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Cover page

Title: Design of a generic smart and wireless sensors network – Benefits of emerging technologies

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ABSTRACT

More than technological questions, the generic potentiality of a wireless sensors platform drives the way engineers could design the system. A complex equilibrium must be found between the desire to implement generic (at least reusable) functionalities embedded in each wireless sensor of the network and the necessity of electronic optimizations in view of reducing energy consumption and dimensions. Nevertheless, nearly each specific application that has to be implemented on a wireless sensors network can be approached through a generic way of thinking.

As an example, a relevant solution consists in designing a sensor that is the compilation of heterogeneous electronic boards plugged one onto the others; one is the mother board that ensures fundamental functions from signal processing to wireless communications and some are pluggable boards each dedicated to a specific sub-function (data acquisition, conversion from a sensing component, filtering,...). But the wireless constraint and the wish of generic designs ask the questions of time synchronization, energy consumption... thus emerging technologies and protocol standardization (Zigbee, Wi-Fi) could provide immediate answers.

French Public Works Laboratory (LCPC) has recently developed a generic wireless platform that fits many applications needs such as U.A.V. instrumentation, bridge or quarries monitoring... By including the TCP/IP stack and an embedded ucLinux O.S. at each sensor level, LCPC could propose a generic and reusable platform on which many applications could be implemented. This article aims at presenting the originalities of that wireless sensors platform and the first positive results and dissemination it recorded when applied to real structures.

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INTRODUCTION

Most of the scientific community and particularly the Wireless Sensors Network (WSN) community know how long and how expensive could be the works associated to small electronic designs that include from radio-frequency communications, power consumption optimizations, or embedded software developments. Embedded works for wireless applications are synonymous of rigorous works. Where simple software and a plugged data-acquisition board is adapted for a traditional PC directly connected to wired sensors, wireless applications must ensure reliable and continuous measurements from months and months without any human interaction or maintenance.

When thinking to a new design in Wireless Sensors Networks domain in view of research such as in view of satisfying the specific needs of an application, genericity and reusability of the works must question engineers and searchers. As evidence, thinking as soon as possible how the same platform could be re-used for other applications or different contexts could lead to positive and profitable results. At this step, a first conclusion could be “it’s easier and less expensive to adapt than it is to create from scratch”.

After few years of specific developments for various WSN 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. By its identity, today’s LCPC platform essentially fits civil engineering applications.

Global design and functionalities of LCPC wireless platform

In most of the cases, as the above figure 1 shows, a typical wireless sensor can be seen as the addition of functional layouts.

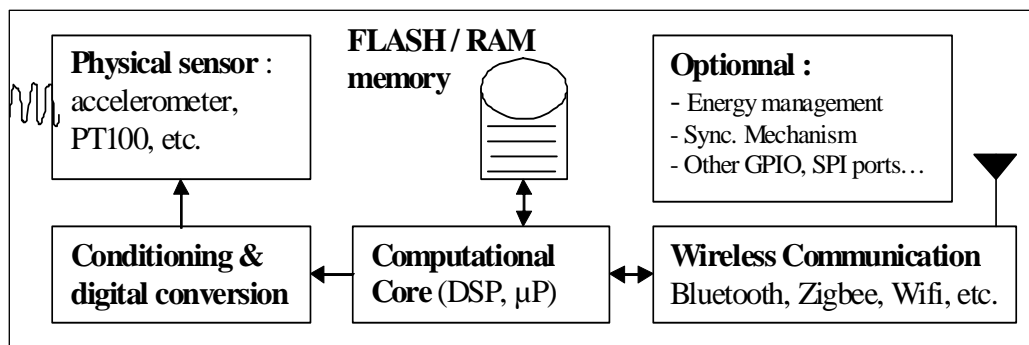


Figure 1: Typical wireless sensor functional layouts.

After a long study of applications where specific layouts have been distinguished from generic ones, LCPC decided to make its WSN platform modular. 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 including hardware filters, analog to digital converters.



Figure 2: mother board, daughter board, and the both plugged one to the other.

The mother board is presumed designed for good -hopefully for few years- and provides the platform cost advantage. Its study and tests took a long time to LCPC; now this product is proposed to any company or laboratory interested in, by the way of LCPC third party partners. Thanks to its exact reproducibility when produced to customers, its cost rapidly decreases.

The daughter board design is the only entity that must be rethought according to the application specific needs. But, as this design is the simplest of the system (compared to microprocessor implementation, memory addressing through buses and electronic layers), its cost is much cheaper than the one a customer would pay if redesigning his WSN entirely and ex nihilo. Moreover, this combination allows user to make low cost and heterogeneous networks by designing as many various daughter boards as required by the application.

BENEFITS AND INTEGRATION OF EMERGING TECHNOLOGIES

LCPC wireless generic platform is the fruit of years of specific developments and technological survey in WSN domain that cover many fields such as micro-electronic designs, wireless communications or smart embedded algorithms. Thus, the platform is, first of all, the “best of the technology” integration that fits LCPC and civil engineering needs.

The standard TCP/IP as the WSN communication protocol

Ten years ago, at the beginning of first TCP/IP wireless implementations via Wi-Fi 802.11b devices, the IP solution was generally precluded for WSN due to the “heavyweight” of that originally wired protocol and due to battery limitations [1]. During years, many teams and companies worked hard to make the TCP/IP protocol viable for wireless sensors [2] and [3]. In parallel, it is notable that 802.11 hotspots deployments have increased from 53000 in January 2005 to 155000 on July 2007, and, more than 50% of US companies have deployed 802.11 networks as of 2006 [4].

The ongoing social and economic evolution of mobility, portable connectivity, and the need of heterogeneous media convergence that emerges those last years elect TCP/IP and especially Wi-Fi ubiquitous. By choosing the IP protocol, LCPC WSN platform gets the same benefits as from a traditional PC network [5]:

- Network reliability: TCP/IP stack ensures reliable transfers of information between sensors,
- Low cost and faster deployment: no need of specific devices, Wi-Fi devices are proposed to all public and requires only traditional computer competences,
- Scalability: IP network can address thousands of sensors up to 100 Mbps.

TCP/IP stacks are now available in integrated electronic devices easy to include in developer’s designs. The figure 3 above shows one of the first self-sufficing Wi-Fi devices

qualified to make an accelerometer sensor wireless. That kind of devices is addressed by the sensor processor via standard serial RS or PCMCIA ports.

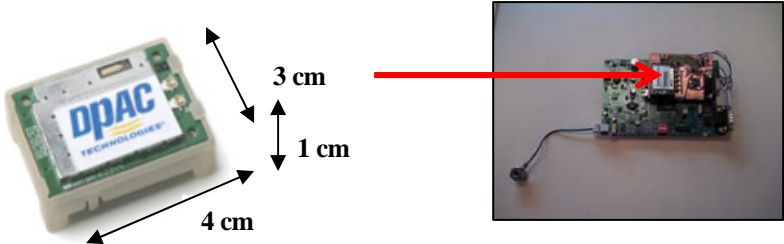


Figure 3: TCP/IP stack available in small device easy to integrate.

Embedding “ucLinux” as sensor Operating System

Implementation of Operating System in embedded world is a quite difficult task that requires high level knowledge in industrial data processing. Choice of an OS for WSN is crucial; adding such a wide software layout between the processor hardware capacities and application algorithms may increase the risk of power overconsumption, of bugs, and requires more RAM and FLASH memories.

Nevertheless, wireless sensor platforms embedding an OS already exist: TinyOS that uses the wireless 802.15.4 standard, BlueCat OS based on Linux, VxWorkx ... [5].

LCPC WSN platform uses a Digital Signal Processor (DSP) as the computational core; this specific processor –an Analog Device BlackFin BF537- has been designed able to run an OS. The “ucLinux” is one of those derived from the Linux family that fits the embedded world. It can be configured to deal with exactly the needed peripherals: SPI bus and/or RS232 port and/or PWM port and/or CAN bus, etc. Thus, it can size from 50 KB only to 4 MB. This OS implementation offers two main advantages.

First, a very high level of abstraction between hardware ports and source code is obtained. As any OS does, ucLinux OS includes many drivers that allow searchers and engineers to program wireless sensors in the ANSI C [6] language using its traditional use; in other words, the OS integrate all specific access to private DSP registries. This reduces consequently the code size and, first of all, makes sensor’s algorithms fully independent from hardware. Thus, the developed code that implements algorithms becomes completely portable and reusable from an application to another. If necessary, ucLinux allow user to write its own drivers.

Secondly, as the majority of OS, ucLinux fully deals with the IP protocol. Thus, porting ucLinux on LCPC mother board where Wi-Fi is the implementation of IP makes sensors fully accessible from any remote PC linked to a Wi-Fi access point. When their Wi-Fi stack is turned on, sensors are directly addressable by means of the universal “Telnet” service.



Figure 4: One-shot expensive sensors installation on a structure.



Figure 5: Sensors addressable via a simple Wi-Fi Access Point and the Telnet service.

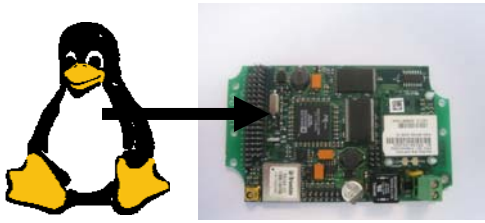


Figure 6: uLinux as the embedded operating system.



Figure 7: Obvious source code reduction and independence from hardware.

Combining embedded OS to Wi-Fi implementation delivers a real breakthrough in structural health monitoring by means of wireless sensors. LCPC wireless sensors can be completely and remotely updated and (re)programmed without any expensive uninstallation from the structure. Moreover, the wireless communication hardware only requires non proprietary devices but typical Wi-Fi access points.

Sensor self and absolute synchronisation by means of a GPS receiver

Time synchronization for wireless sensors networks is often a real need. Typically, algorithms that ensure the structure monitoring at Supervisor level, manage heterogeneous and numerous samples collected by sensors. Those data are used to localize a default, a dangerous tendency or to fill statistical databases.

Thus, most of instrumentation configurations require data able to be compared and time correlated. This need is much more obvious in cases where instrumentation is used for distributed tasks amongst sensor nodes or for control algorithms. Wave propagation in concrete or real-time suspended cables monitoring are applications where sensors time-synchronization requires high accuracy that can reach up to 1 μ S.

Because a sensor is an electronic entity, its natural time-base varies due to quartzes aging and temperature. Thus, time synchronization is an essential sub-function to solve in a WSN. Many solutions [7] exist and can be classified in three categories: distributed synchronization, “Post-facto” synchronization and sensor self –synchronization. Few of them are really able to provide accurate and deterministic dating [8].

LCPC wireless platform provides an accurate and absolute time-synchronisation mechanism by integrating a very small GPS receiver on the mother board. This solution is based on the property of each GPS receiver to output two numerical signals: a sequence of bytes containing absolute time and localization, and, a synchronization binary signal named PPS (Pulse Per Second) that has a period of 1s with a guarantee of +/- 20 nanoseconds. The solution consists in routing the PPS signal to a reset input of one of the processor timers. Then, on PPS rising edge, microseconds timer counter is reset, and, hours, minutes and seconds are updated.

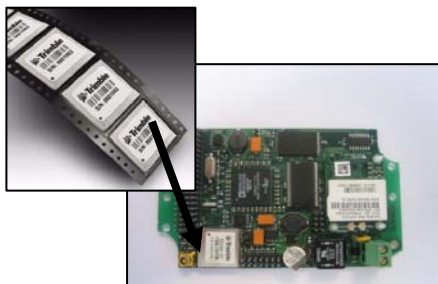


Figure 8: GPS receiver on the mother board.

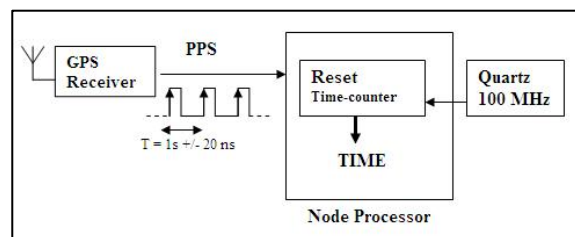


Figure 9: Embedded GPS synchronization principle.

An organized test campaign has been carried out and results are very satisfactory. As every PPS signals synchronously rise up with the same period of 1S +/-20nS, the only drift between two sensors is due to uLinux OS latency (time to raise the appropriate interrupt and to reset timer counter).

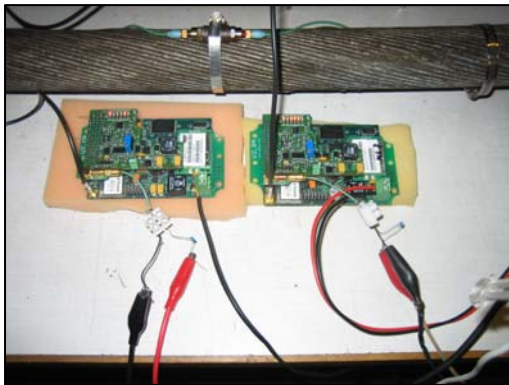


Figure 10: Synchronization test-bench for two wireless sensors.

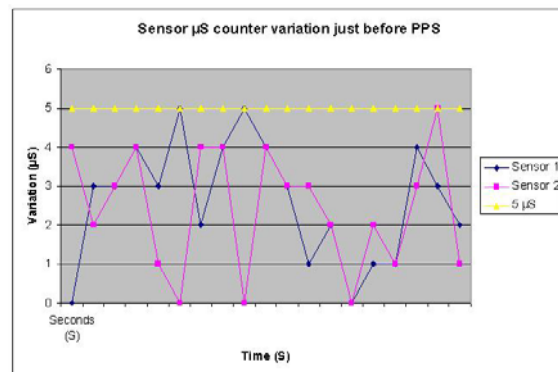


Figure 11: Sensor μ S counter variation just before PPS.

As the figure 10 show, same accurate and synchronous Dirac signals of 1 Hz frequency were injected in two wireless sensors. Figure 11 is the result of 20 measurements of sensor 1 and sensor 2 time counter variation on Dirac rise. Absolute time stamping between two LCPC wireless sensors never exceeds 5 μ S.

APPLICATIONS OF LCPC WIRELESS GENERIC PLATFORM

First applications of LCPC WSN cover internal projects whose needs paved the ground of the wireless platform consequent development.

Unmanned aerial vehicle (U.A.V.) instrumentation

Car traffic is nearly uninterrupted, and France counts approximately 50000 railway bridges and 200000 road bridges that need periodical inspections. Those two constraints lead to the conclusion that structure inspection and integrity checking by means of an instrumented unmanned aerial vehicle (U.A.V.) could reduce the cost of those expensive operations [9].

One of LCPC major instrumentation project refers to the evaluation of a military U.A.V. bought able to fly according to security rules and for turnkey flights (by means of an integrated autopilot). The challenge consists in customizing U.A.V. (figure 12) by embedding the wireless platform and to make it able to control each onboard instrument.



Figure 12: LCPC U.A.V. for structure inspection



Figure 13: Embedded instrumentation

In this case, wireless system is customized to allow real time control of many devices onboard: a camera monitored on a 3D axial robot (figure 13), a laser-meter, GPS receivers, anti-collision system, etc. Embedded ucLinux and the connected point to point IP protocol fit the needs of security and accuracy.

Cable health monitoring

In view of safety, structure durability and cost efficiency, detection and localization of wire breaks in cables is a strategic component in cable monitoring. Knowing the number of breaks and their locations contributes to understand and to supervise the health state of the structure [10].

Acoustic emission emerges as one of the favourite non-destructive evaluation method. In this case, LCPC wireless sensors detect acoustic waves due to wire breaks (figure 14) and accurately date its propagation all along the cable. On such an event, sensors upload their information to a remote Supervisor. Thus, by knowing sensor's location, wave form and its occurred time, Supervisor is able to localize the wire break (figure 16).



Figure 14: LCPC wireless sensor for cable monitoring.



Figure 15: Large scale test under real conditions.

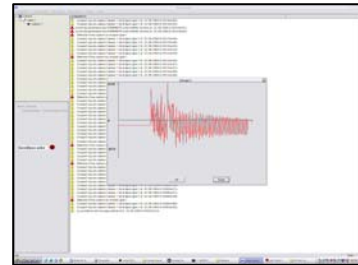


Figure 16: Supervisor able to localize wire breaks.

After large scale campaigns (figure 15) including real structures, LCPC “wire breaks in cable detection system” is actually subject to industrial transfers.

CONCLUSION

LCPC has developed an efficient wireless sensor network platform customizable to a diversity of applications, especially for civil engineering contexts. Its genericity is based on its mother/daughter pluggable boards that respectively integrate recurrent SHM needs and application specific sensing. Integration of a small, reliable and real-time ucLinux OS also furnish gages of the platform perennality. The small GPS receiver and the PPS based synchronization mechanism ensures absolute and very accurate time stamping even if this property limits the use to outdoor instrumentations (thus GPS indoor re-emission could be studied). IP native ucLinux protocol such as any supervision PC and the well known costs associated to Wi-Fi technology contribute to delivers low cost deployments of this platform by excluding any proprietary materials, protocols or antennas.

Energy is a notable aspect that has not been related in this article. The reasons are the following: sensor power consumption is always very application-dependent and LCPC has many unexplored ways to consequently decrease power consumption (that actually concerns few mW): use of DSP sobriety modes, run GPS on cyclic period only, turning on the Wi-Fi module just when necessary, development of daughter board to recover various energies from vibrations, wind or solar cells.

Other efforts will be led soon: more massive use of DSP capacities or development of a set of turnkey daughter boards. Nevertheless, LCPC wireless platform is already subject to industrial transfers and the goal clearly consists in making it as a reference sensor network platform in civil engineering applications. Thus, any kind of contact or cooperation would be appreciated.

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