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DEVELOPING A NEW METHOD TO ASSESS POOR VISIBILITY LEVEL ON ROADS BY DIGITAL IMAGES

Toru HAGIWARA
Associate Professor
Graduate School of Engineering
Hokkaido University
North 13 West 8, Kita-ku, Sapporo,
060-8628 Japan
TEL/FAX: +81-11-706-6214
E-mail: hagiwara@eng.hokudai.ac.jp

Yasuhito KANEDA
Head Manager
Hokkaido Development Engineering Center
Minami 1 Higashi 2, Chuo-ku, Sapporo,
060-0051 Japan
TEL: +81-11-271-3028
FAX: +81-11-271-5115
E-mail: kaneda@decnet.or.jp

Yuji OTA
Head Manager
Docon CO.,Ltd., Consulting Engineers.
Atsubetsu-chuo 1-5-4-1, Atsubetsu-ku,
Sapporo, 004-8585 Japan
TEL: +81-11-801-1520
FAX: +81-11-801-1521
E-mail: yo782@docon.jp

Kiyoshi KIZAKA
Researcher
Technology Research Laboratory, Sekisui Jushi Corporation
Kagami 731-1, Ryuo, Shiga,
520-2596, JAPAN
TEL: +81-1267-3-2671
FAX: +81-1267-3-2666
E-mail: kizakak@sekisuijushi.co.jp

Abstract: This study proposes a new index for estimating visibility under poor-visibility conditions by using digital images from a road monitoring camera. The method allows representation of the amount of visual information based on human spatial frequency characteristics. A laboratory experiment was performed in 2002 under artificial fog. We examined the weighted intensity of power spectra (WIPS) to determine its applicability as a visibility assessment value. The magnitude of WIPS represented the difference in spatial frequencies within the image based on human contrast sensitivity function. WIPS was calculated from the following image-processing procedure. As an initial step, a box measuring 128 × 128 pixels was cut from the original image. The spatial frequency of the cutout image was calculated using two-dimensional Fourier transform, and the power spectrum of the cutout image was calculated. We totaled the WIPS at five spatial frequencies (cycles per degree, cpd): 1.5 cpd, 3 cpd, 6 cpd, 12 cpd and 18 cpd. WIPS were compared with the subjective visibility assessment values (SVAV) given by test subjects. There was a clear relationship between WIPS and total SVAV: WIPS increased as total SVAV increased. These results suggest that WIPS might be an appropriate index for estimating visibility using digital images.

Key Words: Visibility under Hazardous Condition, Image Processing, Power Spectrum, Human Contrast Sensitivity

1. INTRODUCTION

Normally, a driver gains knowledge of the road alignment through the configuration of markings or the landscape ahead. Hazardous visibility conditions caused by fog, snow and the like can blind a driver to such directional cues. To maintain traffic flow, countermeasures for hazardous visibility conditions are required, one of which is the provision of accurate visibility information to the driver and the highway administrator. 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. It would be more cost-efficient to use the many industrial television (ITV) cameras already installed along roads (Figure 1).
The visibility range measured by visibility meter only expresses the subjective visibility of the target during nighttime fog, and not during daytime fog. Such a meter accurately gives fog density, but there are some cases in which it cannot give visibility. For example, under very bright conditions, the target is very difficult to see even when the visual range is not very low. Hagiwara et al. clarified how illuminance of the environment affects the visibility of delineators in fog (1,2). Based on field observations, they found that the visibility of the target during daytime fog depends on both the visual range and the illuminance of the environment. The visual range and the illuminance of the environment during fog are major determinants in the design of luminous delineators that are effective in fog.

Chiba et al. proposed a method to estimate the visibility range during blowing snow according to digital images recorded by roadside ITV camera in winter (3). They tested the relationship between the visibility range measured by visibility meter and the magnitude of standard deviation in luminous intensity of digital images during 10 minutes. The results indicated that it is possible to use the standard deviation of luminous intensity instead of the visibility meter. Kwon proposed the Motorist's Relative Visibility Index (MRVI), which uses digital images recorded by video camera instead of using visibility meter (4). MRVI is based on the visual perception of motorists. MRVI represents the effective visual information of the road image. However, these indexes did not directly consider human visual sensitivity. Thus, it is not certain whether standard deviations and MRVI indicate the subjective visibility of the target.

This study proposes such an estimation method of road visibility using digital camera images. We examined the weighted intensity of power spectra (WIPS) in terms of its applicability as a visibility assessment value. The magnitude of WIPS represented the difference in spatial frequencies within the image based on human contrast sensitivity function. An experiment was carried out to propose a new image-based method of assessing visibility on the road during fog. We used a laboratory where artificial fog can be generated on the scale of a real road. A digital still camera captured images, and a personal computer simultaneously recorded illuminance and transmissivity under fog. The subjects assessed the visibility of the target as quickly as possible, using their foveal vision. The study objectives were these:

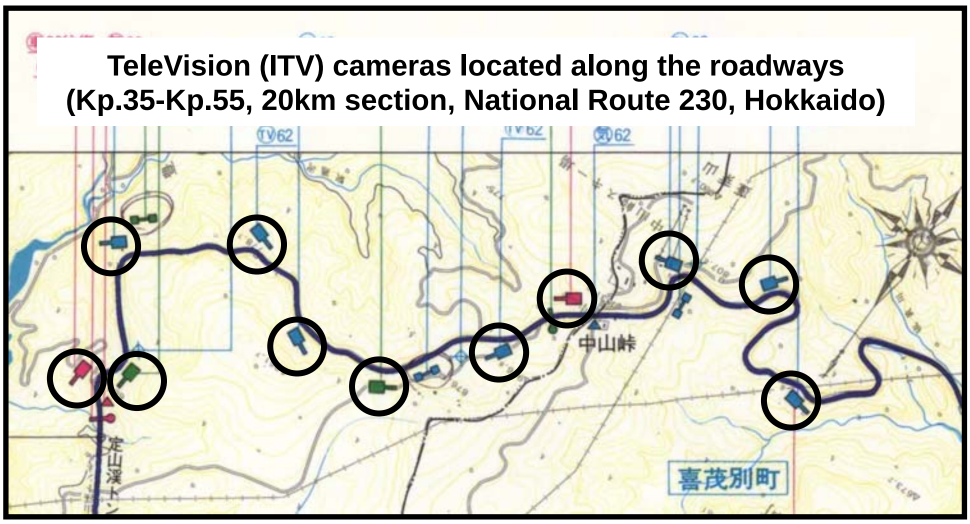


Figure 1. Industrial Television Cameras Installed along Roads.

a) To develop an image-based visibility assessment method and to clarify the relationship between subjective visibility assessment value and the magnitude of WIPS under foggy condition.

b) To propose a system that can provide visibility information to the driver and the highway administrator using digital images recorded by the roadside ITV cameras shown in Figure 1.

2. MEASUREMENT METHODS

2.1 Observation site and subjects

The experiment was conducted in a laboratory of the National Institute for Land and Infrastructure Management in Tsukuba, Japan. The laboratory was selected mainly because it allows comparison between subjective assessment (by test subjects) and an objective index. It was carried out from December 8 to 12, 2002. The laboratory contains a full-scale test road 200 m long, 10 m wide, and 10 m high (Figure 2). The road runs through a transparent tunnel. On the ceiling, 40 large vents deliver artificially generated clouds of fog and 1,000 nozzles generate water droplets that are dispersed by blower. The visual range of the test road can be set between 20 m and 200 m by controlling the steam generating system and water nozzles. One woman and seven men, all in their twenties, participated as test subjects. All were students at the University of Tsukuba. All correctly identified the orientations of all Landolt circles (Figure 3) under clear conditions.

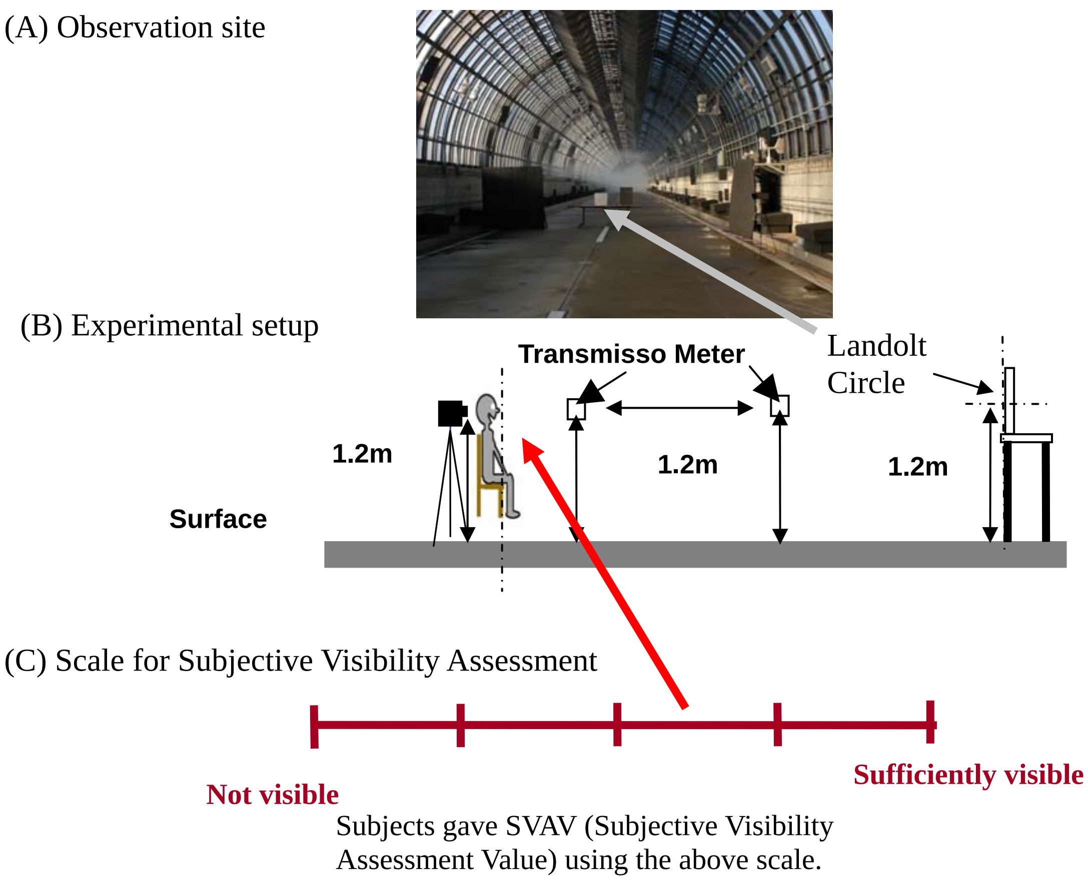
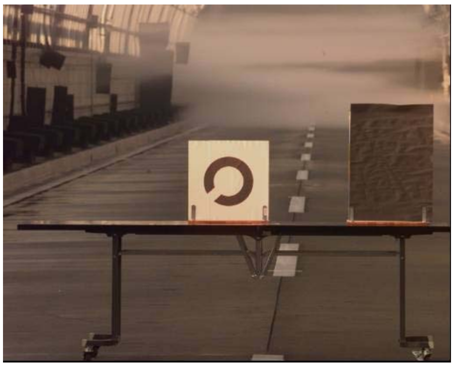


Figure 2. Observation Site, and Scale for Measuring Subjective Visibility Assessment.

(A) Before Fog



(B) During Fog

	T1	T2	T3
Average measured contrast	8.06	1.67	0.864
Size 1 (d=0.03m) (Visual Acuity : 1.0)			
Size 2 (d=0.0375m) (Visual Acuity: 0.8)			
Size 3 (d=0.05m) (Visual Acuity: 0.6)			
Size 4 (d=0.075m) (Visual Acuity: 0.4)			
Size 5 (d=0.107m) (Visual Acuity: 0.28)			
Size 6 (d=0.15m) (Visual Acuity: 0.2)			
Size 7 (d=0.375m) (Visual Acuity: 0.08)			

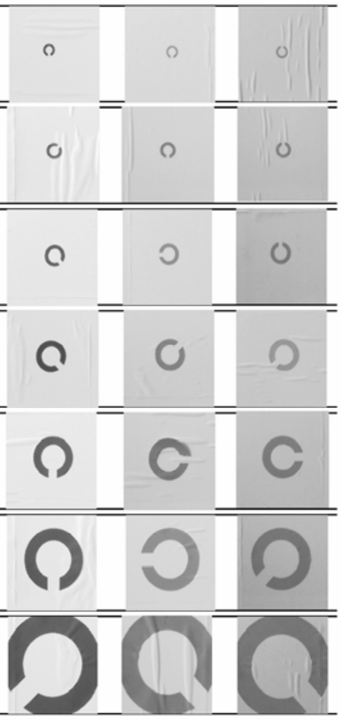


Figure 3. The 21 Landolt Circles used.

2.2 Targets

Twenty-one boards were prepared as targets (Figure 3), each with a different Landolt circle. Seven circle sizes (visual acuity = 0.08, 0.2, 0.28, 0.4, 0.6, 0.8, 1.0) were used. In addition, three circle-contrast levels were used: black circle on white background, dark-gray circle on light gray background, and medium-dark-gray circle on light-gray background. White was the color of the original background. These three gray backgrounds and black background were printed on top by a professional print shop. The board was 0.5 m in height and 0.5 m in width. It was set up on a flat desk in the center of the test road. The center of the board was 1.2 m above the road surface, and the observation distance was 20.0 m.

2.3 Measurement devices

Figure 2 shows the locations of measurement devices, the Landolt circles and the test subjects. A digital still camera was set behind the subjects. The digital camera (Canon EOS-DCS3) recorded the still image of the boards (1,268 × 1,012 pixels). A transmissometer was placed diagonally across the measured area. The projector unit and the photometric unit were set 1.2 m above the ground, with a distance of 10 m between them. The illuminance meter (Minolta T10) was located on the left side of the vehicle, and recorded horizontal illuminance. A PCMCIA data acquisition (DAQ) device plugs into the computer. Three input-output lines are connected to the DAQ device. LabVEW 6.0 was employed in developing the measurement system. The operator clicked the start command on the screen. The computer sent a signal to the digital still camera through the DAQ device, then its shutter was released. Also, the measuring system simultaneously recorded illuminance and transmissivity.

2.4 Experimental design and procedure

The dependent variables in this experiment were the subjective visibility assessment values (SVAV) of Landolt circle. The SVAV was scored on the five-rank scale (Figure 2). The major independent variables were circle size and circle-contrast level. The subjects performed 21 assessments in each test. The presentation order of the 21 circles for each test was randomized. The same circle was presented no more than once per test. The duration of exposure to each circle was a few seconds. In addition, the seating order of the subjects was changed each test. Fog density was another independent variable. The fog density was varied as much as possible at each test to collect data under the conditions of wide visual range. The transmissivity at 10 m ranged from 14% to 63%. Each test took about 30 minutes. The subjects were given instructions regarding the experiments and were then asked to perform a practice test. The subjects were seated facing the Landolt circle. They evaluated the SVAV of the circle and judged the orientation of the circle. After instructions, the fog generator started to make artificial fog. The subjects waited until the fog reached the required fog density level. This took almost 20 minutes per test.

2.5 SVAV vs. Transmissivity at 10 m

Figure 4 shows the relationship between the transmissivity at 10 m and SVAV as a function of seven sizes of circle. In Figure 4, the symbol used to represent each data point corresponds to the circle size. The SVAVs shown in Figure 4 are averages of the values reported by the five subjects. The maximum value is 25 (perfect score for the SVAV), and the minimum is 5. There is no clear trend between SVAV and transmissivity at 10 m. The SVAV tends to decrease with transmissivity for each size of circle. As the circle sizes increases, the SVAVs increase. For circles of the same size, the SVAV tends to decrease slightly with circle contrast.

3. DEVELOPMENT AN IMAGE BASED ASSESSMENT METHOD

3.1 Calculation the weighted intensity of power spectra (WIPS)

Under clear conditions, all circles on the board appear clearly in the image taken by camera (Figure 3). Distributions of grayscale intensities within each image vary widely. Under foggy conditions, circles on the board are unclear or are not visible. Distributions of grayscale intensities narrow and finally reach uniformity as the fog becomes denser. The most common techniques for assessing subjective visibility are computing the distribution of grayscale intensities in an image, and determining the contrast of targets in an image. However, these techniques do not directly consider human visual sensitivity. This study proposes weighted intensity of power spectra (WIPS) as an index for visibility assessment.

As a first step, a box measuring 128 × 128 pixels was cut from the original image. Figure 3 shows all 21 of the cutout images under clear conditions. The box size and location were selected for the following reasons: Fast Fourier Transform (FFT) requires a square image whose pixel dimensions are a power of 2, and we maximized showing the circle of size 7. To show as much as possible of the size-7 circle, the size-7 circle was slightly extended beyond the

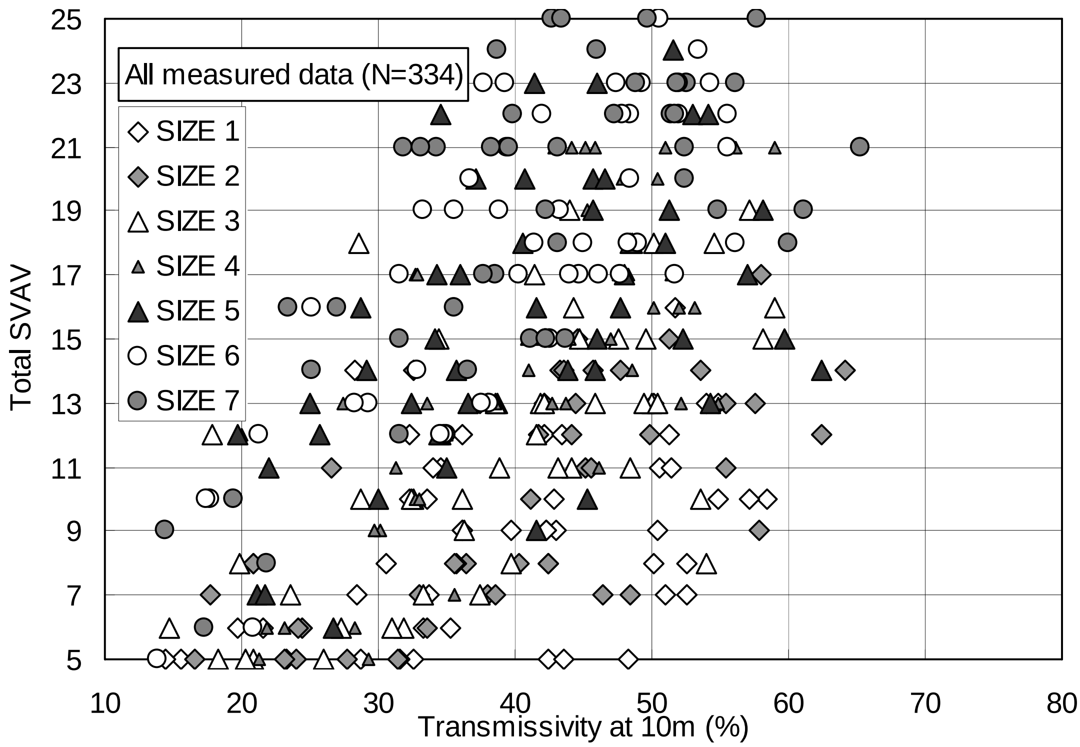


Figure 4. Relationship between Transmissivity at 10 m and SVAI as a Function of Seven Sizes of Circle.

borders of the cutout region. The intensity of each pixel, the "grayscale," was computed from the intensities of red-green-blue (RGB) components recorded in the image, as shown in Equation 1.

$$\begin{aligned} &Intensity\ of\ gray\ scale = 0.299 \times Intensity\ of\ red + 0.587 \times Intensity\ of\ green \\ &+ 0.114 \times Intensity\ of\ blue \end{aligned} \quad (1)$$

Each intensity of three-color components ranged from 0 to 255. The intensity of gray scale was ranged from 0 to 255.

The value of power spectrum means the intensity of grayscale in the cutout image. The unit of spatial frequency is cycles per pixel (cpp). We can translate cpp into cycles per degree (cpd). The horizontal degree of each pixel and the vertical degree of each pixel are calculated by resolution of CCD and visual angle of the digital camera lens. The range of spatial frequency might exceed human sensitivity. The following five spatial frequencies were selected as frequencies that humans can distinguish between each of the cpds by eye: 1.5 cpd, 3 cpd, 6 cpd, 12 cpd and 18 cpd. The vision contrast test system determined theses five spatial frequencies to test the contrast sensitivity of the subject.

WIPS is defined to total the intensity of power spectrum at the five spatial frequencies. Then, the magnitude of WIPS represented the difference in spatial frequencies within the image based on human contrast sensitivity function. Under clear conditions, the power spectra for each spatial frequency are large, and the WIPS is large. Under unclear conditions, these values are small, and the WIPS is small. In addition, these values depend on the circle size and the circle-contrast level. Small circles have small WIPS, and large circles have large WIPS. High-contrast circles have large WIPS, and low-contrast circles have small WIPS.

3.2 WIPS vs. SVAV

WIPS was compared with the subjective visibility assessment values (SVAV) given by the test subjects. Figure 5 shows the relationship between the WIPS and the total SVAV. The diagonal line in Figure 5 is a regression line drawn to include all data. The total SVAV increases as the WIPS increases. The figure shows the distribution of data for all sizes of circle and all circle-contrast levels. The rate of decrease of the WIPS tends to decelerate as the WIPS decreases. Finally, the average of power spectra converges on a constant value, which indicates the existence of a lower limit to the average. These values might have a lower limit of the WIPS in visibility. However, in these cases, the total SVAV were less than 10. These values mean that the target was close to being “not visible.” Thus, it is possible to use estimate the total SVAV according to the WIPS.

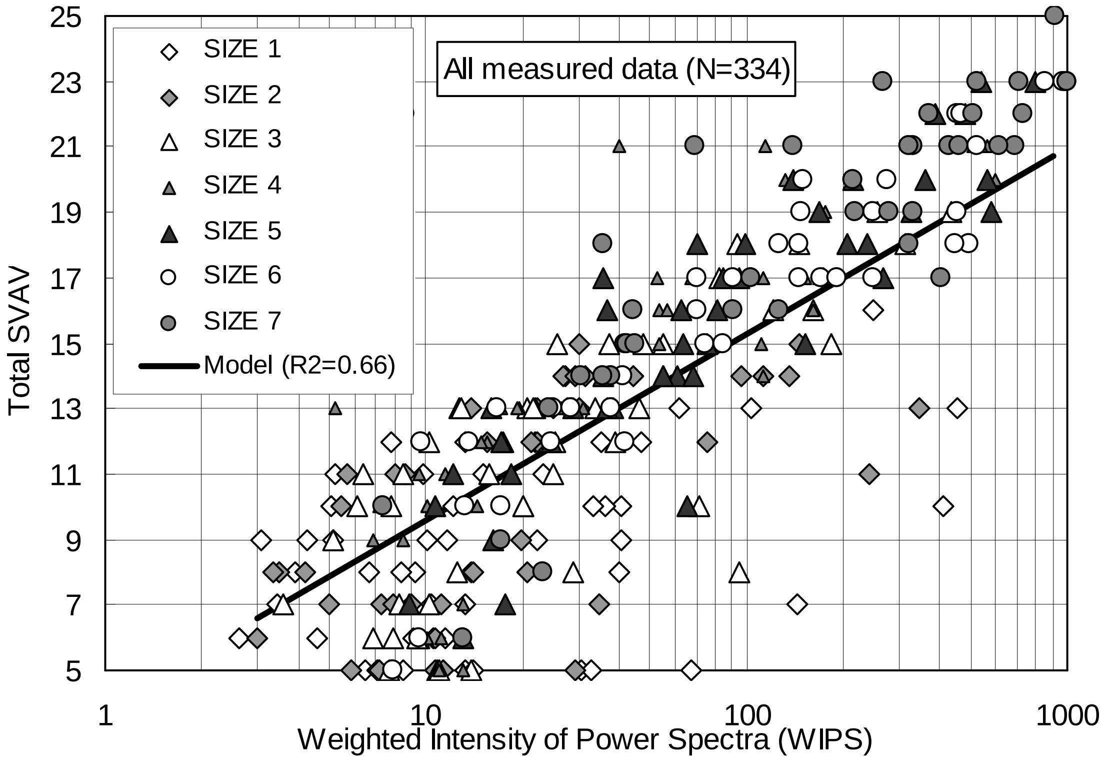


Figure 5. Relationship between WIPS and Total SVAV.

4. APPLICATION OF THE PROPOSED METHOD

4.1 Proposed system

MATLAB was employed to develop a graphic user interface for calculating WIPS and SVAV (Figure 6). MATLAB provides a set of tools for image processing and for creating graphical user interfaces (GUIs). These tools greatly simplify the process of calculating the magnitude of power spectrum and designing and building GUIs. Using the GUIDE Layout Editor, we can lay out easily panels, buttons, text fields, sliders, menus, and so on into the layout area. Figure 6 shows a sample of GUIs for evaluating the WIPS and the SVAV based on images. Before starting the program, you must select the location of camera and number of image. After that, if you click "START" button, the program is executed and shows value of the WIPS and the SVAV on the screen as shown in Figure 6.

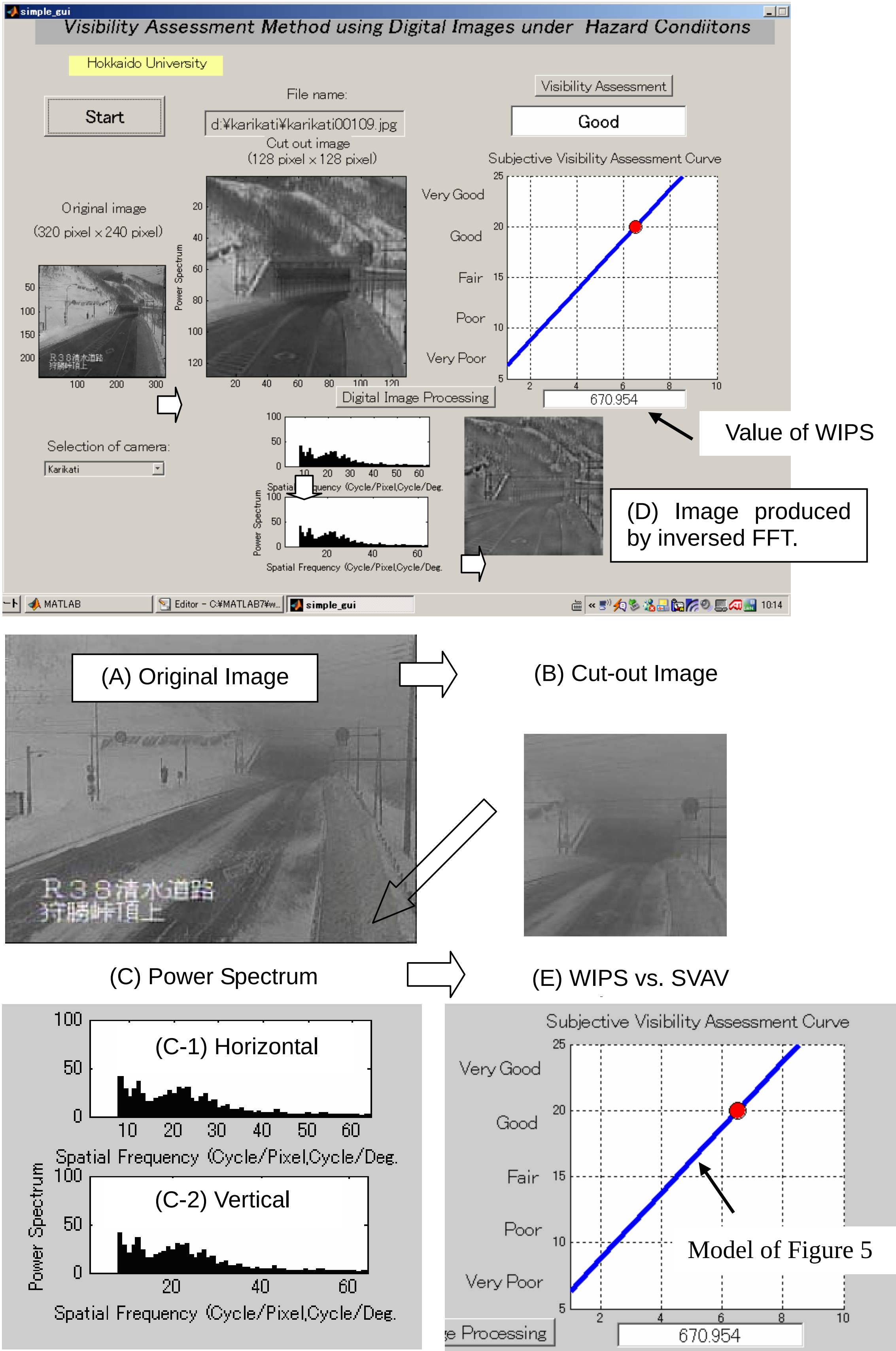
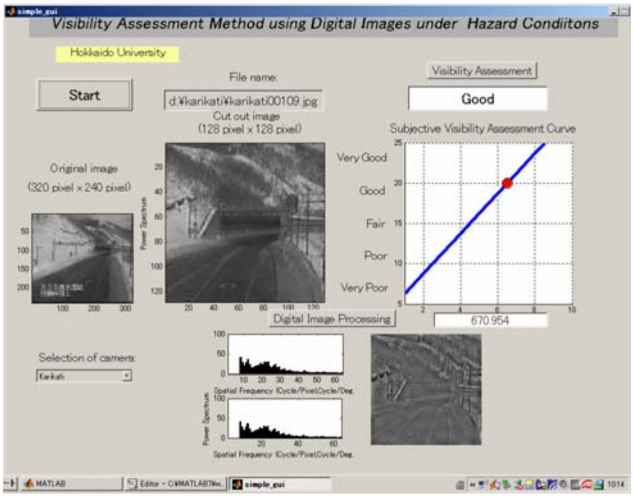
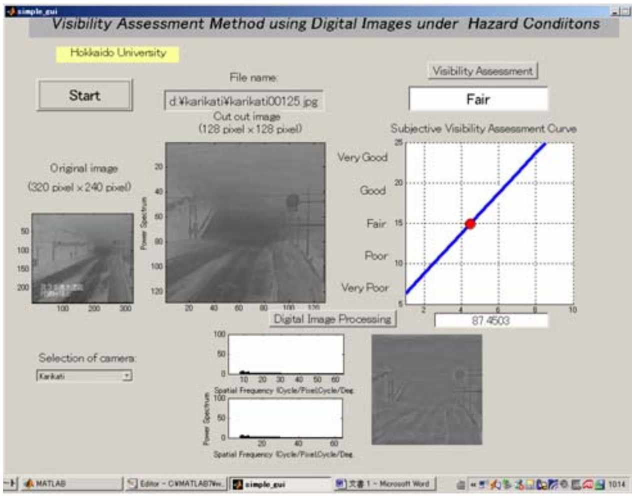


Figure 6. Example of Graphic User Interface for Calculating WIPS and SVAV.

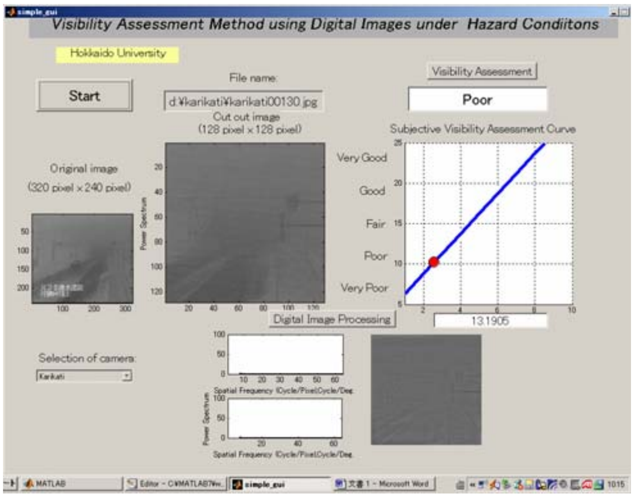
(A) Good



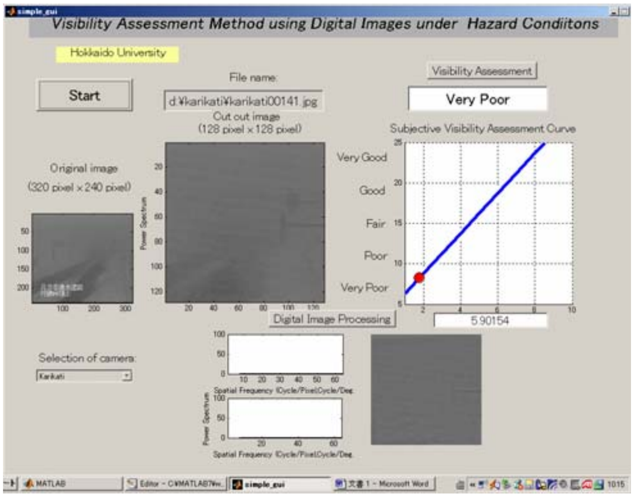
(B) Fair



(C) Poor



(D) Very Poor



(These images were recorded by ITV camera during the 2003/2004 winter at Karikati Pass on National Route 38 in Hokkaido.)

Figure 7. Four Examples of Subjective Visibility Estimated using the Proposed System.

The original image in Figure 6(A) is 320 × 240 pixels. It is of the entire road section and has been converted from an RGB image into a grayscale image. Figure 6(B) shows 128 ×128 pixels cut out from Figure 6(A). The spatial frequency of the intensity of each pixel was calculated using two-dimensional FFT, and the power spectra were calculated. Figure 6(C) indicates the distribution of power spectra for each dimension. The magnitude of power spectra at each frequency is expressed by the intensity of gray level. Figure 6(C-1) indicates horizontal distribution of magnitude of power spectra and Figure 6(C-2) indicates vertical distribution. The magnitude of power spectrum makes it easy to estimate the visibility conditions. The height of each bar increases as the power spectrum increases. The magnitude of power spectra decreases as the visibility decreases, and the range of power spectra narrows as the size of targets in the cutout image decreases. After cpp was converted into cpd, WIPS was calculated from sum of the magnitude of power spectrum for each of the five cpds. In addition, Figure 6(D) shows an image computed from the inverse transform. Spatial frequencies less than 3 cpd and greater than 18 cpd were removed, and the remaining spatial frequencies were converted into a digital image by inverse two-dimensional FFT.

The line plotted in Figure 6(E) shows the regression line of the WIPS to SVAV produced by the experiment. The horizontal axis indicates the magnitude of WIPS scaled as log power spectra. The vertical axis indicates the magnitude of the total SVAV in the range from 5 to 25. The line plotted in Figure 6(E) shows the magnitude of WIPS based on the cutout image (Figure 6(B)). As a trial of indicating a visibility level in image, we might establish four or five levels under which to divide the total SVAV. For example, based on the observations in this study, there are five visibility levels (Figure 6(E)). The first visibility level (Very Good) is over 22.5. It indicates completely clear conditions. The second level (Good) is from 17.5 to 22.5. It indicates clearness sufficient to see all objects in the image. The third level (Fair) is from 12.5 to 17.5. It indicates clearness sufficient to see near objects in the image but not to see distant objects in the image. The fourth level (Poor) is from 7.5 to 12.5. It indicates too little clearness to see near objects in the image. The fifth level (Very Poor) is under 7.5. It indicates complete invisibility. The judgment for Figure 6(E) is “Good,” according to this trial system.

4.2 Application

Original images were recorded by ITV camera during the 2003/2004 winter at Karikati Pass on National Route 38 in Hokkaido. Figure 7 shows two additional samples selected from recorded images. Figure 6 is an example of clear conditions, Figure 7(A) is an example of clear condition, Figure 7(B) is a moderate-visibility condition, Figure 7(C) is an example blowing-snow condition, and Figure 7(D) is an example severe blowing snow condition. The WIPS decreases linearly as the visibility decreases. In Figure 7(A) and (B), all objects in the image is visible. The image computed from the inverse transform is similar to the original cutout image. In Figure 7(B), the upper part of the image is invisible, but the middle and lower parts are visible. Objects belonged to middle and lower image are visible. The image computed from the inverse transform clearly shows these facts. In Figure 7(C), snow particles seem to distribute uniformly throughout the road area, but utility poles for traffic sign and rut shape on the road belonged to lower image are visible. In Figure (D), near-side road surface and the nearest utility pole are visible. The image computed from the inverse transform shows these facts.

5. CONCLUSIONS

This study proposed an image-based method of estimating visibility under conditions of weather-induced poor visibility. Toward developing a model, we conducted an experiment under foggy conditions in which we captured digital images containing various Landolt circles as the targets. Simultaneously with this, the subjects assessed the visibility of the targets. The SVAV was used as an index of subjective visibility of the target.

The magnitude of WIPS represents the difference between the digital intensities of the image under clear conditions versus those under poor conditions. The WIPS reflects a band pass of spatial frequency of the image based on human eye sensitivity. In this, our method differs greatly from previous image-based methods of estimating visibility under conditions of poor visibility. There was a clear relationship between SVAV and WIPS: WIPS increased as SVAV increased. This relationship did not depend on the size or contrast of the Landolt circle. We applied this relationship to assess a few digital images recorded by ITV camera. Total SVAV computed from the images roughly corresponded to visibility conditions estimated from those images. Overall, WIPS has the potential for use in estimating visibility under adverse weather conditions.

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