

Sharpness-aware Evaluation Methodology for Haze-removal Processing in Automotive Systems

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Abstract: This paper presents a new comparison method for haze-removal algorithms in next-generation automotive systems. Compared to previous peak signal-to-noise ratio-based comparisons, which measure similarity, the proposed modulation transfer function-based method checks sharpness to select a more suitable haze-removal algorithm for lane detection. Among the practical filtering schemes used for a haze-removal algorithm, experimental results show that Gaussian filtering effectively preserves the sharpness of road images, enhancing lane detection accuracy.

Keywords: Advanced driver assistance systems, Lane detection, Haze-removal algorithm, Image comparison methodology

1. Introduction

Intelligent in-vehicle systems, such as the self-driving car, the advanced driver assistance system (ADAS), and the camera-based image processing system, are gaining more and more interest in preparation for future transportation systems [1]. Among image processing applications for automobiles, edge-based lane detection and object-recognition algorithms are normally used to ensure reliability. However, the detection and recognition qualities are strongly affected by frequent haze [2].

Therefore, it is necessary to perform dedicated preprocessing in automotive camera systems to remove the haze information. In the previous generalized haze-removal algorithm, unfortunately, overall image quality is the only thing to be enhanced. As the best algorithm is selected by checking the quality of the reconstructed image, it is hard to say if the result is optimal enough to be used in an automotive application for the subsequent recognition process. Compared to the widely used peak signal-to-noise ratio (PSNR) evaluating the global similarity between two input images, it is necessary to use a new evaluation method that can fairly measure important features in automotive solutions. In addition, this evaluation method should be based on the region of interest (ROI) when checking limited regions like roads, lanes, and pedestrian crossings [2].

This paper presents a new performance comparison methodology for haze-removal algorithms in edge-based lane detection systems. The experiment shows properly selected haze-removal algorithms for automotive camera systems.

2. Background

2.1 Haze-removal Algorithm

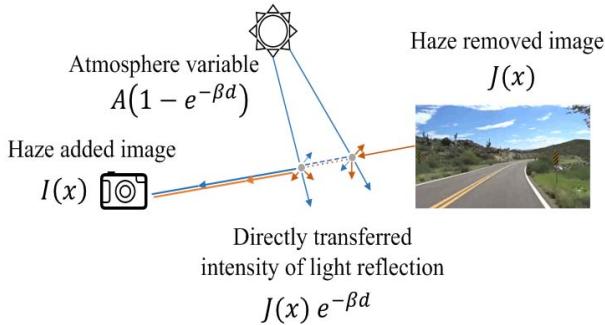
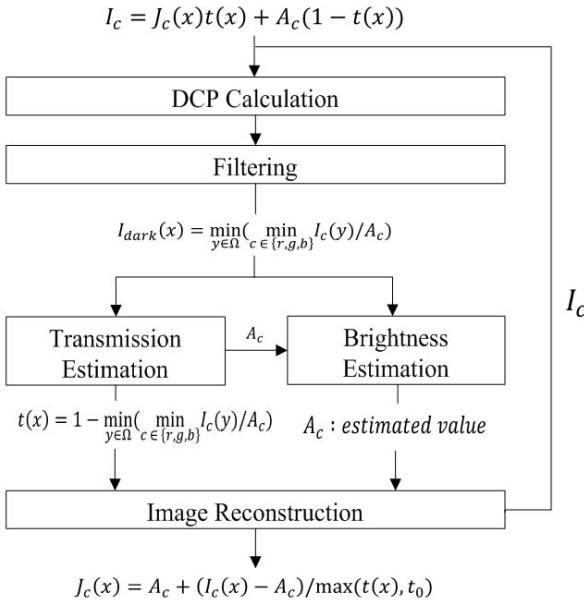
Hazy conditions are caused by weather, smoke, dust, and particle movement. The light scattered by haze can blur the image in the camera, which may create a poor input image. In particular, haze on Korean highways frequently occurs, as depicted in Table 1 [3], and the automotive camera system should ensure reliability in lane detection processes on highways.

Fig. 1 illustrates the widely used physical modeling for haze-removal algorithms. From Fig. 1, haze-removed image $J(x)$ can be extracted by transfer variable $e^{\beta a}$, and the image information loss rate can be determined by ratios of distance d . Also, distance d can be measured from more than two images in the primitive haze-removal processing. Obviously, this additional method can increase total costs.

For a practical solution, most of the conventional haze-removal algorithms apply the concept of dark channel

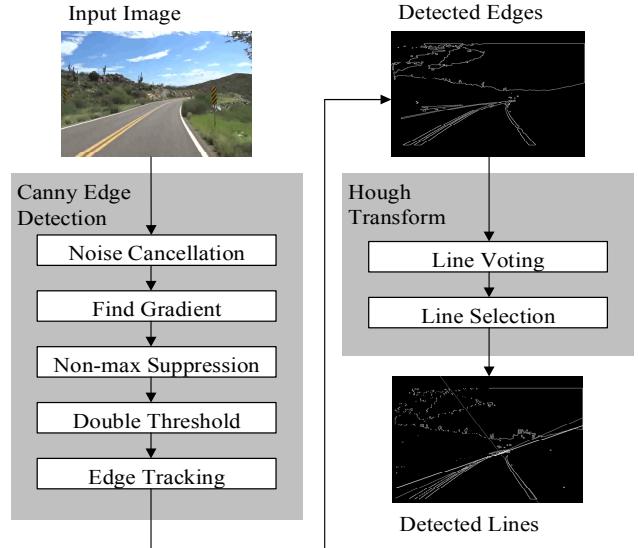
Table 1. Frequently foggy areas [3].

Location	Haze occurrence (days)			
	30-50	51-100	100+	Total
Seoul-Busan	6	3	0	9
West Sea	9	0	0	9
Central	8	3	1	12
Jung-Bu	5	13	4	22
Honam	6	1	0	7

**Fig. 1. Physical model of haze-removal algorithms.****Fig. 2. DCP applied haze-removal algorithm diagram.**

prior (DCP) of a single image. This method can calculate distance d indirectly using haze density extracted from color information [4]. Hence, DCP-based haze-removal processing, in effect, reduces system cost.

Fig. 2 illustrates the process of the conventional DCP-based haze removal. As shown in the figure, the algorithm contains five major steps, and recent research has mainly focused on designing filters after calculating the DCP information, since the image quality from haze-removal algorithms is strongly related to the type of filter. Therefore, the new evaluation method in this paper will consider the various filtering schemes to find the optimal one in terms of the proposed figure-of-metric.

**Fig. 3. Lane detection process using Canny edge detection and the Hough transform algorithm.**

2.2 Edge-based Lane Detection

The lane detection algorithm is one of the key processes in the self-driving and ADAS processes using front vision recorded by a camera system. It is well known that the lane can be detected by combining Canny edge detection followed by the Hough transform [1]. Fig. 3 illustrates the conceptual block diagram of the previous detection scheme.

Assuming a hazy condition, due to the blurred input image, the edge detection process shown in Fig. 3 may lose a large amount of edge information. As the Hough transform votes on every possible line passing through the pre-detected edge point, the missed edges caused by haze reduce the number of voting processes, resulting in misrecognition. As a result, lane detection can be corrupted by the edge vanishing under hazy conditions.

For the lane detection problem, it is obvious that a proper haze-removal algorithm should be carefully selected by measuring the clearance of edges.

3. Proposed Comparison Method

3.1 Conventional PSNR-based Evaluation

The conventional evaluation method of the haze-removal algorithm uses PSNR values, which can be derived as

$$\begin{aligned} PSNR &= 10 \cdot \log_{10} \left(\frac{\text{MAX}_I^2}{\text{MSE}} \right) \\ &= 20 \cdot \log_{10} \left(\frac{\text{MAX}_I}{\sqrt{\text{MSE}}} \right) \end{aligned} \quad (1)$$

where MAX_I , and MSE stand for the maximum pixel value and the pixel differences between the test image and the

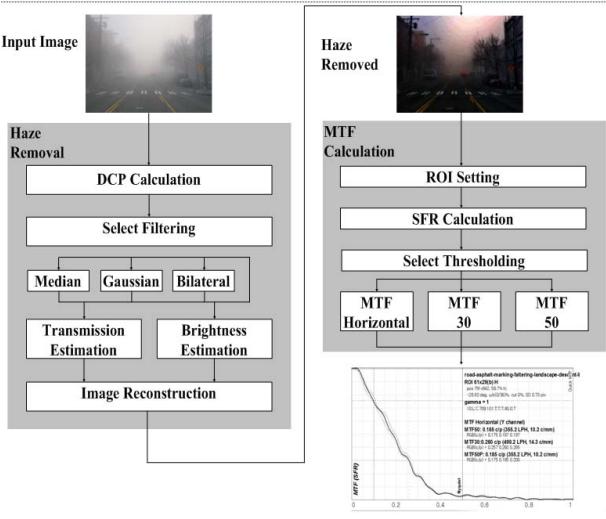


Fig. 4. Proposed MTF measuring system diagram based on OpenCV processing libraries.

reference image, respectively. Because the conventional PSNR-based evaluation calculates similarity between two images, it is widely adopted for evaluating quality in various multimedia systems. However, this method cannot be used to evaluate haze removal in automotive systems, because the sharpness of detected edge information cannot be calculated.

3.2 Proposed Sharpness-aware Evaluation Method for Haze-removal Algorithms

In the haze-removal processing used for the following lane detection system, sharpness information should be calculated to ensure a clear lane in the reconstructed images. In this work, we define the amount of sharpness by using a modulation transfer function (MTF) [7]. In general, the MTF is widely applied in medical image processing to measure the clearance of bone images. By using the luminance ratio, the proposed evaluation method first calculates the transfer function, and then the MTF is derived by obtaining the ratio of input M_i and output M_o [8]. Various MTF ratios can be pre-selected to check the amount of sharpness. In this work, MTF50 is used to measure the sharpness between lane and road pixels [8].

Based on MTF50 values, we developed an efficient software environment for evaluating the sharpness of each haze-removal algorithm. Fig. 4 illustrates the steps of the proposed evaluation environment, which is based on OpenCV libraries. For the various filters used in conventional haze removal, i.e., Gaussian, median, and bilateral filters, the proposed evaluation tool first sets the specific ROI, including both the road and lane pixels, and then, the MTF50 value is calculated by only using the selected ROI. Hence, we can precisely obtain the lane-to-road sharpness, which is the essential information in the following lane detection process. To prevent misjudgment, in addition, several ROI windows are taken from the same images to get the average MTF50 value of each filtering operation.

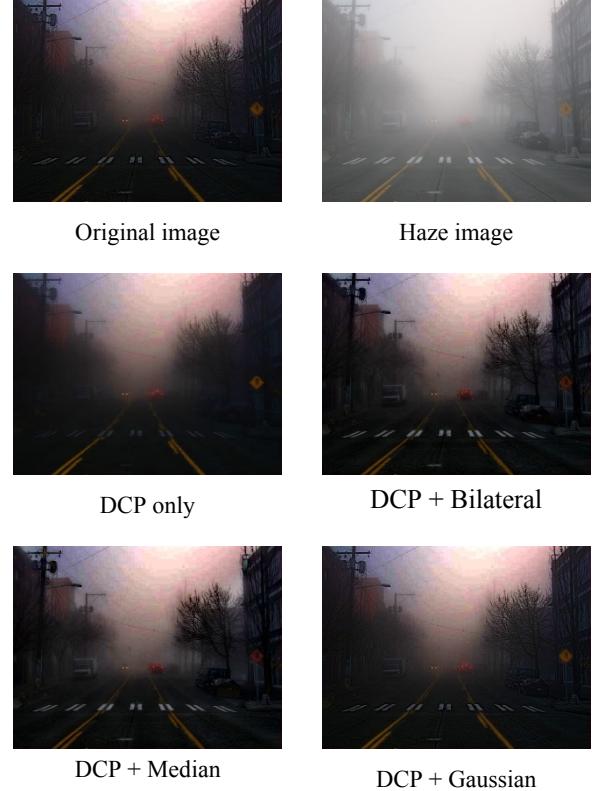


Fig. 5. Haze-removed images and original image.

Table 2. Results of PSNR measure.

Compare target	PSNR (dB)
Haze image	9.5
DCP (no filter)	28.4
DCP + Bilateral filter	29.9
DCP + Median filter	30.1
DCP + Gaussian	30.7

4. Experiment and Verification

4.1 Conventional PSNR Comparison

Fig. 5 illustrates the original, hazy, and different haze-removed filtered images. To check image qualities, two evaluation methods are realized: PSNR-based testing and the proposed sharpness-aware evaluation. The simulation results of PSNR-based testing are shown in Table 2, and it is obvious that the previous PSNR-based testing cannot provide the best filtering option for the lane detection problem due to the small differences.

In reality, moreover, the original reference image cannot be acquired at the same time under hazy conditions. As shown in (1), the PSNR requires two pixel values from the reference image and the testing image [2]. As we cannot prepare the original image by nature, it is basically impossible to apply PSNR-based testing.

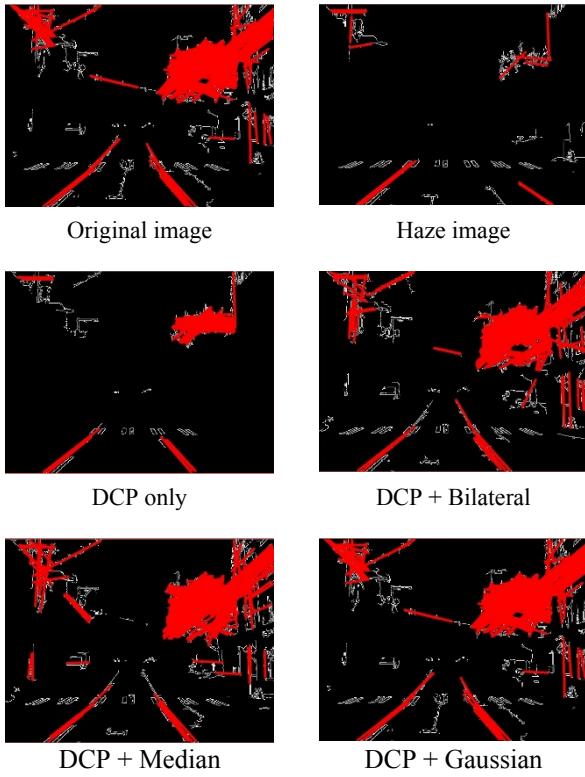


Fig. 6. Lane detection processed images.

Table 3. Results of MTF50 measure.

Compare target	MTF50 ($10^3 c/p$)
Original image	142
Haze image	62
DCP (no filter)	112
DCP + Bilateral filter	130
DCP + Median filter	132
DCP + Gaussian	140

4.2 Proposed MTF50 Comparison

Based on the proposed testing environment, which is illustrated in Fig. 4, MTF50 values are calculated and depicted in Table 3. In contrast to the previous PSNR-based testing, the MTF50 results clearly denote that the Gaussian filter is the best option to preserve the edge information in road images. To verify this conclusion, we also executed the conventional lane detection algorithm on the various filtered images, as shown in Fig. 6. Note that the red lines in the figure are the detected lines from the Hough transform. It is noticeable that DCP + Gaussian is the most promising option for finding the road lanes, compared to the other filtering techniques, and is compatible with the results of the proposed sharpness-aware testing method. In addition, the proposed sharpness evaluation scheme can be used when we cannot find the original image, which is a practical assumption in automotive applications.

5. Conclusion

In this paper, we presented a new comparison method for evaluating the quality of haze-removal algorithms. The proposed method measures the amount of sharpness, which is based on the MTF 50 standard. An OpenCV-based testing environment is also developed to automate the evaluation steps. Compared to the previous PSNR-based work, the proposed sharpness-aware testing provides a more suitable evaluation process for haze-removal algorithms, targeting the lane detection problem in automobiles.

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