Detection of 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. 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 minutes, both under different temperature gradients or in stable conditions.**

***Keywords*-Capacitive sensor; ice detection; road and runway information system.**

I. 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.

In order to detect ice formation on the surface of a road or a runway, embedding the sensors directly on the pavements is preferable. 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 ice sensor was introduced in [10] to detect water and ice on exposed surfaces, based on a capacitance measurement. The sensor was investigated by simulations and experiments, both in laboratory [11] and in the field [12] [13].

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 [10]. 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 a road, with bitumen covering some of them [10] [12]. 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 [12] 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 the objective of test our sensor: its indications are compared with the ice formation and melting over a road model identified by direct inspection.

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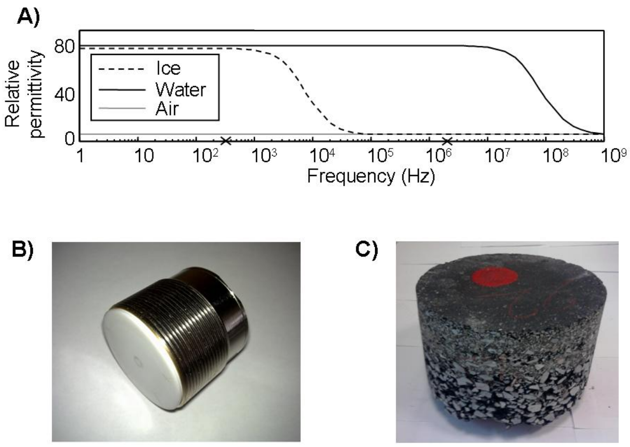

Figure 1. (A) Relative permittivity of air, water (at 25°C), and ice (at -10°C) as a function of frequency. (B) Picture of the ice sensor. (C) Picture of the road core.

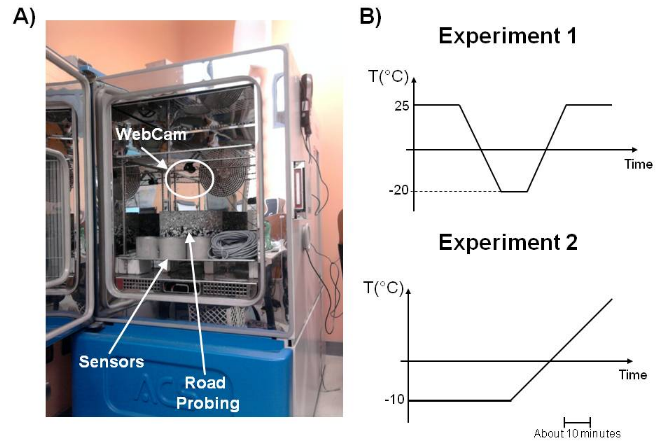

Figure 2. (A) Picture of the experimental setup. Sensors and road core placed in the climatic chamber, together with an USB webcam to acquire images. (B) Representation of the two experiments.

II. Methods

The sensor described in [10] 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 [14]. On the other hand, it is worth noticing that it is not affected by contaminants (e.g. salt) present over the road [12]. Figure 1A 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 (200Hz) and high (20MHz) frequency [10]. The capacitance is measured using a transfer charge circuit. The sensor is shown in Figure 1B.

The road model was obtained using a road core with diameter of 30 cm and thickness of 20 cm, shown in Figure 1C. 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.

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 core, and evaluating the dispersion of the time instants in which phase changes were detected. 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 Figure 2A. 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.

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 water was placed over each sensor and at the center 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

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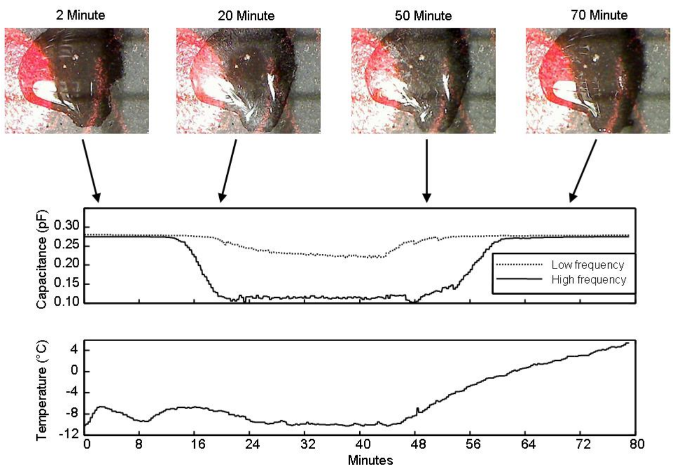

Figure 3. Example of data processing during the second type of experiment. Images captured by the camera are shown on the top. On the bottom, the values of sensor capacitance and the temperature of the climatic chamber are depicted.

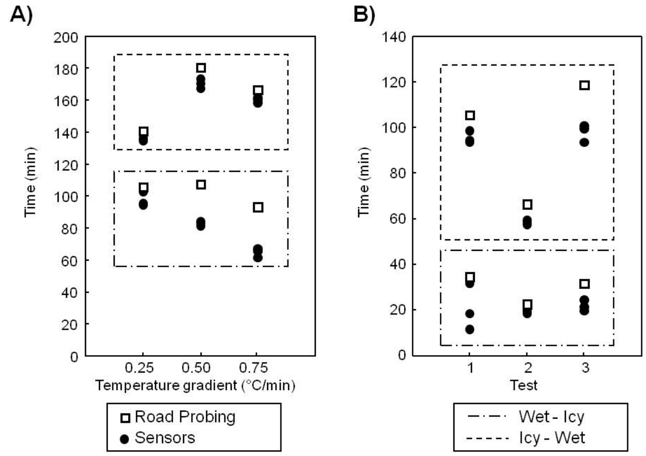

Figure 4. Time instants in which ice formed or melted over the road core compared to the indications of the sensors. A) First experiments, in which different gradients of temperature are applied. B) Second experiments, in which stable conditions at -10°C were maintained by the chamber till water froze and then it was switch off and the door was opened till the ice melted.

reached the temperature of -10°C, the climatic chamber was arranged to keep stable conditions. One mm of tap water was placed over each sensor and at the center 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 Figure 2B.

III. RESULTS

An example of data processing is shown in Figure 3. 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. 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 general results of the experiments are shown in Figure 4. The time intants of formation and melting of ice are shown for the sensors and compared to those in which the same happened over the road model. The indication of the sensors are 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.

IV. CONCLUSIONS

Repeatability and reliability of the estimates provided by the ice sensor are investigated comparing the time instants in which water state transitions occurred over a road core and those indicated by the sensor. Controlling the surface of a road model placed in the same environmental conditions of a sensor is an objective way to get an external validation of its indication.

Repeatability was satisfied, as different sensors provided the same indication with time delay of a few minutes (in line with [10]). Spread of the wet-icy transitions was larger than in the case of icy-wet transition (see [10] 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).

It is worth noticing that there is a deviation between the indications of the sensor and what happens over the road core, as the indications of the sensor anticipate the road

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conditions (of a few minutes, 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. 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. Nevertheless, the precision of the indications of the sensor indicates its feasibility for different applications, such as 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,* Toronto, Canada: VNIS, 1989.

[2] E. Pasero, W. Moniaci, and G. Raimondo, *AWIS: an Airport Winter Information System,* Prague, Czech Republic: SIRWEC, 2008.

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

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

[5] W. Li, J. Zhang, L. Ye, and H. Zhang, *A Fiber-Optic Solution to Aircraft Icing Detection and Measurement Problem,* Kiev, Ukraine: ITCS, 2009.

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

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

[8] H. Gao and J. L. Rose, *Ice detection and classification on an aircraft wing with ultrasonic shear horizontal guided waves,* IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control, vol. 56(2), pp. 334-344, 2009.

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

[10] A. Troiano, E. Pasero, and L. Mesin, *New System for Detecting Road Ice Formation,* IEEE Transactions on Instrumentation and Measurement, vol. 60(3), pp. 1091-1101, 2011.

[11] A. Troiano, E. Pasero, and L. Mesin, *An innovative water and ice detection system for road and runway surfaces monitoring,* Berlin, Germany: PRIME, 2010.

[12] 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, pp. 71-83, 2011.

[13] L. Mesin, A. Troiano, and E. Pasero, *In Field Application of an Innovative Sensor for Monitoring Road and Runway Surfaces,* Venice, Italy: SENSORDEVICES, 2010.

[14] 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 Transactions on Electrical Insulation, vol. 23(5), pp. 801-840, 1988.

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