Title: Wireless transmission system dedicated to SHM of railway infrastructure

Authors: Damian Sala[1]
Piotr Pawłowski[1]
Przemysław Kołakowski[1,2]

ABSTRACT

In-situ measurements collected with standard cabling suffer from the serious disadvantage of no automation, which implies frequent visits to the monitored structure in order to gather the requested data. For minimizing the man effort involved, a system of wireless transmission (WT) of in-situ collected data has been proposed. Principal ideas of such system should be pretty universal in a number of applications related to structural health monitoring (SHM). However each WT system should be customized for a specific application to provide the best performance. The proposed WT system is dedicated to rail traffic monitoring and SHM of railway bridges. The idea is to design smart sensors to be mounted on the bridge and equipped with electronic modules for short-range wireless transfer of SHM data. The far-range wireless transfer from the local bridge unit to remote analysis centre will be performed using the GSM technology.

INTRODUCTION

Many in-situ installations of SHM systems suffer from a troublesome and time-consuming way of data acquisition via standard cables. In order to facilitate data collection related with this way of acquisition, an alternative solution of wireless transmission of the measured data from the field to analysis centre can be proposed. This paper takes up the practical issue of design and implementation of a system for such wireless transmission. The objective of the system mounted on a railway bridge is to transfer 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.

---

[1]Smart-Tech Centre, Institute of Fundamental Technological Research, Polish Academy of Sciences, Świętokrzyska 21, 00-049 Warsaw, Poland, e-mails: dsala@ippt.gov.pl, ppawl@ippt.gov.pl, pkolak@ippt.gov.pl, web: http://smart.ippt.gov.pl
[2]Adaptonica sp. z o.o., R&D company, Szpitalna 32, 05-092 Łomianki, Poland, web: http://www.adaptronica.pl

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 keep both the WIM and SHM parts of the integrated system in service. 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).

Systematic in-situ tests of the WT system will take place in summer 2010 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.

BRIDGE AND RAIL TRAFFIC MONITORING SYSTEM

The investigated object is a 40-m-span, 8-m-height steel railway bridge spanning a channel in Nieporet near Warsaw. The layout of the bridge is typical for railway infrastructure in Poland, so possible adaptation of the system developed for the selected object should be straightforward. The bridge, depicted in Fig. 1, carries just one centrally located railway track and is not subjected to heavy traffic.

FIGURE 1. Railway truss bridge in Nieporet near Warsaw

The in-situ stand, illustrated in Fig. 2, consists of two subsystems 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.

Two levels of wireless transmission will be implemented. 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 smart sensors mounted on the bridge PB and equipped with transceivers. First the PBs receive a signal from DP2 to start collecting 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 the GSM technology of data transfer.

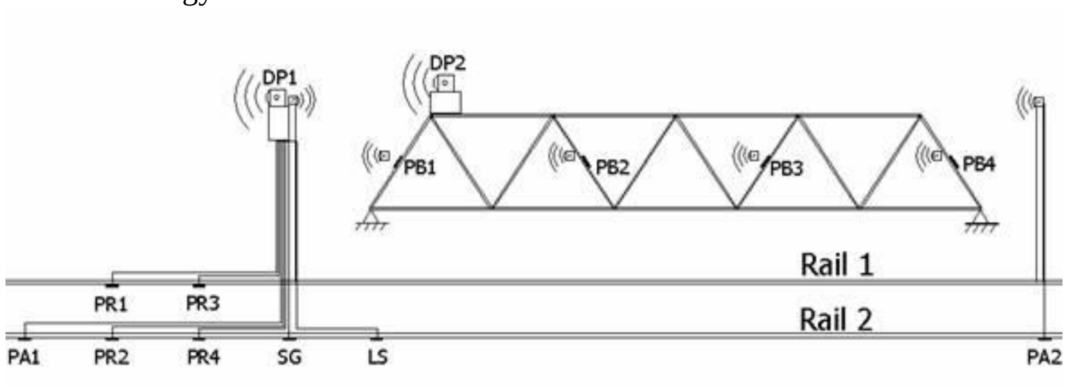


FIGURE 2. Layout of sensors mounted for WIM and SHM purposes and scheme of wireless transmission of data: PA – piezosensor for system activation, PR – piezosensor on rail, PB – piezosensor on bridge, SG – strain gauge, LS – laser sensor, DP – data processing unit

ASSUMPTIONS FOR THE WIRELESS TRANSMISSION SYSTEM

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 (WIM subsystem), they can also be used to monitor daily railway 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 here. 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. 3, 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.

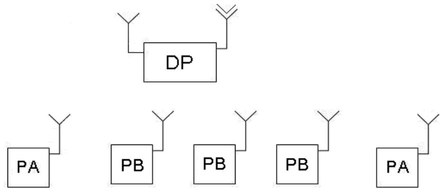


FIGURE 3. Configuration of the short-range WT system

SHORT- AND FAR-RANGE TRANSMISSION

Each measuring unit collects analogue signals from the piezoelectric sensors mounted on the bridge and transfers them to the DP2 unit via an embedded transceiver using a local mode of wireless transmission. A scheme of the integrated bridge sensor is shown in Fig. 4.

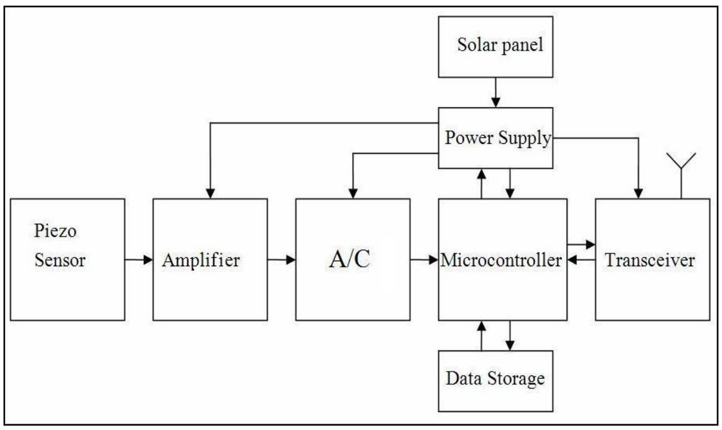


FIGURE 4. Scheme of the integrated bridge sensor (PB)

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 orders of magnitude as the microcontroller of the DP unit needs 0.4 mA in the active state and just 0.6 μA in the passive state.

The integrated bridge sensor will perform analogue to digital conversion of a signal before sending it to the DP2 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 internal-clock-driven triggering signals from the DP2 unit.

The tasks of the DP unit are: sequential collection of digital signals from the piezoelectric 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 emergency *in-situ* acquisition. A scheme of the DP unit is depicted in Fig. 5. Advantage of the GSM technology is taken to transfer the digital data to a remote computational centre.

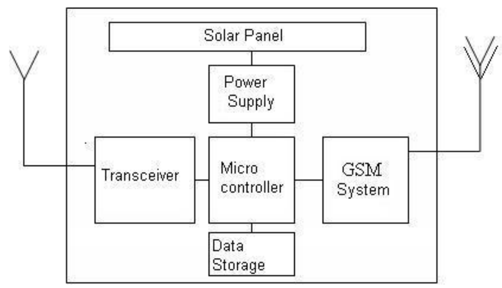


FIGURE 5. Scheme of the data processing (DP) unit of the WT system

TESTS OF THE WT SYSTEM

Tests of the WT system were conducted for both levels of data transmission i.e. short- and far-range.

Short-range transmission tests were performed in laboratory conditions in a building, where the level of electromagnetic background was high. The experimental set-up included two independent transmission modules which contained a 2.4 GHz transceiver and an 8-bit microcontroller (see Fig. 6). One part for data collection was connected to a PC and the other one responsible for packet transmission was placed in different locations. This test was divided into two parts: first inside and then outside the building.

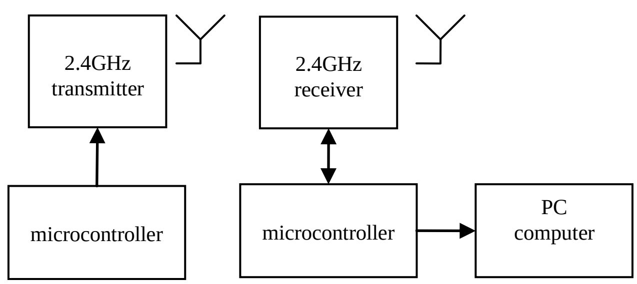
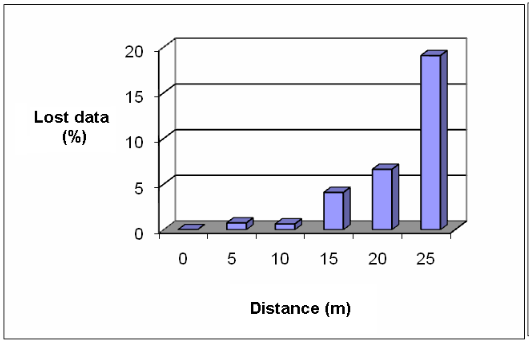


FIGURE 6. Test set-up for the short-range WT module.

Results of the short-range experiment are presented in Fig. 7. This is supposed to simulate the communication between a bridge sensor PB and the DP2 unit.

The far-range tests were carried out in lab conditions too. They relied on a GSM G24 modem, which was connected to a PC computer via the RS-232 port. A server application for reception of data was running on another PC computer connected to the Internet via a mobile phone. The initial signal from a piezosensor is perfectly overlaid with the data transferred by the WT system, which is depicted in Fig. 8.



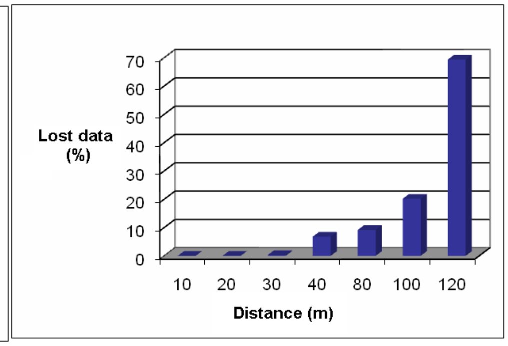


FIGURE 7. Lost data packages vs. distance for the short-range transmission (inside building - left; outside building - right).

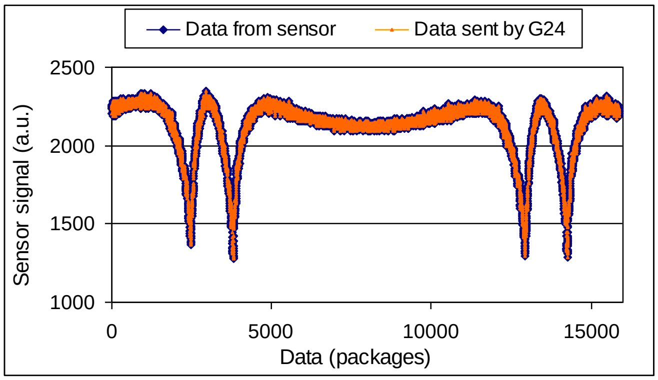


FIGURE 8. Results of the far-range test performed by the G24 modem

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 the local data processing unit. Then the far-range mode of transmission should transfer data from the field to remote centre. First successful laboratory tests of the short and far-range transmission have been described. Future work will be focused on in-situ implementation and testing.

ACKNOWLEDGEMENTS

The financial support from the projects “Smart Technologies for Safety Engineering - SMART and SAFE” – TEAM Programme – granted by the Foundation for Polish Science and “Health Monitoring and Lifetime Assessment of Structures” – MONIT – POIG.0101.02-00-013/08-00 from the EU Structural Funds in Poland is gratefully acknowledged.

The authors express their gratitude to Polish Railways (PKP PLK S.A.) with special thanks to Mr. Kazimierz Szadkowski for his favourable attitude.

REFERENCES

1. Adaptronica sp. z o.o., Contec sp. j. (2009) *A method of monitoring the truss structure of a bridge and a system for monitoring the truss structure of a bridge*, patent pending application no. P. 387115 submitted to the Polish Patent Office (in Polish)
2. Holnicki-Szulc, J. (Ed.) (2008) *Smart Technologies for Safety Engineering*, Wiley.