POLITECNICO DI MILANO

PhD in INGEGNERIA MECCANICA / MECHANICAL ENGINEERING - 41st cycle

THEMATIC Research Field: MODEL ORDER REDUCTION STRATEGIES FOR NONLINEAR DYNAMICS OF PERIODIC STRUCTURES

Monthly net income of PhDscholarship (max 36 months)
1500.0 In case of a change of the welfare rates during the three-year period, the amount could be modified.

Context of the research activity	
Motivation and objectives of the research in this field	The growing interest in mechanical metamaterials and periodic structures has recently opened new frontiers in the design of systems capable of performing complex dynamic functions. Examples include mechanical signal processors, analog neural networks, and nonlinear frequency converters. These devices rely on strongly nonlinear and often time-modulated dynamics to manipulate signals, filter information, or exploit internal resonances. However, accurately simulating and optimizing such systems remains a formidable challenge. In particular, the full-order finite element models of these structures involve millions of degrees of freedom and intricate parameter dependencies, making direct dynamic simulations computationally prohibitive. Classical linear reduction strategies—such as Component Mode Synthesis (CMS)—can alleviate part of the burden, but their applicability is largely confined to weakly nonlinear or purely linear regimes. Capturing strong nonlinearities and parametric variability requires a new generation of model reduction techniques that go beyond traditional projection-based approaches. This research aims to develop and compare advanced model order reduction (MOR) strategies for nonlinear periodic structures. The goal is to obtain efficient yet accurate reduced-order models capable of reproducing essential nonlinear dynamics across parameter variations.

	These models will serve as enablers for the design and optimization of mechanical systems for signal manipulation, analog computation, and frequency conversion.
Methods and techniques that will be developed and used to carry out the research	The candidate will begin by surveying existing projection-based MOR methods, with particular emphasis on those applicable to nonlinear systems—such as modal derivatives, quadratic manifolds, and nonlinear extensions of Component Mode Synthesis. These techniques will provide a reference framework to assess accuracy, efficiency, and scalability when applied to periodic metamaterial cells. Building upon these foundations, the research will explore advanced manifold-based reduction strategies, notably Spectral Submanifolds (SSMs). These offer a mathematically rigorous description of the low-dimensional invariant dynamics underlying nonlinear oscillations and provide a natural extension of modal analysis into the nonlinear regime. By integrating SSMs with substructuring and parameter-dependent formulations, the candidate will aim to develop parametric reduced-order models (pROMs) capable of capturing both geometric and material nonlinearities. The proposed methodologies will be implemented and validated on representative case studies: from nonlinear periodic lattices designed for signal processing, to mechanical analog neural networks, and frequency down-conversion devices exploiting cascade internal resonances. The developed models will be benchmarked against full-scale numerical simulations and, where possible, experimental results available within ongoing collaborations.
Educational objectives	Through this PhD project, the candidate will acquire deep expertise in model order reduction, nonlinear dynamics, and computational mechanics. They will develop proficiency in both classical and modern MOR techniques—ranging from projection-based methods to manifold learning approaches—and gain strong analytical

	and numerical modeling skills. The work will require advanced coding abilities (Matlab/Python/C++), familiarity with finite element analysis, and a solid understanding of dynamical systems theory. Additionally, the candidate will learn to bridge high-level mathematical methods with practical engineering applications in metamaterials and signal-processing devices, positioning themselves at the intersection of applied mechanics, nonlinear dynamics, and emerging computational technologies.
Job opportunities	Our last survey on MeccPhD Doctorates highlighted a 100% employment rate within the first year and a 35% higher salary, compared Master of Science holders in the same field. Partners: STMicroelectronics, University of California San Diego, Delft Institute of Technology, ETH Zurich.
Composition of the research group	1 Full Professors 0 Associated Professors 1 Assistant Professors 2 PhD Students
Name of the research directors	Prof. Francesco Braghin, Ing. Jacopo Marconi

Contacts
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Additional support - Financial aid per PhD student per year (gross amount)	
Housing - Foreign Students	--
Housing - Out-of-town residents	--

Scholarship Increase for a period abroad

Amount monthly	750.0 €
By number of months	6

Additional information: educational activity, teaching assistantship, computer availability, desk availability, any other information
Financial aid is available for all PhD candidates (purchase of study books and materials, fundingfor participation in courses, summer schools, workshops and conferences) for a total amount of € 6.114,50. Our candidates are strongly encouraged to spend a research period abroad, joining high-level research groups in the specific PhD research topic, selected in agreement with the Supervisor. An increase in the scholarship will be applied for periods up to 6 months (approx. 750 euro/month- net amount). Teaching assistantship: availability of funding in recognition of supporting teaching activitiesby the PhD candidate. There are various forms of financial aid for activities of support to theteaching practice. The PhD student is encouraged to take part in these activities, within the limits allowed by the regulations.