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Multi-frame de-raining algorithm using a motion-compensated non-local mean filter for rainy video sequences

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A B S T R A C T

This paper proposes a rain detection and removal algorithm that is robust against camera motion. The proposed algorithm initially detects possible rain streaks by using spatial properties, such as the luminance and structure of rain streaks. Then, the rain streak candidates are selected based on a Gaussian distribution model. Finally, these detected regions are improved with an advanced temporal property in a block-matching process. After the rain detection step, a non-rain block-matching algorithm for each block is performed between adjacent frames to find blocks similar to the block that has rain pixels. If similar blocks are obtained, the rain region of the block is reconstructed by spatio-temporal non-local mean filtering using similar neighboring regions. Finally, a specific post-processing is performed for visibility enhancement and flickering artifact removal. Experiment results show that the proposed algorithm uses only five temporally adjacent frames for rain removal but outperforms previous methods in terms of subjective visual quality.

1. Introduction

Rain and snow are often imaged as bright streaks [1]. Not only can these streaks annoy or confuse the human eye, but they also degrade the effectiveness of any computer vision algorithm that depends on small features. For example, feature-point trackers can fail if even small parts of an image are occluded. If these rain streaks are removed, then the tracker can work with greater accuracy. Also, rain streaks refract and blend light rays, and in general make observed scene colors brighter in corresponding pixel locations.

Many approaches for detecting and removing rain streaks in images and restoring the original scenes have been developed [1–8]. Most of the conventional rain removal schemes assume a static camera environment or use only a single frame [1,2,6,7]. Such an assumption simplifies a de-raining problem, but often becomes a major cause of visual-quality degradation when a camera shooting environment violates the assumption.

This paper proposes a new de-raining scheme that is immune to movements of objects and cameras. First, we initially detect rain streaks by using their luminance property. Second, we eliminate most possible outliers by applying two structural properties, i.e., the sizes and angles of rain streaks. Third, a rain strength map based on a Gaussian distribution model is estimated. Finally, the detected rain regions are updated through two advanced temporal properties, i.e., the linearity of motion vectors and repetition of false detected regions. If the rain detection step is completed, around the detected rain regions, possible rain streaks are removed as follows. Inter-frame block matching is performed using only non-rain pixels between corresponding frames, and a group of blocks similar to each block that has rain pixels is chosen. Then, the rain region in the block is reconstructed via non-local mean (NLM) filtering [9] using the similar neighboring blocks. Finally, we prevent flickering artifacts caused by some surviving rain streaks by employing edge-preserving filtering, and we improve visibility by using a specific visibility enhancement algorithm. The experiment results show that the proposed algorithm outperforms previous methods in terms of detection, removal, and detail preservation, even with a moving camera.

The main contributions of this paper are summarized as follows. First, the proposed rain detection method can find rain streaks of various strengths (e.g., incorrectly focused rain and distant rain) and is also less vulnerable to camera motion. Second, spatio-temporal NLM filtering for rain removal preserves the details of the reconstructed frames and mitigates the blur phenomenon, compared to previous methods.

The rest of this paper is organized as follows. Section 2 reviews some of the previous research. Section 3 deals with rain detection, which is the first step of the proposed algorithm. Then, we propose

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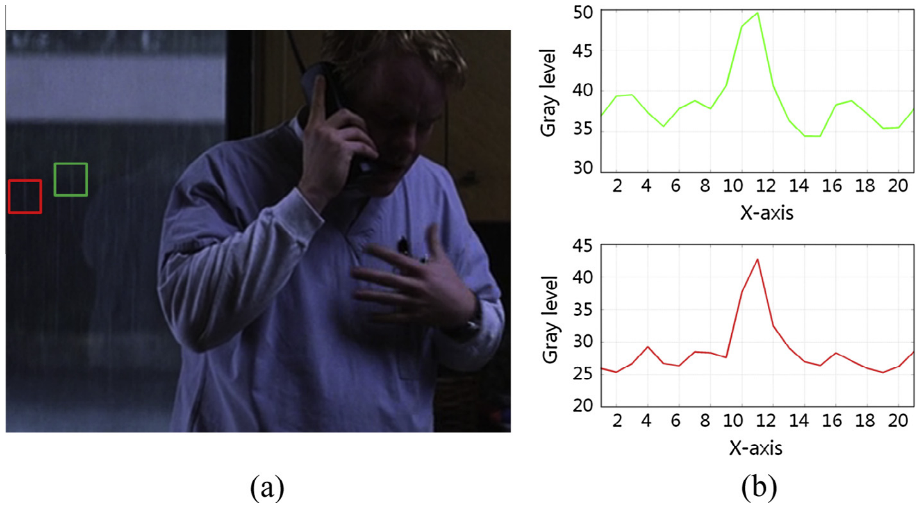

Fig. 1. (a) Original image, (b) the grayscale at horizontal axis of each box center.

an NLM-based rain removal algorithm in Section 4. Section 5 provides intensive experiment results. Finally, Section 6 concludes this paper.

2. Related works

Rain detection algorithms are usually classified into three categories: optical approaches, spatial-domain approaches, and frequency-domain approaches [1–8].

Garg and Nayar proposed a method for rain detection and removal in video, which is based on analysis of the rain's physical and photometric properties and a model of rain's dynamic and chromatic effects [1]. However, they need a large number of frames for calculating the temporal correlation during detection. Furthermore, when a moving object is mixed with a rain streak, false detection between the rain and the moving object may happen.

Zhang et al. proposed a method of rain detection and removal by utilizing *K*-means clustering [2]. They extended the idea of pixel-wise removal by correcting camera motion via planar image alignment and detecting rain streaks with *K*-means clustering. This method may achieve a significant improvement over a simple blending method in cases where a scene is static and its video frames are accurately aligned. However, since the intensity of each pixel over the entire video needs to be collected to get its histogram, the number of calculations in their algorithm is huge.

Barnum et al. proposed an alternative approach based on frequency analysis of rain streaks [3,4]. Assuming that rain streaks in an entire video sequence have similar shapes and orientations, they detected the rain streaks by selecting frequency components that repeatedly occur through the video sequence. Their approach works relatively better than previous methods when cameras or objects move because it can effectively detect rain streaks that satisfy the proposed blurred Gaussian model. However, it has a limitation when detecting rain streaks that violate the blurred Gaussian model.

On the other hand, Xue et al. proposed a rain detection algorithm based on joint spatial- and wavelet-domain features [5]. By using only two frames for rain detection and removal, their approach provides much higher robustness in detecting and removing rain streaks from videos with moving objects, in comparison with existing solutions. They effectively remove outliers by proposing a wavelet transform-domain feature-extraction method. However, their initial detection method, based on temporal frame differences, rarely works with heavy rain.

Recently, Kang et al. proposed a single-image rain streak-removal algorithm based on morphologic component analysis [6]. Their algorithm decomposes a rainy image into basis vectors based on sparse representation. It then clusters the basis vectors into two kinds of components: geometric components and rain streak components. Finally, it employs only the geometric components to reconstruct a rain-free image. The performance of their algorithm depends on clustering basis vectors. When the clustering is not effective, their algorithm may erase textures as well as rain streaks, and yield visual artifacts in a restored image.

Kim et al. proposed a single-image de-raining algorithm using an adaptive spatial NLM filter [7]. They first detect rain streak regions based on a kernel regression method. Next, they recover the rain streak regions using the NLM filter, in which the weights for non-local neighboring pixels are adaptively determined to suppress the impact of rainy pixels on the restoration. Their method is based on kernel regression robust for noise, but it is still hard to detect motion-blurred rain streaks due to its inherent gradient-based approach. Furthermore, with a moving camera, such single-image de-raining shows limited performance.

As one of the state-of-the-art motion-based rain removal algorithms, Chen et al. proposed a rain-pixel recovery algorithm based on motion segmentation of dynamic scene [8]. By jointly considering dynamic property as well as motion occlusion clue for each pixel, both spatial and temporal information are adaptively exploited during rain pixel recovery. However, this method may not work for video scenes having global motion or camera motion.

In order to be immune to camera motion and heavy rain, this paper presents a rain detection scheme utilizing spatial characteristics, such as the luminance and structural properties of rain streaks. We also present a motion-compensated NLM filter for rain removal.

3. Rain detection

Since rain pixels in video sequences have negligibly low spatio-temporal correlations, such as noise, most of the previous algorithms assumed no camera motion, and detected rain streaks by simply using inter-frame differences without motion compensation [1,2,5]. However, such approaches have three drawbacks. First, with heavy rain, rain streaks can temporally overlap due to their occurrence at such a high frequency. Second, if there is fast camera motion, a simple approach using temporal change cannot discriminate rain streaks from moving objects or background. Third, such