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STUDY ON LANE DETECTION IN FOG WEATHER BASED ON HEURISTIC REGION OF INTEREST AND IMPROVED DARK CHANNEL PRIOR

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Abstract. *It is difficult to use traditional methods to detect the road lane accurately in fog weather; in order to solve this problem, a new method based on improved dark channel prior and selected region of interest (ROI-II) was given in this paper. Firstly, the ROI-II of lane images in fog weather is defogged by improved dark channel prior, then the binary images of road edges are obtained by Scharr operator and Ostu algorithm, and finally, the road lane is obtained after Hough transform. Experimental results shown the new method can detect the road lane on fog accurately.*

Keywords: Vehicle active safety, Dark channel prior, Image defog, Region of interest

1. **Introduction.** In recent years, fog has huge influence on people's daily life, especially in road transportation, because fog causing low visibility brings great potential danger for traffic safety. Thus, designing a lane departure warning system that can be used in fog weather would help drivers avoid some potential traffic accidents caused by fog. In such departure warning system, how to detect road lane accurately on fog is the key. Even though there are already many lane detection algorithms [1-3], they have poor performance in lane detection in fog weather.

In the study of image defogging, the dark channel prior algorithm proposed by He et al. [4] is the most representative and it has good performance on image defogging even in heavy fog. In He et al.'s algorithm, soft matting is adopted to smooth the filter transmission images; however, soft matting is a calculation of large sparse system of linear equations, which is very complicated and time-consuming. In order to improve the algorithm's instantaneity, Sun et al. [5] and Pang et al. [6] adopt bilateral filtering to replace soft matting and their improved algorithms have greatly improved the algorithm's instantaneity. However, their defogged images are still too dark for lane detection. In order to improve the brightness of images, Xiao and Li [7] and Shu et al. [8] combine multi-scale Retinex (MSR) algorithm with dark channel prior, even though it turned out that it can improve the image's definition, their algorithms are still time consuming, because they keep using soft matting to smooth the filter transmission images.

In order to solve all the defects mentioned above, firstly, an improved dark channel prior algorithm based on Narasimhan's atmospheric scattering model is proposed in this paper. At the process of improving dark channel prior algorithm, soft matting is replaced by bilateral filtering to improve the real-time image defogging, and multi-scale Retinex (MSR) is used to improve the definition of defogged images. Secondly, in order to avoid defogging the whole picture, the heuristic region of interest (ROI-II) is adopted, Ostu and Scharr filtering are used to get the road edge after defogging the heuristic region of interest. Finally, Hough transform is used to get the road lane. Experimental results show that our method can detect the road lane not only accurately but also rapidly in fog weather.

2. Improved Defog Method. In fog weather, because there are random mediums in atmosphere, the light will be scattered and absorbed when it travels from the road to camera. During this period, see Figure 1, the light that should travel in direct path, deviated from the original propagation path, which depressed the image contrast, making the road lane vague to be detected.

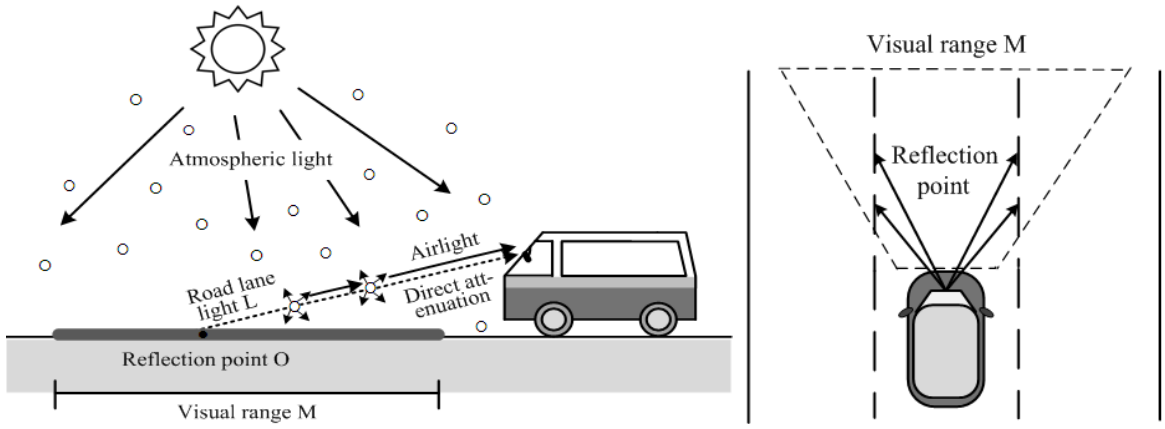


FIGURE 1. Atmospheric scattering model

The most widely used in study of image defogging is the Narasimhan's atmospheric scattering model, which can be described as:

$$L(\beta, \lambda) = L_0(\beta, \lambda)\, e^{-k*d\beta} + A\left(1 - e^{-k*d\beta}\right) \tag{1}$$

where $L(x, \lambda)$ represents the foggy image received by camera, $L_0(x, \lambda)$ represents the reflected light intensity from road lane, k represents the atmospheric scattering coefficient, β represents the scene depth, λ represents the wavelength of light after reflection, $e^{-k*d\beta}$ represents the distribution of transmission rate, and A represents the environmental light intensity [9]. Assuming that light propagates in a homogeneous medium, λ can be treated as a constant, thus respectively making $t(x) = e^{-k*d\beta}$, $J(x) = L_0(\beta, \lambda)$, $I(x) = L(\beta, \lambda)$, and Equation (1) could be abbreviated as:

$$I(x) = J(x)t(x) + A(1 - t(x)) \tag{2}$$

where $I(x)$ represents the images captured by camera, $J(x)$ represents the images without fog, and $t(x)$ represents the transmissivity. According to dark channel prior theory, in the vast majority of local area which does not belong to sky, some pixels always (at least one color channel) have a very low value. Thus, the foggy dark gray image $I_{dark}(x)$ should be calculated, and then the edge of dark gray image is amended.

There is still a certain amount of fog in the sky even in sunny weather. If all the fog in image is removed, the original image will be distorted, and thus there should be a retention coefficient ω $(0 < \omega < 1)$, then calculating the transmissivity:

$$\tilde{t}(x) = 1 - \omega \min_{c}\left(\min_{y \in \Omega(x)}\left(I^{R}_{dark}(y)/A^{c}\right)\right) \tag{3}$$

where A^c represents the atmospheric light intensity on a color channel, and $\tilde{t}(x)$ represents the local area transmission. In order to improve the method's in realtime, bilateral filtering in [6] is used to replace the soft matting to smooth the transmissivity image $\widetilde{t}(x)$, and then the predicted transmissivity is obtained:

$$t^R(x) = \frac{1}{\omega(x)} \sum_{y\in\Omega(x)} G_{h_x}\left(\|x-y\|\right) \cdot G_{h_r}\left(|I_x - I_y|\right) \cdot t(x) \tag{4}$$

where the normalized coefficient $\omega(x) = \sum\limits_{y\in\Omega(x)} G_{h_s}\left(\|x-y\|\right) G_{h_r}\left(|I_x - I_y|\right)$, G_{h_x}, G_{h_y} are Gaussian functions and $G_{h_x} = e^{-\frac{\|x-y\|^2}{2h_s^2}}$, $G_{h_r} = e^{-\frac{\|x-y\|^2}{2h_r^2}}$. Then the defogged image $J_1(x)$ is obtained:

$$J_1(x) = \frac{I(x) - A}{\max\left(t^R(x), t_0\right)} + A$$

One of the reasons that make it difficult to detect the road lane on fog accurately is that the fog weather reduces the contrast level of images [10], in order to solve this problem, MSR is used to improve the contrast level of the defogged image $J_1(x)$, and then the defogged image $J_2(x)$ can be obtained. Because the image defogged by dark channel prior is too dark for lane detection even after calculated by MSR, in order to improve the luminosity, linear modificative method is used to modify the defogged image $J_2(x)$ and the final defogged image J_f is obtained:

$$J_f = \alpha J_2(x) + S(x) \tag{5}$$

where α represents the luminosity correction coefficient and $S(x)$ represents the luminosity correction matrix.

$$S(x) = m_x(i,j) + \frac{D}{\sigma_x(i,j)}\left[J_2(i,j) - m_x(i,j)\right]$$

where $m_x(i,j) = \frac{1}{(2n+1)^2} \sum\limits_{k=i-n}^{i+n} \sum\limits_{l=j-n}^{j+n} x(k,l)$, $\sigma_x(i,j)$ represents local standard deviation, $\sigma_x(i,j) = \frac{1}{(2n+1)^2} \sum\limits_{k=i-n}^{i+n} \sum\limits_{l=j-n}^{j+n} \left[x(k,l) - m_x(i,j)\right]^2$, and D represents the mean values of $J_1(x)$ [11].

In order to compare our improved method with the original dark channel prior algorithm, we download some pictures (http://news.58che.com/news/726843.html) in fog weather to verify our method, one of these experimental results can be seen in Figure 2, the road lane in the red box in both Figures 2(a) and 2(b) are too vague to be seen; however, after defogging by our method, they become very clear.

When it comes to improving the realtime of algorithm, the algorithms proposed by Sun Kang do have better performance, however, it has little difference with He et al.'s when comparing the image defogging results, and thus instead of showing Sun's defogging

(a) Original haze image (b) He et al.'s algorithm (c) Our algorithm

Figure 2. Comparison of image defogging

results in this paper, we only compare the realtime of Sun's algorithm with our method and He et al.'s, and the result is shown in Table 1. It is not difficult to find out that our algorithm has better performance in realtime compared with He et al.'s.

TABLE 1. Comparison of image defogging time

	256 ∗ 192	**320 ∗ 240**	**512 ∗ 384**	**640 ∗ 480**	**1024 ∗ 768**
He et al.'s/s	3.38	5.51	13.79	22.21	64.54
Sun's/s	0.06	0.16	0.21	0.32	0.54
Our method/s	0.10	0.18	0.34	0.43	0.65

Even though our algorithm may cost more time than Sun's due to adopting MSR and luminosity correction matrix, experimental result showed our algorithm has higher contrast level than Sun's. After calculating the contrast level of the images in Figure 3 and Sun's, the experimental results can be seen in Table 2.

TABLE 2. Comparison of image contrast level

	Original image	Sun's algorithm	Our method
Contrast level	0.0952	0.1754	0.2945

It can be seen from Table 2, our defog algorithm is better than Sun's in improving the contrast level of image, which means it will have better performance in lane detection due to the fact that low contrast level of image is the main difficulty for traditional method to detect road lane on fog accurately.

3. **Selection of Region of Interest – ROI-II.** Even though our improved defogging algorithm has greatly improved the real time, if we use that algorithm to defog the whole image, it cannot meet the requirement of real working condition. In order to solve this problem, a static region of interest, shown in Figure 3(a), is selected as the ROI-II [12]. When defogging images, it is only necessary to defog the ROI-II instead of the whole image, which can greatly improve the real time and precision.

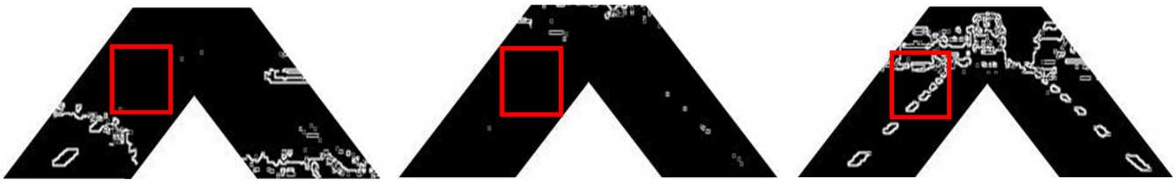
(a) ROI-II (b) Original image (c) He et al.'s algorithm (d) Our algorithm

FIGURE 3. Comparison of image defogging of ROI-II

4. **Lane Detection.** In this paper, Scharr filter is adopted to detect the road lane, because compared with Sobel filter, Scharr filter has the same real time but higher precision. The Scharr filter convolution kernel used in this paper is $\mathrm{G_X} = [-3, 0, 3; -10, 0, 10; -3, 0, 3]$ and $\mathrm{G_Y} = [-3, 10, -3; 0, 0, 0; 3, 10, 3]$.

After using Scharr filter to enhance the edge of road lane, there is still much noise in image. The common practice to extract lane mark line from the multi value digital image is image binaryzation. Otsu method is used to obtain the image threshold and processing. As can be seen in Figure 4, it is obvious that there are almost no road edges in red boxes in both Figure 4(a) and Figure 4(b); on the contrary, the road edge is very clear in Figure 4(c).

After image binaryzation, Hough transform is used to detect the lane.



(a) Original haze image (b) He et al.'s algorithm (c) Our algorithm

Figure 4. Comparison of edge extraction of ROI-II

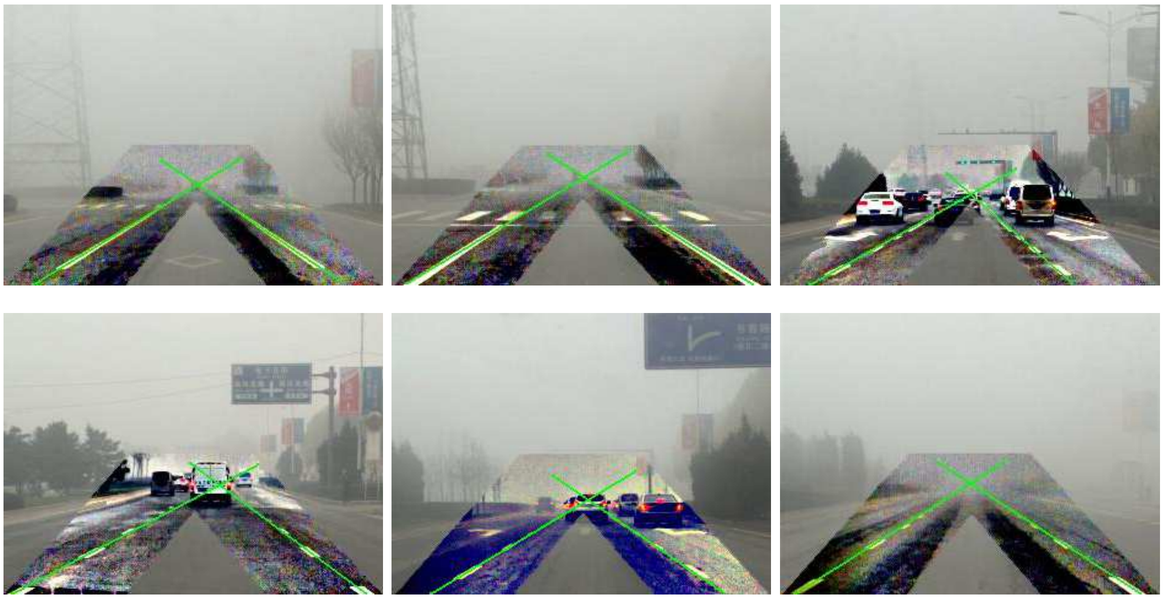


Figure 5. Experimental results

5. **Experimental Results.** Low visibility will reduce the traffic safety; thus, the West Avenue and part of the Aerospace Avenue in Xi'an, where traffic flow is small, are used as experimental site for safety. The experimental time is November 29, 2015 09:00-09:56 and the weather is fog.

Test video data is captured using a CCD camera, with a resolution of $640*480$, mounted on the front windshield of the host vehicle with a width of 1.7m. This camera is mounted at a height of 1.65m, with a pitch angle of $12.58°$, horizontal angle of $39.8°$ and focal length of 916 pixels.

The video is post-processed using an implementation of the algorithm developed in Multi Condition Lane Detection System software, which is based on Visual C++ and OpenCV developed by the author and his experimental team, on the TANK-820-H61 IPC with an Intel Core i5 processor and 3 GB RAM running Windows 7. Figure 5 shows part of the experimental results and it shows our method can detect the road lane on fog accurately.

6. **Conclusions.** In fog weather, it is difficult to use traditional methods to detect the road lane precisely due to the fact that contrast level between the road surface and the lane marking reduces. In order to solve this problem, this paper introduced a new algorithm based on selected ROI and improved dark channel prior algorithm to improve the precision of road lane detection in fog weather. Firstly, the ROI-II of lane images in fog weather is defogged by improved dark channel prior, then the binary images of road edges are obtained by Scharr operator and Ostu algorithm, and finally, the road lane is obtained

after Hough transform. Experimental results of this study showed this new algorithm could detect road lane on fog accurately.

This study still has many limitations. One of the limitations is how to change the new improved algorithm to traditional algorithms automatically when it is under normal lighting condition, because an improved dark channel prior is adopted in this new improved algorithm, and it would sacrifice much precious time for the accuracy of road lane detection. However, the traditional algorithm could meet the demand in normal lighting condition, which would undoubtedly reduce computation load and increase computation efficiency. In the further studies, some monitoring devices, which could detect the real-time weather and send different signals to the system, should be adopted to help lane detection system choose different algorithms, for example, the lane detection system would adopt traditional algorithms when receiving normal signals from the monitoring devices and adopt improved algorithm when receiving special signals.

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