Structural health monitoring meets data mining

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Chapter 3

The Infrawatch Project

The full name of the InfraWatch project is "Data Management of Large Systems for Monitoring Infrastructural Performance", which aims to design, develop and optimise a data management system for measuring and reporting the actual performance of large infrastructural projects. The datasets involved in this project are collected with a sensor network installed on a Dutch highway bridge. In this chapter, we will introduce some background information about the bridge and the sensor network, and give an overview of the specific focus of each sensor type.

3.1 Description of the Bridge

The bridge in this project, shown as Fig. 3.1, is called Hollandse Brug, which is a concrete bridge, built in the late sixties, and opened in 1969. This bridge forms the motorway connection between Amsterdam and the north-east of the Netherlands. The bridge is composed of 7 spans, with a total length of 354 meters. As shown in Table 3.1, each span contains 9 pre-stressed prefab girders, which are connected with in situ concrete and reinforcement steel in transverse direction. In addition, two in situ post-tensioned cross girders are present to reduce rotation and torsion of the girders. Dilatation joints are installed between the girders in

Figure 3.1: The Hollandse Brug - This is a bridge between the Flevoland and Noord-Holland provinces and is located at the place where the Gooimeer joins the IJmeer.

longitudinal direction. Due to this connection, the girders can deform freely, and imposed deformations do not influence the internal stresses.

In the last decades, the condition of the Hollandse Brug decreased dramatically, and after an inspection of TNO (a Dutch organisation for applied scientific research) in 2007, the bridge was considered 'unsafe'. Heavy traffic was blocked from the bridge until a necessary renovation was finished. During renovation, the width of the bridge was also increased with extra girders. Due to these girders, an extra traffic lane in both directions could be realised. In addition to the renovation and the extra girders, a sensor network was installed underneath the first span of the bridge.

3.2 The Sensor Network

The initial goal of the system was very much short-term, with an emphasis on monitoring the curing of the new concrete before re-opening of the bridge, and providing evidence for the renewed safety of the bridge in that period. As the

Table 3.1: Some Parameters of the Hollandse Brug.

Parameters	Value	Unit
Weight of the girders	2,820	kg/m
Number of girders	9	–
Weight of the bridge deck	500	kg/m
Width of bridge deck	34	m
Total bridge deck weight	42,380	kg/m
Elastic modulus	38,500	MPa
Total bending stiffness	$5.91 \cdot 10^{11}$	Nm^2
Girder length	50.55	m

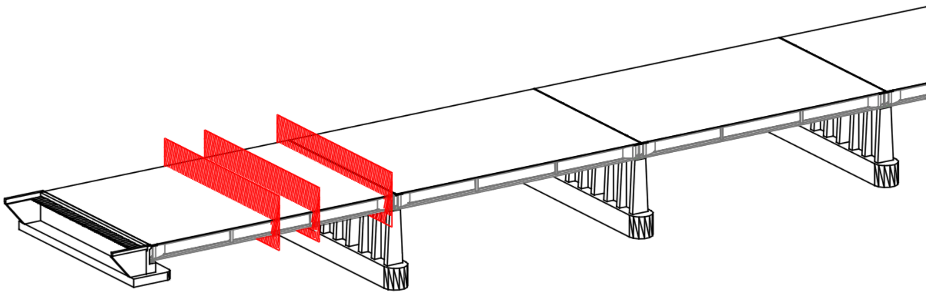

Figure 3.2: The layout of the sensor network on the Hollandse Brug - sensors are installed at three cross-sections within one span.

monitoring system was a major investment, it was then decided to make the system available to the publicly funded InfraWatch project, allowing research into the monitoring of infrastructure and the ageing of concrete bridges. The sensor system has been handed over to the TU Delft and its collection of historic data is available within InfraWatch and the IS2C program as a whole.

The sensor system is installed on one of the spans of the bridge, measuring over 50 meters in length. A total of 145 sensors are placed along the width of the bridge, at three cross-sections of the span. Furthermore, a weather station and a camera were installed. At each cross-section, sensors of various types are placed at a variety of locations, for example attached to the bottom of the deck, under a girder, or embedded in the deck. Furthermore, sensors (especially the strain

Figure 3.3: Sensor locations of one of the three cross-sections - Sensors are either attached or embedded to the deck and girders of the bridge.

gauges) are placed in various orientations, such that the total network senses the bridge in many different dimensions and from a range of perspectives, shown as pictures in Fig. 3.2 and Fig. 3.3. The sensor network features a total of 91 strain gauges, 44 of which are embedded, and 47 are attached. Furthermore, there are 34 vibration sensors, as well as 20 temperature sensors. The sensors are connected to five data-collection computers, sampling data at 100 Hz, and this data is finally recorded on-site in a central computer.

3.3 The Specific Focus of each Sensor Type

The loadings on the bridge not only contain vehicles with various weights, lengths, speeds, and directions, but also include environmental factors such as wind, temperature, rain and so on. The duration of the loadings varies from a few seconds to a couple of hours, or even longer. To show the specific focus of each sensor type, we choose two datasets of different scales: 5 minutes and 24 hours.

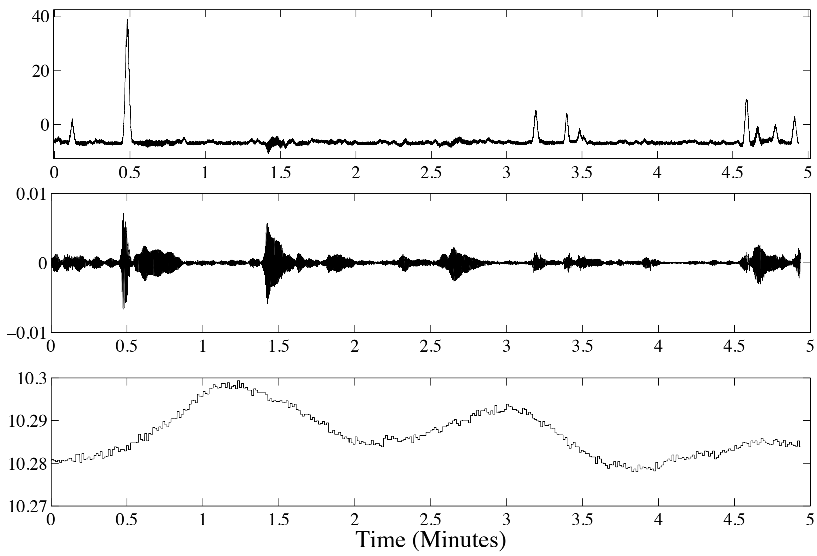

Figure 3.4: Signals of 5 minutes collected with sensors installed on the left side of the bridge - Top: a strain signal; middle: a vibration signal; bottom: a temperature signal.

3.3.1 The Specific Focus of Small Scale

To explore the specific focus of each sensor type on small scales, we choose a dataset of 5 minutes, including 30,000 data points, with a sampling rate of 100 Hz. Fig. 3.4 shows a group of signals collected with a group of sensors installed on the left side of the bridge, and Fig. 3.5 shows a group of signals collected with a group of sensors installed on the right side of the bridge.

The top pictures in the figures mentioned above are strain signals, collected with two different strain sensors, in which small peaks are caused by light vehicles, and big peaks are caused by heavy vehicles. We also notice that strain sensors are more sensitive to vehicles passing by lanes on the same side. For example, there is a group of peaks around 1.5 minutes in the strain signal of Fig. 3.5 (on the right side), but during the same period, we fail to detect any peaks in the strain signal of Fig. 3.4 on the left side.

The middle pictures in the figures mentioned above are vibration signals, collected with two different vibration sensors, which are sensitive to vehicles passing on

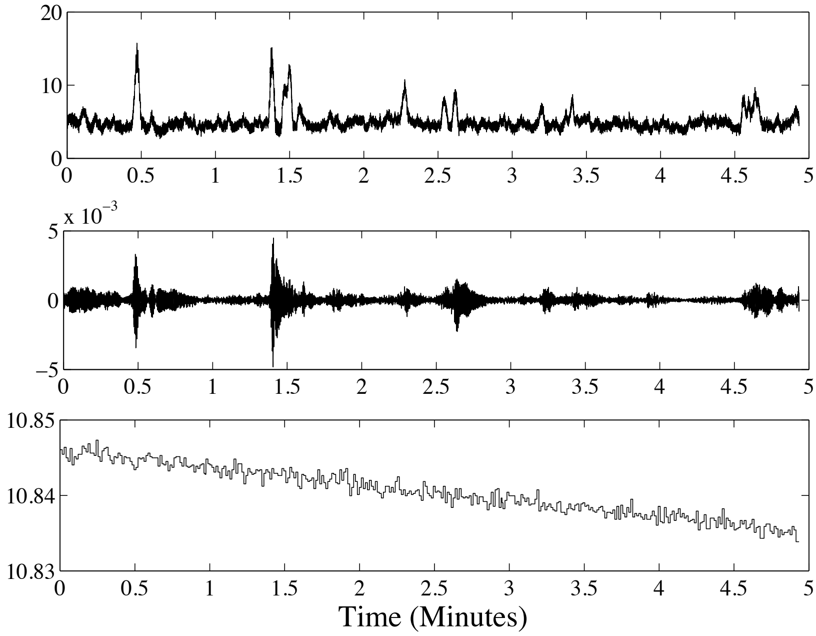

Figure 3.5: Signals of 5 minutes collected with sensors installed on the right side of the bridge - Top: a strain signal; middle: a vibration signal; bottom: a temperature signal.

both sides of the bridge. Compared with peaks in strain signals, the fluctuations in vibration signals last longer, and are capable of catching free vibrations of the bridge.

The bottom pictures of the figures mentioned above are temperature signals, collected with two different temperature sensors, which indicate local temperature changes of the bridge. The temperature sensor in Fig. 3.4 is embedded in the bridge surface, and the temperature sensor in Fig. 3.5 is attached to the bottom of the deck. We notice that temperature measurements vary with locations, and they are insensitive to traffic events.

3.3.2 The Specific Focus of Big Scale

To show the specific focus of each sensor type on large scales, we choose a dataset of 24 hours, composed of 8,640,000 data points, with a sampling rate of 100 Hz.

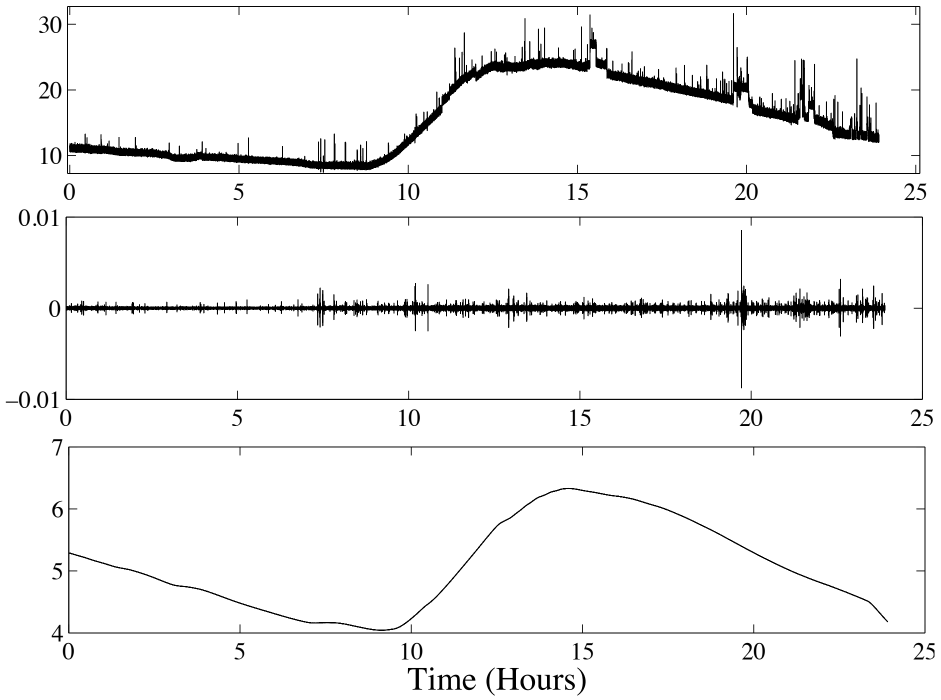

Figure 3.6: Sensor signals of big scale - Top: the strain signal of one day, in which tiny spikes are normal traffic events, jumps are traffic jams, and the baseline drift is temperature influenced; middle: the vibration signal of one day, in which small spikes are vehicles; bottom: the temperature signal of one day.

Fig. 3.6 shows a group of signals of different sensor types.

The signal in the top picture of Fig. 3.6 is a strain signal, which is composed of events of different scales. The tiny spikes in the strain signal represent normal traffic events, such as trucks and cars; the temporary jumps in the strain signal are caused by traffic jams; the slow big drift in the strain signal is caused by temperature changes, which is similar to the temperature variations shown in the bottom picture of Fig. 3.6.

The signal in the middle picture of Fig. 3.6 is a vibration signal, which is sensitive to normal traffic events, but is insensitive to long-term changes such as those due to traffic jams or temperature.

The signal in the bottom picture of Fig. 3.6 is a temperature signal, which represents temperature variations within 24 hours, and is insensitive to any traffic events.