A New Algorithm for Calculating the Daytime Visibility Based on the Color Digital Camera

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Abstract

There are some deficiencies in the traditional daytime visibility calculation method using CCD digital camera: visibility observation value is accurate while using the artificial objects， but expensive; nonzero internal reflection coefficient of the target lead to inaccurate visibility observation results when using natural objects as the target. A new daytime visibility algorithm based on color CCD digital camera is proposed in this paper: we use the color images obtained by the CCD digital camera, then estimate transmission of color digital image by using the knowledge of dark channel prior, and obtain the atmospheric attenuation coefficient form transmission to calculating visibility value. The experimental data show that the max-error of the proposed algorithm is less than 20% which conform to the error provisions of WMO on the meteorological visibility instrument, and simple operation, without artificial target, low cost.

Keywords: *Color digital camera, Daytime visibility, A new visibility Algorithm, Estimated transmission.*

1. Introduction

In recent years, with the development of computer technology and CCD digital camera technology, design and research of CCD digital camera visibility meter rapid development. The United States began research in calculating the daytime visibility based on Video image in 1998[1]. The traditional daytime visibility calculation method based on CCD digital camera mainly includes the frequency domain method and time domain calculation method[2,3], and most of them use gray image—by calculating contrast between the target and the sky background, or calculating frequency change of the target to obtain the visibility value. There are some deficiencies here: visibility observation value is accurate while using the artificial objects，but expensive; nonzero internal reflection coefficient of the target lead to inaccurate visibility observation results when using natural objects as the target. For correcting this error, we need a long-term experiment to fitting reflection coefficient, and recalibrate observations in the fixed environment[1], [4], [5], [6], [7].

Based on several factors of the atmospheric environment impacting atmospheric visibility, according to the atmospheric transport model, a new daytime visibility algorithm based on color CCD digital camera is proposed in this paper: we use the color images obtained by the CCD digital camera, then estimate transmission of color digital image by using the knowledge of dark channel prior, and obtain the atmospheric attenuation coefficient from transmittance to calculating visibility value. The proposed algorithm completes daytime visibility calculation based on color CCD digital camera from the perspective of the image processing. The experimental results show that the new algorithm is feasible, and simple operation, without artificial target, low cost.

2. Algorithm design

2.1 Visibility calculation model

The atmospheric visibility dropped in the atmosphere mainly due to three reasons: the light of object (including self-luminous and reflective) absorbed by the atmosphere before it reaching at the detector; the light of ob scattered by all kinds of atmospheric particulate matter so that it can not reaching at the detector; other background light is scattered into the detector because of the atmospheric particulate matter on the path from the object to the detector. Atmospheric absorption and scattering result in light attenuation jointly. We ignore atmospheric absorption to achieve the proposed algorithm because most of the atmospheric optical attenuation mainly roots in atmospheric scattering.

According to the atmospheric scattering model, the process of atmospheric optical transmission that the light of target reaching at the detector is represented as[8,9]:

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

where x is the plane coordinates of target, I is the scene radiance, J is target light intensity, A is the atmospheric light, t is the atmospheric transmission describing.

The transmission can be calculated with the atmospheric extinction coefficient[8,9]:

$$t(x) = e^{-\sigma(x)r(x)} \tag{2}$$

Where σ is the scattering coefficient of the atmosphere, r is the scene depth. This formula assumed that the atmospheric extinction coefficient is homogeneous on the path from the object to the detector.

According to the Koschmieder's Law [10], the atmospheric visibility can be expressed as:

$$V = -In\varepsilon / \sigma \tag{3}$$

Where ε denotes threshold of visual contrast. According to the rules of WMO, we set the contrast threshold for 0.02[14], which is equivalent to the distance that the target disappears. Formula (3) is expressed as:

$$V = -In0.02 / \sigma = 3.912 / \sigma \tag{4}$$

So, we can get visibility value with transmission t.

2.2 Estimated transmission[11]

We use dark channel prior to estimate transmission. For image J, the dark channel prior[11]:

$$J_{dark}(x) = \min_{c\in\{r,g,b\}}(\min_{y\in\Omega(x)}(J_c(y))) \tag{5}$$

Where J^c is a color channel of J and $\Omega(x)$ is a local patch centered at x. Taking the min operation[11]:

$$\min_{y\in\Omega(x)}(I^C(y)) = t(x)\min_{y\in\Omega(x)}(J^C(y)) + \min_{y\in\Omega(x)}(1-t(x))A^C \tag{6}$$

The min operation is performed on three color channels independently, this equation (6) is equivalent to[11]:

$$\min_{y\in\Omega(x)}(\frac{I^c(y)}{A^c}) = t(x)\min_{y\in\Omega(x)}(\frac{J^c(y)}{A^c}) + (1-t(x)) \tag{7}$$

We take the min operation among three color channels on the above equation and obtain[11]:

$$\min_c(\min_{y\in\Omega(x)}(\frac{I^C(y)}{A^C})) = t(x)\min_c(\min_{y\in\Omega(x)}(\frac{J^C(y)}{A^C})) + (1-t(x)) \tag{8}$$

As A^c is always positive, this leads to $A^c > 0$, then we have[11]:

$$t(x) = 1 - \min_c(\min_{y\in\Omega(x)}(\frac{I^C(y)}{A^C})) \tag{9}$$

So, we can gain region object transmission from image J，then calculate atmospheric visibility. We pick the top 0.1% brightest pixels in the dark channel [8]. Among these pixels, the pixels with highest intensity in the input mage J is selected as the atmospheric light.

It is noteworthy that if the image contains large brightness higher sky area, due to we can not find pixel intensity close to zero in the dark channel, the dark channel prior is not established in this area. J.G. Jiang et al estimated transmission of the bright area by using the tolerance mechanism solely in order to adjust the transmission of the bright areas[12]. But for the proposed algorithm, as the selection of the target area is the dark objects or surfaces, rather than the bright objects or surfaces, the transmission of this dark objects or surfaces is changeless no matter the tolerance mechanism is used or not.

2.3 The selection of target area

The selection of target area in the image needs to according to different situations in this paper. Generally, for obtaining accurate results of choosing target area, two steps judgment should be done: (1) selecting dark objects or surfaces as the target area; (2) judging if there is a bright single channel in target areas. The dark objects or surfaces mean that a channel of the target area will have very low intensity value, which accord with the application conditions of using the dark channel prior. Exiting a bright single channel in target areas means that position of the target area is far, and the baseline is long, so that the range of visibility observable is far. Fig. 1 shows the selection process of target area：

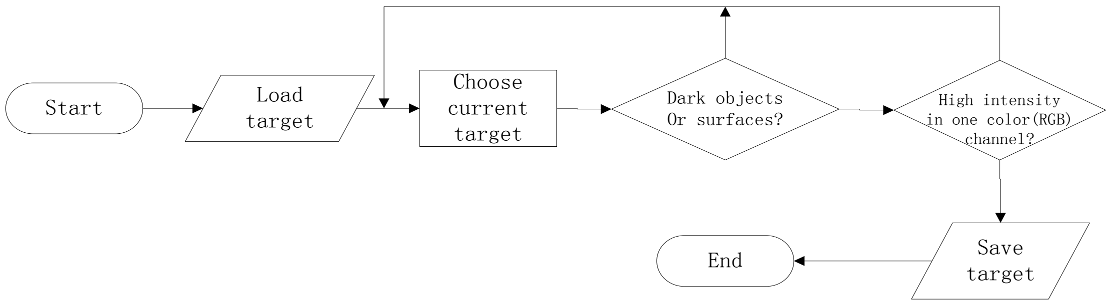

Fig. 1: Flow chart for the selection of target area

Those who need a specification is, condition 2 is not established when visibility is poor. Either channel intensity may be not very high in the situation of poor visibility. And this means that the current visibility range is low. In this case, if we can not find the target area which can satisfy the two conditions at the same time, we abandon condition 2, and only judge condition 1 to discover the optimal target object.

3. Data Processing and A Short Time Experiment

In the experiment, we capture images by using CCD digital camera on the roof of Hefei Institute of Physical Science. The experimental results are compared with the forward scatter visibility meter (FD12). In order to ensure the accuracy of the experiment, CCD digital camera and forward scatter visibility meter keep consistent direction and angle of view in the experiment. For example, the image was taken at 9:00 am on November 6, 2012. Fig. 2 show an original image. The yellow area is the target area, and the area in the red box is enlarged the target details. Fig. 3 show the estimated transmission map from an input image. The experimental procedure as follows: capturing the image by the CCD digital camera, choosing a target area, estimating transmission of the target area, and then calculating the visibility value.

Fig. 2: Original image

Fig. 3: Estimated transmission map

For Fig. 2, we gain visibility value is 1538.2 meters. Visibility value of the forward scatter visibility meter is 1604.8 meters, and the error is 4.15%.

We have collected data from 8:30 am to 11:30 am on November 2, 2012. The weather was clear turning to cloudy with the temperature was 17-23^{o}C, and the wind was east 3-4 level. The lens of digital camera toward the southwest, and resolution was set to 740*480. Every five minutes carried out an information collection and each minute got ten images. We treated average results of the ten images processing value as the visibility value. Fig. 4 shows the comparison of visibility between the proposed algorithm and the forward scatter visibility meter. X-axis represents time while the Y-axis represents the visibility values in meters. The dotted line represents the results of the forward scatter visibility meter, and the solid line shows the results of the proposedthe proposed algorithm.

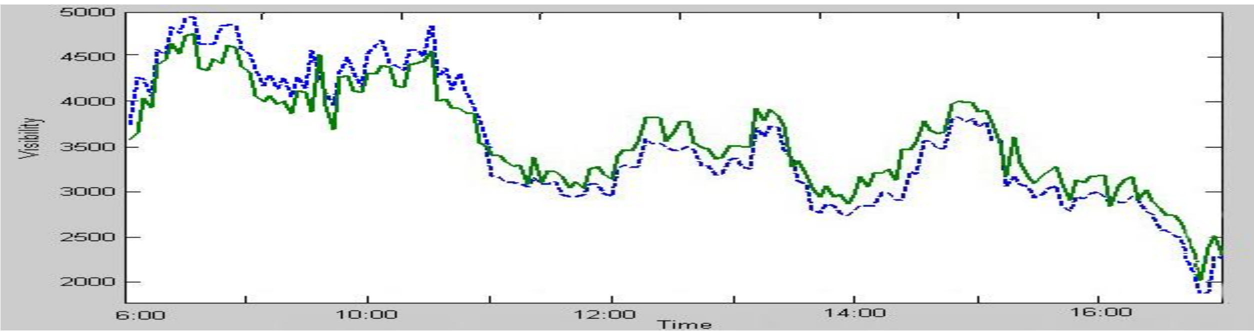

Fig. 4: The comparison of visibility on Nov.2

In Fig. 4, the negative error value indicates that the visibility value of the proposed algorithm is larger than the results of the forward scatter visibility meter. From the experimental results, we can know the correlation coefficient between the proposed algorithm and the results of the forward scatter visibility meter. Their average standard relative error is 6.13%, and the biggest relative error is 8.56%. The correlation coefficient of two results is 0.8124, so that Our results and forward scatter visibility meter's results have a good correlation. Relative RMSE of two results is 6.69%, and that means the difference of distribution between two result is small.

4. Long Time Experiment In the Natural

In order to verify the effect of the proposed algorithm further, a long time experiment was done from November 24 to November 26 in Beijing. The site we chosen is in the south of Beijing with very few human building, and the comparison of visibility between the proposed algorithm and the forward scatter visibility meter is shown in Fig. 5, Fig. 6, Fig. 7.

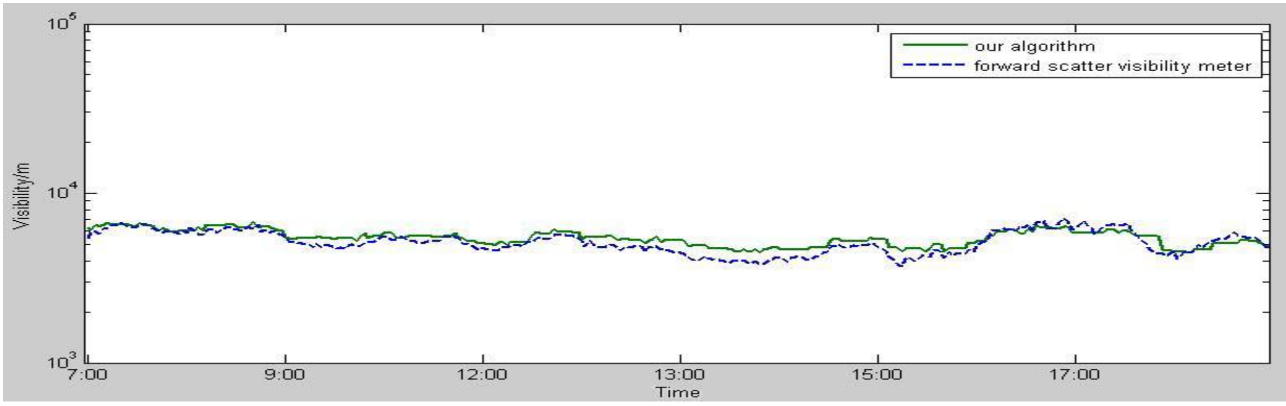

Fig. 4: The comparison of visibility on Nov.24

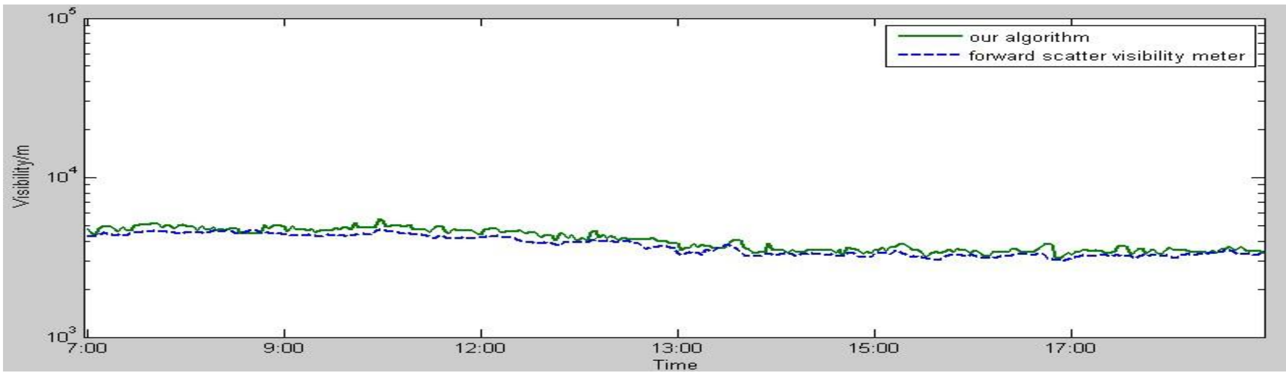

Fig. 4: The comparison of visibility on Nov.25

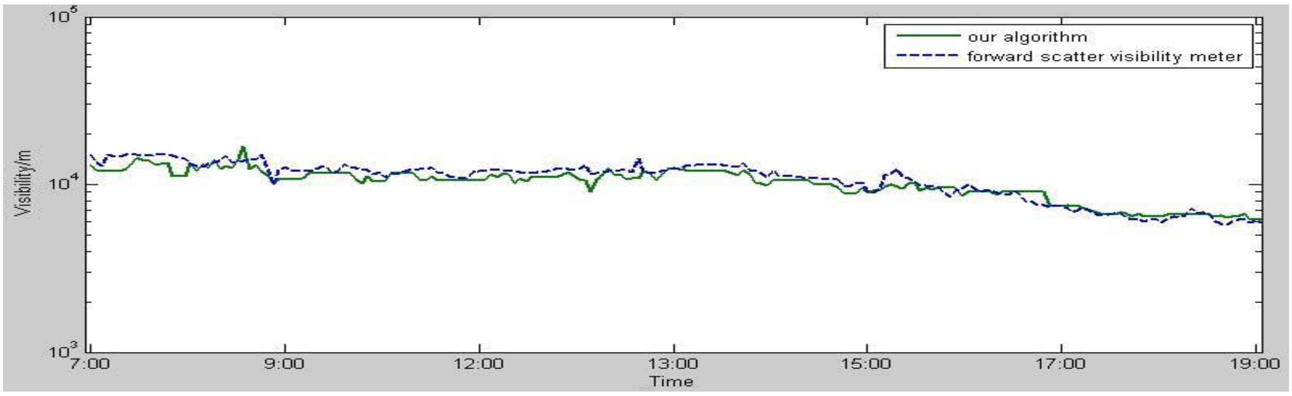

Fig. 4: The comparison of visibility on Nov.26

The correlation coefficient and relative RMSE between the proposed algorithm and the forward scatter visibility meter is shown in Table 1:

Table 1 The correlation coefficient and relative RMSE

Date	Correlation Coefficient	Relative RMSE
2012.12.24	0.7942	7.62%
2012.12.25	0.8120	7.93%
2012.12.26	0.8432	8.18%

According to the experimental results we can know, we known the correlation coefficient the proposed algorithm and the forward scatter visibility meter is less than 0.85, and the difference of distribution between two results is less than 8.2%. Therefore the distribution of the proposed algorithm has good consistency with forward projection instrument results. Cause the error range parameter of FD12 is 10%, so the maximum error of the proposed algorithm is less than 20% which satisfied the error provisions of WMO on the meteorological visibility instrument[13,14], and It proves that the proposed algorithm is feasible. The data processing of this experiment is the same as last experiment.

4. Conclusion and Future Work

A new daytime visibility algorithm based on color CCD digital camera is proposed in this paper. The proposed algorithm can deal natural images directly to gain visibility value, without artificial object and low cost. The proposed algorithm eliminates the error which caused by the no-blackbody characteristics of the target, and obtains good experimental results in visibility observation range 1500-3000m. It’s worth to discuss some questions for this algorithm:

1.The atmospheric light we chosen can not accurately reflect the really atmospheric light. How to gain the accurate atmospheric light from the color image is a problem which is worth studying.

2. In acquiring images with a CCD camera, light levels and sensor temperature are major factors affecting the amount of noise in the resulting image[15]. We further research work is how to de-noise for a more accurate visibility value.

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