Monitoring of architectural heritage with machine learning methods

Abstract

The Architectural Heritage (AH) represents one of the pillars of a country's social and cultural identity, as well as one of its greatest assets. Its protection is a commitment and a responsibility of all generations to come. Like anything else on our planet, assets undergo an evolution over time. Processes of a different nature, chemical, physical, biological triggered by man or completely spontaneous, affect those materials that have been wisely combined over the years to model extraordinary architectures. From a structural perspective, the effects of these phenomena can progress slowly and be perceived only after generations or dramatically fast if triggered by singular events such as earthquakes. Taking measures to mitigate and prevent this damage should be a duty of every developed country.

In the last twenty years of the 20th century, the discipline of Structural Health Monitoring (SHM) was formed and continued to expand across various engineering sectors. It deals with all the processes of implementing a damage detection strategy, which involve observing a structure over time through periodically spaced dynamic response measurements, the extraction of damage-sensitive characteristics and their statistical analysis aimed at determining the current structural state. Its growth was encouraged by the recent technological progress, which has led to the development of increasingly high-performance sensors and instrumentation, capable of automatically acquiring accurate high-frequency measurements at low cost and with the possibility of instantly transmitting online the data they acquire continuously, without needing manual interventions. From the need to extract and synthesize the information enclosed in these large datasets, SHM has naturally moved towards innovative techniques of *Machine Learning* (ML), a branch of *Artificial Intelligence* (AI), which emulates the learning ability of human preserving the advantages of computers, such as computational capacity, speed, automaticity, objectivity, transferability, etc.

Although SHM potentially leads to various advantages over traditional diagnostic techniques, with which it shares the objectives, its approach to Cultural Heritage (CH) has only occurred in recent years. In fact, while other sectors have benefited from the very beginning of the application of SHM, when trying to integrate this procedure into the AH conservation process, some problems arise, related to the complexity of the object involved. This thesis aims to identify and explore the critical aspects of SHM implementation on CH buildings by presenting proposals to address them. It is structured as follows:

Chapter 1: The role of SHM for AH is made explicit and the motivations that lead to turn to this type of approach are explored for different scenarios. The real objectives and limitations are clarified in the definition of what SHM aims to detect and the relationship between structural safety and monitoring systems is probed.

Chapter 2: Vibration-based methods are presented and their application on very different architectural assets is shown, enhancing their peculiarities. Critical aspects are introduced in this chapter and an interesting analogy is outlined. Here, also an overview of the case study of the thesis, the *Sanctuary of Vicoforte* (CN, Italy) is reported.

Chapter 3: Data recorded on the Sanctuary by the static and dynamic monitoring systems, for over ten and three years respectively, are systematically analysed and their correlation with environmental factors is made explicit. Both dependencies already found for other assets and unexpected outcomes emerge from this research.

Chapter 4: Having ascertained the dependence of the diagnostic parameters on the external environment in the previous chapter, here a strategy is proposed to remove it. It is based on cointegration, a technique that comes from econometrics, and ML regression algorithms.

Chapter 5: The issue of the lack of labelled data related to different structural conditions is addressed using a strategy based on Transfer Learning. Virtual data produced with the Finite Element Model (FEM) are exploited to train ML algorithms and support the interpretation of the real measures.

Chapter 6: The design of an experimental test is developed on the FEM of the Sanctuary. The experiment, not yet carried out in practice, aims to obtain data from a like-damaged structural condition. Considerations emerge on the sensitivity of dynamic behavior under certain load conditions, as well as on that of accelerometers and on the trend of historical dynamic data.

Chapter 7: A source of continuous information about the foundation soil of the Sanctuary is identified in remote sensing data. Two geophysical parameters related to the thermal and humidity conditions of the surface, made available by the European Space Agency (ESA), are examined and crossed with those of on-site monitoring.