Non-invasive Road Weather Sensors
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Paul Bridge
Vaisala Inc, 194 South Taylor Avenue,
Louisville, Colorado, 80027 USA
*Email: **paul.bridge@vaisala.com***
Tel: 303 262 4051
Fax: 303 499 1767

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Abstract

Many road authorities have invested in Road Weather Information Systems (RWIS) which provide data from locations around their road networks 24/7. Most of these systems are based on 30 year old technology, in the form of sensors embedded in the road surface to provide information about surface conditions and temperature. Along with atmospheric sensors, the majority of these road weather stations provide authorities with information to help tackle the problems of ice and snow.

The 2003 American Meteorological Society (AMS) Forum on Weather and Highways noted that RWIS significantly benefit highway maintenance operations, particularly winter maintenance. The consensus of transport professionals was that there would be clear benefits from a denser network of road weather observation sites. At the same time it recognized that deployment of RWIS has been limited by their cost and the strong competition for limited funds within state DOTs.

The recent introduction of non-invasive road temperature and condition sensors is providing a cost effective solution for authorities to both obtain improved road weather information and increase the density of RWIS observations. This paper explores the applications and benefits of non-intrusive road sensors with a particular focus on:

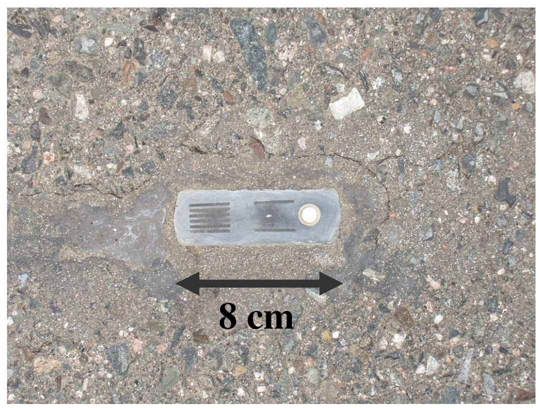
- Winter Maintenance Key Performance Indicators
- Decreasing environmental impact of de-icing agents
- Sensor deployment

Introduction

Traditional RWIS comprise of sensor stations, usually located close to the side of the road, also referred to as Environmental Sensing Stations (ESS), see Fig.1. These ESS collect and report various weather parameters to a central hub or server, where the data is then displayed or ingested in to systems primarily for winter maintenance decision making.

Fig. 1

Example of a 'traditional' ESS set-up to the left with a 10M mast and below is a close–up of an embedded road weather sensor in the pavement surface.



Of the approximately 2500 ESS deployed in the USA, the vast majority of the atmospheric sensors are mounted on dedicated 10m masts, usually with concrete bases and enclosures. Some of the data from the atmospheric sensors is used for numerical modeling, for example air temperature and barometric pressure. Whilst other parameters are used for decision making or triggering automated signs, for example wind, visibility or present weather.
The sensors at the heart of providing road surface conditions (for winter maintenance in particular) are embedded road sensors, or 'pucks' as they are known in the USA. These pucks essentially 'mimic' the road surface and, depending on manufacturer, usually provide readings of:

- Temperature
- Surface State (dry, wet, frost etc)
- Depression of freezing point
- Chemical concentration

However surface pucks do not generally directly measure parameters such as frost or snow amount for example. These are usually calculated to be present by determining surface temperature and examining atmospheric conditions, such as dew point to assess whether frost is present or not. Not surprisingly surface pucks are not always able to provide realistic measurements of the true road surface. Furthermore, it is also known that surface pucks can become depressed slightly below the road surface on occasion, which can lead to pooling of surface water or chemical solution, again giving rise to unrepresentative measurements.

Non-invasive technology

In order to obtain improved road surface measurements, Vaisala has introduced two non-intrusive sensors which were developed in partnership with the Finnish Road Administration.
The capabilities of the non-intrusive optical sensors have already been tested and a number of papers have been published; one is called Vaisala Remote Road Surface State Sensor DSC111 and the other Vaisala Remote Road Surface Temperature Sensor DST111. These sensors are remote in the sense that they can be installed on any post by the road side or a gantry across the road. Thus installation is fully non-intrusive, i.e. there is no need to install anything on the road surface.

Fig. 2 Non-intrusive sensors mounted on an overhead gantry

DST111 is based on measuring long wave infrared radiation between the detector of the instrument and a selected location on the road surface. If this radiation is in balance, then the temperature of the detector and the road surface are equal whereas a non-balance can be calibrated to a known temperature difference. However, this method applied as such measures the apparent radiation temperature, which can be offset by many degrees due to reflection of long wave infrared radiation at the road surface. In DST111 these reflection induced errors are minimized by properly selecting the range of wavelengths in use. The accuracy of the DST111 is within 0.3 °C in typical icing conditions.

DSC111 is based on active transmission of infrared light beam on the road surface and detection of the backscattered signal at selected wavelengths. Most of the backscattered light has traversed through a possible surface layer of water or ice. By proper selection of wavelength it is possible to observe absorption of water and ice practically independently of each other. Since white ice, i.e. snow or hoar frost, reflect light much better than black ice, these two main types of ice can be distinguished as well. The observed absorption signal is readily transformable to water layer, to ice layer or to snow/frost amount in millimeters of water equivalent. With this information it is straightforward to determine the surface state as dry, moist, wet, icy, snowy/frosty or slushy. The information is obtained as a direct measurement and does not alter the surface state of the road, unlike some of the traditional pucks. It also turned out that it was possible to go one step further and model the apparent reduction of the friction coefficient due to ice and water on a road surface.

Friction measurements

It has been established that the DSC111 is able to provide a very good correlation between actually measured and modeled friction values in typical winter weather conditions.

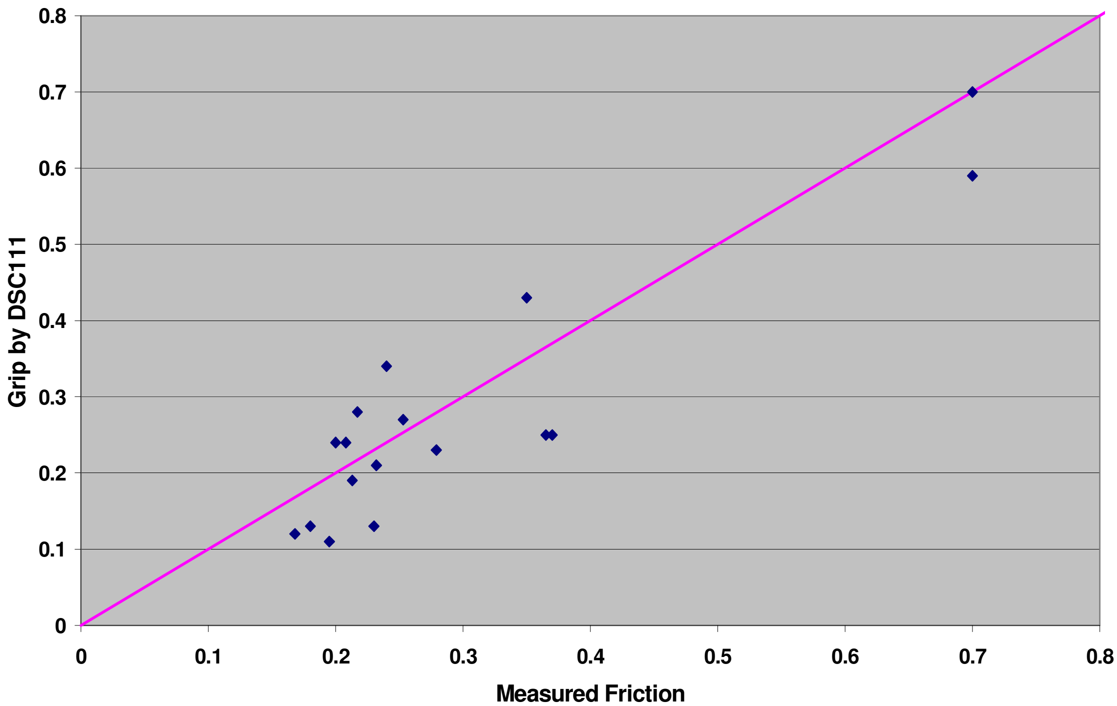


Fig. 3. The modeled grip readings of DSC111 as a function of actual measured friction. The RMS difference is 0.07 units

Since the model has amount of water, ice and snow/frost as input parameters, the effect of various types of ice on the apparent friction can be taken into account. For example, a slushy surface condition can have a reasonably high friction value although the amount of ice is fairly high. On the contrary, a very thin layer of ice can have a dramatic drop of friction especially if the ice is hard and does not contain salt. If there is salt, then ice will build up as a fragile structure with pores filled with salty solution and again friction may stay comparably high. This is the actual reason why nominally dilute solutions are effective in preventing slippery roads.

The RMS difference of the measured and modeled friction values is only 0.07 in friction units. We should take into account that this result is obtained without using surface temperature as a model parameter nor measuring it at all while detecting the surface state. Naturally, more elaborate models could improve the result to some extent.

As previously mentioned, ESS are primarily installed in the first place to assist winter maintenance decision makers to take proper action at right time in order to keep up safety on the roads and save costs of winter maintenance. To decide the right action and time one needs to have a forecast of weather as well. If we ask, what is the most essential information of the ESS for making the right decision? Our answer tends to be; 'road surface temperature and depression of freezing point'. The first would help to understand where we are going and the latter whether there will be ice formation. It turns out that since ice alone does not make road surfaces slick, it is more important to know which kind of ice it is and whether it reduces the friction. For example Hoar Frost, or white ice crystals, do not reduce the surface friction as much as transparent (black) ice.

We define the apparent friction as if a vehicle had a friction reading of 0.80 in locked braking on a dry surface. Naturally some vehicles could have higher or lower actual readings depending on a number parameters like type of tires, roughness and type of road surface, speed, temperature and many others. Our assumption here is that despite these factors the relative reduction of friction due to ice is not a strong function of these parameters, i.e. presence of ice is relatively more important than the other factors in describing the level of slipperiness. Practical evidence, e.g. accident statistics on icy roads, supports this assumption.

There is a simple physical explanation why salt or other deicers can effectively increase apparent friction on road surfaces, even though there may be a comparable amount of ice present. When ice starts to build up on a road surface with a salty solution present, the ice crystals reject salt and thus the solution around the ice crystals will become more concentrated. This increase in concentration stops the further buildup of ice assuming that the surface temperature does not reduce any further. In addition, ice formation releases heat to the surface reducing the speed of icing even though the weather is cooling. In practice, our real life experience is that when ice buildup starts, there seems to be enough time to apply more salt or deicer before the surface is too slick.

The detection threshold of any kind of ice is small enough to enable a direct measure of slipperiness with the surface state sensor. This capability of measuring slickness in the form of a modeled friction reading is opening up new approaches to road weather applications. Ice alone does not make a road surface slick. Thus the relevant question is not what is the surface state but is the surface slick?

The above question is now being addressed by an increasing number of DOT and Public Works representatives, who are starting to utilize friction for winter maintenance operations. In addition, friction data is also being used to fill a void that has existed for years, namely how to objectively measure the success of winter maintenance operations.

Winter Maintenance Key Performance Indicator

Transportation authorities use a variety of parameters to measure the success, or otherwise, of their winter maintenance operations. These include, but are not limited to:

1) Number of road accidents reported
2) Traffic flow
3) Time taken to return the road network to bare pavement
4) Amount of de-icing chemical used
5) Number of complaints received by public
6) Friction

Most of these performance indicators are fairly subjective, as a number of other parameters can also affect the various 'measures'. However friction measurements are proving to be a far more objective method, especially with the increasing trend of DOTs to contract out winter maintenance operations. This has led to a requirement to ensure a fair and independent way to establish a Key Performance Indicator to the effectiveness of winter maintenance operations.

In addition to the above, there are a growing number of other applications areas for non-intrusive sensor technology that are now opening up which will be mentioned in the summary. Amongst these we have already begun trials of triggering spray systems utilizing friction.

Fixed Automated Spray Technology

Frost development on in-land bridge decks is usually more prevalent than on surrounding road networks, see Fig.4 , for two main reasons:

1) Inland bridge decks are on average 2 to 3 °C colder than surrounding roads early in the winter season due to heat loss.
2) Often bridge decks are close to sources of extra available water vapor.

For these reasons, frost usually develops earlier on bridge decks than surrounding roads and for a longer period with a greater frost build-up. This has led to an increasing number of Fixed Automated Spray Technology (FAST) being deployed on bridge decks (and other problematic locations, such as steep grades), whereby de-icing chemicals are sprayed automatically when certain thresholds are met. Normally this is freezing point depression and this in turn can lead to an over use of chemical de-ices, which in turn leads to a greater direct run-off in to nearby water courses.

Currently available automatic deicer spraying systems are typically built on detecting depression of freezing point and comparing that to measured surface temperature. Technically this logic can work safely assuming those parameters are measured correctly. However, the actual needed amount of deicer is fundamentally less than what the depression of freezing point indicates. Vaisala has developed a control logic based on friction which should save both chemicals and associated costs, since the deicer tanks will not need filling up so frequently.

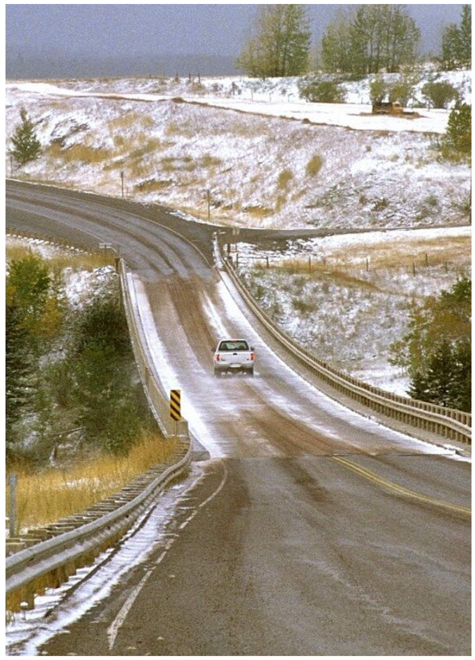


Fig. 4 Ice remains on a bridge deck whilst approach roads are clear

Environmental Impacts of de-icing agents

Most authorities are coming under increasing pressure to minimize the economic and environmental impacts of winter maintenance, particularly the use of de-icing agents. There are numerous papers published highlighting the damage and risks posed by de-icing agents, such as Environment Canada stating that road salts are entering the environment in large amounts and are posing a risk to plants, animals, birds, fish, lake and stream ecosystems and groundwater.
A few of the salient points include:

- Damage to vegetation can occur up to 200m from roadways that are treated with de-icing salts.
- Up to 50.8% of woody plant species are sensitive to NaCl, and many of these have disappeared from Canadian roadsides.
- Of the 15 principal tree genera occurring in Canadian forests, 11 have been rated as sensitive to road salt. Approximately 55% of road-salt chlorides are transported in surface runoff with the remaining 45% infiltrating through soils and into groundwater aquifers (Church and Friesz, 1993).
- Growing concern over the impact of road salt is not limited to Canada. California and Nevada currently restrict road-salt use in certain areas to reduce chloride injury to roadside trees. Massachusetts turned to alternative road de-ices to prevent sodium

> contamination of residential drinking wells. New York State legislators recently proposed a pilot study in the New York City watershed to examine road-salt alternatives that might be more protective of drinking-water quality.

Non-intrusive sensors supply more accurate information to help municipalities to improve their salt management programs, optimize de-icing operations and balance the needs of wintertime mobility and safety with environmental concerns.

Non-intrusive Sensor Installation

It has already been mentioned that most of the traditional ESS currently deployed in the USA are mounted on dedicated 10m masts, usually constructed on poured concrete bases. Since there is no requirement for the associated atmospheric data for the operation of the non-intrusive sensors, we do not necessarily have to utilize dedicated structures. Also the embedded pucks have to be 'cut' in to the road, which also means that the road has to be closed with the necessary traffic management in place and the associated dangers due to the exposure of the workforce. By comparison, non-intrusive road sensors can be mounted on existing street furniture, see Fig.5, which dramatically cuts down on installation costs. This is extremely pertinent to smaller authorities, such as Public Works departments, many of whom have very tight budgets.

Fig. 5 Non-intrusive sensors mounted on existing street furniture in Chicago

Non-intrusive sensors can also be installed at any time of the year, irrespective of weather, so that should a sensor fail it can be swapped out almost immediately, thus reducing downtime. This can be particularly important where redundancy is critical, as in some

instances it has proven impossible to replace embedded sensors for a number of months during the winter due to sub-zero temperatures and adverse weather.
There is no requirement to replace non-intrusive sensors when the pavement is resurfaced, also the sensors can be moved to a different location, should the need arise.

Summary

There are nearly 300 Vaisala non-intrusive sensors in over a dozen countries now deployed in the field, with over 50 of these units in the USA (December 2007). The ease and low cost of the install is allowing a growing network of RWIS, particularly for smaller transportation authorities.
Furthermore, the high resolution of the DST111 and DSC111 to detect ice and changes in friction is allowing for the improvement and development of some new applications. Areas already being trialed or considered include:

- More accurate decision making tool for winter maintenance
- Automatic launching of management actions
- Direct control of message signs
- Weather adaptable speed limit systems
- Key Performance Indicator for winter maintenance
- Information for maintenance of sidewalks and car parks
- Triggers for Fixed Automated Spray Technology
- Intersection signal control
- Semi-mobile platforms for example; emergency evacuation routes or study areas

Acknowledgement

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