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Algorithm and Experiment for Vision-Based Recognition of Road Surface Conditions Using Polarization and Wavelet Transform

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ABSTRACT

Road surface conditions vary with snow, ice, wet and dry during the four seasons in Korea. The change of the road surface conditions can have significant influence on the safety of a running vehicle on the road. Nowadays, there are a lot of CCTVs that are installed to observe the road surface with the unaided eye, and it is common for an administrator to determine the road surface conditions after confirming visually. However, there is a limitation to quickly determine the road surface conditions manually. Thus there is a need for developing a technology that can automatically determine the road surface based on images. In this paper, a recognition algorithm was proposed to extract the state of road surface conditions based on images obtained by a vision camera, and empirical experiment was conducted. The road surface conditions were classified using histogram and wavelet filter based on the proposed algorithm. In order to verify the recognition algorithm, the asphalt road was recorded and a variety of road surface conditions such as dry, snow, ice and wet was utilized as the input data. First, the road surface condition was distinguished into dry and wet using polarization coefficient, and then the dry condition was distinguished into dry and ice using wavelet and frequency characteristic. As a result of experiment, the possibility of vision-based recognition algorithm of the road surface conditions was demonstrated. In the future, it is expected that a way of road surface control through CCTVs would change from manual to automatic recognition with the introduction of latest technologies.

Keywords: *vision camera, polarization coefficient, wavelet transform, road surface condition, image recognition*

1. INTRODUCTION

Road surface conditions are classified into four categories: dry, wet, snow, icy depending on weather conditions. Nowadays, there are a lot of CCTVs installed to observe road surface conditions with the unaided eye, and it is common for an administrator to determine the road surface conditions after confirming visually. However, there is a limitation to quickly determine the road surface conditions manually due to increases of the number of CCTV video data.

As road conditions vary with weather conditions, a technique that automatically collects the information of the road surface would contribute to the traffic safety. For example, when the road is wet or icy, the road surface condition is automatically detected, the alert information is provided to driving cars, and a road management agency can effectively conduct snow removal.

In general, road surface observation is conducted using CCTV or patrol with the naked eye. Even though there is a method of using a sensor embedded in the road surface at specific point, it is almost impossible to control a wide area because of the high initial cost for installation and maintenance.

Therefore, a technique that can cover a wide area with reasonable cost is needed. In this paper, we propose a method that recognizes the road surface conditions using a common vision camera. In order to verify the recognition algorithm, the proposed method is applied to real road images that includes dry, wet, snow and icy conditions during daytime on the asphalt road.

2. REVIEW OF PREVIOUS STUDIES

The previous studies that are related to this study can be divided into two groups, the use of polarization coefficient and the use of wavelet.

2.1 The Use of Polarization Coefficient

When the light is incident on a highly reflective material, such as the water surface, the reflectance varies depending on the vibration direction of light [1]. At this moment, light in the vertical direction component has higher reflectivity than that in the horizontal direction component. Especially, if the incident angle is less than 53 degrees, known as Brewster's angle, the reflectance is close to zero in the horizontal direction component. Therefore, in the case of using polarizing filter to take pictures of road surface, the difference of reflectance is greater between pictures using vertical direction filter and using horizontal direction filter. On the other hand, in the case of a road in the dry state, there is not much difference of reflectance between the light in vertical direction component and the light in horizontal direction component no difference. Thus, in our study, input images collected with Brewster angle for polarization effect were used, and dry and wet conditions were distinguished using the difference of polarization coefficient.

2.2 The Use of Wavelet

In object recognition using discrete wavelet transformation, Arivazhagan et al. extracted a number of features of the image by decomposing the image into a series of high pass and low pass bands, and classified the texture using the mean and the standard deviation of features [2]. Because this algorithm recognizes the texture

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using gray image, RGB images are converted to YUV, HIS, YCbCr, LUV, YCgCb, YIQ images in order to apply color images.

Another previous research is to analyze the biggest energy in the frequency domain. Using the wavelet packet transformation, the entire frequency domain is divided evenly and all frequencies have the same decomposition level [3].

It is difficult to recognize a rotated texture when the texture has directivity. A study to solve this problem, Jafari-Khouzani and Soltanian-Zadeh proposed a method to recognize the texture of the image after compensation for the rotation [4].

Another approach is to classify the image depending on type of texture using wavelet. In other words, it generates the sub-image blocks from the texture image, calculates the difference between the coefficient values of the adjacent sub-blocks after the two-dimensional discrete wavelet transform. After that, it determines the dividing line by region through the threshold filtering [5].

In this paper, a method to recognize the road surface image was proposed after considering the prior studies, and verified the proposed method through recording the actual road surface and applying the proposed method to the recorded data. Furthermore, suggested system contains image acquisition methods for feature extraction and road surface condition recognition algorithm using feature extraction.

3. ROAD SURFACE CONDITION RECOGNITION SYSTEM

3.1 Road Surface Image Acquisition Method

A digital camera was used to acquire two different polarized light images at the same area. Shooting angle was adjusted to be close to the Brewster angle, 37 degrees, so that the polarization characteristic can appear well. The height of the tripod is approximately 1.6m, angle of the eye is taken at 30~45 degrees, as shown in Fig 1. The camera lens used in the experiment was 35mm that has a similar angle to the human vision. Also, gray scale images were acquired. Object distance was set to be short in order to analyze the texture of the road surface clearly.

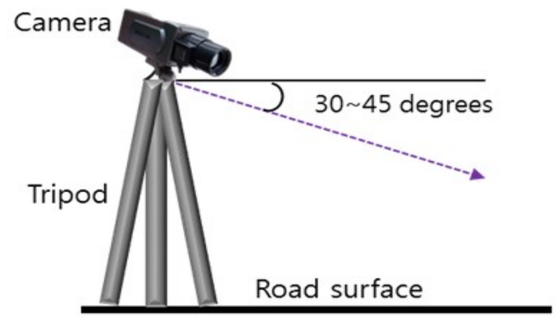

Fig 1: Road surface image acquisition method

3.2 Road Surface Condition Recognition Algorithm

The polarization coefficient values in the vertical polarization image and the horizontal polarization image are calculated from the road image obtained by image capturing apparatus. Using these values, wet surface is distinguished by dividing the region having bigger reflectance and the region having smaller reflectance. At the same time, a horizontal polarized image is used to obtain wavelet coefficient through the wavelet packet converter, and the coefficient is used to divide into snow, freezing, and dry road surface by classifying the texture of road surface.

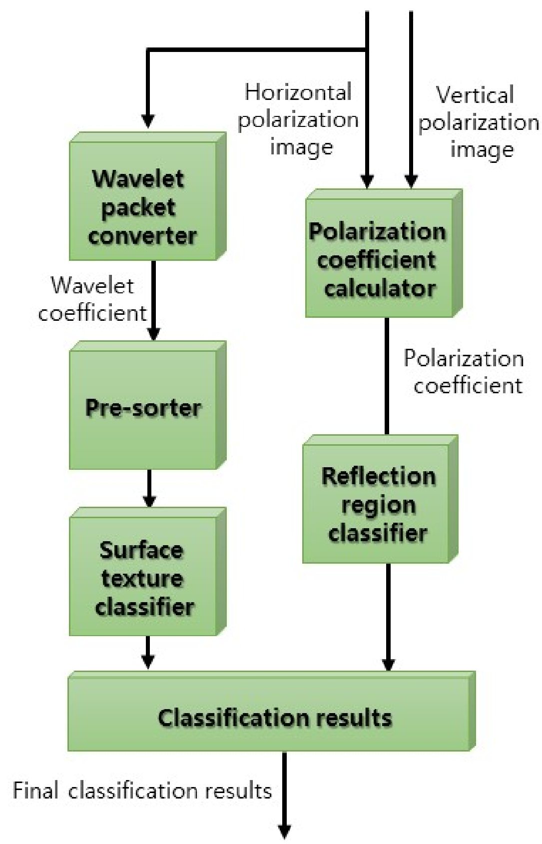

Fig 2: Road surface condition recognition process

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3.2.1 Estimation of Polarization Coefficient

In the result of image analysis, the polarization characteristics appears well in the wet road, so the vertical polarization images appear bright while the horizontal polarization images appear dark characteristics. On the contrary, there is a little difference between vertical and horizontal polarization images because there is no polarization characteristics in dry areas. The polarization coefficient is calculated as follows:

$$H = \frac{I_v}{I_h}$$

where,

I_v: vertical polarization component,
I_h: horizontal polarization component,

Polarization coefficient H ranges from 1 to ∞. The value of H for snow or dry surface with no polarization characteristics is close to 1 while H appears over 1.5 for the wet surface. The values close to 1 are calculated from the dry areas and others are calculated from wet areas.

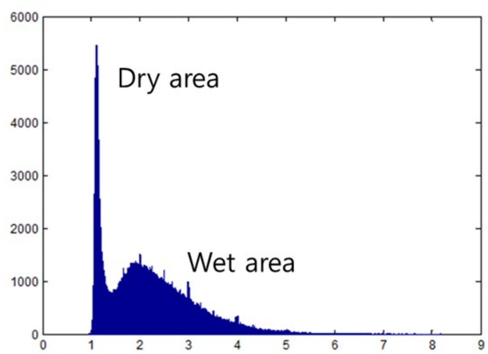


Fig 3: Histogram of polarization coefficient

3.2.2 Reflective Area Classification

After setting a specific threshold (γ), it can be used to divide into two groups, the highly reflective areas having greater reflectivity than γ and the no reflective areas having smaller reflectivity than γ. In the result of experiment, the wet areas of the road had a large polarization coefficient, and less reflective areas such as dry, snow, icy have the value close to 1. Therefore, it can be verified that it is possible to distinguish only wet areas using the polarization. The reasonable range of γ was 1.2 to 1.5, and 1.3 was applied as γ in this paper.

3.2.3 Wavelet Transform and Pre-Sorter

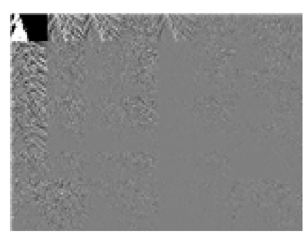
Haar wavelet filter is used to speed up the operation of the recognition algorithm. Snow region in the input image appeared a low frequency part, and other no-snow regions appeared asphalt road surface texture due to a lot of high frequency regions. Icy region existed between snow region and dry region and appeared intermediate frequency.

Snow region appeared the low frequency pattern after primary wavelet transform, the frequency of icy region was relatively higher than that of snow region, and the frequency of dry region was relatively higher than that of ice region. The wavelet transform is applied in the signal and image processing because it is faster than the existing signal processing algorithms based on Fourier transform. The wavelet transform was applied as follows.

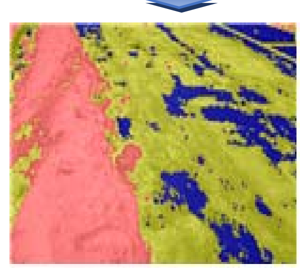
$$(T^{wav}f)(s,\tau) == W_{\varphi}(s,\tau) = |s|^{-1/2}\int f(x)\varphi(\frac{t-\tau}{s})d_x$$

It is possible to obtain a wavelet coefficient vector for each 8*8 block from the result of wavelet packet transform, and the vector is again classified into four clusters using k-means clustering method. Next, the process of pre-sorter is to determine that each cluster represent which condition of the road surface with corresponding the center of each cluster to one of dry, wet, ice and snow surfaces. The advantage of using pre-sorter is to obtain a stable classification performance rather than using each block directly for classifying a surface, and it is possible to distinguish road surfaces by the road surface texture through the wavelet transform and the pre-sorter process for the original image.

(a) Original image



(b) Wavelet transform image



(c) Wavelet Pre-sorter

Fig 4: Wavelet transformation image

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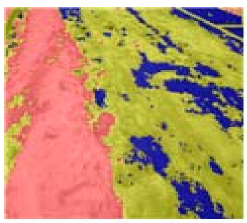
3.2.4 Surface Texture Classification

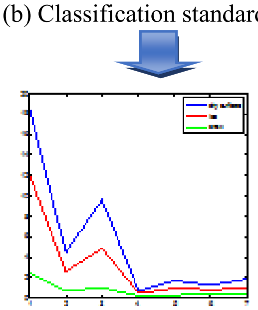
From only the above results, we cannot know that each cluster corresponds to which one among dry, wet, ice, and snow surfaces. Thus it is necessary to figure out the characteristics of the wavelet coefficients for each surface in order to determine the state of surface. For this, a graph was expressed by the average of the wavelet coefficients by templet after acquiring surface templet from recorded images.

The dry and snow areas could be clearly distinguished using wavelet coefficient. However the ice and dry areas were difficult to distinguish relatively. Thus, the distance between average wavelet coefficient obtained from templet and average coefficient of original cluster was calculated to solve this problem. As a result, the dry, snow, and ice for each cluster were displayed in white, blue, and red, respectively.

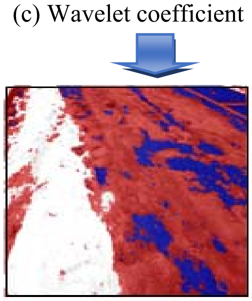


(a) Wavelet pre-sorter

(b) Classification standard



(c) Wavelet coefficient



(d) Texture classification result

Fig 5: Wavelet transformation of image

3.2.5 Road surface Condition Classification

As seen from above, it is possible to distinguish the road surface using both polarization effect and wavelet transform. Therefore, the road surface can be classified into four types, dry, wet, snow and ice considering with the polarization and frequency characteristics. The polarization characteristic is used to separate the wet and dry surfaces, and also wavelet characteristic is used to separate the dry and snow or dry and icy surfaces.

Table 1: Road surface condition classification

Road surface condition	Polarization coefficient(γ) characteristic	Frequency characteristic	Road condition decision criteria
Dry	$\gamma \leq 1.3$	High frequency	Relatively higher
Wet	$\gamma > 1.3$	-	Primary decision with γ
Snow	$\gamma \leq 1.3$	Low frequency	Relatively lower
Ice	$\gamma \leq 1.3$	Intermediate frequency	Relative distance

3.3 Road Surface Condition Viewer

The viewer was coded in MATLAB, and it consists of command key for loading horizontal polarization and vertical polarization image, image display window, and recognition result window at bottom right. The original images are stored in the same path as BMP format. As the recognition result, the program is designed to express each condition in a different color. Blue, green, white and red correspond to wet, dry, snow, and ice condition respectively.

After obtaining the vertical and horizontal polarization images, as a result of the wavelet transform, dry condition is shown in green and wet condition is shown in blue. As shown in Fig 6, the wet condition by the print of wheels was recognized as blue accurately.

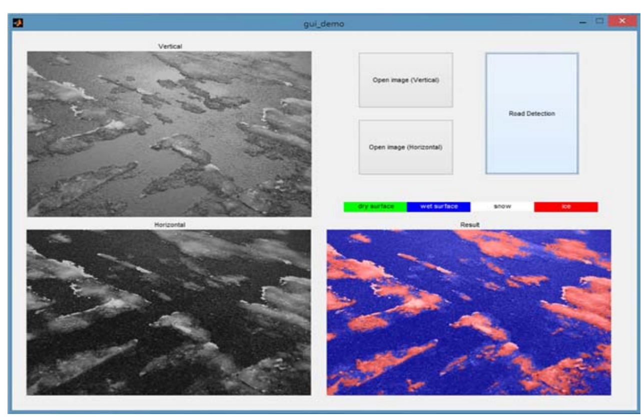


Fig 6: Initial screen of road surface recognition system

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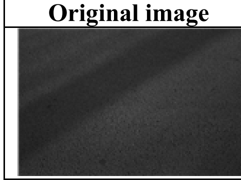
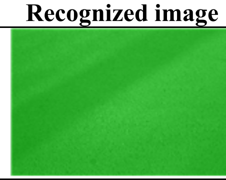
4. ANALYSIS OF RECOGNITION RESULTS

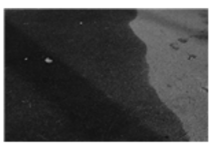
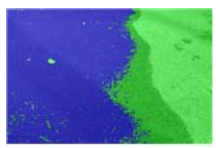
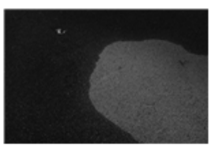
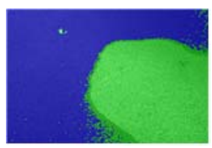
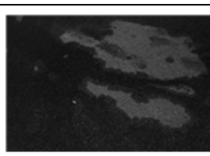
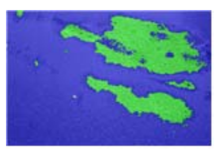
As a result of applying the proposed algorithm, it showed good recognition results. It showed almost exact classification results even though the complicated images mixed by snow, icy, and road surfaces, and it confirms that it is possible to accurately obtain the road surface conditions by only the camera image.

4.1 The Result of Road Surface Recognition by Condition

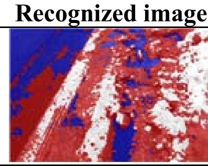
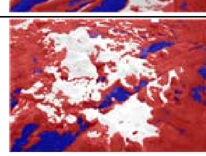
4.1.1 Dry Road Surface Condition

Original image	Recognized image	Result
		Dry road surface condition appeared as green exactly

4.1.2 Dry and Wet Road Surface Conditions

Original image	Recognized image	Result
		Dry and wet road surface were shown as blue and green
		Wet and dry areas were separated clearly
		Wet area in dry region was recognized exactly

4.1.3 Snow and Wet Road Surface Conditions

Original image	Recognized image	Result
		Snow and wet areas were separated, but snow and lane were not distinguished
		Snow and wet areas were separated, and snow and lane were distinguished
		Snow and wet areas were separated, but snow and lane were not distinguished

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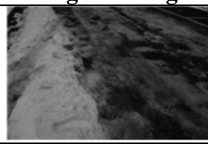
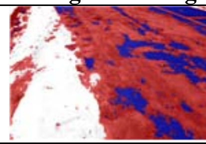
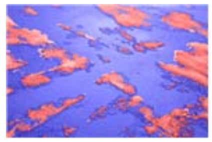
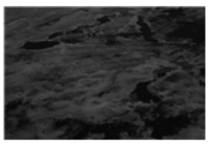
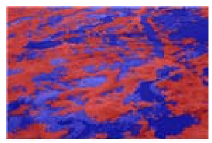
4.1.4 Snow, Icy and Wet Road Surface Conditions

Original image	Recognized image	Result
		Snow and icy areas were classified, and wet area appeared as blue
		Icy and wet areas were recognized exactly
		Icy and wet areas are classified accurately

4.2 Implications of the Recognition Results

The proposed algorithm worked well regarding a variety of road surface conditions overall. It showed precise classifications even though various road conditions are mixed, and it can be said that the road surface conditions can be identified with only visual cameras. In other words, road surface condition can be recognized automatically through CCTV installed on the roads, and also it can be applied to ITS (Intelligent Transport Systems) with continuous research efforts based on the proposed algorithm.

There are two limitations in this study. First, it cannot distinguish lane markings from snow area. Second, recognition error occurred regarding various icy conditions. As shown in the experiment results, since the lane marking have similar polarization and frequency characteristics depending on the circumstances, the accurate distinction was not possible by using only the proposed algorithm. Also, over-detection happened on icy road because the polarization effect does not appear in dark environment such as wet road surface or ponding.

The problem about lane markings can be solved by removing lane information through a pre-processing, and over-detection problem on icy surface can be solved by using more precise frequency analysis. In addition, it is necessary to pre-input much accurately frequency characteristics of icy and wet road surface.

5. CONCLUSIONS

In this study, an algorithm that classifies road surface conditions such as wet, dry, snow, and ice was proposed. The ratio of horizontal polarization component to the vertical polarization component was calculated. As the polarization coefficient was over 1.3, the road was classified as wet condition. Snow road surface was classified after wavelet packet transformation. Also, standard frequency characteristic was drawn between dry and ice road surface using image templet. Finally, the proposed algorithm worked well regarding variety of road surface conditions overall and it can be proved that the road surface conditions can be recognized through the image.

In order to improve the recognition performance of the road surface, lane recognition and pre-classification will be have to interface with the temperature and humidity information. Furthermore, it is necessary to research for recognition performance improvement for concrete road surface in addition to asphalt road, night light or no-light condition, and introduction of high quality frequency analysis.

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REFERENCES

[1] M. Yamada, T. Oshima, K., Ueda, I., Horiba, and S. Yamamoto, A study of the road surface condition detection technique for deployment on a vehicle, JSAE, Vol. 24 (2003), 183~188.

[2] S. Arivazhagan, L. Genesan, and V. Angayarkanni, Color texture classification using wavelet transform, In proceedings of the Sixth International Conference on Computational Intelligence and Multimedia Applications, ICCIMA IEEE (2005).

[3] M.-C. Lee and C.-M. Pun, Texture classification using dominant wavelet packet energy features, Image Analysis and Interpretation, 2000, In proceeding of 4th IEEE Southwest Symposium (2000).

[4] K. Jafari-Khouzani and H. Soltanian-Zadeh, Radon transform orientation estimation for rotation invariant texture analysis, IEEE Transaction on

Pattern Analysis and Machine Intelligence, Vol. 27, No. 6 (2005).

[5] S. Arivazhagan, L. Genesan, L., and V. Angayarkanni, Texture Classification Using Wavelet Transform, Pattern Recognition Letters 24 (2003).

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