

Ice Detection and Forecasting System

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ABSTRACT

In many fields, exact and fast information about the specific environmental conditions are required so as to initiate an appropriate response to the detected environmental conditions. In particular, any information on road sections having ice or moisture formed thereon may help to significantly improve traffic safety. These surface data are typically used to forecast surface conditions and anti-icing. Thus, one of the key components of modern road information systems (RIS) is the monitoring of the current road surface conditions, wherein the detection of the presence of water, snow, ice and the beginning formation of ice, is one of the most important pieces of information for traffic safety. We provide a new ice detection and forecasting system based on a new innovative ice sensor in order to allow surface monitoring, with enhanced accuracy and reliability, especially with regard to water, snow, and ice detection on exposed surfaces and the detection of ice formation at an early stage.

Keywords: ice, forecasting, monitoring.

1. INTRODUCTION

In many fields, exact and fast information about the specific environmental conditions are required so as to initiate an appropriate response to the detected environmental conditions. For instance, an adequate assessment of the environmental conditions on road surfaces may significantly contribute to enhanced traffic safety, since corresponding decisions made by road administrators may be based on this information. In particular, any information on road sections having ice or moisture formed thereon may help to significantly improve traffic safety.

Road Weather Information Systems (RWIS) consist of specialized weather stations that provide information on road surface conditions in addition to standard weather information such as air temperature, dew point, wind speed, etc. The surface data, such as pavement temperature, the presence of moisture and salt on the road, are what differentiate RWIS from ordinary weather stations and what provides the enhanced value for winter maintenance managers faced with the decision of calling out snow plows or travellers wanting to plan their travel route. These surface data are typically used to forecast surface conditions and anti-icing. Thus, one of the key components of modern road information systems (RIS) is the monitoring of the current road surface conditions, wherein the detection of the presence of water, snow, ice and the beginning formation of ice, is one of the most important pieces of information for traffic safety [1].

We provide a new ice detection and forecasting system based on a new innovative ice sensor in order to allow surface monitoring, with enhanced accuracy and reliability, especially with regard to water, snow, and ice detection on exposed surfaces and the detection of ice formation at an early stage. In section 2 is described the basic ice detection system. In section 3 is described and valued two different approaches for ice forecasting and section 4 provides experimental results.

2. ICE DETECTION SYSTEM

The presented ice detection system consist in sensors for measuring air temperature, relative humidity, pressure, the current road surface condition (dry, wet and ice) and salinity index. The measurements of the pavement conditions are performed by means of a set of sensors installed directly in the road surface. As explained previously, the ice sensor is the core element of the system and has been developed completely new in order to solve the drawbacks of the currently available systems. The sensors are connected to the central station by means of serial interfaces (RS-232 and RS485). In the current system we connected three ice sensors and one salinity sensor to the central station, because for most situations such as bridges, three ice sensors seem sufficient. However the system is flexible enough to connect further sensors to the systems via the RS-485 serial interface (see figure 1).

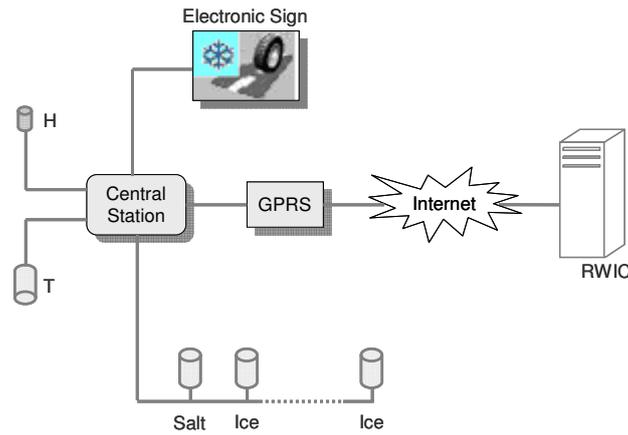


Fig. 1. Ice Detection System

The measured data can be used to generate warnings on electronic signs or displays, but in general the data are transmitted via GPRS to a Road Weather Information Centre (RWIC) for further data processing as will be explained later on.

2.1 Ice Sensor

Conventional ice detection technology relies on large scale sensors that often require elaborate assembly, handling, and installation procedure. Furthermore, most of the systems used e.g. for ice detection on airplane wings [2, 3] cannot be used for road surface conditions monitoring due to the fact, that the systems have to be installed into the surface of the roadway. This requires that the system has to be robust enough to resist e.g. the pressure of cars, or chemical substances that are likely to occur on roadways (such as salt, fuel, or oil) and that could damage or render inaccurate the sensor.

Generally, ice detection systems can be categorized as indirect or direct. Indirect systems do not monitor the actual surface conditions, but instead attempt to predict the presence of ice by measuring several parameters such as air temperature, humidity, pressure, ground temperature and/or water presence. Systems, based on direct measurement, utilize a variety of very different technologies such as microwaves or infrared radiation, which are one of the most reliable but expensive technologies. In this case the ice detection is realized by measuring the waves reflected from the surface under observation, because water and ice have different reflectance coefficients. On the other hand vibrating probes can be used [4]. With this method ice detection is established by analyzing the variations in frequency of the vibrating probe that results from an accretion of ice on the sensor. However, the presence of vehicles or the deposition of dirt can quite easily render ineffective vibrating probes. Anyhow, both methods are quite expensive and cannot be deployed in many critical situations.

Therefore, several less complex and less expensive systems exist that detect the presence of water or ice mainly by measuring the different conductivities or dielectric constants [5] of ice and water by using two pairs of exposed electrodes. These capacitive systems are particularly interesting, because only the stable electrodes have to be exposed to the mentioned stress [6, 7, 8]. Most of these systems, however, detect the presence of ice or water only due to a change of the measured values (capacitance or conductivity) and require a temperature sensor in order to distinguish between them. Obviously, the main drawback of these methods is that the presence of salt in the water on the surface modifies the freezing point of water and therefore the measurement is not reliable any more [9].

In order to solve this problem active solutions exist which determine the freezing point of the liquid on the surface by cooling and heating the liquid on the surface above and below the freezing point, allowing a reliable detection. However, these systems require a lot of electronic for this type of detection, and have high power consumption. For these reasons, the presented sensor system utilizes the advantage of the cheap and efficient technology of the exposed sensor's electrodes, but provides a completely new solution to the problem of the possible contamination of the present water, which renders the system both highly accurate and extremely robust.

Generally, the capacitance value of the electrode assembly depends on the geometrical configuration such as distance, shape, and dimensions of corresponding surfaces of the electrode assembly and also depends on the relative permittivity of the material provided between the electrodes. The relative permittivity, in turn, depends on the temperature of the substance and a measurement frequency with which the capacitor is operated. Thus, we use a new measurement device able to detect small changes of the capacity of an electrode assembly at several different frequencies [10]. As can be seen in figure 2, the relative permittivity of water at

approximately -1°C is substantially constant within a range from DC to about 1 kHz and decreases in the range of approximately 2 kHz-several hundred kHz. On the other hand, the relative permittivity of water of approximately 1°C is substantially constant up to a frequency of approximately 10^9 Hz and decreases within the range of 10^9 to 10^{10} Hz.

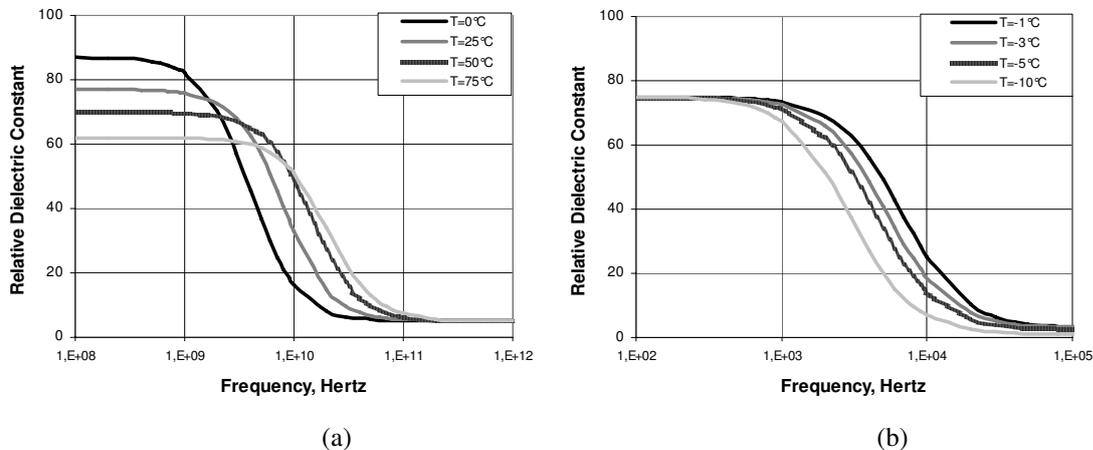


Fig. 2. Relative dielectric constant of H_2O as a function of temperature and measurement frequency, (a) water, (b) ice.

Thus, by means of the multi-frequency capacitive measurement device, a plurality of measurement points are taken in the frequency domain, which then enables a reliable identification of a specified substance, such as water with temperature $+1^{\circ}\text{C}$ and ice at temperature -1°C . Moreover, based on the plurality of measurement points, even the beginning formation of ice may be detected more reliably compared to conventional systems. The explained measurement technique is utilized in the ice sensor shown in figure 2. This sensor comprises also a temperature sensor, which extends the set of available data by the pavement temperature of the location the sensor is installed in. This data is not necessary for the ice detection but very useful for the ice forecasting.



Fig .3. Ice Sensor

This surface data are typically used to forecast surface conditions and anti-icing. However, the fundamental approach of anti-icing consists of spreading salt on roads just before freezing pavement temperatures hit in order to change said freezing temperature. In order to ensure rapid and target orientated interventions, therefore not only the actual information on the present weather situation and the road surface conditions are indispensable, but also the amount of salt on the roadway has to be detected by means of a salinity sensor.

2.2 Salinity Sensor

The salinity sensor provides a salinity index which is proportional to the concentration of the salt spread on a roadway. This sensor is based on a conductive measurement by means of two exposed electrodes. The measured resistance of the substance on the surface of the sensor can be used to reveal the concentration of salts. Since however the conductivity of e.g. liquids depends also on the temperature of the liquid, the used salinity sensor (see figure 4) is already temperature compensated. This salinity index can then be used for both, to organise preventive maintenance strategies and to correctly forecast possible ice formations considering the shift of freezing temperature.



Fig. 4. Salinity Sensor

3. ICE FORECASTING SYSTEM

In order to provide reliable forecasting of ice events we utilized two different approaches: the first is based on artificial neural networks, which renders the system complex but flexible, the second is based on a statistical analysis in order to enhance computation in case several stations have to be analyzed in real time or in case of embedded systems.

3.1 Artificial Neural Networks

Last year NEMEF0 [11], an artificial neural network used to forecast ice on mountain highways was awarded as “electronic project of the year” [12]. This tool uses meteorological data sampled every hour by means of a traditional meteorological station located in a dangerous point of the highway and provides indications about the next future values of the parameters (temperature, humidity, rain, wind and solar radiation) which concur to determine the ice formation. It has to be mentioned that NEMEF0 does not utilise the data coming from an ice sensor but estimates only the presence of ice. Two algorithms are the engine (see figure 5).

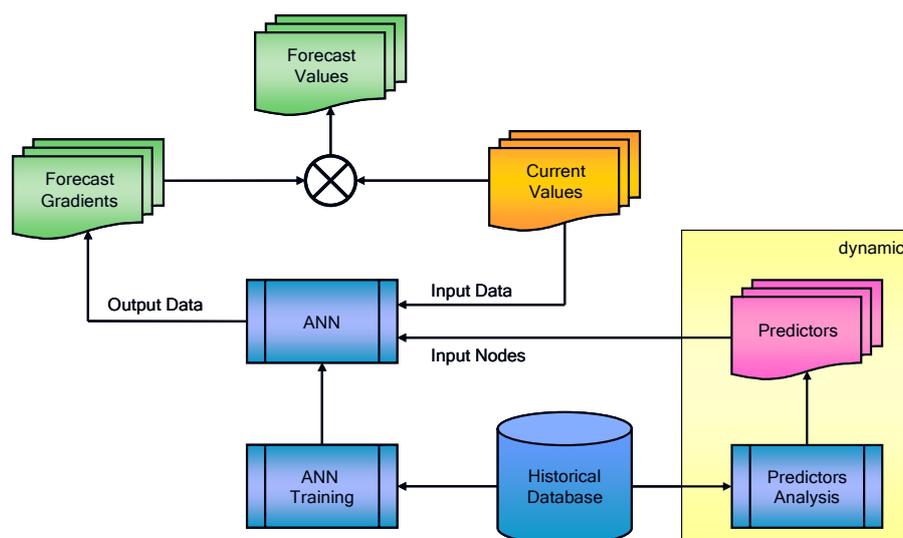


Fig. 5. NEMEF0 System Overview

The first one is based on the Parzen [13] statistical method and dynamically computes the cross entropy among the different classes of parameters, which allows for estimating the best predictors for a certain parameter. These best parameters are used to train a recurrent neural network [14] which forecasts each single meteorological datum. The predicted data are used by an analytical model which determines the danger of ice formation. Main characteristics of NEMEFO are that uses only local parameters coming from a meteorological station. This means that no data coming from satellites or other stations are required. A simple personal computer is requested to use the software.

3.2 Statistical Analysis

With the statistical method we use only the past values of the predictand variable to foresee its future evolution without considering interaction between different meteorological parameters. Then we have to decide how many air relative humidity data in the past are necessary to have an affordable forecast. We use again the Parzen method and it's put in evidence that the last 4 hour values are sufficient to make a good prediction. Let \mathbf{X} be the vector of the last four hour data respect to the forecast time j . We, for each day in the past, take the last four hour values of the parameter to be predicted respect to the instant corresponding to j . In this way we obtain a matrix \mathbf{Z} ($n \times m$) containing the past values for each day. The number of rows of \mathbf{Z} has to be the same of \mathbf{X} ; the number of columns is determined by the number of days recorded in the database. Let \mathbf{Y} a particular day in the past. Then we calculated the mean square error for each past day as shown in the following formula:

$$MSE = \frac{\sum_{i=1}^n (X_i - Y_i)^2}{n} \quad (1)$$

At the end of this calculus we have a vector \mathbf{E} containing the MSE for all the past days. We choose the day with the smallest MSE. In this way it's identified the "match day": this is the day in witch the variable trend is closest to the values of the forecast day at the time j . After this we fit the data of the match day in the next three hours after j with a polynomial of the third order. Then the forecast values are obtained adding to the last measure the gradient of the match day, as shown in the following formula:

$$P(t+1) = m(t) + [p_M(t+1) - p_M(t)] \quad (2)$$

where,

- $P(t+1)$: it's the forecast value
- $m(t)$: it's the measure at the time t
- $P_M(t+1)$: it's the value of the match day at the time $t+1$
- $P_M(t)$: it's the value of the match day at the time t

It's important to underline that $P_M(t)$ and $P_M(t+1)$ aren't the measured data but the value obtained with the third order model. In this way we circumvent the problem of wrong measures and we have a smoothest gradient.

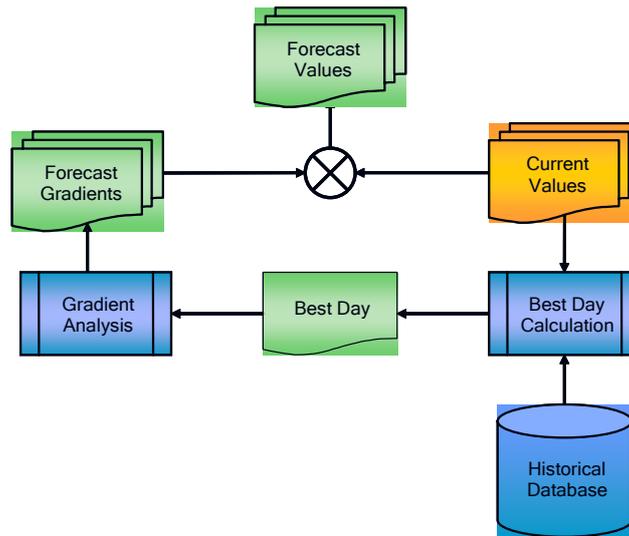


Fig .6. Statistical Analysis System Overview

4. EXPERIMENTAL RESULTS

We have used the artificial neural network system with a database coming from a meteorological station at Save airport in Goteborg (Sweden). This station is equipped with the following sensors:

- Surface temperature at 5 cm depth
- Surface temperature
- Air temperature 2m
- Solar radiation
- Longwave solar radiation
- Precipitation
- Wind speed 10m
- Air humidity 2m
- Air pressure

Then from these variables we calculated others such as the temperature gradient at different levels. We have used the artificial neural network system and the analytical model to predict the meteorological variables and evaluate the ice formation.

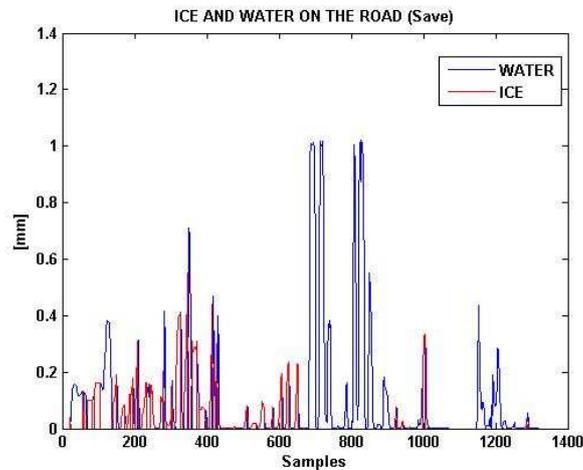


Fig. 7. Ice and water on the road

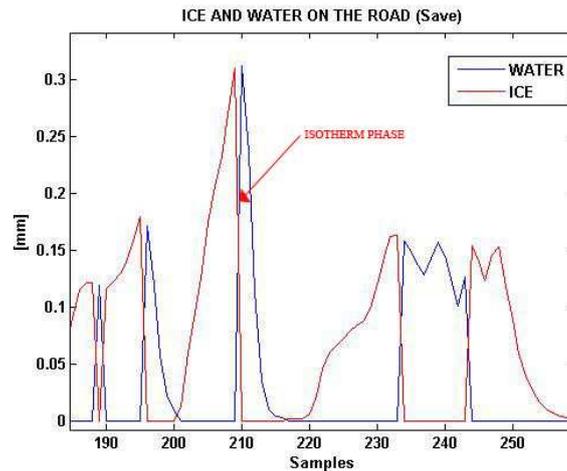


Fig. 8. Isotherm phase

As we can see from the pictures, the model is able to evaluate both the presence of water and ice on the road in a certain moment. Further more in the figure on the right it's well represented the isotherm phase in which there are both ice and water. These results have been supported by expert people judgement. They said that with those values of meteorological variables the presence of ice was highly probable.

5. CONCLUSION

In this paper we have presented both an efficient and low cost ice detection and forecast system. The ice sensors can be embedded in road pavement in order to monitor continuously the asphalt condition. Meanwhile these data can be transmitted (i.e by GPRS or wireless) to a central server on which is installed the forecast system. In this way we can get the probability of ice formation for the next three hours using both meteorological variables and road surface condition. In fact, in the future, we are going to integrate the information given by the ice sensor in the forecast system. We will get two ice forecasts: one by the analytical model and the other using the ice sensor information. In this way the overall system reliability will increase.

6. REFERENCES

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