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Remote Monitoring of Ice Formation over a Runway Surface

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ABSTRACT

The reliable detection of ice formation over a runway surface is an important issue for reducing maintenance costs and improving traffic safety. An innovative 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. Three sensors were embedded, far from each other, in the 4 km long runway of the Turin-Caselle airport to check the state of its surface. Each sensor was equipped with a GPRS modem to send the collected data to a common database. The GPRS based acquisition system was installed more than one year ago showing correct working and automatic reactivation after malfunctions without any external help.

Keywords: ice detection, GPRS, remote monitoring, sensor, runway surface.

1 INTRODUCTION

Monitoring of ice formation is important in many different fields, for instance to alert people walking on walkways or to enhance traffic safety on roads [7]. The assessment of the environmental conditions on road and runway surfaces is attracting attention, as it may significantly contribute to reduce maintenance costs of highways and airports [9]. Indeed, accurate indication on road pavement condition helps agencies to efficiently plan the maintenance (especially during winter), to reduce wear on the vehicle fleet, to decrease chemical, sand and salt usage, and to provide a better level of service by applying anti-icing practices.

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 [2], fiber-optics [15], radio frequency [1], micro-mechanics [4], ultrasounds [5], and inductive [6] effects.

An innovative, low cost sensor was introduced in [10] to detect directly water and ice on its exposed surface, based on a capacitance measurement, to study the relative permittivity of the material placed over it. The sensor is robust enough to be directly embedded in the pavements to detect ice formation on the surface of a runway. Moreover, the sensor measures the temperature on its surface [10]. The sensor was investigated by simulations and experiments, both in laboratory [11] and in the field [8] [12] [13], and results show that the sensor provides indications in line with the environmental conditions, identifying properly the icy condition and indicating the wet state during both rain and fog.

Three sensors were embedded in the runway of the Turin-Caselle airport to check the state of its surface. Since it is about 4 km long, the sensors were placed far from each other, in order to monitor different positions of the runway. Due to the long distance, each sensor was equipped with a GPRS modem to send the collected data to a common database. Using the GPRS modem, the sensor gains access to internet; this gives the opportunity to send the collected data to a remote database. This work presents an innovative system to monitor the data collected by sensors at Turin-Caselle airport.

2 METHODS

2.1 Description of the sensor

The sensor consists of a multi-frequency capacitance measurement system [10] [12]. The capacitance of the electrode assembly depends on the geometrical configuration and dimensions of the electrodes, and on the relative permittivity and thickness of the material placed between the electrodes. The relative permittivity, in turn, depends on temperature and measurement frequency [14]. The relation between the relative permittivity of water or ice and the measurement frequency is shown in Figure 1 for specific values of temperature. The relative permittivity of ice is substantially constant within a range from DC to about 1kHz, and decreases in the range of approximately 2kHz to several hundred kHz. On the other hand, the relative permittivity of water is substantially constant up to approximately 100MHz and decreases within the range from 200MHz to 10GHz. The relative permittivity of air can be assumed equal to 1 and constant for all frequencies. Therefore, at low frequencies (lower than 1kHz) the relative permittivity of water and ice are similar, while the relative permittivity of air is different from the others. Instead, at high frequencies (between 100kHz and 100MHz) the relative permittivity of air and ice are similar, while the relative permittivity of water is different from the others. Thus, it is possible to distinguish between water, ice and air by two capacitive measurements, at low (200Hz) and high (20MHz) frequencies [10] [12].

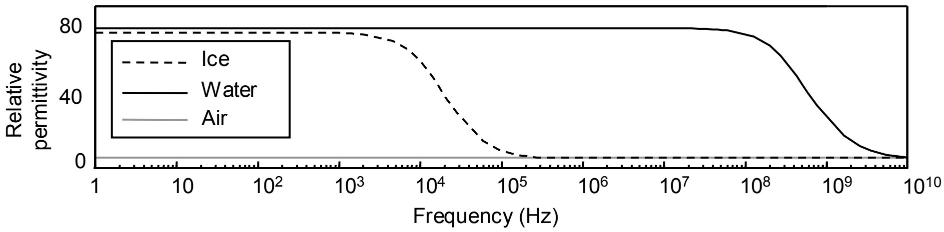

Figure 1. Relative permittivity of water (at 25°C), air, and ice (at -10°C) as a function of frequency.

The sensor consists of a pair of concentric conductive electrodes (with geometry indicated in Figure 2, on the left), which constitute the sensing device, and a transfer charge circuit for capacitance measurement [10] [12]. The transfer charge circuit includes a sensing capacitor (the pair of concentric conductive electrodes), a frequency generator, and a charge detector. Both the electrodes arrangement and the circuitry are implemented on a printed circuit board using commercially available low power components. The sensor is based on a microcontroller (an 8051 core from Silicon Laboratories Inc.). An automatic calibration procedure is included in the sensor to prevent errors in the data due to parasitic capacitances. The device also comprises an internal temperature sensor to account for the variations of the relative permittivity with temperature. A layer of Arnite was mounted over the sensor electrode, for protection purposes. Arnite was chosen because its relative permittivity is nearly constant within the range of temperature and measurement frequency in which the sensor is used. The sensor was included in a metallic box filled with resin, which protects the circuitry from infiltration of water or chemical agents [10]. 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 connection to a data acquisition system (on the bottom). The sensor is shown in Figure 2, on the right.

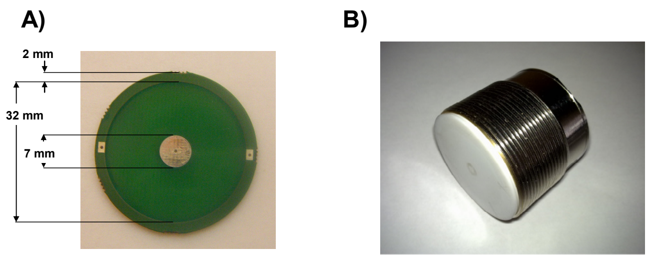

Figure 2. A) The concentric conductive electrodes. B) The sensor.

2.2 Description of the GPRS based data acquisition system

A GPRS based data acquisition system was designed in order to wirelessly transmit the state of the runway surface revealed by the sensor to a common database for the graphical visualization of the condition of the Turin-Caselle airport. The data acquisition system is based, as well as the sensor, on a 8051 microcontroller from Silicon Laboratories Inc., which acquires the data from the sensor, manages the capacitance values in order to obtain the state of the surface of the runway, configures the GPRS modem, and sends the revealed states to a GPRS modem for their transmission to the database. The data acquisition system is designed to be connected with up to 12 sensors. The GPRS modem used for this application is the model "MTSMC-G-F4" from Multi-Tech Systems, Inc. The interface between the microcontroller and the GPRS modem is based on standard UART, and AT commands are used for its configuration. Using the GPRS modem, the system gains access to internet; this gives the opportunity to send the collected data to a remote database. During the design of the system, a particular attention was put on a set of self-reactivation functions because the particular environment (an airport) in which the sensor is used makes hard reaching the system in the case of malfunctions. A picture of the board of the data acquisition system is shown in Figure 3.

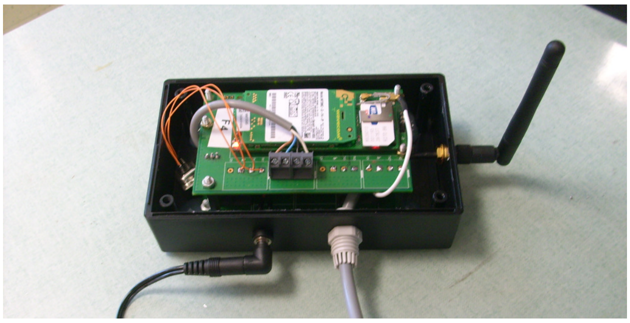

Figure 3. The GPRS based data acquisition system.

In Figure 3, connectors for the power supply of the system (in black) and for the communication with the sensor (in gray) are clearly visible. An antenna was added to the GPRS module to increase the range.
The data collected by the sensors were transmitted using the GPRS based data acquisition system to a remote database, implemented in MySQL, sited in a computer at the Polytechnic of Turin. Data in the MySQL database are accessed by a stand-alone program that saves them to a file and then sends it to the server; a Javascript script reads this file (using an "iframe") and updates web pages according to the received data.

3 RESULTS

3.1 Presentation of the data in a web site

The GPRS based data acquisition system sends the collected data to a server, which stores them into a MySQL database. In order to make this data available to everyone, two web pages were developed. The first web page displays the current state of the runway detected by the three sensors (Figure 4).

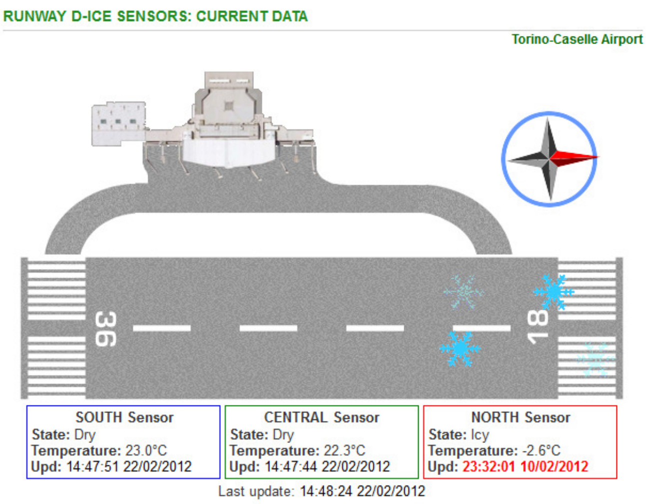

Figure 4. Web page which shows the runway current state.

The runway is represented in the middle of the page, divided into three sections (north, central and south); each of them contains an embedded sensor. According to the detected state, each section shows a different image (nothing to indicate dry, rain to indicate wet, and ice crystals to indicate icy). An older data for the north section was used in Figure 4 to show the icy state. Textual information of the detected state is added at the end of the page, together with the temperature measured by the sensor.
The previous described web page gives the state of the runway in real-time. To provide detailed information about the last 24 hours, a second web page was implemented (Figure 5).

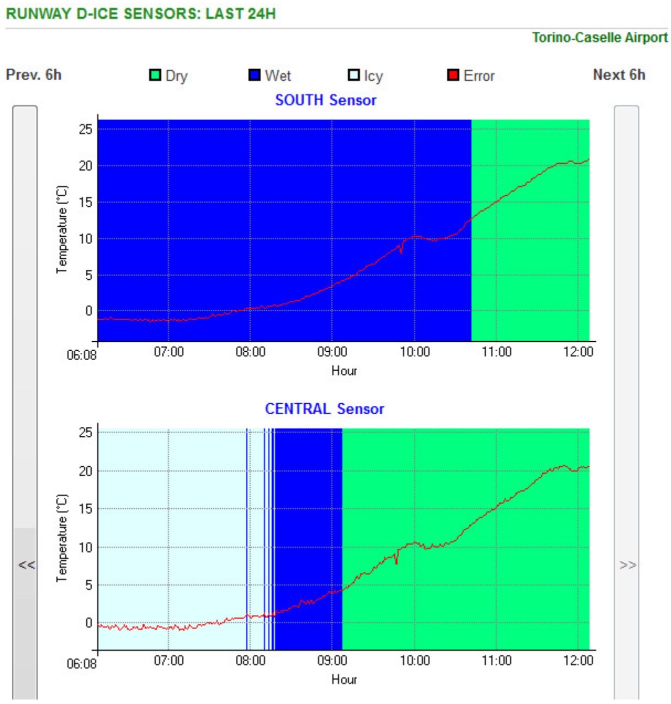

Figure 5. Web page which shows the last 24 hours state.

This web page show both the temperature (the red line) and the state of the runway (the background colour). For example, Figure 5 shows the data collected by the south and the central sensor from about 6 a.m. to about midday. The temperature raised from about -2°C to 20°C for both the sensors. The central sensor sensed the icy state on this section of the runway till 8 o'clock, then the ice melted and then, after about one hour, the surface dried. On the other hand, the north sensor sensed wet state till half past 10, then the surface dried. Using the two lateral buttons is possible to switch the images; each of them shows 6 hours (four images per sensor per day).

3.2 Results about the functionality of the device

A program to monitor the self-reactivation features of the acquisition system was developed. The program asks to the database data from each sensor about a time period; then it displays when the acquisition system of each sensor sends the data and when not. The output of the program are 3 graphs, one for each sensor, like the ones presented in Figure 6.

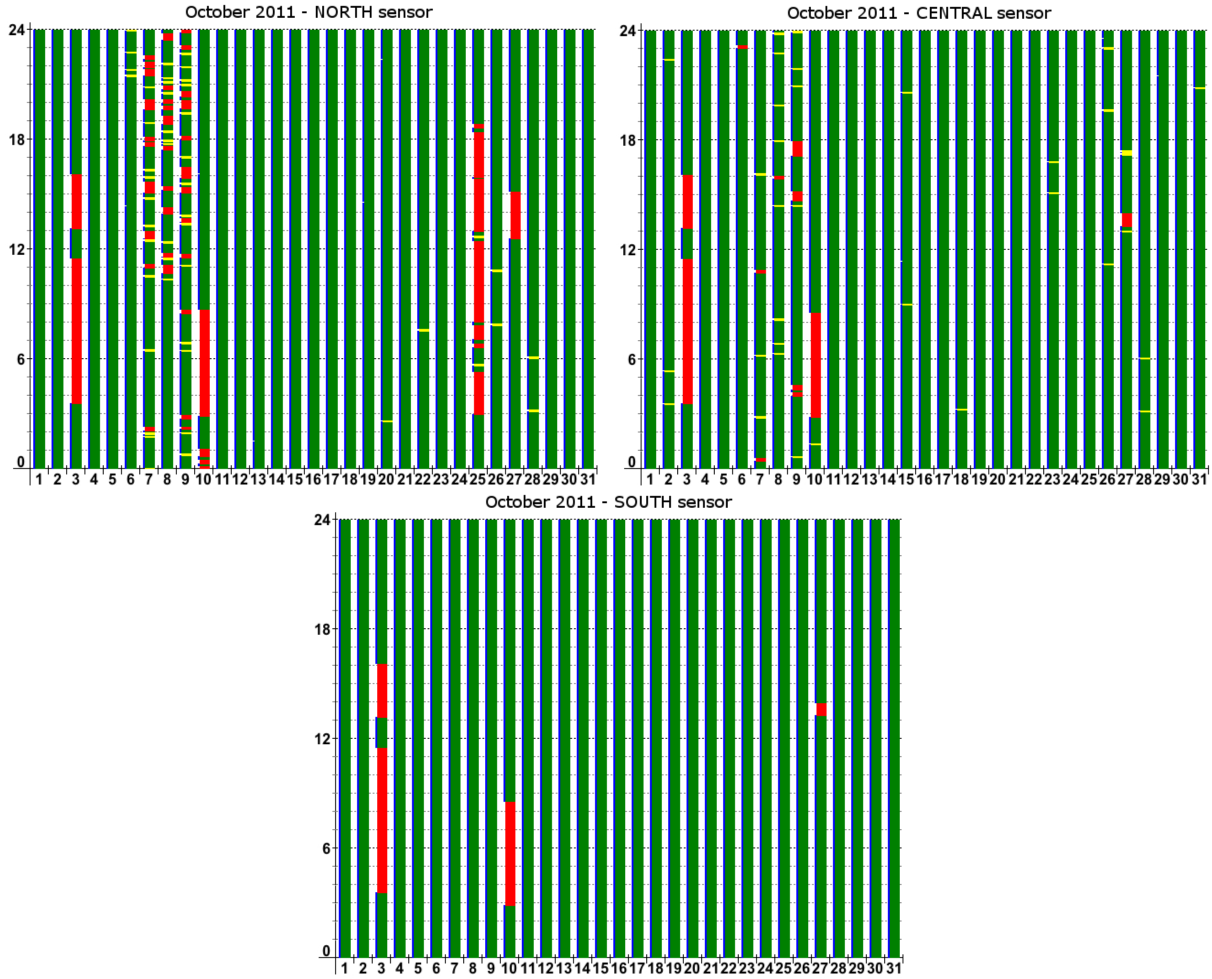

Figure 6. Connection statistics for the GPRS based acquisition systems.

In these graphs the statistics covering a whole month (October 2011) are shown. Each bar represents a day, while on the y-axis there is the time. When the bar is green, the acquisition system is working well. A yellow mark indicates a small malfunction (for less than five minutes), while a red bar shows a sustained error.

If the malfunction is common to every sensor then it can be supposed that there is a server problem (like the ones on October 3rd). Excluding server problems, the only noticeable malfunctions were between October 7th and October 9th; when a network coverage problem is supposed.

These graphs are referred to the month of October 2011, however similar behaviour are obtained for other time periods in which the device is used.

4 CONCLUSIONS

An innovative system to monitor the data collected by sensors at the Turin-Caselle airport was presented. The data are presented on web pages for simple access. The GPRS based acquisition system was installed more than one year ago showing correct working and automatic reactivation after malfunctions without any external help.

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