Doctoral School in Materials, Mechatronics and Systems Engineering

Research subjects proposed for the 36th 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:* M. Benedetti, V. Fontanari

Title: Modelling and simulation of the laser powder-bed fusion fabrication of single struts for architected cellular materials. [1)]

Numerical modelling is becoming more and more important in any aspect involving the simulation and design of components and processes covered in industrial engineering. An emerging manufacturing branch that could greatly benefit from numerical modelling is laser powder-bed fusion (L-PBF), one of the most important metallic additive manufacturing processes. The wide design freedom allowed by 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 make possible to adapt the mechanical, thermal, 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. The present project aims at devising numerical methods suitable to simulate the L-PBF fabrication process of single struts in order to get useful indications for achieving this goal, without expensive trial and errors. The simulations will be validated through an extensive metrological testing campaign undertaken on additively manufactured struts. 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 person:* C. Menapace

Title: Tribological and emission behavior of friction materials obtained through novel processing routes [1)]

The growing interest for environmentally friendly friction materials, to be used for vehicular brake systems, has sparked research efforts aiming at developing new material compositions which might effectively respond both to performance and low pollution requirements. To render more effective and efficient the development process, it is important to find on lab scale already reliable relationship among the identified wear mechanism and the relevant airborne particle emission.
In this research, newly developed copper-free friction materials are pin-on-disc tested, even to evaluate the mass and number of particulate matter (PM) with an average aerodynamic diameter ranging from 10 μm down to less than 1 μm.
This Project is meant to investigate the evolution of the particle emission during the PoD tests in order to gain a better understanding on the relationships among several features of the wear products, like particle distribution, compaction and extension of the friction layers, etc., and the PM emission rate. At the same time, innovative processing techniques have to be optimized to properly consolidate the mix of innovative ingredients.
The results obtained on laboratory level can provide a solid stand point, to select new compositions, to be taken to the bench and, eventually, car test characterization and product certification level.

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

Title: Weathering of organic coatings [1)]

Organic coatings are the most used method for the corrosion protection of several metals as steel, aluminum and galvanized steel.
Several laboratory tests have been developed. The accelerated tests together with electrochemical characterization allow to highlight the properties of these protection systems.
However, some issues remain unresolved, in particular to have the possibility to predict the corrosion behavior during time in the service aggressive environment.
The aim of the research is to try to find a connection between the data of accelerated laboratory tests, electrochemical measurements and natural exposures performed on protective painted systems.
As a material both steel and aluminum alloys protected by organic coatings will be considered.
The identification of the most important parameters of atmospheric environments (humidity, temperature, natural and artificial pollutants) and their influence on the decrease in the protective properties of the coatings is the starting point. Considering the accelerated laboratory tests, the test parameters will be modified trying to find a connection with natural weathering. The electrochemical tests, in particular the

electrochemical impedance measurements, will be of support to obtain useful information both on the state of damage produced by the accelerated and natural tests, having quantitative data.

- *Reference persons:* A. Dorigato, A. Pegoretti

Title: Development of multifunctional polymer composites with self-healing capability [1)]

In the last decades polymer composites have been introduced in an increasing number of applications because of their peculiar combination of properties, not otherwise attainable. Consequently, a strong interest has recently arisen towards the possibility to further promote the reliability and the safety of polymer composites by introducing structural self-healing capabilities. Intrinsic self-healing systems in composite laminates could offer the possibility of repairing the cracks reversibly, through the application of an external stimulus (i.e. usually heat or an electrical input). Even if some examples of intrinsic self-healing systems with good repair efficiency can be found in the open literature, a further development of this technology is required to promote its application in the real life. The aim of this works is thus the development and the systematic investigation of novel composite laminates with self-healing capabilities. Both thermoplastic and thermosetting matrices will be considered, and a comprehensive investigation on the role played by different healing agents will be performed. In this framework, different healing mechanism (i.e. electro-activation through Joule heating effect, electro-magnetic induction, etc…) will be considered. The physical properties of the produced laminates will be correlated to their microstructural features and to their self-healing potential.

- *Reference persons:* A. Motta, D. Maniglio

Title: Advanced fabrication technologies for bone-contacting medical devices. [A1)]

One of the challenges of tissue engineering is the development of technologies for the production of scaffolds with controllable and reproducible properties and architecture.
In the large variety of scaffold production techniques, those included in the family of 3D printing, are among the most promising in terms of automation and repeatability of macro- and micro-structures, even if they impose specific constrains to the characteristics of the materials to be printed. Due to the unique combination of properties such as mechanical tunability, biocompatibility, biodegradability, thermal stability, easy processability, proteins have been used as functional biomaterials, due to their positive interaction with living tissue is required. By the way, just recently they were proposed as possible materials for 3D printing applications because they possess tuneable physical characteristics together with positive biological behaviour. The biopolymers can be used as it is, in combination with other polymers/inorganic phases or specifically engineered by specific chemical/biological functionalization depending on the final application.
The PhD research proposal will focus on advanced 3D fabrication techniques, designed to protein-based materials, with particular interest orthopaedic applications such as bone tissue engineering or improvement of implantable devices.
The printing technique will be tuned starting from the requirements identified in the initial analysis of the target application/clinical needs: particularly rheological properties, extrudability through thin needles or nozzles, methods to induce the solution gelation, effect of the gelation mechanism, and mechanical properties will be defined. The addition of functional groups and inorganic charges will be considered to enhance material biological performances and to tune degradability or stability of the scaffold/device. Moreover, its biocompatibility will be evaluated in in vitro tests.
During the PhD activity the 3D fabrication technique will be also coupled with other fabrication techniques, such as electrospinning or solid fibroin sintering, to realize multifunctional devices. The activity will be developed in collaboration with Research Center of Orthopedic Institute of Rizzoli and University of Maastricht (Merlin Institute)

Mechatronic and Mechanical Systems (area B)

- *Reference person:* F. Pilati

Title: Design and optimization of digital logistic and production systems [1)]

During the latest years logistic and production systems are experiencing a remarkable revolution, in particular due to the digitization of their processes. Indeed, the ubiquitous adoption of cheap sensors enables to obtain in real-time a wide variety of information related to the distribution and manufacturing of goods and components outside and inside the production facilities. The big quantity of collected data represents the raw material of smart logistic and production systems, which could be leveraged to optimize the monitored processes, as real-time urban logistics to deliver different variety of products (e.g. food), factory indoor tracking to dynamically schedule the material flows of industrial plants, digital twin of production processes to efficiently manage the operation of multiple resources and personnel (e.g. through motion capture technologies).
Aim of this research project is the development of intelligent algorithms and methods to exploit the aforementioned data provided by multiple sources and dynamically optimize different critical processes which distinguish logistic and production systems. To reach this goal, several technologies will be tested, evaluated and eventually leveraged to digitize the processes of interest. Specific software will be adopted to implement the developed intelligent algorithms and optimization models for a superior design and management of the distribution and assembly systems of the future. The results obtained will be validated considering multiple criteria to ensure the overall sustainability of the targeted processes and systems, through technical, economic, environmental and social pillars.

- *Reference person:* D. Bortoluzzi

Title: Technological heritage exploitation of the experience of the LISA pathfinder mechanisms [1)]

The aim of a technological demonstration mission is to provide in-flight testing of key spacecraft subsystems in order to reduce the risk of a particularly challenging space project. LISA Pathfinder is an ESA mission flown in late 2015 with the aim to test some technologies which are fundamental for the observation of gravitational waves from space. Among these, the mechanism in charge of the injection of the proof

mass into a geodesic trajectory constitutes a critical subsystem which requires deep analysis and full comprehension, since its in-flight performance was significantly different from the expectation. The research project focuses on the analysis of the LISA Pathfinder flight data of the mechanism operation and on the ground test performed on an EQM. The goal of the PhD subject is to build a consolidated model of the injection of an extended proof mass into a geodesic trajectory on behalf of a mechanism, proposing possible mechanism optimization and/or re-design for the forthcoming LISA mission. The results of the research are considered for possible application in future space missions relying on very accurate precision sensors or accelerometers for spacecraft navigation and/or scientific measurements.

- *Reference person:* M. De Cecco

Title: Perception methods to enable mobile robots path planning and control in poorly structured environments[1)]

Mobile robotics has a great potential to contribute to the growth of our societies. Its applications are increasingly spreading in many applications. A famous example is in intelligent vehicles. Anyhow its effective application faces many challenges that limit its actual implementation. One of them is its ability to sense the environment and share this knowledge with human operators. For this aim, to develop new robotics sensing and Mixed Reality applications to share the workspace with a human being represent important enabling factors.

- *Reference person:* G. Giordano

Title: Dynamical Networks and Biological Applications [1)]

Interconnected systems governed by possibly nonlinear dynamics are ubiquitous both in engineering and in nature. Studying their dynamic behavior is fundamental to understand, predict and control the phenomena around us. An example is dynamic spreading of diseases, cyberattacks or opinions in our hyper-connected world: predicting the evolution of epidemics and containing contagion, or fake news, is crucial. Studying nonlinear dynamical networks is extremely challenging due to their complexity. Parameter-dependent numerical simulations are mainly used to predict their behavior case by case, but the exact models and parameter values are often poorly known. However, some fundamental dynamic behaviors of interconnected systems in nature are preserved despite huge parameter variations and rely exclusively on the system interconnection structure. The goal of this PhD subject is to address some of these challenges by developing novel theoretical approaches, possibly parameter-independent, to analyze and control classes of (nonlinear) dynamical networks and apply these methods to gain a deeper insight into the functioning of complex systems in nature. Applications include biological systems at different spatial scales (from gene regulation networks in cells to whole-body physiological mechanisms) and epidemic models. (for more info email to: giulia.giordano@unitn.it).

- *Reference persons:* E. Bertolazzi, F. Biral

Title: New optimal control methods for complex dynamical systems described by DAEs and/or neural networks [B1)]

Many engineering and biomechanical applications and research problems, such as (but not limited to) ground/aerial vehicle dynamics motion planning, energy management, human/robot prediction, require the solution of large and/or complex non-linear optimal control problems. Dynamical systems of interest may change number of states and dynamic behavior (hybrid system) and are described by differential algebraic equations (DAEs) with possible discrete states or subsystems defined by neural networks.
This PhD will focus on the theoretical and numerical aspects arising in the solution of non-linear optimal control problems applied to the above complex dynamical systems.
The goal of this PhD study is the development and implementation of novel robust and fast convergence numerical methods for the solution of optimal control problems for the above dynamical system with special interest in the fields of multibody and vehicle dynamic.

- *Reference persons:* P. Bosetti, M. De Cecco

Title: Perception methods for Augmented Humans [B2)]

Automation and robotics fostered a strong growth of our society replacing dirty works while increasing the production rate. On the other side our communities are facing an alarming societal challenge with a decrease of work demand and an increase in power concentration in the hands of few subjects/companies.
In this context emerging technologies have the potential to restore the centrality of the human role. Among those technologies there are many that arise from the Measurement/perception world such as natural interfaces in AR together with 3D ToF cameras, eye tracking, wearable sensors just to cite a few and new data elaboration hardware/techniques such as Deep Neural Networks and machine learning, able to augment human capabilities.

Electronic Systems and Integrated Microelectronic Systems (area B)

- *Reference person:* D. Brunelli

Title: Battery-less sensors for Internet of Things [1)]

Internet of Things (IoT) and smart sensors will disrupt the way to conceive manufacturing and many applications. In the near future, many sectors, from smart cities to medical applications, will use the data fusion from hundreds of smart devices. New technologies, interfaces, and

energy autonomy of sensors are some of the hard challenges in this research area. The proposed Ph.D. activity aims at designing and developing a new generation of battery-less embedded architectures and energy harvesting solutions for the Internet of Things.

- *Reference person:* G.-F. Dalla Betta

Title: Micromachined silicon radiation detectors [1)]

This activity aims at developing novel radiation sensors based on bulk micromachining of silicon by means of Deep Reactive Ion Etching (DRIE). These types of sensors exploit the 3rd dimension within the silicon substrate to offer several interesting features, among them enhanced radiation tolerance, high speed, low power consumption, etc. Examples of activities in this field within INFN and EU funded projects are sensors with three-dimensional electrodes (columnar- or trench-shaped) and/or active edges, for High Energy Physics and X-ray imaging applications, and hybrid detectors of thermal neutrons based on perforated silicon sensors coupled with converter materials. The PhD research activity will deal with one or more of these projects and will be focused on the design, TCAD simulation, and experimental characterization of prototypes, both in laboratory and in beam tests also in collaboration with Italian and foreign research partner institutions.

- *Reference person:* L. Pancheri

Title: Monolithic pixel sensor for radiation imaging[1)]

The goal of this activity is the design and characterization of CMOS pixel sensors based on fully depleted silicon, tailored for particle detection, X-ray and Near Infrared imaging. Fully depleted CMOS sensors have gained the attention of the scientific community because they can provide large detector areas with high efficiency and a reduced power consumption if compared to hybrid sensors. The proposed activity will be focused on the development and optimization of the in-pixel sensing device and will be part of a larger project aimed at implementing large-area array sensors for medical, astrophysics and high-energy physics applications in collaboration with research partner institutions. Devices and test structures will be simulated using TCAD tools, and their layout will be designed using commercial CAD software. The devices will be fabricated in a customized deep sub-micrometer CMOS process and validated through extensive experimental characterization.

- *Reference persons:* D. Brunelli, D. Fontanelli

Title: Positioning Systems and ambient intelligence [B3)]

Positioning systems are becoming a pervasive enabler for many engineering applications. For example, autonomous vehicles 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 algorithms and implementing smart localization systems, and embedded electronics solutions for this area.

- *Reference persons:* F. Antonelli, D. Brunelli

Title: Energy-aware IoT Decentralized Smart Architectures [B4)]

The Internet of Things paradigm is driving innovation in several application domains, such as digital industries, healthcare, smart cities, energy, retail, agriculture, etc. IoT architectures have been evolving from an initial centralized approach towards more distributed and edgecentric ones, where everyday-more-autonomous IoT devices are able to interact in a decentralized and effective way. However, the huge variability of requirements that an IoT platform needs to cope with and fulfill to serve such diverse application domains and scenarios suggests that a holistic architectural approach cannot be the solution. Indeed, depending on the specific application context, different challenges emerge, while often conflicting requirements need to be addressed meeting the best trade-offs between energy management and conservation, cognitive capabilities deployed on autonomous devices, latency and bandwidth over low-power communication protocols, timeliness of data exchange, reactivity and reliability in wide area networks. The objective of this PhD is to study, analyze and identify novel energy-aware architectural approaches capable to balance the use of available energy resources within constrained IoT devices with embedded computing capabilities and possible strategies to overcome the existing technological limitations by using blended strategies, such as combination of energy harvesting technologies, computation offloading from the edge to the cloud, adaptive data exchange paradigms, and distributed artificial intelligence along the cloud-to-thing continuum.

- *Reference person:* D. Brunelli

Title: Cellular IoT, AI and Blockchain for production chains [B5)]

In recent years, the management of industrial production and production chains (such as food-chain, quality-tracking) has experienced a considerable evolution from a technological point of view with new enabling technologies such as the Internet of Things dedicated to industry (Industrial IoT - IIoT), 5G communications, artificial intelligence systems (AI) with deep neural network (DNN), and Blockchain-based systems for the certification of information.
The most urgent challenge in this sector is to move these complex software technologies directly to each IoT device characterized by limited computing resources. The Ph. D. topic's goal is to specialize ultralow power embedded hardware systems, based on cellular communication technologies (e.g. Narrowband-IoT), for Machine learning (ML) and Blockchain activities, in new production chain scenarios.

Funding:

1) UNITN
A1) UNITN and DII projects (A. Motta, A. Dorigato, A. Pegoretti)
B1) UNITN and DII project (F. Biral)
B2) DII Projects (P. Bosetti, M. De Cecco)
B3) UNITN and DII projects (D. Fontanelli and D. Brunelli)
B4) FBK
B5) TIM