Preliminary Study on Road Slipperiness Detection using Real-Time Digital Tachograph Data

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Abstract: Faced with the high rate of commercial vehicle-related traffic accidents, digital tachographs (DTGs) are mandatorily installed in commercial vehicles in Korea. However, the current DTGs do not seem to be effective for reducing accidents. One reason for this can be attributed to the absence of useful information for drivers under dangerous road conditions such as black ice. In this study, an innovative technique to identify slippery spots on the road using DTG data is proposed. The DTG can collect two types of vehicle speed: one is wheel rotational speed and the other is vehicle transitional speed. The difference between the two speeds is referred to as wheel slip, which can be exploited as a surrogate measure for detecting road slipperiness. A confidence interval of wheel slip was established using data collected in dry road conditions; if any data point that exceeds the predefined confidence interval is observed, a slippery road spot can be identified. The proposed method was preliminarily tested in four types of winter road conditions and showed satisfactory results.

1 INTRODUCTION

Traffic accidents caused by slippery road conditions are of great concern to society. According to Korean statistics, 7,849 traffic accidents that caused 221 fatalities and 13,736 injuries occurred on slippery roads over the last three years (KNPA, 2017). The fatality rate on icy roads is 27% higher than on dry roads. One study in Sweden insisted that only 14% of drivers maintain appropriate acceleration and deceleration under slippery road conditions and 50% of drivers misjudge slippery road surfaces as normal ones (Bogren, 2010). The risk of traffic accidents is known to increase nine and twenty times under snowy and icy road conditions, respectively (Luque, 2013).

To mitigate the tragic numbers, early detection of slippery spots on the road followed by quick notification to drivers and road managers seems to be imperative. To this end, a road weather information system (RWIS) has conventionally been deployed to gather road weather data (Boon, 2002). However, as RWIS can only collect spot data, its utility could be restricted, given that road slipperiness is known to vary even in short roadway sections (Nakatsuji, 2003). Due to this limitation coupled with the high cost, RWIS has not been extensively deployed in Korea. Recently, as increasing numbers of vehicles are getting connected for various purposes, a new cost-effective approach to detecting road slipperiness using probe vehicles as a mobile sensing platform has been garnering attention worldwide.

Several studies have been performed concerning weather-related hazardous road conditions using probe cars. A probe-based road weather data collection system in Finland was developed by Pilli-Sihvola (2000). The system gathered various road weather-related data, including temperature, humidity, friction, and video images. Probe cars for the system were fitted with various devices—a friction tester, a GPS antenna, an infrared sensor, a combined air temperature and humidity sensor, a video recorder, and a cellular modem. A real-time tire-road friction coefficient estimation system using probe vehicles equipped with a vehicle motion sensor and a differential GPS module was invented by Wang et al. (2004). A novel methodology for tire-road friction estimation using a genetic algorithm and the unscented Kalman filter combined with tire-models and probe vehicle data was proposed by Nakatsuji et al. (2005 and 2007). A probe application for the identification of road slipperiness and coarseness using vehicle body and wheel rotation speeds was demonstrated by Dong et al. (2006). The potential use of data gathered from a Vehicle Infrastructure Integration (VII)-enabled probe vehicle in weather-

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related applications and products for surface transportation was proposed by Petty et al. (2007). A probe-based weather-specific field study in Detroit was conducted in 2009 and 2010 by Drobot et al. (2010) and Chapman et al. (2010). A technique to estimate the maximum friction while simultaneously diagnosing the road conditions was discussed by Koskinen (2010). Recently, Wyoming Department of Transportation (WyDOT) has been deploying a connected vehicle-based road weather information system as part of a connected vehicle pilot project (WyDOT, 2018).

As of 2011, digital tachographs (DTG) have been obligatorily installed on every commercial vehicle in Korea to reduce traffic accidents related to commercial vehicles, for which the accident rate is 1.7 times higher than for general vehicles. A DTG collects several types of vehicle data—location, speed, brake activation, time of driving, etc. A substantial number of DTGs installed on trucks are connected to a truck management center via cellular communications to transmit real-time data for efficient logistics. In this study, a simple but novel technique is proposed to identify slippery road spots using the real-time DTG data. Cargo trucks are considered to be advantageous over other types of vehicles in that they are generally operated throughout the nation on a 24/7 basis. Also, truck drivers tend to choose night driving so as not to be trapped in congestion, so information on icy spots on the road ahead could be highly valued considering that black ice is not easily discerned at night.

2 METHOD

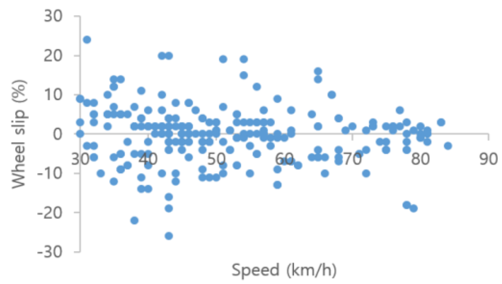
2.1 Basic Concept

On a slippery road surface, vehicle wheels have a high risk of skidding while decelerating, as well as spinning in place while accelerating. This, called wheel slip and expressed in (1), can be measured by calculating the difference between the wheel rotational and vehicle transitional speeds. In a DTG platform, the wheel rotational speed can be measured using wheel pulse sensors installed on each wheel of a vehicle and the vehicle transitional speed can be obtained using a GPS sensor installed in the DTG.

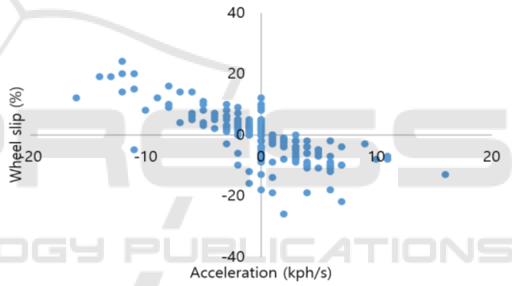
$$s = \frac{w_w r_w - v_w}{w_w r_w},\ 0 \leq s \leq 1 \quad (1)$$

where s=wheel slip, w_w=angular velocity of wheel, r_w=effective wheel radius, v_w=vehicle transitional speed, and $w_w r_w$=wheel rotational speed.

The two speeds are theoretically identical under dry road surface conditions. However, they show some discrepancy due to reasons such as measurement errors of sensors, the characteristics of vehicle tires made of rubber, and so on. Fig. 1 shows values of wheel slip according to vehicle speed and acceleration under dry road conditions: low and high correlation with speed and acceleration, respectively. The high correlation with acceleration was exploited for measuring slippery road spots and the method will be described in the next section.



(a)



(b)

Figure 1: Relationships between wheel slip and vehicle dynamics: (a) speed and (b) acceleration.

2.2 Confidence Interval

The statistical confidence interval concept of a regression line (or equation) expressed in (2)–(4) was applied to identify road slipperiness. According to the identical and independent distribution assumption of the error term of the regression line, the confidence interval of the i-th estimate can be determined. For this study, the dependent variable corresponds to wheel slip and the independent variable corresponds to acceleration of a vehicle.

$$\hat{y}_i = ax_i + b + e_i \quad (2)$$

$$e_i \sim N(0, s_e) \quad (3)$$

$$s_e = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n-2}} \quad (4)$$

where $\hat{y}_i$=i-th dependent variable (estimate), x_i=i-th independent variable (observation), b=y-axis intercept, e_i=i-the error, s_e=standard error of regression line, y_i=i-th observation, and n=number of sample.

For a desired level of false alarm rate (α), a two-sided confidence interval which includes (1-α)*100% of the wheel slip can be defined with its upper and lower limit values becoming thresholds (Thr) of the regression equation for the particular estimate of wheel slip, as expressed in (5). If any wheel slip exceeds the thresholds, a slippery road spot can be identified.

$$\text{Thr} = N^{-1}(\hat{y}_i, s_e, 1-\alpha/2) \qquad (5)$$

where N^{-1}=inverse of normal cumulative distribution function and α=significance level.

Table 1 shows the result of the regression analysis of the relationship between wheel slip and acceleration plotted on the right side of Fig. (1). To determine the statistical confidence interval of the wheel slip, a z-value corresponding to 99.7% was employed.

Table 1: Regression analysis of the relationship between wheel slip and acceleration.

Statistics	Value
Slope (a)	-1.2
y-axis intercept (b)	0.5
Correlation coefficient	0.8
Determination coefficient	0.6
Standard error (s_e)	4.7
Number of sample	259

2.3 Algorithm

Based on the method stated above, the algorithm to identify slippery road spots using real-time DTG data can be established (see Fig. 2). The 99.7% confidence interval (z=3) determined using historical DTG data collected under dry road conditions is employed to investigate whether a current wheel slip calculated using real-time DTG data deviates from the lower or upper limits set by the regression statistics represented in Table 1. If any data point falls out of the limits, the road spot is subsequently identified as slippery. The slipperiness information is not only displayed on the DTG installed in the commercial vehicle for the driver, but transmitted to the traffic management center via cellular communications for following drivers and road managers.

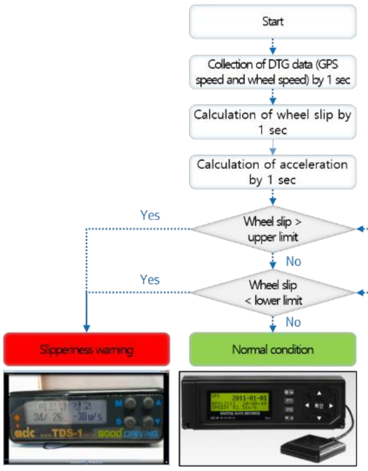


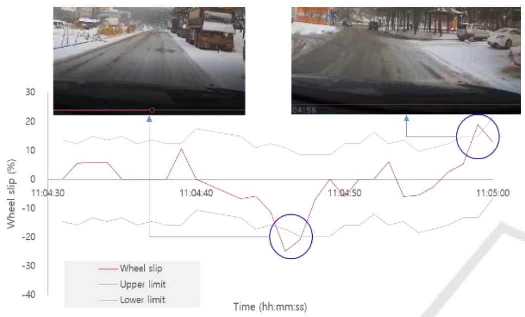
Figure 2: Algorithm for identifying slippery road spot using DTG data.

3 FIELD EXPERIMENT

To verify the proposed algorithm, field experiments under various slippery road surface conditions were performed in the 2017–2018 winter season on local and arterial roads. A passenger car operated by a skilled male driver with more than 20 years driving experience was used for collecting real-time DTG data including GPS coordinates, wheel speed, GPS speed, and so on. For visual verification, a digital video recorder time-synchronized with the DTG was employed to gather video image data. The driver was instructed to slightly accelerate followed by decelerate while driving on the slippery road spots.

Fig. 3 shows the experiment results under four types of slippery road conditions: ice, light snow, slush, and heavy snow. Each slippery condition was diagnosed by the proposed method, where the wheel slips calculated by equation (1) exceeded the confidence intervals predefined by equation (5) and the regression statistics represented in Table 1. Notably, the wheel slips gathered on the icy road surface were more prominent than other surfaces in terms of slippery road identification. This aspect can be recognized as reasonable because the tire-road friction coefficients on icy roads are generally known to be much lower than on snowy or slushy roads (Mcshane, 2003).

(a)



(b)

(c)

(d)

Figure 3: Field test under road conditions: (a) ice, (b) light snow (c) slush, and (d) heavy snow.

4 DISCUSSIONS

Confronted with severe traffic congestion in metropolitan areas in Korea, truck drivers are inclined to operate their heavy vehicles loaded with high-priced freight at night, when road surface conditions are not easily discernible. Hence, road slipperiness information gathered by mandatorily installed DTGs on commercial vehicles for delivering the collected information to following truck drivers, as well as road agencies for a prompt response such as applying chemicals, should be highly regarded. The suggested method is simple but it was proved to reliably collect slippery road spots with an extremely low cost compared to conventional technologies such as RWIS. It should be noted that the proposed method is not applicable solely to DTG data. It can be broadly applied to any devices that can collect vehicle body transitional and wheel rotational speeds. Among such devices are cooperative-intelligent transport systems on-board units and smart-phones receiving on-board diagnostics data of vehicles via the Bluetooth communications.

However, there are some issues to be addressed to improve the performance of the proposed method. In this article, only the wheel slip method based on GPS and wheel pulse sensors is presented to identify slippery road spots. So, the proposed method cannot be applied where there is interference with GPS signals, especially in urban canyons or mountainous areas. An alternative solution to the problem is to use the rotational speed difference between the driving and driven axle (or wheel) of a vehicle. However, since current DTGs do not collect wheel rotational speeds by the axle, the alternative method could not be tested in this study. Furthermore, the proposed wheel slip method can only collect slippery road spots on the wheel track of a vehicle, not on the whole driving lane. So, it is highly recommended to fuse the proposed method with other techniques such as road status recognition using vision sensors to enhance the utilization of road slipperiness information from the perspective of road users.

5 CONCLUSIONS

With rapid advances in wireless communications technologies coupled with the evolving smart car industry, increasing numbers of cars are getting connected. In the era of a connected car environment, more opportunities to exploit vehicle sensors to obtain road status information become possible, such as the possible realization of road operations and maintenance based on IoT, the cloud, big data, and mobile technology. One example of the concept to increase safety under slippery road conditions was presented in this article. Wheel slip, defined as the difference between vehicle's transitional and wheel rotational speeds, gathered by the DTG is employed to recognize slippery road spots. Using the confidence interval of the wheel slip under dry road conditions, wheel slip data observed on slippery roads can be identified. As of January 2018, around 30,000 DTGs in commercial trucks are connected and their real-time data on a second-by-second basis are transmitted to smart truck management centers operated by private sectors. Considering that the total number of commercial vehicles equipped with DTGs is some 400,000, the size of the market for applying the suggested method is substantial.

Due to the absence of a test facility that can simulate various weather conditions, the field tests could not but be limited in this study. The quantitative measure of road slipperiness is the friction coefficient between the vehicle tire and pavement, but the friction is known to have a wide range in similar adverse weather situations. The friction, due to the experiments being carried out on real roads, could not be measured for this study owing to safety concerns. Fortunately, an adverse road weather simulation test bed is under construction with the aid of the Korean government, so the method presented herein could be broadly tested under various friction conditions in the near future in a quantitative manner. Techniques to identify other anomalies on the road such as potholes could be a study subject for subsequent research.

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