Remote monitoring: New cost-effective, self-sufficient and versatile systems will change the way bridges are monitored

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Summary

Remote monitoring of bridges and other structures can serve a wide range of purposes, providing continuous records of almost any variable in a bridge's condition. In particular it has a large part to play in the maintenance of older structures, and in many cases could potentially be used to allow costly and disruptive bridge renewal works to be postponed or even deemed unnecessary. Modern automated monitoring systems can be configured to analyse the data gathered, present it in graphic or tabular format, and make it available to an authorised user anywhere in the world via the internet. Automatic notification by e-mail or SMS of the reaching of predefined alarm values of any measured variable can also be provided. Further potential uses, such as provision of engineering and bridge usage data, also contribute to ensure that automated remote monitoring of structures will continue to become more widely used in the development and maintenance of structures around the world.

Keywords: Monitoring, bridges, structures, measurement, forces, movements, safety, transmission of data, early warning

1. Introduction

Monitoring of bridge structures has developed in a short period of time from the time-consuming, labour-intensive manual exercise it once was, to benefit from the technologies of the Information Age. Monitoring systems are now available which are highly automated, independent and versatile, and which can be tailored to provide almost any type of information that may be required on the condition of a bridge and the environment and loading to which it is subjected. This paper describes some of the uses such monitoring systems can serve and the benefits they can offer, and the development of a typical solution, from identification of need and desired benefits to installation of the system on a structure. Some sample projects are then described to demonstrate the great range of purposes such remote monitoring systems can serve.

2. The need for monitoring systems

Bridge owners need to maintain an understanding of the condition of their structures, and the loading and environment to which they are subjected, for a variety of reasons. Many bridges which were built in the past to different design and construction standards may not necessarily satisfy today's increasingly rigid safety demands. Furthermore many structures may have been built on unstable ground or be subjected to particularly harsh environmental conditions. Therefore in many cases there is a need for structures to be continuously monitored to ensure that relevant data such as changes in bridge movements or bearing forces, which might indicate a critical condition, are recognised sufficiently early to allow remedial action to be taken. The traditional manual bridge inspection is either incapable of picking up the required data, or the inspection interval is not sufficiently tight to ensure that changes in a structure's condition are recognised early enough. Therefore a market has developed for a product which can continuously monitor a structure at reasonable cost to the owner.

Modern monitoring systems can be designed to constantly measure changes in parameters such as length, position, force, pressure or temperature. This information is measured at desired time intervals and recorded for analysis. The potential applications of automated monitoring systems are almost unlimited, but would fall under the following general areas among others:

- Safety concerns – ensuring immediate notification of the occurrence of a change in a bridge's condition that may indicate that the structure is becoming or has already become unsafe to use. Use of such a system can enable the authority to have much-increased confidence in the available information about the bridge's condition, potentially allowing costly and disruptive remedial works to be postponed or even deemed unnecessary.
- Engineering data – supplying records of the loading and movements to which a bridge is subjected, and the structure's response to these conditions;
- Usage data – providing records, such as weight and speed, of traffic using the bridge. Cameras can even be integrated in the system to gather photographic proof of traffic events.

3. Key features of a modern remote monitoring system

In its most basic form, a modern monitoring system consists of a computer unit, at least one sensor (which may measure some variable such as length, position, force, pressure or temperature) and wiring to connect the sensors to the computer unit. A power source is also required (for instance, a connection to the local power supply system), and the computer requires a certain capacity to store data (memory).

A typical central computer unit, with connection points for the cables from each connected sensor, is shown in Figure 1.

These key requirements are summarised in Table 1.

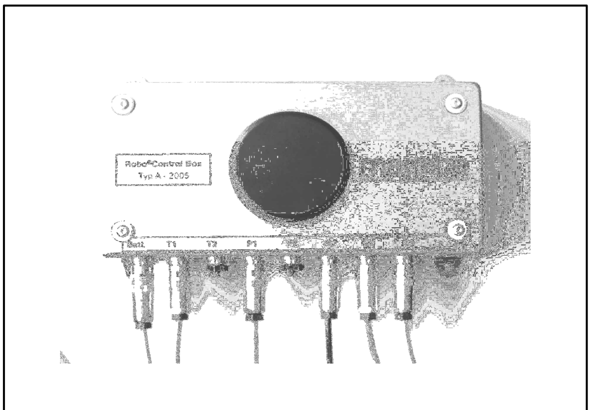

Figure 1: Central computer unit

Required features
Central computer unit (with memory capacity to store data collected)
Sensor(s)
Wiring to connect sensors to central computer unit
Power supply (basic version: connection to local power grid)
Means of downloading data from the central computer unit (e.g. laptop computer)

Table 1: Basic requirements of a modern automated monitoring system

However more sophisticated systems can also offer additional features, to enhance the capabilities of the system depending on local circumstances and clients' requirements.

An independent power supply may be particularly beneficial where the structure to be monitored is not located close to an existing power supply network. Such an independent power supply may be realised by use of battery packs or solar energy panels. A solar panel which provides power to a monitoring system in the Swiss Alps is shown in Figure 2. This solar panel provides the monitoring system with sufficient power to operate 24 hours a day, 365 days a year (regardless of time of day, weather or season). Use of such a solution facilitates provision of a monitoring system in even the most remote area.

Figure 2: Solar panel of monitoring system

The basic monitoring system described above has a capacity to store data, but this data must then be physically downloaded from the computer unit in order to be available for analysis. This may be sufficient in many cases, but often it is desirable to have the data automatically transmitted to another computer. This automatic transmission offers two benefits: firstly, it saves the time and effort required for a trained operative to visit the bridge site to download the data at regular intervals; and secondly, it results in real-time data being available to the bridge owner at all times. This immediate availability of data to the bridge owner may be particularly useful, for example, where safety concerns exist, as the bridge owner will have immediate access to data which may indicate a problem that requires attention (for example, unusually large movement of a bridge deck or excessive force on a bridge bearing).

The data can be transmitted from the bridge via a fixed line telecommunications network, where such a network exists. Alternatively a mobile (cellular) telecommunications network can be used.

Once the data has been transmitted from the site, it may be made available in different ways to the user. It may be e-mailed direct to a user in the form of basic numerical data, or it may be processed by a central server and made available in user-friendly format, using graphs, diagrams and so on. The data can then be exported in the form of a spreadsheet as desired. To further enhance user-friendliness, the processed data can be made available via the internet – an authorised user can log on to a secure website and access the information at any time, from anywhere in the world.

Of course the fact that information is available for downloading at all times does not mean that it will be downloaded when it is needed, or that the importance of the information will be recognised when it should be. Therefore modern monitoring systems can also offer automatic notification by SMS (text message) or e-mail to the bridge's engineers should a parameter's pre-defined alarm values be exceeded or other specified conditions arise.

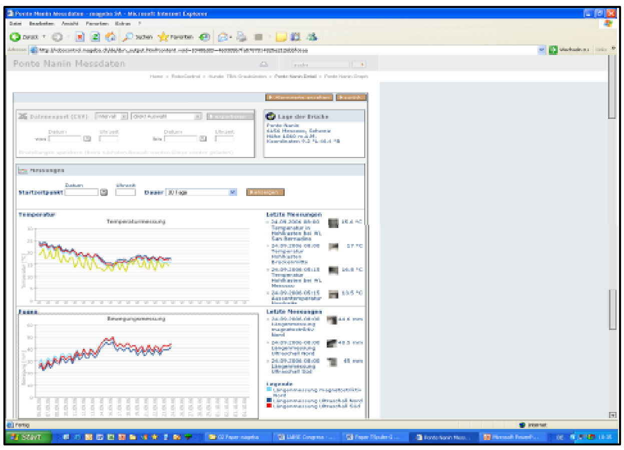

Figure 3: Typical output from computer analysis

Figure 4: Camera on bridge

Finally, it should be noted that additional systems or add-ons may be integrated into a monitoring system as required. Figure 4, for example, shows a camera which was installed on a bridge to automatically record photographic evidence of traffic events.
These optional features are summarised in Table 2.

Optional features
Independent power supply – battery pack
Independent power supply – solar panel
Automatic transmission of data – via fixed line telecommunications network
Automatic transmission of data – via mobile (cellular) telecommunications network
Processing of data and presentation in graphical format
Availability of information via internet (following logging on to secure website)
Automatic notification of the occurrence of "events" (such as excessive movements)
Integration of additional systems such as cameras

Table 2: Optional features of a modern automated monitoring system

4. Development of a monitoring system

If a client believes that an automated system may be of use in the monitoring of a particular structure, or if the availability of the data which a monitoring system can provide could be useful for any other reason, a preliminary consultation to discuss the possibilities is recommended, to confirm that the client's wishes can be satisfied at reasonable cost, and to select the optional features to be included.

A survey of the bridge may be necessary to establish the optimal positioning of the various parts and to facilitate proper planning and logistics, however for uncomplicated systems, the information available from existing drawings is likely to be adequate to allow a schematic solution to be developed. An example of such a schematic representation of a proposed system (showing only type and positioning of sensors) is shown in Figure 5 below.

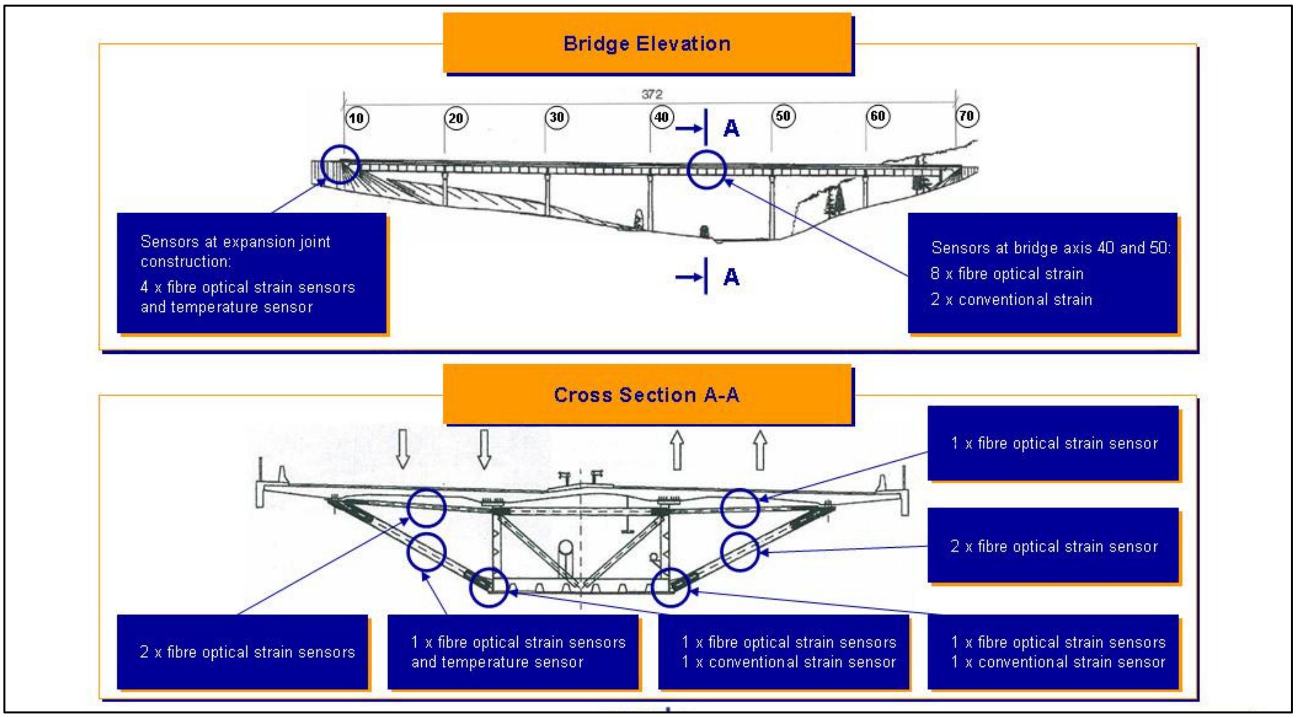

Figure 5: Sample schematic representation of a monitoring solution

It is recommended that the central computer unit should be placed in a sheltered location (such as within the structure of the bridge) to protect it from animals and birds, vandalism, inclement weather, storm damage etc.

When the basic functions, type of results, presentation of data, positioning of equipment and so on have been agreed, a detailed design can be undertaken, with selection of sensors and other materials, estimation of quantities, and proposal of a delivery and installation programme.

5. Installation

Installation of a monitoring system may take as little as a few days, depending on the complexity of the system and the local conditions governing access etc. Very often, the sensible positioning of sensors may present particular difficulties with access, but these can generally be resolved using widely available special access vehicles such as that shown in Figure 6 (used here to install a solar panel for energy supply to the system).

Once the central computer unit, sensors, cabling, power supply, transmission cabling / antenna (if required) and any additional features have been installed, the system is switched on and any necessary calibration of the system is carried out.

Figure 6: Installation of a solar panel

Figure 7: Wiring of central computer

Calibration of the system may be required to ensure that the sensors employed supply meaningful data, in particular in cases where such data is sensitive to temperature. For this reason it is generally advised to incorporate at least one temperature sensor in the system.

When the installation work on site has been completed, the system is tested. Photographic evidence of the installation is recorded, and the site is secured.

6. Outputs from the system

The data recorded by the monitoring system may be simply downloaded onto a laptop computer by cable connection to the central computer unit, or it may be transmitted to a remote server for easy access via the internet. A typical data presentation screen from such a system is shown in Figure 8. This screen gives details of the bridge and allows selection of the output type desired. In this case the user has selected to view the temperature data recorded by the four different temperature sensors on the bridge, over the previous 30 days. Data for any other sensor or group of sensors, over different periods of time (such as 1 week or 1 year), ending on any date, can just as easily be selected for presentation. This allows the change in behaviour of a structure from one season to the next, or from one day to the next, to be assessed.

The data thus presented in graphic or tabular form can then also be exported in spreadsheet format for use in calculations etc.

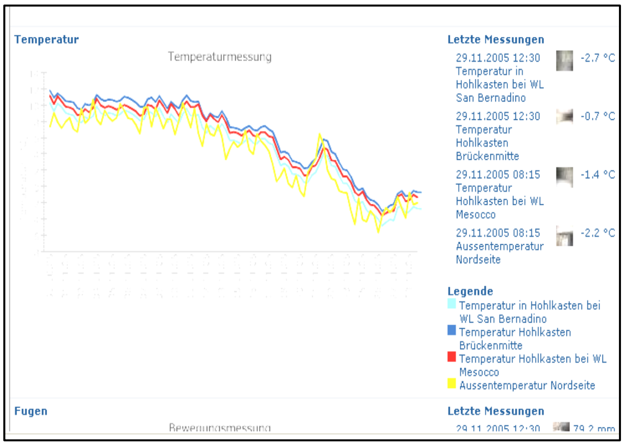

Figure 8: Typical graphical presentation of data

Figure 9: Photographic evidence of traffic event

Presentation of further outputs from the system, such as photographic evidence of traffic events, can also be selected for immediate viewing, as shown in the sample output screen in Figure 9. This screen records the passing of a truck over a bridge where it was necessary to record the number of truck journeys, and also to monitor the weight and speed of each truck to ensure that contractual limits were not exceeded.

Where immediate notification of any predefined change in a bridge's condition is required – for instance where safety concerns exist – a modern monitoring system can be configured to automatically send an SMS (text) message or e-mail to the responsible engineer, allowing appropriate safety precautions or remedial action to be implemented. For example, the system can be programmed to automatically send a notification when any variable (such as the force on a particular bridge bearing) exceeds, or falls below, any particular predefined "alarm value".

7. A solution for every requirement: the range of available systems

Remote monitoring systems can generally be tailored to supply the specific information required by a bridge's engineers. Very elaborate systems, using fibre optic technology, can measure parameters at 100 Hz (100 readings per second), and depending on the proposed purpose, type and number of sensors, can cost several hundred thousand euros. These systems generally deliver data which requires computer analysis to be of use to the engineer.

However simpler systems, using less complex technologies, can directly measure parameters such as temperature, force, displacement (for example, settlement of abutments), inclination, crack width, or traffic volume. These systems can cost as little as EUR 20,000, potentially only a fraction of the cost of equivalent manual monitoring and assessment, and offer the following advantages over more sophisticated systems:

- Simple system, requiring less training for users
- Sensors deliver usable results directly - no software required to analyse the data collected
- Generates less data, meaning that the data can be transmitted from the bridge site by existing mobile telecommunications networks
- Less sensitive to interruption of data supply and transmission
- Requires less energy, meaning that the system can generally be powered by solar energy
- Relatively low initial costs
- Relatively low maintenance and operating costs.

Modern monitoring therefore offers a solution for every situation, ranging from the readily affordable to the highly sophisticated.

8. Sample applications of such systems

(i) Pont Nanin, Canton Graubünden, Switzerland. Some of the bearings of this bridge were originally designed to allow horizontal movement of the bridge deck, but in recent years it was decided to modify the design, resulting in these bearings becoming fixed. The bridge owner decided to install a monitoring system to record the forces acting on the bearings at all times (see Figure 10), to ensure that the bridge's substructure did not become overloaded by this change of design.

(ii) At a bridge over the Danube in Germany, the sliding surfaces of the bridge's bearings suffered from an abnormally high rate of wear, as shown in Figure 11. A monitoring system is proposed to provide data on extent, speed and acceleration of the bridge's movement, in order to understand the various possible root causes of the unusual behaviour, which might include insufficient stiffness of the bridge deck, or increased braking or acceleration forces from traffic.

Figure 10: Monitoring of force at bearings

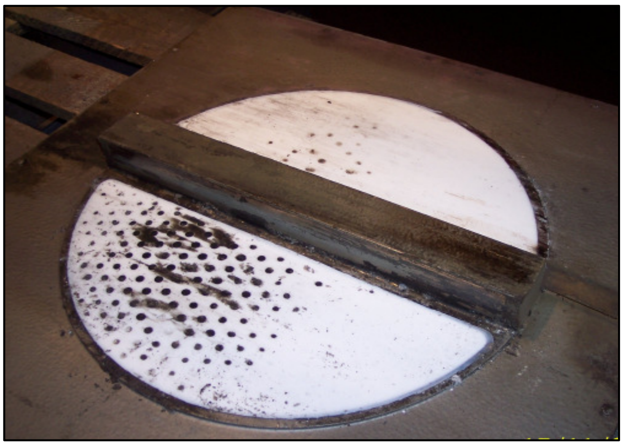

Figure 11: Excessive friction to be investigated

(iii) Incheon Bridge, South Korea (see Figure 12). A monitoring system will be provided to record data relating to the performance of the bridge's unusually large and complex expansion joints, which allow longitudinal movement of up to 2,000mm. This data is desired by the bridge owner, to ensure that the bridge continues to perform as intended, and also by the expansion joint supplier, in the interests of Research & Development.

Figure 12: Incheon Bridge, South Korea

Figure 13: Regulation of bearing height

(iv) Structures, either bridges or buildings, which are located in an area where settlement might be expected to occur, may need to be monitored to ensure that any settlement of the foundations will be recognised early, facilitating timely remediation or preventative works.

A solution which combines a monitoring system with a series of measuring and lifting pot bearings (as shown in Figure 13) offers immediate notification of the occurrence of settlement, and also an immediate solution, whereby the height of individual pot bearings may be easily adjusted as required in order to re-establish the desired support level of each part of the structure.

9. Conclusions

The potential uses and benefits of modern remote monitoring systems to the development and maintenance of structures are almost unlimited. Engineering data can easily be recorded with minimal effort, and made available in any desired format. The more advanced systems offer immediate transmission of information from the structure to be viewed online from anywhere in the world, at any time, and automatic notification by SMS or e-mail to the bridge owner of the occurrence of predefined critical events. These systems can be installed in even the most remote locations, with power supply by battery or solar panel, and transmission of data using mobile telecommunications networks.

The more elaborate systems available, using fibre optic technology and requiring computer analysis of data, offer the capability to collect enormous quantities of data. The authors believe that such systems have an exciting future in the area of research and development, and for special applications, for example those which require the measurement of vibrations. However the majority of structures which would benefit from monitoring technology, such as in the assessment of the suitability of an old bridge to carry modern traffic loading, are likely to be well served by less complex monitoring technologies, at far lesser expense.