. Basis of this algorithm is on displacing of the destroyed pixels with perfect ones.

Inpainting: During the past years, interest in the field of video repairing has increased considerably among the research population. Some examples of the applications of this method are as follows:

Deleting unwanted object: There may be static or dynamic objects in a film which are not desirable.

Revising fiction: Video repairing also can change special scenes of film. For example, it censors a motion which is not suitable for goal.

Repairing video: Some *films* enclose scratch or dust spots or damaged frames which can be deleted with this method.

The applied algorithm is based on this class and repairs the scenes damaged by rain stripes [18].

In this work, a framework is presented for the lost pieces which are moving from background of a recorded video sequence with fixed camera. Generally, the zone which is inpainted may be fixed or moving, located in background or foreground and also may be obstructed with a fence. In painting-based algorithms comprise of two parts. The first part includes simple preprocessing and the second part includes video painting. In the preprocessing stage, almost all sections of each frame are divided into background and foreground and two image strips are created using this division which helps present results based on time and performance of algorithm is enhanced by reducing search space. In inpainting section, we first repair moving objects in the foreground which has been obstructed with the zone which will be inpainted. For this purpose, the holes are filled using priority-based design as far as possible by copying information from the moving foreground in other frames and then the remaining holes bare inpainted with background. Then, frames should be ranked as far as possible to be directly copied. The remaining pixels are filled by expanding texture synthesis spatial techniques in space and time domains. The presented framework has different advantages over artistic algorithms which act with similar types of data and limitation and this permits some camera motions which have simple and rapid implementations not to need statistical models of background and foreground [15].

Generally, we receive binary image using results of Gabor filter recognition and then analyze its pixels. In each frame, the value of each rainy pixel is filled with corresponding pixel value in the next frame, of course, in case that pixel is not rainy in the next frame, otherwise, it is filled with next frames to fill all rainy pixels in a frame with value of the same pixel which is not rainy in the neighbor frames. Of course, we have performed this action until special stage which is given as threshold limit again and this affects accuracy of removal. In this way, using the higher number of the stage, the better removal action will be performed and the higher quality images will be resulted.

4. Experimental Results

The proposed method in this paper is based on this idea that which direction of Gabor filter must be applied to rain streaks in each zone to detect them as accurate as possible. Basis of the work is such that all zones of the video frames are recognized from 0 to 180 with angular changes of 10 degrees through Gabor filter to find the dominant direction in each zone on each frame.

Therefore, dominant direction which has the maximum energy is found in each frame using 18 Gabor filters. Then, we increase the number of Gabor filters (to make possible applying different Gabor filters for each zone) on each frame for more accuracy. The results are available for (1*1), (3*3), (4*4) and (5*5) zones in Figures 11 to 14. To increase accuracy of detection and improve image quality, differential frame has been used instead of main frame meaning that input image of Gabor filter is subtraction of two sequential frames.

Now, these results of detection section are given as the input image to the stage of rain removal which is video repairing. In the set of images of Figure (15), result of detection using dominant direction of Gabor filter (the above figures) is seen and this has been given from the left to the right for detection using Gabor filter (1*1), (2*2), (3*3), (4*4) and (5*5). As appeared in the images, quality of image has improved more acceptably and more strongly than

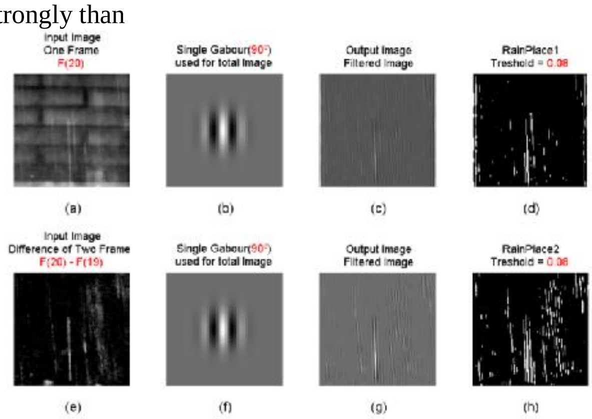

Fig 11: Rain detection of each frame using background subtraction and filtering with Gabor. Figures (a) to (d) relate to frame 20 of main video, Gabor filter in direction of 90 degree, filtered image and rain place after thresholding, respectively. In the next row, image (e) relates to differential image of two sequential frames. Images (f) to (h) are like definitions (b) to (d) which have been executed for differential frame.

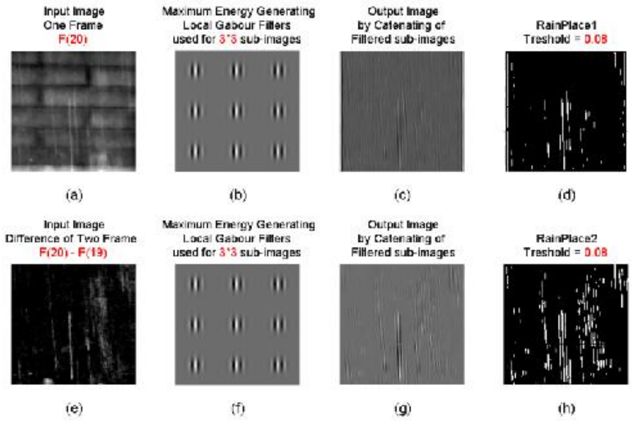

Fig 12: Rain detection of each frame using background subtraction and dominant direction of Gabor filter (3*3). Figures (a) to (d) relate to frame 20 of main video, Gabor filters with dominant directions, filtered image and rain place after thresholding, respectively. Other explanations are similar to Figure (11).

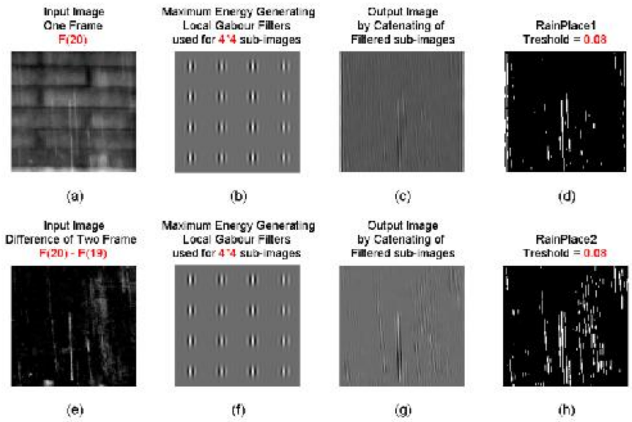

Fig 13: Rain detection of each frame using background subtraction and dominant direction of Gabor filter (4*4). Figures (a) to (d) relate to frame 20 of main video, Gabor filters with dominant directions, filtered image and rain place after thresholding, respectively. Other explanations are similar to Figure (11).

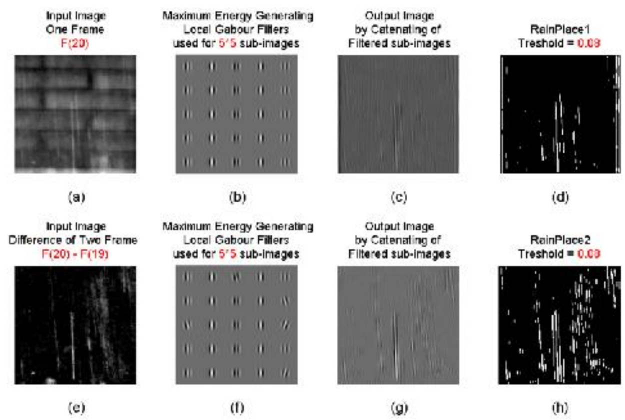

Fig 14: Rain detection of each frame using background subtraction and dominant direction of Gabor filter (4*4). Figures (a) to (d) relate to frame 20 of main video, Gabor filters with dominant directions, filtered image and rain place after thresholding, respectively. Other explanations are similar to Figure (11).

Fig 15: Results of rain removal stage using dominant direction of Gabor filter on comp pool database. In this set of images, result of detection and recognition using dominant direction of Gabor filter (the above Figures) is seen which is given for detection using Gabor filter (1*1) to (5*5) from the left to the right respectively.

Fig 16: Results of rain removal stage using dominant direction of Gabor filter on comp magnolia database. In this set of images, result of detection and recognition using dominant direction of Gabor filter (the above Figures) is seen which is given for detection using Gabor filter (1*1), (3*3) and (5*5) from the left to the right, respectively.

The former algorithms [20] from the left to the right with increase of the number of Gabor filter directions. Of course, it should be noted that the threshold value is not very high because it also leads to image obscurity. For more study and ensuring results of algorithm, operations on other data are tested and its results are given in Figure (16). As it is evident, this image relates to a video with foreground motion of person. Therefore, rain removal is not performed as well with Gabor filter because the foreground is moving and causes error in background directional lines. However, for Gabor filter, there are (3*3), (4*4), and (5*5) from the right to the left, respectively, and obscurity is seen to some extent and progress of this case should be discussed. The proposed method is compared with the results of [1] in Figure 17. As it is seen, the reconstructed frames by the proposed method is less opaque than the method [1] and this is due to the direct placement of information from the rainless frame to the rainy frames and the lack of averaging among the frames. Figure 18 shows another comparison of our method with the methods of Zhang [2] and Nayar [3]. As it is evident, our method has removed the rain effect better than the others.

All of the methods presented in the papers for rain removal are evaluated based on the resulting image and video quality. As far as we know, there is no quantitative evaluation in the papers in this field. With this acclaim, we propose a way to assess the rain removal quality by quantitative values. It is intensity that we report it among the passages. For example, figure (19) is the distribution for a pixel with rain at this image, our result is shown with black and the other method (Kalman Filter [6]) is shown by cyan. We know that the pixel with rain have more light intensity rather than other pixel, our result show it better than other one.

To know how the method works well, we have reported rain rate detection of different methods. In table (1), there are three columns, the first one is measured rain rate by National Climatic Data Center and the second one is the reported rain rate by our method. The result shows that our method could detect rain as well as we expect. At the end, we have reported rain rate by Nayar in third column. By comparison between our method and Nayar's method, we can see the better result for the proposed method. In table (2), we have reported the result of rain removal that shows the success of method in rain removal.

The examined image has 14038 pixels from which 6685 pixels are rainy pixels and the remaining pixels (7353) are not rainy pixels. As the table illustrates, 5421 rainy pixels (TP = 81%) have been removed successfully.

Of course, 327 number of not rainy pixel have been detected as rainy pixels (FP =4%).

5. Conclusion

In this paper, attempt was made to detect and remove rain on video by studying features of rain and extracting them and also using new methods. For this work, the best detection method based on feature has been used. At the beginning, Gabor filter was directly applied with dominant direction introduced to the input data as rainy video frames. Then, to increase accuracy of detection in this algorithm which acted based on dominant direction of Gabor filter, direction of rain stripes were also detected but because this presented method was not able to extract rainy parts, another stage was added to it as background subtraction. In this case, foreground can be separated from background with a background image without any foreground and by reducing it from other frames and applying color zoning and lighting to the images obtained from subtraction. Background subtraction based method was combined with

Fig 17: Comparing the proposed method with method [1]. The left image is result of the proposed method and the right image is result of paper [1]. Another advantage is that rain removal in the proposed algorithm causes obscurity of background scene.

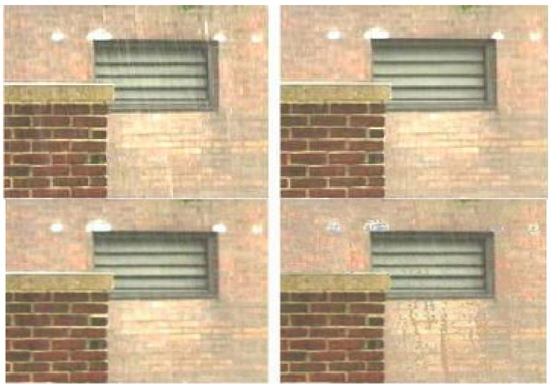

Fig 18: Comparing the proposed method with Zhang's and Nayar's methods. At first row, there are original scene and the result of our method. In the second row, Zhang and Nayar's result are shown. As it is observable, our method has better result for rain removal.

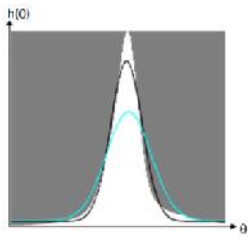

Fig 19: Comparing the proposed method with method [6]. The black one is the intensity of rain pixel for our method and the blue one is for rain removal with kalman filter.

Table 1: A comparison of rain rate measured by rain rate reported.

Type of rainfall	Measured rain rate (mm/hr)	Reported rain rate (mm/hr) by proposed method	Reported rain rate (mm/hr) by Nayar
Light	1.49	0.96	0.93
Moderate	3.631	3.012	2.963
Heavy	14.12	11.47	10.947

Table 2: Removal result based on the use of the Predominant Direction of Gabor Filters.

	Operation of Method	
	Removed	Not Removed
Rainy Pixels	5421	1264
Not Rainy Pixels	327	7026

The method presented based on dominant direction of Gabor filter. Then, detection stage ends by separating foreground including rain from background and video repairing and completion stage can be used for filling zones of pore which are the extracted mobile foregrounds for rain removal stage. In other words, rain foreground is separated from fixed background and we receive the image without recovered rain. This algorithm gives better result than other algorithms considering lack of averaging in neighborhood or sequential frames and also direct placement of frames information. As the future works, we try to remove effects of fixed climate such as fog from video. In rain problem, although we reduced detection error compared with other presented methods, it should be studied yet and better results could be achieved. The proposed algorithm has no high efficiency in the case where mobile object is in background or the background has been obstructed by a person or an object. Therefore, a method should be presented to solve this problem when mobile object is obstructed for some sequential frames.

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