Doctoral School in Materials, Mechatronics and Systems Engineering

Research subjects proposed for the 37th 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 person:* V. M. Sglavo
Title: Production of ultra-high temperature ceramics (UHTC) by electrical field-current assisted technologies [1)]

Carbides and nitrides of transition metals possess a unique set of properties, including high density, chemical durability, corrosion resistance, and exceptionally high melting point, which makes them attractive for a variety of applications under extreme temperatures. For example, ultra-high- temperature ceramics (UHTC) based on Hf, Ta or Zr can be used as a thermal protection system in supersonic jets and as parts of combustion chambers or rocket nozzles. The outstanding inertness makes sintering of UHTC possible only by hot pressing or spark plasma sintering techniques.
Recent studies have pointed out the possibility to reduce by a large extent the sintering times and temperature for the consolidation of ceramic materials through the application of electrical fields and currents.
The aim of the present research activity is to analyze and optimize the consolidation process of UHTC by the use of specifically tuned electrical fields and currents to be carried out at relatively low temperature for obtaining nanocrystalline structures with higher mechanical properties. Processing conditions will have to be calibrated according to the final performances requested to the material.

- *Reference persons:* M. Fedel, F. Parrino
Title: Photocatalytic and photoelectrocatalytic synthesis of high-value added compounds [1)]

The development of innovative catalytic processes under mild and “green” conditions is one of the great challenges of this century. Photocatalytic and photoelectrocatalytic processes are promising alternatives to traditional synthetic routes. In fact, production of high-added value compounds has been reported with excellent yields towards the target species for selected reactions exploiting solar light, using water as the solvent and abundant, stable, and non-toxic catalysts. In this field, however, basic research is still required to enable the transfer of these technologies from laboratory to larger scales. This project aims at investigating the potentialities of selected organic syntheses of industrial interest by using photocatalytic and photoelectrocatalytic approaches, highlighting the mechanistic aspects involved. In particular, novel photoactive materials will be opportunely synthesized and characterized to optimize the performances of the target reactions.

-*Reference persons*: E. Rustighi, V. Fontanari
Title: Structural wave approaches to leak detection[1)]

Pipeline networks are the most economic and safest mode of transportation for water, oil, gases and other fluid products. As a means of long-distance transport, pipelines have to fulfil high demands of safety, reliability and efficiency. Leakage from pipes is a major issue in the water industry, not only in environmental terms, because of wasting an important natural resource, but also in economic and health terms. Acoustic methods predominate in the armoury of available leak detection methods. The correlation method, in which leak noise measurements are made at accessible locations on the pipe (e.g. at hydrants) either side of the leak, is used world-wide. The leak position is identified by the time delay between the measurements made at each location. However, their effectiveness can be limited by a number of factors, among them the knowledge of the actual pipeline and its effect on structural wave propagation. The aim of this project is to investigate new approaches to ameliorate the detection of water leaks from buried pipelines. The approaches will look at improving the pipeline modelling and also the development of fusion data techniques which use acoustic waves detected at the free soil. The project will have both a numerical and experimental component, both in the laboratory and in the field. The project will be carried out in collaboration with local and international institutions

-Reference person: C. Menapace
Title: Development of high entropy alloys[1)]

High-entropy alloys (HEA) are an emerging class of advanced materials, constituted by a single-phase solid solution structure obtained by mixing five or more elements in almost equiatomic amounts. These alloys show superior hardness, high strength, enhanced wear resistance together with a higher thermal stability if compared to traditional alloys and therefore are very promising for different applications as innovative materials. The present research, starting from the most promising HEAs systems, aims at developing (via Powder Metallurgy route) and characterizing new alloys having high temperature mechanical properties.

-Reference person: V. M. Sglavo
Title: Development of P-3DP (Powder-based 3D Printing) technologies for the production of cement-based inorganic materials [1)]

Among the various additive manufacturing technologies, the present research activity will deal with the so-called P-3DP (Powder-based 3D Printing) process suitable to realize complex shapes starting from a powder bed to be locally consolidated by a specific solution sprayed onto it. In particular, cement-based inorganic materials will be considered for potential applications as refractories or components in the construction industry. Both traditional cements (Portland or aluminous cements) and more innovative inorganic binders like magnesium oxychlorides or geopolymers will be considered as room-temperature hardening phases for inorganic aggregates. The fundamental aim is to identify optimal processing conditions to be used with a prototype P-3DP machine and correlate them with the performances of the produced materials.

-Reference persons: S. Gialanella, G. Nollo , F. Tessarolo
Title: Electron Microscopy Methodologies for Bio-MEDical issues (EMM4BMED) [1)]

The multi-analytical nature of electron microscopy techniques constitutes a fundamental support for numerous biomedical applications for both biomedical and clinical research by exploiting the ability to characterize morphology and composition down to the nanometer range. The nanometric dimensions have shown to be fundamental in many aspects of life, viruses and microorganisms as well as nanoparticles are relevant examples related to both the genesis and the treatment of many human diseases.
This PhD research project is aimed at developing methodologies and protocols for ultrastructural and physico-chemical characterization of biological preparations and bioptic tissues leveraging on advanced imaging and analytical techniques of electron microscopy to address relevant research and clinical questions. The outcome of the project will strengthen the research capabilities of the Departmental Electron Microscopy facility, fostering new research perspectives in the biological and medical areas.

Mechatronic and Mechanical Systems (area B)

- *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: the exact models and parameter values are often poorly known. However, some fundamental dynamic behaviours 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 analyse 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.

-Reference persons: M. De Cecco, P. Bosetti
Title Ubiquitous Measurement[1)]

The term Ubiquitous Computing dates back more than 30 years ago, and yet only the recent development in low-cost, low-power computing devices turned it into reality in the last 10 years, or less. Together with these tiny and distributed computing devices, a new wave of distributed measurement devices also came: accelerometers and IMUs, magnetometers, temperature and humidity sensors, optical sensors are nowadays pervasively available and connected to ubiquitous computing.
From this enabling technology emerges the potential of fusing such a huge breadth of information efficiently and—more than else—effectively. This opens new scenarios such as, just as example: 1) decision making based on optimality criteria and/or Artificial Intelligence for production management, fault diagnosis, fleet control, etc.; 2) heterogeneous systems control; 3) context perception for human sensing enhancement.
Together with UC, UM shall leverage on Artificial Intelligence for improving computational effectiveness, on Mixed Reality to increase human perception, optimal control criteria to exploit in a proper way the heterogeneous cluster of information. On this ground, the research shall focus on algorithms, techniques and technologies for UM, focusing on societally relevant applications.

- *Reference person:* A. Del Prete
Title: Learning and model predictive Control for quadruped locomotion [B1)]

What if we could generate complex movements for arbitrary robots with arms and legs interacting in a dynamic environment in real-time? Such a technology would certainly revolutionize the motion capabilities of robots and unlock a wide range of very concrete industrial and service applications: robots would be able to react in real-time to any change of the environment or unexpected disturbance during locomotion or manipulation tasks. However, the computation of complex movements for robots with arms and legs in multi-contact scenarios in unstructured environments is not realistically amenable to real-time with current computational capabilities and numerical algorithms.
The project Memmo aims to solve this problem by 1) relying on massive off-line caching of pre-computed optimal motions that are 2) recovered and adapted online to new situations with real-time tractable model predictive control and where 3) all available sensor modalities are exploited for feedback control going beyond the mere state of the robot for more robust behaviors. Memmo will develop a unified yet tractable approach to motion generation for complex robots with arms and legs.

- *Reference persons:* M. Da Lio, F. Biral
Title: Human-like intelligence for smart human-vehicle cooperation [B2)]

The rider-horse metaphor (H-metaphor) was proposed, back in 2003, as a model of desirable interaction between driver and intelligent vehicles (Flemisch-2003). Norman (Norman_2007) outlines the salient aspects of the interaction as follows:
"Think of skilled horseback riders. The rider ``reads" the horse, just as the horse can read its rider. This interaction is of special interest because it is an example of two sentient systems, horse and rider, both intelligent, both interpreting the world and communicating their interpretations to each other."
Notably, the splitting of authority between the two agents may vary dynamically. On one end, a horse can ride fully autonomously; on the other end, the rider can claim increasing authority levels, till steering the horse's behavior step by step.
Autonomous vehicles might benefit from a similar ability. First, the user experience would undoubtedly improve: imagine if the driver could give hints to the car and feel as if it could ``understand" his/her intentions. Second, such driver-vehicle interaction could relieve the concerns about safety and long-term reliability that affect current autonomous driving technologies (kalra_driving_2016}: for example, the Toyota Research Institute hints that collaborative driver-copilot technologies could fill the safety gap in the transition between human and fully-autonomous driven vehicles
While the H-metaphor describes a desirable form of interaction, it does not tell how to realize a system that produces that interaction. One obvious way to implement interactions between humans and robots is by programming interplays with rules. However, an alternative approach may be to construct the robot's sensorimotor system so that interactions are, as much as possible, emergent.
The goal of this PhD program is to study emergent interactions grounded in natural cognition theories, such as the simulation hypothesis and the affordance competition hypothesis. The working assumption is that the alignment of the co-driver agent (the horse) to the human driver's intentions occurs by biasing the robot's action-selection process: the choice among affordable actions is weighted by biases derived from the human activity. The PhD program will investigate the theoretical principle in cognitive science and elaborate mechanisms for learning/steering a co-driver agent (existing in a driving simulator) to evaluate the emergent interactions. This includes both developing and improving the biasing mechanisms and carrying out interaction experiments with human drivers.

- *Reference person*: F. Pilati
Title: Design and management of learning factories in Industry 4.0 era through digital technologies and quantitative methods [B3)]

The current industrial environment is distinguished by major and radical changes which distinguish its fourth revolution over history, also known as Industry 4.0. Digitalization of production processes is one of the most relevant trends of such an environment. Indeed, the adoption of cheap and reliable sensors ubiquitous displaced in the factory shop floor and connected through the internet enables to collect a huge quantity of real data from the field. These data represent a remarkable source of information and, if properly leveraged, could increment the efficiency of the monitored processes. Furthermore, proper tools and techniques should be developed to enable the factories of the future to learn from themselves, through a proper assessment of the aforementioned quantitative information collected. Aim of this research project is the development of original hardware-software architectures to leverage the stream of data obtainable by the adoption of proper digital technologies to monitor industrial production systems. These architectures are equipped with innovative intelligent algorithms and quantitative methods targeted to the design and management of the factories of the future through the leveraging of such digital data. Moreover, proper mathematical models are proposed to let the production systems learn from themselves considering the aforementioned data sources and continuously improve their performances also with autonomous decision-making processes. The developed architectures are implemented in different industrial environments, as warehousing systems, assembly lines, manufacturing cells and shop floors to ensure an overall sustainability of the considered production processes taking into account technical, economic, environmental and safety aspects.

Electronic Systems and Integrated Microelectronic Systems (area B)

- Reference person: D. Brunelli
Title: Batteryless Tiny Machine Learning for Internet of Things [1)]

The 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, with high capability of Artificial Intelligence directly on resource-constrained IoT devices using the recent Tiny Machine Learning approach (TinyML).

- *Reference person:* G.-F. Dalla Betta
Title: Development of advanced 3D silicon radiation detectors [B4)]

This activity aims at developing novel radiation sensors with three-dimensional electrodes (either columnar- or trench-shaped) deep etched within the silicon substrate to offer outstanding features in terms of radiation tolerance and high speed at low power consumption. Several INFN and EU funded projects are presently running in Trento on this topic, mainly aimed at High Energy Physics applications (e.g., the upgrades of ATLAS, CMS and LHCb experiments at LHC). The PhD research program, to be carried out within the framework of these projects, 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*: E. Tedeschi
Title: Optimization of Power Take-Off systems for Wave Energy Converters [1)]

To achieve the European goal of carbon neutrality by 2050, the contribution of the ocean energy sector needs to be upscaled by a factor of 100 in the next three decades. In particular, in order to better exploit the huge potential of wave energy it is necessary to overcome one of the limiting factors hindering its actual conversion into electricity, i.e. the frequent underperformance of the Power Take-Off (PTO) system. This PhD project will focus on the analysis and optimization of an all-electric PTO solution based on a modular design, which can enhance the efficiency and reliability of the overall power conversion. This will require an integrated approach to the design and control of the electromechanical conversion system, with the twofold goal of maximizing the power capture in different sea states during normal operation, while minimizing the adverse impact in case of contingencies or faults. The control approach elaborated through theoretical analysis and computer simulations will need to be validated for real time applications.

- 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.

- Reference person: E. Tedeschi

Title: High performance electro-mechanical conversion systems for wave energy applications [B6)] additional scholarship

With Europe aiming to be carbon-neutral by 2050 it is imperative to exploit all available renewable energy sources. Due to its high availability and predictability, wave energy could be a major contributor of the green energy portfolio, but technical maturity of wave energy converters is still to be achieved, and intense research and development are needed in the very next years to overcome current technical limitations.
The Power Take-Off system is the core of any power conversion chain that allows transforming the kinetic energy of waves into electricity. It is, however, a critical component needing further investigation and improvement to be able to produce electric power in an efficient and reliable manner. This PhD project will investigate Power Take-Off solutions that are fully electric and based on a modular structure, to better adapt to different types of prime movers, deployment sites and sea conditions. A wave-to-wire model needs to be built to analyze the interactions between the Power Take-off and the other subsystems, both under regular and faulty conditions. The scope is to identify optimized PTO configurations and corresponding control strategies for the maximization of the power extraction and the minimization of faults' impact on the power delivery. Following theoretical studies and software simulations, proposed control solutions should be validated for real time applications.

This scholarship is offered in collaboration with the Norwegian University of Science and Technology (NTNU) in Norway and has special admission conditions for the PhD candidate, who will need to satisfy the entry requirements of both universities. Moreover, the PhD candidate shall spend 18 months at NTNU where he/she will undergo part of the training and research that are part of the PhD project.

Operational Research (area B)

-Reference persons: L. Mich, J. Mylopoulos

Title: From Legal Contracts to Formal Specifications [1)]

Smart contracts are software systems that partially automate, monitor and control the execution of legal contracts. The requirements of such systems consist of a formal specification of the legal contract whose execution is to be monitored and controlled. Legal contracts are always available as text expressed in natural language. The aim of this project is to improve and better support Law practice by translating legal contracts into formal specifications defined in terms of concepts from Deontic Logic. Such specifications can be used for algorithmic analysis of legal contracts as well as support the automation of contract execution monitoring and control. In this context, the PhD activity implies an interdisciplinary study to gather and analyze real-life industrial contracts, design a conceptual model, and test the application of linguistic tools to support the translation of textual contracts into formal specifications.

Funding:

1) UNITN
B1) UNITN and DII project (Del Prete)
B2) UNITN and DII projects (Biral, Bosetti, Da Lio, De Cecco)
B3) DII project (Pilati)
B4) UNITN and DII projects (Dalla Betta, Sglavo)
B5) TIM
B6) DII projects in collaboration with NTNU