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Design and prototyping of wireless sensor nodes for non-contact road-level climate monitoring

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Abstract **– This paper aims to present two sensor node prototypes designed to collect information about road-level climate. These prototypes are part of a Wireless Active Guardrail System (WAGS). One node was designed to perform multi-sensor measurements, which can provide information about the road surface state, such as dry, wet or iced. The second node was developed to provide a quantitative estimation of visibility grade in presence of fog. In the paper, the detailed hardware structures, the sensing mechanisms and several on-field tests are described and discussed.**

I. INTRODUCTION

For an efficient and safety transport on roads, a key task is road state monitoring [1]. Nowadays, it is well known that the main aim of Intelligent Transportation Systems (ITSs) is to enhance the road transportation efficiency and safety by using several advanced instrumentation systems. New electronic technologies, in terms of data acquisition, processing, control and communication (e.g. Wireless Sensor and Actuator Networks, WSANs) play a vital role in achieving all the safety related targets [2]. An idea of design and exploitation of new safety measurement systems has been proposed in the project entitled "Barriera Attiva" (Active Guardrail), which has been funded by the Italian Ministry of Education, University and Research [2].

The "Barriera Attiva" project aims to realize a novel distributed measurement system called Wireless Active Guardrail System (WAGS). Several typologies of WSAN nodes are already available to that aim [2]-[5]. One design target of the project was to find a way of embedding the WSAN nodes onto the guardrail plates. In order to enable an active role for traveler protection along the monitored roads, different physical/chemical quantities have been chosen to be measured and continuously monitored. Since now, two main architectures of WSAN nodes have been developed by the project team [4]: (i) for traffic safety measurements, and (ii) for monitoring several environmental parameters.

The aim of this paper is to present two new prototypes for road-level climate monitoring. These prototypes include a multi-sensor sensing system in order to provide measurements about road surface state and visibility grade in presence of fog. After deployment of two hardware and software platforms, the preliminary results obtained from on-field trials are presented. The research was directed to design and develop the associated electronic and software components and to prove the concept of the proposed measurement systems.

The remainder of this paper is organized as follows. Section II presents a short overview about the road-level climate problems and the importance of monitoring. The proposed prototypes and their internal structure descriptions are presented in Section III. In Section IV, the obtained results from laboratory and on-field tests are reported. Last Section concludes the paper.

II. ROAD-LEVEL CLIMATE MONITORING

Since now, several research studies have been done and financing resources have been allocated to investigate the deterioration of traffic environment under different weather conditions [1],[6]-[9]. The environmental state of the pavement surface is often related to the main causes of car accidents [8]. Weather parameters can influence the traffic safety. It is known that once the weather conditions are favorable, the anti-slide performances are higher for dry asphalt. When the road surface is wet or iced, or when it is raining, snowing, or foggy, the risk of car accidents increases [9].

According to the stated problems above, it can be said that in order to raise the safety of road transportation, methods of measurement and their associated measurement systems must be found. The identification of the state of traffic environment, for example, could help the road users to be informed just in time in order to prevent possible disasters (e.g. swab accidents) [9]. From the available literature, the traffic environment can be identified by knowing the state of [1]: (i) traffic weather, (ii) traffic flow, and (iii) road surface. At least two of the above parameters influence the traffic safety, i.e. the state of road surface and the traffic weather.

In order to develop measurement systems for road-level traffic weather monitoring, information about atmospheric temperature, humidity and pressure, as well as the visibility and the wind speed and direction, is vital

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for the estimation of current traffic safety parameters [9]-[11]. In the following, few scientific papers presenting several ideas of such measuring systems are shortly discussed.

Until now, it has been observed that InfraRed (IR) sensors are sensitive to the water absorption in their spectral range. Taking this phenomenon into account, it was possible to develop measurement systems that detect the presence of water on a surface. Research works presenting the IR sensor technology in order to be used in ice detection have been presented in [11]. In [12], the authors reported a system which uses an halogen lamp emitting in the near IR region. The main disadvantage of this excitation principle is related to the electrical powering of the lamp. A commercial system for ice detection, based upon the use of IR spectroscopy, was proposed and developed by Senseice Innovation [13]. As general properties, this ice detection system is able to differentiate between six states, at every 125 ms: dry, clear ice, snow, sleet and wet clear ice. This smart and sophisticated measurement system involves the spectroscopy where several wavelengths are analyzed. The main drawback is related to the power consumption needs: more than 25W.

The low visibility on the high speed roads (e.g. express, highway, and freeway) leads to delays since the driver is forced to reduce the vehicle's speed, and normally it has also the potential to cause fatal accidents [14]-[17]. Sensing technologies and monitoring systems should be investigated in order to embed information about critical weather issues in the warning panels of road operators with data collected in a distributed way.

One of the aims of the "Barriera Attiva" project is to design a distributed measurement system to provide a distributed traffic safety warning information system based upon measurements from traffic environment under adverse weather conditions. From the above quoted references, it can be said that for a good non-contact road-level climate monitoring system, the guardrails should be instrumented by an optimized spatial and temporal coverage to work jointly in a distributed way. Therefore, the monitoring of the road surface state and the traffic weather, including the driving visibility represents a desirable task. In the next, the first prototypes of two modules of the "Barriera Attiva" WAGS aiming at such targets are presented to validate the design concepts.

III. PROTOTYPING OF INTELLIGENT WIRELESS SENSORS FOR NON-CONTACT ROAD-LEVEL CLIMATE MONITORING

A. Monitoring system for road surface

The proposed system aims to detect

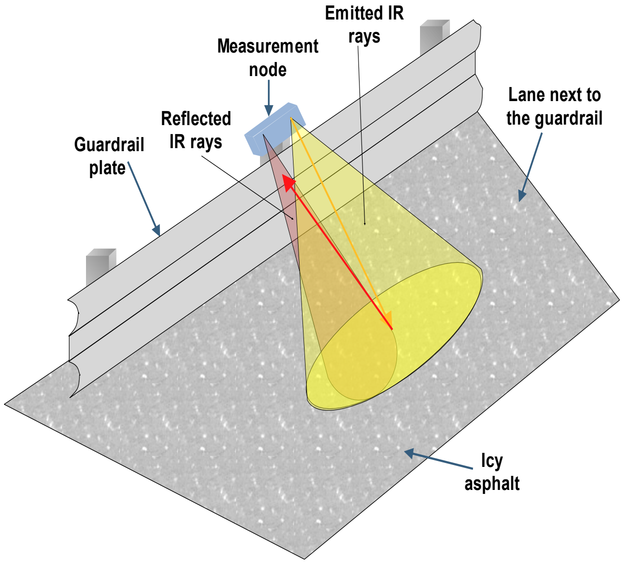

Fig. 1. Monitoring system for road surface state: onsite overview.

the state of asphalt surface as: dry, wet or icy. The processed data are transmitted online to a Monitoring Service System (MSS) and to the available display panels in order to inform the road users about the driving condition on the forward portion of road.

A general overview of the proposed sensor node, acting on the lane near the guardrail, is depicted in Fig. 1. An IR light ray is transmitted to the asphalt surface, which is scattered back to an IR ray receiver. Upon the differences of the IR scattered ray intensity, it can be distinguished if the asphalt surface state is dry, wet or icy.

The block architecture of the proposed hardware for the sensor node is drawn in Fig. 2. It is composed of: (i) one PIR photodiode Hamamatsu S1223 [18], (ii) an array of six IR emitting LEDs, (iii) temperature and humidity sensors SHT25 [19], (iv) an analog signal processing chain, (v) one MDA100 interface board, (vi) an IRIS module [20], (vii) one lead acid battery with the associated power distribution block, and (viii) one specific enclosure. In order to minimize the external lights sources that affect the scattering phenomenon on the road surface (e.g. sun light), the array of IR LEDs emits a light signal modulated at 1 kHz.

The analog signal processing circuit is composed of three stages: (i) a transimpedance amplifier that processes the current signal delivered by the S1223 PIR sensor, (ii) an active filter, and (iii) an envelope detector.

The delivered signal by the envelope detector is digitally converted by the Analog-to-Digital Converter (ADC) available within the IRIS module [20]. In Fig. 3, a picture of the first realized prototype of the road surface state detection monitoring system, available to be integrated on guardrails, is illustrated.

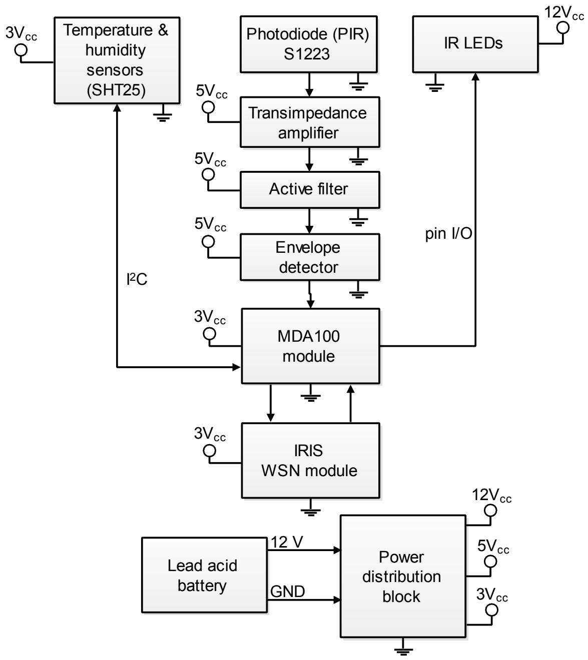

Fig. 2. Measurement system for road surface: block hardware architecture.

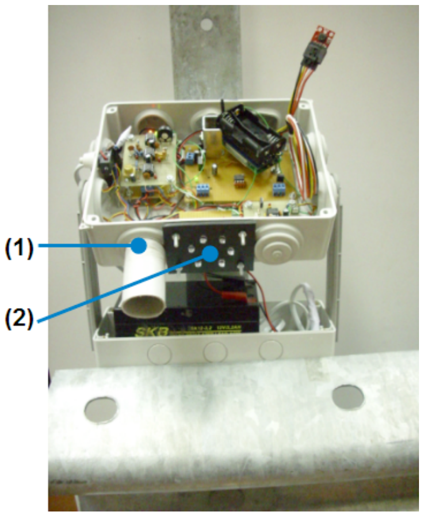

Fig. 3. Monitoring system for road surface state detection: (1) IR receiver, (2) IR emitter.

B. Monitoring system for road visibility

The aim of this monitoring system, in case of usability for traffic safety, is to provide online onsite information to the road users about the visibility in presence of fog. The acquired information is reported as warning signs to drivers that could be displayed by using available traffic panels. The proposed sensing principle used in order to estimate the visibility grade in presence of fog is based on the back scattering of the water particles in the atmosphere together with the dew point assessment.

In Fig. 4, the block architecture of the proposed hardware of the visibility monitoring system is depicted. By measuring the ambient temperature and the relative humidity, it is possible to evaluate the dew point value. At temperatures below the dew point, the water vapor condenses. In this case, two fans are activated to convey the air in a limited area. An infrared LED is used as light source and the light scattered by water drops is measured with a phototransistor. This scattered light is proportional to the water drops concentration in the air. A lower concentration of particles corresponds to a higher visibility.

The systems is composed by the following subsystems: (i) one intelligent sensor type SHT25 for temperature and humidity measurement [19], (ii) a particulate matter sensor type Sharp GP2Y1010AU0F [21], (iii) a Waspmote module [22], (iv) two fans, (v) one lead acid battery with the associated power distribution block, and (vi) one specific enclosure. In Fig. 5, the realized prototype for the measurement system for road visibility state detection, integrated on guardrail plate, is depicted.

The Waspmote module, which embeds an Atmel microcontroller and a radio interface for wireless communication, represents the core processing module for the all information that are acquired from sensors. The ambient temperature and humidity are given by the SHT25 sensor [19]. These measurements are processed to determine the dew point, assuming an atmospheric pressure of 1 atm. If the measured temperature differs from the dew point for less than 2.5 °C, it will be said that the weather conditions that will cause atmospheric haze are predominant [10].

When the weather conditions are satisfied as stated above, the Waspmote module will start the artificial ventilation system, which consists of two fans (2), to perform a measurement of the particle concentration by using a GP2Y1010AU0F Sharp (1) sensor, (see Fig. 5) [21]. This sensor provides a signal proportional to the concentration in mg/m^3 of water vapor particles during the measurement.

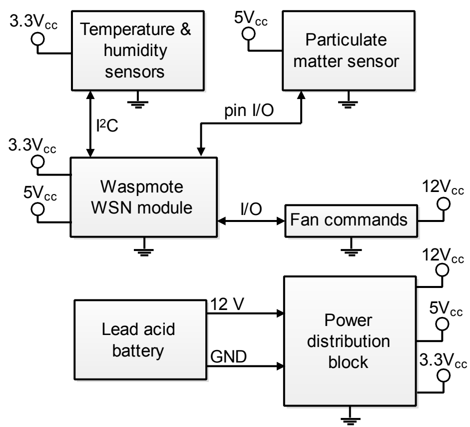

Fig. 4. Monitoring system for road visibility: block hardware architecture.

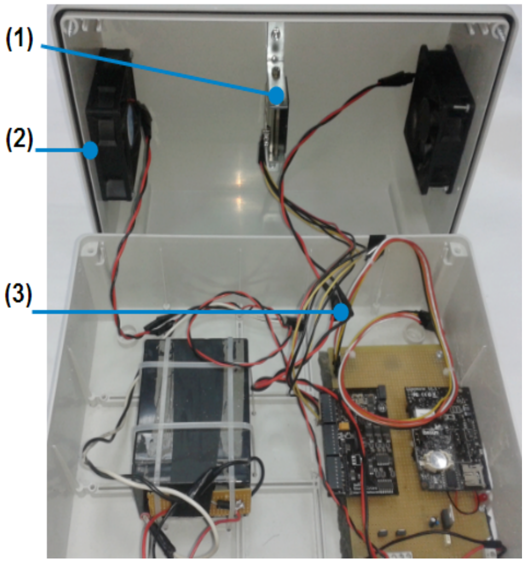

Fig. 5. Monitoring system for road visibility: (1) particulate matter sensor, (2) fan, (3) intelligent sensor for temperature and humidity.

By integrating the individual measurements, three levels of visibilities, such as, poor, medium and good can be discriminated. In order to discriminate the three visibility conditions, experimental tests have been performed for evaluating the two threshold concentration values. The obtained information will be transmitted by wireless radio communication to a gateway node which forwards the data to the service center, MSS.

IV. PRELIMINARY TESTS AND RESULTS

A. Monitoring system for road surface

The first validation of the proposed sensing system was realized by carrying out experimental tests during the day time on a asphalted road. The tests were done in condition of dry, wet and icy asphalt, measuring the voltage generated by the sensing circuitry in case of received IR signals. The obtained results are reported in Fig. 6. The measured values are noted as V_{dry}, V_{wet} and V_{ice}. The averages of the values are $V_{avg\text{-}dry}$, $V_{avg\text{-}wet}$ and $V_{avg\text{-}icy}$. The experimental results show how it is possible to distinguish, based on the acquired voltage supplied by the sensing system, the conditions of road surface such as dry, wet and icy. In particular, the dry condition compared with wet differs with an average of 88 mV, while that of wet and ice condition differs with an average of than 116 mV. The obtained results indicate that the proposed monitoring system gave a reliable output that distinguishes between the surface conditions, such as dry, wet, and icy. The power consumption of the sensor node prototype has been measured as low as 2 W.

B. Monitoring system for road visibility

The first experimental validation of the proposed visibility monitoring system was performed by comparing the concentrations of particles of water vapor existing in the atmosphere with respect to the visibility expressed in terms of distance. In particular, it has been considered as reference distance the distance between three poles of urban lighting system, placed at about 20 m from each other. In Fig. 7, the measured values for high, medium and low visibility in a situation for which it was possible to recognize three poles are reported. The figures show the values of the integrated density value of water vapor and the temperatures reported to the dew point ($T_{dew\text{-}point}$), the measured temperature ($T_{environment}$) and the difference (Δ_T) between the values. If the difference between the value of the environmental temperature and the dew point is greater than 2.5 °C and as it is confirmed by the density values of the particles of water vapor (less than 0.05 mg/m^3), the visibility is high (see Fig. 7.a). In case of a density of the particles of water vapor about of 0.15 mg/m^3, the driving condition regarding the visibility was around of 40 m (see Fig. 7.b). The last test, in Fig. 7.c, the measured values obtained for a visibility less than 20 m are reported. In this case, the difference between the dew point and the environment temperature is less than 2.5 °C, and as it is confirmed by the density of the particles of water vapor with a value of about 0.3 mg/m^3, the visibility is considered to be low. The power consumption of the sensor node prototype has been measured as low as 2.5 W.

V. CONCLUSIONS

In the paper, the initial development of two sensor nodes for distributed wireless measurement systems, to be used for non-contact road-level climate monitoring, has been presented. In order to make the proposed prototypes to be powered by batteries and at a low cost, low power sensors and electronic circuits have been used.

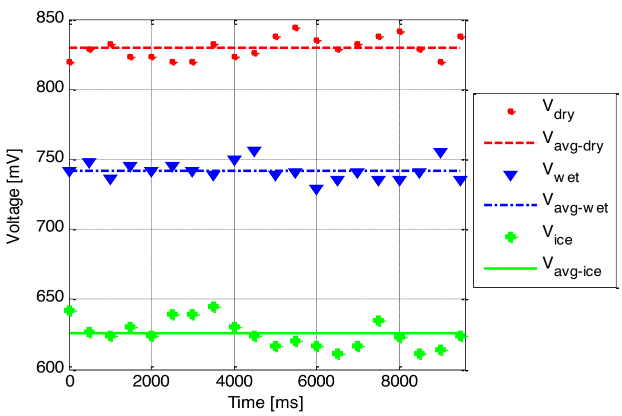

Fig. 6. Day time experimental results for different conditions of the road surface.

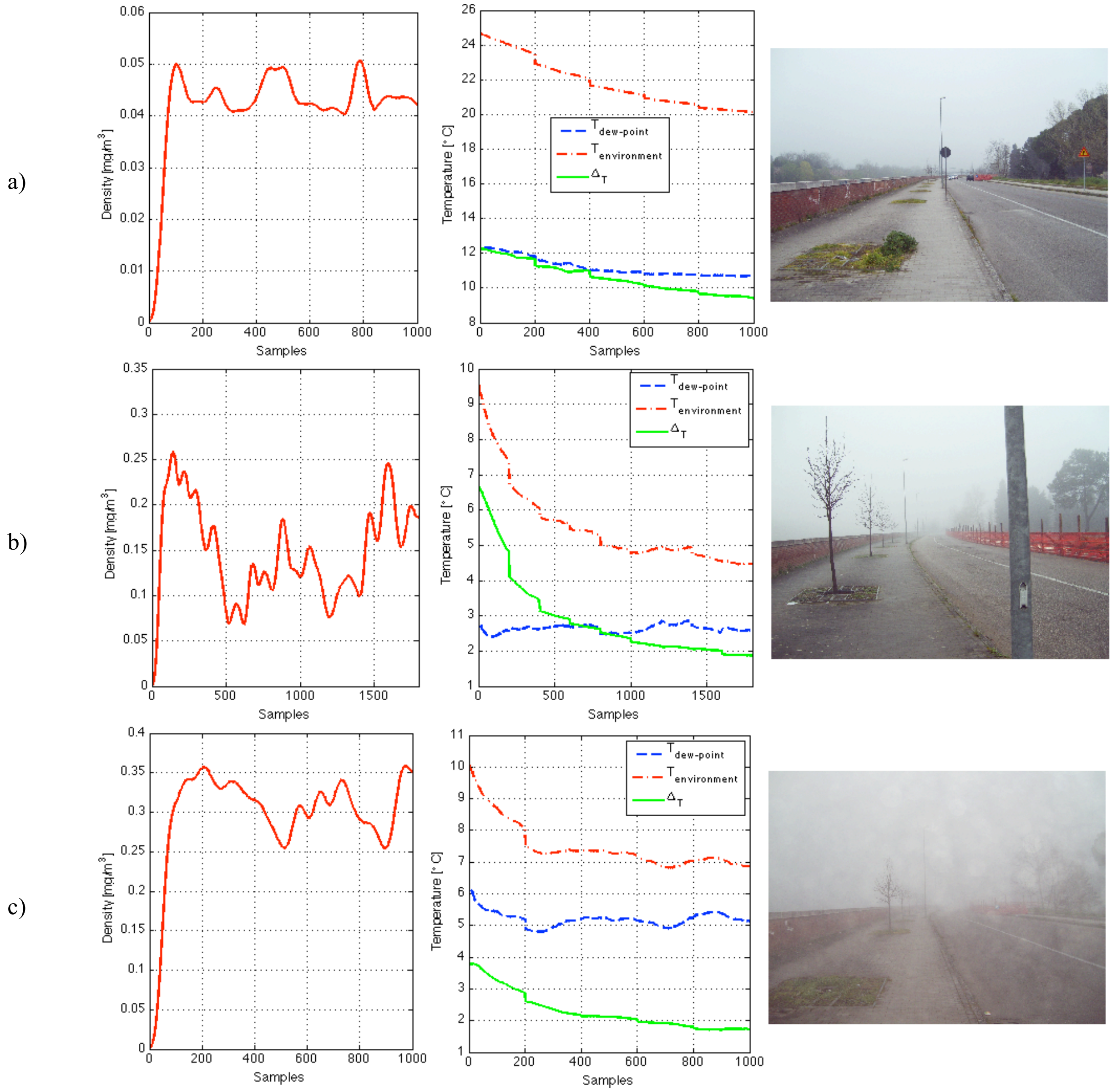

Fig. 7. Results concerning the concentration values of the water vapor, the temperature and the dew point for the visibility conditions for: a) high visibility; b) medium visibility; c) low visibility.

The total power consumption of both the prototypes is five times lower than the power consumption of the systems on the market.

The obtained results from road-level surface monitoring system have proved that the designed system is able to clearly distinguish between the dry, wet and icy states of asphalt surface. Further improvements are tied up to implementation of a software subroutine which needs to be capable of blending the obtained information about atmosphere temperature and humidity in a data fusion mechanism.

The developed prototype for visibility monitoring system has provided three clear mean values that allow distinguishing a grade of in front visibility in terms of distances for 20m, 40m and 60m. As in previous case, one future improvement is routed to develop a data fusion software module that will be used for more accurate evaluation of foggy conditions.

VI. ACKNOWLEDGMENT

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