Assessment of Visibility on Roads under Snow Conditions using Digital Images

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ABSTRACT

It is important to adequately assess visibility on roads during severe snowstorm, so that this information may be provided to motorists and road administrators. This study examines basic methods of assessing poor visibility by using images from a road monitoring camera. An experiment was performed during 30 days in 2001, in the suburbs of Sapporo City, Hokkaido, Japan. Image, illuminance and visibility in snowstorm were recorded at two-minute intervals. Under low visibility, there was little contrast within each image from the monitoring camera, and linear elements in the image tended not to be visible. We extracted the gray levels of the images in high visibility and in low visibility. First, we examined the pixel contrast, in the image, of a target that was selected on a road. Second, we examined the characteristics of the frequencies of extracted gray levels (power spectra) after two-dimensional Fourier transform. The images in clear conditions contained frequency components from low to high. The averages of pixel contrast and power spectra were calculated and compared with the visibility recorded by visibility meter. A close correlation was observed between the average of power spectra and the visibility range, and between the pixel contrast and the average of power spectra. In snowstorms, pixel contrast and average of power spectra decreased as the visibility decreased. The results suggest that assessment of snowstorm-induced low visibility will be enabled by the development of an algorithm that uses pixel contrast and the characteristics of power spectrum identified from images taken by a road monitoring camera.

Key words: Image, Snowstorm in the daytime, Visibility, Luminance, Pixel Contrast, Power Spectra

INTRODUCTION

Motorists in snowy regions encounter hazardous visibility conditions induced by snowstorms. Highways should be equipped with adequate cues to road geometry and should provide drivers with hazard information. Snowstorm is a factor in multi-vehicular collisions, especially those in daytime. For example, a 186-vehicle pileup, the biggest ever in Hokkaido, occurred during a snowstorm at 08:40 on March 15, 1993. Many of the drivers claimed that visibility at the time of the accident was almost zero and that they could not see the illuminated delineators set at 50-m intervals along the center of the expressway. Ishimoto et al. (1,2) indicated that the degree of visibility can change very suddenly during snowstorm, depending on time and place, which suggests that it is very difficult to predict visibility. The ideal solution would be to install visibility sensors at frequent intervals along the road to evaluate visibility in real time at any location. However, cost considerations make this unfeasible. Instead, it would be cost-efficient to use the many ITV cameras already installed along roads, assuming that their digital image data could be analyzed to determine visibility in snowstorms of various intensities.

This study proposes such camera-image-based assessment of road visibility. There are two image-based methods of assessing the visibility on a road (3,4). One is to calculate the pixel contrast of a target in the image. Variation in pixel contrast should correspond with snowstorm-induced visibility fluctuation. The other is to assess the visibility condition using the entire image. There is thought to be a relationship between the variance of luminance value of all images and the visibility. This study proposes two methods of visibility assessment.

Field observation was carried out to develop a new image-based method of assessing visibility on the road during snowstorms. We selected a road section where snowstorm-induced visibility hindrance occurs quite often. Automated observation simultaneously recorded images taken by digital

Table1 Specifications of visibility meter and illuminated meter

Visibility meter
Visibility measuring method : Forward scattering Source : Infrared LED Range : 10～9999ｍ Response time : 5 seconds Output : RS-232C (digital)

Illuminance meter
Receptor : Photo diode (wavelength 850 nm) Range : 0-20,000 lx Analog output : 0-10 VDC

Figure 1 Observation site and recorded image

still camera, illuminance and visibility alongside the highway. The study objectives were these:

To clarify the relationship between the pixel contrast and the visibility range in daytime snowstorm.

To reveal the relationship between the average magnitude of power spectra calculated by Fast Fourier Transform (FFT) and the visibility range as a function of the selected area size.

To show the relationship between the average of power spectra and the pixel contrast during snowstorm.

This study proposes an image-based system of assessing visibility conditions without visibility meter.

MEASUREMENT METHODS

Observation Site

The experiment was conducted on Prefectural Route 112, which runs between the cities of Sapporo and Tobetsu (Figure 1, lower half). The investigated section has 6 straight lanes and is oriented north-south. This section is close to Okadama Airport in suburban Sapporo. Snowstorms often occur at this section in winter as a result of the surrounding open terrain. Thus, traffic control devices are required, to provide visual cues to motorists. Figure 1 (upper half) shows illuminated delineators and pole-mounted road lighting at the center of the road and an overhead illuminated delineator at the shoulder. The overhead delineator, which was developed in Hokkaido, indicates the road edge to the snowplow operator.

Measurement Devices

Observations were carried out between February 18 and April 4, 2001. Unfortunately, snowstorms occurred less frequently than usual. The measurement devices, including a digital still camera (Casio QV-2800UX), an illuminance meter and a visibility meter, were installed on a pole (Figure 2). The camera was about 3.2 meters above the ground. To examine the directional effect of snowstorm, the camera and the illuminance meter were faced northeast. Table 1 shows the specifications of the visibility meter and the illuminance meter. A notebook computer recorded visibility. A data logger recorded illuminance. The camera recorded digital images. These three types of data were recorded independently at two-minute intervals. The three recording systems were synchronized weekly, at the start and end of measurement. All the devices were powered by commercial electric power.

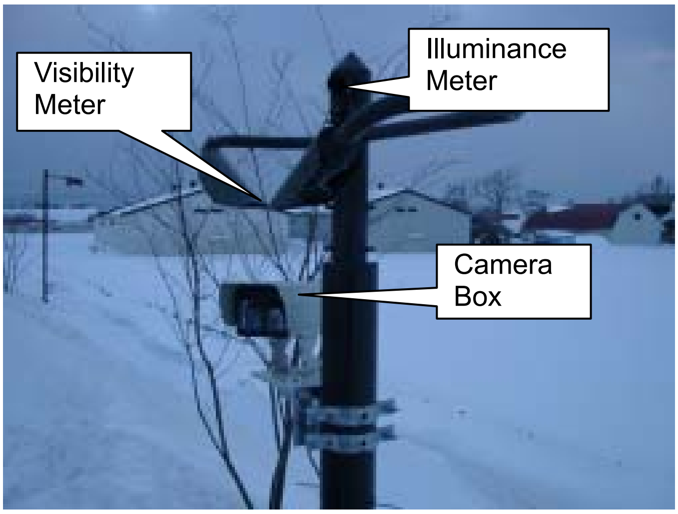


Figure 2 Measurement devices

Figure 3 Location and coordinate value of target and background

Pixel Contrast

Figure 3 shows the locations of target and background in the digital image. These were cut from the digital image as a square area (5 x 5 pixels). The digital luminance of both the target and the background were calculated by averaging the digital luminance values of 25 pixels in each image. In this study, the pixel contrast was obtained by dividing the absolute value of difference in digital luminance between the target and the background by the digital luminance of the target. A photometer can be used to measure luminous contrast of target; however, it is difficult to simultaneously measure the luminance of a target and a background using a photometer. In addition, measurement using a photometer does not allow identification of the target. Okamura, et al. conducted an experimental study to use a CCD (charged-coupled device) instead of a photometer to evaluate the visibility of targets (5). They indicated that it is possible to convert pixel contrast into luminous contrast without reference to exposure value. In this study, pixel contrast of image is used to assess visibility.

Spatial frequency of recorded image

This study proposes using two-dimensional distributions of gray levels of all pixels in the image. Under clear conditions, all objects in the road scene appear clearly in the image taken by camera. Distributions of gray levels vary widely. Under snowy conditions, objects are unclear or are not visible. The distribution of gray levels is uniform. The most common technique to assess the distribution of gray levels in an image is spatial frequency analysis. The gray levels of all pixels in the image are extracted. Two-dimensional Fourier transform is applied to calculate the frequency spectrum of image. Two-dimensional Fourier transform of image was computed using standard Fast Fourier Transform procedure. The image taken under clear conditions contained frequency components from low to high and the power spectra of each frequency indicate large magnitude. Under snowy conditions, the distribution of high frequency components becomes small and reaches zero as the snowstorm intensifies. Also, the magnitude of power spectrum of each frequency is expected to decrease with increase in snowstorm intensity. In this study, the average of power spectra of all frequencies is employed as an index of road visibility. In addition, we calculated the magnitude

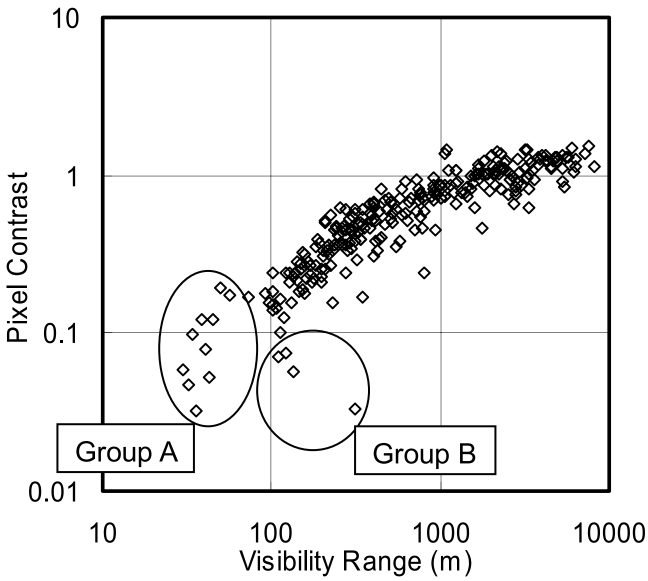


Figure 4 Pixel contrast versus visibility range in the daytime (number of data: 270).

in scaled form as log power spectrum, and then drew a scatter plot to represent this magnitude as gray levels from 0 to 255.

MEASUREMENT RESULTS

Data Analysys

Observations were carried out from February 16 to April 4, 2001. Each record includes date, time, image (800 x 600 pixels) taken by digital still camera, illuminance and visibility. Unfortunately, snowstorms occurred less frequently than usual. February 25 was the only a day when the visibility was less than 100 m in daytime. Thus, the 270 records from 08:00 to 16:58 on February 25 were used for analysis.

Contrast versus visibility range

Figure 4 shows pixel contrast vs. visibility. The pixel contrast does not decrease linearly as the visibility range decreases but instead plots as a convex curve. The rate of decrease of pixel contrast accelerates as the visibility range decreases. This non-linear reduction may be attributable to uneven distribution of snow particles.

When the pixel contrast is less than 0.2, scatter plots seem to fall into two groups: Group A and

Group B (Figure 4). In Group A, visibility ranges are almost the same, but pixel contrasts distribute from 0.03 to 0.2. Photo A and Photo B (Figure 5) are examples of Group A. The visibility in both photos is almost 40 m, but pixel contrast shows large difference. Photo A is an example of an image with low visibility and high pixel contrast. The upper half of photo A seems to have higher visibility than the lower half. Photo B is an example of an image with low visibility and low pixel contrast. Snow particles seem to distribute uniformly throughout the road area. Thus, difference in pixel contrast of the target between the photos could be attributed to difference in visibility conditions within the road area and difference in visibility conditions between the area around the target and the area of the visibility meter. (The visibility meter was at roadside at a height of 3.2 meters.) In contrast, photo C in Figure 5 is an example of Group B. Snow adhered to the face of the target. Thus, the pixel contrast is low except where visibility is not very low. The same phenomenon was observed for snow clouds generated by running trucks.

Power spectra versus visibility range

Two types of image were used to calculate the power spectra of spatial frequency from the digital luminance value of each pixel. One image is 512 x 512 pixels (Figure 6(A)). It shows the entire road section. The other image is 256 x 256 pixels (Figure 6(B)), from which a 512 x 512-pixel box was cut. The 256 x 256-pixel image was a small central part of the 512 x 512-pixel image.

Figure 7 shows the relation of the average of power spectra to visibility range. The average of power spectra decreases almost linearly as the visibility decreases. Figure 7(A) shows scatter plots using images of 512 x 512 pixels, and Figure 7(B) shows scatter plots using those of 256 x 256 pixels. The equation in each graph is a regression model where the visibility range is the dependent variable and the average of power spectra is the independent variable. The slope of the regression line for 256 x 256 pixels is steeper than for 512 x 512 pixels.

Photo A : Visibility 39 m, Pixel contrast 0.121

Photo B: Visibility 32 m, Pixel contrast 0.047

Photo C: Visibility135 m, Pixel contrast 0.057

Figure 5 Two examples in group A of Figure 4 and one example in group B.

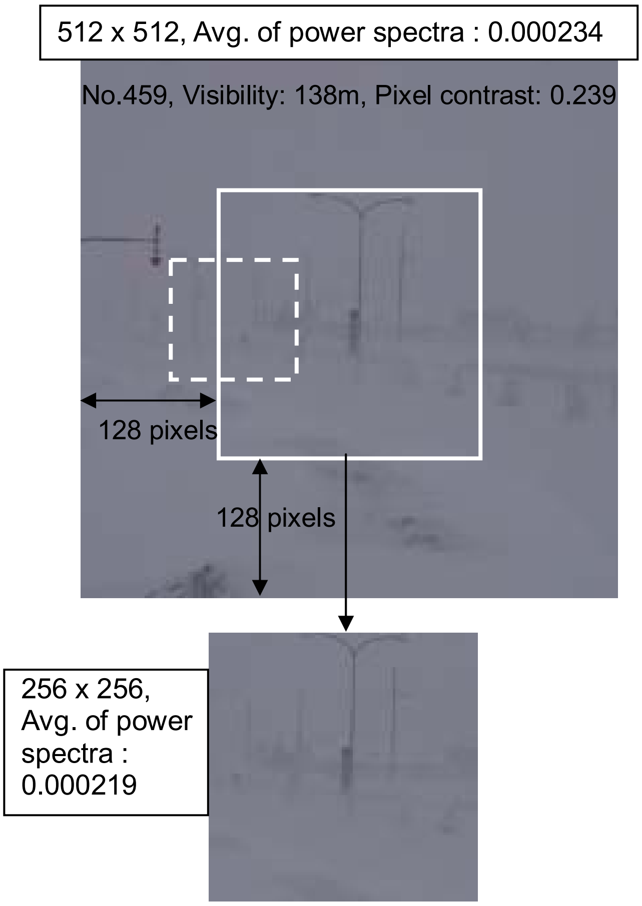


Figure 6 512x512 pixels and 256x256 pixels

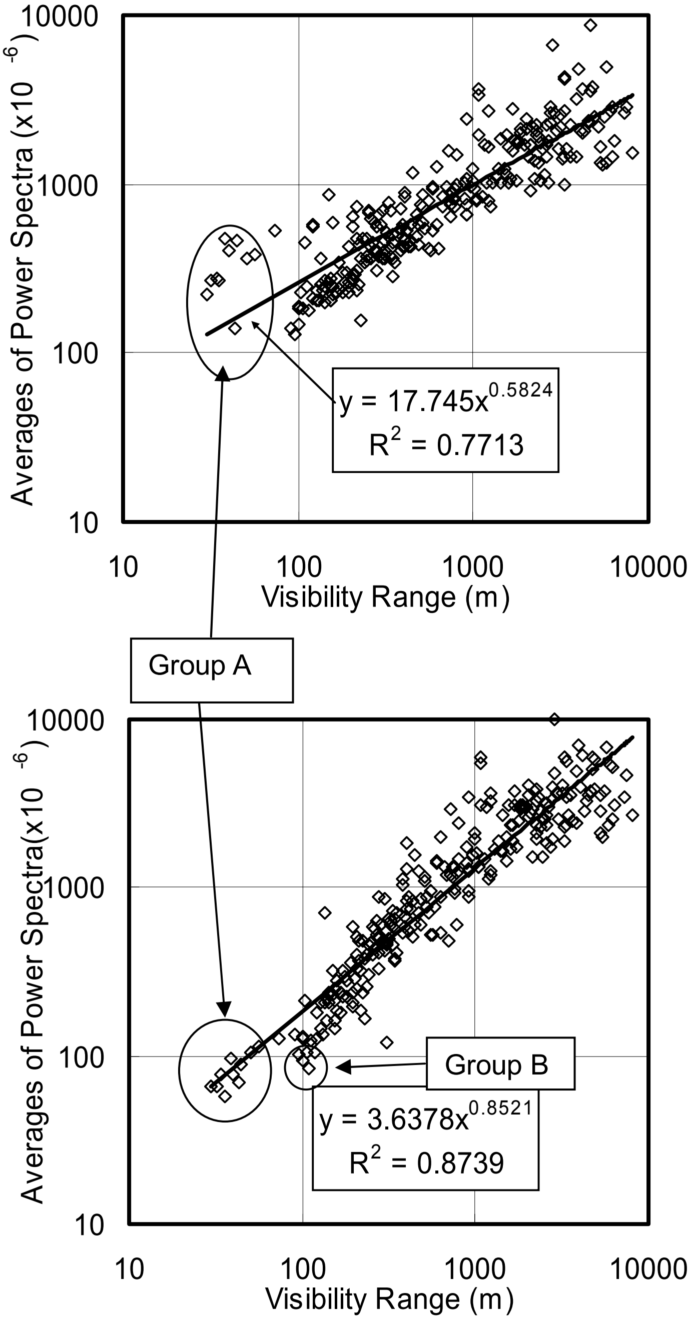


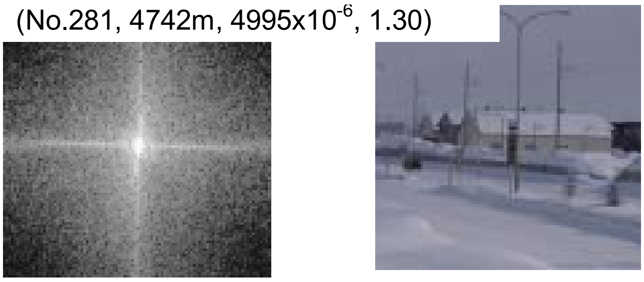
Figure 7 Averages of power spectra versus visibility range (number of data: 270)

Figure 8 shows the original images and the scatter plots of magnitude in scaled form as log power spectra. These images have horizontal and vertical symmetry. The magnitude of power spectra at each frequency is expressed by gray level of each pixel. The magnitude of power spectra increases as the pixel becomes whiter. The horizontal line (x axis) indicates horizontal space frequencies of the gray levels of the original image; the vertical line (y axis) indicates vertical frequencies of the gray levels of the original image. The distance from origin to pixel increases as frequency increases. The photos in Figure 8 show that the area of white pixels decreases as visibility decreases, and the white pixels become darker as visibility range decreases. These results show that the scatter plots of magnitude of power spectra make it easy to identify visibility conditions.

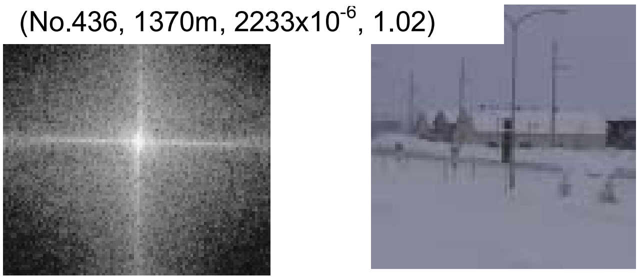
In Figure 7(A), some data (Group A) are plotted above the regression line when the visibility range is less than 100 m. Averages of power spectra range from 300 to 500, excepts where visibility is roughly 40 m. These data are close to the regression line in Figure 7(B). However, Group B in Figure 7(B) is not close to the regression line.

In Figure 9, photo AL (512 x 512 pixels) and photo AS (256 x 256 pixels) are examples of Group A, and photo BL (512 x 512 pixels) and photo BS (256 x 256 pixels) are examples of Group B. In photo AL, the periphery of the image (i.e., the area close to the camera) seems clear. The center of the image (i.e., the lane area) seems barely visible.

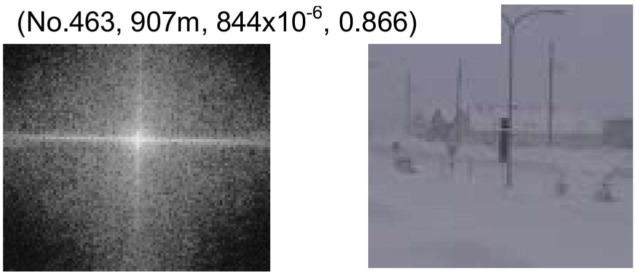
(No.281, 4742m, 4995×10^{-6}, 1.30)



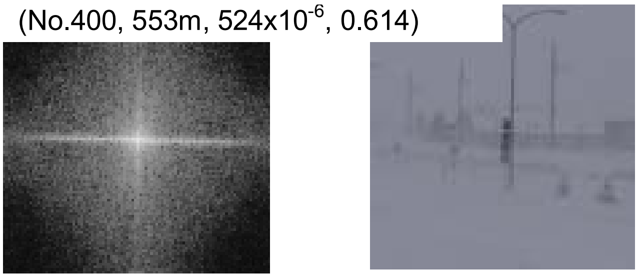
(No.436, 1370m, 2233×10^{-6}, 1.02)



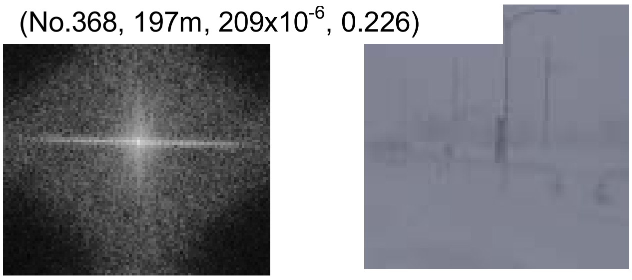
(No.463, 907m, 844×10^{-6}, 0.866)



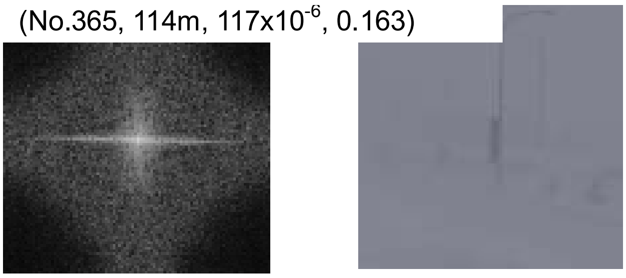
(No.400, 553m, 524×10^{-6}, 0.614)



(No.368, 197m, 209×10^{-6}, 0.226)



(No.365, 114m, 117×10^{-6}, 0.163)



(Photo number, Visibility range, Avg. of power spectra, Pixel contrast)

Figure 8 Distribution of power spectra and it's original image.

Group A : uneven blowing snow