Wireless transmission system for a bridge application

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ABSTRACT: Acquisition of measurements in situ usually suffers from a serious inconvenience which is the lack of automation and the consequent necessity of frequent outdoor actions by the measuring team. In order to improve this situation, a system of wireless transmission (WT) of measurement data has been proposed. Such system should be very useful in a number of applications related to structural health monitoring (SHM). This paper reports a customized application of the WT system to rail traffic monitoring and SHM of a railway bridge. The idea is to equip sensors mounted on the bridge with electronic modules able to transfer data to the local processing unit on the bridge in the short-range wireless mode. Once the data has been collected by the local unit, it will be wirelessly transferred in the far-range mode to a remote analysis centre using the GSM technology.

1. INTRODUCTION

Many in situ installations of Structural Health Monitoring (SHM) systems suffer from a troublesome and time-consuming way of data acquisition via standard cables. To alleviate the man effort related with this way of acquisition, an alternative solution of wireless transmission (WT) of measured data from the field to analysis centre can be proposed. This paper takes up the practical issue of designing and implementing a system for such wireless transmission, mounted on a railway bridge and transferring data to a remote analysis centre.

The developed WT system constitutes a part of an integrated patent-pending monitoring system proposed by Adaptronica and Contec (2009) for railway bridges. The integrated system consists of two components – weigh in motion (WIM) part for identification of train load and SHM part for assessing the bridge state. The proposed WT system will be implemented in both the WIM and SHM parts of the integrated system. Two aspects of wireless transmission are considered – short range (in the vicinity of the bridge) and far range (from the bridge to the centre of analysis).

Thorough in situ tests of the WT system will take place in summer 2009 as a part of monitoring campaign carried out on the railway truss bridge in Nieporet near Warsaw, made available for experimental research by Polish Railways. In this paper only laboratory tests will be presented.

2. THE INTEGRATED MONITORING SYSTEM

2.1. Layout of the monitoring system for railway truss bridges

The investigated object is a 40-m-span, 8-m-height steel railway bridge over a channel in Nieporet near Warsaw. The layout of the bridge is typical for railway infrastructure in Poland, so possible transfer of systems developed for the chosen object should not be difficult. The bridge, depicted in Fig. 1, carries just one centrally located railway track and is not subjected to heavy traffic. The line is a sort of northern by-pass of the Warsaw railway junction.

Fig. 1 Investigated railway truss bridge in Nieporet

The in-situ stand, illustrated in Fig. 2, consists of two parts corresponding to the WIM and SHM parts of the integrated monitoring system. The WIM part is supposed to identify dynamic load exerted on rail by passing trains. This load will provide input for the SHM system, mounted on the bridge. The role of the SHM system is to collect dynamic responses of the structure using piezoelectric sensors. On the basis of these responses and a calibrated numerical model, identification of possible damage in the bridge will be performed as described in Holnicki-Szulc (2008).

The layout of sensors for the WIM and SHM parts of the whole system is shown in Fig. 2. Each part of the system will work independently in the sense of data collection and transfer. The only link between the two parts is provided by activating sensors, connected to the WIM system, which should remotely initiate the acquisition of data in the SHM system.

There will be two levels of wireless transmission realized. The first level is a local, short-range transmission. First the activating sensor initiates acquisition in the WIM system and also informs the data processing unit (DP1) of the WIM system to transmit a signal to wake up the data processing unit (DP2) of the SHM system using short-range WT. Another local WT takes place between the DP2 and the piezoelectric sensors mounted on the bridge (PB) and equipped with transceivers. First the PBs receive a signal from DP2 to collect data as a train is passing, next they transmit the data to DP2 as soon as the train has left the bridge. Once the data from the WIM and SHM systems have been acquired, an independent far-range transmission starts for both the parts taking advantage of up-to-date GSM protocols for data transfer.

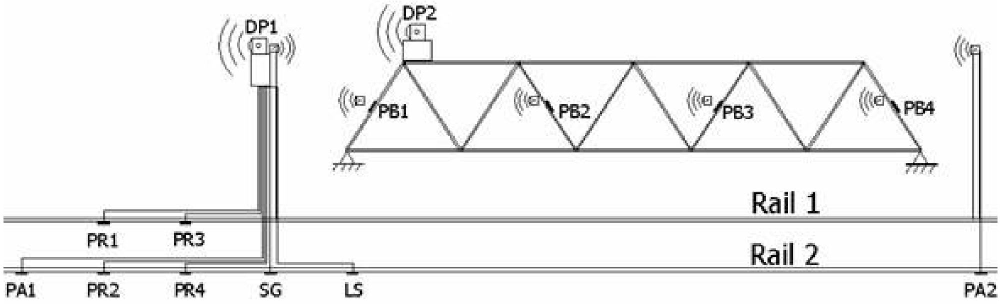

Fig. 2 Layout of sensors mounted for WIM and SHM purposes and scheme of wireless transmission of data: PA – piezosensor for system activation, PR – piezosensor on rail, PB – piezosensor on bridge, SG – strain gauge, LS – laser sensor, DP – data processing unit

2.2. Sensors used and data to be transferred

Piezoelectric sensors were chosen to collect strain responses in time. An example of a piezo-ceramic sensor is shown in Fig. 3.

Fig. 3 Piezoelectric sensor used for collection of responses

As the integrated system consists of two parts, there are two types of time signals recorded by piezo-sensors. These time signals need to be pre-processed in situ before starting their wireless transfer to a remote centre.

The first type of signal corresponds to the load identification block and the associated weigh in motion procedure for running trains. An example of the time signal detected by the weighing piezosensors on the rail (PR), is depicted in Fig. 4.

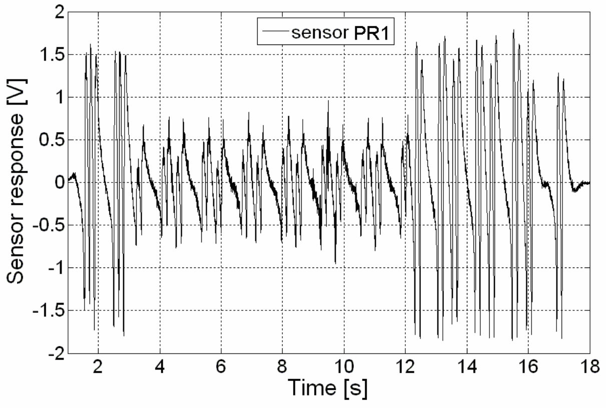

Fig. 4 Time signal collected by the WIM subsystem

The second type of signal corresponds to the bridge health monitoring block and the associated damage identification procedure. An example of the time signal captured by piezosensors on the bridge (PB) is shown in Fig. 5.

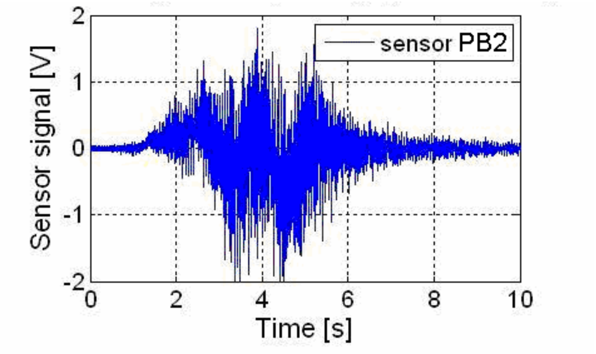

Fig. 5 Time signal collected by the SHM subsystem

3. COMPONENTS OF THE WIRELESS TRANSMISSION SYSTEM

3.1. General assumptions

The main assumption is that both parts of the integrated monitoring system transfer data independently. The reason for making the transmission independent is a much more frequent need to process the WIM data. Apart from identifying dynamic load, they can also be used to monitor daily traffic. The analysis of the current bridge state (SHM subsystem) is performed regularly but not necessarily on daily basis. Therefore the amount of data and frequency of transmission for the WIM and bridge DP units will be different. Another explanation is that the WIM point may be located too far from the bridge, so one unit for the whole monitoring system might be impractical.

In the authors' opinion, the wireless system for the bridge application should be characterized by a relative simplicity, high reliability and low energy consumption. The major challenges to be faced from the electronic viewpoint are:

- equipping the system with a maintenance-free source of power,
- designing durable small-size and energy-saving components of the wireless transmission system,
- pre-processing of time signals in situ and optimizing them for far-range wireless transfer.

Detailed proposition of the wireless solutions will be focused on the bridge (SHM) subsystem later on. This is explained by the fact that both the short- and far-range transmission has to be implemented for the bridge. The far-range transmission for the WIM subsystem will be analogous.

The proposed bridge system, schematically shown in Fig. 6, consists of three major components – a number of the measuring units integrating piezoelectric sensors with associated electronics described as PB, the DP unit and two activating sensors (PA). The role of the activating sensors is to wake the system up for the time of train ride only and put it in a passive mode afterwards.

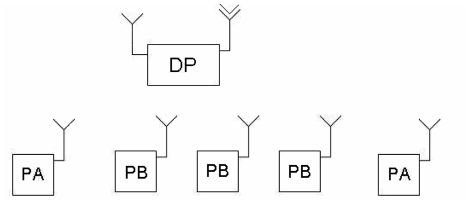

Fig. 6 Scheme of the local wireless transmission system

3.2. Integrated bridge sensor

Each measuring unit collects analogue signals from the piezoelectric sensors mounted on the bridge and transfers them to the DP unit via an embedded transceiver using a local mode of wireless transmission. A scheme of the integrated bridge sensor is shown in Fig. 7.

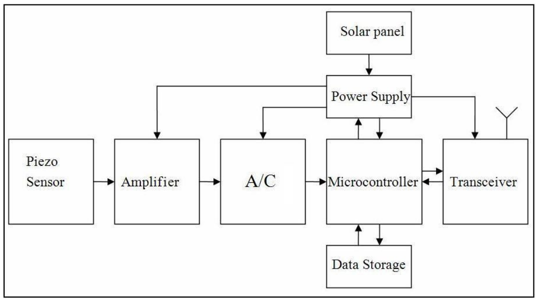

Fig. 7 Scheme of the integrated bridge sensor (PB)

The proposed electronics associated with each measuring unit is designed so as to keep the power supply at the 50 mW level. At first stage of testing, a lithium-ion battery will be used. Subsequently, a solar cell should be provided to recharge an in-built battery for long-term, maintenance-free operation. A crucial feature of the system resulting in significant energy savings will be its intermittent operation. The system will be activated by one PA from each direction. It will remain active only during the passage of a train over the bridge. Otherwise it will switch to a passive, energy-saving mode. The only sensors operating in the stand-by mode will be the two activating sensors PA. The difference in energy consumption is 3 order of magnitude as the microcontroller of the DP unit needs 0.4 mA when active and just 0.6 μA when passive.

The integrated bridge sensor will perform analogue to digital conversion of a signal before sending it to the DP unit. To this end, a 12-bit analogue-digital converter providing proper sampling will be used. The available short-range transmission distance is estimated to reach approx. 100 m. All measuring units are supposed to start data acquisition simultaneously thus have to be properly time-synchronized by triggering signals from the DP unit.

3.3. Data processing unit

The tasks of the DP unit are: sequential collection of digital signals from the bridge sensors, signal compression and transfer to a remote computing centre for analysis. Thus the DP unit should consist of a transceiver to collect the signals from various measuring units, microcontroller for signal processing, sufficient memory buffer enabling storage of data and additional RS-232 port for possible *in-situ* acquisition. A scheme of the DP unit is depicted in Fig. 8. Advantage of the GSM protocols is taken to transfer the digital data to a remote computational centre.

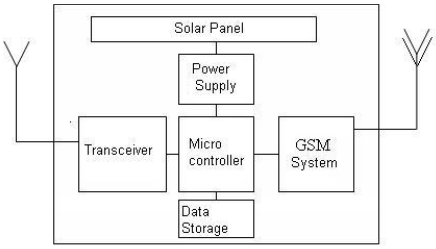

Fig. 8 Scheme of the data processing unit (DP)

4. FIRST ASSEMBLY AND LABORATORY TESTS

Currently the work is focused on development of specific modules (see Fig. 9) of the system for both the short- and far-range wireless transmission. The electronics of the PB has been assembled and tested in the laboratory. It is planned to install and test the whole system of wireless transmission in situ in 2009.

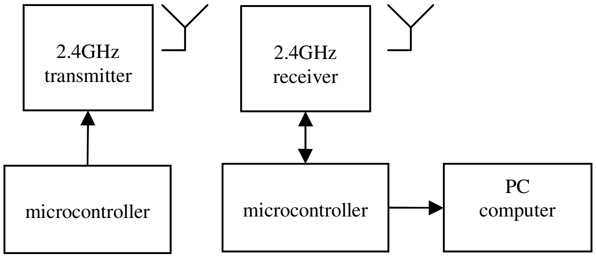

Fig. 9 Set-up for the short-range WT module tests

The short-range transmission system for the PB electronics was tested in laboratory conditions inside a building located in the centre of Warsaw, in which the level of electromagnetic background was high. The experimental set-up included two independent transmission modules each one consisting of a low-power 2.4 GHz transceiver and an 8-bit RISC microcontroller. The receiver was connected to a stationary PC computer, which was used as a data storage unit. The transmitter module was placed in different locations at distances from 0 to 30 m from the receiver. Each transmitted package consisted of 2 bytes of data. Due to difficult test conditions, the power of the transmitter was set to 0 dBm and the length of the transceiver address was 40 bits.

The results, presented in Fig. 10, show that the performance of the tested low-power system decreases rapidly at distances beyond 20 m. Preliminary tests conducted earlier at the in-situ stand (cf. Fig. 2) proved that the maximum operating distance can be extended to 50 m, which is satisfactory for the developed SHM system for the bridge.

Fig. 10 Lost-to-sent data ratio vs. transmission distance for the short-range WT module (lab-test conditions)

5. CONCLUSIONS

An original system for wireless transmission of data has been presented. Its in-situ implementation is envisaged for a railway truss bridge. The system is supposed to operate in two modes. In the short-range mode the data is transferred from the sensors mounted on the bridge to a local data processing unit. Then the far-range mode of transmission should transfer data from field to a remote centre of analysis. First successful laboratory tests of the short-range transmission have been described. Future work will be concentrated on the in-situ implementation and testing.

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