MONITORING OF ROAD STRUCTURES – REAL TIME ACQUISITION AND CONTROL OF DATA

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ABSTRACT

The growing socio-economical importance of roads and of their structures and infrastructures, together with the most recent technological advances, encourage the development of structural health monitoring systems that, to be effective, must acquire relevant data continuously and autonomously making it available on-line or in appropriate databases. If these systems are also capable of processing data in real time and set off alarms based on the quantities acquired, they can be used to control the safety and may give an important contribution to the maintenance of structures such as bridges and tunnels, and infrastructures such as road embankments and slopes.

This work presents a system with these capabilities, developed at LNEC, which can be applied to control the safety and maintenance of road structures and infrastructures.

After a short general description of this system, several aspects are focused, such as the control of networks of the data acquisition systems, the automatic transmission, the real time removal of erroneous values, the alarm triggering and the processes of acceptance, identification and storage of data.

Finally this work refers the installation of the system developed, in several railway and road bridges, located in Portugal. The installation of this system in several structures has given an important contribution to its development.

KEYWORDS

Structural Health Monitoring; Real Time Processing; Automatic Wireless Transmission; Automation; Bridges and Viaducts

1 INTRODUCTION

Structural health monitoring was traditionally carried out by running periodical measurement campaigns. These were conducted by groups of technical staff that, during several days, performed measurements relevant to the safety and preservation of structures and infrastructures.

In the recent years semi automatic monitoring systems were developed and implemented. These systems, which are capable of acquiring data continuously and independently, are composed by networks of data loggers that acquire and store data in their internal memories. The data acquired by these monitoring systems can be manually downloaded locally or remotely via GSM modems.

The system described in this work was developed in LNEC and is considered to be the next step in the development of structural health monitoring systems. This system is able to acquire, process and transfer relevant structural and conservation data, make it available on-line, store it in relational databases and trigger alarms.

The system developed is already installed and working in two railway bridges, São João Bridge and the new railway crossing over river Sado, and it's being installed in several long span road bridges.

2 STRUCTURAL HEALTH MONITORING SYSTEM

2.1 Overview

The monitoring system described in this work is able to autonomously acquire data from several networks of data loggers via TCP/IP or serial port (RS232 or RS485). It also includes a compact industrial computer installed in the monitored structures, a server located at LNEC, and communication units such as HSDPA routers to establish the connection between LNEC and the monitored sites, radio modems and *wifi* access points and gateways.

The industrial computer that controls the network of data loggers also sends data to a server in LNEC. This server receives, identifies and stores data from all the structures monitored. It also allows the data to be viewed and accessed by the structures' owners through internet. Figure 1 shows a scheme of the monitoring system idealized and developed.

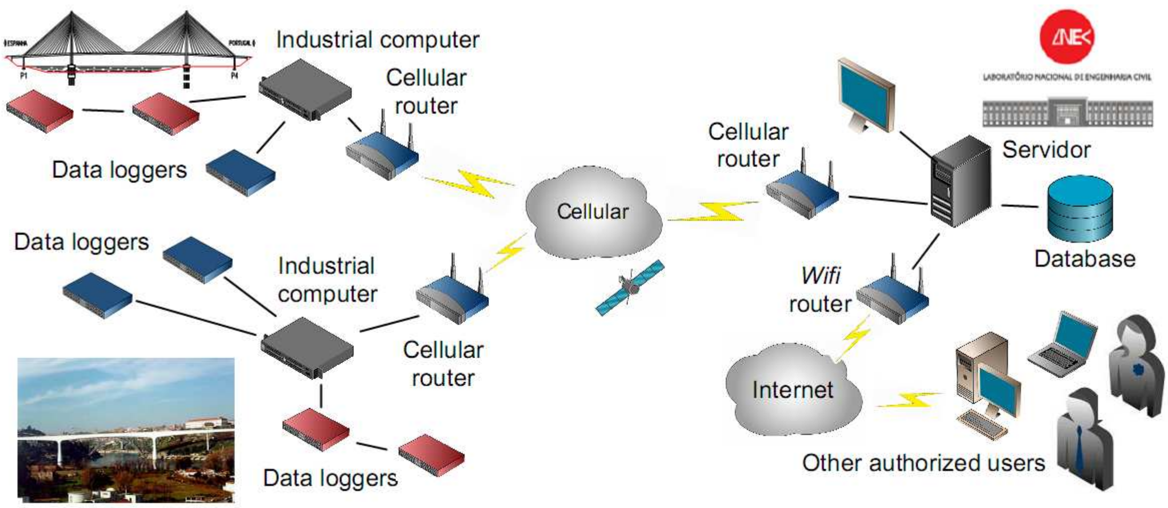

Figure 1 – Structural health monitoring system.

The procedures and routines carried out by the system are mainly written in LabVIEW programming language, however other languages are also used such as Hayes Command Set to control the communications between structures and LNEC, command line scripts to control the operating systems and the file systems, SQL for storage in relational databases and the data loggers native languages for controlling these units.

2.2 Data acquisition

The data acquisition process requires execution of procedures that can be ran locally on the data loggers or on a computer that is controlling them, leading this last option to simpler, more flexible and, most of the times, more economical monitoring solutions because it standardizes procedures and communications and allows the use of simpler and less expensive, data loggers. However, the installation and use of a compact industrial computer requires drivers or, in other words, links between the language in which the main procedures are written (LabVIEW) and the data loggers native language. These procedures (drivers) must be able to send commands to the data loggers in a suitable way. Usually the drivers provided by the manufacturers do not show full compatibility with the loggers' expected behavior.
The drivers written and included in the monitoring system described in this work allow the communication and control of several brands and models of data loggers through serial port and can be divided into two groups according to the data acquisition philosophy: through queries, i.e., sequences of questions and answers made to each data logger, and through the acquisition of a streams of data in which the data loggers are programmed to send data continuously to the computer who reads it according to the idealized monitoring behavior. The first driver design philosophy allows more control over the acquiring process. It is possible, through this method, to change the acquisition process at any time however, the second approach allows for much greater sampling rates. The flowcharts for the high-level procedures of both driver design philosophies are shown in Figure 2.

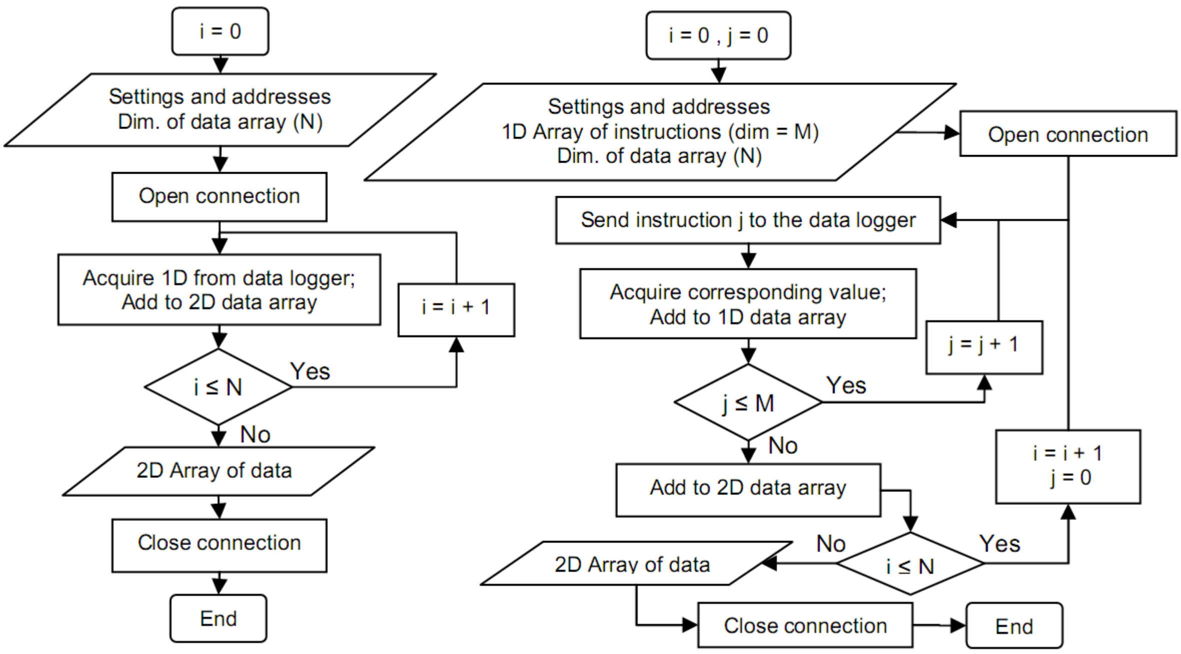

Figure 2 – Acquisition driver procedures.

2.3 Real time processing

The processing carried out by the system, in real time, uses statistical method for removing unwanted values from the data acquired and is based on the modified z-score method, already studied in bridge monitoring [1]. It allows the identification of outliers, z_i, in samples of any dimension using their median, $\tilde{x}$, the median of $|x_i - \tilde{x}|$ and a normalization constant, c_1.

The outlier identifier of this method is shown in Eq. (1) assigns the same weight to upper and lower deviations around the median value. To overcome this issue an identifier proposed by Rousseuw and Croux [2] (shown in Eq. (2)) was used, which is based on the modified z-score method but more efficient when applied to asymmetrical samples since it is based on the medians of their consecutives values. This procedure can be time and memory consuming, especially when applied to high sampling rates.

$$z_i = \frac{|x_i - \tilde{x}|}{c_1 \times \text{median}\left(|x_i - \tilde{x}|\right)} \tag{1}$$

$$z_i = \frac{|x_i - \tilde{x}|}{c_2 \times \text{median}_i\left(\text{median}_j |x_i - x_j|\right)} \tag{2}$$

The identification of the outliers is made by comparison with reference values, Z(N,α), which, for the system developed at LNEC, were obtained from Little and Rubin [3] for a confidence interval of 95%. The process of identification of outliers considers a second condition, shown in Eq. (3), which is defined to prevent false detections in steady samples, with small ratio deviations from the absolute value.

$$z_i = \begin{cases} \leq z(N,\alpha) \rightarrow \text{valid value} \\ > z(N,\alpha) \rightarrow \dfrac{(x_{MÁX} - x_{MIN})}{x} \begin{cases} \geq 5\% \rightarrow \text{outlier} \\ < 5\% \rightarrow \text{valid value} \end{cases} \end{cases} \tag{3}$$

After removing the outliers, and in case the removals are less than 20% of the sample size, the system computes the average of the “clean sample” and returns it as valid data acquired, otherwise the sample is considered invalid.

2.4 Transmission and storage of data

The processes of transferring data from the monitored structure to the database located at LNEC are carried out with the main concern of preserving the data acquired.

Inexistence of file directories or the files themselves can be troubling and even make the procedures stop. For that reason the system always checks for the existence of the file and the directory to write and if one of them does not exist, it is automatically created prior to the writing of data. Moreover it also searches for the file headers and writes them in case they are not yet created. This process is carried out twice after the acquisition procedure has been carried out. First using a permanent file, which is stored locally on site, secondly for a temporary file, which is to be sent to LNEC.

The temporary files are automatically compressed and sent to LNEC, by GPRS or HSDPA, for being stored, according to a predefined schedule. Their compression is a crucial task since it reduces the size of an ASCII file up to 99% (for a .zip file extension), reducing greatly the time of transfer and, thus, the probability of failure or corruption of data. The compressed files are labeled with headers and their extensions changed to allow their identification, by the routines running in LNEC, as data is being acquired. These routines check for the existence of files, according to their extension, and identify them as compressed data files or alarm files. When a compressed data file is detected, the system will uncompress it and store the data according to the headers it contains.
The on-line availability of data is made using a web server located at LNEC to enable viewing data through a browser. The setting of web servers on the compact industrial computers placed on site, where there is usually low data transfer rate available through cellular communication, could compromise the regular data transfer, which is considered to be the most important task of the cellular communication. The limitations concerning data transfer through cellular communications have already been noticed in previous monitoring works [4].
The system routines executing in LNEC also include the rearrange of the received data so that it can be stored in relational databases, using SQL and a commercial database management system.

2.5 Triggers and alarms

The setting of alarms based on real time data acquisition can be of extreme importance for controlling the safety of road structures and infrastructures. They can prevent unsafe structural situations, help guaranteeing the monitoring system's good functioning, and also allow to change it's behavior over time according to, for example, losses of power or communication, extreme ambient conditions such as atypical wind speed or earthquakes, etc.
These routines identify alarm situations based on a modified Schmitt Trigger comparator circuit, whose behavior is illustrated in Figure 3. The modification, carried out for the monitoring system developed, consist on the possibility of setting alarms when the trigger returns 1 (upper trigger) or when it returns 0 (lower trigger).
The alarm routines can be based on an unlimited number of acquired measurements and allow the setting of conditions based on groups of values. It is possible to define an alarm that only sets off if all values of a group activate the Schmitt trigger (AND condition) or if at least one of the values triggers it (OR condition. Other conditions can also be defined.
When an alarm is triggered a file is created, on the site's industrial computer, and sent to LNEC. The server, which receives an ".alarm" extension file, reads its' headers and sends SMS or e-mails to a list of predefined numbers or addresses.

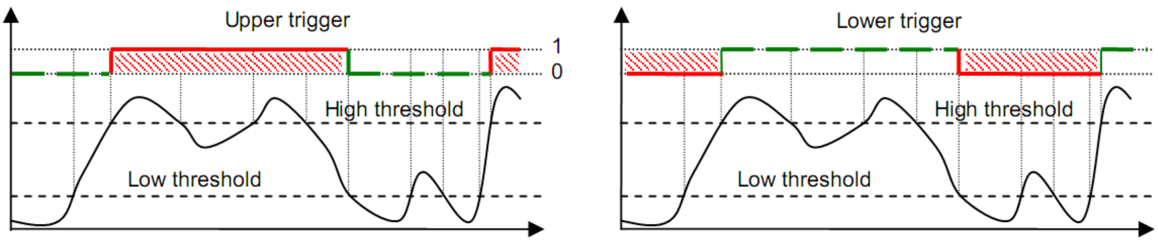

Figure 3 – Trigger based on Schmitt circuit.

3 APPLICATION TO REAL ROAD STRUCTURES

So far the described monitoring system has been totally installed in two railway bridges: São João Bridge (Porto) and the new crossing over River Sado (Alcácer do Sal). At the moment it is also being installed on two road bridges: Salgueiro Maia Bridge (Santarém) and International Bridge over River Guadiana.
São João is a framed bridge with a 250m central spam. It is being monitored with a network of 7 data loggers connected by optical fiber and acquiring data from 242 measuring devices. Data is regularly sent, from this bridge to LNEC, twice a day. The New crossing over River Sado is a steel-concrete composite bow string bridge with three 160m span. It is still in construction phase and has a network of 5 data loggers that will control a total of 250 measuring devices in exploration phase.
The road bridges in which the system is being installed are both cable-stayed bridges. The Salgueiro Maia bridge has a 250 m central span and a network of ten data loggers acquiring data from 243 measuring devices. The International Bridge over River Guadiana has a central spam of 324 m and the monitoring system consists of a network of 4 data loggers controlling 85 measuring devices.

4 CONCLUDING REMARKS

The monitoring system developed in LNEC carries out the tasks for which it was idealized: automatic acquisition, long distance transfer and storage, real time processing and alarm triggering.
The system is installed and running flawlessly, up to the moment, in two railway bridges: São João Bridge (Porto) and New crossing over River Sado (Alcácer do Sal).
The experience acquired suggests that the system's architecture is adequate for structures and infrastructures monitoring systems whose purpose is to control safety and maintenance often or in real time. Procedures like storage and sharing of data must not be executed on the remote (on site) computers otherwise the integrity of data can be compromised.
The analysis of the acquired data and the challenges faced in the installation of the system on the two railway bridges suggests that the developed system is successful in processing the data to remove outliers and in alarm triggering.
In the future it is expected that this system will be installed in all road bridges whose monitoring is carried out by LNEC.

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