Chapter 13
Large-Scale Sensor Network Analysis:
Applications in Structural Health Monitoring

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ABSTRACT

Sensors are increasingly being used to monitor the world around us. They measure movements of structures such as bridges, windmills, and plane wings, human's vital signs, atmospheric conditions, and fluctuations in power and water networks. In many cases, this results in large networks with different types of sensors, generating impressive amounts of data. As the volume and complexity of data increases, their effective use becomes more challenging, and novel solutions are needed both on a technical as well as a scientific level. Founded on several real-world applications, this chapter discusses the challenges involved in large-scale sensor data analysis and describes practical solutions to address them. Due to the sheer size of the data and the large amount of computation involved, these are clearly "Big Data" applications.

DOI: 10.4018/978-1-4666-4699-5.ch013

1. INTRODUCTION

Sensors are increasingly being used to monitor the world around us. They measure movements of structures such as bridges, windmills and plane wings, vital signals of humans, atmospheric conditions, and fluctuations in power and water networks. In many cases, this results in large networks with different types of sensors, generating impressive amounts of data. In this chapter, we look at a specific case in considerable detail - a sensor network attached to a large highway bridge - and demonstrate what generic techniques may be required to analyze this data (Knobbe et al., 2010; Vespier et al., 2011).

1.1 Bridge Monitoring

Structural health monitoring, i.e. the monitoring of the behavior of man-made structures such as bridges, tunnels and buildings, is an important case for large-scale sensor data analysis (Knobbe et al., 2010). Many existing structures are now past their design lifetime, and complex degradation processes such as corrosion and excessive load cycles can sometimes cause unpredictable behavior (ASCE, 1990). Monitoring their dynamic behavior is key in understanding how fast they are degrading and predicting when critical maintenance, or even replacement, is needed. This requires the infrastructure to be equipped with a network of sensors, continuously measuring and collecting various structural and climate features such as vibration, strain and weather conditions. This continuous measuring process generates a massive amount of streaming data which must be analyzed over large time intervals.

One such structure is the ‘Hollandse Brug’ (Holland Bridge), one of the busiest highway bridges in the Netherlands. The bridge was opened on June 1969, but on April 2007 inspection measurements showed that the bridge did not meet quality and security requirements. Subsequently, it was closed in both directions to freight traffic, and most of the bridge deck has since been replaced. To monitor the bridge’s behavior, and avoid such abrupt bridge closures in the future, a sensor network was installed to learn how the bridge, and many other bridges like it, degrades over time and to use this data to plan future maintenance more accurately.

The monitoring system comprises 145 sensors that measure how the bridge responds to external forces, at several locations along its span (see Figure 1 for an illustration). The following types of sensors are employed:

- 34 ‘geo-phones’ (vibration sensors) that measure the vertical movement of the bottom of the road-deck as well as the supporting columns.
- 16 strain-gauges embedded in the concrete, measuring horizontal longitudinal stress, and an additional 34 gauges attached to the outside.
- 28 strain-gauges embedded in the concrete, measuring horizontal stress perpendicular to the first 16 strain-gauges, and an additional 13 gauges attached to the outside.
- 10 thermometers embedded in the concrete, and 10 attached on the outside.

These sensors measure at 100 Hz, yielding about 4 GB of data per day, or well over a terabyte of data per year. In addition, a weather station measures wind speeds, rainfall and solar radiation, and a video camera provides a live stream of the traffic on the bridge. This system creates a constant influx of high-throughput data. While manageable over short intervals, this data needs to be collected over many years for detailed analysis, quickly turning this fast data into big data. It may be clear that this requires a radical departure from current field-testing approaches that rely of spreadsheets and proprietary data-acquisition software with capacity limitations.

A small 1-minute sample of the strain and vibration data is shown in Figure 2. One can easily

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