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Wireless Monitoring of Pavement Temperature Based on Low Cost Computing Platform †

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Abstract: Nowadays, the preservation, the maintenance, the rehabilitation and improvement of the road network are key issues. Many of the parameters that define the road surface conditions are influenced by various environmental factors, mainly temperature. Hence the importance of having databases enriched form real-time monitoring systems that enable the analysis and modeling of the properties of the road. The main goal of this work is the design and development of a road monitoring system for temperature measurement at different pavement depths, capable of transmitting the information to a moving vehicle. The practical realization required a modular device, of easy installation, low cost and with reduced energy consumption. The proposed monitoring system makes easy the auscultation procedure, improving the reliability of the measures collected which, in turn is the basement to estimate the useful life of the pavement. The results of the tests and validation of the proposed prototype in either static system with two types of pavement (asphalt and concrete), and in real driving situations, demonstrate the good performance and accuracy of the proposed monitoring system.

Keywords: road temperature; wireless; sensor network; pavement

1. Introduction

Up to date, monitoring systems of industrial processes have demonstrated the importance and economic benefits of the application of network-based solutions and Artificial Intelligence techniques [1–3]. Monitoring of infrastructures is essential to build the next generation of predictive models. Nowadays, the monitoring of road quality is a fundamental issue for the socio-economic development of a country [4–6]. Hence the importance of preserving the good condition of these infrastructures is growing very fast. For this reason, periodic assessments of the condition of the pavement are made, based on the visual inspection and auscultation of the same. This last procedure consists in the measurement, collection and analysis of the different functional parameters (e.g., comfort, safety, uniformity) and structural (related to the resistant capacity) aiming at diagnosing the current state of the road and even, its possible trend [7–9].

Some of these parameters are influenced by environmental conditions (humidity, temperature), such as deflection, so it will be necessary to correct or standardize the results. For its calculation, two devices are mainly used depending on the type of road (composition and pavement layers and layout), falling weight deflectometer and curviameter [10–12]. Infrared thermometers are used for temperature recording, but it has been proved that the surface temperature was not the most appropriate, as it is influenced by certain specific effects, shadows, wind, cloudiness, etc. For this reason, regulation demands that it be taken at a depth of 5 cm, making the process more complex. In addition, for more detailed studies, temperature gradient measurement in the complete section of the pavement is necessary.

On the other hand, in the last years a great development of wireless sensor networks (WSN) is taking place in different areas such as home automation, automotive, agriculture, industry, environment, etc. These networks are made up of devices capable of recording information from the environment and transmitting it wirelessly to a central device. It is worth mentioning the wide experience in the use of these devices in road monitoring, from state traffic control, pollution measurement, weather conditions, etc. [13–16].

The main goal of this work is the design and development of a road monitoring system based on temperature measurement. The design and deployment of a computational architecture and a sensoring system are a must to perform an efficient monitoring. From the best of authors' knowledge, these are the main contribution of this work. In addition, the adoption of the proposed equipment will improve the performance of the auscultation equipment by improving the accuracy of the measurements and it will diminish the prolonged stops and road cuts for temperature measurement. This paper is organized as follow. Section 2 shows an overview of the solution adopted, followed by a more detailed analysis of each element of the system; Section 3, results and discussion. Finally, Section 4 outlines some concluding remarks.

2. System Design

The prototype consists of a system to collect temperature measurements of the pavement at different depths (see Figure 1). It is composed of a central unit and nodes. These, have several sensors attached to a support that is inserted in the roadway and will be responsible for carrying out the measurements. They will also be powered by an external battery, which will be charged by a solar panel. The information collected by these sensors is transmitted to the central unit installed in a vehicle when it is circulating near the node.

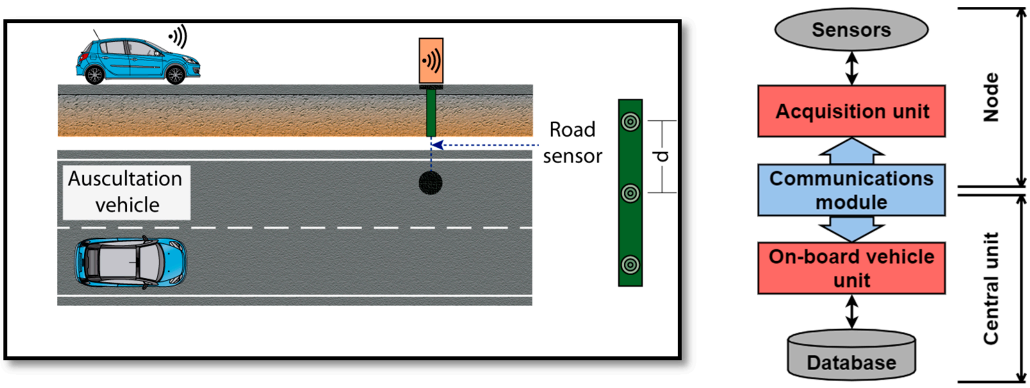


Figure 1. Conceptual diagram of the proposed monitoring systems including the main subsystems.

2.1. Node

Each node consists of the Libelium Waspmote v1.1 (based on Arduino with Libelium's own libraries) with the XBEE-PRO 802.15.4 EU module, the DS18B20 temperature sensors, and a battery and solar panel as power supply (see Figure 2).

The temperature sensors are the DS18B20 (Maxim Integrated) with a temperature range from −55 to 125 °C, with ±0.5 °C of precision (−10 to 85 °C), and programmable resolution from 9 to 12 Bits. 1-Wire protocol is applied because only one port is required for communications (send/receive) and it is possible to place several devices in series. Each node has 4 sensors placed on a support, separated 5 cm from each other, allowing the acquisition of surface temperature measurements up to a depth of 15 cm. This simplifies the installation (or replacement) and provides modularity to the system. Furthermore, a special resin is added to improve contact and orientation with the pavement section.

It also acts as a protective layer. Power is provided by a battery Li-ion (6600 mAh, 3.7 V) and is recharged by a rigid solar panel (234 × 160 × 17 mm, 7 V, 500 mA).

(**a**) (**b**) (**c**)

Figure 2. (**a**) DS18B20 support; (**b**) node sensors set; (**c**) Libelium Waspmote with XBEE module.

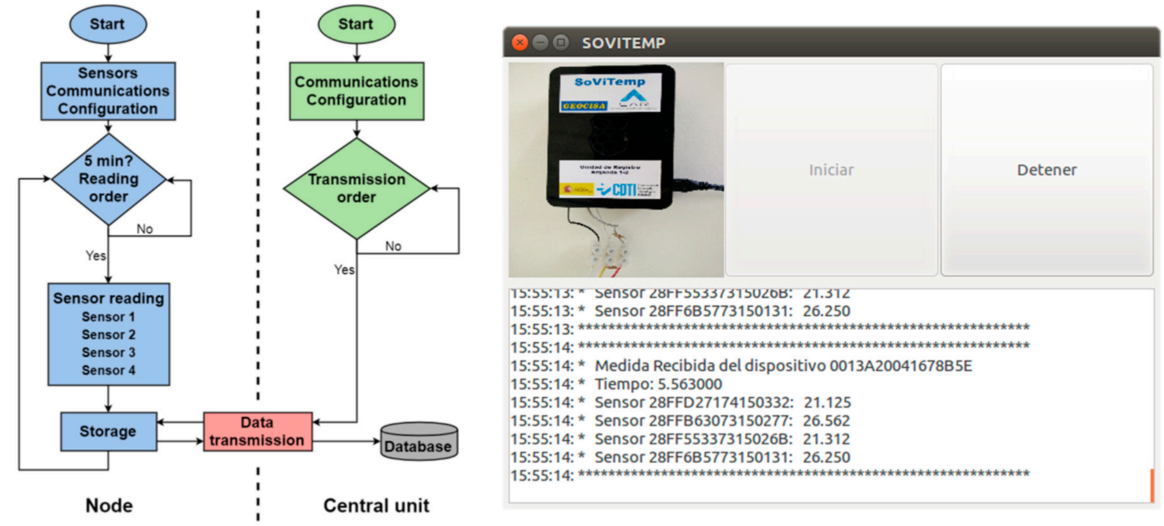
2.2. On-Board Vehicle Unit and Communications.

On the vehicle side, a Libelium Gateway device is placed to act as a coordinator. This unit has another XBEE module, similar to the nodes, and its function is to transmit and receive the relevant messages to the computer (USB port) for later use or storage. In terms of communications, although the 802.11p protocol is the most appropriate for vehicular environments (wide operating ranges, high transfer rate), it is decided to use 802.15.4 because it seeks to reduce energy consumption and costs. Although the transfer rate is lower, the amount of information to be transmitted is not high and it offers an enough transmission distance for the purpose of the system. In addition, this protocol has already been used in previous works obtaining satisfactory results [17].

2.3. Software

The key factor in the design of the measurement and communication programs of the prototype is the time window in which the required information can be transmitted, as well as its size. The measurement process of each sensor can be extended up to 750 ms (at highest resolution) and by adding the stages of request, processing, formation, transmission and reception of the message, the total process time in case of an on-demand reading approach would be considerable. This could significantly affect the speed of the vehicle because the real range of communications can be drastically reduced under certain environmental conditions. Because of significant temperature changes do not occur in short periods of time, it is decided that the reading is performed periodically (5 min). The data are stored and transmitted the ones closest to the moment the request occurs. However, it is possible to send the temperatures of certain periods of time for later analysis. This part is developed in the Waspmote's IDE.

The software of the coordinating unit is developed in C/C++ and its function is to make the request to the nodes. It is implemented in a computer on board the auscultation vehicle. Figure 3 shows the diagram for this program and a screenshot of the user interface.



(**a**) (**b**)

Figure 3. (**a**) Block diagram of the computational procedure for measurement and communication; (**b**) data acquisition software capture.

3. Results and Discussion

Once the sensors and controllers have been calibrated and configured, and the reading programs have been developed, several tests are carried out to determine the viability of the system.

3.1. Test 1. Static Data Acquisition System

The first test is used to determine the functionality and strength of the devices. As can be seen in Figure 4, nodes have been installed at two different points on the test track of the Centre for Automation and Robotics in Arganda del Rey. The different types of pavement of the road (asphalt and concrete) will be used in order to observe the variation in temperature behavior in each one.

Every 5 min, the sensors are prepared, read, checked for errors, measured, transmitted to a computer located in the track's own facilities (blue circle), and stored in a daily file.

Figure 4. Test track of Centre for Automation and Robotics in Arganda del Rey (Madrid.) Detail of the installed nodes.

In case of any eventuality that may cause data loss, a daily backup of the file is made on a remote server through the SFTP protocol. The measurement register is developed over a period of at least one year. A database with the temperatures of both nodes will be elaborated which, together with the information collected by the meteorological station of the centre, will be used to develop a model for estimating the representative pavement temperature to predict the useful life of the road. Figure 5 shows the behavior of the daily mean temperature of each node during one year testing period (August 2016–August 2017).

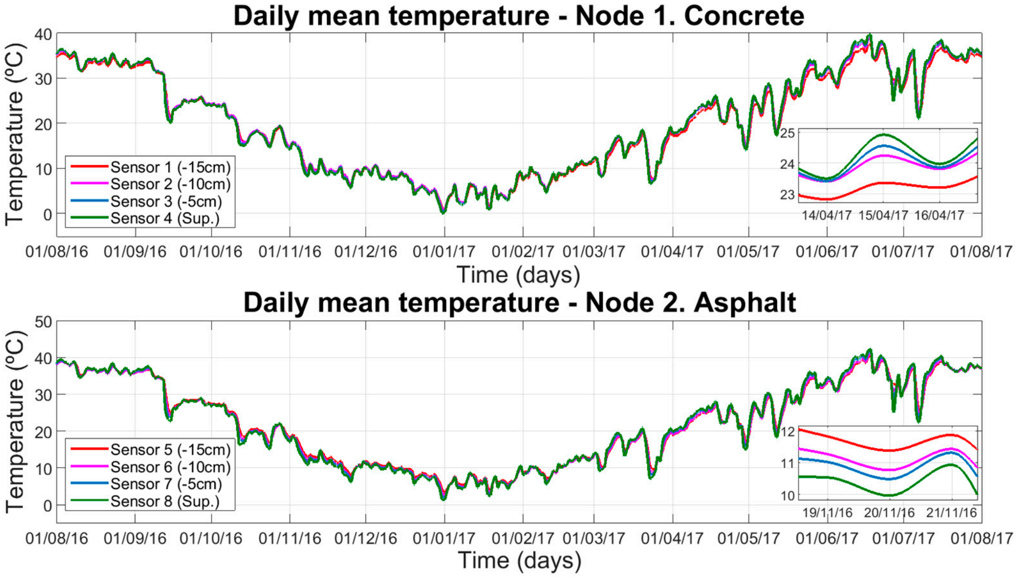


Figure 5. Behavior of the temperature in two different pavements measured by two different nodes.

Figure 6 shows the temperature fluctuation on a winter and summer day (18 January 2017 and 16 July 2017 respectively).

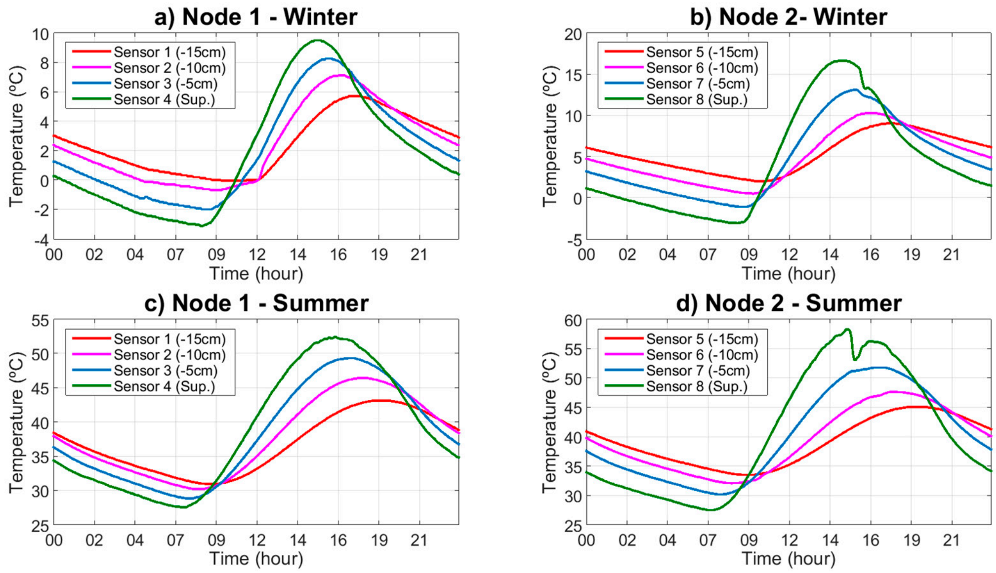


Figure 6. Behavior of the pavement temperature using both nodes according in different seasons.

3.2. Test 2. Dynamic Data Acquisition System. Auscultation Vehicle

The purpose of the test is to verify that the data are sent and received under different circumstances. To that end, an acquisition unit was installed on the road and a vehicle equipped as auscultation unit (see Figure 7). Several tests were carried out at different speeds simulating obstacles that reduce the transmission range of the device.

According to the results obtained in both tests, it is relevant to remark the deep correlation between occasional events (solar radiation, cloudiness, precipitation, shadows …) and surface temperature. It has been checked that the time frame for sending and receiving information is adequate and the robustness of the system, obtaining an error rate in the test period of less than 1%.

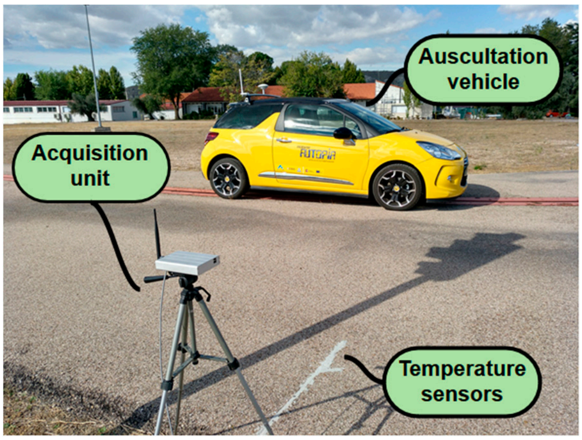


Figure 7. Overall view of the dynamic test.

4. Conclusions

In this work, a monitoring system was designed and implemented for the measurement of road pavement temperature at different depths and its transmission to a moving vehicle, whose main goal is to optimize the auscultation process/procedure, improving the collected measures, which in turn, is the key to estimate the useful life of the pavement. The results of the tests and validation of the proposed prototype in either static system with two types of pavement (asphalt and concrete), and in real driving situations show that the required targets have been achieved in terms of economy, energy consumption, accuracy, reliability, simplicity and modularity.

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Author Contributions: Alvaro García and Jorge Godoy have designed and implemented the monitoring systems and have written the paper. Juan Jesus Muñoz has been in charge of user requirements and specifications, and the implementation and evaluation of the measurement system. Rodolfo Haber has participated in the design of the system and experiments, and defining the technical and scientific structure of the article.

Conflicts of Interest: The authors declare no conflict of interest.

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