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Experiences of Mobile Road Condition Monitoring

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ABSTRACT

A new approach to monitor road surface conditions primarily for winter maintenance purposes has been developed and tested. The sensor is called Road Condition Monitor RCM411 and it is based on optical detection of surface condition by near infrared spectroscopy. A model is used to estimate coefficient of friction starting from the measured surface condition. The design utilizes only solid state electrical and optical components enabling long lifetime in mobile use. The sensor can be installed easily within a few seconds to a passenger vehicle equipped with a ball joint type of a trailer coupling and an electricity outlet. The data is transmitted by a Bluetooth connection to a cell phone near the driver and communicated further to a remote server to be displayed, e.g. on a map interface, or for any other use. The performance of RCM411 was tested during the winter season 2010-2011. The sensor distinguishes all important surface conditions fairly reliably. The measurement range of water layer is from zero to three millimetres with a resolution limit of about 30 μm. The model to estimate coefficient of friction has been tuned to correspond to an accelerometer based friction meter μTEC. This enables verification of absolute friction whenever there is need for accurate values. Standard deviation of the difference in the friction readings of the two sensors is typically on the order of 0.10 units in most wintery surface conditions.

Keywords: friction, mobile friction, condition mapping, surface state, winter maintenance

1 INTRODUCTION

Measurement of friction to control quality of winter maintenance operations has been discussed extensively during the last twenty years. There are some comprehensive reviews about theory as well as practical considerations of measuring friction, e.g. [1-5]. We will not go into details of friction basics in this work, but encourage the reader to search the literature or to have a brief look at Ref. [6]. Apparently friction could provide a unique measure of slippery conditions and thus would enable evaluation of quality of winter maintenance from an objective point of view. Friction could be used also as a tool of learning and teaching best practices of winter operations. Nevertheless, we should not forget the value of public information about slippery roads. Despite of numerous means of measuring road friction, it is widely used only in some Nordic countries and even there not for its full potential. One of the reasons may be that friction measurements have turned out to produce controversial results presumably due to some misunderstandings of basic physics.

The methods to measure road friction have been previously divided to three groups, which are force based, acceleration based and indirect means of measuring friction [6]. In this work we report a new sensor based on measuring friction indirectly by detecting surface state and using a model to produce friction. The evaluation of the new sensor is based on an accelerometer based absolute friction meter μTEC.

The new sensor is called Road Condition Monitor RCM411. It is an optical instrument equipped with a transmitter to send a probe light pulse and a detector to measure the back scattered light. With a proper selection of wavelengths it is possible to distinguish presence of water and ice, the credentials to determine friction on wintery road surfaces. In the following chapters we will describe basics of the sensor, show its performance and some field test results.

2 ROAD CONDITION MONITOR RCM411

Presence of water on surfaces can be measured optically by detecting absorption at certain near infrared wavelengths. This technique has been applied for detecting moisture content on materials. To be able to measure presence of water and ice at least two absorption wavelengths are needed. The basic principle of the technique is revealed in Ref. [7]. Fundamentally we are using that same detection principle but employing modern electrical components, processors and solid state light sources.

The sensor of RCM411 is shown in Figure 1. The body of the sensor is 75 mm round cylinder of 100 mm length. There is an M12 cable connector at the back end of the sensor, which delivers power 9 - 30 VDC to the sensor and returns a digital message to be forwarded to display and communication unit. The sensor employs only solid state components and does not contain any moving or wearing parts allowing thus a potentially long lifetime. A similar design of a moisture content monitor has been running over 6 years without a need of service except of occasional checking of window cleanness.

Figure 1. The sensor of RCM411 with the sensor window shown on the lower right corner.

RCM411 is designed to be installed on a towing bar equipped with a 50 mm ball joint and an electric outlet to power trailers. Figure 2 shows an example of RCM installation to a passenger vehicle. In this case the sensor is located to follow the left wheel track. To avoid splashing of water, slush or mud on the sensor window, it has been protected by a tube with an open low end and a lid towards driving direction. The lid will help to keep the measuring tube not getting blocked by drifting snow. If the exhaust tube is very close to the opening of the measuring tube, it is advisable to change the sensor to the right side of the car or prevent exhaust entering directly to the measurement tube especially while still being in parked position. Exhaust gases contain large amounts of water vapour, which may enter the measuring tube and finally condense on the window causing fake signals.

Figure 2. RCM411 installed to a passenger vehicle equipped with a 50 mm trailer ball joint.

The sensor cable connects to a small box on the sensor support arm. There is a BlueTooth module in the box to communicate the measured data to a user interface inside the car. The other cable going to the same box delivers power from the trailer connector to the BlueTooth module and the sensor. A standard user interface of RCM411 is a cell phone either with a Symbian S60 or an Android operating system.

In Figure 3 there is a screen shot of a Symbian user interface. The scale is from 0.00 at the bottom of the screen to 1.00 at the top. Thus the three green lines correspond to 0.25, 0.50 and 0.75 of friction. The colour of the line reveals the surface state so that dry, moist, wet, slushy, icy or snowy/frosty states are coloured correspondingly as green, blue, light blue, violet, red or white. Thus there have been snowy and icy sections of road in the example of Figure 3. The occasional yellow spots represent results measured by braking and using the absolute µTEC Friction Meter to record friction.

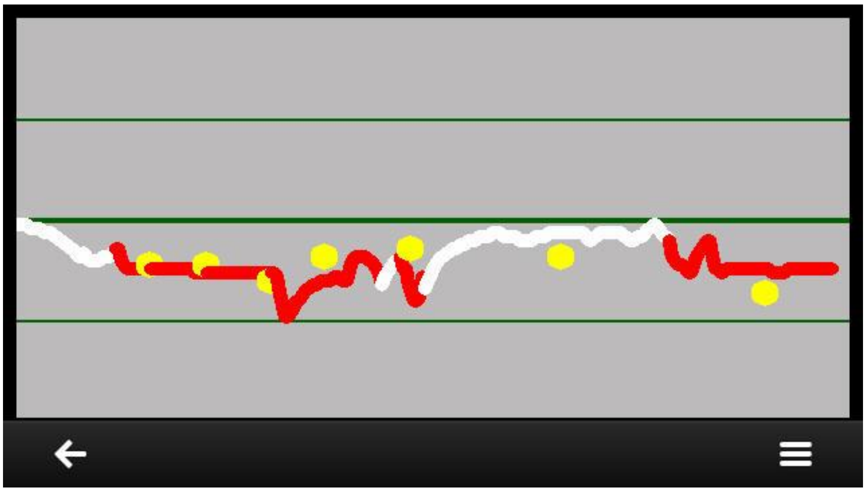

Figure 3. Symbian user interface of the RCM 411 display in Nokia E7.

In Figure 4 there is a photograph of an Android user interface. The left half of the screen is reserved for the µTEC Friction Meter and the right half to the results of RCM411. Here also yellow spots correspond to the results of the µTEC Friction Meter and the last result is also shown as a number on the left side. The thin blue line is water layer thickness in millimetres. The first quarter of the scale from 0.00 to 0.25 mm is linear. Over the 0.25 mm line the scale continues so that doubling in the scale means fourfold of real value. Thus the level at 0.50 corresponds to 4 times 0.25, i.e. 1 mm of water layer or black ice and the top of the screen corresponds to 4.00 mm.

Figure 4. Android user interface of the RCM411 display in Huawei Ideos X5.

With these user interfaces it is very handy to follow actual development of friction by location. Since current cell phones employ also a GPS locator, it is easy to communicate the results to a map interface, which can be updated by a server enabling to follow the measuring vehicle in real time. In Figure 5 there is an example of a test run taken in the night of 6.12.2011 in Helsinki. The colour of the line following the route turns from green corresponding to high friction near 0.70 through yellow with about 0.40-0.50 friction finally to red at about 0.30 level of friction. Main roads were treated whereas all minor tended to be badly frozen in that night. The map interface allows detailed study of, e.g. exit locations to observe possible need of additional salting.

Figure 5. Colour coded friction results of a test run in 6.12.2011 near Helsinki city.

3 PERFORMANCE OF RCM411

We have tested RCM411 in the laboratory environment as well as in the field. The challenges are much tougher in the field due to splashing of water and slush, drifting of snow, dirt, uneven surface condition and so on. Especially with optical sensors it is very challenging to keep the sensor window clean under all conditions. The approach we have taken is relying on a principle using a long narrow tube so that the probability of splashes getting up to the sensor window is dramatically reduced. That seems to work fairly well in most conditions. The most challenging case is drifting snow at temperatures where snow can easily float but still stick to surfaces. In those cases the sensor tube may start collecting snow until the tube gets blocked. If this happens the user has to remove snow out of the tube and possibly also clear the window surface. Nevertheless, we have been able to drive thousands of kilometres without cleaning the sensor window or removing snow although the list of conditions has included long sections of wet, snowy and slushy surface states.

Figure 6 shows a laboratory test of water layer thickness. A small area on a test piece of asphalt was separated by a barrier and fixed amounts of water were added over this area. The x axis shows the actual calculated thickness of water layer and the y axis the response of the RCM411 in millimetres from zero to 3 mm. The resolution limit of detection is on the order of about 30 µm which corresponds to thinnest layers of ice able to reduce friction a measurable amount [8]. The upper limit at about 3 mm is caused by increasing absorption with thick layers.

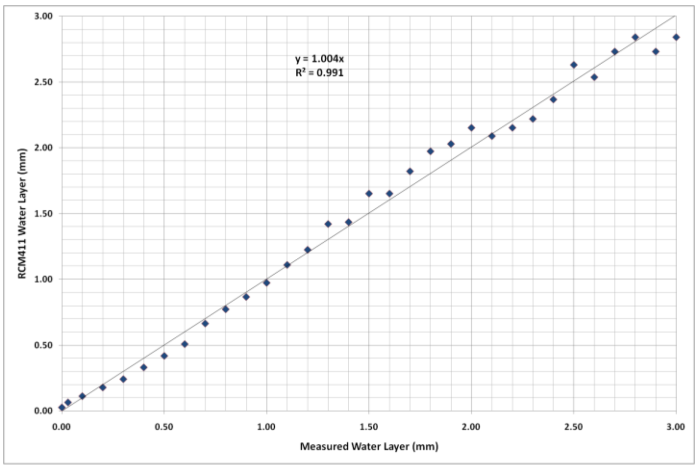

Figure 6. RCM411 performance in measuring thickness of water layer.

The most powerful way of using RCM411 is to follow development of friction while driving as in the examples of the figures 3 and 4. In Figure 3 the horizontal sections of the red line correspond to black ice, which was very even as well as the response of RCM411. If one makes an absolute measurement of friction by µTEC in those cases, it is possible to confirm the right level of friction and to get an idea of the accuracy of the modelled RCM411 friction. Our testing in the winter seasons 2010-2012 supports that standard deviation of the difference between µTEC and RCM411 results is on the order of 0.10 in friction. This difference naturally varies by surface state, but it seems to be the right order of magnitude for surface states like snow and black ice. It is also feasible to implement an automatic calibration feature of RCM411 by employing the µTEC results.

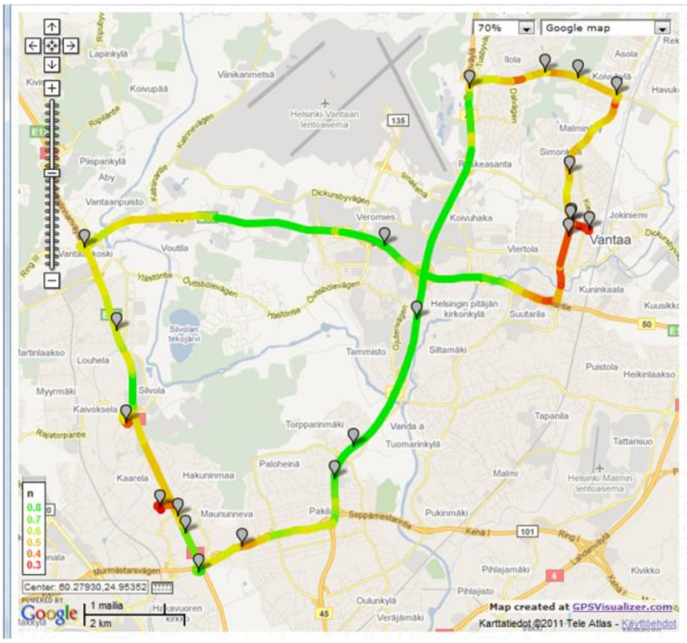

Figure 7. A test run of RCM411 and µTEC near Helsinki in 27.01.2011.

Figure 7 shows how RCM411 and µTEC can be used for quality control of winter maintenance. Mapping the measured friction as a colour coded line is a powerful tool to reveal differences in friction. The test run in Figure 7 was driven within about one hour and the weather had been the same in the whole area. The route was on main roads with equal level of service except the north-eastern part in the figure with friction 0.30-0.45 (red – yellow). Despite the same level of ordered service there seems to be large variation in observed friction. For example the eastern road from south to north (Road 45) was practically dry with maximum friction whereas the western road (E12) was apparently icy with reduced friction. To learn optimal winter maintenance it is essential to see these differences and then work out what was done differently. With this process it is possible to find out reasons why two roads with similar weather conditions end up in different surface condition and likely with the same money spent per kilometre.

4 CONCLUSIONS

We have developed and tested a new type of an optical mobile sensor called Road Condition Monitor RCM411. The sensor can measure road surface condition, layer thickness of water or black ice and estimate coefficient of friction due to presence of snow, ice or slush on the surface. The sensor is quickly installed to any vehicle equipped with a 50 mm ball joint to tow a trailer. Cell phone applications for Symbian and Android phones are used for user interface and to communicate with other remote systems in real time allowing for example mapping of data on a server application.

The model to predict friction is based on the measured surface condition. Due to the nature of this approach the modelled friction may not always accurately correspond to the actual friction. To avoid controversy the user interface includes an absolute Friction Meter µTEC based on deceleration measurement during lock braking. Thus the readings of µTEC can be readily compared to the results of RCM411. It is thus feasible to combine the results so that RCM411 readings are automatically adjusted or even calibrated according to actual friction values whenever available and this can be done either in the phone or at an upper level, e.g. in a server communicating with the application.

RCM411is designed to be a tool for winter maintenance and especially for quality control. In addition it is a powerful tool to reveal differences in service level and to do root cause analysis of the differences. Also we should not forget the public information about slippery roads or aquaplaning warning. There has been some discussion about using the friction information to control active spreading of salt based on measured information of current friction level. Finally, airport maintenance has to report thickness of water layer as well as friction.

5 REFERENCES

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