DEVELOPMENT OF SNOWFALL MEASURING DEVICE BASED ON IMAGE PROCESSING TECHNOLOGY

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1. Outline

In heavy snowfall regions, snow removal is a critical task for ensuring safety of users of roads.

Before commencing snow removal work, the road administrator usually develops a snow removal vehicle allocation plan. During the planning procedure, the administrator must determine snowfall conditions through visual measurement because of a lack of appropriate sensors that can measure snowfall conditions in real time.

Meanwhile, thanks to the advancement of information and communication technology, studies on image processing technology for application in traffic flow monitoring have reached a level that allows several systems to be successfully put to practical use. One example of such efforts is a national project that has been in progress in recent years to develop an ITS (Intelligent Transport System), with the aim of realizing an advanced road traffic system. Under this project, the development of measuring technology using surveillance cameras is underway at an increasing pace.

Furthermore, the Ministry of Land, Infrastructure and Transport is now promoting the improvement of the information highway as part of its efforts to build an extensive information communication infrastructure. Here again, technology for processing road surveillance images captured with a surveillance camera is growing in importance with improvements in the infrastructure.

Against this background, we have studied snowfall measurement with the aim of establishing an effective method for identifying snowfall conditions in real time by processing images captured using a surveillance camera.

To date, many researchers have published studies for snowfall measurement using image processing technology. Examples include studies for a device that captures images of snowflakes while they are falling freely inside a windbreaker tower to measure the density and falling velocity of the particles (2)(3)(4) and a study for a snowfall detection method in which a target made of a flat plate is set out and snowflakes in a rod shape are extracted in front of that target for detection of a snowfall (5). All these studies measure snowfall by extracting snowflakes through image processing and putting them to microanalysis.

We have invented a new method, in which the snowfall condition is identified by measuring changes in screen texture caused by a snowfall, instead of micro-analyzing a snowfall as in conventional methods.

When identifying individual snowflakes through image processing, two factors are required: sufficient contrast and accurate binarization. One feature of our method is its ability to provide effective measurements in a relatively lower-contrast environment.

This paper gives an outline and the measuring algorithm of our method in Section 2, shows the results of an experiment conducted in Naie, Hokkaido in Section 3, and summarizes our study in Section 4.

2. Snowfall measuring method based on image processing

Fig. 1 shows the configuration of our system. The system captures images using a CCD camera installed outdoors and inputs the image data captured to an image processor. The system then processes the image data using snowfall measurement processing software installed on a special board for image processing, and outputs the results to a data collecting device.

During the capturing process, the CCD camera targeted a black plate installed for detection of snowfall. The horizontal distance between the camera and the plate was 20 meters.

The black plate, which was used as a backdrop for facilitating the detection of snow, was coated for water-proofing in order to prevent snowflakes from depositing. In addition, a lighting fixture was installed to light the plate to enable detection during at night.

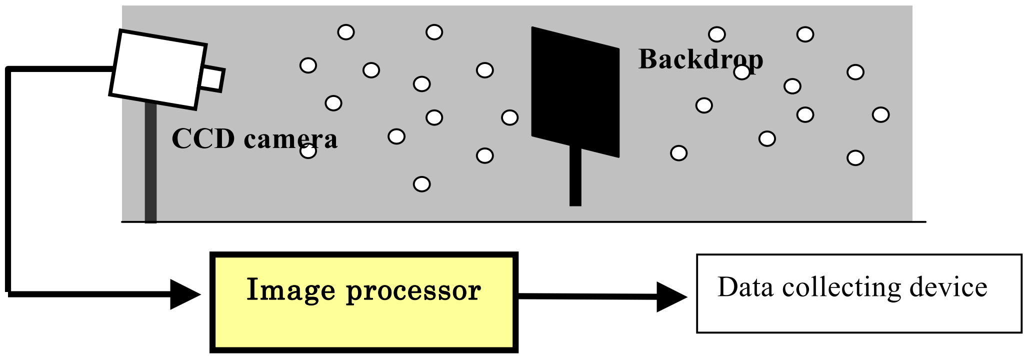


Fig. 1 Configuration diagram for snowfall detection and image processing system

Our snowfall measuring method based on image processing is described below.

1) Setting of measuring area

A measuring area, which is displayed on the input screen, is set within the black plate installed for the purpose of detecting snowfalls. However, since Fast Fourier Transform is used for image processing, one condition imposed is that the number of sample dots in the measuring area should be a 2 factorial.

"Number of pixels in area to be measured = 2^n"

Sample dots can be set to be coarse or dense, depending on how the plate looks (i.e., its size on the screen).

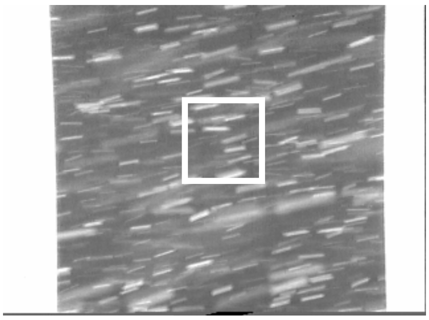


Fig. 2 Setting of measuring area

2) Conversion of tone

The image processor converts analog signals sent from the surveillance camera to digital signals (A/D conversion), and the resulting signals are input into the image memory at regular intervals. Image signals are converted to 8-bit 256 tone levels ("0" for dark to "255" for bright).

3) Calculation of power spectrum by 2D Fast Fourier Transform

Fourier Transform process is performed on the tone-converted images of the measuring area and the texture of the screen is measured. The power spectrum obtained by Fourier Transform process is used to obtain characteristics of the texture in coarseness/denseness or orientation. In the case of images with a coarse texture, shade signals are concentrated at lower frequency components. The finer the texture of an image is, the greater number of higher frequency components the image has. A power spectrum has its origin of frequencies at the center. It consists mainly of lower frequency components near the center, and its frequency becomes higher as it moves toward the edge of the area.

The power spectrum for a measuring area can be obtained, using a 2D Fourier Transform expression, as follows:

$$F(u,v) = \sum_{x=-\frac{M}{2}}^{\frac{M}{2}} \sum_{y=-\frac{N}{2}}^{\frac{N}{2}} (x,y)\left[\cos 2\pi\left(\frac{ux}{M}+\frac{vy}{N}\right) - i\sin 2\pi\left(\frac{ux}{M}+\frac{vy}{N}\right)\right]$$

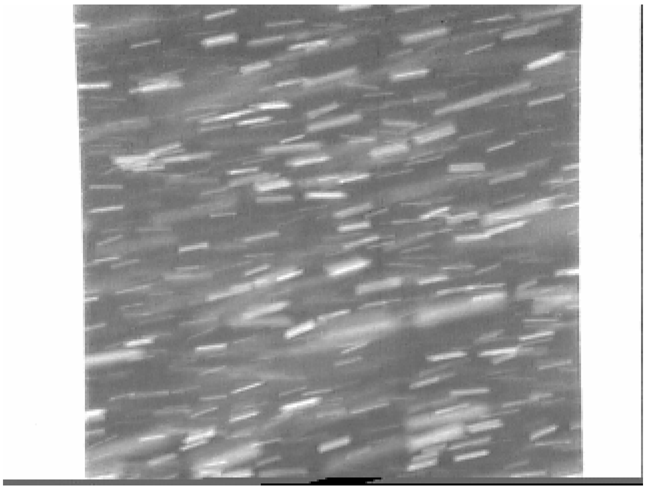
$$P(u,v) = \sqrt{R^2 + I^2}$$

$$PM = \sum_{u=-\frac{M}{2}}^{\frac{M}{2}} \sum_{v=-\frac{N}{2}}^{\frac{N}{2}} P(u,v)$$

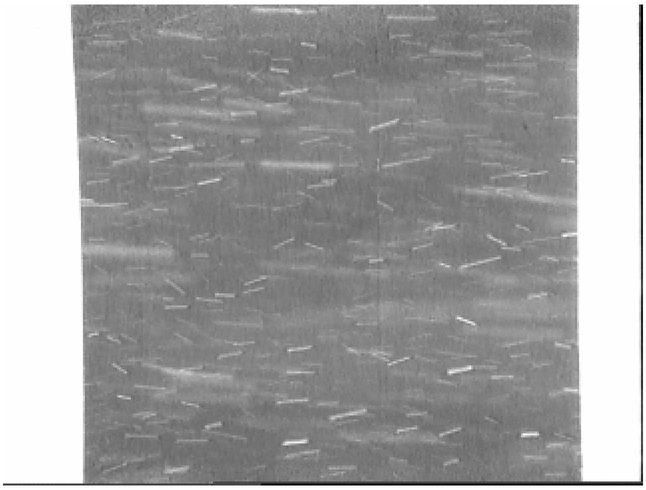
F (u,v)	: Polar coordinate value of power spectrum (M/2≤u≤M/2) (N/2≤v≤N/2)
f (x,y)	: Luminance value for measuring area (M/2≤u≤M/2) (N/2≤v≤N/2)
R	: Real part of F (u,v)
I	: Imaginary part of F (u,v)
P (u,v)	: Intensity of power spectrum
PM	: Sum total of power spectrum

Fig. 3 shows snowfall conditions and Figs. 4 through 7 shows the examples of calculation of power spectrum for different snowfall conditions.

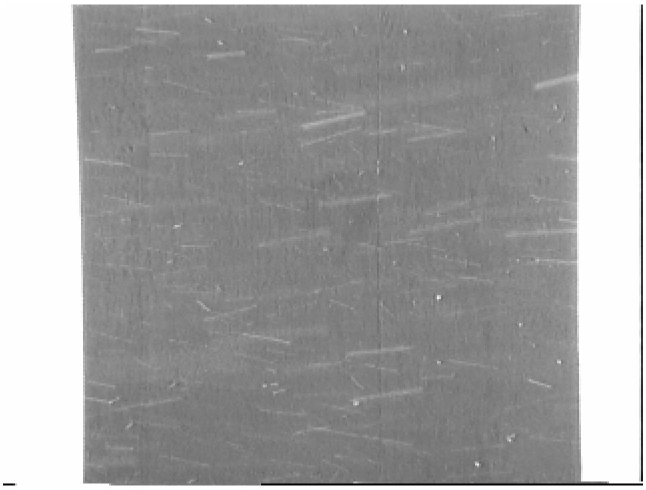
These results show that as a snowfall intensifies, its power spectrum tends to have a greater number of high frequency components.



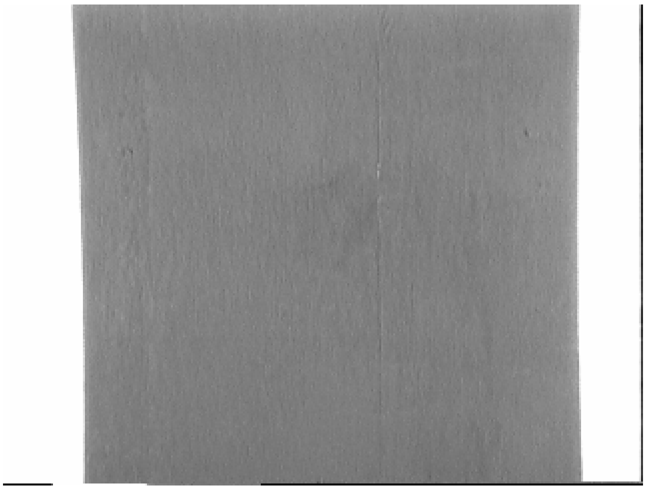
Snowfall condition (intense)



Snowfall condition (medium)



Snowfall condition (weak)



Snowfall condition (none)

Fig. 3 Snowfall conditions

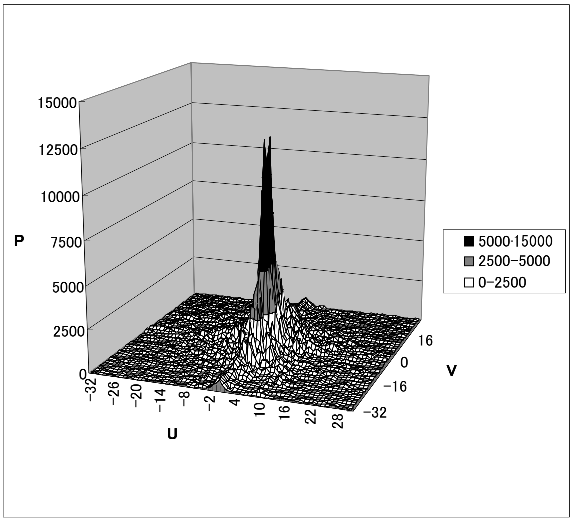


Fig. 4 Power spectrum of snowfall (intense)

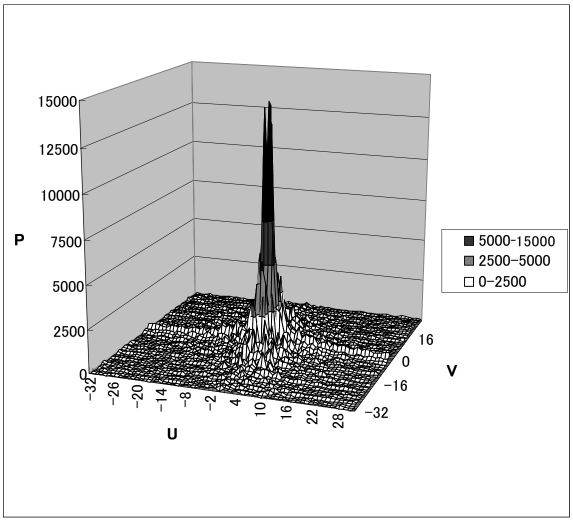


Fig. 5 Power spectrum of snowfall (medium)

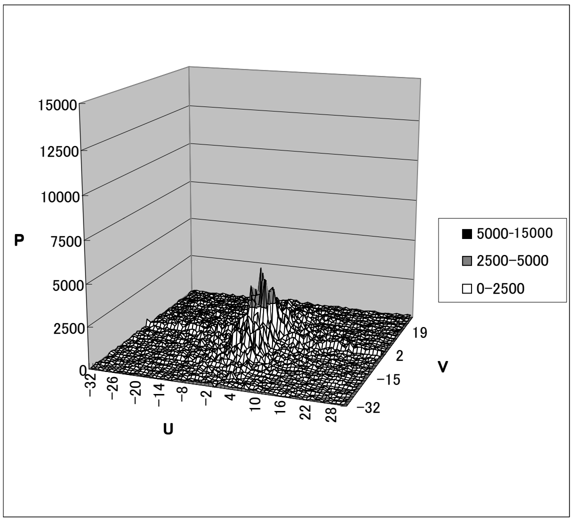


Fig. 6 Power spectrum of snowfall (weak)

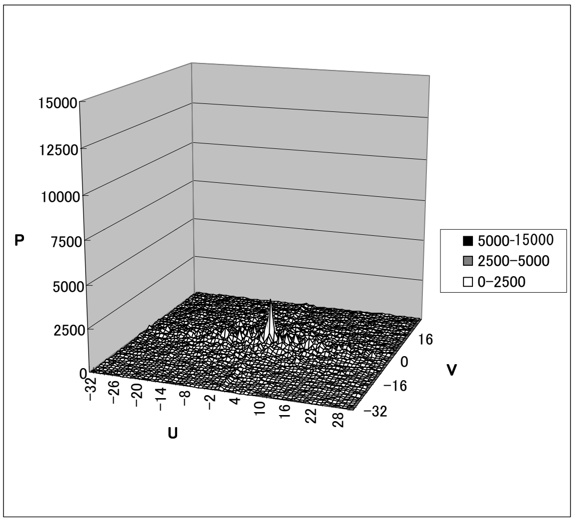


Fig. 7 Power spectrum of snowfall (none)

4) Determination of snowfall intensity based on sum total of calculated power spectra

Table 1 below shows the sum totals of power spectra of different snowfall conditions.

Table 1 Changes in power spectra for different snowfall conditions

Snowfall condition	Total sum of power spectra
Intense	1181291.1
Medium	1015720.0
Weak	885125.7
None	399316.7

This table suggests that it is possible to determine the intensity of a snowfall according to the total sum of its power spectra.

It is further considered that an output value from image processing can be converted to a snowfall rate by using the correlation between actual snowfall rate [cm/h] and results output from image processing.

A snowfall rate refers to a value expressed as the height of a water column, which is obtained by converting the amount of snowflakes falling in a container placed on the ground per unit hour into the amount of liquid, i.e., water obtained by melting the snowflakes.

3. Snowfall measuring experiment

A field experiment using a real machine was conducted in order to investigate the actual correlation between the snowfall measurement obtained from image processing and the actual snowfall rate. The experiment took place over two different periods, January 20 through 25 and February 22 through 25, 2000, in Naie-cho, Sorachi-gun, Hokkaido, Japan.

At the site of experiment, data were collected, processed, and stored in a PC on an in realtime basis. At the same time, the actual amount of snowfall was measured.

The actual amount of snowfall was measured, using snowflakes collected for five minutes in a container whose measured base area is known. These snowflakes were then melted into water and weighed. The measured weight was converted into the snowfall rate (i.e., precipitation per unit area and per hour [cm/h]), using the base area of the container and the specific gravity of water.

Fig. 8 CCD camera and backdrop plate

3.1 Method of evaluating experiment results

The results of the experiment were evaluated by comparing snowfall indexes output by the image processing algorithm and data of snowfall rates obtained by manual measurement at five-minute intervals.

Table 2 shows a list of the results obtained through detailed analysis of experimental data.

Table 2 List of experimental evaluation data

	Date of measurement	Time period	Remarks
1	Jan. 25, 2000	9:30 to 10:30	Daytime
2	Jan. 25, 2000	12:00 to 14:00	Daytime
3	February 25, 2000	8:15 to 9:40	Nighttime

3.2 Results of measurement during daytime

In order to evaluate correlation between results output from image processing and snowfall rate [cm/h], a diagram showing the correlation between data (1) and (2) for snowfall during daytime was prepared (9).

In addition to this, a polynominal approximation expression was defined.

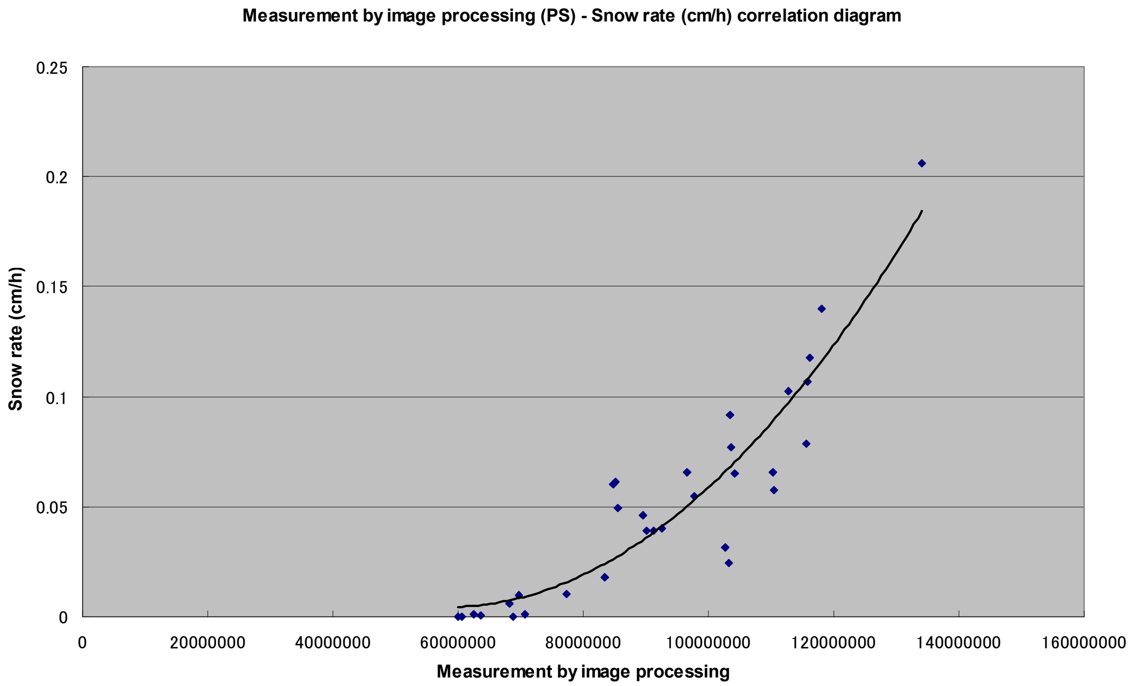


Fig. 9 Correlation diagram for measurements obtained from image processing and snowfall rate during daytime

Using this correlation, values output from image processing can be converted into the snowfall rate. Fig. 10 shows a comparison between snowfall rate obtained by converting measurements obtained from image processing and the value obtained by manual measurement (i.e., true value).

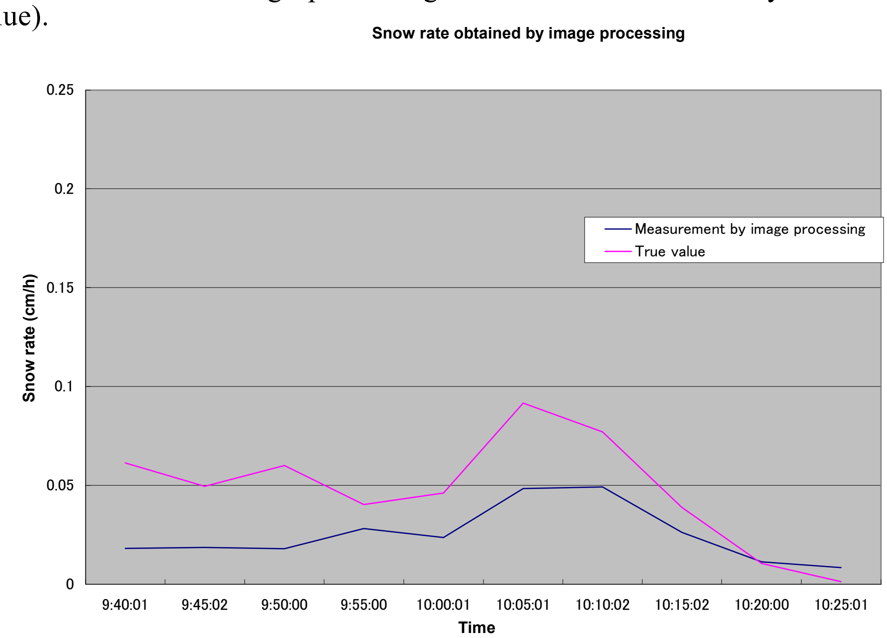


Fig. 10 Data of snowfall during daytime (1)

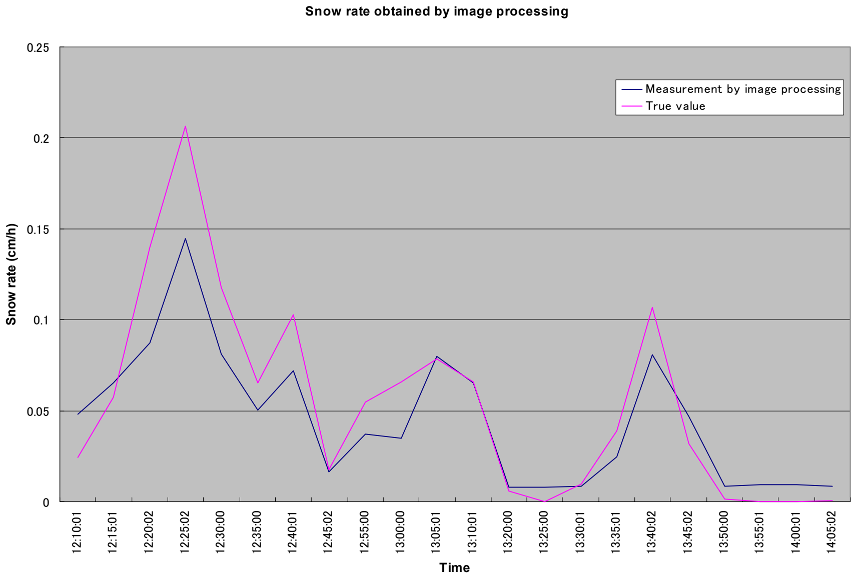


Fig. 11 Data of snowfall during daytime (2)

3.3 Results of measurement during nighttime

Similar analysis of nighttime data gave a correlation diagram as shown in Fig. 12.

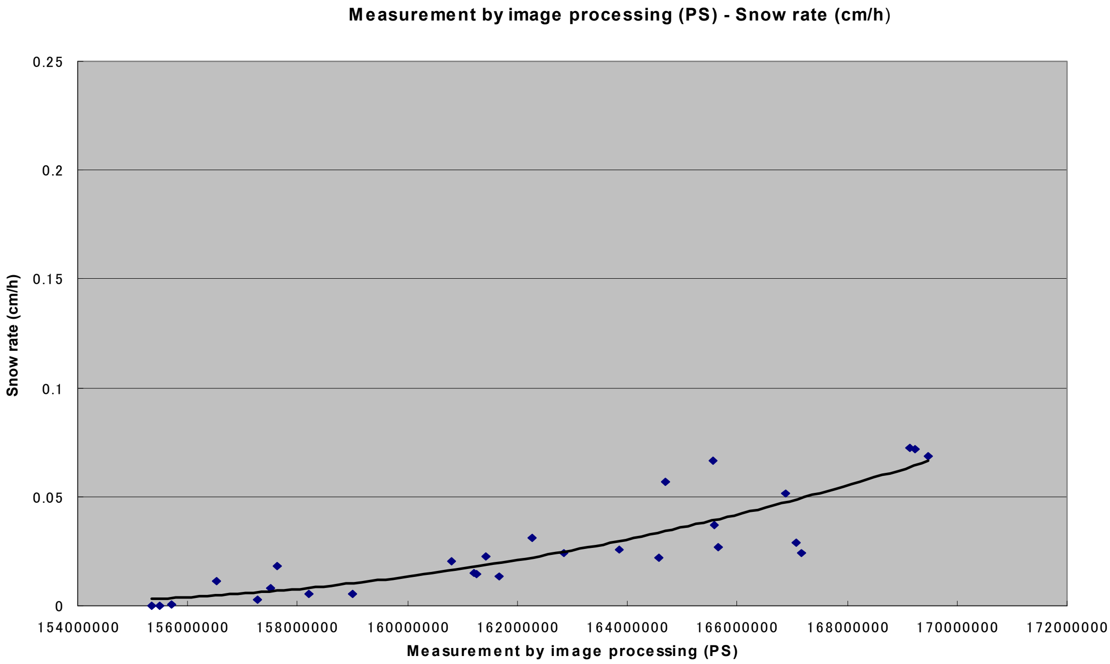


Fig. 12 Correlation diagram for measurements obtained from image processing and snowfall rate during nighttime

Fig. 13 is a chart showing evaluation by comparison between measurements of snowfall rate obtained by conversion using the above-mentioned approximation expression and measurements of snowfall rate obtained by manual measurements (i.e., true value).

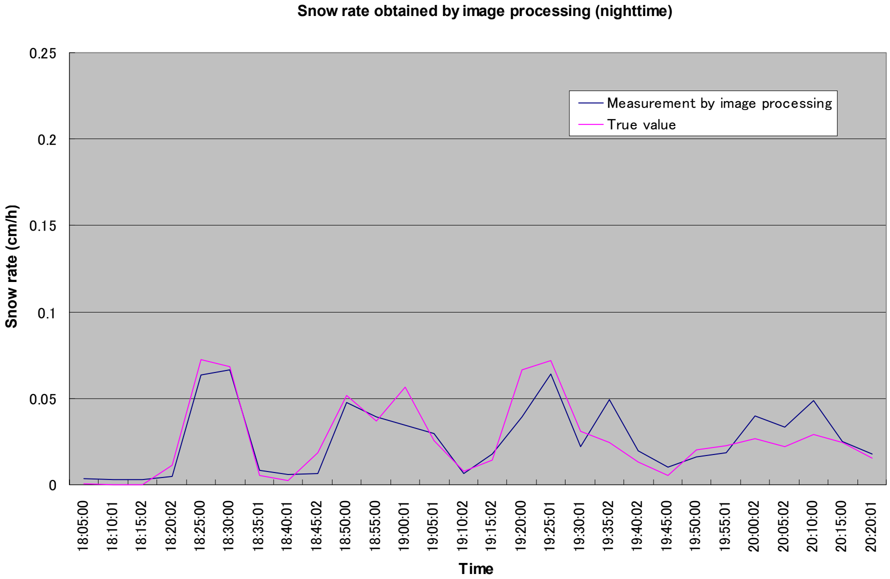


Fig. 13 Data of measurements during nighttime

4. Summary

The following facts were identified through the experiment described above.

① For both daytime and nighttime, measurements obtained from image processing (power spectra) have a correlation with snowfall rate. These measurements can be converted into snowfall rate, using a polynominal approximation expression.

② Realtime measurement of snowfall rate is possible.

Our method of measuring snowfall by image processing thus enables real time identification of snowfall condition, thereby allowing prompt snow removal activities and helping the road administrator conduct snow and ice management more effectively.

Several issues to be addressed hereafter were identified, as follows:

① Effect of wind

It was found that a strong wind tend to reduce the level of measurements by image processing.

In order to prevent this, a method for eliminating the effects of wind needs to be developed.

There are two possible methods for this.

a) Use of electronic shutter

By using a CCD with an electronic shutter to fire the shutter electronically, snowflakes can be captured accurately, thereby lowering the probability of failing to capture snowflakes and consequently preventing measurements from being lower than true values.

b) Countermeasure in relation to physical installation conditions

Effects of wind can be eliminated by providing an enclosure or finding the optimum installation conditions, for example, distance between the backdrop plate and camera.

② Calculation of snow depth

In the experiment of the present study, focus of evaluation was on snowfall rate (i.e., precipitation as measured by melting snowflakes into water). For management purposes, however, snow depth is also a very important factor in determining snow conditions. It is therefore necessary to measure snow depths using a snow plate or other means, and evaluate the snow depth measurements thus obtained. In addition, a conversion approximation expression to convert measured data into snow depths must be defined.

Literature

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