Metrological approach of new sensors used in structural health monitoring

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ABSTRACT

The rise of new technologies and the use of new sensors in structural health monitoring rise from a need increasing for knowledge and sounding in real time of constructions in the civil engineering. Safety requires the reliability of the results and the answers given by the sensors. In this context it is essential to carry out thorough metrological studies making it possible to extract uncertainty associated with the result according to the need and the context of use, in order to better evaluate the degree of confidence according to the requirements one fixed.

The metrological studies can be done with various methods according to the situation and to the nature of measurements. Indeed currently the international reference for the calculation of uncertainties is the famous GUM "Guides to the expression of uncertainty in measurement" published in 1993 which proposes a procedure of evaluation and expression of uncertainty called analytical approach. It is currently the most traditional method of reference. But as uncertainty touches now with all the measurable sizes and that the processes of measurement are increasingly complex and the settings in equations of all the components of uncertainty become difficult even impossible, in order to stage with this problem several laboratories have worked for a few years on a classification of four methods, the first is the traditional method based on the GUM, the second approach consists in composing the uncertainties estimated starting from the characteristics of the method. The third method consists in using the values of fidelity of a method published in the exit of interlaboratories comparison and finally the last uses theses intercomparisons to determine the performance of a laboratory. The two first approaches are applied in-house in only one laboratory whereas the two last are applied when several laboratories intervene.

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INTRODUCTION

Metrology and tests are closely bound [1], indeed we can establish that if we make measurements without carrying out tests, we seldom carry out tests without measurements.

The components of a test are subjected to the concepts, operations and requirements of metrology, would be only by the means of the operations of checking or calibration of the used measurement materials. A process of relevant test must thus take account of the whole of this information, of metrological nature.

In addition, a process of test and a process of measurement face the same requirements as regards quality of produced information. We wish in particular to have uncertainty associated with the measurement or test [2,3]. This narrow overlap between the two worlds forces to call upon identical concepts, or at least coherent, when we must answer questions of comparable nature.

After some metrological definitions, we will propose the study carried out on a new acoustic system developed at the LCPC and whose first objective is to detect and to locate the wire ruptures which intervene in the cables of the bridges [4,5].

The system allows the detection of the new ruptures once installed but not the ruptures which could have intervened before installation. A first operational generation of this system designed by the LCPC, was industrialized and equipped several bridges in France [5].

The new system aims are recording and exploitation of the acoustic signals for better ruptures localization and new criteria of diction. We want also to perform the acoustic system in its sensor-network topology and the real-time monitoring of cables.

INTRODUCTION TO THE METROLOGICAL STUDY

Any operation of measurement is ineluctably sullied with errors [7]. Theses errors originate in the measurement system and the quantity itself.

The measurement system

The system of measurement is never perfect. It can be sensitive to the environment (effects of the temperature, of the hygroscopy...), it is certainly not faithful (since when the observations are repeated, we observe a dispersion of the values).

The bad definition of the quantity to measure is itself a source of errors

It should be considered that it would be necessary to provide many details to define in an exhaustive way the quantity object of measurement.

MEASURMENT PROCESS ANALYSIS

The correct analysis of the measurement process is doubtless the most difficult and most delicate task to estimate the uncertainty. This analysis require technical skills and analysis feeling. It can be practiced only by someone who control the measurement technique. The development of the "better" mathematical model requires to have finely analyzed the measurement process so as to identify the factors of possible influence, which will be identified like "causes of errors". We will take guard so that the term usually used of "causes of errors" indicates an influence quantity on the measurement result which can exploit at the same time on the error and on the uncertainty.

There is a technique, based on Ishikawa diagram also called the fishbone diagram which allows starting from a brainstorming and a very good knowledge of the measurement process to imagine and to count all the causes.

We analyze successively, the contribution of the means, the measurement method, the surrounding medium, the operator and the measured object (mesurand). Figure 1 shows a general fishbone diagram.

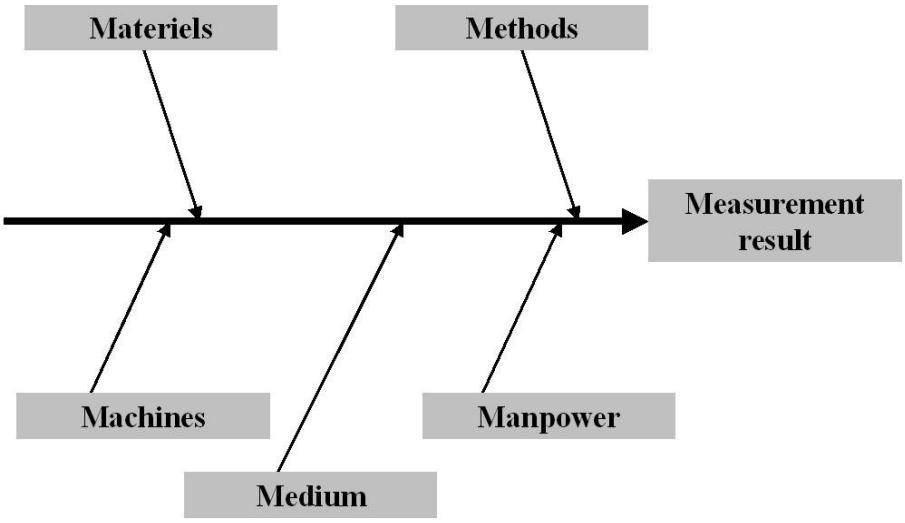

Figure 1. Ishikawa diagram

RUPTURE DETECTION: PRINCIPLE

When a rupture occurred in a cable, an acoustic wave is generated and detected by the sensors physically placed along the cable. An accelerometer is the sensitive element of each sensor. Each sensor embed a processor that permanently digitizes signal from the accelerometer and compare its amplitude to a predefined threshold. If the signal amplitude exceeds the threshold, this value is recorded and precisely dated. Then, those two datas (amplitude and time detection) are sent to supervisor [5].

The supervisor communicates with sensors and "knows" sensor relative locations (L12, L23,…) and is so able to locate the point of rupture X.

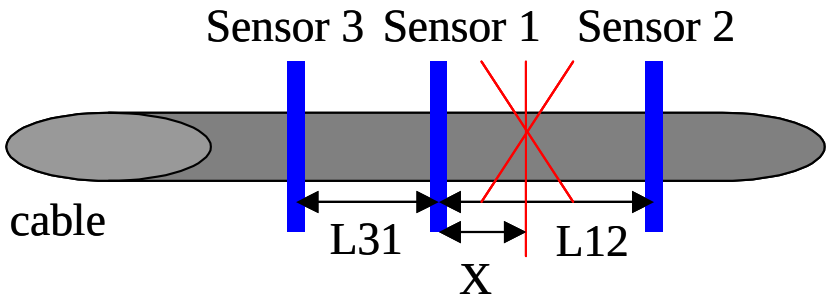

Figure 2. Rupture localization by acoustic sensors

The supervisor identifies sensors 1,2 and 3. sensors 1 and 2 are the two sensors that received the wave first. That means that the break thus occurred between those two sensors. Sensor 3 and sensor 1 enable one to compute the speed "V" of the wave. From these datas it determines the localization "X" as follows [5].

$$V=L31/\Delta t31 \quad (1)$$

$$X=1/2*(L12-V*\Delta t12) \quad (2)$$

Where Δtij denotes the delay in event detection between sensor i and sensor j.

SYSTEM CARACTERISATION

We can divide our acoustic system into two blocks; the first is the input data block constituted by:

- The sensors placed along the cable (3 at least) and which measure permanently the acceleration.
- The GPS information provided to each sensor by the satellites.

- The different actions proposed to the operator using the supervisor.

The second is the output data block constituted by the information given by the supervisor:

- The waves recorded by the sensors.
- The detected and located ruptures on the cable.
- The system events.

Influence factors

The place of installation of the sensor on the cable is full of consequence: if (as recommended) the sensor is fixed directly on the cable, the measured wave is closer to the real phenomenon, whereas if for practical reasons (access, cost of installation, …) the sensor is fixed differently then the measurements are strongly influenced by "the medium" surrounding the cable.

There is a strong dependence of the sensor response to its fixing. Indeed if the sensor is strongly fixed or not, the wave could be completely undetected by the system. The fixation system have a big influence on the result.

The sensor is sensitive to : accelerometers drift and limits, the analogical-numeric converter quality and limits (this element permit the conversion of the accelerometer signal on a 16 bits samples), the electromagnetic compatibility which could, if its raised, influence the behavior of the electronic components, and at least the good GPS cover (sometimes a satellite cover can provide erroneous information.

There is no losses on-line, all transmitted octets are received.

Each sensor has a synchronization mechanism based on recovery of the absolute hour transmitted by the GPS. The sensors have a resynchronized base of time all the 1s by the P.P.P signal of the GPS. A counter of 1/100 of a µs is reset at each P.P.S top. The precision of the P.P.S being of 200ns and the interruption of the reset is 1 µs. All the sensors receiving the satellite are synchronous on the basis of universal time with +/- 1µs.

The threshold are fixed by “training” of the cable. We try to pace the sensors thresholds “right at the top of noise” but as low as possible. Generally around 1 to 4g.

Figure 4 . The wireless platform.

CONCLUSION

This article is the beginning of the metrological study of the acoustic system. Nerveless the results obtained at this time are very promising , we hope at end to have a relative uncertainty around 10%.

When the system is in optimal conditions, the detection is assumed at 100%. The crucial point at time is to find the better solution to resolve fixation problems which are the probably most important part in the uncertainty.

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