Laboratory test of five different optical road condition sensors

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Introduction

Wintertime, the number of accidents increases considerably. Particularly when roads are covered in snow or ice. It is therefore beneficial to be able to detect such conditions, both in order to warn road users and to inform maintenance personnel such that suitable measures can be taken. One method to detect contaminants on a road is optical road condition sensors. These often use several wavelengths in the NIR/SWIR -spectrum to classify the type of contaminant on a road. One issue with such sensors is that it is difficult to validate their results. On a road, several types of contaminants are often present at the same time, while it can be difficult to know exactly where the sensors look.

Method

In this study five different sensors, two stationary and three mobile, were tested in a walk-in cold laboratory at a temperature of -3°C for ice and snow and +10°C for liquid water. This was done in order to better understand how reliable such sensors are, and to get an idea of how consistent results different sensors give compared to each other. The tested sensors were Vaisala DSC211 (stationary), Metsense 2DRoad (stationary), Teconer RCM411 (mobile), Metsense MetRoad Mobile (mobile) and MARWIS (mobile). The parameters that we compared were the classified contaminant as well as the derived friction and water-film thickness. Since the mobile sensors can be expected to operate over several different types of asphalt, those were tested on two substrates with different types of asphalt. One gray “old” asphalt and one black “new” asphalt. The stationary sensors were only tested on the gray asphalt. Before the test began, all sensors were calibrated to the gray asphalt plate. The exception was the MetRoad Mobile sensor, which is calibrated using a sheet of white paper.

Three different types of contaminants were tested in this study; water, ice and snow. The water film thickness was controlled by submerging the substrate in a water-filled container and adjusting the water level to get the desired film thickness. Ice was frozen onto the substrates in very thin layers until a suitable thickness was reached. The ice thickness was measured using a depth penetrometer after finishing the sensor tests. When testing the sensor abilities on snow, three different snow types were used; fresh snow, old snow and coarse-grained spring-snow. The fresh snow is the type of dendritic snow that can be expected to fall on a road during a snowstorm. Old snow is fine-grained snow, similar to what can be expected to be found on a road with a compacted snow crust a few days/weeks old. Finally, spring-snow is the type of snow which can be expected to be found on roads where water is present, e.g. a snowy road during spring or a salted road some time (several hours) after a snowstorm. Since snow also exists in a large range of densities, from 50 kg/m^3 for very loose fresh snow to 800 kg/m^3 for firn in glaciers, the snow types were compressed to different densities using an MTS uniaxial compression device. The snow types and their densities can be found in Table 1.

Results and discussion

Classification

The classification results, presented in Table 1, show that the two stationary sensors performs very well in detecting what contaminant which covered the substrate. The only misclassification of the stationary sensors was that the DSC211 considered coarse spring snow as ice. For the mobile sensors, the classification results were more varying. MetRoad and MARWIS correctly classified both substrates when dry, while RCM411 classified the black asphalt as being moist. Looking at substrates with water films ranging from 0.5 to 3 mm, two of the sensors (MetRoad and RCM411) classified some of the water films

Table 1 Results from the classification tests of the optical sensors.

Surface description			Classification result				
Condition	Plate	Details	DSC211	2Droad	RCM411	Metroad	Marwis
Dry	Gray		Dry	Dry	Dry	Dry	Dry
	Black		-	-	Moist	Dry	Dry
Wet	Gray	0.5 mm	Wet	Moist	Wet	Moist	Wet
		1.0 mm	Wet	Wet	Moist	Frost	Wet
		2.0 mm	Wet	Wet	Slush	Ice	Wet
		3.0 mm	Wet	Wet	Wet	Wet	Wet
	Black	1.0 mm	-	-	Moist	Moist	Wet
		2.0 mm	-	-	Wet + slush	Wet	Wet
		3.0 mm	-	-	Wet	Ice	Wet
Ice	Gray	0.5 mm	Ice	Ice	Ice	Frost	Ice
		0.9 mm	Ice	Ice	Ice + snow	Ice	Ice
		2.2 mm	Ice	Ice	Ice	Ice	Wet
		3.5 mm	Ice	Ice	Ice	Ice	Wet
	Black	0.6 mm	-	-	Ice	Frost	Ice
		0.9 mm	-	-	Ice	Ice	Ice
		2.6 mm	-	-	Ice + slush	Wet	Wet
		3.7 mm	-	-	Ice	Wet	Wet
Snow	Gray	Fresh 150	Snow	Snow	Snow	Snow	Snow
		Fresh 450	Snow	Snow	Snow	Snow	Snow
		Fresh 750	Snow	Snow	Snow	Snow	Snow
		Old 420	Snow	Snow	Snow	Snow	Snow
		Old 620	Snow	Snow	Snow	Snow	Snow
		Spring 530	Ice	Snow	Snow	Snow	Ice + snow

as ice and slush respectively. This error persisted also on the black asphalt substrate. The algorithm used by MARWIS, however, correctly classified all wet samples on both plates. When looking at ice, the RCM411 correctly classified all samples on both substrates. MetRoad gave correct classifications on the gray substrate, while thick ice (>2 mm) on the black substrate was classified as “wet”. MARWIS classified thick ice (>2 mm) as wet on both substrates. The issue the mobile sensors has with distinguishing between water and ice does not seem to be related to the underlying substrate, but rather related to the water/ice film thickness. While a water film thickness of more than 1 mm probably is uncommon on a road, ice films this thick can certainly be expected. An inability to detect such ice films can be serious. This is, after all, one of the more important tasks when detecting road conditions. Both in order to warn road users against slippery conditions which might be hard to detect by eye, and when it comes to inform maintenance personnel that action is required to increase traction on a road.

When the gray substrate was covered with the different snow types and densities, all sensors classified the contaminant as snow. The only exception was the coarse grained spring-snow, which was classified as ice or ice and snow by the DSC211 and the MARWIS respectively. The reason for this is likely the reduced reflection from coarse-grained snow fooling the algorithms that they were looking at ice. This particular snow-type is probably not so common on a road, making this a minor issue. A larger problem with snow, however, is related to how it is defined. Snow exists in many different shapes and densities. On a road, this can result in snow that is blown off the road after the first pass of a car, or snow which is extremely hard and dense and which in every aspect but the color should be considered as ice. In this study, the fresh snow 150 kg/m^3 corresponds to the first case while the fresh snow 750 kg/m^3 corresponds to the second case. Being aware that both these conditions would give the same road condition status from optical sensors is hence important when using this type of sensors during wintertime.

Friction

The analysis of the friction coefficients provided by all sensors but the 2DRoad, was somewhat different from the classification results, as friction values would have to be validated in the field and there is hence no correct answer to compare with. However, the friction values acquired in this study can still be interesting to look at in order to get an idea of how consistent the sensors were relative each other. Prior to analyzing the friction data, all surfaces that were misclassified were removed from the dataset.

The friction coefficients on dry (green markers), wet (red markers) and icy (blue markers) plates were plotted in Figure 1a. In most cases, the friction values seemed reasonable. The friction for a dry road was in the range 0.7-0.8, as water was added the friction was reduced somewhat (except for MetRoad Mobile), and as the waterfilm thickness was increased the friction was reduced to values between 0.4 and 0.7. On the icy plates, the MARWIS stood out by clearly giving too high friction coefficients, from 0.5 to 0.65. For the other sensors, the range of friction coefficients (0.1 to 0.3) are all within literature values for ice. However, looking at the breaking distances corresponding to the sensor friction coefficients (Figure 1b), it is clear that these small differences in friction values actually corresponds to a huge range in the actual driving conditions. The calculated breaking distance (assuming a speed of 60 km/h) gives breaking distances on ice from 50 to 150 m. Having different sensors indicating such large differences in driving conditions on the same surface is clearly problematic, and it means that

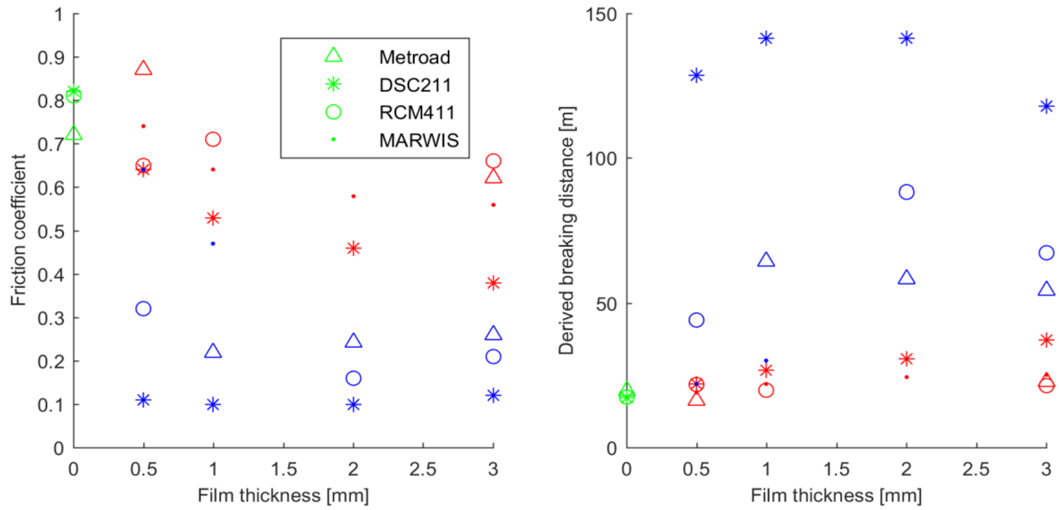

Figure 1 a) Friction coefficient provided by the different sensors on films of water (red markers) and ice (blue markers). The dry asphalt reference is given as a 0 mm film thickness (green markers). b) Shows the derived breaking distance from the acquired friction coefficients, assuming a velocity of 60 km/h.

friction estimates on ice should be interpreted with caution. Considering that there are other, more reliable means to measure friction, these might be preferred. However interpreted with caution optical road condition sensors can be a useful supplement to more accurate methods for measuring friction.

The friction values on snow ranged between 0.25 and 0.4, values well within the limits found in literature, with MARWIS and RCM411 giving somewhat lower values than the other sensors. The sensors, with the exception of RCM411, gave more or less constant friction values irrespective of snow type. As was pointed out in the classification-results section, this is clearly not correct as the very compact fresh snow is expected to have a much lower friction than the uncompacted fresh snow. The RCM411 did show a slightly lower friction value for the highly compressed snow (0.3) than for the uncompressed snow (0.4). However, the RCM411 friction on spring-snow was even lower (0.2), a result which requires field-testing. It seems like optical sensors treat snow as being one material, with one set of properties. Considering the large range of snow types and driving conditions they can provide, this may be a limitation to the use of optical sensors for friction estimates.

Water film thickness

Water film thickness is only measured by three of the tested sensors; the DSC211, the RCM411 and the MARWIS. The results (Figure 2) showed that all sensors could register increased amounts of water on the substrate. The absolute thickness, however, was highly variable between the sensors with results varying with a factor of 2 - 3. Naturally, this meant that the accuracy was limited, correspondingly. MARWIS consistently measured too shallow, with an error of -40 to -60 %. The DSC211 constantly measured too high, with errors in the range of 40-100%. The RCM411 measured too shallow for the thinner films (>2mm), but too high for the thicker films. The RCM411 data point at 3 mm is not included, as the sensor saturated before reaching this thickness. Replacing the gray asphalt with the black had a dramatic effect on the measured water film thickness. For MARWIS the measured value decreased to half of that on the gray plate, increasing the error from minus 40%-60% to minus 80-100%. For the RCM411, on the other

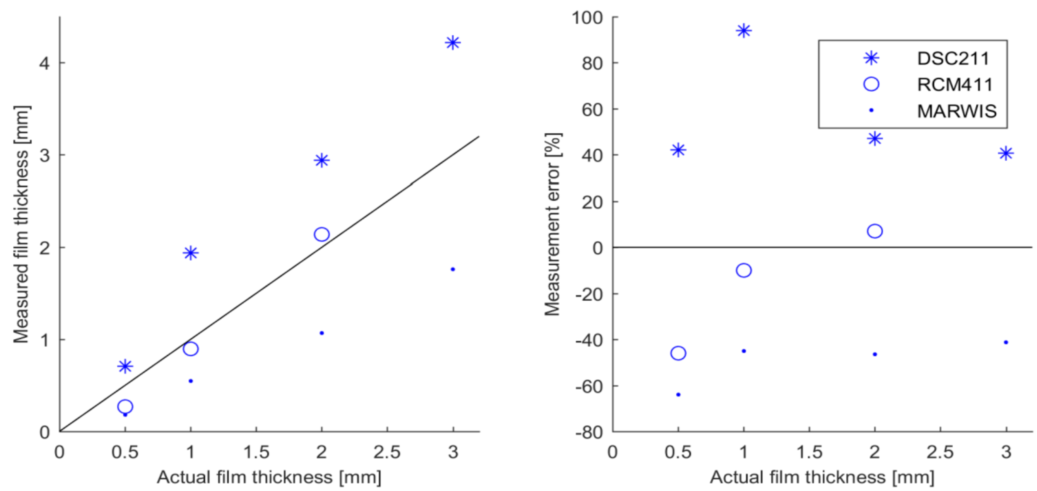

Figure 2 a) Measured water film thickness as a function of actual water film thickness. b) The error in measured water film thickness for the different sensors.

hand, the measured film thickness was doubled, increasing the error from 10-40% to near 100%. Overall, water-film thickness seems to be much less reliable than the sensor resolution implies, and users should be aware of this when interpreting the results. However, considering the large span of film-thicknesses on roads (30 µm – 3 mm) and the fact that there are few alternatives when it comes to measuring the water-film thickness on roads, an accuracy of a factor two to three may be adequate.

Conclusions

A laboratory test of five different optical sensors was performed to learn more about the capabilities and limitations of the data they can provide. The following conclusions could be made:

- The classification algorithms were in general good at identifying the contaminant on asphalt substrates. The mobile sensors, however, had some issues of distinguishing between ice and water. Another limitation to be aware of is that none of the sensors distinguishes different snow types, meaning that hard packed icy snow and soft loose snow both were considered as the same contaminant.
- The friction estimates of the optical sensors were in general in agreement between the sensors, with values that agrees with the literature for the corresponding contaminants. Care should, however, be taken on icy conditions were small differences in friction values corresponds to large differences in driving conditions. As mentioned above, the sensors also do not distinguish between different types of snow, meaning that hard icy snow will get the same friction estimate as soft fluffy snow.
- Measurements of water film thickness on the gray asphalt substrate on which the sensors were calibrated, all sensed increasing water film thickness, having errors in the range of -50 to +100%. By changing the substrate to black asphalt, these errors increased by a factor two. Still, considering that there are few other alternatives for measuring water film thickness over large stretches of roads, this kind of errors may very well be acceptable.