



PhD Programme in Materials, Mechatronics and Systems Engineering

Research subjects proposed for the 42nd cycle

A mandatory attachment to the application is a **description of the research project** (maximum 4 pages).

The research project proposal must include: i) a title, ii) an introduction to the problem with reference to the state of the art, iii) a clear description of the research aims and content of the research, iv) an estimated timeline of the intended activities, and v) literature references.

The project's topic must fall within the Doctorate's fields of interest, **preferably** focusing on one of the following research subjects.

Important! A candidate's choice to apply for **reserved-topic scholarships** implies a preference for that specific scholarship over non-reserved (free) ones.

Reserved-topic scholarships are contingent upon the execution of a **specific research theme** that requires specialized skills. Applicants interested in these scholarships must carefully verify the research topics and the required competencies as outlined in this document.

Suggested research topics for free scholarships, funded by UNITN

Title: Sustainable buildings and infrastructures durability: addressing corrosion challenges in low-carbon concrete

Reference persons: F. Deflorian, M. Fedel, S. Rossi

The production of cement used in concrete generates between 7% and 8% of CO₂ global emissions. This has sparked significant interest in reducing carbon emissions, especially considering that clinker production is the primary contributor to the CO₂ produced by the concrete industry. Consequently, the substitution of the binder has become the main strategy to address this issue. However, this approach presents challenges related to corrosion of steel rebar. This research intends to deepen the understanding of the corrosion and passivation behavior of steel reinforcement in low-carbon cementitious systems. Special attention will be given to the role of cement chemistries (specifically calcium compounds, sulfides, and chlorides) and, in particular, how reduced alkalinity promotes localized or other forms of corrosion. The ultimate goals are to understand, from a mechanistic perspective, the corrosion mechanism of steel rebars in low-carbon cement formulations and to develop effective, sustainable solutions to enhance the durability of reinforced concrete structures.



Title: Singlet oxygen-driven photocatalytic processes for green and sustainable applications

Reference persons: S. Dirè, M. Fedel, F. Parrino

Photocatalysis generally relies on electron transfer processes, which mainly result in the formation of highly oxidizing and unselective radical species. However, it has been recently discovered that modifying the surface of photoactive semiconductors may result in the prevailing formation of singlet oxygen, an oxidizing species with a more specific chemistry towards targeted compounds. The current project aims at investigating chemical or electrochemical modification strategies of selected semiconductors capable of triggering photocatalytic or photoelectrocatalytic formation of singlet oxygen. The most performing materials will be thoroughly characterized and applied both for the green and sustainable synthesis of industrially relevant compounds and for the selective photoreforming of microplastics.

Title: Innovative materials and processes for the realization of sodium-ion batteries

Reference person: V. M. Sglavo

The shift toward sodium-ion batteries (SIB) is driven by the urgent need for lithium-independent, cost-effective energy storage. However, the "lab-to-market" transition is currently hindered by the high energy costs and chemical instabilities associated with the in-house synthesis of ceramic electrolytes. The present research proposal advocates for a shift in focus leveraging commercially available polycrystalline powders—for example, NASICON ($\text{Na}_3\text{Zr}_2\text{Si}_2\text{PO}_{12}$) and Mg-doped β "-alumina—to prioritize device-level integration and manufacturing scalability. To overcome the traditional barriers of high-temperature sintering ($>1000^\circ\text{C}$), which often lead to detrimental sodium volatilization and excessive grain growth, innovative sintering process will be considered as, for example, the Cold Sintering Process, so to densify ceramic precursors at temperatures below 300°C . In this way it should be possible to maintain the precise chemical composition of the high-purity starting powder and integrate the ceramic scaffold with thermally sensitive polymer-salt binders (e.g., PEO-NaTFSI) to form a flexible "ceramic-in-polymer" composite that mitigates mechanical brittleness. The materials will be subjected to intensive physical, chemical, electrical and mechanical characterization to identify proper solutions for the development of innovative SIB.

Title: Designing durable and reusable composite joints for sustainable engineering structures

Reference persons: A. Pegoretti, A. Dorigato

Structural joints play a fundamental role in composite structures, which are widely used in advanced sectors such as aerospace, automotive, and energy. The inability to manufacture large monolithic components makes the use of joining technologies unavoidable, with adhesive joints being particularly effective due to their ability to distribute loads and reduce stress concentrations. However, the durability of such joints is often limited by several damage mechanisms, including adhesive debonding, delamination, fatigue, and environmental degradation. These phenomena lead to a progressive loss of performance and may result in the premature replacement of components, with significant environmental implications. Indeed, composite materials are associated with high energy consumption during production and are difficult to recycle, making lifetime extension a priority from both an engineering and a sustainability perspective. Several strategies have been developed to improve the durability of composite joints, including surface engineering, the use of toughened adhesives, joint geometry optimization, and the adoption of structural health monitoring (SHM) techniques. More recently, significant attention has been



devoted to innovative solutions such as self-healing adhesives and re-bondable systems, which enable, respectively, the recovery of mechanical performance after damage and the possibility of disassembling and reusing the joint. The integration of these approaches represents a promising pathway to significantly enhance the service life and sustainability of composite structures.

Within this framework, the objective of the present PhD research is to develop innovative strategies for extending the service life of structural composite joints through a multi-objective approach aimed at exploring the development of: (i) self-healing adhesives, (ii) re-bondable joint systems and (iii) end-of-life disbondable adhesives. The first approach is based on thermosetting adhesives (epoxy or acrylic) modified with thermoplastic particles, capable of activating diffusion and local reflow mechanisms to promote crack closure, as well as on the use of vitrimer systems, characterized by dynamic covalent bonds that enable stress relaxation and self-healing. The second approach focuses on the development of reversible joints based on adhesives that, through the presence of thermoplastic phases or vitrimer-like dynamic chemistries, allow controlled debonding and subsequent re-bonding without significant loss of performance. The last approach will be focused on the preparation of disbondable thermosetting adhesives by the addition of thermally expandable phases, such as expandable graphites or capsules. The integration of these strategies will enable the development of more durable, repairable, and reusable joints, contributing to reduced maintenance requirements and overall environmental impact.



Reserved-topic scholarships

Title: A - Integrated Structural and Probabilistic Methodologies for Biological and Epidemiological Systems

Reference person: G. Giordano

Funded by: UNITN and Department of Industrial Engineering, project UE HE ERC INSPIRE, G.A. 101076926, CUP E63C22003020006

The PhD student will contribute to the development of integrated structural and probabilistic methodologies for biological and epidemiological systems, within the ERC project INSPIRE. INSPIRE Project: Systems in nature are extremely robust, despite huge uncertainties and variability. Studying their nonlinear dynamic behaviour is challenging, due to their complexity and the many parameters at play, but crucial to understand important phenomena, such as cellular dynamics, onset of diseases, epidemic spreading. Parameter-dependent simulations can predict the behaviour of natural systems case by case. Yet, the exact models and parameter values are poorly known, while qualitative behaviours are often preserved even with huge parameter variations, because they rely on the system interconnection structure. Parameter-free structural approaches can check whether a property is preserved for a whole family of uncertain systems exclusively due to its structure. However, when an expected property fails to hold structurally, novel approaches are needed to understand why, which system features prevent it, and which key parameters must be finely tuned to enforce it. INSPIRE will develop a unifying framework to analyse and control families of uncertain dynamical systems in biology and epidemiology, which integrates for the first time structural, robust and probabilistic methods, tailored to the peculiarities of natural systems. The project will provide: i) methodologies to assess (practically) structural properties and unveil the mechanisms that enable/prevent a property, identifying the key parameters or motifs; ii) control paradigms that leverage such an insight to guarantee a desired global property through targeted local interventions; iii) scaling and aggregation approaches that exploit the properties of subsystems to mitigate computational complexity. The project outcomes, a mathematical theory as well as algorithms to analyse and control complex uncertain systems in nature, will strongly support the analysis and design of biomolecular feedback systems with a desired behaviour, the identification of therapeutic targets, the prediction and control of epidemic phenomena.



Title: B - Modular Motion Planner for Autonomous Vehicles based on Model-Structured Neural Network

Reference person: G. P. Rosati Papini

Funded by: UNITN and Department of Industrial Engineering, funded with a grant from the Ministry of University and Research under D.D. No. 1236 of 1-8-2023 - Bando FIS 2; project FIS-2023-03684 "Structured neural network framework for modeling and control of autonomous systems - Neu4mes", CUP E53C24003800001

This research aims to develop a modular and fully differentiable planning framework for autonomous systems based on model-structured neural networks (MSNNs). The objective is to design a general-purpose planner that can operate across heterogeneous scenarios and systems—ranging from structured to unstructured environments and different hardware platforms. The proposed approach builds on structured representations of dynamically feasible motion primitives derived from analytical control principles. These primitives define a continuous control



manifold, which is discretized into a salience-based representation encoding feasibility, optimality, and environmental constraints. MSNN will be used to learn how to evaluate and combine these primitives, while explicitly embedding system dynamics and control constraints within the architecture. This design ensures that the planner remains physically grounded and interpretable, while enabling adaptability through learning. By construction, the MSNN-based formulation will make the entire planning pipeline differentiable, allowing end-to-end optimization and tighter integration between perception, decision-making, and control. The central objective of this research is generalization. The study aims to develop a planner capable of adapting seamlessly across diverse hardware and robotic systems, such as ground vehicles, aerial drones, and legged robots, without the necessity of platform- or scenario-specific modifications. Moreover, investigating how MSNNs can incorporate parametric system models and adapt to variations in actuation, dimensionality, and mobility (e.g., wheeled, legged, or flying systems). The overall goal is to provide a scalable and interpretable planning framework that combines structured control knowledge with learning, achieving flexibility across heterogeneous autonomous systems while maintaining real-time capability.



Title: C - Reconstruction and localisation of small impulses through innovative dynamics-based techniques

Reference persons: D. Bortoluzzi, G. P. Rosati Papini, P. Bosetti

Funded by: UNITN and Department of Industrial Engineering, funded with a grant from the Ministry of University and Research under D.D. No. 1236 of 1-8-2023 - Bando FIS 2; project FIS-2023-03684 "Structured neural network framework for modeling and control of autonomous systems - Neu4mes", CUP E53C24003800001

This research aims to develop advanced methods for reconstructing unknown impact forces in structural systems using vibration-based measurements. In many practical applications, direct force measurement is not feasible, requiring indirect estimation from structural responses. Existing techniques such as deconvolution and purely data-driven machine learning often suffer from instability, noise sensitivity, and limited physical interpretability. The proposed study includes model-structured neural networks (MSNNs) that embed physics-based modal decomposition within neural architectures. Instead of treating force reconstruction as a black-box problem, the network will be designed to respect structural dynamics, incorporating modal parameters (e.g., natural frequencies and mode shapes) directly into its layers or loss functions. This hybrid approach combines the interpretability and efficiency of modal methods with the adaptability of neural networks. The performance of the model-structured approach will be compared with more classical approaches, in order to identify optimal neural architectures and required model complexity for the proposed applications. The research will focus on improving robustness under noisy measurements and limited sensor configurations, including single-sensor scenarios. It will also integrate uncertainty quantification and explore optimal sensor placement strategies. Furthermore, the framework will be extended to include impact localization, enabling simultaneous estimation of force magnitude and position. The expected outcome is a scalable, interpretable, and real-time capable hybrid framework for impact force reconstruction in complex engineering structures.



Title: D - Multimodal Simultaneous Localization and Mapping for autonomous navigation in unstructured environments

Reference persons: M. Camurri, D. Fontanelli

Funded by: UNITN and Department of Industrial Engineering, project UE HE MAGICIAN, G.A. 101120731, CUP E63C23000730006

Mobile robots, and legged robots in particular, are transitioning from research laboratories to industrial applications for commercial applications such as inspection, maintenance, and asset monitoring. In particular, thanks to their superior mobility, legged robots are increasingly being developed to solve complex tasks in heavily dynamic and/or unstructured environments, including (but not limited to): search & rescue, tree health monitoring, precision agriculture, space exploration. In this context, at the foundation of every autonomous system is the need to solve the Simultaneous Localization and Mapping (SLAM) problem. SLAM systems are in constant evolution with the development of new sensing and AI technologies. Therefore, they are expected to be deployed in progressively harsher environments. The objective of this research is to study and develop novel SLAM and perception algorithms for dynamic mobile robots (legged, tracked, flying) while addressing at least one of the following aspects (a) increase robustness against perceptual degradation (e.g., degenerate geometries, low visibility) and dynamic environments (b) achieve same or superior performance with a reduced number of, noisier, and cost effective sensors (c) tightly integrate SLAM solutions within robot autonomy, effectively transitioning from classical SLAM approaches to complete Spatial AI solutions that can handle ill-posed navigation tasks and work under incomplete information.



Ministero
dell'Università
e della Ricerca



UNIVERSITÀ
DI TRENTO

Title: E - Defect engineering in thermoelectric perovskites by non-conventional sintering

Reference person: M. Biesuz

Funded by: Department of Industrial Engineering, funded with a grant from the Ministry of University and Research under D.D. No. 1802 of 21-11-2024 - Bando FIS 3; project FIS-2024-02390 "Non-conventional sintering for defects engineering in oxide thermoelectrics", CUP E53C25002360001

Description: Thermoelectrics (TEs) convert temperature differences into electric power or transport heat via electric current. They are strategic for miniaturized generators, refrigerators, and energy harvesters, transforming waste heat into electricity. The best-performing TEs, characterized by a high figure of merit ($ZT > 2$), are semiconductors based on heavy elements (Te, Pb, Bi, Sb...) with tailored charge carrier concentration, and low thermal conductivity. However, such materials pose significant concerns due to their toxicity, environmental impact, disposal challenges, high cost, and unstable supply chain.

TE oxides offer a promising alternative to overcome such limitations but generally exhibit lower ZT values, particularly for n-type conductors. The project aims to enhance ZT in n-type oxides by introducing an innovative approach focused on deep microstructural, structural, and defect tailoring.

Recent advancements in non-conventional sintering (NCS) have greatly expanded the range of possible sintering conditions, including variations in processing time, temperature, heating/cooling rates, E-fields, external pressure,



solvents, and reactive atmospheres. NCS not only offers opportunities for reducing the carbon footprint and tailoring microstructures but also enables the creation of out-of-equilibrium materials.

Starting from the most studied thermoelectric oxide (doped Sr titanate), the research questions behind this PhD position are: “*Can we change the transport properties (electrical and thermal) by using NCS to tailor the defect chemistry? Can this microstructural engineering, down to the nano- and Ång-structure, improve ZT beyond traditional values?*”

The project will integrate advanced sintering tools (rapid, field-assisted, low-temperature...) with state-of-the-art materials characterization (transport properties, HRTEM, positron annihilation, synchrotron diffraction...) to correlate processing-structure/defects-properties.

Title: F - New concepts of electrostatic energy harvesters based on electroactive materials

Reference person: G. Moretti

Funded by: Department of Industrial Engineering, project UE HE ERC fIEAP, CUP E63C24001590006

The transition to sustainable energy is driving rapid advances in energy harvesting technologies across a wide range of power scales, from portable electronics to large-scale systems capable of exploiting still underused renewable sources such as ocean waves. In this context, electrostatic generators based on electroactive polymers are emerging as a particularly promising technology, owing to their modularity, scalability, and ability to operate effectively in conditions where conventional electromagnetic machines are less effective.

A particularly promising emerging technology is represented by *dielectric fluid generators (DFGs)*. DFGs are soft and lightweight energy harvesters that combine flexible dielectric polymers with dielectric fluids to achieve direct mechanical-to-electrical energy conversion, without requiring mechanical transmissions, rigid moving components, or permanent magnets. From a functional standpoint, they behave as variable electrostatic capacitors: when mechanically deformed, their capacitance changes, enabling them to operate as charge pumps and produce direct-current electrical power.

While closely related devices based on dielectric polymers and fluids (the so-called *zipping actuators*) have become very popular in soft robotics, their potential as energy harvesters has only begun to be explored. This opens a compelling research opportunity, since DFGs may offer energy and power densities far beyond those achievable with other direct-conversion approaches, including triboelectric and piezoelectric harvesters.

This PhD position is offered in the framework of the ERC Starting Grant project **fIEAP** and will focus on the development of new DFG concepts and their application over multiple scales, from ultra-low-power portable harvesting to large-scale wave energy conversion. The successful candidate will investigate innovative dielectric fluid generator architectures, develop models and control strategies to evaluate their performance, and design and build experimental test benches to validate prototypes and characterize their operation.