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A smart and wireless sensors network for cable health monitoring

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Abstract

In the collection of possible non destructive techniques used for bridges, acoustic emission is a favourite non-destructive solution towards health monitoring of cables of suspended bridges. A first generation of such an acoustic system made of a supervisor and a distribution of wired sensors fixed onto bridge cables have been developed and deployed on several bridges in France. The aim of this article is to present the new generation of this acoustic system redeveloped by implementing algorithms on a distribution of smart and wireless sensors. Each sensor of the platform consists of a small electronic layer including a TCP/IP stack and an embedded µClinux Operating System. Sensors are able to detect and to record the full shape of acoustic waves due to wire breaks while they are kept synchronized by means of a GPS method.

Résumé

Parmi les différentes techniques de contrôle non destructifs possibles appliquées pour les ponts, l'émission acoustique est la solution favorite pour la surveillance des câbles. Une première génération d'un tel système acoustique composé d'un superviseur et d'une distribution de capteurs fixés sur les câbles a été développée et déployée sur plusieurs ponts en France. L'objectif de cet article est de présenter la nouvelle génération de ce système acoustique développée par l'implémentation d'algorithmes sur une distribution de capteurs sans fils et intelligents. Chaque capteur consiste en une carte électronique intégrant le protocole TCP/IP et un système d'exploitation embarqué µClinux. Ces capteurs sont capables de détecter et d'enregistrer la forme d'onde complète provenant de la rupture d'un fil et sont synchronisés par une méthode GPS.

Keywords

Cables, diagnostic, WiFi, monitoring, acoustic.

1 Introduction

For safety, structure durability and cost efficiency reasons, monitoring civil engineering structures and especially cable stayed and suspension bridges is sometimes necessary. The installation of an acoustic monitoring system allows the detection and the monitoring of the degradation of civil engineering cables by the recording of acoustic events mainly associated with severe breaks of wire. It should be noted that this technique allows the testing of the whole cable and not only of the external part as in the case of a visual inspection of the structure. Acoustic emission is a usual non destructive technique used for cable monitoring which consist of detecting and localizing individual wire-breaks that could occur in cables from various types of bridges [1-4]. By knowing the number of wire-breaks and their localization on cables, this system delivers to structure's manager knowledge on its health [3,5,10-11] This confirmation could lead structure's managers to repair cables [6], to stop traffic etc. To reach such a diagnostic tool, specific instrumentation must be thinked, this article underlines how accurate wireless sensors must be (up to few microsecond) and how reliable wireless communications have to be. Those technical challenges that have been solved pave the ground of promising future developments in terms of wireless and smart sensors developped in LCPC laboratories.

2 Acoustic emission for wire-breaks detection

The principle of the system is based on the detection of an acoustic wave which is emitted on a wire break in the two opposite directions of the corresponding cable.

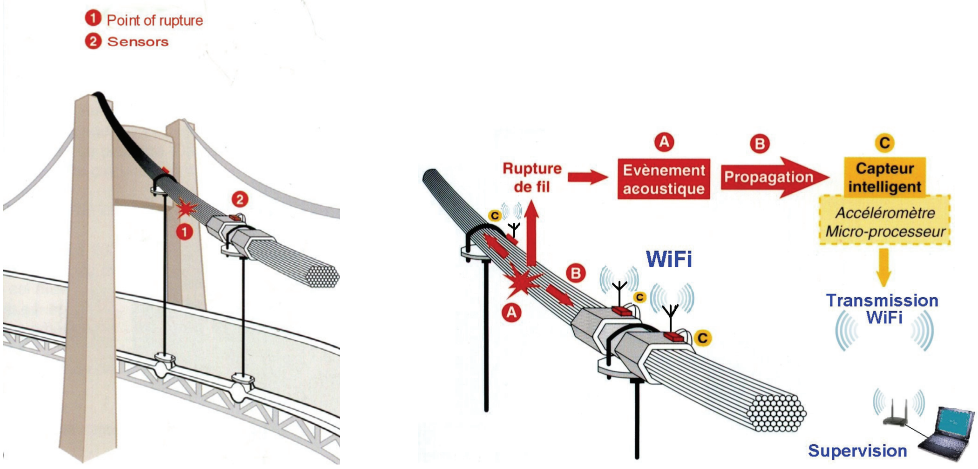

Figure 1. *a) Wire-break occurrence in a cable b) Wave detection by sensors*

This acoustic wave propagation is detected by a set of acoustic sensors along the monitored cable [7]. In this application, the sensitive element selected for each sensor is an accelerometer. Each sensor is assumed to be an electronic entity that embeds a processor. It is programmed to permanently digitize electric signals from the accelerometer and to compare its amplitude to a predefined threshold (an acceleration threshold defined around few 'g'). This threshold is different from zero due to the fact that there is always a minimum of acoustic activity in cables. If the amplitude of a recorded sample from the signal exceeds the threshold, this value is recorded and time stamped. Then, the sensor sends that information to a remote supervisor as shown in figure 1.

The rupture localization is performed by a supervision system from sensor relative locations and occurrence times (time-stamped signals). When wire break signal is detected by 3 sensors (at least), a real wave propagation rate can be computed. Due to environmental conditions existing on bridges, some uncorrelated signals can be computed by the supervisor and criteria based on acoustic wave velocity and the number of sensors which have detected break signal are applied.

3 Implementation on sensors network. Toward a new instrumentation

3.1 First generation

This Structural Health Monitoring (SHM) application has first been implemented through a system based on smart and wired sensors (Motorola 68HC11 as embedded processor). The wired communication bus technology used the serial RS485 link. Several bridges of different type (suspension, prestressed, cable stayed) have been instrumented and monitored with success by such this system [6-8]. Even if the system delivered clear-cuts results from laboratory configurations and under real conditions, its massive deployment as well as is actual maintenance makes it expensive and subject to technological improvements.

3.2 LCPC generic wireless sensor platform

After active technological survey specific developments in Wireless Sensors Network (WSN) [14] applications, LCPC took the decision to develop its own generic wireless platform. LCPC goal is to develop a WSN platform for which simplest (or none) hardware and software modifications can cover a large range of applications. This modularity takes form in a sensor made of a "mother board" that integrates redundant needs (computation, communication, data storage) and a pluggable "daughter board" that integrates application specific needs such as the sensitive element (accelerometer, temperature, pressure,...) or its specific conditioning design.

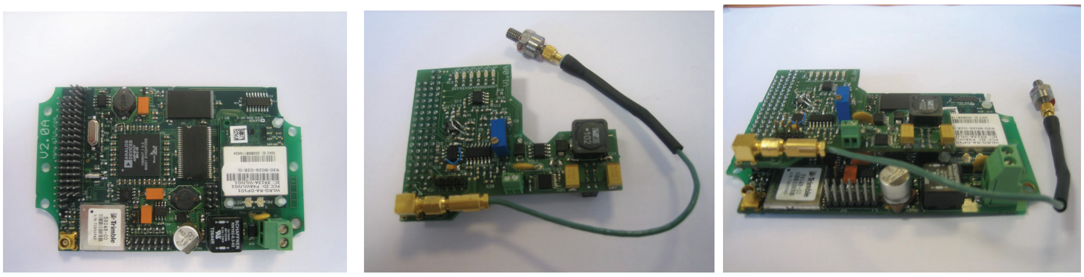

Figure 2. *a) Mother board b) Daughter board c) both plugged one to the other*

The mother board is presumed designed for good and provides the platform cost advantage. Thanks to its exact reproducibility, its cost rapidly decreases. The daughter board design is the only entity that must be designed according to the application specifics needs. This combination allows user to make low-cost and heterogeneous networks of sensors by designing as many various daughter boards as required by the application.

Implementation of Operating System in embedded world is a quite difficult task. The sensor core processor -Analog Device BlackFin BF537- has been produced able to run such an OS. The "ucLinux" is one of those derived from the Linux family that fits the embedded world.

That implementation offers two main advantages. First, a very high level of abstraction between hardware peripherals and source code is obtained. As any OS does, ucLinux OS includes many drivers that allow users to program wireless sensors in the standard ANSI C language, sensor's algorithms become fully independent from hardware. Secondly, as a majority of OS, "ucLinux" fully deals with the IP protocol. Even if IP protocol has often been seen as an heavyweight protocol for wireless develoment, its recents evolutions make it available for WSN implementations [15].Thus, porting ucLinux on LCPC mother board where Wifi is the implementation of IP makes the sensor fully accessible from any remote PC linked to a Wifi access point.

Combining embedded OS to Wifi implementation delivers a real breakthrough in structural health monitoring by means of wireless sensors. LCPC wireless sensors can fully and remotely be updated without any expensive removing operation from the structure. The result is the following: any sensor, Access Point or supervision PC of the LCPC wireless system could be seen as an IP entity such it would be in a traditionnal network of computer under Linux operating system. Each sensor can be adressed, ping and remotly accessible via *Telnet* command.

Most of instrumentation systems require data able to be time correlated. Thus, time synchronization is an essential sub-function to solve in a WSN. LCPC wireless platform provides an accurate and absolute time-synchronisation mechanism using GPS algorithms

[16]. The synchronisation mechanism implemented in LCPC platform uses the ability of a small GPS componant (welded on the mother board) to deliver a PPS signal that is a common and absolutly synchronised (G.M.T.) signal that rises up every 1 sec at an accuracy of 20 nanoseconds. By connecting the µS time counter reset input of the platform to the PPS signal, it could deliver an event time-stamping up to a few µS. Moreover, by an real-time algorithm able to take into account temperature (that influence on quartz drift) and natural quartz error, LCPC platform is able to time-stamp any event at an accuracy of less than 4 µS. This level of accuracy fits the need in cases of wave propagation where typical velocities reach ~ 5000 m/s and wished localization are about few centimenterss.

4 Acoustic system implementation on the new LCPC WSN

The wire-break in cables monitoring system have first been implemented on this new LCPC WSN platform as its capacities fit the desired needs: signal algorithms are performed and sensors are able to deliver the full shape of the signal on threshold event. Absolute time-stamping -thanks to the GPS method- performs events localization and simplify data management. The use of a the worldwide Internet Protocol for sensors communication (implemented through the WiFi 802.11g wireless standard) radically simplify system supervision. From now, it consists of a binary executable file running on a traditional PC.

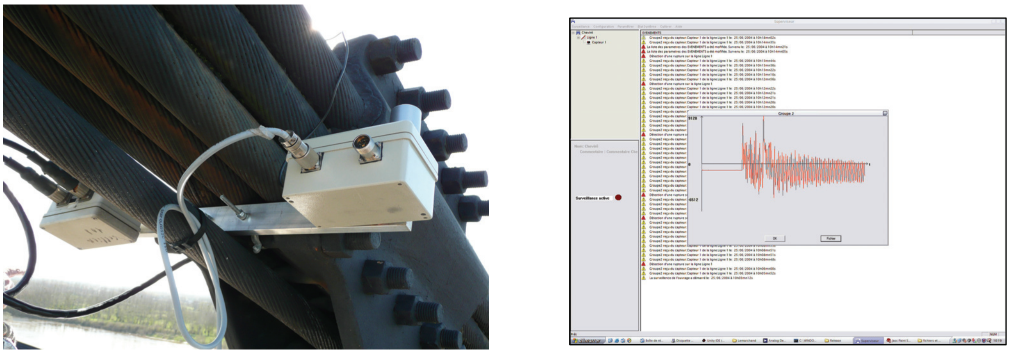

Figure 3. *a) Both systems deployed b) Full signal shape recorded.*

LCPC is testing this new acoustic system by means of 20 sensors on a suspended bridge where the previous generation is already set. Because this system is recent, sensors are still wired but only for energy (8 to 24V) so instrumentation cost is already cheaper. Thanks to active works in terms of energy harvesting and solar cell recovery, LCPC wireless platform will be fully autonomous on 2009.

5 Conclusions

This acoustic monitoring system has been developed (3rd generation) and has been applied for several decades in France by LCPC [12-13]. It already made possible to safeguard several bridge threatened of destruction. These last years, this method has been extended to the monitoring of prestressed concrete bridges with cables in cement grout; the instrumentation of the Pont Neuf Bridge of Foix has validated the concept.

New design of sensors embedding "ucLinux" as the Operating System and TCP/IP for communications is a breakthrough in thinking instrumentation. New sensors can fully be remotely reconfigured without any physical removing from the bridge. Even if basic wires are still necessary for long term monitoring period, LCPC platform is actually subject of converging efforts in order to make sensors fully wireless.

Acoustic emission method requires further studies in wave propagation and characterisation when applied to cables and especially for wire-breaks detection but existing LCPC method has already proved a certain efficiency. Its implementation on the LCPC wireless sensor platform should offer soon a new, simplest and less expensive tool for bridge managers.

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