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수막사고 위험 방지를 위한 가시광 통신 기반 도로 습윤상태 검지 기술의 실험 검증

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Experimental Demonstration of VLC based Road Wetness Detection Techniques for Preventing Danger of Hydroplaning

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요 약

최근 차량의 안전한 운행을 위해서 노면의 습윤 혹은 결빙 상태를 정확하게 검지하는 문제는 매우 중요하다. 본 논문은 일반적으로 대부분의 차량에 장착되고 있는 발광 다이오드 (LED) 램프를 기반으로 가시광 전송 방식의 도로 표면 상태를 검지하는 기술을 제안한다. 한 개의 안개 LED 램프와 2개의 주간 주행 LED 램프로 이루어진 3개의 LED를 이용하여 도로 표면에서 반사되어 오는 빛을 측정하여 도로 상태를 검지하게 된다. 제안된 기술은 평면 도로 뿐만 아니라, 상향 및 하향 경사 도로 표면의 상태도 검지할 수 있도록 설계하였으며 제안 기술의 증명을 위해 실내외에서 실험을 수행하였다. 실험 결과에 의하면 제안된 기법은 전방 약 0.68m에서 5.1m 까지 검지가 가능하며 도로의 젖은 상태 추정에 있어서 약 92% 의 정확도를 보여주어 신뢰성 있는 도로 표면상태 검지 기술로 확인되었다. 따라서 제안하는 노면의 습윤상태 검지 기술로 수막현상으로 인한 위험을 방지할 수 있을 것으로 예산된다.

Key Words : diffuse light reflection, light emitting diodes, optical sensors, road transportation, vehicle safety, visible light communication

ABSTRACT

The detection of road surface wetness or iciness is a critical issue for safe driving, particularly in bad weather condition. A novel road wetness detection technique based on visible light communications is presented. It employs three light emitting diodes that represent a single fog lamp and two daytime running lamps mounted on most vehicles. Road surface under test is illuminated by these light emitting diodes and the scattered-diffused light reflection from the road surface is captured to detect the road wetness. The proposed technique is also capable of detecting the road wetness on both upslope and downslope. To verify the performance of the proposed technique, experiments were conducted indoors as well as outdoors. Experimental results demonstrate that the proposed technique can detect the surface wetness over a distance range of 0.68 m to 5.1 m ahead and yield an estimated wetness level with an approximately 92% success probability. Therefore, the proposed technique could prevent the hydroplaning that may occur, due to road wetness.

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Ⅰ. Introduction

Nearly all new cars come with light emitting diode (LED) based fog lamps (FLs) and daytime running lamps (DRLs) that are mounted to increase the illumination level with no glare. These lamps not only improve car visibility for other road users but also increase driving visibility and safety at all times, particularly under bad weather conditions, i.e., rain, fog, dust, and snow. Recently, the LEDs fitted in vehicle have been applied to provide safety related data transmission to the drivers on the road in the form of vehicle-to-vehicle communications since LED provides better efficiency for illumination [1,2].

As vehicle safety technologies evolve, passive safety systems, such as road signs, airbags, and seatbelts, have been shifted to active systems where technologies ensure accident prevention rather than the minimal impact of accidents[1,3]. One of the most hazardous road conditions is wet road surface, which potentially induces hydroplaning to passing cars, thus resulting in the loss of tire traction or grip on the road[4]. Therefore, from a vehicle safety perspective, the road surface wetness can be regarded as the most crucial information.

Some interesting techniques to detect the road surface wetness have been proposed using acoustic, optical and image based technologies[5-10]. To detect both object and collision, microwave or ultrasonic sound waves were employed to analyze backscattering properties of waves on the road surface. Some authors also included the road wetness [5-7]. Radar based technologies appear to be more desirable in terms of interference, but they may not be suitable for all vehicles in general, due to their relatively high price. On the other hand, an optical based technology to enhance driving safety has been proposed[8]. It resorts to a laser beam projector, along with a detector to assess road surface conditions, based on the reflected rays from the surface. Unfortunately, this technology does not cover a large area of the road surface due to limited coherent beaming, let alone a high price. As an alternative optical beaming technology, a combination of IR beam and IR camera could be employed. This technique is primarily applied for collision detection, but it could also be used for road wetness detection, although it is prone to various thermal interferences from other vehicles[9].

Extensive studies have been undertaken for image based road surface detection using camera[10-12]. It provides the evaluation of not only road surface wetness, but also road shape, road pattern, obstacle identification, and long distance night sight[10]. On-board video systems based on polarization changes of reflection on surfaces suffer from low accuracy in poor lighting[11,12]. These camera-based solutions include a high level of graphics processing for high-resolution vision, thus involving a long processing time. As a result, it could be inappropriate for fast decision making on the road[10-12].

In this paper, a road surface wetness detection technique based on the VLC technology is proposed to prevent hydroplaning. The proposed technique uses LED lamps already fitted in vehicles and offers a large area detection coverage in a very short processing time as an affordable and efficient solution. A preliminary study was conducted to assess its viability[1]. It was demonstrated that the VLC based technique is practical for determining a level of wetness on the road[1]. It used a combination of an LED FL and a photodetector (PD) installed on car’s front bumper for road illumination. With the predefined data set transmitted, the technique collected diffuse reflections from the road surface.

The present study extends to propose a highly accurate road surface wetness detection technique with more LEDs involved and with additional detection capability for both upslope and downslope. To elaborate it further, the study utilizes three LEDs and PDs, instead of a single LED and PD. Three LEDs are an FL and two DRLs and are configured for a different detection range and a different level of precision. FL provides stronger illumination, thus supporting a longer range detection up to several meters ahead while DRLs, on the other hand, are flickered to provide a short range detection up to

0.68 meter. Since the road surface is not always flat in practice, we propose slope detection capability for both upslope and downslope.

To analyze and verify the proposed technique, an indoor static experimental set was established to identify three levels of road wetness under conceivable road conditions: upslope, downslope, bright, dark and flat roads. Moreover, an outdoor experiment was carried out to verify the robustness and reliability of the proposed technique. The experimental results reveal an approximately 92% success probability for the detection of the road wetness levels under the considered ambient light and road inclination conditions and also offer a detection distance of 5.1 m ahead. In the experiments, the transmission data rate was set to 1 kbps, which is sufficient for vehicles travelling at a speed of up to 125 km/h.

The rest of the paper is organized as follow.

Section 2 presents the proposed technique. Section 3 presents experimental results and analysis in detail. Conclusions are drawn in Section 4.

Ⅱ. Proposed Road Wetness Detection Technique

Light is reflected into two types of reflections: specular and diffuse reflections. Specular reflection occurs from smooth surfaces such as mirrors or a calm body of water. Diffuse reflection can be observed from rough surfaces (Lambertian) such as clothing, paper, and asphalt roadway, where an incident light ray is reflected at many angles[13]. For wet surfaces where water is filled in the crevices and smooths out the surface, the reflection will be largely specular. However, some of the diffuse reflection rays will bounce back towards the incident angle, i.e., the light source. The proposed detection technique is based on this diffuse reflection bounced back to the light source.

The water on the road surface affects the diffuse reflection through two phenomena[13]. First, the water filled in a rough surface makes the road smoother, thus acting like a specular surface, which would minimize the diffuse reflection. Second, the total internal reflection within a water puddle occurs, given that the water level is sufficiently deep[13]. These will cause fewer reflections bounced back towards the light source. Therefore, a deeper water puddle will result in much reduced diffuse reflection rays, thus making the detection more challenging.

The proposed road wetness detection technique uses three LEDs to illuminate the road surface and three PDs to detect diffuse reflection from the surface in order to evaluate a wetness level of road surface. One of the three LEDs is an FL. This lamp is assumed to be always on and used for a long-range measurement, i.e., coarse wetness level detection and slope detection. The other two LEDs are two DRLs that are modulated at low flickering rates for fine and more accurate short-range measurements. It is worth noting that two different flickering rates were employed for two DRLs, because the different rates will result in diverse diffuse reflections that impact constructively on the detection of wetness levels.

Ⅲ. Experiment and Analysis

3.1 Experiment Setup

The experiments were conducted in an indoor room under two ambient light conditions (bright and dark) and also in dark outdoor condition, to demonstrate the robustness and efficiency of the proposed technique. It should be noted that the outdoor experiments were conducted in dark condition, due to the fact that FL is largely turned on in bad weather condition, e.g., rainy weather where very low sunlight would exist. For the ease and convenience of the measurement campaign, the experiment setup was configured to represent a 1:17 scaled down representation of a real vehicle. It is believed that this scale-down experiment would not cause any adverse effect on the results.

Figure 1 shows a schematic that includes PDs, FL and DRLs. Two DRLs (DRL1 and DRL2) only were employed in the proposed configuration, instead of many LEDs used in real vehicles. Two DRLs use two different flickering rates for the experiments. A focusing lens was also mounted to

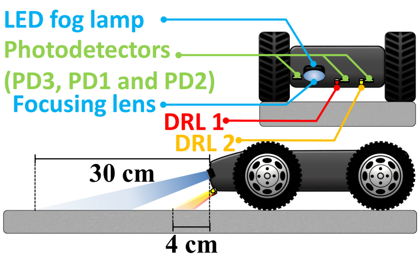

Fig. 1. Scale-down experiment setup.

the FL to generate a narrow angle beam as in a real FL. Considering that both the left and right set of lamps on a car have a nearly identical output light distribution, we carried out the experiment only for the right set of lamps. Three PDs were mounted adjacent to each lamp so that the diffuse reflection rays could be readily detected. The illumination distances were 30 cm and 4 cm for FL and DRLs, respectively on the scale-down experiment.

Table 1 shows the key parameters for the experiment setup. A sampling rate of 1 kHz was utilized for all three PDs. This rate can be considered sufficient for a vehicle travelling at a speed of up to 125 km/h with a margin of error up to 70 cm in a real scale. As noted earlier, the FL was turned on at all times, while the DRL1 and DRL2 were flickering at 125 Hz and 250 Hz, respectively. All LEDs were operated at 3.3 V producing 5 lm luminous flux. The FL and the DRLs produced 6000K and 10000K color temperature, respectively.

A predefined data pulse train was first generated using a computer and was then transmitted via two MCUs (ATmega328P and ATmega1280) after the intensity modulation of the DRL1 and DRL2 were performed. Three PDs were used to capture diffuse reflections and then the data were processed by ARM Cortex M4 MCU. All analysis and evaluation were carried out offline using a computer. The experiment was performed to measure a coarse wetness level from the intensity of PD3 and to count the pulses from both PD1 and PD2. A further process was carried out to refine the wetness level detection, based on the received intensity and the pulse count. Finally, a decision error was computed

Table 1. Experiment parameters

Description	Value
Photodetector	TEMT6000, 1 – 1000 lux, 60° field of view
LED FL	5 lm, operated at 3.3 V, 6000K color temperature
LED DRL1/DRL2	5 lm, operated at 3.3 V, 10000K color temperature
DRL1/DRL2 flickering rate	125 Hz/ 250 Hz
Illumination range	30 cm for FL; 4 cm for DRLs
Sampling Rate	1 kHz
Asphalt block roughness	Approximately 3.7 m/km[15]

by comparing the decision output from the processed data with the actual wetness level, thus measuring success probability of the proposed technique.

For the present study, we consider three levels of wetness, i.e., dry road surface (no water), 1 mm and 15 mm water puddle depths (WPD). Figure 2 (a) shows a graphical representation of the test-bed while Figure 2 (b) shows a photo of the outdoor experiment. As noted above, the effect of ambient illuminance was analyzed to verify the robustness of the proposed technique under strong (bright) or weak (dark) light interference conditions. The ambient illuminance was measured using a light meter facing upward above the PDs as shown in Figure 2 (a).

In addition, we conducted the experiments in three possible road inclination scenarios, i.e., flat, upslope and downslope. Figure 3 shows the inclination experimental setup using two asphalt blocks to replicate the road slope for both upslope and downslope. The inclination angle was set to 15°, which is considered to be higher than an average

(a) (b)

Fig. 2. Proposed road wetness detection experiment: (a) indoor experiment test-bed; (b) outdoor experiment.

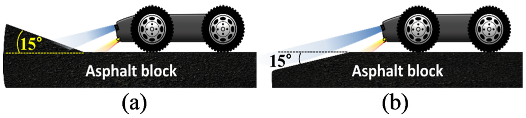

Fig. 3. Experiment setup for slope detection: (a) upslope; (b) downslope.

angle of most roads[16]. For each water level, therefore, we conducted the experiments for three inclination scenarios and repeated eight times to obtain an average value. During the eight repeated measurements, we considered the ambient light conditions (bright and dark) at equal times.

3.2 Experiment Results and Analysis

The experimental results were obtained from PD1, PD2 and PD3, corresponding to DRL1, DRL2 and FL for the detection of the diffuse reflections, respectively. Table 2 shows measured average illuminance levels from both three PDs and the considered environments. A direct FL beam with a maximum illuminance level of 1350.7 lux refers to a head-to-head illumination measurement at a 30 cm optimum projection distance. The illuminance level of 91.4 lux for PD3 represents the farthest intensity detection. As an intensity reference value for the dry road condition, we use the direct FL beam shown in Table 2. This is valid as the dry condition can provide the intensity of the direct FL beam in practice.

The coarse wetness level and slope detections are performed by PD3. Both PD1 and PD2 capture diffuse reflections originated from DRL1 and DRL2 over a predefined 50% duty cycle of the pulses, respectively. The illuminance intensities of these

Table 2. Illuminance measurements

Description	Average Illuminance
Dark ambient (indoor)	9.4 lux
Dark ambient (outdoor)	16.5 lux
Bright ambient	199.5 lux
Direct FL beam	1350.7 lux
PD3 / PD2 / PD1	91.4 lux/ 108.6 lux/ 84.6 lux

pulses are impaired by both the road surface roughness and the wetness levels. Therefore, the intensity values from PD1 and PD2 could vary significantly. A dynamic threshold adjustment was carried out to differentiate between the pulses and the noise in the reception[14]. Finally, the number of pulses was counted to measure the road surface wetness more accurately. It should be noted that the pulse count is an additional measure for the accuracy of the road surface wetness measurement in addition to the intensity values from PD3. That is, a higher number of the pulse count indicates more diffuse reflections bounced back from the road, thus implying a drier road condition.

Since we employ two different flickering rates for DRL1 and DRL2, their diffuse reflections will provide different characteristics of the road wetness. For this reason, the pulses are counted using two methods to detect the road wetness over a short distance. First, the mean threshold (M1) method is employed. This method uses the mean of input intensity as the threshold to identify the pulse peaks. Second, the normalized mean threshold (M2) is applied. Unlike M1, this method uses the normalized mean value of the received intensity values to the reference intensity of the FL beam as the threshold. From the experiments, it was found that these M1 and M2 methods provide accurate detection results for PD1 and PD2, respectively.

Figure 4 shows the received intensity from PD3 as a function of WPD for three road inclinations and also for both bright and dark environments. Since the water depths greater than 15 mm do not show any significant difference, we conducted the experiments for a water depth of up to 15 mm. A total of 94,000 data samples were recorded in the experiments for PD3. From this measurement, it can be found that the difference between the dry and wet road surfaces exists in terms of intensity.

In addition, Figure 4 shows the received intensity from PD3 against three different road inclinations (flat, upslope and downslope). It can be seen that the intensity levels vary as the slope changes. Among these inclinations, the upslope exhibits the largest value. This is because the PD3 is closer to

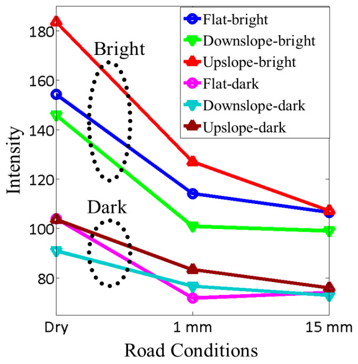

Fig. 4. Indoor experiment results: received intensity from PD3 for flat, upslope, and downslope surface under bright and dark environment.

the road surface. It can also be observed that the intensities at 15 mm converge at a particular value for the dark environment. This convergence could, however, be considered a worst-case scenario with a large amount of water on the surface, thus making the detection less accurate. Even so, with an appropriate adjustment of PDs and their positions, this level of water could still be detectable from the proposed configuration. Moreover, when this intensity-based detection is combined with the method using the pulse count described, the accuracy of the proposed technique is much improved.

On the other hand, Figure 5 shows the pulse count based measurement for both PD1 and PD2 under bright and dark environments. A total of 374,000 data samples were generated and processed

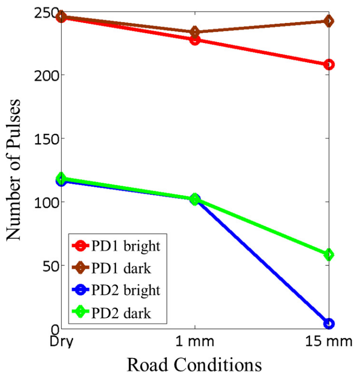

Fig. 5. Indoor experiment results: the number of pulses from PD1 and PD2 under both bright and dark environments.

for this measurement. It can be seen that a marginal variation exists over the three considered WPDs. However, when this method (PD1, PD2) is complemented with the intensity-based method (PD3), it gives higher precision of up to ± 4 cm (experiment scale) for the detection.

Figure 6 and Figure 7 shows outdoor experiment results. A total of 36,000 data samples were generated and processed for this outdoor measurement. The received intensity from PD3 decreases as WPD increases for all three different road inclinations (flat, upslope and downslope). Figure 7 shows the pulse count results for both PD1 and PD2 in the outdoor experiment. The decrease in the pulse count occurs for both PD1 and PD2, when the WPD increases. It can be noted that when the pulse count results are combined with the received intensity results from PD3, the proposed technique yields accurate estimation over three different WPDs with the precision of ± 4 cm (experiment scale),

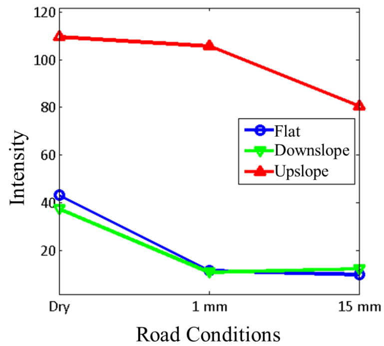

Fig. 6. Outdoor experiment results: received intensity from PD3 for flat, upslope, and downslope surface.

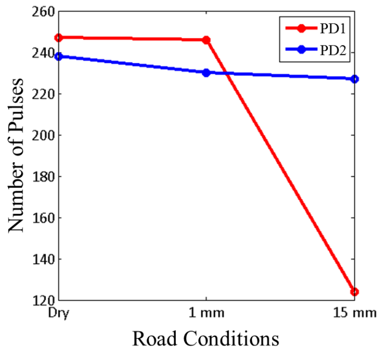

Fig. 7. Outdoor experiment results: the number of pulses from PD1 and PD2.

which is identical to the indoor experiment results.

Among nine different scenarios under which the experiments were conducted with 504,000 samples, eight errors out of 99 trials were recorded, thus yielding a success probability of approximately 92%. In addition, the minimum distance for the road wetness detection was found to be 0.68 m from the two-stage detection. It should be noted that the success of each experiment is defined by the correct detection of the wetness levels. The three road conditions of dry, 1mm and 15mm were chosen as representatives of possible wet road surfaces for the purpose of experiments.

It was found that the illumination distances were 30 cm and 4 cm for FL and DRLs, respectively, in the scale-down experiment. These distances correspond to 5.1 m and 0.68 m at real distance, respectively, when a more powerful LED of up to 1300 lm is used in practice. Moreover, the measured illuminance (see Table 2) is identical to an illuminance of 1300 lux in practice. It could, therefore, be viewed that the scale-down implementation of the proposed technique is validated.

Ⅳ. Conclusion

An efficient road wetness detection technique has been presented. The experiments were established indoors and outdoors to verify its effectiveness and reliability with three different water levels and road slopes considered, under dark and bright environments. The experimental results show that the wetness levels are accurately estimated with an approximately 92% success probability. The proposed technique is capable of measuring the road wetness detection at a distance of up to 5.1 m ahead. The present technique could further be enhanced to provide a further improvement in terms of its precision and reliability by using additional DRL LEDs, diverse flickering rates and higher sampling rates. Nonetheless, the proposed technique can be considered an efficient active safety technology in automotive industry to prevent hydroplaning by providing advance information of a road wetness level.

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