Urban atmospheric visibility measurement in the different cut-off frequencies

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***Abstract*—Urban atmospheric visibility is closely associated with our daily life, such as navigation and human health. In the traditional, visibility is measured by professionally trained people. Meters and technologies were proposed to replace the traditional measurement. Digital image processing technology is one of schemes to measuring visibility. Since the good visibility contains more detail data, the high pass filters were used to analyzed and the high frequency information. The cut-off frequency is the key parameter of the performance. In this paper, we use two high pass filters, ideal high-pass filter and homomorphic filter, for visibility monitoring. In the experiments, synthetic and real images are used to show the comparison of the performances between different cut-off frequencies.**

***Keywords*—Atmospheric visibility, digital image processing, high-pass filter, cut-off frequency.**

1. INTRODUCTION

The level of atmospheric visibility affects our quality of life. Low visibility is a negative factor for aviation, sailing, the safety of traffic and human health, causing serious damages. Apart from the natural causes such as rainfall, fog and sand storm, other causes of low visibility include huge amount of particulate matter (PM) and harmful gases [1, 2, 3, 4].

Visibility is the longest distance at which the outline of an object can be recognized [5]. Human eyes used to be the major means of measurement for the atmospheric visibility. Individual subjective experiences produce adverse effects on such measurement with discrepancies between measurements by different people. Some researchers propose Ideal high-pass filter allows all the frequencies outside of a circle with radius D_0 (cut-off frequency) to pass while filtering all the information with such radius with the center as that in the image. If cut-off frequency exceeds a certain range, the accuracy of the calculation rapidly declines [11], adversely affecting the result of the experiments. to measure visibility with digital image processing[6, 7] by using instruments such as PWD22 [8]、VAISALA and telephotometer [9]. Despite the objectivity and accuracy of such measurement, high costs of the equipments and maintenance have kept many researchers from using them.

Digital image processing makes images clearer and more accurate through computers. This method is widely used in the medical field, agriculture, the examination of production line, air quality, matching fingerprints and recognition of vehicle plates. It can also be applied to analyze atmospheric visibility by images of different time domain and frequencies [10, 11, 12].

Some researchers propose to cut off high frequency information from the images before calculating visibility index value by using such information. Sobel mask filter [13], scalable filter, ideal high-pass filter, homomorphic filter and Haar can be employed to enhance marginal information. Filtered images are then the basis for calculating visibility index value [14] before being compared with the actual determined visibility index value. Some other researchers analyze the contrast between the object and the background of images [15], or discerning visibility from linearity in the digital information from the images [16].

Ideal high-pass filter allows all the frequencies outside of a circle with radius D_0 (cut-off frequency) to pass while filtering all the information with such radius with the center as that in the image. If cut-off frequency exceeds a certain range, the accuracy of the calculation rapidly declines [11], adversely affecting the result of the experiments.

This research studies the relationship between the visibility index value calculated from the filtered information and that from professionally trained observers. Linear regression is employed for such analysis. Linear regression is an approach with which one studies the relationship between the least square (R^2) and one or multiple independent and dependent variables. The closer R^2 is to the value 1, the relationship between the two is better than when R^2 value approaches 0. Therefore, one can determine the optimal cut-off frequency through R^2.

In this paper, the optimal cut-off frequency is determined by using ideal high-pass filter and homomorphic filter. The aim is to produce better visibility index value consistent with the actual visibility.

2. QUESTION AND METHODOLOGY

Through image simulation, visibility index values are determined by ideal high-pass filter with different cut-off frequencies. The question is related to the simulated images. Fig.1 and Fig.2 are the simulated images in this research. Fig. 1 is a clear image of a building with strong contrast. Fig.2 is an image with weaker contrast. The visibility index values for these figures should be similar because the buildings in these images are easily recognizable for the human eye. Because we believe that different cut-off frequencies will affect the visibility index value, we use different cut-off frequencies (10 and 60) to calculate the index visibility value of these two images.

Whether the visibility index values of the images are similar, we use the following formula to calculate similarity [11], with definition of

$$similarity = \frac{2v_1v_2}{v_1^2v_2^2} \times 100\% \qquad (1)$$

Fig. 1 and Fig. 2, Fig. 3(a) and Fig. 3(b) are shown the produced through the ideal high-pass filter with cut-off frequency of 10. Fig. 1 and Fig. 2, Fig. 3(c) and Fig. 3(d) are shown the produced through the ideal high-pass filter with cut-off frequency of 60. The calcalation of visibility index values and their similarities are listed in TABLE 1.

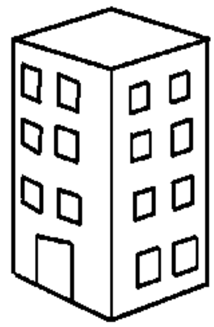


Fig. 1 Building with stronger contrast

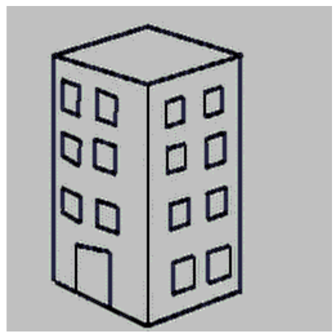
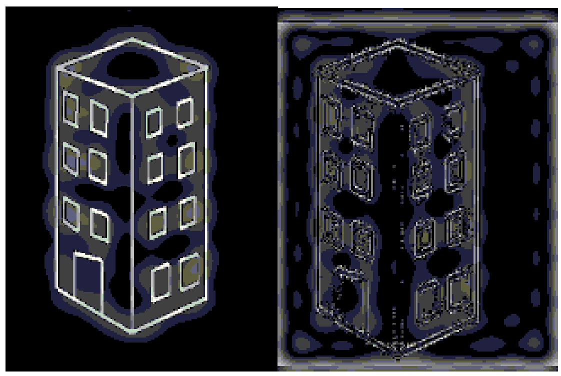
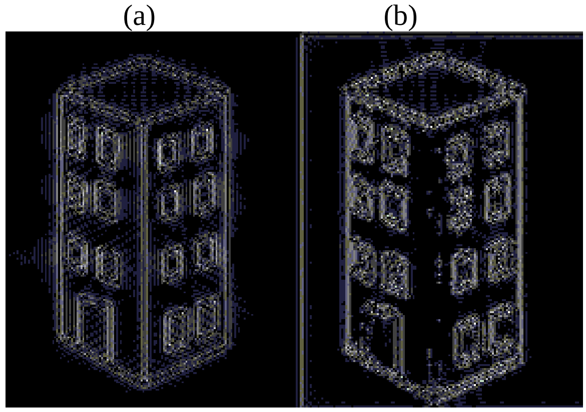


Fig. 2 Building with weaker contrast



(a) (b)



(c) (d)

Fig. 3 Images from the ideal high-pass filter:
(a) From Fig. 1, with cut-off frequency of 10;
(b) From Fig. 2, with cut-off frequency of 10;
(c) From Fig. 1, with cut-off frequency of 60；
(d) From Fig. 2, with cut-off frequency of 60.

TABLE 1 The comparison of visibility index values calculated from different cut-off frequencies**.**

cut-off frequency	10	60
Fig. 1	9.3287	4.2192
Fig. 2.	11.7123	4.5424
similarity	97.4659	99.7283

As a result, cut-off frequencies at 10 and 60 produce different visibility index values. In other words, cut-off frequencies have effects on the result when calculating visibility index value through high-pass filter.

2.1. Ideal high-pass filters

Spatial filter is about changing the intensity of pixels and correcting distribution of illumination of images. An image is composed of different frequencies from high to low. High frequency has larger illumination changes while low frequency has smaller illumination changes. High-pass filtering intensifies high frequency information while weakens the low frequency part. Low-pass filtering does just the opposite, and a fuzzier image is usually generated. High-frequency filter, in contrast, intensifies the high-frequency information of images.

The following equation is discrete Fourier transformation of $f(x,y)$ of the image size is MxN

$$F(u,v)=\frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y)e^{-j2\pi(ux/M+vy/N)} \quad (2)$$

$f(x,y)$ is the image, and the size of the image after Fourier transformation is MxN.

H(u,v) of ideal high-pass filtering is defined as

$$H(u,v)=\begin{cases}0 & if D(\text{u, v}) \le D_0\\ 1 & if D(\text{u, v}) > D_0\end{cases}$$

(3)

The u and v are horizontal and vertical pixel location of function H. D_0 is the parameter of the filter, and it is also referred to as cut-off frequency. One can use D_0 to determine the scope of cut-off high frequency. During filtering, all frequencies within the scope of D_0 will decay, while all frequencies outside the scope of D_0will pass through. Lastly, filtered images went through Fourier transformation and became new images. Visibility index can be obtained from the average of gray scale values of the filtered image.

2.2. Homomorphic filters

To resolve the problem of non-uniform illumination of images, one has to increase the contrast, especially for those darker sections of images. For photographed images, some parts may be brighter, which can make the shadows look darker. In this case, one has to reduce illumination but partially increase the contrast.

The brightness of an object of an image consists of two coefficients; one is illumination from light sources on the object and the other is illumination reflected by the object itself. For an image, if $f(x,y)$ is the brightness of pixel (x,y) of the image, Therefore, an image can be expressed as the illumination and the product of the reflectance.

$$f(x,y)=i(x,y)r(x,y) \quad (4)$$

Then $i(x,y)$ is illumination, $r(x,y)$ is reflectance. Homomorphic filtering can change the intensity of illumination and reflectance, and images from homomorphic filtering will be clearer than non-filtered ones. High frequency is the one with greater changes at the edge of an object or in the grayscale, while low frequency is areas that are smoother.

Homomorphic filter parameters r_H and r_L control the filtering effect of the high frequency and low frequency. Homomorphic filter function is defined as

$$H(u,v)=(r_H-r_L)[1-e^{-[D^2(u,v)/D_0^2]}]+r_L$$

(5)

After homomorphic filtering, the information will be processed by Gaussian high-pass filtering, and the defined as

$$H(u,v)=1-e^{-D^2(u,v)/2D_0^2}$$

(6)

The Gaussian high pass filtered image is further processed by Fourier transformation to obtain the average of grayscale values of the image. This average can be used to calculate the visibility index.

3. EXPERIMENTS

Photographed images went through high-pass filtering and homomorphic filtering for calculating the visibility index. Buildings were photographed from the same location, and their visibility might be affected by shadows produced by sunlight. Nevertheless, the investigators considered that these shadows are unlikely to affect visibility.

We use the images is in Reference [11] the database A. At the end, a total of 172 images were obtained. Every time photographing took place, a professionally-trained observer was presented too to determine atmospheric visibility by naked eyes and to record the results.

In experiments which are not optimized, The R^2 values are 0.7718 and 0.8584 for ideal high-pass filter and homomorphic filter, respectively. With optimized statistics from the experiment, the R^2 values are 0.8426 and 0.8612 for ideal high-pass filter and homomorphic filter, respectively. This result is indicated in Fig. 4 and Fig. 5.

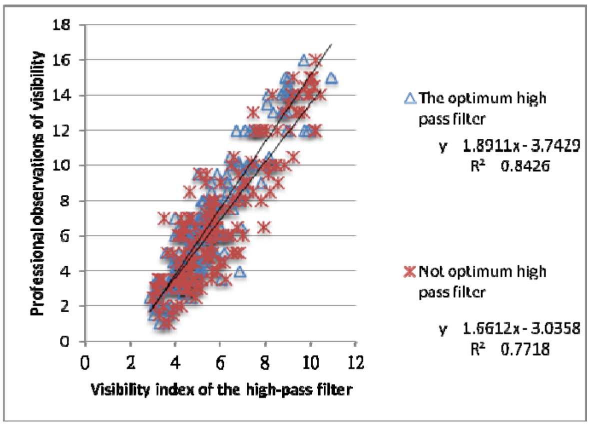


Fig. 4 Comparison of idea high-pass filtering

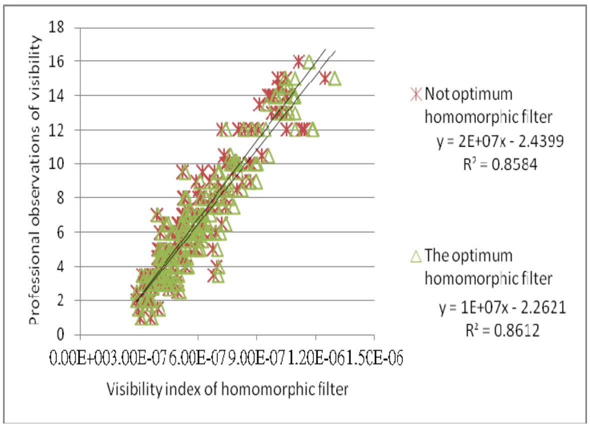


Fig. 5 Comparison of homomorphic filtering

In order to understand the images under the parameter from homomorphic filter, we also conduct experiments with different parameters (r_H, r_L) and record the R^2 as a result. As shown in Fig. 6, when r_H =1.9 and r_L =0.9, the result for the visibility index enjoys a better linearity relationship with the values from observation.

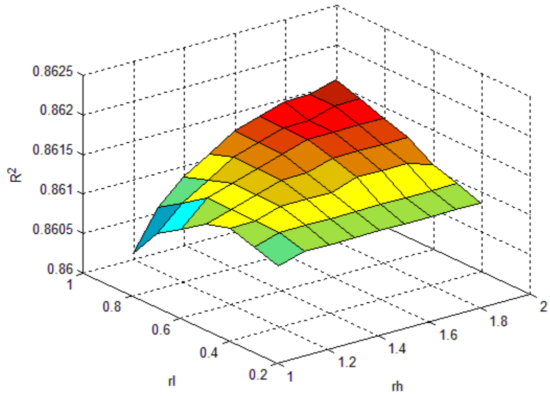


Fig.6 Comparison homomorphic filtering between r_H and r_L

4. CONCLUSIONS

The atmospheric visibility is an important indicator or factor for observing the environment and the safety of traffic. Past research has proposed to determine visibility index value through digital image processing, but has not studied the effects of cut-off frequencies on the visibility index value of images.

Ideal high-pass filter and homomorphic filter are used in this present analysis while calculating the visibility index value based on the differences between pixels. In the experiment, changing the parameter of homomorphic filter does not substantially affect the R^2 values while it produces better R^2 values than those in the past research. Finding the optimal cut-off frequency is the important aim of this research. In the simulated experiment, different cut-off frequencies influence the similarities between images. To conclude, cut-off frequency influences the visibility index values. Thus, the ideal high-pass filter and homomorphic filter produce better results with optimal cut-off frequencies.

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