Variation in Motorist Visual Range Measured by Vehicle-Mounted Sensor

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A motorist's visibility in blowing snow varies as topography, vegetation, road alignment and elements change along a highway. Traffic accidents caused by the rapid changes of visual range have been increasing in snowy regions of Japan. A vehicle-mounted visual range sensor composed of a light projector and receiver has been developed to investigate the variable visibility at the eye level of motorists. Continuously measured visibility traveling at 80 km/hr showed intense fluctuations changing from 1000 m to 40 m in a few seconds where the highway environment changes from a narrow road cut to an embankment with wide fetch distance. It is important for highway maintenance to detect the locations and conditions of the hazards along a highway beforehand in order to develop mitigation measures. The vehicle-mounted sensor can detect hazards along a highway while driving, and it is also useful for condition monitoring by maintenance patrols.

Highway closures caused by limited visual range and snowdrifts in blowing snow are a major concern in Hokkaido, the northernmost island in Japan. Proper use of snow control facilities such as snow fences, snow-break forests, and snow shelters has been improving visibility and reducing snowdrifts on highways, and the usage of these measures has been studied under the conditions of local topography, weather, and narrow highway right-of-way typical in Hokkaido (*1*). Optical guides such as snow poles, delineators, and roadside trees have been erected to improve traffic safety under conditions of poor visibility. Visual range monitoring has been developed and is operational on a few highways. Short-term predictions of hazardous conditions on highways are developed by using the real-time visual range and other weather data. As a result, the road closures have been decreasing each year. Beginning in 1992, the use of studded tires was restricted on the basis of seasonal and road surface conditions. However, a traffic accident involving 186 vehicles that occurred in a snowstorm on a slippery, snowy expressway between Sapporo and the Chitose airport in March 1992 pointed out the need for a higher level of snow control and technology on winter road maintenance during bad weather. On-board visibility monitoring might be a way to reduce such traffic accidents. The vehicle-mounted visual range sensor has been developed to detect such hazards and to investigate characteristics of visibility at a motorist's eye level.

VISIBILITY SENSOR

Instruments for measuring visibility in blowing snow were developed by Schmidt (*2*) and Tabler (*3*) in the United States and Takeuchi (*4*) in Hokkaido; research in both countries began in about 1971. These monitoring systems have been operational for traffic control on highways. Visibility (V) is defined in terms of the extinction coefficient (σ) on the assumption of uniformity of both light and atmosphere (*5*), that is,

$$V = 1/\sigma \ln 1/\varepsilon \quad (1)$$

where ε is the threshold brightness contrast (*6*) and σ is proportional to concentration of snow, fog, and other airborne particles at eye level. The attenuation of light in traversing distance L is given by the Bouger-Lambert law in the form

$$B = B_0 e^{-\sigma L} \quad (2)$$

where B is the brightness of light at L and B_0 is the initial brightness. From Equation 2,

$$\sigma = 1/L \ln 1/T \quad (3)$$

where T equals B/B_0 and B/B_0 equals the transmissivity. From Equations 1 and 3 visibility can be presented as

$$V = [L/(\ln 1/T)] \ln 1/\varepsilon \quad (4)$$

This is the theory of the transmissometer type of visibility sensor (*4*). The sensor was calibrated simultaneously by observing black square visual targets in snowstorms. The size of the visual targets was designed for a constant visual angle of 0.5 degrees from the observer. The transmissivity measured by the visibility sensor has been shown to compare closely to observed visual range except at visibilities less than 20 m where visibility falls below the theoretical curve (*4,7*). In the lower visibility range, the visible snow particles and their afterimages appear to reduce visibility. In addition, visibility observed by the eye is somewhat shorter than that observed from photographs and television. Because traffic essentially comes to a standstill at visibility less than 30 m, the deviation from the theoretical curve at lower visibilities is not important for practical use on highways. The transmissometer visibility sensor is the standard on highways in Japan today.

VEHICLE-MOUNTABLE VISUAL RANGE SENSOR

Because fixed visibility sensors are installed along the side of highways, their output is not necessarily representative of the

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visibility at motorist eye level, especially in blowing snow because of the vertical distribution of snow concentration and visibility. The vehicle-mountable visibility sensor has been developed to measure continuously the visibility at motorist eye level. The sensor is composed of a light projector and receiver, the optical axes of which cross as shown in Figure 1. The light from the projector is scattered by airborne snow particles in the sampling area, and some of the reflected light from the particles is measured by the receiver. Because the intensity of the received light is in proportion to the snow concentration, visibility is inversely proportional to the intensity. The light from the projector is regulated to make constant brightness and modulated at 1-kHz frequency to reduce the effect of outside light such as sunlight and illumination. Snow accretion on the lenses is prevented by transparent window covers. Because the brightness of the projected light can be reduced by the accumulation of dirt and other contaminants on the window covers and lenses, the brightness is automatically controlled to be constant by an optical guide element attached to the outside face of the lens. Temperature-sensitive elements such as the projector lamp and photo receiver are controlled by feedback from the light guide. The block diagram of the sensor is shown in Figure 2.

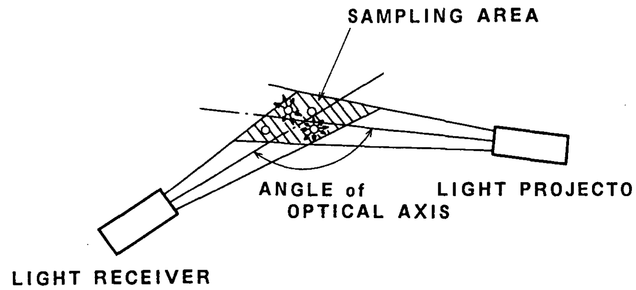

FIGURE 1 Infrared light from projector is scattered by snow particles in sampling area. Some reflected light from particles is received by receiver.

Determination of Optical Axis

The optical axis of the projector and receiver is adjusted at an angle to reduce the size of the sensor. A larger angle is desired to improve the accuracy for the limited dimension required for vehicle mounting. The output voltage in relation to the angle was measured in two conditions: blowing snow and fog. The voltage increases in proportion to the angle as shown in Figure 3. The output characteristic in relation to the angle is somewhat different in blowing snow than in fog. However, the output voltage is the same at the angle of 130 degrees. The 130-degree angle is suitable for measuring vis-

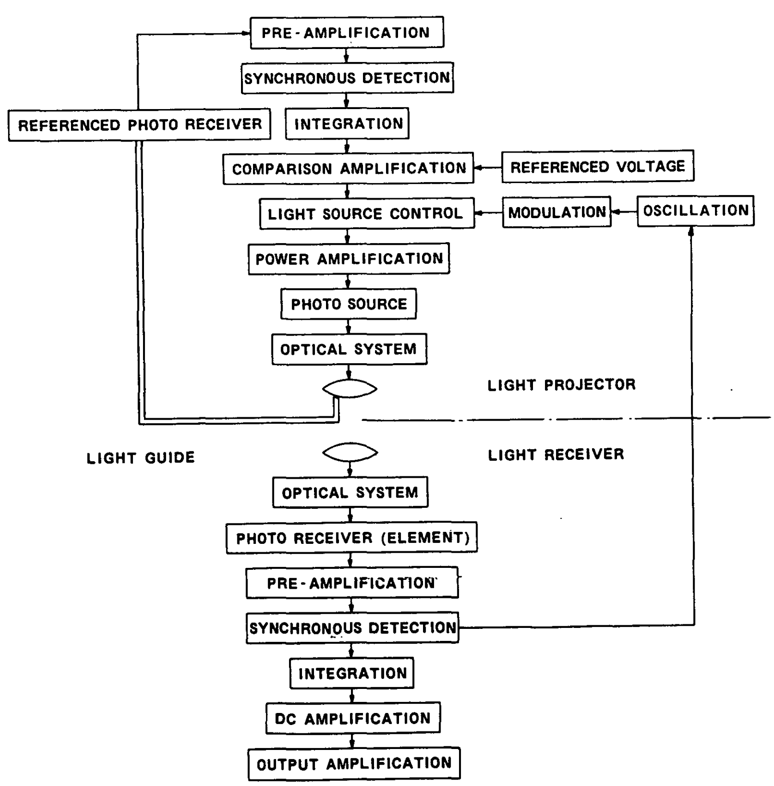

FIGURE 2 Block diagram of vehicle-mountable visibility sensor.

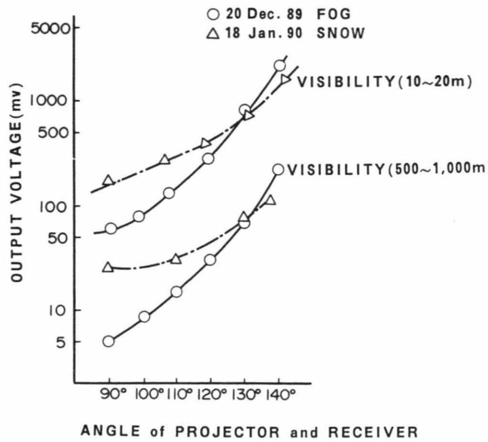

FIGURE 3 Relation between output voltage and angle of axis measured in snow and in fog.

ibility in blowing snow and in fog under comparable conditions (output voltage). Therefore, a 130-degree angle is chosen as the optical axis of the sensor.

Sensor Calibration

Field experiments were conducted to compare the vehicle-mountable sensor with the standard transmissometer visibility sensor (Figure 4). Data are recorded on a two-channel strip chart, with visibility measured by the transmissometer on the left channel and by the sensor on the right, as shown in Figure 5. The transmissometer visibility sensor measures transmissivity, and the sensor being calibrated measures the intensity of the reflection from snow particles in the sampling area. The transmissivity is in inverse proportion to the reflection. As visibility decreases, the trace on the left chart moves to the right while the trace on the right moves to the left. The

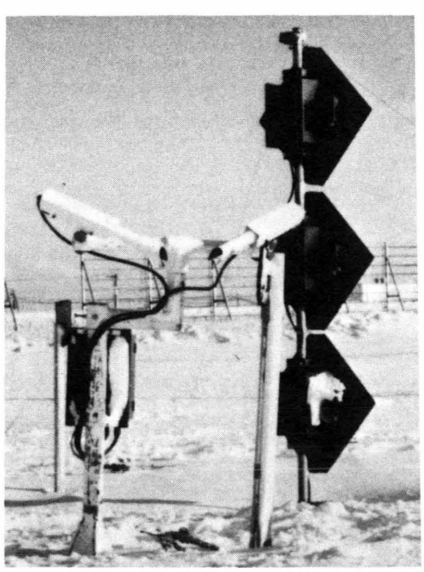

FIGURE 4 Field experiments for calibration of sensor against transmissometer.

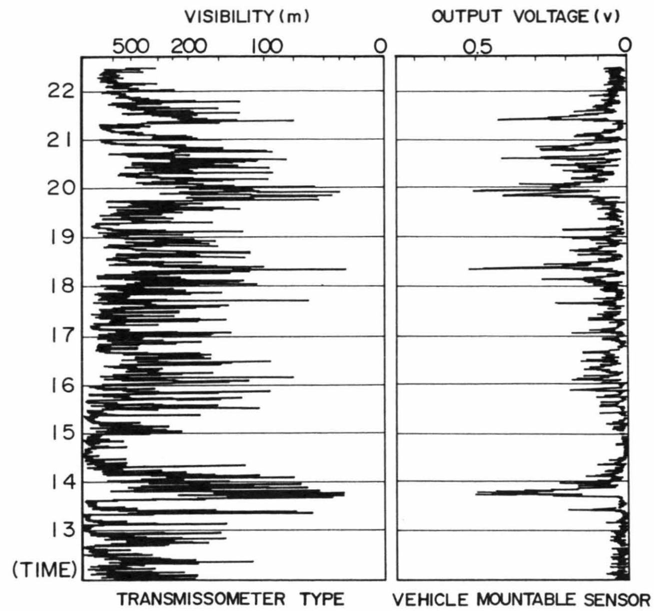

FIGURE 5 Example recorded from field experiment of two types of visibility sensor shows good correlation between them.

recorded data in Figure 5 are examples measured in blowing snow with falling snow.

The output voltages of the sensor are closely related to the visibility measured by the transmissometer type of sensor as shown in Figure 6. The experimental equation of visibility measured by the sensor can be expressed as a function of output voltage. The vehicle-mounted sensor is therefore able to measure the real-time visibility at motorist's eye level while traveling.

VARIATION IN VISIBILITY

Visibility varies not only in blowing snow but also in falling snow and fog. However, the variation in visibility is most extreme in blowing snow: it causes traffic accidents, which are increasing and becoming serious problems especially on expressways in snowy regions of Japan. Visibility at a point varies because of changes wind speed and intensity of pre-

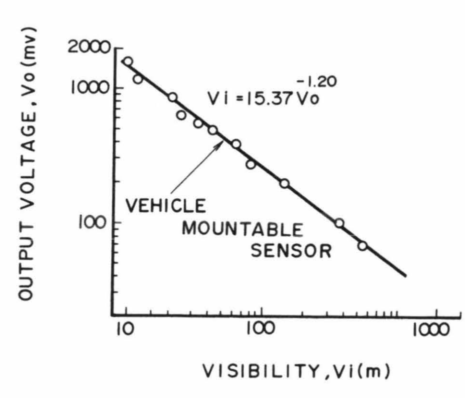

FIGURE 6 Comparison of transmissometer.

cipitation. However, the variation becomes even greater when moving, because of changes in the surrounding topography, vegetation, and road geometry. Motorists encountering white-out conditions without warning are at high risk of becoming involved in accidents. It is important for snow-control operations as well as for traffic safety to know how visibility varies with location.

Visibility was measured continuously by the vehicle-mounted sensor while traveling along a highway. The sensor was fixed to the front bumper of the vehicle at a 1.2-m height as shown in Figure 7; 1.2 m is the typical motorist's eye level for standard Japanese passenger cars. The data were sampled at 20 per second and recorded on a digital recorder. The measurements were made at 80 km/hr on the 98.6-km-long expressway between Sapporo and Fukagawa. An example of the visibility measured in blowing snow along the expressway is shown in Figure 8. There are two places, noted at the 91.3- and 92.5-km posts in Figure 8, where visibility changed from 1000 m to 40 m in seconds. At both locations the topography changes from forest-covered cuts to bare embankments, resulting in whiteout conditions. Similar variations in visibility in blowing snow were associated with changes in vegetation and road elements along the highway.

Another type of visibility problem is the poor visibility in the whirl of snow generated by high speed vehicles on snow-covered highways. Driving the measurements reported here, the observer encountered snow whirls in the wakes of passing vehicles. The variation in visibility caused by passing vehicles

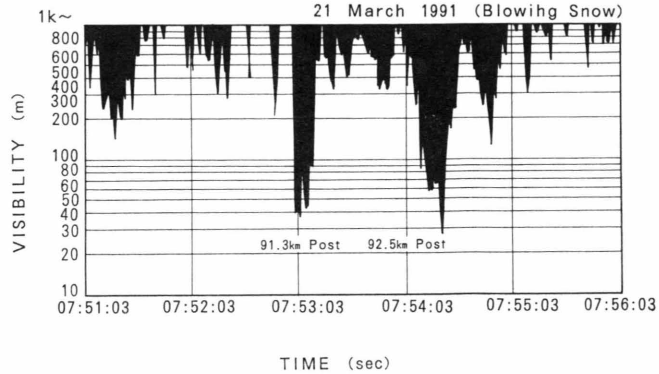

FIGURE 8 Example of variation in visibility measured by sensor traveling at a speed of 80 km/hr along expressway in blowing snow. Two locations where visibility fell below 100 m were measured where conditions changed from forest-covered cuts to bare embankments.

FIGURE 7 Sensor mounted on vehicle for observation; sampling area is set at 1.2 m height from road surface.

is shown in Figure 9. The poorest visibility in Figure 9 was caused by the passage of a large truck. The variation in visibility is related to the cycle of the wake. During the measurements, visual conditions were monitored simultaneously by a video tape recorder located alongside the vehicle driver. The vehicle driver's perception of visibility conditions and the record taken by video tape recorder agree well with those recorded by the sensor. Because the sensor is installed in front of the vehicle and the sampling area is situated ahead of the sensor, the vehicle generates no turbulence effect during measurement. The resulting measure of visibility did not show any sensitivity to vehicle speed. However, there could be such an effect if there is a strong cross-wind relative to the direction of travel.

DISCUSSION OF RESULTS AND CONCLUSION

The vehicle-mountable visibility sensor was developed to measure continuously the visibility at motorist eye level while traveling along highways. Several runs of experimental mea-

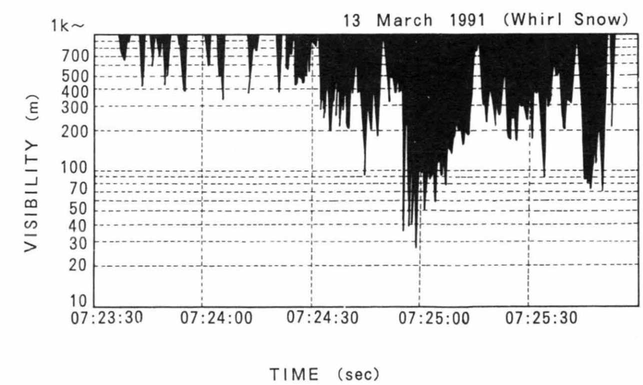

FIGURE 9 Example of reduced visibility caused by passing vehicles in fine weather.

surements the along the 98.6-km expressway show that the sensor is good enough for operation in any weather. Observed variations in visibility in blowing snow were caused by changes in surroundings along the expressway. That the observed visibility changed from 1000 m to below 40 m in a short time indicates that there is high potential for traffic accidents at such places. It would be difficult for motorists to react to such sudden changes in visibility, especially in slippery road conditions. It is very important for traffic safety to improve poor visibility by properly located snow-control measures or warning lights. The sensor is useful for quickly detecting hazard zones requiring protection from blowing snow. Both large- and small-scale variations of visibility would cause traffic accidents for vehicles traveling at high speed on slippery snow-covered roads. Although small-scale variations in visibility may not have an observable impact on traffic safety, information on proper speed and spacing provided to motorists could improve highway safety in blowing snow. Installing the sensor on patrol cars will provide motorists such information in the future.

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