Application of Semantic and Big-Data Technologies to Structural Monitoring

In-use contribution

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Large civil engineering structures, such as hydro electrical power plants, bridges, and airports, play an important role in today's society, providing it with multiple services and capabilities. However, a failure in a structure such as a dam, bridge or power plant can produce catastrophic events with widespread impact on human life, the environment, and on the economy. Reducing the risk of such failures requires proactively acting instead of reacting, which implies being able to continuously assess the safety of such structures. Structural assessment depends, on the one hand, on accurate information about the structure, and, on the other, on updated information provided by sensors and other means that monitor its dynamics.

Structural monitoring relies on using a set of sensors to periodically acquire data as a means of measuring properties of a structure (e.g. displacement, extension). Originally, data acquisition was carried out manually using mechanical or electrical devices, which produced a discrete and limited set of values that could then be correlated with long-term behaviour series. Later, the development of electronic data loggers and programmable controllers capable of automatically acquiring and transmitting data, led to the deployment of permanent monitoring systems that generate large volumes of data. This data is fundamental to understand the dynamics of a structure, to detect deviations to its expected behaviour, and, to act accordingly in case of need.

Structural monitoring manages multiple types of different sensors deployed on a structure, which can vary in number from a few dozens to thousands. Thus, sensors must be efficiently characterized due to their diversity and quantity. Moreover, structural monitoring not only deals with the operation of sensors in terms of data acquisition, but must also consider dependencies between sensors, and the impact of supporting processes, such as maintenance, replacement, and calibration.

Semantic technologies are a computational technique that can used to address some of the problems behind structural monitoring as they enable (i) the computational representation of sensors, sensor types, and corresponding sensor data; (ii) the integration of multiple sensors and data; and (iii) the analysis of sensors and data.

We have been exploring the application of semantic technologies (graph databases and ontologies) to analyse sensors, sensor dependencies, as well as determining their role in structural monitoring. We

have applied this solution to the analysis of a scenario provided by the Portuguese National Laboratory for Civil Engineering (LNEC). The application uses ontologies to represent deployed sensors, and logical reasoning to analyse correlations and dependencies between sensors, and to check their compliance against a set of requirements.

Current generation data acquisition systems for structural monitoring are relatively inexpensive, have high acquisition rates, and provide accurate measurements. Current sampling rates may reach 1000Hz, which makes possible to properly characterize structural responses without aliasing. As a result, sensors are able to capture small-scale structural responses that are generated by phenomena such as wind and car traffic. As an example, the 2.2 Km long “25 de Abril” suspension bridge in Lisbon has 87 sensors operating at 500Hz. Each sensor generates 1.800.000 samples per hour. In total, all sensors generate 3.758.400.000 measurements per day. And the number of sensors will soon be extended to more than 200. This bridge is assessed through the combined analysis of several variables using numerical structural models along with machine learning algorithms, neural networks, and clustering methods. With the data from the 87 sensors, the assessment of the structural integrity of the bridge requires analysing variables on a space of 1.44×10^{19}.

Structural monitoring can be classified as a “big data” problem due to (i) the volume of data, including the absolute volume of data, and the implicit volume of data that derives from data correlation and dependencies, (ii) the velocity required to capture the data and process it within a reasonable time interval, and (iii) the variety of sensors and sensor types and corresponding data that needs to be managed and integrated. Big-data techniques provide the means to perform structural monitoring while handling the volume, velocity and variety of the underlying data. In particular, structural monitoring benefits from exploiting big-data storage (e.g. Cassandra) and processing (e.g. Spark/RSpark and Hadoop/rHadoop).

The presentation will address the following topics: (i) Characterization of the structural engineering domain, in particular structural monitoring and structural assessment; (ii) Role of acquisition, integration and analysis in structural monitoring; (iii) Types of analysis in structural monitoring; (iv) Challenges (analysis of sensors, analysis of data, volume of data, velocity of processing and analysis, variety of sensors and data sources); (v) Applications of semantic technologies to structural monitoring; (vi) Applications of “big-data” technologies to structural monitoring; and (vii) Open issues.

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