A Comparative Study of Low-Cost and Professional Accelerometric Monitoring Systems for Structural Health Monitoring in the Campi Flegrei Area

Francesco Colace
DIIn
Università degli Studi di Salerno
Fisciano, Italy
fcolace@unisa.it

Domenico Santaniello
DISPAC
Università degli Studi di Salerno
Fisciano, Italy
dsantaniello@unisa.it

Giusy Strollo
DIIn
Università degli Studi di Salerno
Fisciano, Italy
gstrollo@unisa.it

Alfredo Troiano
NetcomGroup
Napoli, Italy
a.troiano@netcomgroup.eu

Allan Tucker
Brunel University
London, UK
allan.tucker@brunel.ac.uk

Angelo Lorusso
Facoltà di Ingegneria e Informatica
UniPegaso
Italy
angelo.lorusso@unipegaso.it

Abstract— **Italy is highly exposed to natural and geodynamic hazards due to its complex geological setting, widespread seismicity, and hydrogeological vulnerability. Among the most distinctive phenomena affecting the Italian territory is bradyseism, a process characterized by slow and cyclic ground uplift and subsidence generated by pressure variations within volcanic systems. This phenomenon is particularly evident in the Campi Flegrei caldera, where recurring ground deformations and seismic swarms raise increasing concerns regarding the resilience of public infrastructures and urban settlements. Within this context, this paper presents a Structural Health Monitoring framework implemented in the Municipality of Quarto (Southern Italy), aimed at supporting the continuous monitoring and predictive assessment of public buildings exposed to long-term geodynamic stress. The proposed framework integrates Internet of Things technologies, Operational Modal Analysis, Digital Twin paradigms, and Machine Learning techniques within a unified monitoring ecosystem. The experimental campaign involves two strategic public buildings instrumented through different sensing technologies. A school building is monitored using a network of low-cost MEMS accelerometers integrated with ESP32-based IoT devices, while the municipal building is equipped with a professional-grade monitoring infrastructure based on high-precision Dewesoft instrumentation. The dual deployment enables a direct comparison between low-cost and professional monitoring systems in a real operational environment. Preliminary results demonstrate the capability of low-cost sensor networks to identify the principal dynamic characteristics of monitored structures and support predictive monitoring applications. The proposed framework highlights the potential of scalable and economically sustainable monitoring solutions for improving urban resilience in territories affected by seismic and bradyseismic phenomena.**

Keywords—SHM, IoT, MEMS

I. Introduction

The increasing frequency of natural hazards and the growing vulnerability of urban infrastructures have stimulated significant research efforts toward the development of intelligent monitoring systems capable of supporting preventive maintenance and risk mitigation strategies [1][2].

Among the geodynamic phenomena affecting the Italian territory, bradyseism represents one of the most challenging. Characterized by slow and cyclic vertical ground movements associated with volcanic processes, bradyseism can generate cumulative stresses on buildings and infrastructures over extended periods. The Campi Flegrei area near Naples represents one of the most studied examples of active bradyseismic environments worldwide. Recent episodes of ground uplift and increased seismic activity have renewed concerns regarding the safety of public buildings and the resilience of urban systems. In such contexts, continuous Structural Health Monitoring (SHM) becomes a fundamental tool for understanding structural behaviour, identifying anomalies, and supporting decision-making processes. Recent advances in Internet of Things technologies, low-cost sensing devices, cloud infrastructures, Artificial Intelligence, and Digital Twin technologies provide unprecedented opportunities for the realization of scalable monitoring ecosystems capable of operating at urban scale. This paper presents the results of the "Per un Comune 4.0" initiative developed in the Municipality of Quarto. The project aims to investigate the feasibility of integrating IoT-based sensing technologies, Digital Twins, and Artificial Intelligence techniques into a predictive monitoring framework for public buildings located within a bradyseismic territory. Particular attention is devoted to evaluating the reliability of low-cost sensing technologies through direct comparison with professional monitoring systems. This aspect is particularly relevant for public administrations seeking economically sustainable solutions capable of supporting large-scale monitoring programs.

II. Smart Monitoring Framework

The proposed framework is organized around five main components:

- Structural characterization of monitored buildings;
- Digital Twin generation;
- IoT sensing infrastructure;
- Data analytics and Operational Modal Analysis;
- Artificial Intelligence and predictive monitoring.

The workflow starts with historical and structural investigations of the monitored assets, followed by digital surveying activities and Digital Twin creation. Sensor networks continuously acquire structural and environmental data that are transmitted to a cloud-based infrastructure for storage, visualization, and analysis.

III. Digital Twin and IoT Infrastructure

The experimental campaign involves two strategic public buildings located within the Municipality of Quarto. The first case study is a school building equipped with a network of low-cost MEMS accelerometers connected to ESP32-based IoT devices. The second case study is the municipal building, instrumented using professional Dewesoft equipment characterized by higher measurement precision and acquisition capabilities. Continuous measurements are acquired under both ambient vibration conditions and real seismic events. Raw accelerometric signals are processed through a dedicated Python-based pipeline including detrending, filtering, spectral analysis, frequency-domain transformation, and modal parameter extraction. Operational Modal Analysis techniques are subsequently employed to identify natural frequencies and vibration modes of the monitored structures.

IV. Comparative Assessment of Low-Cost and Professional Monitoring Systems

The core contribution of this research lies in the direct comparison between low-cost and professional monitoring infrastructures.

Several performance indicators are considered:

- Modal frequencies;
- Vibration signatures;
- Signal quality metrics;
- Frequency-domain characteristics;
- Temporal variations in structural response.

The objective is to evaluate whether low-cost MEMS accelerometers can provide information comparable to that obtained through professional-grade Dewesoft systems.

This validation is essential for assessing the feasibility of large-scale monitoring programs in public buildings where budget constraints often limit the deployment of traditional SHM infrastructures.

V. Comparative Assessment of Low-Cost and Professional Monitoring Systems

The collected dataset is exploited to develop predictive monitoring services based on Artificial Intelligence techniques. Convolutional Neural Networks are investigated for vibration pattern recognition through spectral image analysis, while recurrent architectures such as LSTM networks are employed to model temporal dependencies and identify anomalous structural behaviours. The integration of AI techniques with Digital Twins enables the development of predictive maintenance services capable of supporting proactive infrastructure management.

Conclusions

This paper presented a smart monitoring framework for public buildings located in a bradyseismic urban environment. The proposed ecosystem integrates Digital Twins, IoT technologies, Operational Modal Analysis, and Artificial Intelligence within a unified Structural Health Monitoring architecture. The comparative analysis between low-cost MEMS-based sensor networks and professional Dewesoft instrumentation represents the main scientific contribution of the work. Preliminary results suggest that low-cost sensing technologies can provide meaningful information regarding structural dynamics and may represent a viable solution for large-scale monitoring programs. Future developments will focus on long-term observation campaigns, expansion of the monitored building portfolio, and further integration of Digital Twin technologies and AI-based predictive services to support urban resilience in the Campi Flegrei area.

References

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