Mobile Road Weather Monitoring

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ABSTRACT

Road Weather Information Systems (RWIS) consists of specialized weather stations that provide information on surface conditions on the pavement surface in addition to standard weather information such as air temperature, dew point, wind speed, etc. The classic approach is to install a limited number of RWIS at critical points. In this project a different method is proposed and studied in order to allow preventive winter maintenance without installing numerous RWIS. This is achieved by means of a system able to monitor the current weather conditions directly on the maintenance vehicles. Different systems are already available for those highway maintenance vehicles. However those systems are either to expansive to allow for installing them on many vehicles or they are not reliable and accurate enough for a correct preventive maintenance planning.

Keywords: pavement, condition, monitoring, maintenance.

1. INTRODUCTION

Road Weather Information Systems (RWIS) consists of specialized weather stations that provide information on surface conditions on the pavement surface in addition to standard weather information such as air temperature, dew point, wind speed, etc. The surface data, such as pavement temperature, presence of moisture and salt, and freezing point of liquid 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. The fundamental approach of anti-icing consists of spreading salt on roads just before freezing pavement temperatures hit. However in order to ensure rapid and target orientated interventions, the actual information on the present weather situation and the road surface conditions are indispensable. The classic approach to install a limited number of RWIS at critical points is however not satisfying. Since most of the critical events, such as ice formation, occur first at certain critical points, such as bridges, an installation of a RWIS at any of those critical points would be necessary in order to correctly determine the road conditions and to intervene properly.

In this project a different method is proposed and studied in order to allow preventive winter maintenance without installing numerous RWIS. This is achieved by means of a system able to monitor the current weather conditions directly on the maintenance vehicles. Different systems are already available for those highway maintenance vehicles [1]. However those systems are either to expansive to allow for installing them on many vehicles or they are not reliable and accurate enough for a correct preventive maintenance planning [2].

2. SYSTEM OVERVIEW

The system is equipped to measure air temperature, humidity, surface temperature, pressure, and position (via GPS). An infrared temperature 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 measured data can then be used for directly controlling the Electronic Spreader Controls (ESC). However in order to allow for a central management at the Road Weather Information Centre this data can be transmitted by means of GPRS for further data processing or geographical mapping [3].

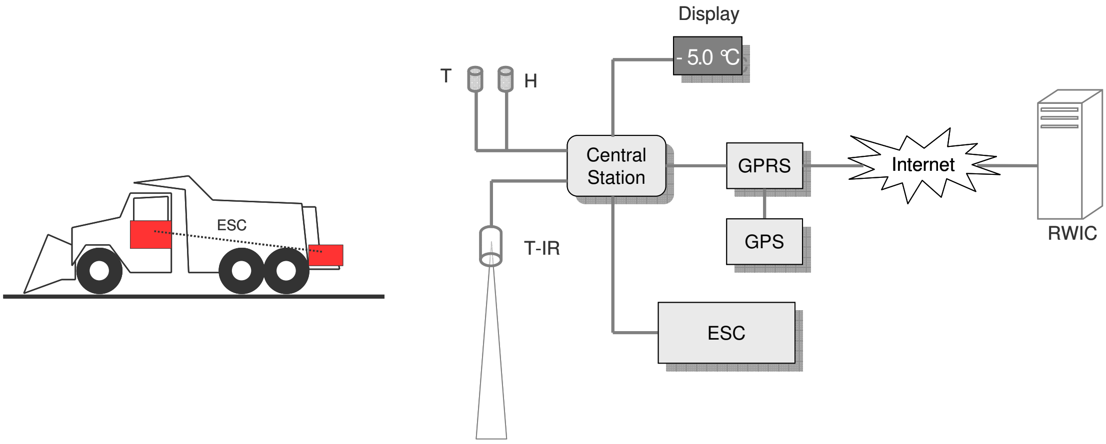

Fig. 1. Mobile Weather Station - System Overview

3. INFRARED TEMPERATURE SENSOR

A thermopile senses infrared radiation, which is emitted by any object. A thermopile detector generates a signal which is a function of the object temperature T_{obj} and the sensor temperature itself T_a. The total heat power P_{rad} received from the object at temperature T_{obj} is given according the law by Boltzmann to [4]

$$P_{rad} = K \cdot \varepsilon \cdot (T_{obj}^4 - T_a^4) \tag{1}$$

with ε being the emission coefficient of the specific body. For a perfect black body ε is 1, however, for most substances, ε is in a range of 0.8 to 0.95. The variable K is called the instrument factor and mostly contributes to the fact that the sensor has only a limited field of view.

For a fixed ambient temperature, the output of the thermopile, which is proportional to P_{rad}, shows a (more or less exact) T^4 dependence. Due to filters in front of the thermopile, however, this power of 4 will rarely be true, because only a limited spectral region is passed through. The correct behavior needs to be determined for every application therefore independently. Therefore the following equation is often valid in describing the output voltage of a thermopile:

$$V_{TP} = S \cdot \varepsilon \cdot (T_{obj}^{4-\delta} - T_a^{4-\delta}) \tag{2}$$

with S being the sensitivity of the sensor and δ the correction factor.

As can be seen in equation 2, the output signal will shift, when the ambient temperature changes. For any practical usable device, this behavior must be corrected. This correction procedure is called ambient temperature compensation. It is aim of this compensation to ensure that a user measures an output voltage which is independent from the sensor temperature [5].

3.1 Analogue Compensation

In most state of the art sensors ambient temperature compensation of the output signal is performed by analogous compensation (see figure 2). The circuit is designed in a way that a voltage is generated, which matches exactly the loss or gain in output voltage due to any ambient temperature change [6].

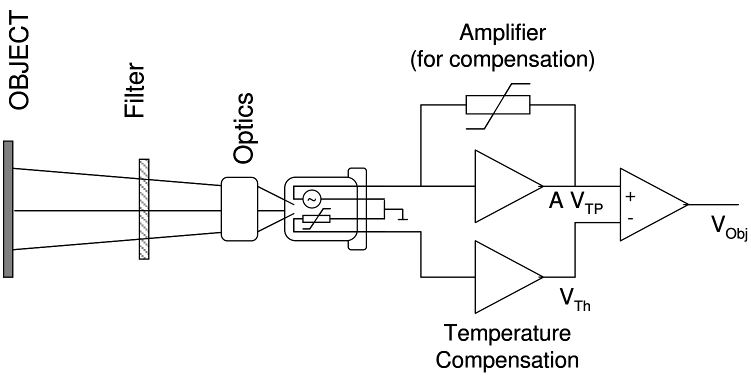

Fig. 2. Analogous Ambient Temperature Compensation

A practical solution the thermopile signal is amplified by a first amplifier by an amplification factor A. Parallel to this, a thermistor in the sensor housing measures the ambient temperature by a thermistor. For a limited temperature range, the thermistor behavior R(T) can be approximated by a 4th power behaviour

$$R(T_a) = R_0 - \zeta \cdot T_a^4 \quad (3)$$

with ζ being a proportionality factor and R_0 a constant. A constant electrical current through the thermistor generates accordingly a voltage, which is subsequently amplified by a factor A_{Th} to amount to V_{th}. This voltage is proportional to R:

$$V_{th} = V_0 - \alpha \cdot T_a^4 \quad (4)$$

This voltage is added to the thermopile signal by means of a second operational amplifier. This amplifier is called the compensation stage. The resulting voltage at that stage is then

$$V_{out} = A{\cdot}V_{TP} - V_{Th} = A{\cdot}\ S \cdot \varepsilon \cdot (T_{obj}^{4-\delta} - T_a^{4-\delta}) - (V_0 - \alpha \cdot T_a^4) \quad (5)$$

To make equation (5) independent of the sensor's temperature T_a, the terms containing T_a, must be canceled out, which means that the following relation must be fulfilled:

$$A = \alpha / (S \cdot \varepsilon) \quad (6)$$

However, since this compensation is only valid for a certain temperature range, this compensation is not very precise. Therefore we perform digital compensation in order to compensate over the complete measurement range the sensor's temperature.

3.2 Digital Compensation

Since analogous compensation does not compensate the ambient temperature completely, we read both the pre-amplified thermopile voltage and the thermistor signal by an analog to digital converter.

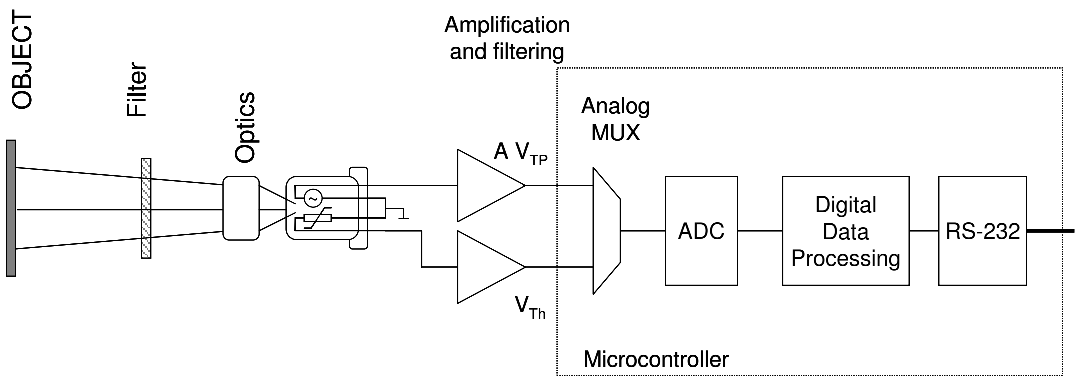

Fig. 3. Digital Ambient Temperature Compensation

By means of digital data processing the thermistor voltage is converted in order to match the $T_{obj}^{4-\delta}$ behavior of the thermopile.

$$V_{Sens} = f(V_{Th}) \quad (7)$$

This voltage can then be added (with a corresponding correction factor) to the thermopile voltage in order to obtain a correctly compensated signal V_{comp}.

$$V_{comp} = A{\cdot}\ S \cdot \varepsilon \cdot T_{obj}^{4-\delta} \quad (8)$$

In the current version the measured voltages are afterwards converted into the corresponding temperature signals by means of a reverse lookup-table and transmitted digitally via a RS-232 interface in readable ASCII strings.

Fig. 4. Infrared Temperature Sensor

3.3 Further Optimization

The above procedure is sufficient if the receives only infrared radiation from the measured object and does not receive any further radiation. There are, however, components needed which are in the optical path, such as filters or mechanical protections from dirt, which might absorb and emit infrared radiation. As long as these components have the same temperature as the sensor itself, no net radiation transfer takes place. However, in case the sensor is brought from a warm room, such as a garage, outside, then, these components generate an additional signal based on this optics temperature T_{optics}:

$$V_{TP} = S \cdot \varepsilon \cdot (T_{obj}^{4-\delta} + C \cdot T_{optics}^{4-\delta} - T_a^{4-\delta}) \tag{9}$$

Common infrared sensors do not compensate this temperature signal or assume that this temperature signal changes in the same manner as the sensor's temperature. However, for outdoor applications, especially for roadway monitoring, the thermopile sensor is mounted inside a case with a protection lens in front. Therefore, this closed system has a higher time constant than the optics part, and consequently the measured object temperature does not reflect the real object temperature. As can be seen in figure 5a and 5b the thermopile sensor responds slower than the optics part to a change of the reference temperature (objects and ambient temperature). In the ideal case the infrared sensor should measure the reference temperature, however, since the optics temperature change is not compensated, under- or over-shoots will happen (see figure 5c).

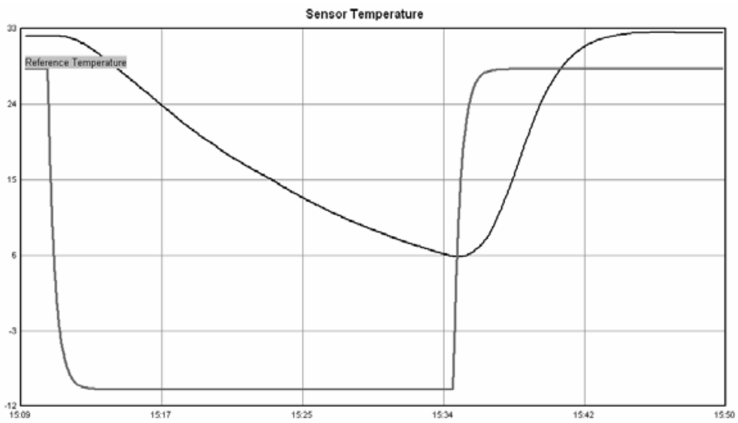

Fig. 5a. Sensor temperature change due to change of reference temperature.

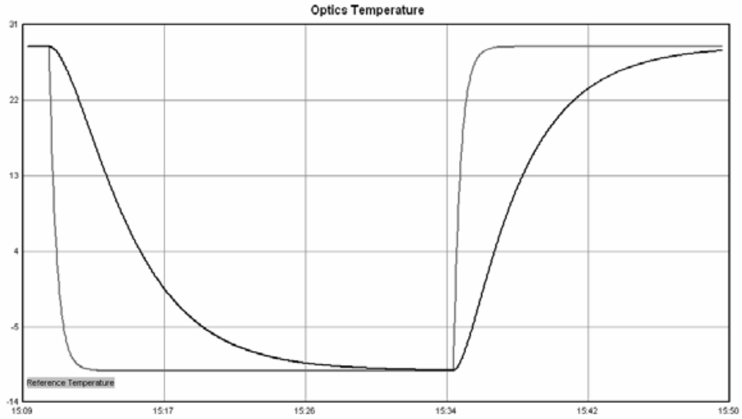

Fig. 5b. Optics temperature change due to change of reference temperature.

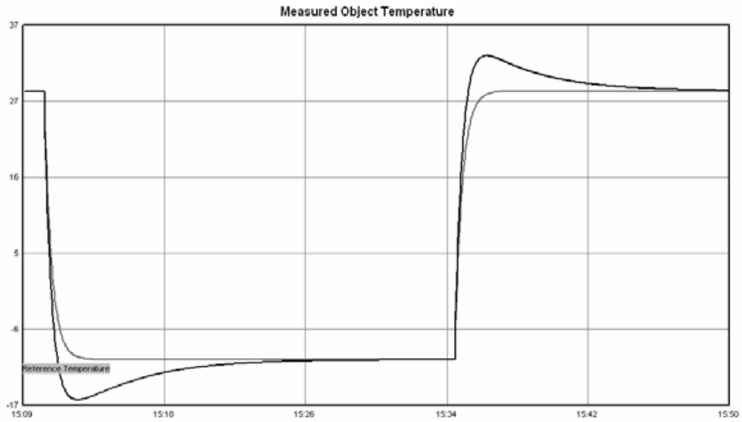

Figure 5c: Measured object temperature compared to reference temperature.

Therefore the developed infrared sensor comprises also a second temperature sensor for compensating the temperature influence of the optics part.

4. EXPERIMENTAL RESULTS

The described system has been mounted on a salt spreader and tested during different weather condition. In order to evaluate the measured data at low temperature, measurements up to an altitude of 2000 meters have been performed in the period of November 2005. Representative data can be seen in figures 6a to 6e.

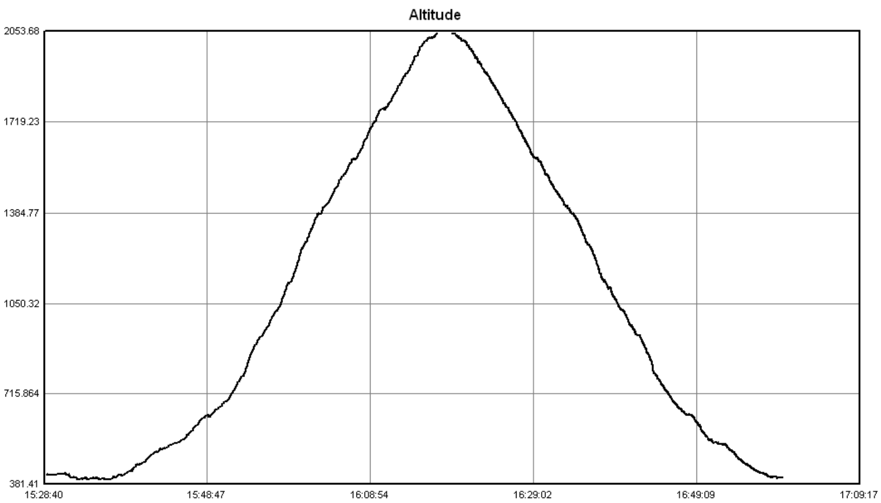

Fig. 6a. Altitude Measurements

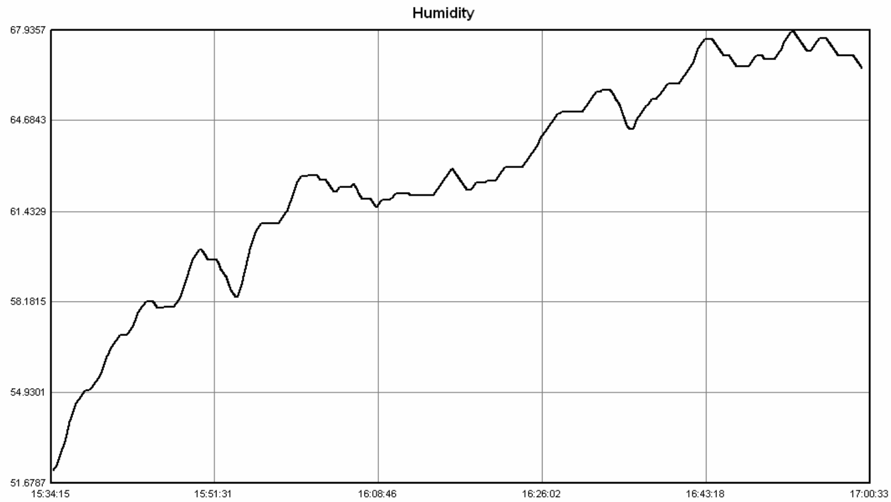

Fig. 6b. Relative Humidity Measurements

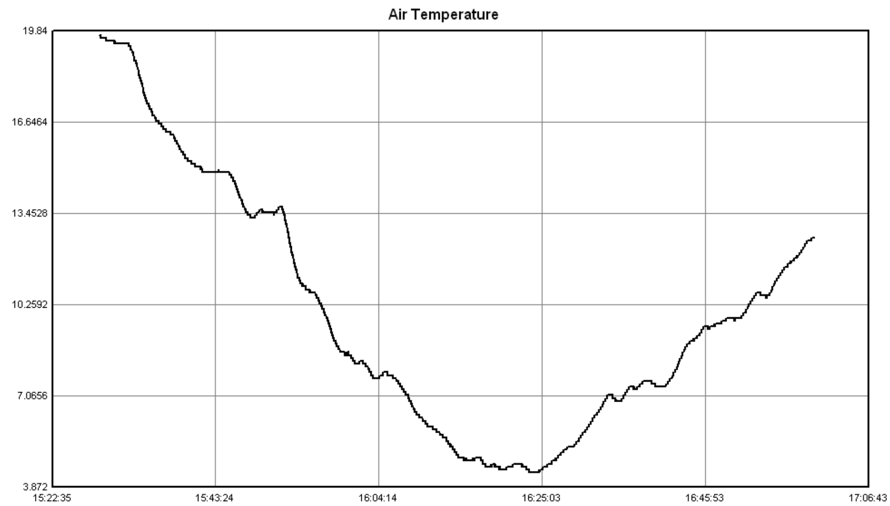

Fig. 6c. Air Temperature Measurements

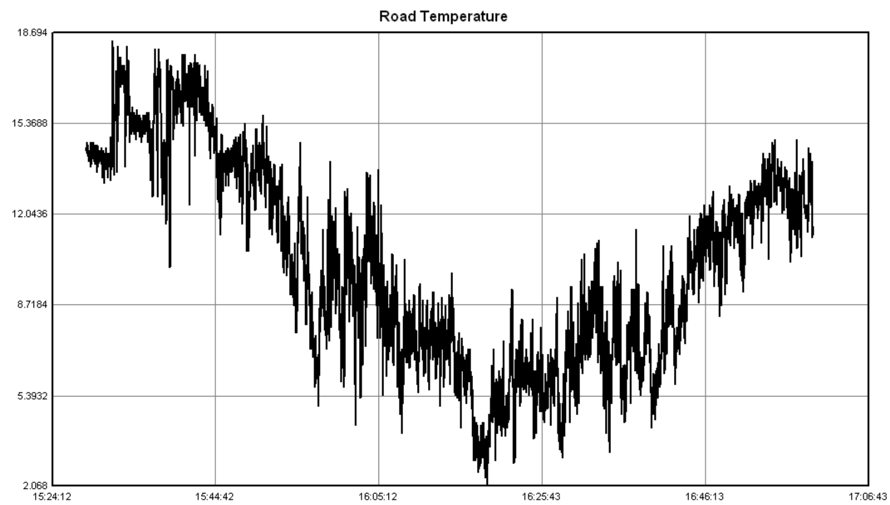

Fig. 6d. Road Temperature Measurements

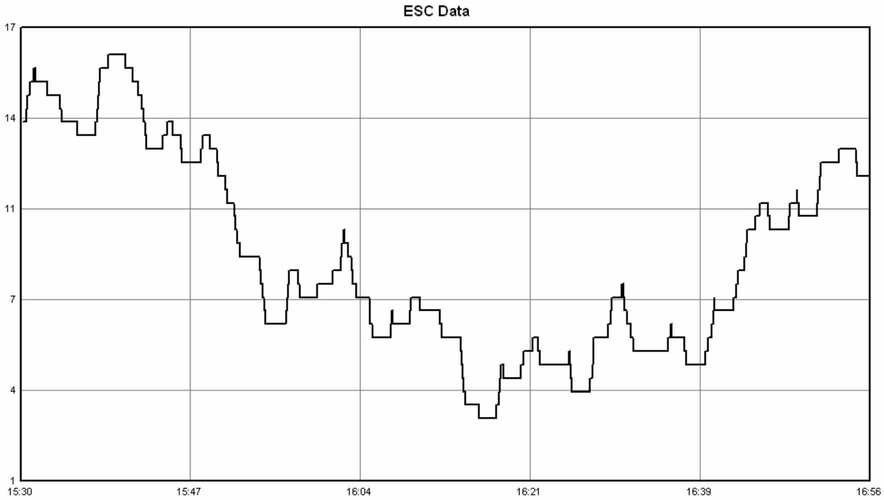

Fig. 6e. Filtered Road Temperature Measurements for ESC

5. CONCLUSIONS

As described in the previous paragraphs, the system is very efficient and allows to monitor the pavement condition with high accuracy. So the road winter maintenance staff can use efficiently the salt spreaders and scatter the salt only in real dangerous situations. As a consequence a big amount of salt and money can be saved and the both pavement and groundwater are protected by corrosion and pollution respectively. In this way a road risk map can be elaborated by a central server that collects all data coming from mobile stations. Then the road maintenance center can control the most critical points and gives useful alarms.

6. REFERENCES

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