Road friction monitoring

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ABSTRACT

Slippery roads cause thousands of accidents each year. One reason for accidents is the difficulty to evaluate correctly the road friction. A study made in Finland indicates that almost half of the persons misjudge the friction. Some equipment is available for the friction detection but thus far their results are not reliable enough for this task. In this paper, we study the use of near-infrared (NIR) camera for reliable road condition detection. The obtained results indicate feasibility of the system. However, the camera is sensitive for varying lighting conditions so the system should be advanced further.

Keywords: NIR camera, polarisation, road condition, road friction, road monitoring

1 INTRODUCTION

Slipperiness of roads is typically due to snow, ice, water or their combinations. The water in its different states reduces the friction which then lessens the grip of tyres on the road. The slippery roads cause material damages, personal injuries and deaths. They are currently great concern in northern Europe but there is not available accurate system to inform how slippery the road is. In Finland, the official body for traffic (Liikennevirasto) in their web pages gives just a general estimation of road conditions: normal, poor and extremely poor road condition. There can be some additional descriptions like windy, heavy snow fall or road is snowy.

The detection of snowy, wet or icy road is often very easy for a person with normal vision. The exception is so called "black ice" which is very difficult to separate from the road. Although the detection of these factors is easy the estimation of friction is not. A study done in Finland suggests that almost half of the people cannot correctly judge the available friction in a road [6]. Automatic road friction detection system would be thus useful for safety because drivers could take the adverse and locally varying road conditions into account. It would be also useful for road operators who could take necessary maintenance services like salting or snow ploughing.

A lot of research has been therefore done for friction estimation especially in the countries where long winter time causes significant safety risk. Many of them suggest extraction of friction information wheel speed (braking or throttling) or from chassis motion sensor but this information cannot be used in advanced driver assistance systems (ADAS) to induce interventions due to reliability problems (see e.g. Anderssen et al.[1]). Other has suggested optical methods like infrared, near-infrared or polarization.

Use of polarization intensity changes has been suggested by Yamada et al.[7]. They also suggested that texture could provide additional information to improve the overall road surface condition estimation. Our application have improved processing schema. The polarisation has been suggested also for black ice detection by Yusheng and Higgins-Luthman [8]. Their patent describes a measurement system which uses polarisation filters and active lighting. The goal is to detect the icy puddles located in the front of the car.

Our earlier studies ([3][4][5]) we showed that friction information can be implemented as a part of general monitoring system. In these studies we showed that stereo camera pair with polarisation filters in the front of the optics can be used for reliable road condition measuring. The goal of this paper is show that near-infrared and polarization can be combined and used with NIR camera to get more reliable results. This feasibility of friction measurement is studied by using an implemented optical system for this purpose and arranging test areas. The implemented system is based on combining near-infrared (NIR) and polarisation measurements (wavelength range is 0.9 - 1.7 µm), and texture analysis (graininess). We have made the measurements of different road conditions in different seasons for evaluating the feasibility. The obtained results indicate that combining texture information from NIR images and polarisation is useful. However, the camera is sensitive for varying lighting conditions so the system should be advanced further.

2 DATA COLLECTION

One of the important aspects of testing was to create a suitable test conditions. These test results were used also as training samples for the detection system. Therefore it is especially important to find the differences between different states of water on the road surface. We accomplish this by pouring water on snowy road and let it become frozen (winter test), by covering the test surface area with snow (winter test) and by moistening the dry asphalt road (summer test). These areas were then imaged with a special near-infrared (NIR camera). We also used our stereo camera system [3][4] as reference system to verify detected road condition. The NIR camera was installed on road side unit (RSU) which was developed during ASSET-Road-EU-FP7 project. Fig. 1 shows used Xenics XS-1265 NIR camera with RSU unit.

Figure 1: Road side unit (RSU) with Xenics XS-1265 NIR camera. All the test images were capture with this unit. Vehicle on background was carrying stereo camera unit.

The NIR camera has a wavelength range of 0.9 - 1.7 µm. The selection was based on physical properties of snow, ice and dry road: the ice can be distinguished from snow or dry road on the wavelengths above 1.5 µm. Since the intensity is sensitive to illumination level, we also tested the use of polarisation information for modelling in the second experiment. This system utilises visible wavelengths and near infrared band below 950 nm band. In referenced stereo camera system the polarisation filters were attached in the front of the optics so that both the horizontal and vertical polarisation could be measured. It is known that the ice or water tend to reduce the vertically polarised light. Thus polarisation changes can be useful for detecting slippery roads.

Fig. 2. displays two images taken at different seasons (winter and summer) with the NIR camera. The image taken on the winter clearly shows difference between ice and snow. The white parts on the surface of ice are due to irregularities and snow. The smoother the surface of ice is the more dark it appears. The summer image shows also clear difference between dry and wet road. When the water starts to evaporate on the wet areas then these areas start to appear lighter. The images taken indicate that the NIR camera used is suitable for road condition monitoring and friction evaluation.

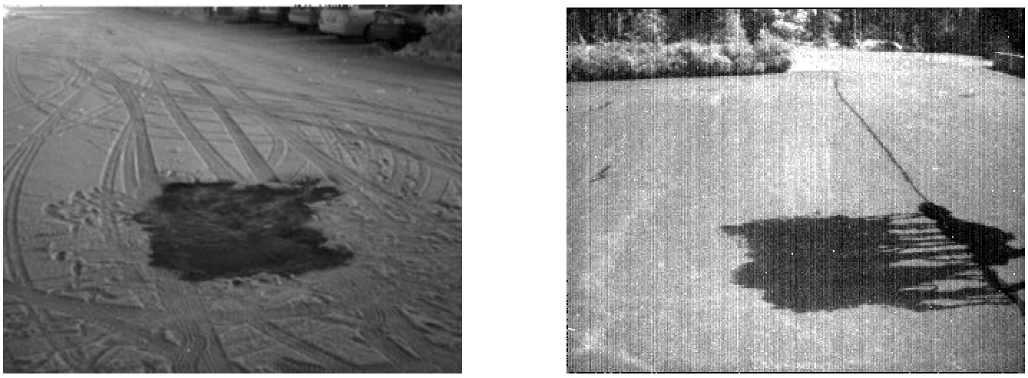

Figure 2. NIR image shows clearly the difference between ice and snow (left side). The image is taken in the winter. The moistened road surface is clearly similar than the dry asphalt road (right side). The image is taken in the summer time.

3 ANALYSIS METHODS

The images taken were divided into training and testing sets. The regions of interest (ROIs) were manually selected from the training set images. The ROIs consisted road areas which were clearly snowy, icy, wet and dry. They were then subjected for further analysis. The analysis included intensity and graininess (i.e. texture) calculations. Intensity is merely an average of greyscale values located inside the ROI The graininess analysis has been suggested to analyse style of an artist in the paintings [2] but it seems to be useful also for the road condition evaluation.

The graininess measure implemented here use the low-pass filtering to the NIR images which makes them more blurry. The low-pass filtering was realized with Wiener filtering. The evaluation of graininess is based on contrast evaluation. The contrast difference between the original and the low-pass filtered images gives then information concerning the amount of high frequency band elements. These elements are correlated with blurriness of the low-pass filtered image.

The contrast (C) is defined as the difference of the adjacent pixels aligned horizontally or vertically. The overall contrast is then the sum of differences computed on rows and columns respectively. The contrast is used to determine the graininess of an image S using the following equation:

$$S = \frac{C_{original} - C_{filtered}}{C_{original}} \tag{1}$$

This calculated graininess value can be related to frequency content which is manifested by differences between adjacent pixels. These two parameters were enough to separate different road states (dry, wet, snowy, icy) which has been made by using a training set. This result was confirmed using the test set images with known class.

Another measure used in road condition evaluation was polarisation. Especially the difference between two polarisation states showed to be correlating to friction. The polarisation difference is simply defined as:

$$I_{diff} = I_{horizontal} - I_{vertical} \tag{2}$$

where $I_{horizontal}$ and $I_{vertical}$ are measured intensities with a horizontal and vertical polarization filter, respectively. Polarisation difference based on horizontal and vertical polarisation is calculated only with stereo camera. With NIR camera it’s possible to use only one camera and therefore we use intensity on whole image area. This can be calculated with same algorithm using zero image instead if intensity of vertically polarized image:

$$I_{diff} = I - I_{zeroimage} \tag{3}$$

4 RESULTS

To evaluate the road conditions, an optical camera system was implemented on the test sites. Image analysis software which can be used with the camera to classify the surface condition was developed too. We tested plain intensity and graininess but the results were not promising. The graininess and polarisation combination has much higher correlation to road conditions and frictions.

Fig. 3 shows results for summer test where the surface of the road was watered. As this figure indicates, dry and wet surface can be clearly separated by using the graininess and polarisation factors. The samples are spreading along diagonal axis from low polarisation and graininess values to higher values. The dry samples (plain asphalt) were clustered in three tight but separate areas which did not change during the measurement although the camera position and lighting conditions were changed. The polarisation is sensitive to road friction: the polarisation increased as the road dried up. The ellipsoids in the image indicate the calculated model.

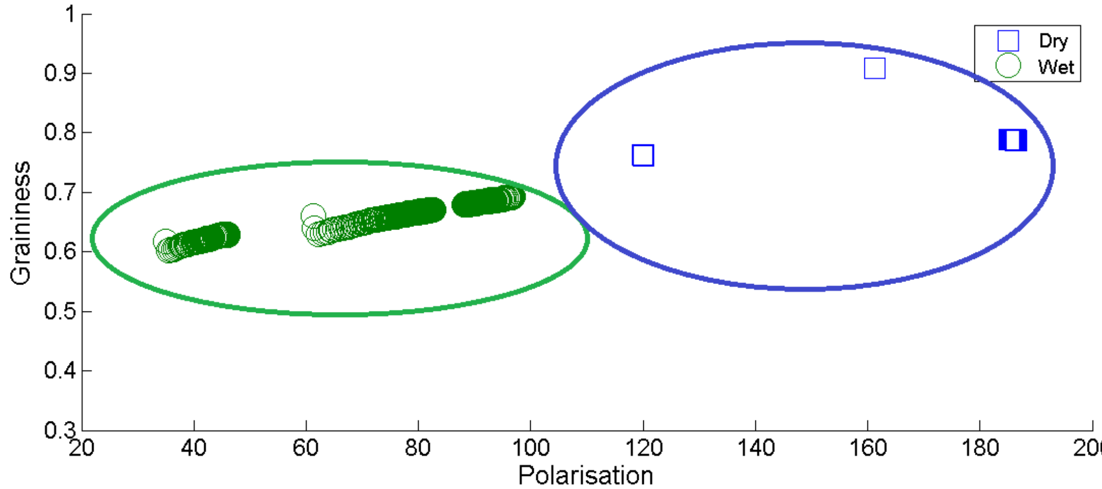

Figure 3: Graininess and polarisation teaching samples for dry (square) and wet (circle) road condition

Fig. 4 shows the results for the winter test. The samples of snowy and icy are partly overlapping and there are outliers. The overlap is caused partly by the use of whole wavelength range and non-uniformity of ice surface. Other reason is snow on the icy surface. It was noticed that graininess calculation for icy and snowy surfaces is greatly affected by varying illumination conditions. Despite the outliers it is possible to cluster and separate two different groups.

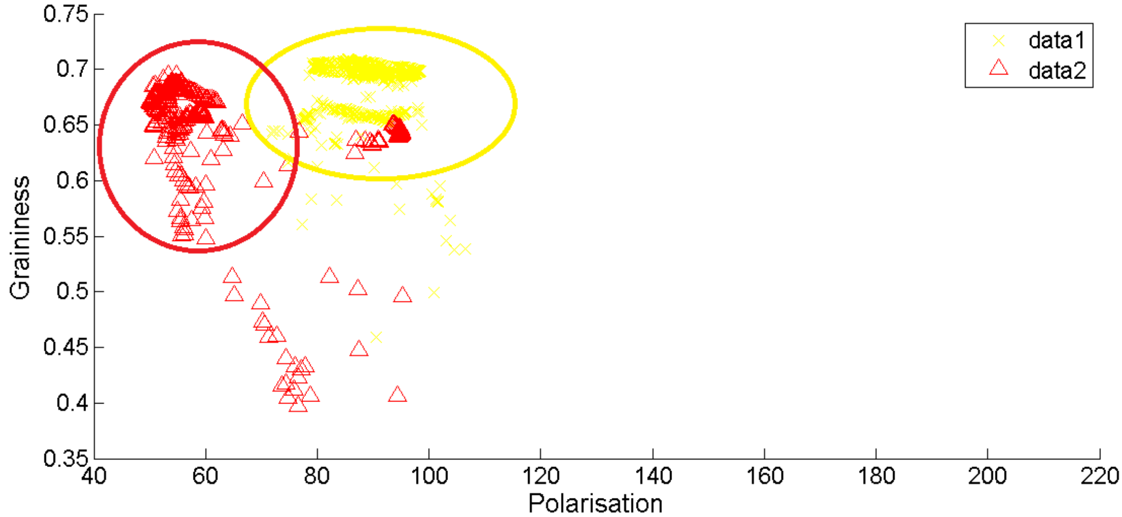

Figure 4: Teaching samples for snowy (cross) and icy (triangle) road condition and classification borders for them.

The final classification borders are shown in Fig. 5. The classification borders are on the same diagonal line overlapping each other's. The wet, ice and snow surface values overlap because they all contain water which is detected by the NIR camera. The overlapping might be prevented by selecting the wavelength area better (e.g. by using only values over 1.5 µm. On the other hand, watery and icy road can have similar friction. Finally, the friction value was then approximated from a look-up table as suggested in the literature.

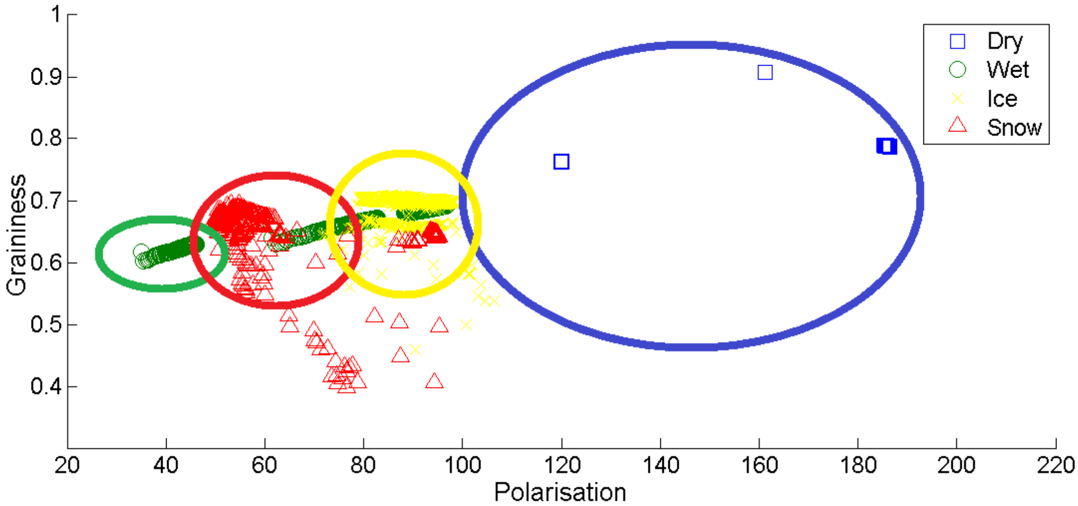

Figure 5: Final classification borders for dry, wet, snowy and icy road surface. The graininess and polarisation parameters can be used in a classifier which is able to separate four different road surface conditions: dry, wet, ice or snow. Note that the wet, ice and snow surface values overlap because they all contain water which is detected by the NIR camera

This system was tested also on real lane monitoring situation Fig. 6. The detection area on the road was fixed. It was noticed that sometimes the system evaluated the friction wrongly when bypassing cars passed the detection area. This can be solved either using techniques to detect cars and exclude them or to filter outliers and determine prevailing road condition from detection centre of mass.

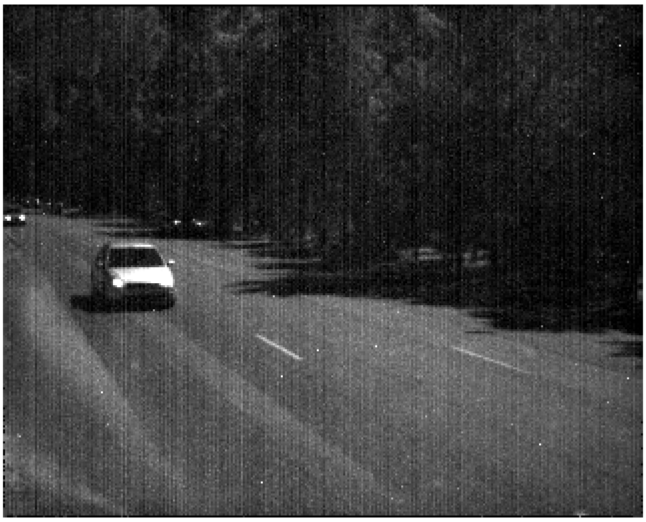

Figure 6: Example of real lane monitoring situation at summer time (dry road). In this case bypassing vehicles caused false detections but these can be filtered in final analysis.

5 CONCLUSIONS

Our goal was to study the feasibility of polarisation and texture (graininess) for road condition and friction evaluation. Results from the tests are encouraging and show that separation between road conditions is possible to make with NIR camera and polarisation information. It was important to use texture measure called graininess to get reliable results.

The polarisation seems to be sensitive to road friction. When the road dries up or icy surface become less snowy, then polarisation increases. The polarisation and graininess values were combined to develop another friction estimation model. This model was also able to separate the road states.

Still, there were problems in detection. The NIR camera seems to be rather sensitive to varying lighting conditions. With stereo camera polarization is measured from difference of vertically and horizontally filtered images. With NIR camera we used original intensity image. Variation in image intensity will change the polarisation values. Naturally this makes the classification more difficult and not very robust as the class boundaries are defined under certain lighting conditions.

Unfortunately, the current system is not able to adjust the brightness of images automatically. Aperture needs to be adjusted physically opening or closing the objective. Programmatically this could be done by stretching histogram of an image (which does not work with images that are too bright) or by changing the evaluation time. Further improved could be a better selection of wavelength range and advanced data processing which could exclude passing cars.

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