Detection of Road Surface Conditions in Winter using Road Surveillance Cameras at Daytime, Night-time and Twilight

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Summary
Detection of road surface conditions is a critical issue for safe driving in winter. Because the stopping distance of vehicles on snowy roads is considerably longer than in dry conditions. Conventional detection methods face many problems such as deployment costs and detectable period of time. In this paper, we propose a method for detecting the road surface conditions that is time-independent. The method for detecting the road surface conditions is based on texture features and the Mahalanobis distance by using the road surveillance cameras. It has been concluded that road surface conditions can be identified as wet or snow at daytime, night-time and twilight.

Key words:
Road Surface Condition, Road Surveillance Camera, Image Processing

1. Introduction

Hokuriku in Japan where authors live in, there is known to have the world's heaviest snowfall in winter. The road surface condition in the winter is a significant factor behind traffic safety. Snow or ice on the road works to reduce friction between tires and the road. Longer distances are required for stopping vehicles, which increases the risks of traffic accidents.

In order to know what kinds of information are needed by road users in winter, questionnaire survey was carried out using the Internet. The result is shown in Fig.1, indicating that the information on the road surface condition is most significant. Fig.2 shows the types of information required by drivers on road surface conditions. From the result, it was considered that not only the CCTV camera image but also detailed detection data should be provided to drivers. For providing the information, the detailed detection of road surface conditions is essential.

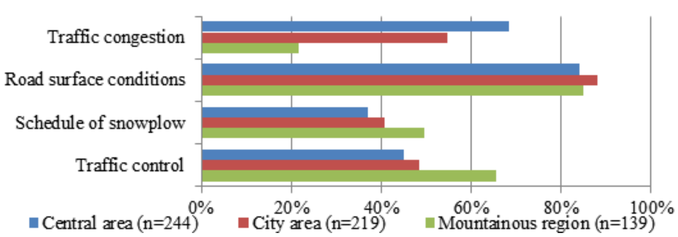

Fig. 1 Road information required by drivers.

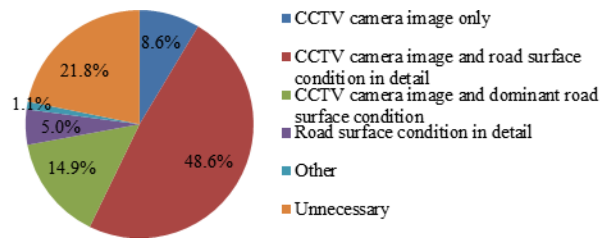

Fig. 2 Types of information on road surface conditions required by drivers.

So far, many researchers have proposed a variety of methods to detect road surface conditions using laser radar and infrared detectors. The laser radar method evaluates road surface conditions based on backscattering ratios for different polarizations, or the time difference necessary for the reflection of the laser [1-2]. In the infrared detector method, several different wavelengths are irradiated onto the road surface and road surface conditions based on the difference in the intensity of the reflected light are computed [3-4]. These methods, however, have not been widely applied for detecting the condition of public highways because of the high deployment costs.

On the other hand, the method using visible cameras does not require expensive equipment, and can, therefore, be the practical solution for detecting road surface conditions. In this method, the particle and direction of the texture or polarization characteristics of the image are used to detect road surface conditions [5-6]. These methods using visible light camera had been used in the daytime only. We had proposed a road surface condition detection method of night with a visible camera [7].

In this paper, we propose a method for detecting road surface conditions in all the time. It was possible by adding the data of daytime and twilight to our method. This method is time-independent and can be used to efficiently detect road surface conditions inexpensively since road surveillance cameras are already installed on public roads.

The CCTV camera used in the experiments is owned by the Ministry of Land, Infrastructure and Transport and Tourism, and has been installed on the test section of public roads. In addition to the camera used for this experiment, CCTV cameras have already been installed at approximately 9,000 locations on national roads throughout Japan [8]. By using images from the CCTV

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camera, this research shows the proposed method is also applicable to detect the conditions of other roads where CCTV cameras have been already installed.

2. Proposed method

In the proposed method, time is defined as follows: daytime is irradiated by sunlight, night-time is irradiated by streetlight and twilight is irradiated by both sunlight and streetlight. First, the road area is extracted from the images captured. Next, the texture feature of the road area is computed. Finally, road surface conditions are detected by using the Maharanobis distance based on the training data set. Fig.3 shows the outline of detection method.

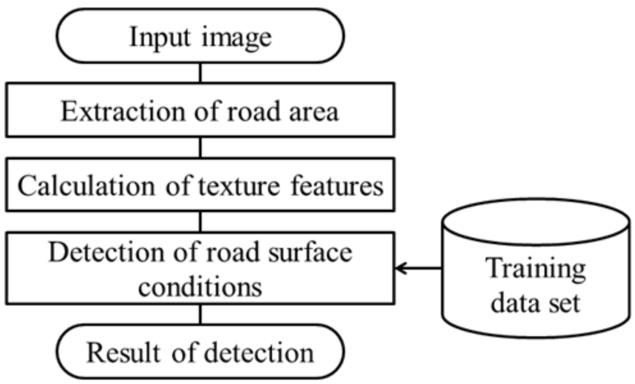


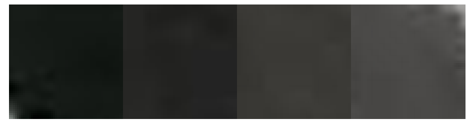
Fig. 3 Outline of detection method.

2.1 Extraction of road area

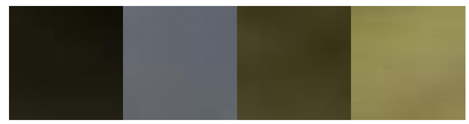
Actual video captured from the CCTV cameras contained noise such as rainfall, snowfall and vehicles. First, it is necessary to remove this noise in order to accurately detect the road surface conditions. Noise reduction was executed by using the time median filtering [9], which calculates the time direction median of each pixel from multiple frames such as video. Moving objects were eliminated, if those are smaller than half a frame.
Second, only the road area was extracted from the images to remove the area outside the road. The proposed method considers that the road area is known in advance because the camera is fixed in the same position and viewing angle. Moreover, the caption for the location name in the image was excluded from the detection area. Lastly, the road area was divided into blocks of 20 x 20[pixels].

2.2 Calculation of texture features

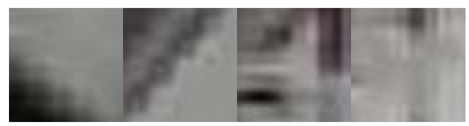
Calculate the texture features of block images in order to quantify the pattern and texture of the road surface. First, intensity histograms are generated from gray-scale block images. Next, texture features are calculated by an intensity histogram method [10-11] of low calculation cost. Fig.4 shows an example of training images. Fig.5 shows an example of intensity histograms of the training image. In Fig.4, wet is dark and smooth image although snow is bright and rough image. Looking at the differences, the index of brightness/roughness chose the texture features of average and contrast/variance, energy and entropy.



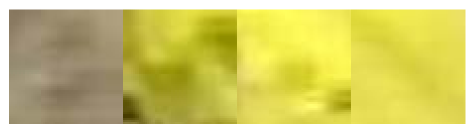
(a) Wet (Daytime).



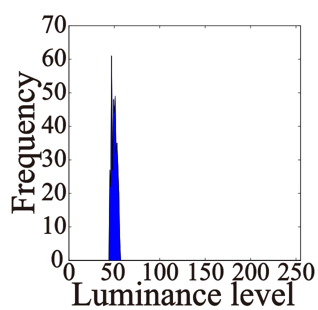
(c) Wet (Night-time).

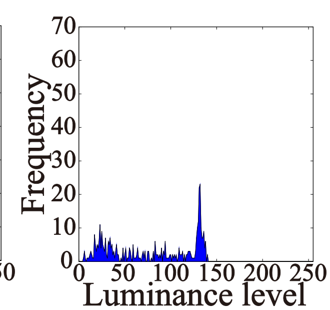


(b) Snow (Daytime).



(d) Snow (Night-time).
Fig. 4 Outline of detection method.





(a) Wet. (b) Snow.
Fig. 5 Intensity histograms of training images.

Considering these characteristics, mean (MEN) and contrast (CNT) of the texture features were selected as the index of brightness, while variance (VAR), energy (EGY) and entropy (EPY) were selected as the index of roughness. These texture features are calculated from the equations (1)-(5), where l is the luminance value and P(l) is the normalization frequency of luminance value l.
In Fig.5, dry and wet areas are represented by the symmetry and the sharp histogram, while snowy is represented by asymmetry and the blunt histogram. From

these characteristics, the skewness (SKW) of texture features was selected as the index of distortion while kurtosis (KRT) was selected as the index of height. These texture features are calculated from the equations (6)-(7), where the STD is the square root of the VAR.

$$MEN = \sum_{l=0}^{255} lP(l) \tag{1}$$

$$CNT = \sum_{l=0}^{255} l^2 P(l) \tag{2}$$

$$VAR = \sum_{l=0}^{255} (1 - MEN)^2 P(l) \tag{3}$$

$$EGY = \sum_{l=0}^{255} P(l)^2 \tag{4}$$

$$ENT = -\sum_{l=0}^{255} P(l) \log P(l) \tag{5}$$

$$SKW = \frac{1}{STD^3} \sum_{l=0}^{255} (1 - MEN)^3 P(l) \tag{6}$$

$$KRT = \frac{1}{STD^4} \sum_{l=0}^{255} (1 - MEN)^4 P(l) \tag{7}$$

2.3 Training dataset generation

The training dataset is generated as a prerequisite for our experiments. First, the texture features are calculated from the training images. A total of 100 training images were used each time, place and each road surface condition. Next, a training dataset is generated from the texture features of each road surface condition in daytime and night-time. It is possible to reduce the effect of sunlight and streetlight at twilight. Fig.6 shows an example of scatter plot of texture features of mean and entropy.

2.4 Detection of road surface conditions

Road surface conditions are detected by the Mahalanobis distance [12] based on the training dataset. The Mahalanobis distance is used to take into account the fact that variance is different for each class (wet, snow) of training dataset. The Mahalanobis distance between texture features of block images and each class of training dataset is computed. The result of the detection is the road surface condition of the shortest class.

3. Experiment

An experiment was conducted using 100 still images taken in two places on a national road during two days. Fig.7-9 shows an example of experimental images. Ground truth was evaluated by visual observation of experts at roadside locations. The blue/white circle in Fig.7-9 (a) represents ground truth of snow/wet. The blue/white square in Fig.7-9 (b) represents the correct detection of snow/wet. The red square in Fig.7-9 (b) represents a false detection.

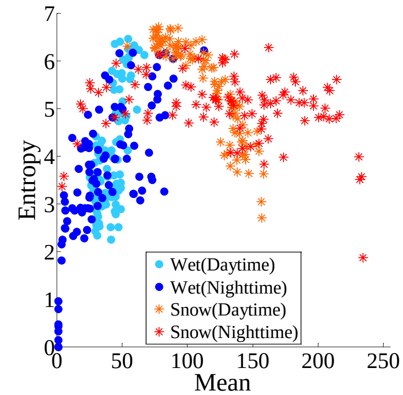
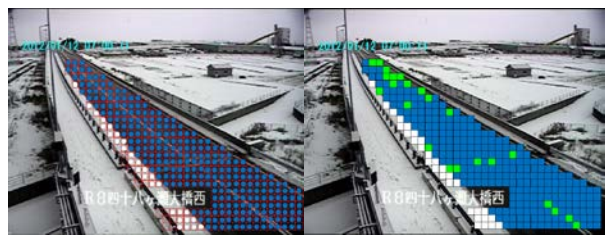


Fig. 6 Scatter plot of texture features.



(a) Ground truth. (b) Detection result
Fig. 7 Experimental images at daytime.

(a) Ground truth. (b) Detection result
Fig. 8 Experimental images at night-time.

(a) Ground truth. (b) Detection result
Fig. 9 Experimental images at twilight.

4. Considerations

From Fig.7, 9 (b), a false detection occurred in the areas of the white line when road surface condition was wet at daytime and twilight. The areas were mistaken for snow with high luminance because the luminance level of the white line is higher than wet. Accordingly, as prior processing, it is necessary to remove the areas of white line from the detection area beforehand.

In Fig.8 (b), a false detection occurred in the areas of far from streetlights when road surface condition was snow at night-time. Areas of low light quantity are likely to cause misclassification because texture features are significantly influenced by the light quantity. Therefore, it needs including new features does not depend on changes in light quantity.

Table 1: Distinction accuracy [%].

Time	Place	Wet	Snow	Total
Daytime	Place A	89.2	82.7	88.6
	Place B	88.0	94.7	
Night-time	Place A	85.5	85.6	77.7
	Place B	66.7	72.8	
Twilight	Place A	75.4	97.5	88.0
	Place B	85.2	93.8	

5. Conclution

This paper proposes a method to detect road surface conditions in winter, which is time-independent and uses road surveillance cameras on the roads. Experiment results show that this method is applicable for daytime, night-time and twilight. As a next step, it is necessary to improve the versatility by conducting experiments in various places.

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