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# Experimental Validation of a Sensor Monitoring Ice Formation over a Road Surface

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**Abstract:** The reliable detection of ice over road surfaces is an important issue for reducing maintenance costs and improving traffic safety. An innovative capacitive sensor was developed to detect the presence of ice on its surface, and its repeatability, stability and reliability were assessed in simulations and experiments described in previous papers. The indications of the sensor are compared in this paper with the objective identification of ice formation or melting over a road surface in laboratory, under dynamic or stationary conditions, using tap water or a solution with 5 % of salt concentration. The sensor provides indications which are in line with the condition of the road surface, with a mean error in the identification of the time instants of ice-wet and wet-ice transitions lower than about 10 and 40 minutes in the case of tap water and salt water, respectively, both under different temperature gradients or in stationary conditions. Moreover, the indication provided by the sensor always anticipates the formation of ice over the road surface.


**Keywords:** Ice detection, Road information system, Road pavement condition.

## 1. Introduction

Detection of ice formation found important applications in different fields. For instance, an adequate assessment of the conditions of road surfaces may enhance traffic safety [1]; detection of ice on the surface of the runway of airports can improve safety during take off and landing of the aircrafts [2]; finally, the detection of presence of ice on walkways may prevent people falls.

Different technologies were developed to detect ice, depending on the application. Some techniques put directly the sensor in contact with the surface over which ice may form, others allow for a remote sensing. Different sensors were developed exploiting different physical principles, e.g. concerning vibration [3], electro-optics [4], fiber-optics [5], radio frequency [6], micro-mechanics [7], ultrasounds [8], and inductive [9] effects.

To embed the sensors directly in the pavements is preferable to detect ice formation on the surface of a road or a runway. However, the previously indicated methods are not feasible for this application since they are not enough robust or they are based on indirect measurements. Thus, an innovative, low cost sensor was introduced in [10, 11] to detect water and ice on exposed surfaces, based on a capacitance measurement. The sensor was investigated by simulations and experiments, both in laboratory [12] and in the field [13, 14].

Reliability and repeatability of the estimates were investigated in laboratory conditions by comparing the instants in which ice formation and melting were identified by different sensors [11]. The sensors provided indications close to each other, with a spread of the time instants in which a state transition was identified in the order of a few minutes. However, the surface of the sensor is flat and very different from that of the road, which is a rough surface due to the bitumen. Moreover, the sensor blocks percolation of water, which is very important in determining the road surface conditions. Thus, the icing and melting processes on the sensor and on the surface of a road may have a deviation, which is difficult to predict. In order to address this issue, some sensors were embedded in the Turin Airport, with bitumen covering some of them [11, 13]. Nevertheless, the icing process over a bituminized sensor may be different from that of a road even if the two surfaces are the same, since percolation under them is different. Moreover, the indication of a bituminized sensor is still mediated by the sensor, so that it cannot be considered as an external reference. The METAR (METeorological Aerodrome Report) message of the Turin Airport was considered in [13] as an external, objective indication. Data were acquired for 10 months. Rain, fog, and snowfall events were highly correlated with the output of the sensors, but correlation with ice could not be assessed. In the same paper, the indications of the sensor were compared to those of a mathematical model of indirect ice prediction from meteorological data. Correlation was low and, trusting on the sensor indications, it was suggested that a precise prediction of ice formation should require an adaptive model which fits local weather data and ice formation on the specific road under consideration, instead of a simple general law. Thus, also the mathematical models proposed in the literature to relate meteorological variables to ice formation are not considered as reliable independent references to test the sensor.

This work is devoted to an objective test our sensor. Its indications are compared with the ice formation and melting over a road model placed in the same environmental conditions, controlled in laboratory. However, the road can be dirty by contaminants or de-icing material, thus the test was performed both using tap water and water containing salt in a percentage of 5% to wet the road model and the surface of the sensor.

## 2. Methods

### 2.1. Experimental Setup

The sensor described in [11] consists of a multi-frequency capacitance measurement system. The capacitance is related to the relative permittivity of the material placed over the sensor, which depends on temperature and measurement frequency [15], and on the geometrical configuration and dimensions of the electrodes. Fig. 1 shows the relation between the relative permittivity of air, water and ice, and the measurement frequency for specific values of temperature. Due to the variations of relative permittivity with frequency, it is possible to distinguish between water, ice, and air by two capacitive measurements, at low (200 Hz) and high (20 MHz) frequency [11].

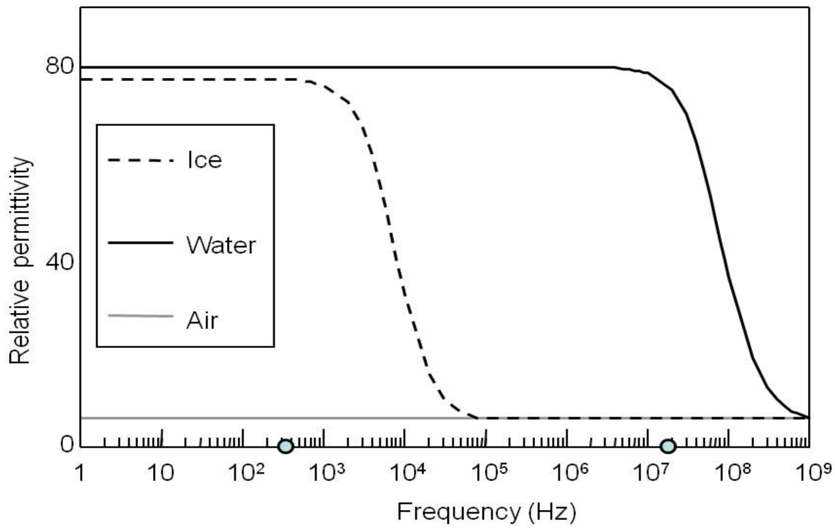


**Fig. 1.** Relative permittivity of air, water (at 25 °C), and ice (at -10 °C) as a function of frequency.

A picture of the sensor is shown in Fig. 2A. The capacitance is measured using a transfer charge circuit implemented on a printed circuit board using commercial available low power components. The sensing electrodes are directly implemented on a printed circuit board, with geometry and dimensions shown in Fig. 2B. The electrodes are directly connected to the capacitance measurement circuit. A layer 3 mm thick of Arnite was mounted over the sensor electrodes, for protection purposes. The device was included into a metallic box filled with resin, which protects the circuitry from infiltration of water or chemical agents. The only exposed parts are the Arnite covering the sensor (on the top) and the connector for the power supply of the circuitry and for the transmission of data to a personal computer. An automatic calibration procedure is included in the sensor to prevent error in the data due to parasitic capacitances.

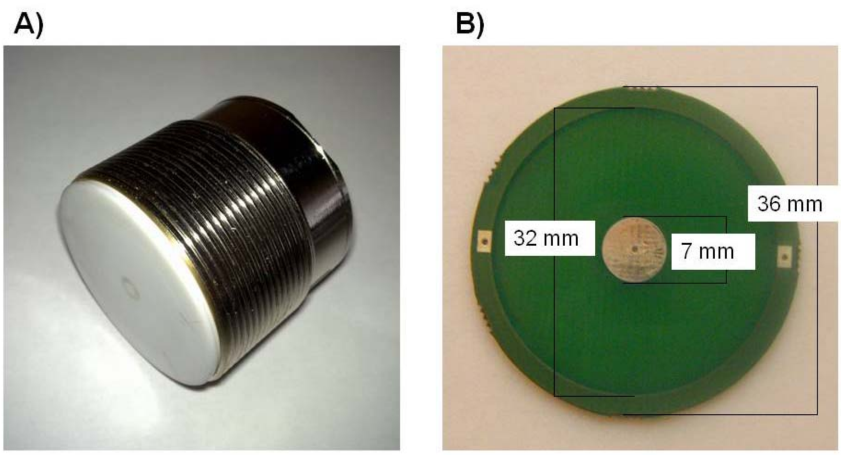


**Fig. 2.** A) Picture of the sensor; B) Picture of the sensing part of the device, the two circular electrodes.

The road model was obtained using a road core with diameter of 30 cm and thickness of 20 cm, shown in Fig. 3. It does not contain the sensor and is constituted by three layers, with asphalt and concrete with different granularity, allowing a good distribution of loads and a proper drain and filtration. The road core is a representation of the asphalt of the runways of the Turin-Caselle airport.

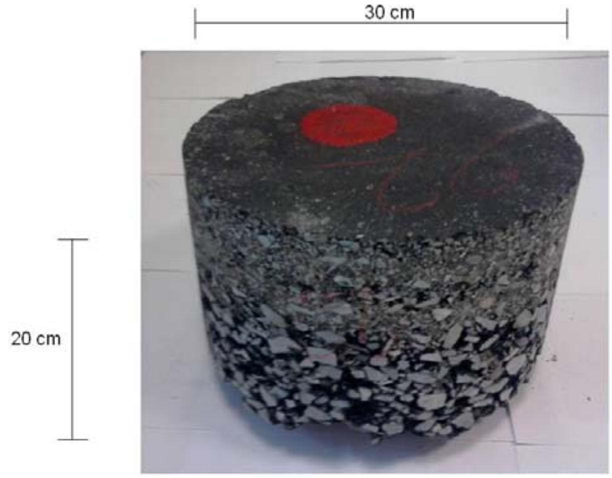


**Fig. 3.** Picture of the road model used for the experiments with an indication of the dimensions.

Experimental tests were executed inserting the sensors and the road core in a climatic chamber (Angelantoni - Challenge 250; temperature range for climatic test from -40 °C to +180 °C), as shown in Fig. 4. Sensors were connected to a data acquisition system via the RS485 communication protocol, for the collection of the data. At the top of the climatic chamber, an USB webcam (Logitech - QuickCam Pro 9000; operative temperature range from -20 °C to +60 °C) was inserted to acquire images from the road core in order to detect the formation of the ice over it. A PC was used to store images from the USB webcam and sensory data from the acquisition system using the RS232 protocol. Images and data were simultaneously acquired using a sampling frequency of 1 sample per minute.

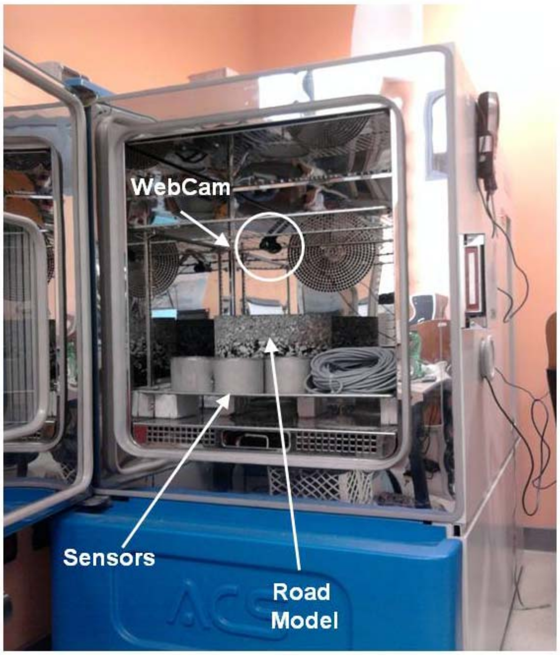


**Fig. 4.** Picture of the experimental setup. Sensors and road core placed in the climatic chamber, together with an USB webcam to acquire images.

### 2.2. Experimental Protocol

In order to compare the indication of presence of ice provided by the sensor with the ice formation and melting over a road, experimental tests were performed applying the same environmental conditions to three sensors and to the road model, and evaluating the time instants in which phase changes were detected.

Two different experimental tests were performed, the first imposing a linear gradient of temperature, the second leaving the climatic camber in static condition. Specifically, in the first test, the sensors and the road core were first introduced into the climatic chamber with a temperature of 25 °C, for approximately 10 minutes in order to wait that the indications of the sensor became stationary. Then, 1 mm of tap or salt water was placed over each sensor and at the centre of the road core. Different temperature gradients were applied and the time instants in which the sensors identified ice formation and the road core surface froze were investigated. Specifically, the climatic chamber was arranged to reach -20 °C with different temperature gradients equal to -0.25 °C/min, -0.5 °C/min, and -0.75 °C/min. During this period, the water froze. Once reached the minimum temperature of -20 °C, the climatic chamber kept stable conditions for approximately 10 minutes, and then it was arranged to reach 25 °C with opposite temperature gradient. During this period, the ice melted. The climatic chamber kept the temperature of 25 °C for approximately 10 minutes. Then, sensors and the road core were dried.

In the second test, sensors and road core were first placed in the climatic chamber. Then, the chamber was arranged to reach -10 °C with a temperature gradient of -1 °C/min. Once reached the temperature of -10 °C, the climatic chamber was arranged to keep stable conditions. One mm of tap or salt water was placed over each sensor and at the centre of the road core. After closing the chamber, the water placed over the sensors and the road core froze. Then, the climatic chamber was open at ambient conditions and the ice melted. Finally, sensors and the road core were dried. This experiment was repeated in three different days in order to investigate the repeatability of the data.

A representation of the two experiments is shown in Fig. 5.

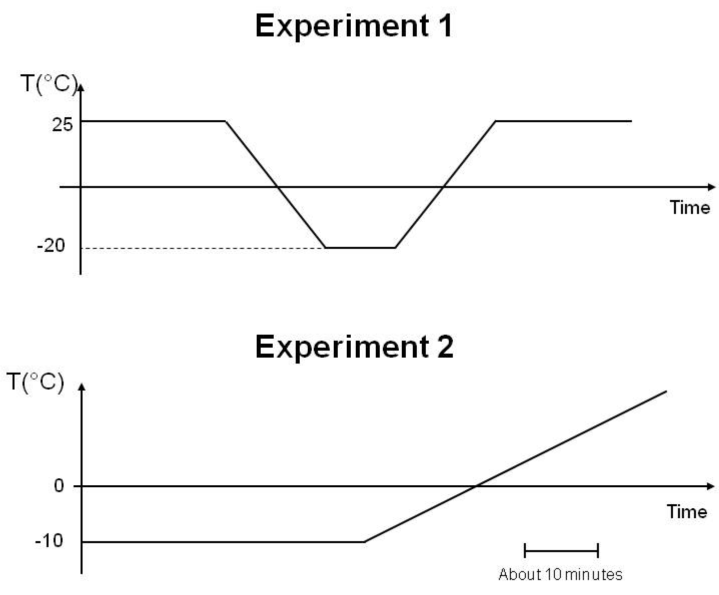


**Fig. 5.** Representation of the two experimental protocols.

These experiments were performed both using tap water and with a solution of water in which salt was added with a value of salinity of 5 %. Salinity was measured using a portable refractometer (RealOcean - PR-S1; salinity range from 0 to 100 %).

### 2.3. Analysis and Presentation of Results

To discriminate between the different possible states of the surface of the sensor (dry, wet, or icy), an algorithm was developed in [11] based on the measured capacitance values obtained at the two considered frequencies. Data were first digitally low-pass filtered (to reduce high frequency and instrumentation noise). From these data, jumps in the values of capacitance were associated to a variation of the state identified by the sensor (dry-wet, wet-icy, icy-wet, and wet-dry). Abrupt variations of the capacitance were identified based on the first time derivative of the data. A jump was considered significant if the first-order derivative was higher than a threshold value estimated during the calibration.

In this work, only the wet-icy and the icy-wet transitions were of interest. The time instants of state transitions were estimated for each sensor. They were compared to the time instants in which water over the road core started to ice or the ice started to melt. These instants were identified by visual inspection of the images captured by the camera.

## 3. Results

An example of data processing is shown in Fig. 6. The images captured by the camera allowed for the identification of the time instants in which water over the road core started to ice, or when ice started to melt are shown on the top. A synchronous detection of the sensor capacitance (one example is shown in the figure) indicates the formation or melting of ice over the sensor. Data from the camera and from the sensors were compared in terms of the time instants in which ice was formed or melted over the road core and those in which state transitions were identified by the sensors.

The results of the two experiments are shown in Fig. 7 for the tap water and in Fig. 8 for the salt water.

The time instants of formation and melting of ice for tap water are shown in Fig. 7 for the sensors and compared to those in which the same happened over the road model. The indication of the sensors is repeatable: in the first experiment, the standard deviation (STD) of identified transition instants is about 3 and 2 minutes for the wet-icy and icy-wet transition, respectively; for the second experiment, STD of the identified transition instants is about 4.5 and 2.5 minutes for the wet-icy and icy-wet transition, respectively. Moreover, their indications are in line with the formation or melting of ice over the road core: mean difference between the mean transition instants identified by the sensors and the actual time of state change of water over the road model was about 11 and 2.5 minutes, for the wet-icy and icy-wet transition, respectively, during the first experiment; for the second experiment, the mean difference was about 5 and 7 minutes for the wet-icy and icy-wet transition, respectively. There was always a negative bias between the indication of the sensors and the conditions of the road.

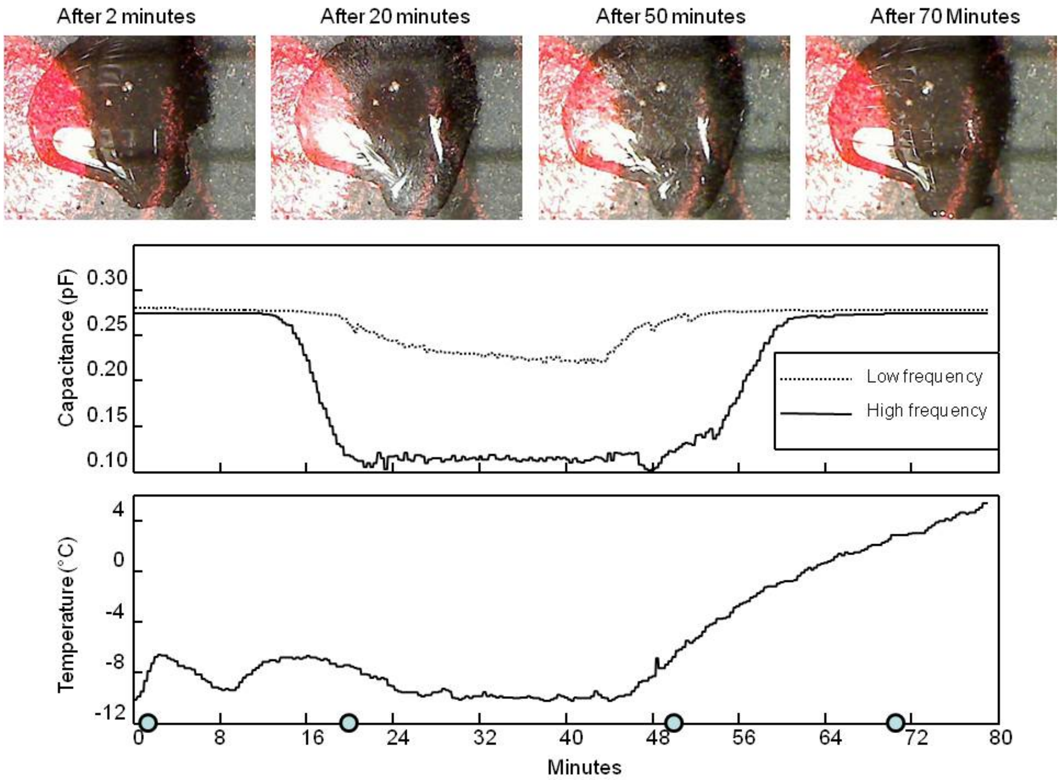


**Fig. 6.** Example of data processing during the second type of experiment. Images captured by the camera are shown on the top. On the bottom, the values of sensor capacitance and the temperature of the climatic chamber are depicted as functions of time. The four time instants for which images are shown are indicated by circles in the bottom panel.

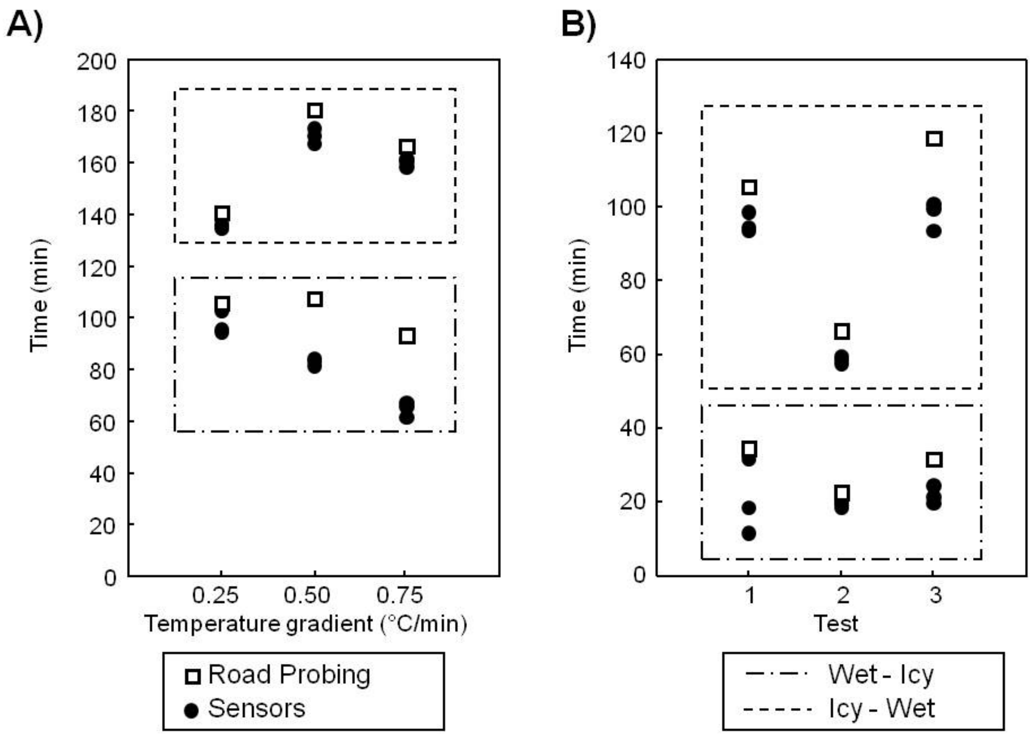


**Fig. 7.** Time instants in which ice formed or melted over the road core compared to the indications of the sensors in the case in which tap water was used: A) First experimental protocol, in which different gradients of temperature are applied; B) Second experimental protocol, in which stable conditions at -10 °C were maintained by the climatic chamber till water froze and then it was switch off and the door was opened till the ice melted.

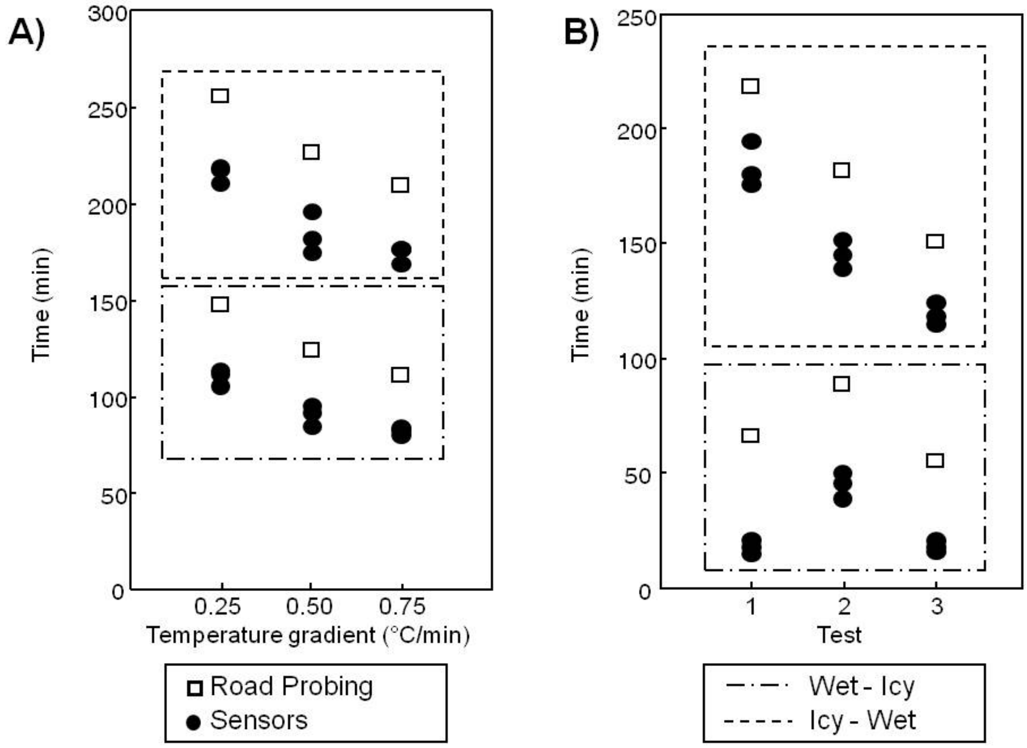


**Fig. 8.** Time instants in which ice formed or melted over the road core compared to the indications of the sensors in the case in which salt water was used: A) First experimental protocol (different gradients of temperature are applied); B) Second experimental protocol (water was frozen and then the door of the climatic chamber was opened till the ice melted).

The time instants of formation and melting of ice are shown in Fig. 8 for the experiments with salt water at 5% of salinity. Again, the indication of the sensors is repeatable, even if the range of time instant in which the state transition was identified is larger than in the case of tap water: indeed, in the first experiment, the STD of identified transition instants is about 5 and 10 minutes for the wet-icy and icy-wet transition, respectively; for the second experiment, STD of the identified transition instants is about 6 and 10 minutes for the wet-icy and icy-wet transition, respectively. Moreover, their indications are in line with the formation or melting of ice over the road core: mean difference between the mean transition instants identified by the sensors and the actual time of state change of water over the road model was about 33 and 43 minutes, for the wet-icy and icy-wet transition, respectively, during the first experiment; for the second experiment, the mean difference was about 45 and 33 minutes for the wet-icy and icy-wet transition, respectively. Also in the case of salt water, the indication of the sensors anticipated the conditions of the road.

## 4. Discussion

A low cost capacitive sensor for the estimation of road condition was developed to support information systems assuring security and efficient maintenance of roads or airports during winter. Performances of the sensor were investigated in simulations, laboratory, and in the field by the authors in previous papers, which indicated that the dry and wet condition was reliably identified. Reliability of ice detection could only be assessed in the laboratory and only considering the spread of the indications of different sensors placed in the same conditions. An external reference was needed to check the reliability of ice detection in the field.

In this paper, repeatability and reliability of the estimates provided by the ice sensor are investigated comparing the time instants in which water froze over a road core with those indicated by different sensors. Controlling the surface of a road model placed in the same environmental conditions of a sensor is considered as an objective way to validate its reliability. This objective validation was still lacking, even if much information on the sensor was already gathered, indicating its reliability and repeatability in identifying dry and wet conditions [10-14, 16]. Moreover, previous studies supported also the capability of the sensor to recognize when its surface was icy [10, 12], but the goal is to identify icy conditions of a road, which has a surface which is different from that of the sensor.

Here, both tap water and salt water were used to wet the road core and the sensors. When considering tap water, repeatability was satisfied, as different sensors provided the same indication with time delay of a few minutes (in line with [11]). Spread of the wet-icy transitions was larger than in the case of icy-wet transition (see [11] for discussion about this result). The reliability of the estimates was also satisfied, as the delay between the state changes identified by the sensors and those obtained over the road were reasonably low (lower than about 10 minutes in all experiments considered). In the case of salt water, the spread of the wet-icy transitions was again larger than in the case of icy-wet transition, as in the case of tap water. In general, the spread of the estimations was larger using salt water than performing the same experiment using tap water. Indeed, temperature should be lowered below zero to freeze salt water. This requires longer times in the climatic chamber (as indicated in Figs. 7 and 8). In such conditions in which the temporal scale is dilated with respect to the case of tap water, small differences between sensors (quantity and distribution of water over their surface or salt concentration) are reflected in a larger spread of the indication of the sensors.

It is worth noticing that there is a consistent deviation between the indications of the sensor and what happens over the road core: the indications of the sensor anticipate the road conditions (of a few minutes, both in case of tap water and salt water, as stated before). Ice forms before over the sensor, due to the smooth surface of the sensor, which facilitates the formation of ice crystals on it than over the road. Moreover, ice melts before over the sensor than over the road core: this is probably due to the low power consumption of the electronics, which warms the surface of the sensor. Nevertheless, caution is recommended before exploiting this deviation in order to predict road surface conditions, as the time delay surely depends on the specific weather conditions.

## 5. Conclusions

This paper is devoted to the use of an external reference to check the reliability of ice detection over a road. The states of the road were identified precisely by the sensor, indicating its feasibility for road condition monitoring, especially during winter. This implies that the sensor could support road information systems for security and maintenance purposes. Possible additional applications of the sensor, still to be assessed, are ice forecasting or identification of different liquid solutions.

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## References

[1]. N. S. T. Lee, H. A. Karimi, and E. J. Krakiwsky, Road information systems: impact of geographic information systems technology to automatic vehicle navigation and guidance, in *Proceedings of the*

*Conference on Vehicle Navigation and Information Systems*, Toronto, Canada, 11-13 September 1989, pp. 347-352.

[2]. E. Pasero, W. Moniaci, and G. Raimondo, AWIS: an Airport Winter Information System, in *Proceedings of the XIV Standing International Road Weather Commission (SIRWEC' 08),* Prague, Czech Republic, 2008.

[3]. C. Barre, D. Lapeyronnie, and G. Salaun, Ice detection assembly installed on an aircraft, *U. S. Patent*, 7000871, 21 February, 2006.

[4]. M. Anderson, Electro-optic ice detection device, *U. S. Patent*, 6425286, 30 July 2002.

[5]. L. Wei, Z. Jie, Y. Lin, and Z. Hong, A fiber-optic solution to aircraft icing detection and measurement problem, in *Proceedings of the International Conference on Information Technology and Computer Science (ITCS' 09),* Kiev, Ukraine, 2009.

[6]. J. T. Abaunza, Aircraft icing sensors, *U. S. Patent*, 5772153, 30 July 1998.

[7]. R. DeAnna, Ice detection sensor, *U. S. Patent*, 5886256, 23 March 1999.

[8]. H. Gao and J. L. Rose, Ice detection and classification on an aircraft wing with ultrasonic shear horizontal guided waves, *IEEE Trans. Ultrason., Ferroelectr., Freq. Control*, Vol. 56, Issue 2, 2009, pp. 334–344.

[9]. H. Lee and B. Seegmiller, Ice detector and deicing fluid effectiveness monitoring system, *U. S. Patent*, 5523959, 4 June 1996.

[10]. A. Troiano, E. Pasero, and L. Mesin, A Road Ice Sensor, *Emerging Technology*, Shah Miah, InTech, in press.

[11]. A. Troiano, E. Pasero, and L. Mesin, New System for Detecting Road Ice Formation, *IEEE Trans. on Instr. and Meas.,* Vol. 60, Issue 3, 2011, pp. 1091-1101.

[12]. A. Troiano, E. Pasero, and L. Mesin, An innovative water and ice detection system for road and runway surfaces monitoring, in *Proceedings of the Conference on Ph. D. Research in Microelectronics & Electronics (PRIME' 2010),* Berlin, Germany, 2010.

[13]. A. Troiano, E. Pasero, and L. Mesin, In the Field Application of a New Sensor for Monitoring Road and Runway Surfaces, *Sensors & Transducers*, Vol. 10, 2011, pp. 71-83.

[14]. L. Mesin, A. Troiano, and E. Pasero, In Field Application of an Innovative Sensor for Monitoring Road and Runway Surfaces, in *Proceedings of the International Conference on Sensor Device Technologies and Applications (SENSORDEVICES' 2010),* Venice, Italy, 2010.

[15]. A. Von Hippel, The dielectric relaxation spectra of water, ice, and aqueous solutions, and their interpretation: critical survey of the status-quo for water, *IEEE Trans. on Elec. Insul.,* Vol. 23, Issue 5, 1988, pp. 801-840.

[16]. A. Troiano, E. Pasero, and L. Mesin, Detection of Ice Formation over a Road Surface, in *Proceedings of the International Conference on Sensor Device Technologies and Applications (SENSORDEVICES' 2011),* Nice/Saint Laurent du Var, France, 2011.

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- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
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