METHODS OF MONITORING THE ROAD SURFACE FREEZING SECTIONS FOR PREVENTION OF ICY WINTER ROAD DISASTERS ON THE HIGHWAYS

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ABSTRACT

In most developed countries more people are killed in winter road crashes than any other weather related disaster. Monitoring the current surface conditions on roadways is critical to reducing winter traffic accidents. During thirty or forty years, to identify the current surface condition on roadways, some technologies have been applied. But these technologies are currently introduced with high cost and performed within the limited scope.

In South Korea, with the winning of the 2018 Winter Olympics bid, Korean government is now faced with this technology development needs because winter road management is the successive main factor of Winter Olympics. Meanwhile, the winter traffic accident fatality in Korea is very high, and it is required to provide accurate information about road surface condition with low-cost.

In this regard, this study is aiming at devising a road surface condition detection system with low cost and appropriate accuracy. This is what we have firmly decided using the video image processing (VIP) technology because of low-cost and fast installation. VIP is expected to help implement the low-cost and high-efficiency detection system. VIP is based on the classification algorithm which discriminates the polarization images clusters by utilizing stereo cameras.

Keywords: Road surface monitoring, Image processing

INTRODUCTION

The role of public ITS (Intelligent Transportation System) is to secure the safety and conveniences of citizens. First of All, most priority would be the safety information service. In this point, Next ITS in Korea is planned around the safety service. In addition, together with the hosting of the 2018 Pyeongchang Winter Olympics, the road safety in winter has the most priority development project. But the road management capability of Korea for adverse weather (collection, provision and management) is very insufficient.

The traffic accidents on icy road on the surface for the 3 recent years were a total of 5037 cases, causing 206 deaths. The fatality rate for 100 cases of accident is 4.1 that is about 1.5 times higher than the fatality rate of 2.7 in overall traffic accident of the same term. Besides, in transportation planning of the Pyeongchang Winter Olympics, safe mobility is expected to be absolutely critical. In this light, collection of real-time road surface condition data 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.

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.

There have been many researches on the surface detection field. However, many researches and technologies have not been applied for monitoring roadways. In Japan, Serizawa and others have completed the
relevant base technologies in road surface reflection in road lightening and others in 1967, and Imamura and others developed optical sensor for monitoring the road surface moisture using the reflection flux polarized in 1979 and 1982. Fujitsu’s Keiji Fujimura and others developed the mobile-concept road surface sensor in 1988. Namely, it developed the sensor that detects the road surface in mobile-type. In recent days, NILIM’s Isao Yamamoto and others developed the CCTV-based surface detection sensor. In Europe, there is an active researches on VTT’s prototype stereo camera measuring polarization differences. In recent days, stereo vision and polarization imaging are used to apply in the Robot navigation.

Accordingly, this study attempts to develop a system that can detect road surface condition with low cost, high reliability. For this purpose, we utilizes the traditional PSD(Permanent Surface Detection) in combination with innovational MSD( Mobile Surface Detection) technology.

TRENDS REVIEW OF ROAD SURFACE DETECTION TECHNOLOGY

In this section, we review the leading researches and development practices on the mobile-based road surface condition information sensing. Doo-gyu Kim et al. (2010) developed a pre-estimate methodology of the surface friction coefficient for improving mobility of the robot. They devised a methodology to estimate the friction coefficient by extracting information that is represented as material composition ratio from image obtained from the front of a mobile robot (robot’s eye). 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 images learned utilizing a total of six materials (sky, earth, tiny 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. For instance, Maria Jokela et al. (2009) conducted a research on the system to determine the road surface conditions in real time from moving vehicles, by utilizing a stereo camera. To replace the expensive laser-based portable road surface condition detection sensor, they 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 iCORS stereo camera (640*480 pixels). As a result, more than 90% accuracy was identified in detection of frozen road surface.

In Sweden, Pär Ekström, et al (2008) proceeded with a research project titled IVSS (Intelligent Vehicle Safety Systems) with Swedish Road Administration of VTI. 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.

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.

**Tab. 1: Technology development practices at home and aboard**

<table>
<thead>
<tr>
<th>Researchers</th>
<th>Equipment used in the research</th>
<th>Key methodologies</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doo-gyu Kim et al. (2010)</td>
<td>Camer-ast(robot’s eyes)</td>
<td>Estimation of the friction coefficient utilizing images</td>
<td>Verification of the estimation results by utilizing load cell</td>
</tr>
<tr>
<td>Maria Jokela et al. (2009)</td>
<td>Stereo cameras</td>
<td>Image processing by utilizing the polarization characteristics</td>
<td>Verification through utilization of expensive equipment</td>
</tr>
<tr>
<td>Pär Ekström et al. (2008)</td>
<td>Sensor inside the car (ABS, ESP, outdoor temperature sensors, etc.)</td>
<td>Estimation of the road surface conditions by utilizing car movement and environmental information</td>
<td>Transmission of estimation results to a central control center</td>
</tr>
<tr>
<td>CERI, Japan</td>
<td>CFT (Continuous Friction Tester)</td>
<td>Direct measurement of the friction coefficient and estimation of the road surface conditions</td>
<td>Transmission of the estimation results to a central control center and utilization in the road management</td>
</tr>
</tbody>
</table>

**SYSTEM DEVELOPMENT**

Now(2012), Korea has operated the technology to estimate icing by burying the temperature and humidity sensor on the paved area of around 1cm. This method is relatively accurate but it has very narrow scope with easy damage to unable to expand after the pilot project that it was disposed. Of course, it is partially used for the WIM sensor calibration. In addition, it may take the role as the auxiliary sensor for winter road management. However, it has certain limit as the central sensor to expand and supply the surface information.

Therefore, under this research, the review has undertaken as the method to link the mobile information of prove car in combination with the CCTV of permanent station. Through this combination technology, we can expand the detection area compared to the past with low cost, high reliability.

**Permanent Surface Detection(PSD) at roadways**

The fixed stations for Permanent Surface Detection(PSD) are usually located in areas identified as the problem spots of winter accidents or the cold regions for winter maintenances. Stations are also usually placed in locations of unusual weather or remote from other forms of communication. Since bridges and other elevated roadways typically freeze before road surfaces, sites are typically located near a bridge so both a road and bridge reading can be done at the same time.

We developed a suite of PSD to monitor winter road surface conditions. Our R&D’s Key is to facilitate existing CCTV with low cost. For auto detection of the surface condition, existing CCTV needs to be altered a little. On the existing CCTV, New filter was installed with the bracket that consecutively filming for the vertical and horizontal polarization.

Through this system, the vertical polarization image and the horizontal polarization image are compared
and the auxiliary sensor facilitates the humidity and temperature sensor.

**Fig. 1: Permanent Surface Detection (PSD)**

**Mobile Surface Detection (MSD) mounting the Car**

MSD is to collect Road Surface Detection as we drive. MSD is not new. Many vehicles today display the air temperature outside as we drive; however, for transportation authorities this is not enough. They need surface condition, air temperature, pavement temperature, and moisture sensors etc for providing much more real-time information about the road surface to public users. For the most part this data was only available to the driver themselves or maybe the vehicle was equipped with some sort of data recorder for analyzing the data upon their return.

Now with the ever increasing coverage and reduced cost of communications, agencies can transmit the data along with the vehicles coordinates, so that decision makers have an even better understanding of the surface weather. Ministry or government vehicles of all types can be equipped with sensors and communications systems, allowing for a huge network of mobile data filling in the gaps for the fixed road weather stations. 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 using a stereo camera. In theory, it was similar to the system implemented by Maria Jokela et al. (2009), but it could be said a more advanced system because it considers environmental conditions during the process of determination.

**Fig. 2: Mobile road surface condition information detection system**
Road Surface Classification

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. Since the light has an electromagnetic characteristic, it proceeded to make the wave motion. If this light was passed through 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 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 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 angle

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>
<thead>
<tr>
<th>Road surface conditions</th>
<th>Polarization properties</th>
<th>Temperature</th>
<th>Wavelet characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry surface</td>
<td>Polarization coefficient ≤ reference value</td>
<td>Normal temperature</td>
<td>Relatively higher high-frequency components</td>
</tr>
<tr>
<td>Wet surface</td>
<td>Polarization coefficient &gt; reference value</td>
<td>Normal temperature</td>
<td>Very large DC component, and almost no remaining components</td>
</tr>
<tr>
<td>Snowy surface</td>
<td>Polarization coefficient ≤ reference value</td>
<td>Below zero</td>
<td>Relatively even distribution of high-frequency components</td>
</tr>
<tr>
<td>Icy surface</td>
<td>Polarization coefficient ≤ reference value</td>
<td>Above zero</td>
<td>Relatively even distribution of high-frequency components</td>
</tr>
</tbody>
</table>
Conclusions and Future Research Directions

This study was focused on road surface condition information as part of efforts to reduce road traffic accidents and achieve the advancement of road management capabilities through the road system intelligence.

Reliable and accurate information is key. At this viewpoints, we focused to improve the detection rate of the road surface condition information detection system, more accurate phase analysis in the image processing process was needed.

If periodic synchronization through automatic settings of the camera according to weather or ambient light was not made at the time of image acquisition, a significant change in the values of polarization coefficients occurs.

In addition, changes in the values of polarization coefficients were found in such cases of photographing with the sun behind as the camera facing the sun with a New-degree angle, respectively. Meanwhile, an observation found that there were phenomena in which polarization coefficient was high due to the difference in relative brightness towards think-looking areas due to the shadows made by tree branches or wires.

For the advancement of the existing polarization coefficient characteristics, it was required to conduct a research for more accurate detection in more diverse environment through matching and phase analysis after the system development and construction by making a change from the current two-phase polarized stereoscopic image of 0 and 90 degrees to the three-phase image of 0, 45 and 90 degrees.

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