

Doctoral School in Materials, Mechatronics and Systems Engineering

Research subjects proposed for the 38th cycle

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

The research project must contain: i) a title, ii) an introduction to the problem with reference to the state of the art, iii) a clear description of the aim and the content of the research, iv) an estimation of the time sequence of the intended activities, v) literature references.

The project must be in one of the research areas of the Doctoral Programme, **preferably** on one of the following research subjects:

Materials Science and Engineering (area A)

- *Reference persons:* A. Dorigato, L. Fambri

Title: Novel multifunctional polymer composites for energy conversion technologies ¹⁾

In the last century, global CO₂ emissions have increased about 10 times, and around 75% of the worldwide CO₂ emissions are correlated to energy produced from non-renewable sources, such as gas, oil, and coal. Therefore, an increase in the efficiency of the energy production systems is of utmost importance for ensuring the sustainable development of the modern society. The general aim of this PhD work is to develop novel multifunctional polymer micro and nanocomposites to be applied in different energy conversion technologies. The attention will be focused on Barocaloric Materials for solid state cooling and on Phase Change Materials for high efficiency thermo-electric generators.

Nowadays cooling is responsible for more than 25% of the total electricity consumption in the world, and this figure is predicted to further increase in the next decade. Barocaloric effect (BCE) belongs to the solid-state caloric technologies for cooling and heat pumping that are rising because of their prerogative of employing solid-state materials as refrigerants. The solid-state nature of the refrigerants avoids the accidental release of refrigerants in the atmosphere, contrary to what happens with traditional vapor compression systems. BCE occurs as a solid-state transformation generated by a variation of the hydrostatic pressure of the system. Such transformation could provoke an isothermal entropy change (ΔS_T) or an adiabatic temperature variation (ΔT) in the barocaloric material, despite of the isothermal or adiabatic nature of the process. Only very recently, the research on barocaloric materials is receiving a deal of attention due to the demonstration of giant barocaloric effects in shape-memory alloys. Regarding polymers, there is still a lack of literature, despite their high caloric potential. Very recent findings suggest that commercial refrigeration devices based on barocaloric effect from elastomer polymers can be envisaged in the near future. Therefore, the first goal of the PhD project is to develop novel polymer composites for barocaloric applications, possessing elevated tailorability with respect to large temperature change, high fatigue resistance, high materials efficiency and rapid heat transfer during thermo-mechanical cycling. The most suitable methods and tools for an optimized use of these materials for barocaloric cooling will be detected.

The inevitable electrical energy loss during utilisation is eventually converted into heat, which, in the absence of a proper heat management system, can seriously affect the safety of electrical equipment and energy devices. In order to overcome this problem, thermoelectric conversion technology based on the Seebeck effect uses temperature differences to generate electricity. In this way, waste heat can be partially converted in electrical energy. The larger the temperature difference between the cold and hot sides of the thermo-electric generator (TEG), the higher is the power that can be generated. Assuming a constant temperature at the hot side, the temperature at the cold side should be as low as possible for a high thermoelectric power generation. Organic Phase Change Materials (PCMs) possess high enthalpy near the phase transition temperature and can absorb a large amount of latent heat, allowing them to maintain a constant temperature at the cold side of the TEG, which makes them attractive for use as thermal management materials in industry. Recent studies demonstrated that, upon a proper nanomodification of the PCMs, it is possible to obtain novel multifunctional materials possessing elevated thermal energy storage capability, coupled with high thermal conductivity and dimensional stability, and with electrical insulation properties. Therefore, the second objective of this PhD is to develop novel

multifunctional PCMs, to be applied in TEGs to increase their efficiency and their electrical power output. Particular attention will be devoted to the correlation between the microstructural features of these materials and their thermo-mechanical behaviour. A detailed comparison with the PCM systems already present in literature for the same application will be carried out.

- *Reference persons:* M. Benedetti, M. Pellizzari

Title: Laser powder bed fusion fabrication of architected cellular materials for biomedical applications ¹⁾

The wide design freedom allowed by laser powder bed fusion (L-PBF) makes possible the fabrication of architected cellular materials. In essence, they consist of elementary strut-based cells that are repeated periodically to fill the 3D space of a component. They permit to adapt the mechanical, thermal, and biological properties to the specific needs of the application. Unfortunately, when the fabrication process is pushed towards sub-millimetric geometrical details, there is a systematic deviation of the actual from the as-designed geometry of the component. This necessitates a careful setup of the process parameters along with strategies aimed at compensating geometrical inaccuracies. In addition, the strong dependency of microstructure (crystals orientation, porosity, surface and bulk printing defects) and mechanical properties (elastic modulus, yield and fatigue strength) upon the strut orientation with respect to the building plane necessitates an optimization approach to identify the most suitable part orientation in order to meet the desired objective function and satisfy microstructure, performance and manufacturing constraints. Students interested in this project should be highly motivated, have an aptitude for both programming and experimental work, and will be rewarded by the acquisition of technical skills that are highly appreciated in the industrial field.

- *Reference persons:* D. Diré, F. Parrino

Title: Development of hybrid inorganic/organic nanocomposites with enhanced thermal conductivity ¹⁾

Materials with both high thermal conductivity and excellent electrical insulation are required in advanced electronic applications. In fact, high computing microprocessors under operating conditions could release a considerable amount of heat, which causes mechanical stress, poses severe limits to nominal frequencies, and eventually reduces the life-time. Moreover, good processing ability, flexibility, superior corrosion resistance and low electrical conductivity are required to design small, flexible, and portable devices. While polymers are characterized by most of these latter properties, they show low thermal conductivity, generally ranging between 0.1 W/mK and 0.5 W/mK. The project aims at finding innovative solutions to enhance polymers' thermal conductivity through the development of hybrid nanocomposites made of bare or functionalized ceramic nanoparticles and ladder-type silsesquioxanes embedded in polymeric matrices. Nanocomposites will be optimized in composition, characterized and tested and in order to correlate their chemical and structural properties to the possible mechanisms of heat transfer.

-*Reference person:* G. Sorarù

Title: Porous polymer derived ceramics for water purification ¹⁾

The polymer-to-ceramic (PDC) route enables the facile processing of porous ceramics with tunable pore size from the micro- to the meso- to the macro-porous range. PDCs belonging to the Si-C-N-O family display excellent high temperature stability and corrosion resistance. PDCs are considered nanocomposites comprising an amorphous network and a free carbon phase. They have shown good potential in the field of water purification both as sorbents for organic pollutants and as membranes for water filtration. With this project we aim at studying the processing of PDC membranes which combine the filtrating and the adsorption functionalities for water remediation. The membrane, having hierarchical porosity, will be obtained by tape casting a solution containing a preceramic polymer with a molecular spacer and different fillers (silica sol, PDCs aerogels, etc.). The adsorption capacity toward different organic pollutants will be assessed by measuring adsorption isotherm and kinetics while the filtration efficiency will be measured via a dead-end membrane filtration system.

-*Reference persons:* E. Rustighi, G. Straffelini

Title: Reduction of brake particulate matter emissions through system vibration control. ^{A1)}

During a typical braking process, 40-50% of wear debris generated from the mating interfaces are converted into airborne particulate matter (PM) and released into the atmosphere. This contributes to air pollution, which claims over half a million adult lives prematurely every year in the European region. In this study, a novel way to limit emissions from brake systems is proposed, based on the minimization of the vibration of the mating bodies.

Model friction material formulations will be firstly investigated in a laboratory pin on disc apparatus. To reduce/modify the vibrations, different damping systems will be investigated, both numerically (through specific modeling) and experimentally (through specific accelerometer and other devices). In particular, the role of damping ingredients (such as rubber particles) will be investigated, together with the role of external damping devices, placed at the interface between the friction material and the system holder. Subsequently, the investigation will be focused on the optimization of commercial friction materials. In addition, specific tests will be carried out using a dynamometer, in order to properly simulate the braking cycles, and then obtain information on the vibration-emission relationship in conditions close to the real brake situations. It is expected that the use of this method for reducing emissions can accompany the optimization phase of the brake squeal noise of friction materials, thereby, providing new design perspectives.

- *Reference persons:* A. Quaranta, G.-F. Dalla Betta

Title: Development of hybrid detectors for monitoring of mixed radiation fields ^{A2)}

The aim of the activity is to develop innovative sensors for ionizing radiation based on the coupling of micropatterned silicon photodetectors with nanostructured materials and scintillators through different manufacturing procedures. The detector structure will be studied in order to monitor different radiation fields, namely gamma rays, energetic ions, and neutrons. In particular, for the development of imaging detectors for thermal neutrons, new methods for filling 3D-silicon sensors with converters based on sensitive isotopes will also be studied.

Mechatronic and Mechanical Systems (area B)

- *Reference persons:* M. Da Lio, F. Biral

Title: Methodologies for validation and testing of self-driving technologies ¹⁾

The deployment of self-driving systems is hindered by corner and edge cases (the so called 'long tail problem'). The Ph.D. program should study methods based on a combination of simulations and experiments for efficient discovery of corner and edge cases and for developing focused testing and validation of self-driving systems.

On the one hand, the program should focus on corner case generation, such as manipulating observed near misses or using traffic agents to create realistic human mistakes.

On the other hand, the program should also compare different self-driving architectures (for example, layered control versus more traditional programmed architectures such as those based on sampling based approaches) to determine the relative merits and weaknesses.

Finally, the program should also address the question of balancing and combining experiments with simulations optimally. To this end in the Ph.D. program there will be the chance to test the different self-driving architectures both on real vehicles and in simulated digital copy of the real scenario. We expect the output of the Ph.D. to influence the current self-driving deployment programs.

- *Reference person:* D. Bortoluzzi

Title: Development of a critical space mechanism based on the in-flight experience of a technology demonstration mission ¹⁾

Mechatronic systems often play a critical role in the operation of satellites. In particular, customised mechatronic systems need to be designed, developed, qualified and operated on board scientific payloads with very tight functional and performance requirements and are assigned challenging tasks. In the detection of gravitational waves from space, the successful experience of the LISA Pathfinder mission produced key data for the improvement of the mechanism in charge of the initialisation of the scientific phase, i.e. the injection of the proof mass into the nominal geodesic trajectory inside the Gravitational Reference Sensor. On the project side, much effort is spent to re-design the critical parts of the mechanism (Grabbing Positioning and Release Mechanism - GPRM), based on a deep analysis of its in-flight operation of the units which equipped the LISA Technology Package, science payload of the spacecraft. The research project aims at the conversion of the flight experience of the LISA Pathfinder mission into a reliable, tested and improved design of the GPRM mechanism and its operation strategies for the forthcoming LISA mission.

- *Reference persons:* L. Zaccarian, A. Del Prete

Title: Lyapunov-based Nonlinear and hybrid control schemes for autonomous aerial systems ^{B1)}

This PhD position is funded by the PRIN 2020 entitled “Design Of Cooperative Energy-aware Aerial platforms for remote and contact-aware operations (DOCEAT)”, CUP n. E63C22000410001, numero di protocollo 2020RTWES4, which aims to develop and integrate cutting-edge paradigms, architectures, algorithms and tools enabling the analysis, design and operation of energy-aware autonomous aerial systems capable of interacting remotely and in contact with uncertain and unstructured environments. Industrial Drones contain control loops mostly based on linear approaches applied to linearized dynamics. Extending these solutions to more general and energy efficient drone architectures (such as tilt-rotors, convertible drones or other non-standard coplanar multirotor architectures) is a nontrivial task, due to the nontrivial interplay between the translational and rotational motion. In this context, hybrid nonlinear control techniques have proven to be effective solutions for overcoming intrinsic limitations of standard continuous-time feedbacks and for providing effective obstacle avoidance algorithms where left-right and on-off decisions can be effectively encoded in the hybrid formulation.

In this PhD, which will be carried out in collaboration with the project partners (Politecnico di Milano, University of Rome, Tor Vergata, University of Bologna and University of Padova), we will start from certain prototype high-performance drone architectures, which will come already equipped with a detailed model and simulator. Starting from the given model, we will address the hybrid control problem and the obstacle avoidance problems, by exploiting hybrid Lyapunov stability certificates, both for the analysis and the design of feedback controllers.

- Reference persons: A. Del Prete, L. Zaccarian

Title: Control of autonomous aerial systems in the presence of interaction with the environment ^{B3)}

This PhD position is funded by the PRIN 2020 entitled “Design Of Cooperative Energy-aware Aerial platforms for remote and contact-aware operations (DOCEAT)” (CUP n. E63C22000410001, protocol number 2020RTWES4), which aims to develop and integrate cutting-edge paradigms, architectures, algorithms and tools enabling the analysis, design and operation of energy-aware autonomous aerial systems capable of interacting remotely and in contact with uncertain and unstructured environments. The realization of the drone-of-the-future platform requires the robust management of contacts and physical interaction methods, based on hybrid systems and automata, robust control, stochastic control. Moreover, the high requirements in terms of safe energy-aware navigation, call for the use of advanced data-driven modeling, control and estimation methods (e.g., Reinforcement Learning algorithms), which will be investigated in the project. The activities of the student will be carried out in collaboration with the project partners (Politecnico di Milano, University of Rome, Tor Vergata, University of Bologna and University of Padova), and will include: the investigation of control algorithms for aerial movements with intermittent contacts; the development of a software framework in C++ and Python for the deployment of control on real autonomous aerial systems; the validation of the above-mentioned framework through experiments on the available platforms.

Electronic Systems and Integrated Microelectronic Systems (area B)

- Reference persons: D. Brunelli, D. Fontanelli

Title: Positioning and Sensing per Ultra-low Power Internet of Things ¹⁾

Positioning and sensing systems are becoming a pervasive enabler for many IoT engineering applications. For example, autonomous vehicles and distributed sensors represent a potentially disruptive yet beneficial change for many sectors of our society, from logistics to environmental monitoring to transportation. Moreover, the synergy with the environment enhanced with Artificial Intelligence will be the breakthrough technology in the next future for many different application domains. The proposed Ph.D. activity aims at designing and developing intelligent algorithms and embedded electronics solutions for this area.

Operational Research (area B)

-Reference person: D. Di Caprio

Title: Algorithms and models for strategic decision-making in smart environments ¹⁾

Nowadays, organizations can achieve tangible benefits from emerging technologies such as connected and mobile devices, robotic process automation, 3-D printing, virtual reality (VR)/augmented reality (AR) devices, artificial intelligence, cloud computing techniques, blockchain and 5G/6G wireless communication networks. In doing so, they must account for the risks and vulnerabilities associated with these technologies.

The development of advanced technologies and smart systems is increasingly affecting all the activities of businesses and services challenging the traditional human interaction and collaboration in many different ways. Serious concerns arise from issues such as personal privacy and ethics, reputation and identity, addiction and overuse/misuse, technostress and IT anxiety, governance of data and algorithms, digital divide and information inequalities, among others.

These features highlight the importance of developing decision support systems able to manage the complexities arising within smart environments and make decisions based on the available data in a predictive or adaptive manner.

The present research project aims at developing and characterizing smart strategic decision-making approaches where formal models are defined to account for different levels of uncertainty affecting evaluations and/or available data while supporting practical implementations via both common and ad hoc developed software. The objective of the formal models is the design of mathematically sound processes for optimal decisions. Fuzzy sets and preferences, multiple criteria decision-making techniques, multi-layer multi-objective optimization problem formulations are some of the tools that may be useful and whose knowledge is required. The mathematical models should reflect the dynamic interactions taking place across variables and could incorporate the design of search algorithms able to mimic the behavior of both firms and customers when acquiring/exchanging information.

- *Reference person:* M. Brunelli, F. Pilati, D. Viesi

Title: Development of an innovative multi-objective optimization framework for Smart Energy Communities, including energy and power flow modeling ^{B2)}

Energy communities are at the forefront of the EU Green Deal strategy. Since 2016 a number of works have been done by FBK-SE covering the planning of several municipalities and regions based on EnergyPLAN+MOEA. However, these case studies are lagging behind in respect to some aspects: (I) full integration of the multiple decision variables that maximize flexibility, (II) Multi-Node solutions that enhance the synergies between different local, regional, national and transnational scales, (III) holistic approaches among energy-environment-economy-society, (IV) interaction with geospatial models dedicated to land-use, urban planning, mobility, etc., (V) embedding of both climate mitigation and adaptation. Moreover, the current approach is missing the integration of a power flow analysis. Therefore, the overarching goal of this PhD is to develop an innovative multi-objective optimization framework for Smart Energy Communities, including energy and power flow modeling.

Funding:

1) UNITN

A1) UNITN and DII project (Straffellini)

A2) UNITN and INFN

B1) UNITN and PRIN 2020 (DOCEAT)", CUP n. E63C22000410001, numero di protocollo 2020RTWES4

B2) FBK

B3) PRIN 2020 (DOCEAT)", CUP n. E63C22000410001, numero di protocollo 2020RTWES4