Efficient Road Surface Detection Using Visible Light Communication

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Abstract— This paper presents an efficient road surface detection technique based on visible light communication (VLC). It uses light emitting diodes (LED) based car headlamps to illuminate the road surface and capture the diffuse and specular reflections from the road surface. Experiments are conducted indoors to validate its detection scheme and accuracy. Moreover, the proposed VLC based road surface detection is found to accurately estimate the level of wetness on wet roads.

Index Terms— VLC, Light Reflection, Road Surface, Active Safety Technology.

I. INTRODUCTION

Light Emitting Diodes (LEDs) have been growing popular in lighting industry and their applications have become attractive. The power efficient illumination and very fast blinking rate of LEDs have been a driving force behind VLC technology [1]. LEDs are used in everyday life, including automotive lighting applications, i.e., headlights, taillights, indoor lights and blinkers.

In addition, there are other automotive lighting applications using LEDs such as fog lamps and daytime running lamps (DRLs). These lamps help the drivers view the road ahead and/or notify other drivers to avoid possible collision due to poor visibility. These lights are usually placed at low height near the road surface because diffused light reflection is required to help the driver view both the road's conditions and the road verges.

The paradigm of safety is currently shifting from passive safety system, i.e., air bag and seat belt, to active technologies. Active technologies aim to prevent an accident before it happens, while passive technologies only minimize the impact of the accident.

The active safety technology usually employs several vision beaming technologies utilizing camera, radar, microwave (sonar), infrared, or laser, in order to help evaluate road conditions. This technological assistance would provide faster judgment as to the road conditions to overcome driver's vision limitation.

A beaming technology to enhance the driving safety has been proposed using invisible light such as laser [2], through which the reflection of road surface is detected by a specific receiver. Although it provides a degree of accuracy for road surface detection, it is expensive and does not represent a large area of road surface due to limited coherent beaming.

Another technology associated with the road surface detection is based on infrared beam solution. It utilizes a camera and infrared signal [3]. That is, infrared is used to beam the road. This technology is often applied for collision detection rather than road surface detection. In addition, IR camera is not affordable to install in vehicle.

More interesting solutions are sonar/radar based using microwave or ultrasonic sound waves [4]. These technologies are also used predominantly for collision and object detection rather than the road surface detection. However, the benefit of this radar technology is that it is very safe from interference since it uses designated frequency. Due to a relatively high price, this solution can be suited to luxurious vehicles only.

Recently, extensive research works have been undertaken for the road surface detection or evaluation using camera. It provides not only surface detection but also road shape, road pattern, obstacles/object identification, long distance night sight and the like [5]. The camera solution can include a high level of graphics processing for high-resolution vision. Therefore, it involves a high processing time that would be unsuitable for faster judgment on the road.

The proposed detection technique is based on VLC transmission technologies using fog lamps, to help the driver judge whether the road's surface is wet or not. An LED beams the surface of the road and photodetectors receive the signal from the diffused reflection. Our present work is confined to wet condition on the basis of the fact that it is one of the most dangerous conditions often caused by rain in the form of hydroplaning.

II. VLC-BASED SURFACE DETECTION

When a light beams surface, three mechanisms occur on the surface: reflection, transmission and absorption. Among these, the present work relies upon the reflection.

This diffused reflection is the light reflection from a rough surface. That is, an incident light ray is reflected at many angles rather than one angle as in the case of specular reflection. The diffuse reflection usually happens when the incident light hits a rough surface (Lambertian surface) [6].

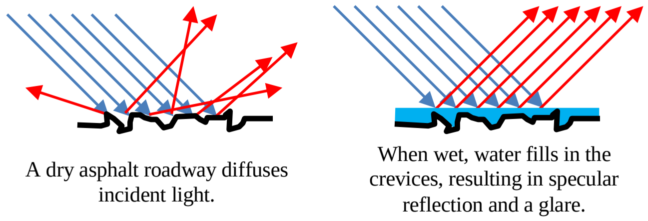

Fig. 1. Light reflection on dry asphalt roadway and wet asphalt roadway.

Some of the diffused reflection rays bounce back around the angle of incident ray. This is the basis of detection in the proposed VLC solution. Figure 1 shows the light reflection.

As mentioned earlier, our focus is the detection of wet surface using VLC. The diffused reflection is affected by the water on the road surface in two phenomena [6]. First, water filled rough surface makes the road smoother, thus acting like a specular surface. This would minimize the diffused reflection. The second phenomenon is total internal reflection within the water puddle if the water level is sufficiently deep [6].

The total internal reflection occurs between two different fluid medium, i.e., air and water, with different refractive indices [6]. When the incoming ray of light enters the water, it will be refracted before bounced back by the diffused reflection. Then, at angles greater than or equal to critical angle (θ_C), the diffused reflection will also be reflected back into the water by this total internal reflection. This causes lesser reflection bounced back into the photodetector. Figure 2 depicts the total internal reflection.

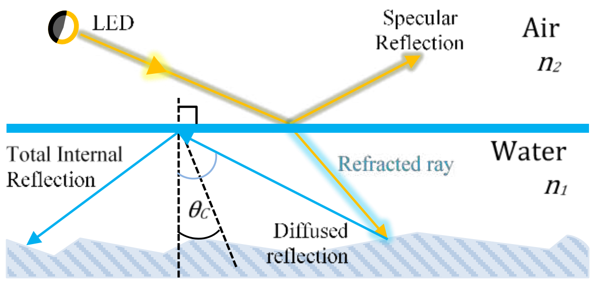

Fig. 2. Total internal reflection inside the water

Therefore, the deeper the water is, the less the diffused reflection will be. This means that every change in the water level of the surface can be measured.

Given that n_2 is the refraction index of air and n_1 is the refraction index of water/liquid, which is denser than air, the critical angle is given by (1).

Any incident ray coming from below the water surface with an angle greater than θ_C will be reflected back into the water.

$$\theta_c = \arcsin\left(\frac{n_2}{n_1}\right) \tag{1}$$

A simple photo comparison between dry and wet asphalt surface is shown in Figure 3. This photo evaluation proves this underlying principle for the road surface detection used in the present study.

Fig. 3. Photo comparison between wet and dry asphalt surfaces

III. Experiment Setup

For the experiments, we use a fog lamp (LED) to beam the road surface and we receive reflection from a photodetector placed inside headlight compartment. Figure 4 shows the structure of the experiment setup. Although the color of a fog lamp in practice is yellow or white, we use a white color fog lamp. A 1W LED is used due to power limitation.

Figure 5 shows the indoor experiment setup. This setup consists of two microcontroller units (MCU), a white 1W LED and a photodetector. Atmega328 is used as MCU for both the LED signal and photodetector. TSL252R photodetector is connected to MCU, which then transmits the received voltage to a computer using serial communication.

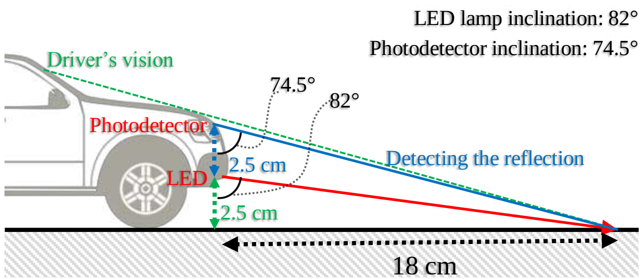

Fig. 4. Structure of experiment setup.

A light meter was used to measure light intensity which accuracy level is ±0.5 lux with a sampling period of 1sec. The LED uses 2.719V and draws 61.6mA when it is connected to the MCU board.

IV. Experiments and Analysis

Prior to actual measurements of the received signal from the photodetectors, we performed reference value measurements without reflection from the light source. The measured light intensity was 867 lux on average and also measured ambient light illuminance incident from surrounding indoor walls is approximately 1 lux (±0.5 lux).

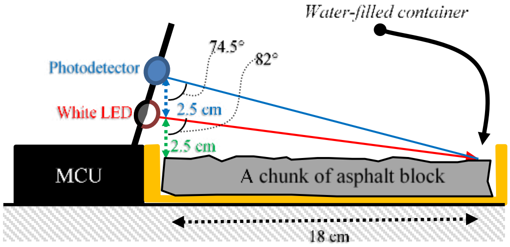

Fig. 5. The real indoor-experiment setup.

A. Light Intensity Measurement

The light intensity test was conducted, focusing on light intensity measurement of the diffused reflection bounced back from the situated road surface. The 1 Hz pulses were emitted for this measurement.

Figure 6 shows the measurement results for 5 different levels of road wetness, i.e., dry, barely wet (no water puddle), wetness less than 1mm, 1mm wetness and 15mm-deep water puddle. The results show that approximately 12 lux was observed for the dry condition, whereas the wet condition was measured about 7 lux. Note that the received signal was amplified by a factor of 50 for clearer visualization.

It is also found that the thicker the water layer is, the shorter the pulse duration is, i.e. spikes. When the water level was too high, no diffuse reflections were observed.

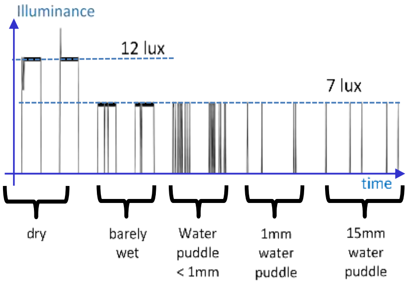

Fig. 6. Light intensity test

B. Light Pattern Measurement

We carried out further experiments by transmitting simple burst data with a low blinking frequency. This is done for enhancing its accuracy of the detection. This will provide accuracy even when there is a sudden change of vehicle movement and also an abrupt change of wetness level occur.

Table I shows the measurement results in terms of change in illuminance level for each water level. Figure 7 illustrates pulse patterns obtained. It can be observed that as the water level gets deeper, the pulses become narrower and spiky. The short pulses mostly disappeared, due to the water specular reflection and some total internal reflection.

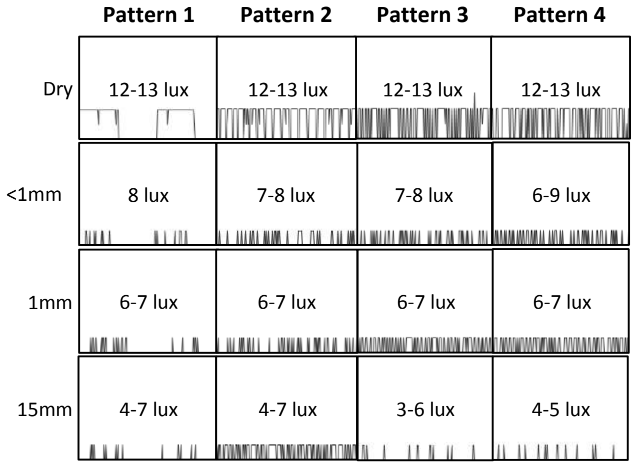

Fig. 7. Indoor pattern test results

V. Conclusion

The experimental investigation of VLC based road surface detection was presented. Focusing on the wet road condition, the road surface detection scheme was found to be reliable. The pulse pattern measurements revealed consistency in that the water level on the road was proportional to the amount of the diffuse reflections. A water level beyond the maximum detectability from reflection would not result in any returned diffuse reflections, i.e., all the light rays undergo specular reflection and total internal reflection in the water. A more rigorous work is underway to address other road conditions and outdoor measurements for higher accuracy and reliability is being carried out.

Acknowledgment

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