Vol. 4, No. 10 October 2013 ISSN 2079-8407
Journal of Emerging Trends in Computing and Information Sciences

http://www.cisjournal.org

A Study on Development of Mobile Road Surface Condition Detection System Utilizing Probe Car

[1*] Youngmin Kim, [2] Namcheol Baik, [3] Jonghun Kim
[1, 2, 3] Korea Institute of Construction Technology, Goyang-city, Korea
[1] ymkim1007@kict.re.kr, [2] nc100@kict.re.kr, [3] kjh4004@kict.re.kr

ABSTRACT

With the winning of the 2018 Pyeongchang Winter Olympics bid, Korea is now faced with the technology development for the winter road management system. Meanwhile, a review of the types of traffic accidents in Korea revealed that traffic accident fatality due to bad weather conditions is very high, and it is required to provide accurate information about road surface condition as safety information to the driver. This study is aiming at devising a road surface condition detection system utilizing on-road vehicles (probe car). With probe car based road condition detection system, it is possible to expand the coverage of road condition information detection. Toward this end, this study attempts to design and establish the road surface condition detection system by using the image processing. With image processing, it is possible to detect road surface condition with relatively low-cost. In this study, we implement stereo camera-based mobile image processing system to detect road surface condition with moving vehicle. This system can distinguish road condition to four status : dry, wet, snowy, icy.

Keywords: *Road surface monitoring, Image processing, Stereo camera, Polarization, Wavelet Transform*

1. INTRODUCTION

Since the 1980s, the rapid dissemination of automobiles has been made in Korea, which was once the country with highest traffic accident rate in the world. With the formulation of various measures to reduce traffic accident after the 1990s, the number of traffic accidents in 2012 further decreased compared to that of the 1980s. However, Korea still ranks high on the list of the traffic accidents based on OECD standards. In a related move, various means for improving traffic safety have been established. Meanwhile, the development of intelligent transportation system (ITS) started from the field of information provision and traffic flow status improvement to relieve traffic congestion in the early stage. However, the continuous development of society has stimulated discussions on ‘quantitative spread’ of contents provided by ITS as well as ‘qualitative expansion’. That is, ways to apply ITS for reduction of traffic accidents to the field of road traffic safety improvement is actively sought. For instance, securing of safe mobility right, based-on the utilization of ITS, has emerged as a major agenda even in national-level transportation plans, and there has been continued demand for technologies related driving support.

Meanwhile, need for acquisition of advanced winter road management capabilities and development of related technologies have been raised for a successful hosting of the upcoming Pyeongchang 2018 Winter Olympics. In transportation planning of the Pyeongchang Winter Olympics, movement through the road is expected to be absolutely critical. In this light, collection of real-time road surface condition data on entire road section monitoring level needs to be facilitated the progress of the competition (movement of athletes, media groups and visitors to stadiums within 30 minutes). To this end, development and application of related technologies have been strongly proposed [1].

Fig 1: 2018 Pyeongchang Winter Olympics transportation plan

In this regard, this study directs its attention to road surface condition information (information about the state of the road surface) as a methodology to help achieve advancement of traffic information services and road management capabilities. If the condition of the road surface that changes frequently is collected and provided by utilizing high technologies, advancement of management capabilities that enables real-time examination of dangerous road sections or sections that require snow removal will be achieved in terms of road management. Accordingly, this study attempts to develop a system that can detect road surface condition on all sections of the road continuously. After establishing the system to detect the road surface condition in real time by utilizing moving vehicles (probe cars), the success rate of detecting and recognizing the four conditions of the road surface (wet, dry, snow and icy surfaces) is tested and analyzed.

2. REVIEW OF TECHNOLOGY TRENDS FOR ROAD SURFACE DETECTION

In this section, we review the leading researches and development practices on the mobile-based road surface condition information sensing. In Korea, there is a study case for developing a pre-estimate methodology of the surface friction coefficient for improving mobility of the robot [2]. In the research, the robot can estimate the friction of the ground with extracting information that is represented as material composition ratio from image obtained from the front of a mobile robot (robot's eye, camera based). After determination of textures using Textron, a segment was generated by merging terrain images partially through discriminating the similarity of textures. The friction coefficient was estimated by creating the material composition ratio of the new visual information by utilizing a Bayesian classifier after calculation of the material composition ratio through image learning with six materials (sky, earth, pebbles, gravel, wood and asphalt). For the evaluation of the estimated friction coefficient, a comparison with the friction coefficient which was directly measured by using a load cell was made. Test results showed that the error rate of the friction coefficient estimation was 4.1%, showing improvement by 20% compared to the existing pre-estimation methods (slip estimation method utilizing geographic information).

In Northern Europe, where is the region of very low temperature and many snowfalls in winter, various studies for the road surface condition detection has been conducted. Among these studies are research and development (R&D) practices for collection of road surface condition information of section unit. There is a research using stereo camera to determine the road surface conditions in real time from moving vehicles [3]. To replace the expensive laser-based portable road surface condition detection sensor, the system was developed a stereo image-based vehicle-mounted system, utilizing an analysis of polarization properties and graininess, and identified its applicability for road monitoring purposes. A comparative evaluation with existing expensive laser-based equipment (Vaisala DSC111) was conducted by applying an algorithm to determine the road surface conditions to the IcOR stereo camera (640*480 pixels). As a result, more than 90% accuracy was identified in detection for icy road surface.

In Sweden, Swedish Road Administration and VTI (the Swedish National Road and Transport Research Institute) proceeded with a research project titled IVSS (Intelligent Vehicle Safety Systems). In the IVSS project, a methodology to determine the road surface conditions utilizing the movement of vehicles was developed. The methodology, which was named SRIS (Slippery Road Information System), was designed to collect environmental information of a point at which vehicles are driving, movement information of the point by utilizing built-in systems related to slip movement (ESP, ABS, etc), and external environment measurement sensors (outdoor temperature sensors, wiper operation sensors, etc.). A technology to separate the road surface conditions into a total of five steps (non-slip, rainfall, cold rain on the road, icy, and icy due to frost) by combining the above information with weather information of weather observation points. For verification of the system, tests were conducted by utilizing 100 probe cars on the road around Gothenburg and Stockholm between 2007 and 2008. Test results showed a high potential of commercialization of the system [4].

In Hokkaido, Japan, the Civil Engineering Research Institute for Cold Region (CERI) utilized CFT (Continuous Friction Tester), for road maintenance and management. Originally, the CFT was designed to measure friction of an airport runway. However in Japanese case, the CFT has been utilized to acquire information about sliding status of main roads in real time when attached to the rear of the vehicle. The location information of the point where road management vehicles are operated was acquired by the GPS sensors, and it was transmitted to a central control station, along with road status information determined by the CFT. Managers working in a road traffic control center utilized this information to determine the need to implement snow clearings in a specific road [5].

Table 1: Technology development practices for mobile-based road surface condition detection

Researchers	Equipment used in the research	Key methodologies	Features
Doo-gyu Kim (2010)	Cameras	Estimation of the friction coefficient through application of a Bayesian classifier utilizing images	Verification of the estimation results by utilizing load cell
Maria Jokela (2009)	Stereo camera	Image processing by utilizing the polarization characteristics and texture graininess analysis	Verification through utilization of existing expensive equipment
IVSS (2008)	Sensor inside the car (ABS, ESP, outdoor temperature	Estimation of the road surface conditions by utilizing car movement and	Transmission of estimation results to a central control

	sensors, etc.)	environmental information	center
CERI, Japan	CFT (Continuous Friction Tester)	Direct measurement of the friction coefficient and estimation of the road surface conditions	Transmission of the estimation results to a central control center and utilization in the road management

3. SYSTEM DEVELOPMENT

3.1 Concept of Mobile Road Surface Condition Detection System

This study attempts to develop a probe car-based road surface condition detection system that can perform road surface monitoring on the entire section on the road, not a specific section, by utilizing the image processing. A review of related technology development trends revealed that the application of a methodology to determine road surface conditions by image processing was the best solution in terms of system construction cost (possible to implement a low-cost system by utilizing general-purpose cameras) and system maintenance (possible to minimize hardware maintenance costs as a software-intensive system).

The mobile road surface condition detection system developed in this study was designed to divide the road surface status into a total of four conditions (dry, wet, snowy, and icy) through analysis of the polarized images after image acquisition with a stereo camera. Actually, it was similar to the system implemented by [3], but it could be said a more advanced system because it considers environmental conditions during the process of determination. For a more detailed description of the system, the 'introduction to algorithms' in Section 3.2 introduced an algorithm to determine road surface conditions by utilizing the image processing, the heart of the system. And the 'system configuration' in Section 3.3 described technologies applied to implement the image processing algorithm and detailed hardware components that make up the system.

Fig 2: Mobile road surface condition detection system

3.2 Introduction to Algorithms

In this study, we apply image processing algorithm to determine the road surface condition. In the image processing algorithm, the polarization properties of the light hold the major part of the theory [6, 7, 8]. Since the light has an electromagnetic characteristic, it proceeded to make the wave motion. If this light was passed though a polarizing filter, it would be decomposed into components with specific wave motions. Horizontally polarized light (in case there exists only a horizontal component when the light is polarized) and vertically polarized light (in case there exists only a vertical component when the light is polarized) have properties in which horizontally polarized light was absorbed, not being reflected in the boundary surface with different characteristics in specific angle of incidence, called Brewster's angle. The Brewster angle on the surface of the water is about 53 degrees (37 degrees compared to the ground). When the surface with the water is photographed with vertically/horizontally polarized light under the condition that is consisted to the Brewster's angle, a difference in brightness between two images occurs. By utilizing this property of the light, the wet area on the road surface can be detected through image processing that compares the differences in brightness between images photographed with vertical polarization and horizontal polarization.

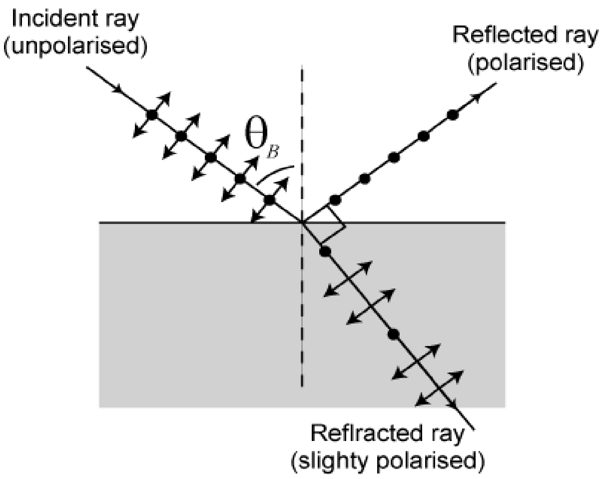

Fig 3: Polarization properties of the light in Brewster's angle

Vol. 4, No. 10 October 2013 ISSN 2079-8407
Journal of Emerging Trends in Computing and Information Sciences

http://www.cisjournal.org

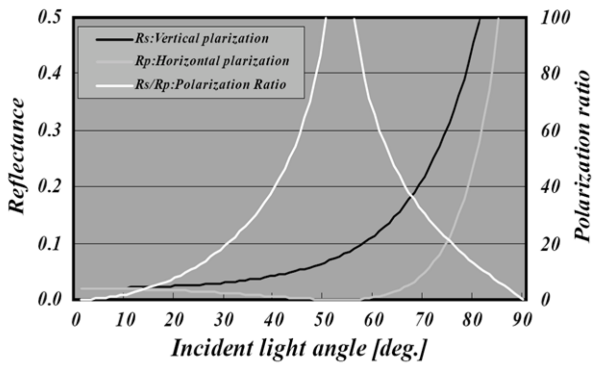

Fig 4: Reflectance curve for incident polarization on the surface of the water (Yamada et al. , 2003)

Meanwhile, a texture graininess analysis methodology that utilizes the wavelet packet transform was applied to distinguish dry/snowy/icy road surfaces. The wavelet transform could divide an image into several sub-band images that contain the image. Since the original image can be analyzed without an error by synthesizing each Sub-band through the wavelet transform, it has been widely utilized as a texture analysis solution. Through the wavelet transform, the wavelet coefficients were extracted from the image. The following Table 2 shows the road surface classification standards used in this study. External environmental conditions (determined as snowy and icy road surfaces only in sub-zero conditions) were added to the image processing techniques utilizing the wavelet transform as shown below.

Table 2: Road surface classification standards for study

Road surface conditions	Polarization properties	Temperature	Wavelet characteristics
Dry surface	Polarization coefficient ≤ reference value	Normal temperature	Relatively higher high-frequency components
Wet surface	Polarization coefficient > reference value	Normal temperature	-
Snowy surface	Polarization coefficient ≤ reference value	Below zero	Very large DC component, and almost no remaining components
Icy surface	Polarization coefficient ≤ reference value	Above zero	Relatively even distribution of high-frequency components

The image is classified by utilizing the K-means clustering technique to the image obtained through the camera. The K-means clustering technique is a method to minimize the variance between each cluster and distance as the algorithm that binds given data with k-number of clusters. If the center of the i-th cluster is assumed to be X_i, and the set of points that belong to the cluster S_i, the total variance is calculated as follows.

$$V = \sum_{i=1}^{k} \sum_{j \in S_i} |x_j - X_i|^2$$

The objective of the algorithm is to find out S_i that minimizes the above value. The algorithm starts from setting the initial X_i randomly and repeats the following two steps.

- Cluster settings: For each point, the closest cluster to the point is sought and allotted.
- Readjustment of the center of the cluster: X_i is the reset by the average value of points in each cluster.

In case the cluster is not changed, repetition is stopped, and if it is changed, the same process is repeated until the cluster does not change. In this study, the wavelet coefficients extracted from images are classified by utilizing the K-means clustering method, and an algorithm is designed to classify the road surface status into three road surface conditions (dry, wet, snowy and icy surfaces) by utilizing an image.

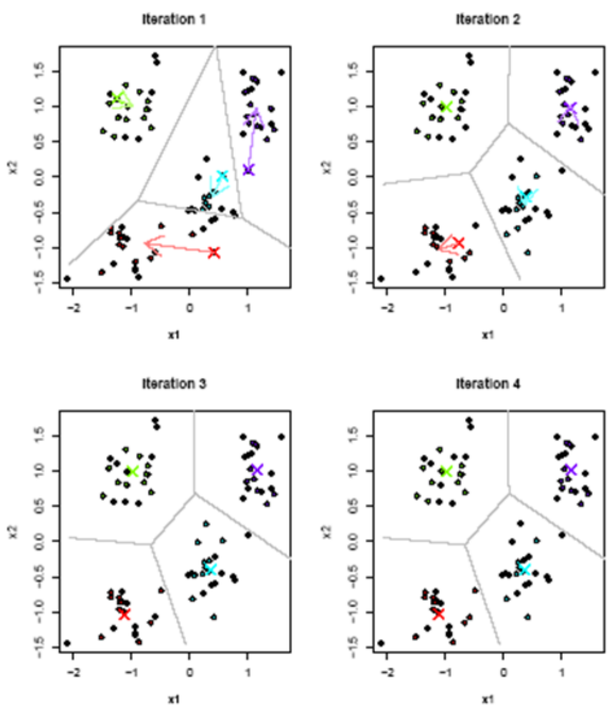

Fig 5: Classification process utilizing K-means clustering

Vol. 4, No. 10 October 2013 ISSN 2079-8407
Journal of Emerging Trends in Computing and Information Sciences

http://www.cisjournal.org

3.3 System Configuration

In this study, we develop a probe-car based road surface detection system with image processing algorithm which mentioned in Section 3.2. For driving the image processing, the system must gather horizontal polarized image and vertical polarized image for same road surface simultaneously. To fill up this requirement, we introduce a stereo camera module to image collection unit of the system. Originally, the stereo camera is used to measure the distance utilizing image processing. However, in this study, we select it as an imaging collection module in that stereo camera can obtain two synchronized images at the same time. In the image collection module, polarization filters are attached in front of the lens of stereo camera module, for collect horizontal/vertical polarized images.

In addition, GPS module is attached to store image collecting locations, and temperature sensors (atmospheric temperature measurement sensor and non-contact type temperature sensor for direct photographing of road surface temperature) and humidity sensors were added to the system configuration to utilize external environmental information (temperature and humidity) in determining road surface conditions. Meanwhile, connection with ECU (Electronic Control Unit) is tried by utilizing vehicle's OBD-2 terminals under the judgment that movement information of the car and ambient air temperature information of vehicles could be extracted from the vehicle platform, but this method is not utilized in the process of determining the actual road surface conditions since the number of variables possible to be utilized in the security level of OBD-2 step was limited.

Operation of the image processing algorithm and control of the entire system are achieved by an exclusive program installed in image processing module (laptop computer). In implementation of the camera control functions, a control function to adjust the brightness of the image that is changed depending on weather and time is implemented. The control elements include automatic exposure control On/Off, shutter exposure time control, RGB gain control, and synchronization of the brightness between left/right-side cameras. In addition, stereo matching function is implemented to compensate for inconsistency (inevitably occurred since the baselines were separated from each other) of photographing location between left/right-side images of the stereo cameras.

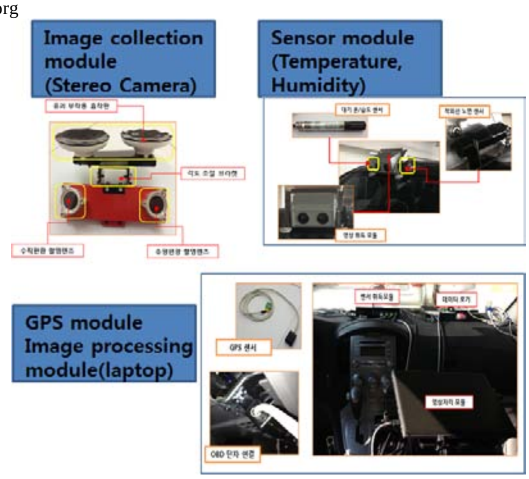

Fig 6: System configuration

Meanwhile, the program is designed to ensure identification of results on the particular part among acquired images by setting the region of interest (ROI) in operation program. Based on this program, surveillance area could be set by avoiding the area that was not the road during vehicle operations. On the program, the detect result of road surface ROI is shown as the image, which consists of 4 colors. (Dry: grey, Wet: blue, Icy: red, Snowy: white)

Fig 7: Representation of ROI for image processing

4. SYSTEM INSTALLATION ON PROBE CAR AND FIELD TEST

4.1 Selection of Mounting Location for Image Collection Unit

Selection of equipment mounting location in probe car is important issue for mobile sensing system. It was required that the image collection unit that needed to acquire images under the road conditions in bad weather should acquire a clear image of the road for image processing. And image collection unit must have sufficient collection performance even when exposed to bad weather environment. To select the install location of image collection unit, we considered both interior installation and exterior installation. The test results are summarized as in the following Fig 8 and Fig 9.

Vol. 4, No. 10 October 2013 ISSN 2079-8407
Journal of Emerging Trends in Computing and Information Sciences

http://www.cisjournal.org

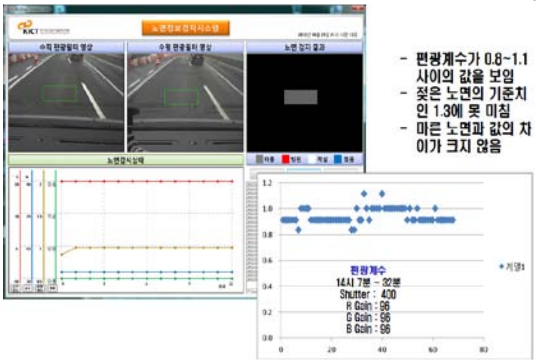

Fig 8: Distribution of polarization ratio (Mount location: interior)

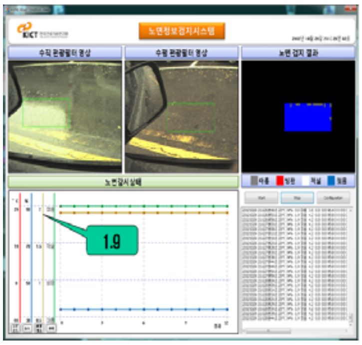

Fig 9: Distribution of polarization ratio (Mount location: exterior)

We focused the effect to polarization ratio (the brightness difference between horizontal polarized image and vertical polarized image) according to unit installation location. As identified in Fig 8, in case the image collection unit was mounted on the interior, polarization properties of light could not be utilized since the values of the polarization ratio fell significantly due to the effect of the front glass. In particular, it was confirmed that the diffuse reflection of windows led to the degradation of collected images, resulting in the difficulty of its application to image processing. On the other hand, when the image collection unit was mounted on the outside of the vehicle as shown in Fig 9, the values of polarization ratio were normally obtained, like the theory. And quality of image was sufficient enough to conduct image processing. Unlike study case of [3], we decided to install image collection module outside of the car, with sealed waterproof case and finishing the lens contacts with UV filters. And we attach environmental sensor module on the waterproof case, to detect the road surface temperature directly. To mount the image collection module on the rooftop of car, we use four suction pads, to minimize the effects of the vibration.

The point of equipment installation on the rooftop was determined in which fulfill the Brewster's angle condition and minimization of interference with the vehicle bonnet. We selected Hyundai Grand Starex model as a probe car. Fig 10 shows installation conditions of image collection module (and sensor module, also). The part in which the most accurate surveillance was made was approximately 5.5m ahead of the installation location, and it was confirmed that the point about 10m ahead of the vehicle could be monitored, considering the angle of view of the lens.

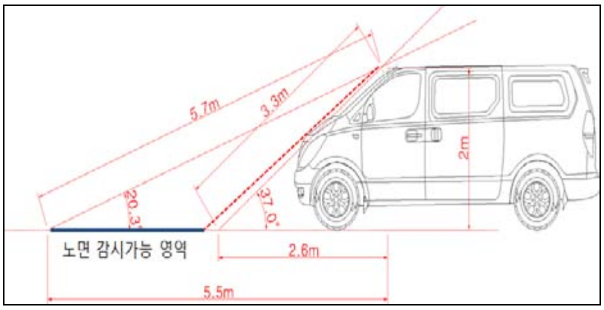

Fig 10: Conception of installation of image collection module

4.2 1st Field Test

The primary field test was performed by utilizing the systems installed in the probe cars to check the smooth running of the algorithm. The first test focused on whether dry and road surfaces were clearly distinguished in the environment where the vehicle was running. In the first test conducted in November 2012, the test was performed by increasing the speed of the probe car up to 50km/h. Test results showed that an algorithm to detect wet road surface due to the difference of polarization was carried out smoothly even under the environment where vehicles were driven. However, as the driving speed was faster, the blur phenomenon of images increased, and the images could not be collected in the wet road surface reproduction section due to the limitation of collection period (1 second). (See the following Fig 12 and Fig 13) Meanwhile, it was found that the change in the polarization coefficients in the region of interest according to the driving speed was small, which indicated that detection performance of the equipment was dependent on the performance of camera's shutter speed.

Fig 11: 1st field test (2012.11.)

Vol. 4, No. 10 October 2013 ISSN 2079-8407
Journal of Emerging Trends in Computing and Information Sciences

http://www.cisjournal.org

Fig 12: Wet road surface detection
(Screen capture, driving speed: 0km/h)

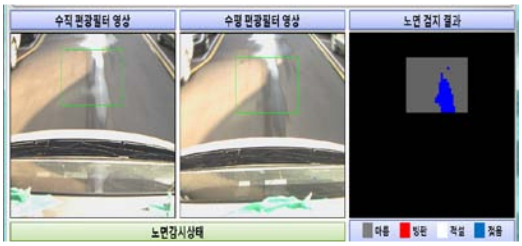

Fig 13: Wet road surface detection
(Screen capture, driving speed: 50km/h)

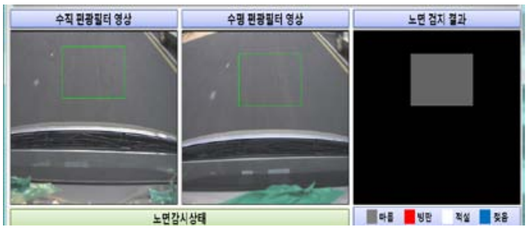

Fig 14: Dry road surface detection screen

Meanwhile, additional tests for the snowy and icy conditions were performed in December 2012 since there was no snowy during the first test period. However, even in this case, the tests were carried out only about stationary status due to the failure to plenty driving space. The purpose of the test was to determine the discrimination of an algorithm to determine wet/snowy/icy road surfaces by utilizing the wavelet transform among the image processing algorithms. A comparative analysis between image processing results that utilize systems and confirmed by the naked eye was conducted with snowy and icy road surfaces as targets. Fig 15 shows the results of image processing on the snowy road surface. Most of the ROI was normally determined as snowy area. However, some wet areas were detected in pixels, which was due to the road snow melting or error that occurred during the matching process of stereo images.

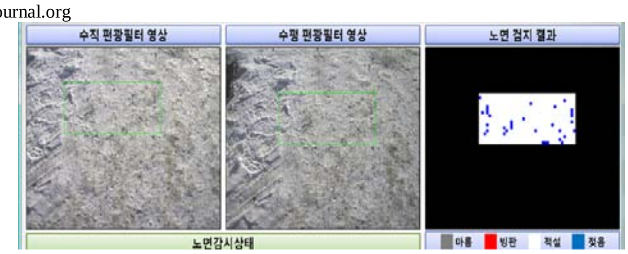

Fig 15: Snowy road surface detection screen

Fig 16 shows the results of image processing on the icy road surface. A large portion of the bottom of the left side of the ROI with obvious signs of freeing was determined as the icy area, and the part that partially melted away in the sun was found to be the wet area.

Fig 16: Icy road surface detection screen

Test results showed the high applicability of the system. Based on the results, the plans to perform system verification were established in relation to driving conditions on the road during winter months when various road surface conditions existed.

4.3 Performance and Review of the 2nd Field Test

The test on the actual road with winter conditions where consist of snowy and icy road surfaces was carried out on the premises road of the Korea Institute of Construction Technology in February 2013. In consideration of road environment and safety of vehicles, the highest operation was limited to 30km/h, and a total of 174 images were acquired as samples. On the day of the test, the weather was clear and dry, but the temperature was very low.

Test results showed that detection rate of 95% or more was found under the wet road surface, and the detection rate of 85% or more in snowy road surface. However, the low detection rate of 30% was found under the icy road surface.

Table 3: Field test results

Segment	Total	Dry road surface	Wet road surface	Snowy road surface	Icy road surface
Number of classification	174	37	66	38	33
Number of successes	143	36	63	33	11
Number of failures	31	1	3	5	22
Detection rate	82%	97%	95%	87%	33%

The above results found that the improvement of detection rate on the icy road surface was required to enhance the completeness of the system. In the image processing algorithm, icy road surface was distinguished by a texture analysis, which was configure to make classification utilizing the smooth texture of a frozen road (frequency distribution was due to characteristics of the wavelet coefficients). However, there exist many cases where these characteristics did not appear in icy road surface that occurred on the actual road. Meanwhile, since it was often difficult to determine the icy road surface immediately with the naked eye, an intensive review on this matter was required in future modification and complement of the image processing algorithms.

4.4 Performance Evaluation Based on Lab Test

With the field test in February 2013, the performance of the probe car based system can be estimated roughly. To estimate the system performance in quantitative method, we performed lab test with image samples which are obtained during the outdoor test.

We select 100 sets (Total 200 images, 1 set is composed vertical polarized image and horizontal polarized image which are obtained at the same time from the stereo camera) of sample images, which can be distinguished 25 sets for one status. The image sample which is selected in this process is the ‘clear and obvious’ image, that is enough to classify the status with the eye through the entire image portion. To calculate the performance factor, we matched the detected condition and real condition (naked eye-witnessed condition) for every 8×8 pixels unit from 100 image sets.

For total 19,127 units (8×8 pixel based) that are used in the lab test, the correct counted unit are 10,422 units, so it can be said that the accuracy of the image-processing based system is about 54.5 percent. This rate is lower than the field test accuracy (82%). In the field test, the system shows only one dominant state (the state that has the major portion in ROI) that is originated from the image processing process. So we can get correct detected result from the system, if there are some incorrect results in ROI region. That is, the performance rate from the lab test shows the necessity for the enhancement of image processing model.

5. CONCLUSIONS AND FUTURE RESEARCH DIRECTION

In this study, we focused on road surface condition as a part of traffic safety information, for using to reduce road traffic accidents and achieve the advancement of road management capabilities. To detect the real-time condition of entire road section, the probe car-based road surface condition detection system was developed. This system can classify road surface condition to four conditions (dry, wet, snowy and icy), utilizing image processing. We developed stereo camera& probe car–based detection system and evaluated the performance on the real winter road condition.

For enhancement of the system, we consider following directions on the future research.

- Enhancement on the stereo matching process

In this research, we utilize the baseline distance of stereo camera module for stereo matching. But for the more accurate stereo matching, we consider to utilize laser pointer to make fixed matching points on both vertical polarized image and horizontal polarized image. With the fixed matching points by laser pointer, the more detailed image matching can be accomplished.

- Enhancement for using polarization feature of light

In this research, we use the polarization property of the light when reflect the water surface, with vertical polarized image and horizontal polarized image. For detail usage of polarization property, it can be utilized that the wet area detection method with addition of 45 degree polarized image [9].

- Algorithm improvement for detecting icy road surface

As seen in section 4.3, the system has problems for detecting icy road surface correctly. In the image processing algorithm which is used for the study, icy road surface is distinguished by wavelet coefficients and temperature. That process is based on the assumption that icy road surface has the smooth surface feature. But in the real case that faced in the real-road field test, we checked that the correct detection is somewhat difficult with that assumption. So, it is needed to add another feature of the icy road surface on the image processing step, with the additional analysis of the icy road surface image.

6. ACKNOWLEDGEMENTS

This study was carried out with the support of research funds of the project, titled “Development of Technologies for Advancement of Hazardous Roadway Information Service under Inclement Weather”, its own major business (mission-type) of Korea Institute of Construction Technology.

REFERENCES

[1] The Korea Transport Institute, "Transport Countermeasure Strategies for the PyeongChang Winter Olympic Games", 2011.

[2] Doo-gyu Kim, Ja-young Kim, Jihong Lee, Dong-Geol Choi, and In-So Kweon,"Utilizing Visual Information for Non-contact Predicting Method of Friction Coefficient", Journal of the Institute of Electronics Engineers of Korea SP, Vol. 47 No.4. pp. 399-405, 2010.

[3] Maria Jokela, Matti Kutila and Long Le,“Road Condition Monitoring System Based on a Stereo Camera", Intelligent Computer Communication

and Processing, IEEE 5th International Conference on. pp 423-428 , 2009.

[4] Per-Olof Sjölander, Swedish Road Administration, “SRIS-Slippery Road Information System”, IVSS Project Report, December 2008.

[5] Roberto A. Tokunaga, "Winter Road Management using Friction Testing", 1st KICT-CERI Joint Seminar for Winter Road Maintenance. Sep 2011.

[6] Muneo Yamada, Toshihiro Oshima, Koji Udea, Isao Horiba and Shin Yamamoto, "A study of the road surface condition detection technique for deployment on a vehicle", JSAE Review 24, pp. 183-188,2003.

[7] Lim, Sung Han, Ryu, Seung Ki and Yoon, Yeo Hwan, "Image Recognition of Road Surface Conditions using Polarization and Wavelet Transform", Journal of the Korean Society of Civil Engineers (in Korean), Vol. 27, No. 4D, pp. 471-477, 2007.

[8] Han, Tae-Hwan, Ryu, Seung-Ki, "The Recognition and Segmentation of the Road Surface State using Wavelet Image Processing", Journal of the Korean Institute of Illuminating and Electrical Installation Engineers, Vol. 22, No. 4, pp. 26-34, 2008.

[9] Bin Xie, Zhiyu Xiang, Huadong Pan and Jilin Liu, "Polarization-Based Water Hazards Detection for Autonomous Off-road Navigation", IEEE/RSJ International Conference on Intelligent Robots and Systems. pp. 3186-3190, 2007.

AUTHOR PROFILES

Youngmin Kim received the master degree in traffic engineering from Seoul National University in 2011. Currently, he is a Research Specialist at Korea Institute of Construction Technology. His research interest covers intelligent transportation systems, road surface monitoring.