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Remote Monitoring of an Experimental Motorway Section – An Enabling Technology of the 5th Generation Road

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Abstract: Since users expect long-lasting roads, road system managers must maintain infrastructures that are tailored to the needs of traveling, offer a growing number of services, are meticulously maintained, and are resilient to weather events. However, with societal issues and budget constraints, it becomes difficult for managers to ensure the optimal operation of their networks. To tackle this huge challenge, The French institute of science and technology for transport, development and networks (IFSTTAR) has launched the 5th Generation Road program. This program aims to design full scale demonstrators, which integrate the numerous innovations that are already available in research centers, and to demonstrate the synergy among them. After presenting the general objectives of the 5th Generation Road program, this paper presents one example of a demonstrator that concerns remote monitoring of an instrumented motorway section.

Key words*: Instrumentation; Remote monitoring; Smart pavement.*

Introduction

Private and public research centers offer numerous technologies. What is missing is a strong willingness to test and industrialize all the promising solutions and gather together the innovations in all fields on the same site. These innovations may benefit from two recent technological trends. Firstly, energy, materials, and information are converging fields, which means that in the near future road infrastructures will be able to transport not only people and goods but also energy and information. Secondly, the development of smart vehicles can potentially benefit road infrastructures, in particular through the development of cooperative systems. A holistic approach, which would cover the different aspects of road construction, operation and maintenance, road energy and environment, is necessary. This is exactly what the 5th Generation Road (R5G) implementation program is envisioning: a new road generation, built through a systemic approach, which gathers the best current ideas and demonstrates the synergism among them.

A Technical Approach that Encourages Risk-Taking

Often, when a new technical solution is proposed to answer an open call for tenders, failure is not allowed, and this situation limits the risk taken by the company. Indeed, the failure of the tested solution would be very problematic for the image of the company. In the same way, companies are unlikely to propose complex systems that gather the competencies of different industries, e.g., car manufacturers and the road industry. Consequently, early stages of innovative solutions are not likely to be implemented. Conversely, the design, the construction, and the operation of full-scale research demonstrators, where risk is mainly (not entirely) taken by the road authority, is likely to make a great difference. Indeed, thanks to such demonstrators, the most innovative, and risky, solutions, especially those proposed by research centers, are more likely to be tested and problems related to their implementation identified and further solved. However, these demonstrators must show a clear improvement over the past and propose a technological breakthrough so as to best meet societal objectives.

Methodology

So as to examine all the aspects related to roads, the R5G program is being elaborated following a systemic approach, which will be adapted to the type of considered road network.

Priorities

First, the program has been organized into a 2D matrix. The first dimension deals with the type of network. Each type of road has its own particularities in terms of design, construction, and operation. Four different types of road networks can be classically considered: urban, periurban, interurban, and secondary networks. In a second dimension of the matrix, the technical domains have been organized into four interdependent elements. The first element deals with the low carbon design, construction, and maintenance of roads. The second element deals with the automation of traffic and operations. The third element relates to the resilience of road networks regarding climate change and their energetic efficiency. Finally, the fourth element concerns the acceptability (social, juridical, economical) and, in particular, the methodology to follow to reach these objectives (see next section). This organization of the priorities is presented in Fig. 1.

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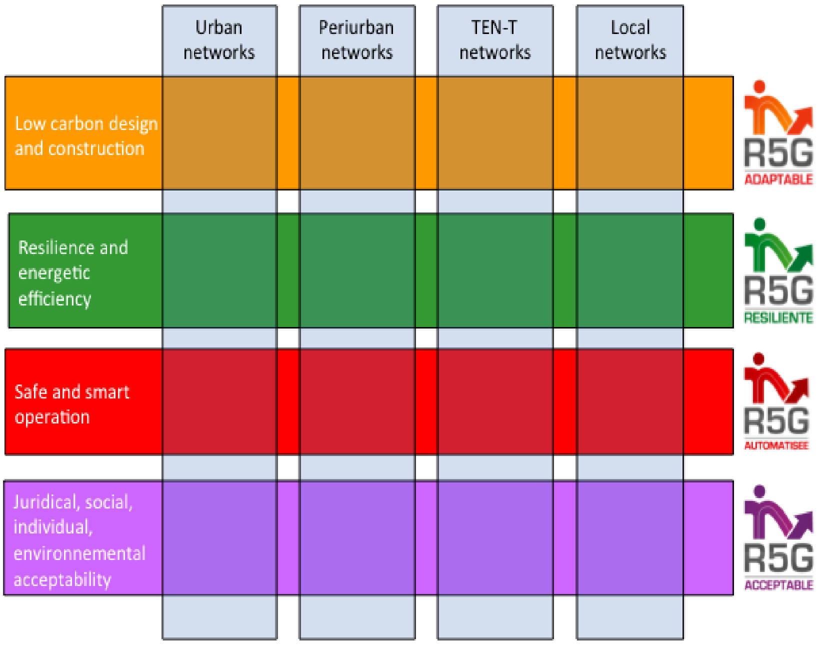

Fig. 1. Priorities of R5G Program.

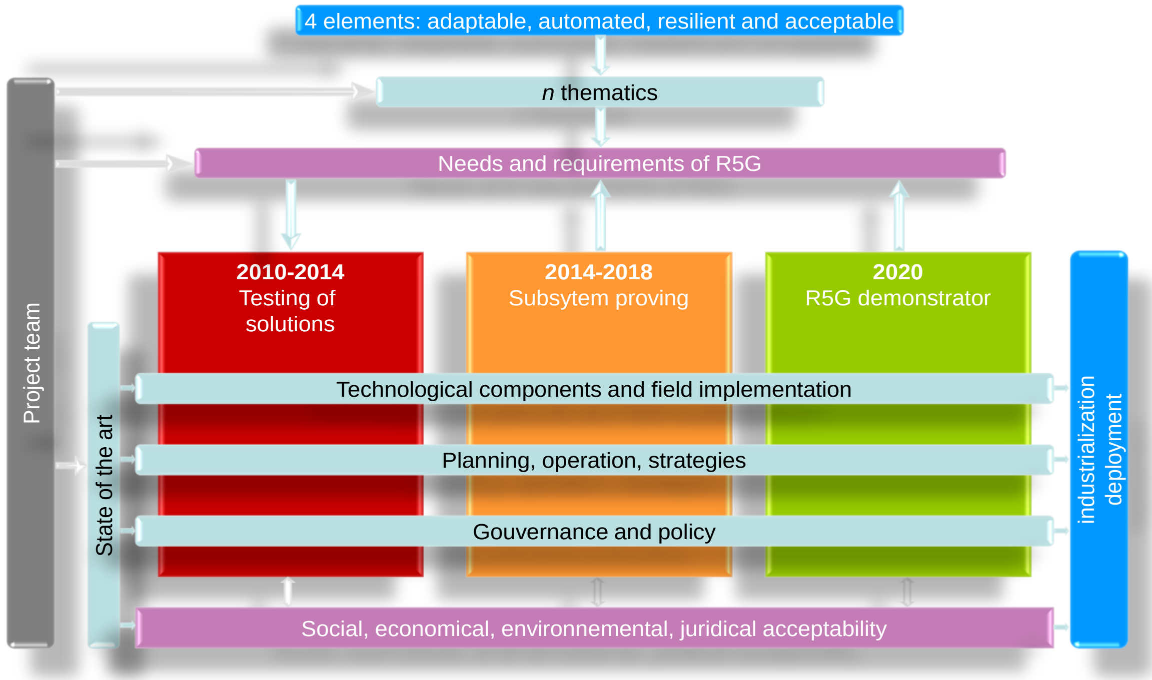

Fig. 2. Organization of R5G Project.

System Approach

With issues and technical areas being identified, a methodology must be developed to create a synergy between the four elements. An approach that could be described as systemic is proposed to allow consideration of the needs of different stakeholders of the road system. Thus, in order to build the R5G demonstrator, the first step is to identify the needs of society, users, operators, and industry. These requirements contribute to the specification of the four elements (adaptable, automated, resilient, and acceptable), but also to the emergence of new solutions on the borderline between these elements. However, given the number of possible topics, it is not sensible to directly build a demonstrator R5G. It is then proposed to first carry out thematic or sub-R5G demonstrators. We deduced a first organization of the program in Fig. 2.

The first phase (2010-2014) is dedicated to the testing and the labelling of single innovations, which are ready to be implemented in research demonstrators. The second phase (2014-2018) will be devoted to the integration of several innovations in a few research demonstrators, which will ultimately allow designing full a R5G demonstrator (2020) through the cross-fertilization of the different research demonstrators.

Fig. 3. Real-time Skid Resistance Prediction on Wet Road and Advisory Speed Computation on the Test Track of Ifsttar in Nantes.

Fig. 4. PEGASE Platform.

Subsystem Proving – Design and Construction of Full Scale Research Demonstrators

Urban Road Demonstrator

Such a demonstrator would demonstrate the ability to design, build, maintain, and operate a mobility solution made of shared vehicle fleets made of automated electrical shuttles. These shuttles would be recharged in motion by infrastructure based recharging solutions and would evolve in open environments where conflicts with other modes of transport, such as cycling or walking, may be possible.

High Speed Automation of Highways

The urban Defense Advanced Research Projects Agency (DARPA) challenge has shown that autonomous driving was possible. In the United States, Nevada recently authorized the circulation of automated vehicles. However, such vehicles are very expensive to equip due to the use of high-end vehicle sensors. Having a highly cooperative intelligent infrastructure allows the realization of a lower cost automation of the driving task. The ABV (Low Speed Automation) project led by The French institute of science and technology for transport, development and networks (IFSTTAR) is developing solutions for the low speed automation. The remaining challenge consists in realizing a demonstrator of high-speed highway automation.

Road and Energy

Different innovations can be used to better manage energy in the road sector. First, important energy savings can be achieved using low temperature asphalts or emulsion treated materials, or also low rolling resistance pavements. Secondly, different technical solutions or concepts arise to harvest energy from roads: solar road, piezoelectric road, geothermic equipment of the surroundings, etc. Solutions are also under development regarding winter maintenance of roads using geothermic heat storage or self-maintaining surface materials. Finally, inductive charging allows transferring the harvested energy to the passing electric vehicles. A demonstrator, which would evaluate the synergism of these technical solutions, is clearly desirable.

Efficient and Self-Explaining Local Road Networks

The low volume roads call for better speed management, which goes beyond hotspot identification and automated speed enforcement. Inspection and audit procedures are still restricted (at least in Europe) to main roads. Concepts like self-explaining roads, forgiving roads, or intelligent speed adaptation are dedicated to highly trafficked roads as well. In this demonstrator, we aim to develop a methodology to efficiently diagnose low volume road networks and still enhance their safety level, for example, by forecasting the friction level (see Fig. 3) and the meteorological visibility, so as to deduce relevant speed recommendations.

Smart Instrumentation of a Motorway Section

The PEGASE Instrumentation Platform

Recent progress in instrumentation and monitoring of engineering structures has increased considerably the possibilities of automated follow-up of behaviour of transport infrastructures. This progress has in particular led to:

- the miniaturizing of transducers and associated instrumentation
- the reduction of instrumentation cost and energy consumption
- the enormous increase of data storage and processing capacities
- the possibility of wireless data export and remote control of the acquisition system.

This progress makes it possible, today, at a reasonable cost, to install smart monitoring systems on real roads, to follow parameters like traffic, climate conditions, mechanical response, and material deterioration.

For this type of monitoring, IFSTTAR has developed a wireless platform (PEGASE, see Fig. 4). This platform has been made modular to fit the need of being reusable without any expensive and long developments [1]. This modularity resides in a sensor made of a “mother board” that integrates redundant needs (computation, communication, data storage) and a set of pluggable “daughter boards” that integrate application-specific needs such as the sensitive elements (accelerometer, temperature, pressure, etc.), its specific conditioning design including hardware filters, analog to digital converters. The main characteristics of PEGASE are the following [2]:

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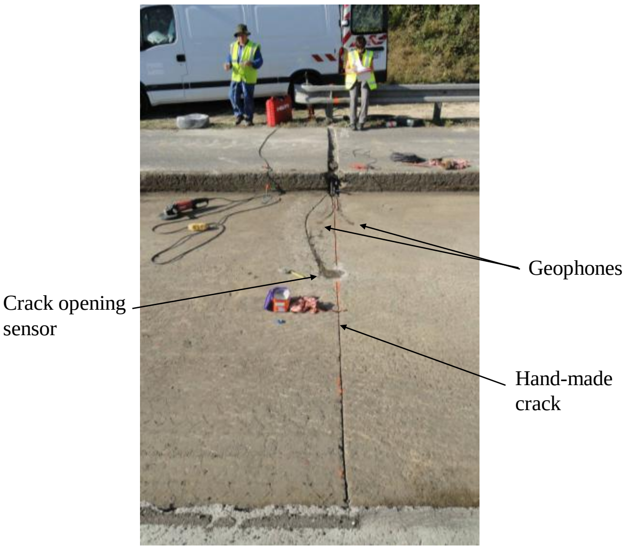

Fig. 5. Installation of the cCrack Opening Sensor and the 2 Geophones on the Top of the Gravel Stabilized with Cement.

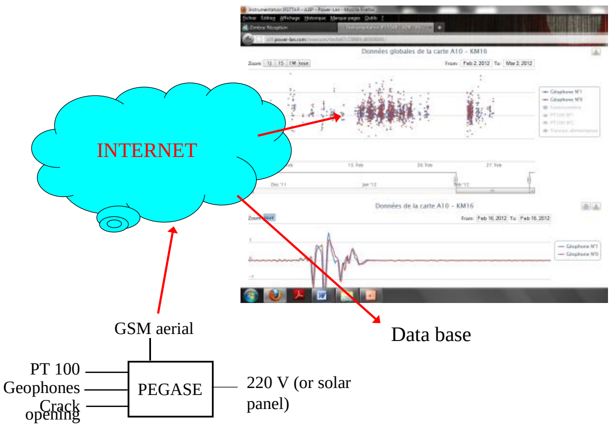

Fig. 6. Visualization of the Graphs on a Web Site.

- use of TCP/IP/Wi-Fi as the wireless protocol
- use of Analog Device low-power Blackfin BF537 as core processor
- implementation of a small and low-power GPS receiver to ensure localization and, first of all, absolute time synchronization up to few µs
- uClinux as the embedded operating system : allows high level of abstraction while PEGASE algorithms are then programmed using standard ANSI C language.

The main advantage of the PEGASE platform is the possibility of remote programming of the board to implement new data acquisition and processing algorithm, to modify or suppress existing ones, etc.

Since its first version on January 2008, PEGASE has been used in various configurations including bridge inspection or cable health monitoring. One of the last configurations of PEGASE is for instrumentation of an experimental motorway section.

Motorway Instrumentation Project

The objective of the project has been to assess the possibilities of monitoring a motorway section renovated with a new technique of in-place retreatment with cement. In this project, a first experimental instrumented section was built to validate the construction technique. This section, located near Paris, consists of three kilometers of a slow lane for heavy trucks and carries 4,500 heavy vehicles a day. Due to the high traffic level, this section is very difficult to close for monitoring or measurement purposes, and therefore a remote control instrumentation is particularly interesting for this type of motorway section. The new structure is made of 30 cm of recycled material stabilised with cement (Elastic modulus E = 5000 MPa, 7% of cement), 22 cm of high modulus asphalt mix (HMA), and 2.5 cm of very thin asphalt concrete (VTAC). On the top of the cement treated sub-base layer, three types of sensors were installed (see Fig. 5):

Fig. 7. View of the Instrumented Section and Data Monitoring System.

- a crack opening sensor using a non-contact inductive displacement transducer.
- geophones, placed on each side of the crack, under the wheel path.
- temperature probes (PT100) installed on the top of the gravel layer and on the top of the high modulus asphalt mix layer.

All the sensors are connected to the PEGASE data acquisition wireless platform, developed by IFSTTAR, which allows real-time data recording and processing. The PEGASE system makes it possible to use a slow acquisition rate for the temperature and crack opening measurements, and to record the geophone response under continuous vehicle traffic at high frequency (1 kHz). The geophone measurements are then treated to calculate the maximum deflections, and store only a limited number of complete vehicle signals per day. The amount of stored data is thus considerably reduced. Another very interesting feature of the PEGASE system is that the data is sent automatically to a server, by Global System for Mobile Communications (GSM) network, every four hours. The data can then be consulted, and graphs of different measurements can be visualized directly on a web site, from any computer (Fig. 6).

This innovative instrumentation allows monitoring, for the moment, the vertical deflection of the pavement under real heavy vehicle traffic (by analysis of the geophone measurements) and the evolution of the crack in the cement-treated subbase, due to thermal variations and traffic loading. An extension will be implemented soon to add strain gauge sensor measurements.

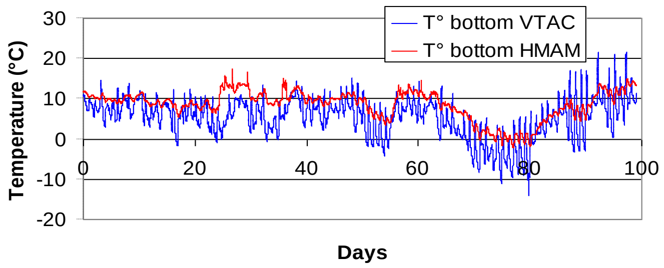

Fig. 8. Example of Temperature Measurements Since November 24th, 2011.

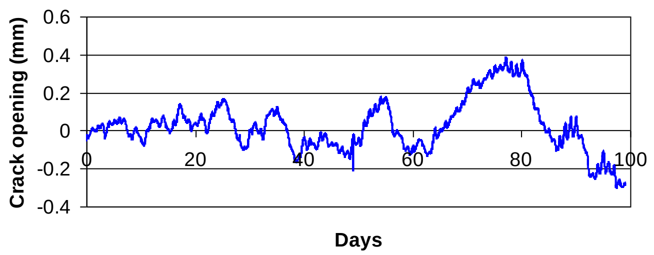

Fig. 9. Example of Crack Opening Measurements Since November 24, 2011.

The motorway section was instrumented in September 2011, and measurements have been recorded since November 24, 2011. Fig. 7 shows the configuration of the on-site instrumentation and acquisition system. On the site, a 220V power supply was available, but the system has low power consumption, and can also work with solar cells and batteries.

Temperature measurements and crack opening measurements are recorded continuously every 5 minutes. Figs. 8 and 9 show the temperature and crack opening measurements, over a period of 100 days. Daily temperature variations at the bottom of the very thin asphalt concrete can reach more than 10°C. Daily temperature variations at the bottom of the High Modulus Asphalt (HMA) are only of about to 2 or 3°C. In France, there was a very cold period in February (days 70 to 80). During this period, the temperature in the surface course went down to about -10°C, and the temperature at the bottom of the HMAC was about 0°C. These continuous temperature measurements give detailed information on the temperature conditions in the pavement, which can be useful for analysis of the other transducer data, but also to model the thermal and thermo-mechanical response of the pavement.

The crack opening measurements indicate, on this newly constructed pavement, variations of width of the crack of about +/-0.4 mm, over the measurement period (Fig. 9). These variations appear correlated with the temperature variations at the bottom of the HMA layer. When the temperature increases, the width of the crack decreases (the crack tends to close). During the cold period in February (days 70 to 80), in particular, the width of the crack increased significantly, by about 0.4 mm. These measurements show the possibility to monitor the evolution of cracks in a cement-treated pavement subbase due to thermal effects. Monitoring over a longer period will show if evolutions of the crack due to deterioration by traffic can also be detected.

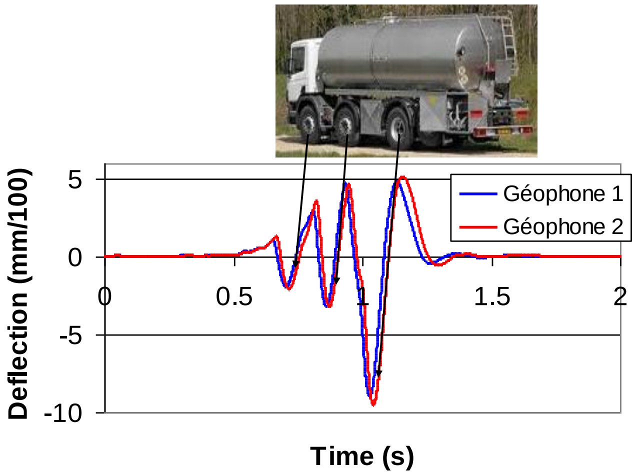

Fig. 10. Integrated Signal of Geophone Under a Truck with 3 Axles.

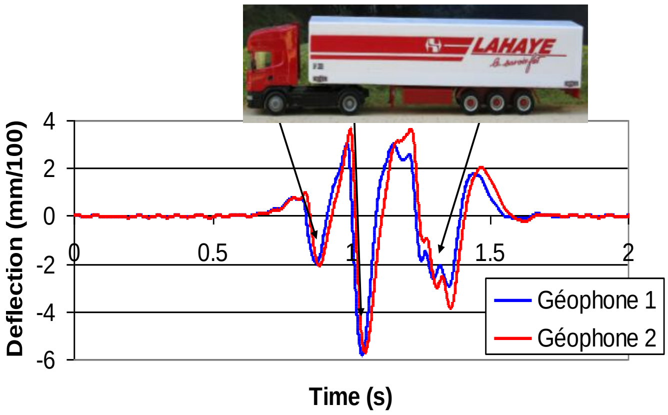

Fig. 11. Integrated Signal of Geophone Under a Five-axle Truck.

The geophones allow measurement of the variations of the vertical displacement velocity of the pavement under the real traffic passing on the motorway. The geophone measurements are performed at a frequency of 1 kHz. The geophone signals are then integrated to determine the vertical displacement, on top of the cement treated subbase, under the passage of heavy vehicles. The advantage of the geophones is that they have a very high sensitivity, and are therefore able to measure the very small vertical deflections of the stiff cement-treated layer (about 0.1 mm). However, their disadvantage is that they have a minimum response frequency of 6 Hz, which leads to some distortion of the displacement signals. Therefore, some work is under way to calibrate and correct these measurements using a reference vehicle with known axle loads. The possibilities of this measurement technique appear very promising. The geophones allow clear identification of the axle configurations of the different heavy vehicles. For example, Figs. 10 and 11 show signals obtained for two different vehicle silhouettes: a three-axle heavy vehicle and a five-axle vehicle with tridem rear axles. While work is still needed to fully explore this data, it seems possible to use both to follow the mechanical response of the pavement and to characterize the traffic loads.

Conclusion

Motorway sections for heavy traffic, such as the one which has been instrumented, have thick pavement structures, leading to very low deflections. To maintain a high level of service, they require regular structural surveys. Generally, these are made in France using deflectographs, measuring the deflection and radius of curvature under 130 kN axle load. However the sensitivity of these measurements is generally not sufficient to detect the initiation of damage on such rigid pavements. Internal instrumentation, such as the one presented in this paper, allows more accurate measurement of the mechanical response of the pavement and its evolution. In particular, very encouraging results have been obtained in this study with new types of instrumentation, like geophones, for the measurement of deflection, and non-contact displacement transducers for the measurement of crack opening.

Using the PEGASE wireless data acquisition platform, it has been possible to develop an innovative system for the monitoring of this experimental motorway section, associating :

- Continuous monitoring of the pavement response at high frequency (1 kHz) under traffic, and real time processing of this data, to store only selected, relevant measurements.
- Possibilities of remote programming of the PEGASE Platform to modify the data acquisition and data treatment procedures.
- Remote transfer of the data to a server via the GSM network.
- Easy access to the data through the Internet.

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