A Novel Approach of Icing Detection on Railway Infrastructure by means of Surface Sensors

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Abstract— **[Icing on railway infrastructure is especially critical on overhead power lines and on the railroad tracks. Especially, frozen track switches can heavily affect train schedules since these are crucial parts of the railway network. Continuous heating is the worst option, both environmentally and commercially. Thus, alternatives to preserve energy while maximising safety are asked for. This paper describes a measurement campaign with meteorological sensors, as well as surface sensors originally designed for wind turbine rotor blades and presents selected events recorded at a railway switch in the 2018/2019 winter season in the Swiss Alps.]**

Keywords— ***icing detection, railway infrastructure, wireless sensor, critical infrastructure, track switch***

I. INTRODUCTION

Icing on railway infrastructure severely affects various components, such as tracks, signals, level crossings, overhead power lines (including insulators), bridges and track switches. While methods have been developed to remove ice and snow from tracks and overhead lines by means of e.g. special vehicles, infrastructure cannot be kept ice-free under all circumstances. Track switches remain a weak point of the infrastructure since they represent crucial points of the railway network. In the worst case, they fail to lock in the end positions, thus blocking the route [1]. In Alpine regions such as Austria or Switzerland, with railway lines crossing mountain passes, several thousand track switches are therefore heated throughout the winter season, consuming megawatts of electricity in order to ensure safe operation. For efficient control of these heaters, reliable measurements at the switch are necessary. Such information is typically derived from temperature and possibly also air humidity sensors in combination with control logic that may be site specific. In use cases where a larger amount of track switches is monitored and controlled by a single sensor, the relevance of this environmental information is limited. [2], [3]

On wind turbines, to give an example from a different field, de-icing (removing ice which has built up during dedicated time slots) is more common than anti-icing (keeping surfaces free from ice during operation.). This is mostly because the large surface areas and the hight wind speeds cause a huge energy demand. However, in aeronautics it is crucial to have anti-icing systems using just the necessary amount of energy [4], [5].

This paper presents first results of a measurement campaign between October 2018 and March 2019 with mechanically flexible, thin (below 2 mm) and solar powered self-sustaining sensors with their main application currently being icing detection on wind turbine rotor blades, i.e. in harsh environments.

The motivation for the measurement campaign was twofold: first, to assess which kinds of measurement at which positions would be required to achieve effective state estimation of the track switch and second, to test the viability of energy self-sufficient icing sensors that need to operate continuously over several cold months on components of a track switch. This means that the sensors are exposed to the harsh railway environment, most of the positions without direct sun exposure. Several different sensors have been mounted onto a railroad switch operated by BLS in the Swiss Alps which is regularly exposed to ice and snow during winter season. Measurement data from the aforementioned icing sensors and surface temperature sensors was continuously logged during winter 2018/2019.

II. EXPERIMENTAL SETUP

The novel sensor approach relies on commercially available icing sensors for wind turbines which are powered by solar energy and wirelessly transmit acquired measurement data (based on an impedance measurement principle [6]) to a receiver (see Fig. 1).
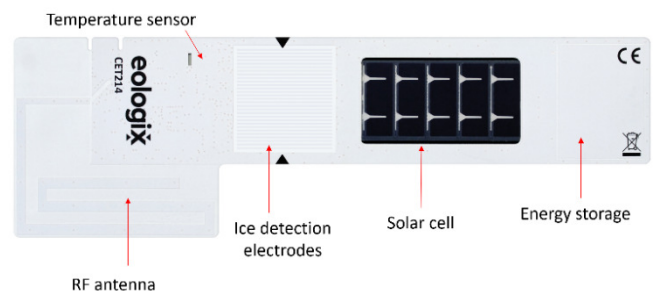

Figure 1: Picture of the wireless sensor as used e.g. on wind turbine rotor blades. Red arrows are showing key parts of the sensor: radio frequency (RF) interface for data transmission to the receiver, a temperature sensor, the

impedance measurement area (icing detection), a flexible solar cell for energy harvesting from daylight and the energy storage for dark time operation.

A track switch in the Swiss municipality of Kandersteg was equipped with five of these ice sensors distributed in a cross section through the track switch, a host of temperature sensors along a 17 m stretch of the track switch (stock and tongue rails) as well as a weather station. The sensors were operating mostly without interruption from October 2018 to April 2019. Figure 1 – (b) being a zoomed-in section of (a) - depicts the schematics of the measurement setup while Figure 2 shows a photograph of the central part of the setup.
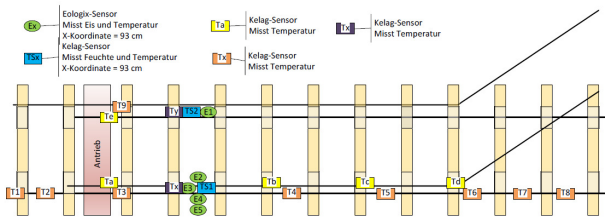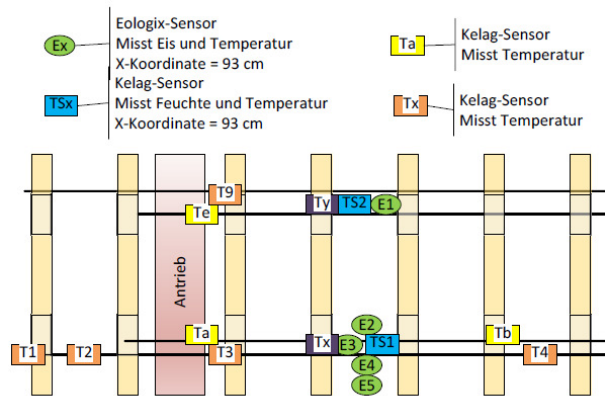

Figure 1(a): Test location overview.

Figure 1(b): Schematic view of the sensors and their location on the key parts of the track switch. The green icons are ice sensors E1-E5 while temperature measurements are taken from T3-T5.

Figure 2: Locations of ice sensors (green), temperature sensors (grey) and temperature/humidity sensors (blue). Ice sensors E1, E2, E5 have been mounted horizontally on purpose-made steel plates due to their mechanical dimensions (lengthwise).

Since there are no sensor mounting surfaces available on standard tracks, the BLS workshop fabricated steel plates similar in weight and presumably similar thermal conductance and thermal capacity to the slider, which is the mechanical part that supports the weight of the movable parts of the switch. If the surface of the slider was iced, this could lead to blocking of the switch. Icing sensors were mounted to the surface of these steel plates. The underlying hypothesis in the experiment design is that due to the same weight both of steel plate and slider, the temperatures measured on the steel plate may show similar behaviour as the slider with a somewhat constant offset. This means that e.g. a drop in temperature of the steel plate should be relatable to a drop in temperature of the slider as well. In a future application, the controller of the switch heater could then react to such a temperature drop and would start heating.

In addition to these sensors, meteorological data (such as ambient temperature, relative humidity, wind speed, solar radiation and precipitation) was recorded at the side of the track but within few meters from the switch.

III. RESULTS AND DISCUSSION

Three exemplary events from the measurement campaign of winter 2018/19 were selected for further analysis. The diagrams below contain the following data in four subplots each:

- top subplot:: rain intensity (blue) in millimeters per hour and relative air humidity in % (red)
- second subplot: maximum wind speed in meters per second (blue) and solar radiation in Watts per square meter (red)
- third subplot: E1-E5 icing indication where an iceSignal of 1 equals a free surface, 2 is a very thin ice layer (below 1 mm thickness) or water droplets on the sensor surface at positive temperatures, iceSignal = 3 equals a clear ice layer of at least one millimeter (or a thicker layer equivalent to the contained air volume), iceSignal of 4 equals 10 mm or thicker ice. This signal is depicted separately for each sensor.
- bottom subplot: the dashed black line represents the track temperature as mean value of T3-T5 (compare Figure 1), the dotted black line showing the ambient temperature data of the meteorological station and the colored graphs of E1-E5 are the temperature readings which are included in each of the icing sensors.
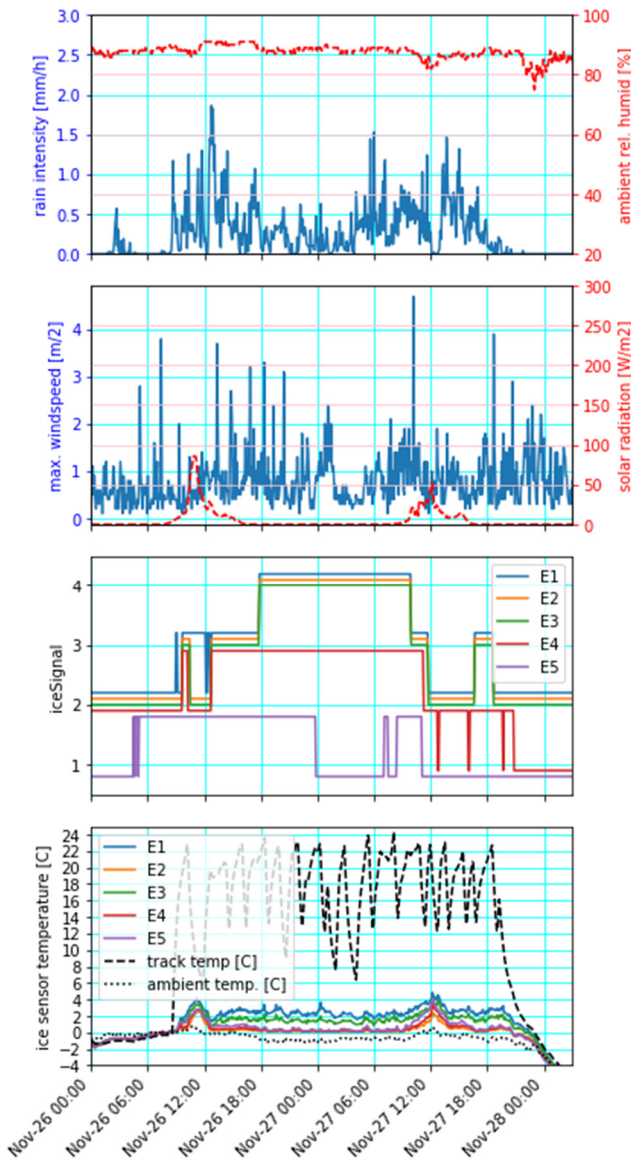
Figure 3: Measurement data over time between November 26th and November 28th, 2018. All sensors deliver data in this period without interruption.

Figure 3 shows a typical heating event: with a track temperature going below 0°C, heating is being activated and operates in cycles. It can be clearly seen that the temperature levels are far above what would be considered necessary to keep the track free of ice. Solar radiation is low (corresponding to cloudy weather throughout both days) and the surface status is already a thin ice layer when the event starts at Nov. 26th, 0:00. Around 18:00 at the same day, the situation gets worse. Obviously, switch heating (approx.. between Nov. 26th, 5:00 until Nov. 27th, 20:00) does have a (reduced) effect on the icing sensors as well as the solar radiation peaks which clearly correspond with peaks in the E1-E5 temperature measurement data. Given that the ambient temperature is below zero over most of the period, it is reasonable that thick ice can persist on the E1-E4 icing sensors while the temperature reading is already showing positive values.

It is also noteworthy that temperature and icing vary significantly over the lateral cross-section measured by the five ice sensors. This indicates that microclimate is an important factor to consider when measuring track switches.
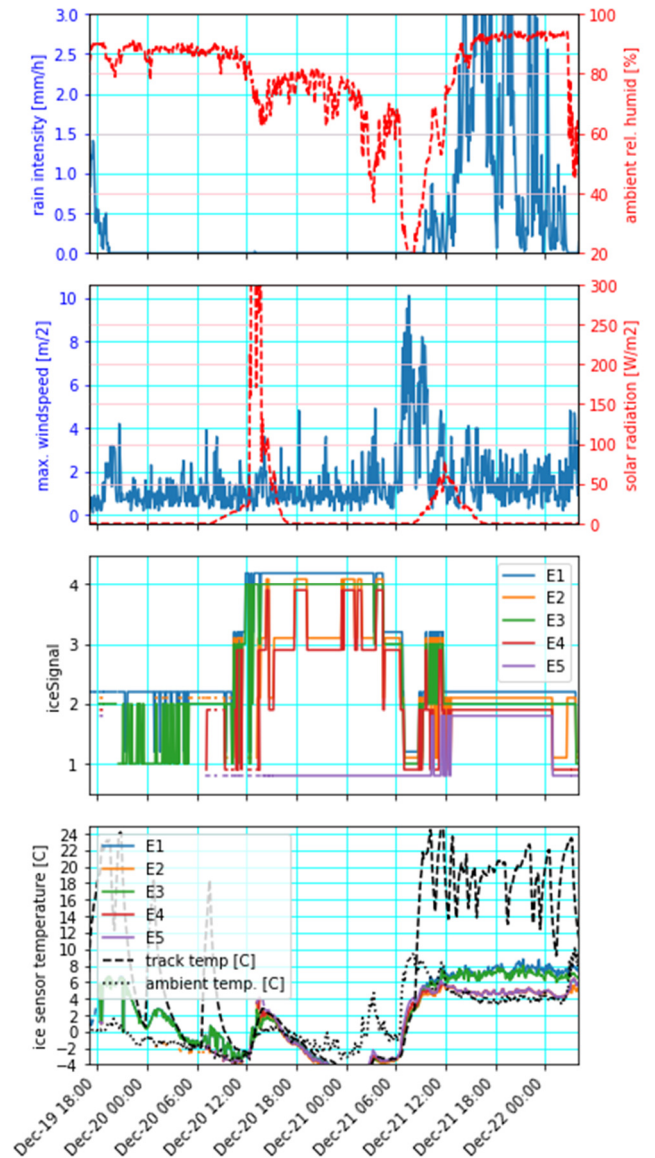

Figure 4: Measurement data over time between December 19th and December 22nd, 2018. Some icing sensor data have not been recorded in beginning of the period.

In Figure 4, an event of two and a half days' duration is depicted. Initially, precipitation and low temperatures trigger the heating for two cycles while no ice is observed on the E1-E5 sensors. On December 20th, 12:00, 4 of 5 sensors show a relevant ice layer. Ice accretes to thick layers >10 mm and is removed only after December 21, 9:00 when another series of heating cycles is started which again can be estimated from the temperature sensor readings of E1-E5 (compare Figure 3). It is likely that the combination of comparatively high wind speed at increased temperatures (up to 8°C ambient) which helped to remove the ice naturally while the track heating was not active.
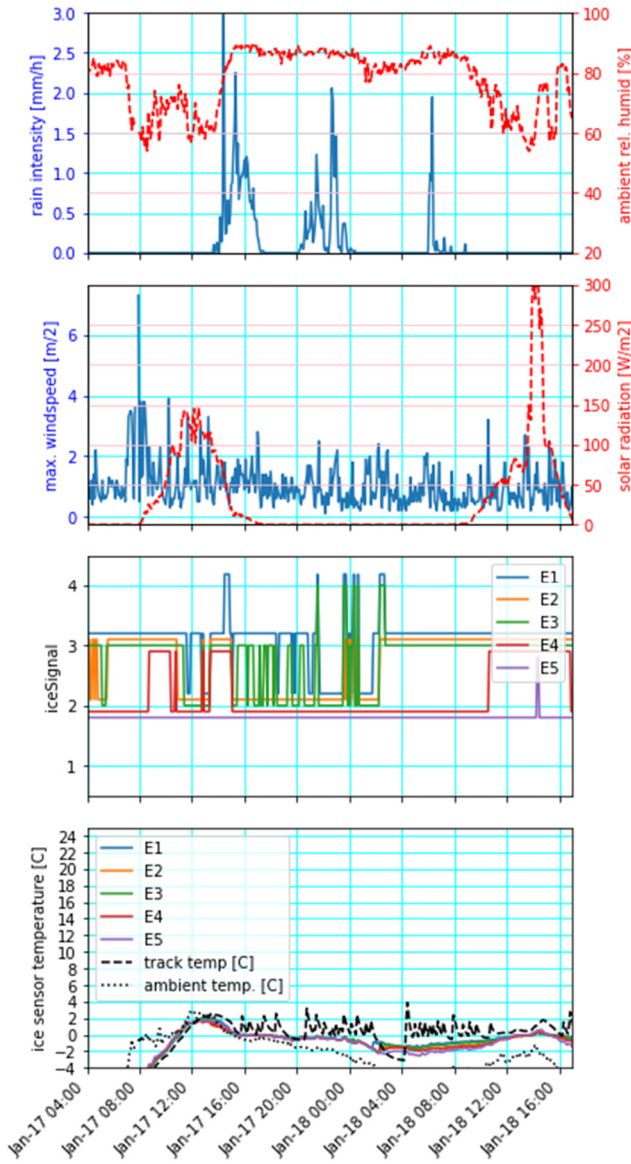
Figure 5: Measurement data over time between January 17th and January 18th, 2019. Ambient and track temperature are not available in the beginning of the observed period.

Figure 5 depicts a time interval when the heating is working close to an optimum, when activated. Thin ice layers are present on al sensors except E5 during the observed period, however, an ice signal of 4 is rarely reached and the track is heated only a few degrees over ambient temperature, thus minimizing required heating power. In a further optimization iteration, depending on requirements, the "ideal" state would be sensors not exceeding an iceSignal of 2 while at the same time keeping heating energy demand as low as possible.

Figure 6 shows the availability of the sensors. It needs to be mentioned that the sensors have been put in locations within the structure and between components of the railway switch which are especially challenging for wireless transmission. The biggest part of the reported non-availability is due to packet losses in RF communication.
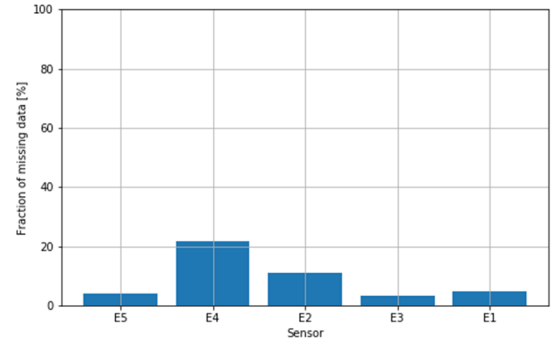

Figure 6: Relative non-availability of ice sensors during the deployment.

IV. CONCLUSIONS

The ice sensors worked reliably and provided well usable data which correspond to the meteorological conditions. After having worked flawlessly for half a year between or close to the tracks, the surface of the sensors was not yet covered by dense iron dust. This may relate to the erosion protected surface (based on commercial polyurethane tape).

Even the sensors which were located between stock rail and tongue rail received enough solar energy; the energy harvested was sufficient, and no other energy source had to be used.

Packet losses due to the harsh environment in terms of the wireless RF data link need to be addressed since continuous data availability is a critical point in this application.

Sensors with a large surface footprint are difficult to apply on track switches; respectively the designers of track switches did not have such sensors in mind during design and therefore there is hardly any space for sensor mounting, even for sensors with mechanical flexibility and minimal thickness such as those chosen for this experiment

Either, surfaces are added to track switches, or sensors are redesigned with a smaller footprint in order to make mounting even easier.

V. OUTLOOK

The collected data will be used to learn about possibilities to improve the efficiency of the heating control system, thus reducing total energy consumption and making rail transport even more environmentally friendly while maintaining the system safety at the highest possible level. The data will also be used to study the relationship between environmental weather data and ice signals as well as to better understand the microclimate in a track switch.

The sensor design will be optimized with respect to smaller footprints, and improved RF link capabilities, e.g. by choosing a different antenna and/or adjustment of transmission power.

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