DEVELOPMENT OF THE SEAMLESS LOW COST & HIGH EFFICIENT ROAD SURFACE INFORMATION MONITORING SYSTEM USING THE IMAGE PROCESSING

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ABSTRACT

To observe real-time road surface condition, many road authorities use "Road Surface State Sensor", as a component of "Road Weather Information System" (RWIS). Although RWIS has many necessities for road maintenance and information service, the usage is very limited, especially in the road surface detection. That's because the sensing technology which applied to current road surface state sensor is a little bit expensive, so there are problems of expending sensor to the broad scale road network.

In this paper, we introduce our concepts of composition road surface monitoring system with image processing. We developed spot-based low-cost road surface detection system, using polarize filter rotation module in front of CCTV (Closed-circuit television). To overcome the 'blank area' between the spot-based detection systems, we realized mobile road surface condition detection system, with stereo camera module and image processing. With the field test on several road conditions, we expect to apply our solution of road condition monitoring for winter road management with some big event in South Korea, for example 2018 Pyeongchang winter Olympic games.

ABSTRACTO

Para observar condiciones superficie de la carretera por tiempo real, muchas autoridades viales utilizan "Sensor Estado superficie de la carretera " , como un componente del " Road Weather Information System" (RWIS) . Aunque RWIS tiene muchas necesidades para el mantenimiento de carreteras y el servicio de información, el uso es muy limitado , especialmente en la detección de superficie de la carretera. Eso es debido a que la tecnología de detección que se aplica al sensor de estado de superficie de la carretera actual es un poco caro , así que hay problemas de gastar sensor a la red de carreteras de gran escala .

En este investigación, presentamos nuestros conceptos de la composición del sistema de monitoreo superficie de la carretera con el procesamiento de imágenes (Image processing). Desarrollamos sistema de detección de superficie de la carretera bajo coste con sede in situ, utilizando polarizar módulo de rotación del filtro delante de CCTV (Closed Circuit TV) . Para superar el ' área en blanco "entre los sistemas de detección basados en punto , nos dimos cuenta de sistema de detección de estado de la superficie de carreteras móvil, con el módulo de la cámara estéreo y procesamiento de imágenes. Con la prueba de campo en varias condiciones de la carretera , esperamos aplicar nuestra solución de monitorización de la condición de ruta para la gestión de carreteras de invierno con algún gran evento en Corea del Sur, por ejemplo 2018 Pyeongchang Juegos Olímpicos de Invierno.

1. INTRODUCTION

With the development of Intelligent Transportation System (ITS) technologies, the application of ITS solution is broaden to road safety and road maintenance, from road traffic management. The Road Weather Information System (RWIS) is an essential system for road weather related works, such as snow removal and variable speed limit (VSL) service. In South Korea, the installation of RWIS for major road is increasing gradually, with the expansion of ITS. Many road authorities in South Korea feel empathy about the need of RWIS establishment, but the cost of RWIS cause a problem in the ITS installation phase. Especially the road surface state sensor costs relatively higher than another component of RWIS. In this regard, this study focuses on detecting real-time road surface condition monitoring. By developing low cost & high efficient road surface state information monitoring system through an image processing, we expect the more detailed usage of road weather in various ITS fields.

2. PRIOR STUDIES AND TECHNOLOGIES FOR ROAD SURFACE CONDITION MONITORING

For judgement road surface state, the most primitive and widely used methodology is the naked-eye observation by road authority’s worker. According to the spread of ITS, road worker can check the road status and determine if the road is snowy and icy with CCTV image through ITS center. To reduce the effort of road workers, road surface state sensor of RWIS is regarded as one of the best solution for road condition detection. Road surface state sensor collects real-time road condition for specific point on the road. Road surface state sensor provides the highly enhanced road maintenance capacity to a road manager through the automatic weather information acquisition (ex: if snow-cover occurred in a specific road section), and provides various road situations information that help safety driving to a driver. (ex: if the road in a specific section is icy)

The road surface sensor types mainly include an infrared light laser-based sensor or ground embedded sensor (As Fig. 1). The infrared light laser sensor identifies road surface conditions by using a principle that reflexibility of incident light is changed for each road surface condition. In the case of the ground embedded sensor, the sensor measures the temperature of the road, and the road surface condition is identified by a way that the sensor measures the thickness of water film through small-sized radar [1, 2].

Figure 1 Ground embedded road surface state sensor (by Lufft, Germany)

Due to functional aspects, the need for road surface state sensor is very high for road authorities in South Korea. However, only few sensors are installed in road field in Korea. This is because road sensor is a relatively expensive system. In particular, road surface sensor can collect real-time road surface condition for only of specific points, which means there is a technological limit in handling the entire roads of wide areas. According as additional solutions such as the thermal mapping, etc. need to be applied for expecting road surface conditions on all sections of roads.

So, many countries try to develop a road surface monitoring system that is available to comprehend a road surface condition more intuitively and at a lower cost. Particularly it can be confirmed that Northern Europe and Japan, where a winter time is long and the amount of snowfall is a lot, is interested in developing new technological for road condition detection.

2.1 Case of Japanese Technological Development

Japan, in particular the northeast region that is represented by Sapporo is considered a much snowfall place worldwide, for which the study on the acquisition and use of road information to secure winter time traffic safety is aggressively conducted in the level of the nation of Japan.

The National Institute for Land and Infrastructure Management (NILIM) used CCTV for detecting road condition automatically [3, 4]. This system can classify road surface condition into a total of five types (dry, damp, water filmed, snowy, and icy). Also, NILIM studied for various sensing modules (laser, radar, optical fiber sensor) for detecting real-time road surface condition [3].

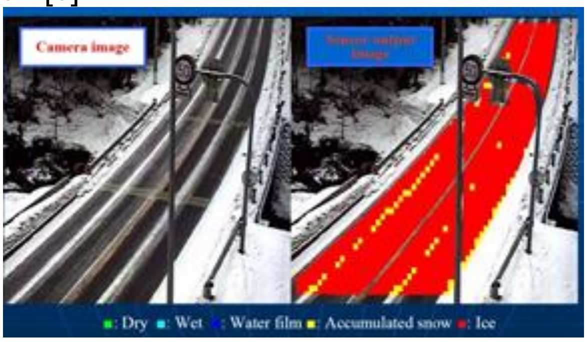

Figure 2 CCTV-based road surface monitoring system (by NILIM, Japan)

The Civil Engineering Research Institute for Cold Region (CERI) in Hokkaido tested the continuous friction tester (CFT) for collecting road slippery information [5]. Originally CFT measures the friction of runway, but by CERI, CFT is used for acquiring real-time friction of some arterial road, by being attached to the posterior of a road management vehicle. With CFT and GPS sensor, road worker can use real-time road surface information to determine if snow-removing work for a specific road area is needed or not (Fig. 3).

Figure 3 Winter road maintenance system with CFT (by CERI, Japan)

2.2 Case of Technological Development in Northern European Countries

The northern European countries have a very long winter, so these countries have engaged in obtaining technical skills of the road weather field from an earlier time. Finnish company, Vaisala, shows a representative case that succeeded in commercialization of RWIS. Vaisala's solution for road weather is exported about 20 countries worldwide [2]. Swedish company Sten Löfving has developed 'Road Eye', a non-contact typed road surface monitoring sensor using infrared laser, and now places it on the market [6]. Road Eye sensor features that it developed as a very small laser sensor, thus the Road Eye (sensor) can be mounted on a vehicle to comprehend a real time road surface condition of the travel path (Fig. 4).

Figure 4 Road Eye SD laser sensor (by Sten Löfving, Sweden)

The system named "Slippery Road Information System (SRIS)" is developed by Swedish Road Administration and VTI [7]. In the SRIS system, road surface conditions can be distinguished into a total of five types (no slippery, rainfall, rainfall on the cold road, icy, icy by frost. The methodology of SRIS can be summarized that the system defines road slipperiness by special movement in slippery road (ABS, ESP) by probe car and real-time weather observation information. A total of 100 probe cars were used to test SRIS on the roads surrounding Gothenburg and Stockholm between 2007 and 2008 and as its result, SRIS was determined to have a high possibility of commercialization (Fig. 5).

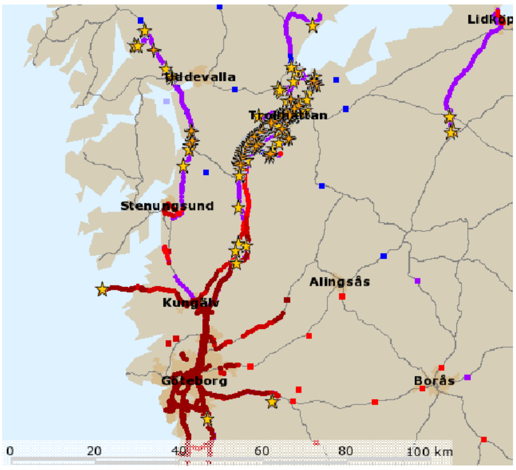

Figure 5 Slippery Road Information System (by IVSS project, Sweden)

Technical Research Center of Finland (VTI) developed a road surface monitoring system using stereo camera, for monitoring a road surface condition at a low cost [8]. The study implemented technologies that identify wet areas using the characteristics of light polarization, and identify snowy areas through the analysis of graininess. By comparison with laser-based high cost equipment (Vaisala DSC111), this stereo camera based system indicate 90 % or higher accuracy of 90 % for icy road detecting.

Figure 6 Road surface monitoring system with a stereo camera (by Finland)

2.3 Korean Technological Development for road surface monitoring

Recently, South Korea also realizes of the importance of acquiring real time road surface condition information. Korea Institute of Construction Technology (KICT) produced road monitoring system in 2011 [9] – system in which the near infrared (NIR) filter is attached to a CCTV visible ray image, and accordingly the characteristics of polarizations of NIR image and VR image are used for this system to divide a road surface condition into total of four types (dry, damp, snowy, icy). Through a comparison with the ground embedded road sensor (IRS21) currently used for RWIS, the accuracy of monitoring was produced, which resulted in the finding that around 90 % of accuracy is secured compared to the conventional equipment.

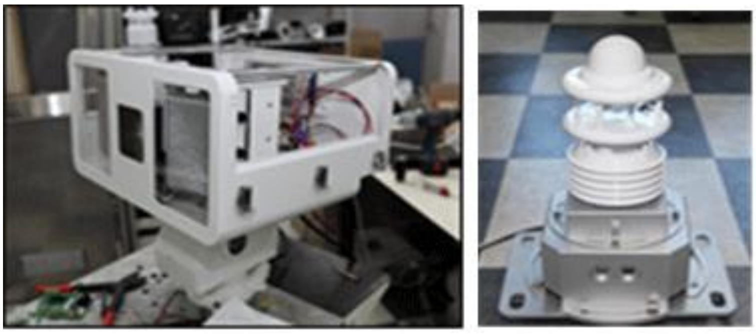

Figure 7 Road surface condition monitoring system (by Korea)

Lim et al. (2007) and Han, Ryu (2008) developed the image processing algorithm that is used to identify a road surface condition through digital image [10, 11]. They devised the algorithm focused on distinguish wet road surface by using the light polarization characteristic and on discerning of dry/snowy/icy parts on roads by using the wavelet packet transform and K-means clustering algorithm. Finally, road surface can discriminate into four states: “Dry, Wet, Icy and Snowy”.

3. CONCEPT OF SEAMLESS ROAD SURFACE MONITORING SYSTEM

3.1 System Overview

The purpose of this study is development of ‘The effective road surface condition monitoring system with low cost & high performance’. In detail, this purpose can be summarized into cost-down of point-based road surface state sensor and development of ‘seamless’ road surface detection system using probe car.

To accomplish first objective, we map out the statistic road surface condition monitoring system using a CCTV, a main component of ITS. This method can appeal to road manage authority that road authority can monitor both real-time video image and road surface condition with one equipment.

Meanwhile, to overcome a ‘blank’ on the road surface condition monitoring system due to point-based detection, we present a concept of the ‘seamless’ road condition monitoring system’. In South Korea, more than 70 percent of the entire nation covered with mountain. So it is very often that weather changes dramatically along the road. According to this characteristic, it is difficult to check the road surface conditions over all road sections only with point-based measurement. That is, for the purpose of monitoring in the regions with such conditions, it will be appropriate to form the monitoring system probe car-based mobile monitoring system. The ‘probe car based mobile road surface condition monitoring system’ is the automated road surface state detection system along the probe car’s path. With probe car based system, road authority can collect real-time road surface condition of many paths simultaneously.

The overview of our suggestion for seamless road surface condition monitoring system devised by this study can be described as shown in Fig. 8.

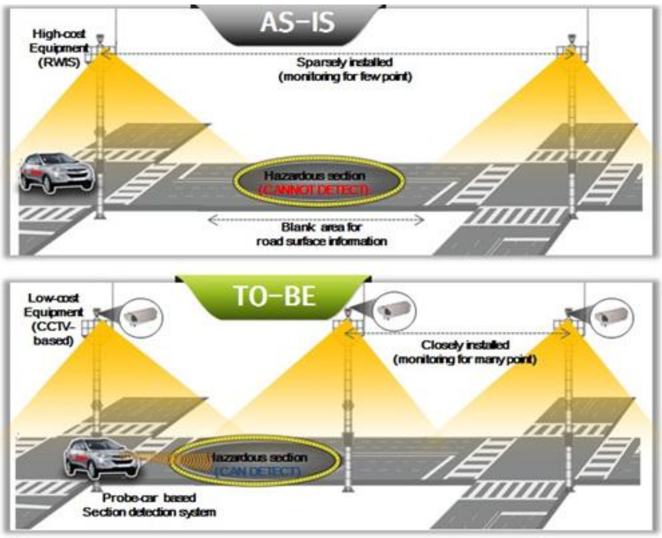

Figure 8 Development concept of seamless road surface condition monitoring system with image processing-based method

Actually, the system which is related road surface condition measuring is considered somewhat expensive. So in many study cases, the researchers only focus on one measurement system type: location-based statistic system or probe car-based mobile sensing system. In this article, we suggest using ‘fusion’ location-based system and mobile-based system. We expect that expensiveness of the system can be overcome due to cost down of an image processing module according to the recent enhancement of computer calculation process capabilities, and physical limits to data transmission/receipt according to development of wireless communication networks, and development of information storage and processing technologies that are represented by big data.

3.2 Definition of Requirement of System Development

For development of system, the 'road surface condition identification algorithm using the polarization property and wavelet transform [10, 11]' is adopted to the system. This algorithm is can be summarized into 'detection of wet road surface using the brightness difference between horizontal polarized road surface image and vertical polarized road surface image' and 'detection of dry/icy/snowy road surface with texture analysis using wavelet transform and k-means clustering'. For implementing this algorithm into road surface condition detection system in road fields, following four requirements should be met to the system:

1) Simultaneous acquisition of vertical/horizontal polarized road surface images

Based on algorithm, the identification of wet road surface is conducted by the brightness difference of vertical polarized images and horizontal polarized images. That is, it should be possible to acquire the vertical/horizontal polarized images for same road surface simultaneously. Especially for CCTV-based system, it must be accomplished with one camera body and lens.

2) Guarantee of the image quality for texture analysis

Based on the algorithm, the classification of dry/snowy/icy road surface is conducted by the texture analysis methodology based on the wavelet packet transform and K-means clustering algorithm. That is, for driving the algorithm, the image quality obtained from the road surface monitoring process should maintain clearly, enough for the application of wavelet transform based texture analysis. If the image is contaminated by dirt or dot on the housing, the accuracy of texture analysis can fall down dramatically.

3) Conditions for the wet road surface judgment

The Brewster's angle, which is the incidence angle that brightness difference of vertical polarized image and horizontal polarized image has maximum value, is different with surface condition. For the water surface, Brewster's angle is about 53 degree (about 37 degree against the ground surface). So, for detecting wet road surface with polarization property of light, the ideal condition for installing the camera is 37 degree against ground. But actually, it is almost impossible to take a shot for the image with maintaining exact Brewster's angle condition on the field. So it is important that setting a criteria for deciding whether road surface is wet or not, according to the brightness difference of two images. In the previous study for algorithm [10, 11], the criteria for brightness difference is set by 1.3.

4) Acquisition and usage of information about surrounding condition

To detect road surface condition with image processing, it is important to use surrounding condition, such as air temperature and humidity. Snowy and icy road surface only occur in winter season, which air temperature falls down under 0 degree Celcius. When the road surface stays wet condition, it can be assumed that the air humidity stays high condition. This method is quite useful to determine road surface condition, because it is very 'common sense'. If the system only relies on image processing, the reliability of the system could be fall down, because the system can't apply this 'common sense' in the detection procedure.

Based on the above four system requirements, the detailed designs and manufactures of system components will be progressed.

4. SYSTEM IMPLEMENTATION

As of the current (Jun, 2013) study process, the development of 1st prototypes for system components (road surface auto monitoring system in the unit of point based on CCTV image, probe car based mobile road information monitoring system) has been completed.

4.1 Development of CCTV-Based Road Surface Condition Monitoring System

The CCTV-based road surface condition monitoring system is the static road surface monitoring system, with some modification on widely-used CCTV system. The major works for developing system is to satisfy requirement of system (mentioned in Chapter 3.2) with maintain original CCTV's system structure. This system is designed and developed in the following terms:

1) Simultaneous acquisition of vertical/horizontal polarized road surface images

For acquiring the vertical/horizontal polarized images from one CCTV camera simultaneously, we developed small-sized 'polarization filter rotating module' (as Fig.9) and installed on the front side of the camera (inside of CCTV housing).

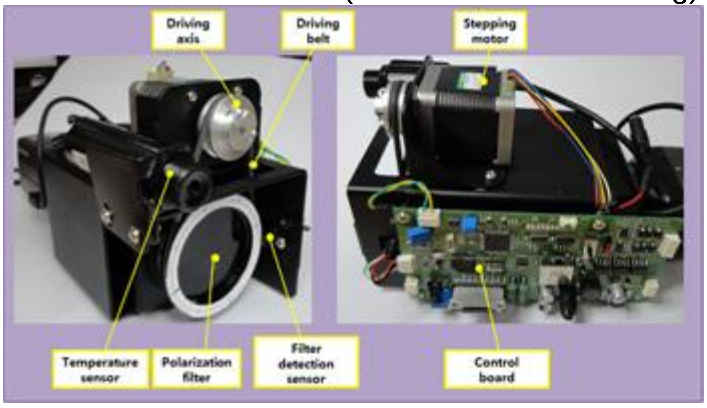

Figure 9 Polarization filter rotating module for CCTV-based system

The horizontal/vertical polarized images are acquired by rotating the polarization filter by 90 degree. In this study, it is presumed the road surface conditions are same for a time required for filter rotating. It takes around 3 seconds for a filter rotation, and image processing is progressed by using the vertical/horizontal polarization images that were shot at the same point at the interval of around 3 seconds.

2) Guarantee of the image quality for texture analysis

The CCTV cameras currently used in ITS can be distinguished into SD type (0.4 million pixel) and HD type (1 million pixel or more), and recently many systems are transferring to HD type camera, according to the technical development of CCTV camera. In this study, we use SD type camera (0.4 million pixel camera) for system development, and we found that even in SD type camera condition, it is enough for texture analysis based image processing while in severe weather condition. That's because the camera module should be faced to ground with near Brewster's angle condition (about 45 degree to ground), so the front part of camera housing isn't exposed to the rain or snow directly.

3) Conditions for the wet road surface judgment

The road surface monitoring angle should be maintained to be close to the Brewster's angle by using PTZ (Pan/Tilt/Zoom) function of CCTV. However, since the region of interest (ROI) can be changed occasionally according to the characteristics of CCTV operation, we set a specific ROI on the road (about 12 m front from the CCTV installed point) which has about 45 degree angle between camera and ground. In this pre-set condition, it is determined to be appropriate in consideration of the number of brightness difference (1.3) which applied to the algorithm and the brightness difference of polarization images according to incident angles.

4) Acquisition and usage of information about surrounding condition

To satisfy ‘common sense’ for road surface condition detection, air temperature & humidity and road surface temperature are acquired for identifying road surface condition. In particular, the temperature (air and road surface) is an important factor to decide whether the current condition is winter condition or not. In this study, we attach a temperature-humidity sensor on the system, for checking the temperature and humidity of observation points to use them as the bases for identifying the road surface condition. Also, we install road surface temperature detection non-contact thermometer, to measuring road surface temperature directly. In the identification algorithm, the road surface condition can be identified as a snowy and icy road only when air and road surface temperature falls under a certain temperature, and the wet road, snowy road, and icy road related to the water on ground surfaces should be identified only when a certain level of humidity or higher is observed. In this study, in consideration of the characteristic of an equipment installation field (Ansan city, Gyeonggi Province, South Korea) where there are many volumes of large vehicle traffic, the temperature-humidity sensor is installed at 4 m away from the ground to avoid calescence due to the passages of vehicles.

Fig. 10 shows the overview of the CCTV-based road surface condition monitoring system developed by applying the above system design details, and the photo of its actual installation on a road. In the Fig. 10, the right part of picture is the condition monitoring results with dedicated analysis program. In the result of image processing, grey means ‘Dry’, blue means ‘Wet’, red means ‘Icy’, and white means ‘Snowy’.

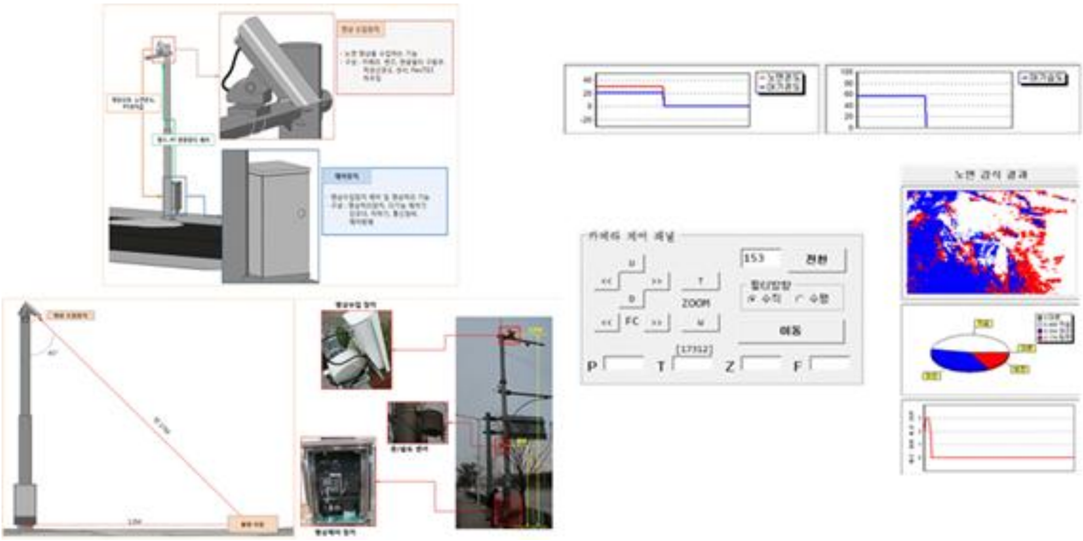

Figure 10 CCTV-based road surface condition monitoring system development

5) Characteristic of CCTV-based system

This system is featured by the ‘relatively low-cost system’, in contrast to the current RWIS’s road surface state sensor. We expect that only about $2,000 more to the CCTV system, to add road surface condition monitoring function. Moreover, current road surface state sensor has only ‘road surface condition monitoring’ function, this system can be used road surface condition monitoring, as well as conventional CCTV's usage (Traffic monitoring, Accident monitoring, so on), because this system maintains an intrinsic function of CCTV.

4.2. Development of Probe Car-Based Road Surface Condition Monitoring System

In addition to development CCTV-based road surface condition monitoring system, probe car-based mobile road surface condition monitoring system is developed for 'seamless' road surface condition detection. For developing the probe car-based mobile road surface condition monitoring system, the same road surface condition discrimination algorithm for CCTV-based system is applied. However in mobile system, the horizontal polarized image and vertical polarized image must be gathered in the same time. Also, many aspects for CCTV-based system should be changed to other forms, for satisfying mobile sensing characteristic.

1) Simultaneous acquisition of vertical/horizontal polarized road surface

In the CCTV-based system, the image processing procedure is designed on the presumption that 'the road surface condition maintains same while 3 seconds of filter rotating time'. However in the mobile system, this presumption can't be used because the shooting location changes when a delay time occurs. Thus, in the probe car based system, a vertical polarized image and horizontal polarized image must be collected exactly same time. So, we use a stereo camera to acquire both images at the same time. In the image processing phase, two images are physically matched and the image processing is conducted only for overlapping shot areas. This approach is somewhat similar to VTI's method [8]. Fig. 11 shows the brightness difference from horizontal/vertical polarized image from one stereo camera module.

Figure 11 Brightness difference for wet road surface condition with stereo camera:

(Left: horizontal polarized image // Right: vertical polarized image)

2) Guarantee of the image quality for texture analysis

The stereo camera module which is available on the market of South Korea is only one type, using 0.3 million pixel (640*480) image sensor. It is about the same condition with the camera which is used in CCTV-based system (SD type camera). So it was determined the application of the relevant stereo camera module is enough for the image processing.
However, in the equipment installation step, it was found the diffused refraction of the image occurs due to the window of a vehicle, thus the image collection part (stereo camera) should be put on the roof of a vehicle. Also, the characteristic of polarization (brightness difference between vertical/horizontal polarized images) is very weak when the camera module is located inside of the probe vehicle. (As Fig. 12)

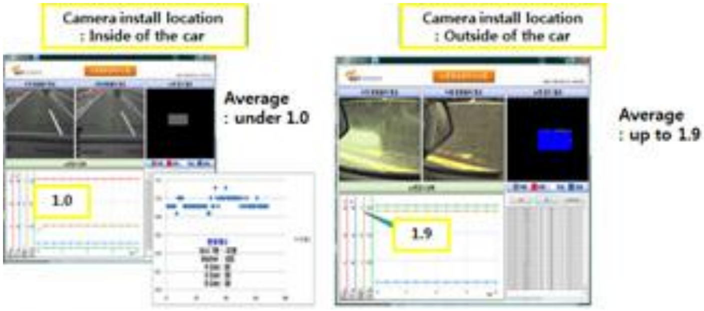

Figure 12 Polarization characteristic according to camera install location

(Left: inside the car // Right: outside of the car)

In VTI’s approach [8], the camera is installed inside of vehicle. But in this study, we installed camera module on the rooftop of the probe car vehicle according to the test result.

3) Conditions for the wet road surface judgment

When a stereo camera based image collection part is attached to a vehicle, the Brewster’s angle condition should be considered. As for deciding the install location of stereo camera on the probe car, as mentioned earlier, the camera module should be installed on the roof top of the car. In addition, the camera module should satisfy Brewster’s angle condition. However when the camera module is mounted to the vehicle with bonnet, there is interruption for road surface image due to bonnet. So, we designed another process for selecting ROI, to select only ‘road surface area’ from the image sets.
With the installation of camera module, it is measured that monitoring region can reach about 8m ahead of the vehicle, according to the spec of the probe car (Hyundai Starex) and field of vision (FOV) of the stereo camera module.

4) Acquisition and usage of information about surrounding condition

It is quietly similar to CCTV-based system. We use a temperature-humidity sensor and non-contact thermometer to measure surrounding condition.

5) Another aspect for probe car-based mobile system

According to the characteristics of the mobile monitoring system, recording for detecting monitoring location is required. We use GPS sensor module on the system, to record the real-time location information while the road surface condition definition work is performed. Also, we add acceleration sensor (G-sensor) to record the shock when a certain level of shock or higher one is monitored during vehicle travel.
Meanwhile during the study process, for implementing the function similar to the identification of road surface condition using the movement of vehicles implemented by SRIS [7], the OBD (On Board Diagnosis)-2 terminals of the Electronic Control Unit(ECU) were connected to acquire the vehicle wheel speed data, but it was defined that it requires moreover OBD-2 PID (Parameter IDs) area which is easily accessed to general user.
The next Fig. 13 shows photos that the ‘probe car based mobile road surface condition monitoring system’ developed by this study. is mounted on a vehicle. In the Fig. 13, the right part of picture is the road surface condition monitoring results with dedicated analysis program. Grey means ‘Dry’, blue means ‘Wet’, red means ‘Icy’, and white means ‘Snowy’, same as CCTV-based system.

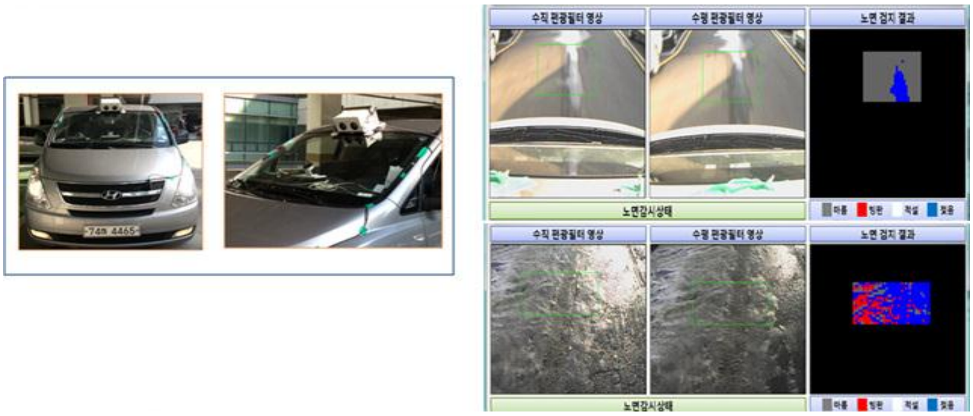

Figure 13 Probe-car based mobile road surface monitoring system concept

6) Characteristic of probe car-based system

Compared to VTT's stereo camera based system [8], stereo camera module is attached to the outside of the vehicle in our system, also we considered surrounding environmental factors (temperature of ground/air, humidity of air) to define road surface condition. In addition, our system has shock monitoring function using a GPS sensor and acceleration sensor. This function can be used to detect damage on the pavement, such as 'Pothole'.

The manufacturing cost for probe car-based system mainly depends on the cost about stereo camera module. In 2012 (when a prototype system was manufactured), the cost of the stereo camera module was about $1,000. So, it is expected that the cost possibly will not be highly beyond the expected cost of the CCTV-based system described before (around $2,000 including an installation cost).

4.3 System Performance Measurement and System Supplementation Measure

The performance of a road surface state sensor can be represented by 'Accuracy'. For measuring accuracy of the system, in this study we selected the comparison procedure between state classification result from system and eye-witness based classification result. This is because actually in many road work places, the identification of road surface condition relies on road worker's witness.
The identification accuracy for system is calculated by system-base classification result and eye-witness based classification results (as true value), based on the images acquired from the field in Feb. 2012 (CCTV-based system) and Feb. 2013 (Probe car-based system).
The result for accuracy of developed system is as shown in Table 1 and 2.

Table 1 System evaluation result for CCTV-based system (2012.2.)

Segment	Dry road surface	Wet road surface	Snowy road surface	Icy road surface
Number of Classification	22	2	37	34
Number of Successes	18	2	32	31
Number of Failures	4	0	5	3
Classification Accuracy (%)	82	100	86.5	91.2

Table 2 System evaluation result for probe car based system (2013.2.)

Segment	Dry road surface	Wet road surface	Snowy road surface	Icy road surface
Number of Classification	37	66	38	33
Number of Successes	36	63	33	11
Number of Failures	1	3	5	22
Classification Accuracy (%)	97	95	87	33

Based on the test results, followings can be confirmed for the future study.

- Low classification accuracy about 'Icy' surface condition, especially in probe car-based system: As confirmed in [Table 2], classification accuracy for icy road surface is relatively lower compared to the road surfaces of other conditions. This means that to detect icy road condition, we must consider another feature in image processing procedure, also it needs to use surrounding condition (temperature, humidity, so on) more intensively. That is, for identifying an icy road surface, it is needed to review other characteristics in addition to the temperature and texture conditions used by the current system.

- The necessity for long-term observation for system: In the study case of NILIM [3], it takes about 3 years for tuning the system with high classification accuracy. That is, we must consider more and more cases which can be occurred in real road condition. The state of road cannot be classified only 4 conditions. The important thing is: How to match such various conditions to a few 'defined' conditions. For example, the snowy road surface can be divided many sub states: such as 'pressed snow' and 'new snowfall'. The important factor in developing detecting system is the capability for many different conditions. To accomplish this goal, It is determined the processes similar to those are needed in this development too, and this need is considered to be reviewed simultaneously with the enhancement of system hardware components.

- Development of the methodology for fusion between monitoring data: According to the configuration of this system, the methodology for the data fusion (linkage) between static monitoring results of specific points and monitoring results along path is required.

5. CONCLUSION

In this study, we suggested a new detection method with image processing for road surface condition. For overcoming the high cost & location limitation of the road surface state sensor, This study pushes ahead with the development of a low cost road surface condition monitoring system based on image processing. Using widely used CCTV structure, we developed low-cost road surface condition monitoring system based on image processing method. Also, to overcome the limitation for road condition measuring with point-based detection system, we devised probe car-based mobile road surface condition monitoring system with stereo camera.
Actually, this technology now stands on the stage of prototype system. For enhancement and commercialization of system, it seems to be required to apply another image processing technologies for gaining features on the road surface image to enhance the

system accuracy, and develop the methodology of data fusion between heterogeneous monitoring systems.

It is expected the seamless low cost road surface condition monitoring system based on image processing targeted to be implemented in this study will be available as traffic safety information for the forthcoming enhancement of road maintenance and for the enhancement of road users' safety in the bad weather. Meanwhile the results of this study are expected to be available for road traffic safety management in the case of large events in winter, such as Pyeongchang Winter Olympics (in 2018). In Pyeongchang, all visitors must be able to travel between stadiums in 30 minutes. (Stadiums are separated about 30~50km), so very detailed road management and road weather information service should be provided to the drivers, to prevent severe road accident. With the development of our system, we expect that our system can contribute successful game operation in 2018.

6. ACKNOWLEDGEMENT

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