Summary

Over the last decades, a change of paradigm toward advanced numerical simulations and virtual prototyping has encouraged the exploration of nonlinear techniques for system identification (SI). In its broadest sense, nonlinear SI concerns the determination of nonlinear models by combining information from data with those coming from a priori knowledge of the system. In structural applications, systems inherently exhibit nonlinear behaviour due to the presence of elements such as joints, innovative energy dissipation devices, and degrading components, whose behaviour can be difficult to predict, understand, and monitor. In that case, nonlinear SI plays a significant role for understanding the structural response and can achieve high levels of efficiency with reduced computational effort if the identification problem is properly constructed by considering convenient variables and relationships. Despite this potential, the modelling and identification of nonlinear behaviour of structures under seismic, or more generally, dynamic excitation is still an open issue to date, mainly due to the complexity of model formulation and parameter definition.

This thesis addresses these challenges by developing instantaneous identification tools for nonlinear and time-varying systems. The methods exploit the time localisation of spectral components to estimate nonlinear parameters from non-stationary responses, extending the concept of local stationarity to complex dynamical systems. The main contributions include the development of novel numerical and experimental strategies for identifying nonlinear and time-varying structural behaviour. The advantage of these methods is twofold: (i) they provide practical and easily scalable tools to extract nonlinear and hereditary characteristics from non-stationary data; (ii) they can be combined with specifically designed experimental tests, allowing reliable characterisation of structural behaviour under realistic conditions.

The topics summarised above are developed in the thesis in the following order.

Chapter 1 introduces the reader to the definition and the role of SI in structural dynamics, with particular attention on defining the motivations and challenges behind its nonlinear counterpart.

Chapter 2 presents an extensive overview of the nonlinear identification techniques and their different classifications.

Chapter 3 reports on identification techniques for signals whose statistical properties change over time and admitting a time-localisation of their spectral components. Limitations of existing identification strategies are also pointed out.

Chapter 4 proposes a novel identification technique based on the combination of a Volterra series approach with linear time-frequency transforms for time-varying systems under random excitation. This is benchmarked numerically on single- and multi-degree-of-freedom Duffing oscillators.

Chapter 5 employs a Wigner-Ville transform for the identification of a classical and bistable Duffing oscillator without relying on explicit analytical expressions, as done in Chapter 4. More specifically, the procedure proposed here exploits the energetic information coming from quadratic transforms for parameter estimation from markedly non-stationary responses.

Chapter 6 exploits the bistable dynamics introduced in Chapter 5 for seismic energy dissipation purposes. An instantaneous probabilistic identification technique is proposed for validating the experimental data gathered from a tailored prototype testing machine, also for dealing with uncertainties.

Chapter 7 extends the numerical investigation and experimental validation to the case of bistable systems presenting a not perfectly elastic behaviour by employing the prototype testing machine described in Chapter 6.