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Highway Visibility Prediction Model Based on Dark Channel Prior Theory

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Abstract: *Visibility is an important indicator of road safety, and accurate estimation of visibility is an important guarantee for safe travel. This paper aims to explore the evolution law of heavy fog and predict the change trend of heavy fog. Firstly, this paper establishes the expressway visibility prediction model based on the dark channel prior theory, and solves it combined with canny edge detection algorithm. Then, according to the obtained visibility curve with time, a heavy fog prediction model is established by Fourier transform algorithm. Finally, the model is analyzed and the improvement direction is put forward.*

Keywords: *Visibility, Fourier Transform, Dark Channel Prior Theory*

1. Introduction

Visibility is an important indicator to judge travel safety. Although there are visibility meters and other equipment on the market to judge the visibility, it is not easy to be popularized and used in a large scale due to its high cost, low precision, small detection range and other factors. Therefore, it is of great significance for the orderly operation of traffic and people's safe travel to find the factors affecting the change of visibility and explain the relationship between visibility and ground meteorological observation data.

In this paper, a visibility estimation algorithm independent of the observed data of visibility meter is proposed, and the visibility estimation is realized by the algorithm. For a section of Expressway video, the variation curve of Expressway visibility with time is drawn; Then, according to the variation law of visibility with time, a mathematical model is established to predict the change trend of heavy fog.

2. Establishment and solution of model

2.1. Visibility Prediction Model

A visibility estimation algorithm independent of the observed data of the visibility meter is established. After analysis, it is known that the visibility takes the atmospheric extinction coefficient as the only variable. It is proposed to adopt the visibility detection algorithm based on the dark channel prior theory to transform the problem of establishing the visibility estimation algorithm into the problem of calculating the atmospheric extinction coefficient.

The relation formula between visibility and atmospheric extinction coefficient:

$$\mathrm{MOR}=\frac{\log(F/F_0)}{-\sigma}=\frac{\log(0.05)}{-\sigma} \tag{1}$$

MOR represents visibility, σ is the extinction coefficient.

(1) Dark channel prior knowledge [1]

According to the dark channel prior theory, when the outdoor fog free image is taken as the research object, in the three color channels of R, G and B, in some areas of the image except the sky area, the pixel value of Yidi port in a certain channel will be small. Therefore, it can be judged that except for the sky area, the dark channel value of the rest of an outdoor fog free color image basically tends to 0. Therefore, the expression formula of the dark channel corresponding to an image is:

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$$J^{dak}(x) = \min_{y \in \Omega(x)}(\min_{c \in \{r,g,b\}} J^c(y)) \tag{2}$$

$J^{dak}(x)$ is the dark channel picture after operation, J^c represents one of the three color channels R, G and B in the image, Ω_x is a neighborhood centered on x, $\min_{c \in \{r,g,b\}}$ is the minimization of a single pixel in an image, $\min_{y \in \Omega(x)}$ is the minimum pixel value existing in the neighborhood of pixel x.

(2) Atmospheric transmittance

Mathematical model of haze image defined by cosimead's law:

$$I(x) = J(x)t(x) + A(1 - t(x)) \tag{3}$$

I represents the detected image, J represents the intensity of the scene where the target is located, A represents the intensity of atmospheric light in the environment, t represents the transmittance of the propagation medium in the environment, x is the coordinates of pixels.

(3) Refinement of Atmospheric Transmittance Based on guided filtering

The core of this method is to assume that there is a local linear relationship between the guidance image and the filtered output image.

$$\boldsymbol{q_i = \alpha_k I_i + b_k, \forall i \in \omega_k} \tag{4}$$

p represents the input image, q represents the output image, I represents a guide image, ω_k represents a window centered on a pixel k.

(4) Atmospheric visibility estimation

Step 1: lane line detection

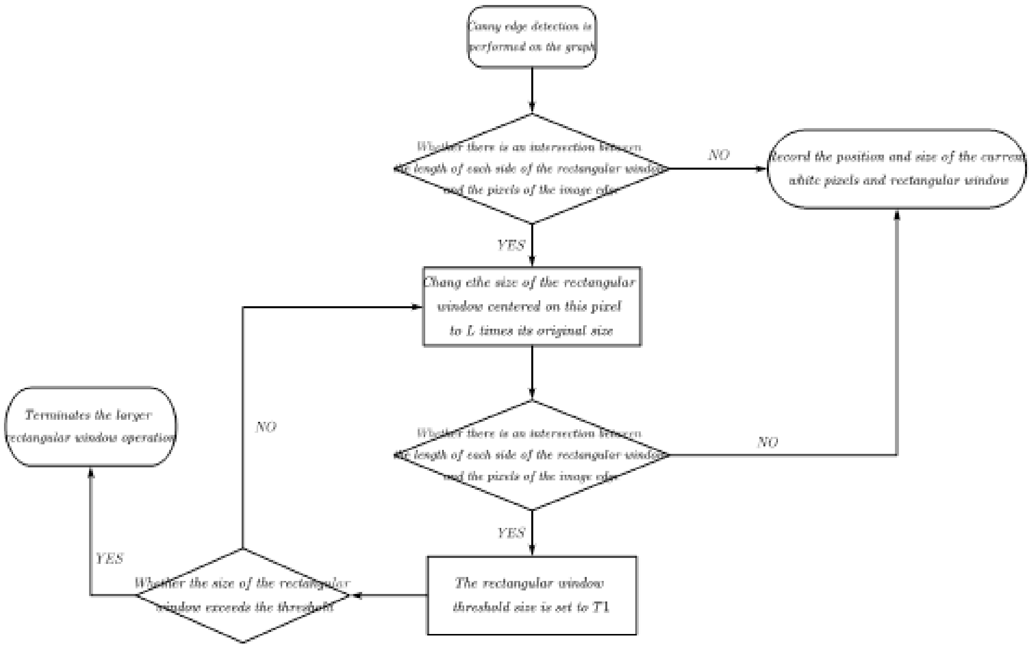

Figure 1: Flow chart of lane line detection

Step 2: extinction coefficient acquisition

Since the video screenshot used is from the expressway monitoring video, the length of each lane line is 6m, and the interval between the front and rear adjacent lane lines is 9m, so the extinction coefficient can be calculated. Solution formula of extinction coefficient of smooth horizontal plane:

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$$\beta(i)=\frac{\left|\ln\frac{t_1}{t_2}\right|}{L}$$
$$\beta=\frac{1}{N}\sum_{i=1}^{N}\beta(i), i=1,2,\cdots,n \tag{5}$$

$\beta(i)$ represents the extinction coefficient corresponding to any lane line $R(i)\ (i=1,2,\cdots,n)$ in the image, L is the distance of the lane segment, t_1 represents the atmospheric transmittance after refinement at the front end of the lane line, t_2 represents the atmospheric transmittance after refinement at the rear end of the lane line, N represents the number of lane lines detected in the detection image.

2.2. Visibility solution formula

When the extinction coefficient formula and visibility formula are known, the specific solution formula of visibility can be obtained:

$$V=\frac{3N}{\sum_{i=1}^{N}\beta(i)} \tag{6}$$

To sum up, the image processing flow is as follows: input the original image, process it with the dark channel a priori theory and Cauchy Mead's law, then conduct the guidance filtering processing, and then carry out Canny edge detection and lane line detection. Finally, bring the relevant data into the visibility formula and output the visibility.

2.3. Heavy Fog Prediction Model

2.3.1. Data Processing

Since the results obtained in 2.1 fluctuate frequently up and down, we believe that the reason for the frequent fluctuation comes from a small range of fog. Small fog will not affect the overall trend of fog in this question, and greatly increases the complexity of the model in this question. Therefore, the fog concentration at each time point is taken as the average value of nearly 30 points, so as to smooth the curve and eliminate the influence of ultra-small fog on the model.

2.3.2. Time Series Model ARIMA (P, D, q)

Differential autoregressive moving average model is to process the data differentially, and then convert it into a stable time series, and then establish the model. By comparison, we use ARIMA (0,1,2) time series model with high accuracy to predict fog concentration. However, considering the influence of mass fog in heavy fog, the Fourier transform model is obtained by optimizing the model.

2.3.3. Fourier Transform Model [2]

$$F(\omega)=F[f(t)]=\int_{-\infty}^{\infty}f(t)e^{-iwt}dt \tag{7}$$

ω represents frequency, t represents time, $e^{-i\omega t}$ is a function of complex variables.

Because it is difficult to reasonably predict this problem by using time series and mathematical analysis, the method of mechanism analysis is used to predict the change trend of fog concentration. After observing the image, it is found that the image curve processing is similar to the superposition of multiple trigonometric functions. In the mass fog, the fog concentration will appear in higher areas and the visibility will be lower. Therefore, the intersection between air and fog, fog and mass fog, and between mass fog and its internal mass fog can be regarded as the superposition of trigonometric functions.

Based on this, we analyze the model and believe that the fog concentration is determined by the number of cloud fog. In this model, the fog concentration curve is decomposed into sinusoidal function

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images with different frequencies. Each sinusoidal image has corresponding amplitude. The function with large amplitude is the fog with high concentration, and the one with small amplitude is the fog with low concentration. Ideally, the fog of various sizes and models appears according to a certain time law, and the fog is roughly divided into four sizes and models. Considering that the time is in the morning and the fog has a dissipation trend as a whole, it is considered that the amplitude of the trigonometric function $k(t) = at + b$ is a function of time. With the change of time, the concentration of each kind of fog is decreasing. For the background fog, the first-order function is also used to express that its concentration also decreases with time. Finally, the following equations are listed:

$$\sigma(t) = \sum_{i=1}^{4} (a_i t + b_i) \sin(c_i t + d_i) + ex + f \tag{8}$$

This formula vividly shows that the large fog is formed by the superposition of different small fog. The function added before the sinusoidal curve is the attenuation function to show that the mass fog concentration decreases with time.

2.3.4. Solution of Heavy Fog Prediction Model

The values of each sine curve a_i, b_i, c_i, d_i, e, f after Fourier transform are obtained by MATLAB fitting toolbox, and the goodness of fit $R^2 = 0.9834$ is obtained.

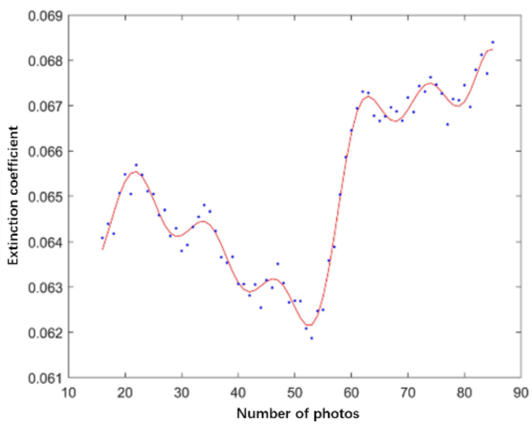

Figure 2: Fitting curve of extinction coefficient

Then, in order to predict the change trend of fog concentration in the future, the fog concentration is described by extinction coefficient and visibility value, and t is substituted into Fourier equation from 100 to 200 to predict the change of fog concentration (extinction coefficient) in the next 72 minutes, and then the visibility change is calculated by extinction coefficient.

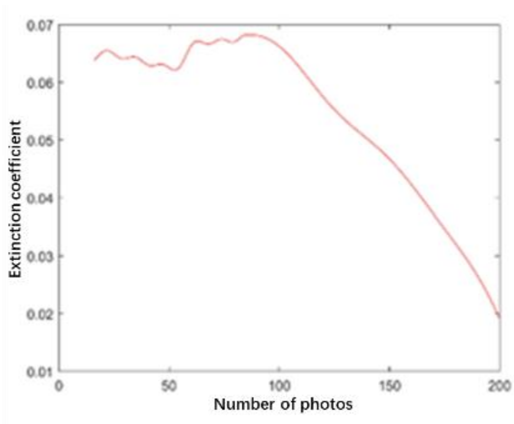

Figure 3: Change curve of extinction coefficient

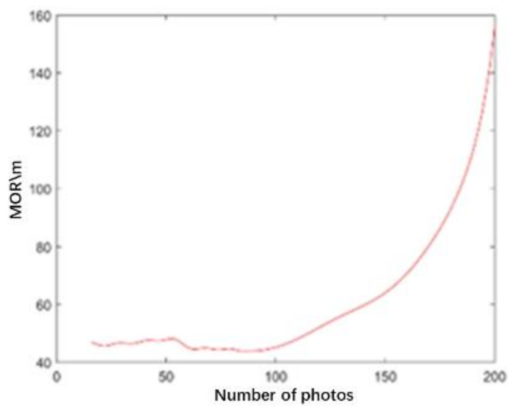

Figure 4: Change curve of visibility

It can be found from the images that the extinction coefficient decreases gradually after 100 images,

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indicating that the fog concentration decreases gradually; At the same time, the visibility increases gradually after 100 sheets. At the same shooting speed, when the number of photos reaches 200, that is, the time reaches about 72 seconds and the visibility reaches 150, it is considered that the fog has basically dissipated.

3. Improvement Direction of Heavy Fog Prediction Model

1) For the data with large up and down range and frequent changes for many times, the average value of 30 surrounding points is used in smoothing. Here, it can also be considered that the adjacent points have a large amount of information and obtain a large weight for the current point, and the weight value can be normally distributed around the current point.

2) In this paper, the trigonometric function selected to describe the concentration characteristics of the fog can also generate the fog with random amplitude and probability of occurrence by Monte Carlo method. Through optimization, the most appropriate probability of occurrence of a certain fog concentration and duration can be found, and the probability of fog dissipation at each time point can be obtained by multiple prediction.

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