Doctoral program in Autonomous Systems (DAuSy)

List of Research Themes - XL cycle

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Reference Themes “DM 629/2024” and “PATTI TERRITORIALI”

Application XL cycle - p. 15

reference ID: from A01_PNRR629_PT to A09_PNRR629_PT

A01_PNRR629_PT Optimal design and operation of robotized and automated warehouses. (Polytechnic University of Bari, Dotoli / Carli)

Research description:
Warehousing is indeed one of the oldest logistical problem in human history. As soon as societies began to transition from nomadic lifestyles to settled communities, the need to store surplus food and other goods became apparent. To this day, tasks such as designing and managing warehouses are regarded as challenging due to the crucial role played as a central hub for storage, processing, and distribution within the supply chain. In the context of Logistics 4.0, the advent of robotized and automated warehouses represent a significant evolution in logistics and supply chain management, leveraging cutting-edge technologies to improve various aspects of warehouse operations [1]. Robotized and automated warehouses come in various types, each designed to address specific operational needs, ranging from conventional systems, such as cranes, automated forklifts, carousels, and automated dispensers, and recent robotic automated systems, based on free-roaming retrieval robots such as shuttles, automated guided vehicles, and drones. Independently from the typology, the use of robotized and automated warehouses brings multiple advantages from increased efficiency and cost savings to enhanced safety and customer service. These advantages not only affect operational performance but also enable businesses to remain competitive in a rapidly evolving market landscape [2]. However, robotized and automated warehouses face several challenges that can impact their effectiveness, reliability, and widespread adoption [3]. Among the key challenges there are the following aspects, which are the main focus of this PhD research proposal:
1. System analysis, aimed at assessing the operational level performance indicators as a function of the given warehouse configuration.
2. Design optimization, aimed at maximizing warehousing efficiency, productivity, and flexibility while minimizing costs, energy consumption, and downtime.
3. Operational policy making, aimed at identifying the impact of different operational policies on the system performance.
For the sake of addressing the above mentioned challenges, this PhD research will be conducted in accordance with the following main interdisciplinary activities:
- Design of the physical layout of the warehouse, including both the placement of storage areas, picking stations, packing zones, and loading docks, to maximize space utilization, streamline workflows, prioritize energy efficient configurations, and ensure seamless interaction between retrieval robots and central control systems.
- Development of intelligent collaborative robotic solutions, to ensure efficient, safe, and ergonomic human interaction in shared workspaces and to automatize repetitive and labor-intensive tasks while reducing manual intervention and increasing consistency.
- Online adaptation and dynamic optimization of workflows using data analytics, to eliminate bottlenecks and improve efficiency, while reconfiguring picking paths, refining batch processing, implementing just-in-time inventory practices, and developing strategies for effective coordination among multiple retrieval robots.
To show the effectiveness of the developed solutions, simulations and tests on realistic scenarios will be conducted, with a particular reference to practical logistic applications of newly developed order picking systems.
The research activities will be conducted at the Decision and Control Laboratory (http://dclab.poliba.it/) of Polytechnic of Bari, while a period of at least six months will be carried out at foreign institutions.

References:
[1] Tutam, M. (2022). Warehousing 4.0 in Logistics 4.0. Logistics 4.0 and Future of Supply Chains, 95-118.
[2] Custodio, L., & Machado, R. (2020). Flexible automated warehouse: a literature review and an innovative framework. The International Journal of Advanced Manufacturing Technology, 106, 533-558.
[3] Azadeh, K., De Koster, R., & Roy, D. (2019). Robotized and automated warehouse systems: Review and recent developments. Transportation Science, 53(4), 917-945.

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A02_PNRR629_PT Interconnected Digital Twins. (Polytechnic University of Bari, Piro)

Research description:
As well known, the Digital Twin paradigm was born to represent a physical object, a process, or a cyber-physical system through the collection, analysis, and processing of data collected (in real-time) using sensors, actuators, IoT devices, robots, and other sources integrated and/or connected to the object or reference system. Scientific literature has well highlighted the benefits of using the Digital Twin paradigm in the control and management of simple and complex systems, in various application scenarios. However, the challenges deriving from an increasingly interconnected world promote multi-disciplinary research activities towards the study and experimentation of innovative technological methodologies and solutions capable of enabling and exploiting the interconnection of Digital Twins (including heterogeneous ones, associated with different environments): the autonomous, safe, scalable and efficient interaction and cooperation of Digital Twin can offer an important turning point in the creation of new services for sustainable production, logistics and the circular economy, the management of intelligent buildings and infrastructures, the management of energy and water sources, the control of smart cities, agriculture, any type of healthcare service, mobility, etc. Therefore, the potential offered by interconnected Digital Twins would also contribute to the definition of concrete solutions in line with the 17 Sustainable Development Goals (SDGs) defined in the "2030 Agenda for Sustainable Development" by the United Nations (UN).
The interconnection and effective use of Digital Twins to support services for the secure control and monitoring of interconnected cyber-physical systems and related application services requires, however, an in-depth study of various technical and technological aspects of interest for the different sectors of Electrical and Information Engineering such as (for example) automation, telecommunications, electronics, information technology, and bioengineering. Therefore, the research project would stimulate a variety of research activities regarding the design, study and testing of:
- Integrated and efficient telecommunications technologies for the optimized management of interconnected Digital Twins;
- Development of algorithms and intelligent control systems enabling or supporting interconnected Digital Twins, based on big data and artificial intelligence, for intelligent environments such as smart cities, autonomous vehicles and mobile robots, smart grids, sustainable mobility systems, smart buildings and smart home;
- Advanced systems for real-time monitoring and maintenance of networks, platforms, infrastructures, and services managed via interconnected Digital Twins;
- Design of autonomous systems and cybersecurity frameworks to support interconnected Digital Twins to ensure reliability, correct functioning, and security;
- Test platforms for emerging and advanced techniques for applications, autonomous systems, and cyber-physical systems to support interconnected Digital Twins;
- Use of interconnected Digital Twins in the advanced management of energy and water sources, mobility services and systems, industrial plants, sustainable cities, telemedicine, and bioengineering systems;
- Integration of interconnected Digital Twins for the management of electronic components and devices.
Independently from the specific topic of interest, the research activity formulated through this project proposal will consider the following contributions:
1. Scientific contribution: The research project will promote the development of new methodologies and tools enabling and/or based on interconnected Digital Twins that significantly enrich and extend the current state of the art.
2. Technological and economic contributions: The results obtained will be shared with the main national and international stakeholders, stimulating their interest in investing in development activities on the topic and obtaining a faster "time-to-market".
3. Social contribution: The scientific, technological, and economic contributions listed above will provide concrete responses to the goal set by the UN in the 2030 Agenda, including: "ensuring access to affordable, reliable, sustainable and modern energy systems for all", "building resilient infrastructure, promoting inclusive and sustainable industrialization and fostering innovation", "making cities and human settlements inclusive, safe, resilient and sustainable", "ensuring sustainable consumption and production patterns", etc.

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A03_PNRR629_PT Intelligent autonomous systems for real-time guidance and support to robotic surgeons. (Polytechnic University of Bari, Bevilacqua)

Research description:

Robotics has significantly changed several surgical procedures allowing different enhancements compared to traditional laparoscopy such as improved dexterity, ergonomics, motion scaling, high-precision movements, and tremor filtering. Surgeons must master such technology to ensure high safety and effectiveness standards, so novice surgeons undergo intensive training in virtual and simulated surgical scenarios. Surgical proctoring, where an instructor oversees the actions of other surgeons, enables hospitals to maintain standardized surgical quality across multiple sites. Severe issues may occur due to the extremely dynamic and safety-critical environment. By directing the leading surgeon toward the most effective intervention, surgical proctoring enables sustaining high-quality intervention, intervening physically or verbally in crucial moments. However, certified expert proctors are becoming extremely limited in opposition to the demand for high-quality robotic surgical training. Besides robotic surgery, robot-assisted intra-operative navigation systems are gaining growing importance, as they allow surgeons to directly perform surgical procedures while maintaining full control of the tools with their hands, achieving a very high level of precision. For example, an anthropomorphic robot can be used to constrain the movement and the line of action of different tools that need to be maneuvered by the surgeon. Additionally, in such scenarios, the surgeon's skills clearly represent an important key factor in ensuring a high-quality result, thus highlighting the need for oversight throughout the entire procedure.

Intelligent autonomous systems can address this issue by delivering real-time guidance and support directly to surgeons, thus improving the quality of procedural implementation. Advanced computer vision algorithms and machine/deep learning methods can be utilized to automatically understand the surgical scenario and provide useful feedback, substantially reducing the physical and mental strain on surgeons while enhancing the efficiency of surgical procedures. Additionally, various robot movement strategies can be analyzed with the aim of constraining certain actions or poses that could harm the patient.

Based on these considerations, the aim of this research project is to study, design, develop and validate innovative autonomous systems to support the surgeon during robotic surgery procedures. This challenging objective can be achieved by the means of the methodology detailed in the following steps:

1. Perform a literature search of state-of-the-art approaches concerning intelligent autonomous systems to support the surgeon during robotic surgery or robot-assisted procedures. Realizing a comprehensive literature review will be the first task of the Ph.D. student.
2. Design and develop an autonomous system. The system will use advanced imaging and sensing technologies, such as endoscopic intra-operatic imaging and robot kinematics and kinectics to real-time evaluate the quality of the procedures, and magnetic resonance imaging and/or computed tomography to create 3D reconstructions of the internal anatomy of the patient, so that the system could compare a possible pre-operative plan with the actual procedure.
3. Design and develop a virtual environment that aims at simulating simple surgical procedures. An in-house dataset might be this acquired by asking surgeons with different skills to perform the same task.
4. Validation of the implemented intelligent autonomous systems in preclinical and clinical studies, demonstrating their potential to enhance robot-based surgical procedures and the quality of care for patients. A series of surgical procedures, such as brain or prostate biopsies, or spine stabilization surgery, will be defined and tested within the laboratory using a real robot-based intraoperative navigation system and specific phantoms.
5. To provide visibility of the main technical and scientific achievements, the Ph.D. student will submit research results to the following academic venues: international conference, such as MICCAI, IEEE ISBI, IPMI, BMVC (KPI: > 1 per year), high-profile journals, such as IEEE TMI, Elsevier Computers in Biology and Medicine, Elsevier Computer Methods and Programs in Biomedicine, Elsevier Artificial Intelligence in Medicine, Elsevier Journal of Biomedical Informatics (KPI: about 2 for the 3 years). When possible, scientific works will be published via Open Access, or shared in pre-print versions through academic websites. Produced datasets will be shared according to the Findable, Accessible, Interoperable, Reusable (FAIR) principle, by using for example Zenodo and IEEE dataport.

Research activities of the Ph.D. student will produce several contributions alongside the following items.

1. Scientific contribution. In line with the expectations on that topic, at both EU and National (for example, those identified with the definition of PNRR initiatives) levels, the Ph.D. student will develop innovative methodologies, tools, and programs in the context of autonomous systems to real-time guidance and support directly to a surgeon, surpassing the current state of the art.
2. Technological and economic contributions: Obtained results will be presented to national and international stakeholders, thus increasing their interest to invest in hard development activities and obtain a faster time to market.
3. Societal contribution. Scientific, technological, and economic impacts will guarantee an enhancement in the quality of care of patients treated with surgical robots, thanks to the novel methodologies and tools proposed throughout the research work. Increase in the quality of care will contribute in creating a sustainable, green, and resilient future for our planet.

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A04_PNRR629_PT Autonomous systems for real-time monitoring of fragile subjects. (Polytechnic University of Bari, Dell'Olio)

Research description:
This PhD project focuses on developing autonomous systems for real-time monitoring of fragile individuals, such as elderly patients with chronic illnesses and individuals with disabilities. The aim is to improve the quality of care through continuous and accurate monitoring of physiological parameters, activity levels, and overall well-being.

Key objectives include the development and optimization of wearable inertial sensors (accelerometers and gyroscopes) and multi-wavelength photoplethysmographic sensors to accurately estimate vital parameters like heart rate, SpO_2, and blood pressure. Advanced classification algorithms will be designed to recognize human activities in real-time and identify critical situations to ensure timely interventions during emergencies. Integration with IoT technologies will ensure continuous and reliable communication for remote monitoring.

The research will be conducted in three main phases: a comprehensive literature review and conceptual design, system development and prototyping, and extensive testing and validation in real-world scenarios. This project aims to advance wearable systems for proactive health management, particularly in domestic environments, contributing significantly to the field with new methodologies and tools.

Results will be disseminated through major conferences and publications, with a focus on technology transfer and intellectual property protection.

References:
C. Botrugno et al., "AI-based Multi-Wavelength PPG Device for Blood Pressure Monitoring," MEMEA 2024.
C. Botrugno et al., "Smart combination of ECG and PPG signals: an innovative approach towards an electronic device for vital signs monitoring," IWASI 2023.

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A05_PNRR629_PT Optimization of networked smart energy systems. (Polytechnic University of Bari, Dotoli/Amirante)

Research description:
The increasing energy demand and penetration of distributed generation and storage as well as the growing shift from traditional schemes to aggregative complex entities (e.g., smart grids) imposes a severe degree of complexity to energy systems, thus requiring a radical change. Energy systems need to be arranged in intelligent networks, capable of receiving two-way energy flows, making producers and consumers interact in accordance with energy trading and sharing mechanisms, and determining consumption/generation/storage profile in advance. In this perspective, each energy system become a smart resource node within a networked virtuous infrastructure. Following this paradigm, several communities have explicitly stated specific objectives to transform their underlying energy systems into sustainable networks of self-sufficient prosumers and prosumagers. The added-value of these networked smart energy systems (NSESs) goes beyond economic benefits to wider sustainability payoffs, for instance, deferring the need of grid extension. Nevertheless, the full implementation of NSESs present various barriers. First, an organizational paradigm for the management of interdependent energy activities has to be defined according to predefined goals. However, independently from the implemented architecture, the success of NSESs relies on how the energy systems are optimally designed and operated. After all, final users expect a tangible financial and even higher sustainability reward from the operation of NSESs. As a consequence, the necessity of developing effective design and operation optimization frameworks tackling such an expected objective is imperative.
The overall objective of the PhD project is thus to define innovative design and operational frameworks for NSESs, as enabling tools to transform the energy sector from a rigid system to a flexible and sustainable asset. In particular, novel mechanisms integrating optimization, Integrated assessment modeling, and machine learning will be developed aimed at making NSESs capable of conveniently trading local energy exchanges, optimally sharing common energy resources, leveraging on loads flexibility, pursuing instantaneous self-consumption, while reducing overall costs and improving sustainability.
To show the effectiveness of the developed framework, all the proposed solutions will be tested and validated before on simulations and then on real scenarios in practical energy applications with a focus on energy community and smart buildings. The research activities will be conducted at Polytechnic of Bari, while a period of at least six months will be carried out at foreign institutions.

References:
[1] Siano, P. (2014). Demand response and smart grids—A survey. Renewable and sustainable energy reviews, 30, 461-478.
[2] Caramizaru, A., & Uihlein, A. (2020). Energy communities: an overview of energy and social innovation (Vol. 30083). Luxembourg: Publications Office of the European Union.

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A06_PNRR629_PT Robots-as-a-service in the digital industry. (Polytechnic University of Bari, Dotoli/Cacucciolo)

Research description:
Ensuring flexibility is one of the main objectives of industrial companies since it helps businesses respond to market changes quickly and effectively [1]. In particular, flexible automation is ideal for complex manufacturing systems in specific domains, such as the automotive sector that is undergoing a significant transformation due to vehicle manufacturers' high product mix and high-volume assembly requirements [2]. Robots-as-a-service (RaaS) for flexible manufacturing plays a key role in all sectors of industry for the ability to produce different products on the same line, for flexible routing --the ability for multiple robots to perform a required action on a specific part-- that copes with capacity challenges, for the reduction of equipment obsolescence, and for the capability of using vision systems to manage quality in real-time, i.e., artificial intelligence, machine learning, and 3D vision [3]. Indeed, RaaS is becoming more and more popular since it is convenient for companies that have the benefits of robotic process automation by leasing robotic devices and accessing a cloud-based subscription service, cost-effective, and easy to implement.
The overall objective of the current PhD project is to define an innovative framework for the implementation of a plug and produce robot in industrial scenarios, which guarantees the maximum flexibility for the customer and thus the minimization of the required time for set-up and reconfiguration. To this aim, flexible robotic arms with the corresponding mechanical aspects, i.e., statics, kinematics, and dynamics must be considered, and state of the art control algorithm must be deeply studied, analyzed, and then developed. In accordance with the RaaS definition, robotic architectures in presence or absence of optimization for trajectory planning/re-planning and tracking problems, collision avoidance, and collision detection issues must be designed to be suitable for any type of task (i.e., pick and place, assembly, machine tending, quality inspection, etc.) in the production line, in combination with physical and virtual devices (sensors, tools, digital twins, etc.).
To show the effectiveness of the developed flexible framework, all the proposed solutions will be tested and validated before on simulations and then on real robot manipulators in practical industrial applications with a focus on the automotive and/or logistic sector.
The research activities will be conducted at Polytechnic of Bari, while a period of at least six months will be carried out at foreign institutions.

References:
[1] Bahrin et al. 2016. Industry 4.0: A review on industrial automation and robotic. Jurnal teknologi. 78, 6-13.
[2] Dammacco et al. 2022. Designing complex manufacturing systems by virtual reality: A novel approach and its application to the virtual commissioning of a production line. Computers in Industry, 143, 103761.
[3] Buerkle et al. 2023. Towards industrial robots as a service (IRaaS): Flexibility, usability, safety and business models. Robotics and Computer-Integrated Manufacturing, 81, 102484.

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A07_PNRR629_PT Safe and Ergonomic Human-Drone Interaction in Logistics. (Polytechnic University of Bari, Carli/De Cicco)

Research description:
Unmanned Aerial Vehicles, commonly referred to as drones, are mobile flying robots that play a critical role across various fields and applications due to their versatility and ability to access areas that are difficult or dangerous for humans [1]. As drone involvement in human activities becomes more prevalent, achieving a natural, efficient, and effective Human-Drone Interaction (HDI) is becoming crucial and is a fertile ground for research investigations [2]. Specifically, HDI refers to the study and design of systems and interfaces that facilitate effective and intuitive interaction between humans and drones: this field encompasses various aspects, including user interface design, control methods, communication protocols, and the social and ethical implications of drone use. Until recently most contributions regard HDI in outdoor contexts, such as photography, structural inspections, and sports applications [3], whilst only a few works address HDI for indoor industrial applications [4].
Given the promising use cases of drones in logistics, including inventory management, freight transport, inspection, and surveillance, this PhD research proposal will address safe and ergonomic HDI for pick-and-delivery operations in industrial warehouses. Specifically, safety, ergonomics, and efficiency will be investigated as key challenges in HDI:
1. In Human-Robot Collaboration and/or Interaction, safety takes precedence over efficiency and ergonomic concerns. Safety is the fundamental requirement enabling operators to work alongside "fenceless" manipulators. This is accomplished by complying with technical specifications like ISO/TS 15066, encompassing Speed and Separation Monitoring and Power and Force Limiting operation methods.
2. Ergonomics refers to the posture of operators and its evaluation is imperative to prevent injuries associated with repetitive and hazardous tasks and to appropriately design workspaces.
3. Finally, efficiency is regarded as the enhancement of the entire industrial process, contributing to the profitability and productivity of companies.
To show the effectiveness of the developed solutions for safe, ergonomic, and efficient HDI, simulations and tests on realistic scenarios will be conducted, with a particular reference to practical logistic and industrial applications.
The research activities will be conducted at Polytechnic of Bari, while a period of at least six months will be carried out at foreign institutions.

References:
[1] Hassanalian, M., & Abdelkefi, A. (2017). Classifications, applications, and design challenges of drones: A review. Progress in Aerospace sciences, 91, 99-131.
[2] Tezza, D., & Andujar, M. (2019). The state-of-the-art of human–drone interaction: A survey. IEEE access, 7, 167438-167454.
[3] Ayamga, M., Akaba, S., & Nyaaba, A. A. (2021). Multifaceted applicability of drones: A review. Technological Forecasting and Social Change, 167, 120677.
[4] Van Waveren, S., Rudling, R., Leite, I., Jensfelt, P., & Pek, C. (2023, March). Increasing perceived safety in motion planning for human-drone interaction. In Proceedings of the 2023 ACM/IEEE International Conference on Human-Robot Interaction (pp. 446-455).

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A08_PNRR629_PT Intelligent and Efficient Human-Robot Collaboration. (Polytechnic University of Bari, Dotoli/Papangelo)

Research description:
The Fourth Industrial Revolution, also known as Industry 4.0, is reshaping the way individuals live and work while providing a substantial influence on the manufacturing scenario. One of the key enabling technologies that has made Industry 4.0 a concrete reality is without doubt collaborative robotics, which is also evolving as a fundamental pillar of the next revolution [1]. The so-called Industry 5.0 paradigm reinserts proactively humans back into the automation chain, allowing operators and robots to work significantly more closely together [2]. In contrast to robots that predominantly work independently from humans and often reside in a cage, collaborative robots (cobots) co-exist in the same environment together with humans, without renouncing to safety or efficiency [3].
The goal of this PhD research proposal is to develop innovative frameworks for human robot collaboration (HRC) by ensuring the best trade-off between safety and ergonomics for the operator and efficiency for the industrial process.
In particular, the research activities of this PhD project will focus on the following key aspects:
1. Sensing and Perception: Equipping robots with advanced sensors allows to accurately perceive their surroundings and human collaborators, while developing algorithms that can interpret human actions and intentions is crucial to anticipate movements and collaborate effectively.
2. Trust and Acceptance: Building trust among human workers regarding the safety and reliability of collaborative robots involves, one the one hand, a clear communication and predictable robot behavior and, on the other hand, an intuitive interface that allows non-experts to interact with and control robots easily.
3. Adaptability and Flexibility: Creating systems that can dynamically allocate tasks between robots and humans is essential to satisfy real-time conditions and profit by capabilities of cobots, which in turn learn from human collaborators and adapt to new tasks and environments without extensive reprogramming.
4. Regulations and Interoperability: Adhering to industry standards and safety regulations is fundamental for deploying cobotics in various sectors as well as for ensuring that cobots from different manufacturers work together seamlessly in a collaborative environment.
The research activities will be conducted at Polytechnic of Bari, while a period of at least six months will be carried out at foreign institutions.

References:
[1] Ferraguti et al. 2020. A unified architecture for physical and ergonomic human–robot collaboration. Robotica, 38(4), 669-683.
[2] Cherubini et al. 2016. Collaborative manufacturing with physical human–robot interaction. Robotics and Computer-Integrated Manufacturing. 40, 1-13.
[3] Proia et al. 2022. Control Techniques for Safe, Ergonomic, and Efficient Human-Robot Collaboration in the Digital Industry: A Survey. IEEE Transactions on Automation Science and Engineering. 19(3), 1798-1819.

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A09_PNRR629_PT Robust robotic manipulation and planning under uncertainties. (University of Trento, Iacca/Roveri)

Research description:
The main objective of this project is to develop hybrid control and task and motion planning algorithms for robotic applications that take into account the uncertainty of the task, for example, due to sources of variability in the environment in which the robot operates, or to the variability of the shape of the objects to be manipulated, which may not be known a prior. The prop osed research project is highly multidisciplinary, combining the study of Artificial Intelligence models with robotics and innovative manipulation technologies, including soft grippers. The problem of manipulation and task and motion planning in dynamic contexts characterized by uncertainties will be addressed from two complementary points of view, i.e. at a software level (i.e. through AI models) and at a hardware level (i.e. through forms of "embodied intelligence").

References:
[1] Zanetti, Alex; Dal Moro, Devis; Vreto, Redi; Robol, Marco; Roveri, Marco; Giorgini, Paolo, "Implementing {BDI} Continual Temporal Planning for Robotic Agents" in IEEE International Conference on Web Intelligence and Intelligent Agent Technology, WI-IAT 2023, Venice, Italy, October 26-29, 2023, USA: IEEE, 2023, p. 378-382. Atti di: WI-IAT 2023, Venice, October 26-29, 2023. - URL: https://doi.org/10.1109/WI-IAT59888.2023.00062 . - DOI: 10.1109/WI-IAT59888.2023.00062
[2] Sayar, Erdi; Iacca, Giovanni; Knoll, Alois, "Curriculum learning for robot manipulation tasks with sparse reward through environment shifts" in IEEE ACCESS, v. 2024, 12, (2024), p. 46626-46635. - URL: https://ieeexplore.ieee.org/document/10480429/authors#authors . - DOI: 10.1109/ACCESS.2024.3382264
[3] Garrett, Caelan Reed and Chitnis, Rohan and Holladay, Rachel and Kim, Beomjoon and Silver, Tom and Kaelbling, Leslie Pack and Lozano-Pérez, Tomás, “Integrated Task and Motion Planning" in Annual Review of Control, Robotics, and Autonomous Systems, Volume 4, 2021 https://doi.org/10.1146/annurev-control-091420-084139.

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Reference Themes “DM 630/2024”

Application XL cycle - p. 16

reference ID: from B01_PNRR630 to B21_PNRR630

B01_PNRR630 Methodologies and protocols for innovation and interoperability between Internet of Things standards in home automation. (Polytechnic University of Bari, Cordeschi)

Research description:
The advent of the Internet of Things (IoT) as an enabling paradigm has determined the beginning of the driving period of the revolution in the home automation sector, allowing users to connect, control and automate home devices through wireless networks. The proliferation of devices and, above all, different protocols and standards, has led to fragmentation and the consequent lack of interoperability, limiting the large-scale adoption of home automation as a solution. This research project aims to examine this scenario in detail, with the aim of designing concrete solutions. In this sense, particular attention will be paid to the emerging Matter standard, together with other interoperability solutions for devices interconnected via wireless networks and protocols, to provide an in-depth overview of the main standards IoT for home automation.
The objectives of the Research are: 1. Conduct a detailed study of the Matter standard by examining its architecture, communication protocols, security and compatibility with existing devices. 2. Examine other IoT standards for home automation, such as Zigbee, Z-Wave, Thread and BLE, and their possible interoperability. 3. Evaluate the security and privacy measures, identifying best practices to protect home data and devices from attacks. 4. Examine practical implications for home automation, including costs, ease of installation and user experience.

References:
[1] R. Kaur, P. Vats, M. Mandot, S. S. Biswas and R. Garg, "Literature Survey for IoT-based Smart Home Automation: A Comparative Analysis," *2021 9th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO)*, Noida, India, 2021, pp. 1-6, doi: 10.1109/ICRITO51393.2021.9596421.
[2] S. Yao, L. Feng, J. Zhao, Q. Zhao, Q. Yang and W. Jiang, "PatternBee: Enabling ZigBee-to-BLE Direct Communication by Offset Resistant Patterns," in *IEEE Wireless Communications*, vol. 28, no. 3, pp. 130-137, June 2021, doi: 10.1109/MWC.001.2000346.
[3] Z. Wang et al., "A Survey on IoT-Enabled Home Automation Systems: Attacks and Defenses," in IEEE Communications Surveys & Tutorials, vol. 24, no. 4, pp. 2292-2328, Fourthquarter 2022, doi: 10.1109/COMST.2022.3201557.

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B02_PNRR630 Intelligent image processing and decision support systems for skin lesion management in proximity healthcare. (Polytechnic University of Bari, Bevilacqua)

Research description:

The implementation of telemedicine services, i.e., providing medical care through telecommunications infrastructure and technology, has evolved significantly in recent years, becoming a crucial component of modern healthcare. Among telemedicine applications, proximity telemedicine, or telemedicine of proximity, stands out for its ability to enhance healthcare accessibility, especially in underserved or remote areas. This model emphasizes the use of telemedicine services within local communities, ensuring that patients can receive timely and effective medical attention without the need for extensive travel or costs. The importance of proximity telemedicine can be discussed from multiple perspectives, including accessibility, quality of care, cost-effectiveness, and overall patient satisfaction. The implementation of such a model for providing healthcare requires the introduction in these facilities of intelligent systems supporting patients, healthcare providers and caregivers in all the phases of the care process.

With the growth of digital health in recent years, teledermoscopy has become an increasingly popular platform for dermatologists and patients. Teledermoscopy has been successful in mass screening events and reaching underserved areas that are remote from local dermatologists. Inclusion of clinical and dermoscopic images has been shown to improve the diagnostic accuracy of teledermatology by approximately 15% while adding only 1 to 2 minutes to consultation time. In fact, the management concordance between mobile teledermoscopy and face-to-face (FTF) assessment is generally positive, with 81% to 91% full or partial diagnostic concordance. With the transition of care from FTF to telemedicine appointments, teledermoscopic images should be utilized to improve the diagnostic accuracy of telehealth visits, which are often less accurate than FTF appointments.

In addition, recent literature made evident that intelligent algorithms for image processing and decision support could support this care approach from many point of views, such as when and how to take photos, which area frame in the foreground, but also the automatic characterization of the image by the extraction of features supporting it.Intelligent procedures and autonomous systems can address issues related to this task, supporting patients and the healthcare systems in general, thus improving the quality of procedural implementation. Advanced computer vision algorithms and machine/deep learning methods can be utilized to automatically understand the scenario and provide useful feedback, substantially reducing the physical and mental effort of all the actors enrolled in the procedure.

Based on these considerations, the aim of this research project is to study, design, develop and validate innovative intelligent image processing and decision support systems for skin lesion management in proximity healthcare, thus requiring the employment of telemedicine services.

This challenging objective can be achieved by the means of the methodology detailed in the following steps:

1. Perform a literature search of state-of-the-art approaches concerning intelligent image processing and decision support systems for teledermoscopy, with an in-depth analysis on skin lesion management. Realizing a comprehensive literature review will be the first task of the Ph.D. student.
2. Design and develop of a methodological and technological framework to support acquisition, processing and decision in the reference domain.
3. Design and develop a virtual environment that aims at simulating a teledermoscopy scenario, by considering an in-house dataset or, if not possible, dataset available in the literature.
4. Validation of the implemented of the designed and developed framework.
5. To provide visibility of the main technical and scientific achievements, the Ph.D. student will submit research results to the following academic venues: international conference, such as MICCAI, IEEE ISBI, IPMI, BMVC (KPI: > 1 per year), high-profile journals, such as IEEE TMI, Elsevier Computers in Biology and Medicine, Elsevier Computer Methods and Programs in Biomedicine, Elsevier Artificial Intelligence in Medicine, Elsevier Journal of Biomedical Informatics (KPI: about 2 for the 3 years). When possible, scientific works will be published via Open Access, or shared in pre-print versions through academic websites. Produced datasets will be shared according to the Findable, Accessible, Interoperable, Reusable (FAIR) principle, by using for example Zenodo and IEEE dataport.

Research activities of the Ph.D. student will produce several contributions alongside the following items.

1- Scientific contribution. In line with the expectations on that topic, at both EU and National (for example, those identified with the definition of PNRR initiatives) levels, the Ph.D. student will develop innovative methodologies, tools, and programs in the context of image processing, decision support systems and telemedicine, surpassing the current state of the art.

2- Technological and economic contributions: Obtained results will be presented to national and international stakeholders, thus increasing their interest to invest in hard development activities and obtain a faster time to market.

3. Societal contribution. Scientific, technological, and economic impacts will guarantee an enhancement in the quality of care of patients treated with this approach, thanks to the novel methodologies and tools proposed throughout the research work. Increase in the quality of care will contribute in creating a sustainable, green, and resilient future for our planet.

References:

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B03_PNRR630 Vision guided robotic assembly for automotive components in manufacturing and remanufacturing industry. (Polytechnic University of Bari, Bevilacqua/Dotoli)

Research description:
The electric vehicle (EV) market is growing rapidly so, in a few years, we will have a considerable number of batteries that will have reached the end of life (EOL) for use in vehicles, but which can be used successfully in second-life applications, for example, as stationary energy storage system. In the last years some studies are already being made to develop specific technologies and processes for the recycling, remanufacturing, and reuse of electric vehicle batteries. An important step in many of these processes is the disassembly of EV EOL batteries, which represents a challenging task due to unpredictable batch sizes and volumes, as well as significant variations in battery design between different car models.
Automated dismantling of lithium-ion batteries down to the cell level offers the opportunity to regenerate or reuse individual cells or recover raw materials through recycling. However, there are some risks in the dismantling procedures. These risks include the release of toxic gases, the release of chemicals, or the occurrence of thermal instabilities, which may pose a fire or explosion hazard if disassembled incorrectly. For these reasons it is desirable to disassemble the batteries using automatic systems without, or with limited, human intervention.
The target of this PhD proposal is to design and implement a vision-guided flexible robotic system that can automatically detect the geometry/characteristics of batteries and adapt the robot's behaviour accordingly to manipulate them.
Vision-guided robotics has been one of the major research areas in the mechatronics fields in recent years. The aim is to emulate the visual system and the adaptation ability of humans to allow the development of intelligent machines able to perform complex tasks and replace humans in repetitive or dangerous jobs. The applications of visually guided systems are many, from automatic manufacturing, product inspection, counting and measuring to medical surgery. They are often found in tasks that demand high accuracy and consistent quality which are hard to achieve with manual labour. Tedious, repetitive, and dangerous tasks, which are not suited for humans, can now be performed by robots. Using visual feedback to control a robot has shown distinctive advantages over traditional methods and is commonly named “visual servoing”. Hence, vision is a part of a robot control system providing feedback about the state of the interacting object.
The development of new methods and algorithms for object tracking and robot control has gained particular interest in industry with the Industry 4.0 paradigms. While 2D object recognition has been well studied, developed, and successfully applied in many applications in industry, 3D object recognition is relatively new. The main issue involved in 3D recognition is the huge amount of information which needs to be dealt with.
Image segmentation algorithms are available to separate the image into regions that are meaningful for the specific task and subsequently recognize the parts being processed using deterministic or heuristic approaches. The most efficient and robust object recognition algorithms are based on AI and feature extraction. An advantage of these approaches is their ability to recognize an object also in the presence of lighting, translation, rotation, and scale changes. Several convolutional networks have been developed for this scope. For example, U-Net, PSPNet, FPN, LinkNet for the segmentation and Mask R-CNN for object detection.
The system under study will therefore be composed of: Robot, 2d/3d Vision system, control system (PLC an PC), image processing and decision-making algorithms, adaptive gripper.
The 2D/3D model of the processed battery will be acquired by a special industrial vision system which will feed an artificial intelligence system to estimate both the best trajectory of the robot and the right picking position. A self-adapting and flexible gripper guided by the AI system will also be reconfigured.

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B04_PNRR630 Human Interaction with Digital Twins of Intelligent Industrial Systems. (Polytechnic University of Bari, Dotoli/Carli)

Research description:
The emergence of the fourth industrial revolution, commonly referred to as Industry 4.0, has been primarily propelled by advancements in digital technology. Currently, a further transformation emphasizing customization and enhanced user experience is unfolding. As a consequence, the Industry 5.0 paradigm is gaining momentum to provide a different focus and point of view and highlights the importance of human-centricity to support changes in manufacturing processes and value-driven transformations requested by societal needs [1]. The resulting challenge for research activities is to explore how digital enabling technologies can foster human-centric automation ensuring a deeper comprehension of physical phenomena during the engineering simulation, deployment, and operational phases of industrial systems. To this aim, as reported by a recent study on Industry 5.0 [2], one of the key enabling technologies consists of a new technological framework driven by artificial intelligence of things (AIoT), which emphasize the integration of Digital Twin (DT) and Artificial Intelligence (AI) as a cornerstone for promoting advanced intelligent manufacturing. The use of AI aims at making models designed for recursive theoretical processes increasingly accurate, while the vast amount of data generated by internet of things (IoT) devices enable intelligent decision-making, automation, and optimization in various industrial domains. The incidence of random phenomena induced by human behaviour or by predictable external events with different root causes (faults, failures, etc.) thus entails the use of increasingly sophisticated DTs, obtainable thanks to the AIoT driven approach, which is the focus of this research proposal.
This research proposal is focused on the definition a control-oriented framework for the implementation of AIoT in industrial scenarios through the use of IoT and DT technologies, with the aim of enhancing the interaction between humans and complex industrial systems throughout all design, deployment, and operational phases. Such a framework is intended to include the following key components and features:

- IoT devices collect data from the physical world and humans through sensors, actuators, and other embedded technologies.
- Data is then processed, analyzed, and interpreted by AI algorithms to extract valuable insights, detect patterns, make predictions, and build digital models based on DTs.
- DTs are used to optimize processes, improve efficiency, enhance safety, and create personalized experiences and enhanced human interaction.

The research will be conducted in accordance with the following main activities:

- User interface design, accounting for human factors and ergonomics;
- Human-in-the-loop simulation, assessing the impact of different control strategies, operational procedures, and human factors on system behavior;
- Collaborative robotics and intelligence machines development, ensuring safety, efficiency, and productivity in shared workspaces;
- Online adaptation and learning in automatization, decision-making, and optimization, enabling continuous improvement and optimization of system performance.
- Security and privacy compliance, throughout the collection, processing, and storage of sensitive data.

To show the effectiveness of the developed framework in the entire lifecycle of industrial systems, all the innovative solutions will be tested and validated before on simulations and then on real manufacturing processes in practical industrial applications with a focus on the automotive sector.
The research activities will be conducted in close collaboration between the Decision and Control Laboratory (http://dclab.poliba.it/) of Polytechnic of Bari and MASMEC SpA (https://www.masmec.com/), which is an Italian company specialized in automated and robotic solutions for complex manufacturing systems. Furthermore, part of the research activities will be carried out at foreign institutions for at least six months.

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B05_PNRR630 Intelligent systems for industrial robotics. (Polytechnic University of Bari, Dotoli/Carli)

Research description:
Robots are widely employed in industrial assembly lines and manufacturing systems, offering a multitude of benefits that contribute to increased efficiency, productivity, safety, and competitiveness. To meet these objectives, industrial robotic systems encompass a wide range of technologies and methodologies aimed at enhancing the capabilities, efficiency, and adaptability of industrial settings [1]. In particular, leveraging advanced information and communication techniques, such as artificial intelligence, machine learning, computer vision, sensor fusion, intelligent decision making and control, robots are enabled to perform complex tasks with autonomy, flexibility, and precision [2].
However, industrial robotic systems face several challenges that can impact their effectiveness, reliability, and widespread adoption. One of these key challenges concerns the task planning and scheduling [3], which is the main focus of this PhD research proposal. Indeed, intelligent robotic systems can autonomously plan and schedule tasks based on dynamic factors such as resource availability, task priorities, and deadlines, while task planning algorithms optimize the allocation of robotic resources to maximize efficiency, throughput, and utilization in industrial production processes.
This PhD research project is focused on the study and analysis of the state-of-the-art methodologies for task planning and scheduling problems in manufacturing processes and then the design of innovative industrial architectures and intelligent control methods in presence or absence of optimization for task planning/re-planning and scheduling/re-scheduling combined with tracking problems, collision avoidance and collision detection issues. To this aim, the following key aspects and features will be investigated:
- Complexity of production environments, with multiple factors influencing task execution, material shortages, changing priorities, and unexpected events.
- Variability in task requirements, in terms of complexity, duration, resource requirements, and precedence constraints.
- Resource constraints, including workspace limitations, payload capacities, speed constraints, and energy constraints.
- Tradeoff of optimization objectives, such as minimizing makespan, reducing energy consumption, maximizing throughput, or minimizing production costs.
- Real-time adaptation to uncertainties and disturbances that can affect task execution.
- Integration with human workers, alongside human factors, such as worker safety, ergonomics, and cognitive workload.
To show the effectiveness of the developed solutions, simulations and tests on real robots will be conducted, with a particular reference to practical industrial applications of task planning and scheduling, such as automated and robotic welding.
The research activities will be conducted in close collaboration between the Decision and Control Laboratory (http://dclab.poliba.it/) of Polytechnic of Bari and Comau SpA (https://www.comau.com/), which is an Italian multinational company in the automation field company specialized in advanced and robotic solutions for complex manufacturing systems. Furthermore, part of the research activities will be carried out at foreign institutions for at least six months.

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B06_PNRR630 Algorithms for management and control of mobile agent fleets. (Polytechnic University of Bari, Dotoli/Carli)

Research description:
In the Logistics 4.0 paradigm, which aims at creating intelligent, interoperable and autonomous logistics environments, the problem of managing and controlling fleets of mobile agents is attracting enormous interest for efficient and sustainable logistics. Traffic management of cooperating agents for cargo handling in automated warehouses of smart factories and distribution centers is a significant challenge for real-time control aimed at predicting and preventing congestion, while ensuring productivity and business flexibility.
The overall objective of this PhD project is the optimal management of a fleet of mobile agents within a warehouse 4.0 [1 -3]. This category of problems differs on the basis of boundary conditions such as the structure of the warehouse, the type and number of agents, and any further constraints. The warehouse could be more or less large and branched, could have corridors in one or more directions or a matrix structure. The agents can be automated guided vehicles (AGVs), possibly of different types, or hand trucks. The traffic manager may need to fully manage each individual agent or, in the case of "smart" agents [4], can work at a superior level in agent routing to minimize congestion and maximize performance.
This PhD research proposal consists in the study, design, and development of mobile agent traffic management algorithms that are particularly effective in addressing the following problems:
1) task planning and assignment,
2) route calculation, and
3) resolution of any conflicts.
In order to improve the efficiency of mobile agents, maximize productivity, and minimize downtime, the main challenges in this research will lie in the definition of algorithms aimed at tackling these deeply interconnected sub-problems, or in separately or partially or completely coordinated.
All the innovative solutions will be tested and validated before on simulations and then on real logistic scenarios.
The research activities will be conducted in close collaboration between the Decision and Control Laboratory (http://dclab.poliba.it/) of Polytechnic of Bari and E80 Group SpA (https://www.e80group.com/it/), an Italian company specialized in automated solutions for Logistics 4.0. Furthermore, part of the research activities will be carried out at foreign institutions for at least six months.

References:
[1] Zhe Liu et al. “Prediction, planning, and coordination of thousand-warehousing-robot networks with motion and communication uncertainties”. In: IEEE Transactions on Automation Science and Engineering 18.4 (2020), pp. 1705–1717.
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B07_PNRR630 Decision and control techniques for autonomous mobile robots in unstructured environments. (Polytechnic University of Bari, Dotoli/Cacucciolo)

Research description:
Autonomous mobile robots and vehicles are nowadays topics of increasing interest in the industrial sector. Several fields can be improved by mobile robot innovation, namely, agriculture, outdoor navigation, and critical industrial environments.
Autonomous mobile robots for unstructured terrains have been a significant research topic in recent years [1]. Although remarkable progress has been made in robotic navigation and control, autonomous navigation of mobile robots in outdoor harsh environments, such as unstructured terrain, is still an open problem. The design of robust sensing and control systems for outdoor mobile robots capable of overcoming issues related to dynamic environments, unexpected obstacles, terrain conditions variations and vegetation is still challenging.
The proposed Ph.D. project deals with the development of a prototypal autonomous mobile robot composed of an electric mobile platform to be adapted with a modular base which is capable of integrating manipulators and performing activities in outdoor environments. The mobile robot will be capable of autonomously moving through different fields on arbitrary rough terrains along a specific trajectory.
The Ph.D. candidate will be responsible for the analysis and implementation of techniques, algorithms and controlling methods to collect and process data provided by a plethora of onboard proprioceptive and exteroceptive sensors (e.g., encoders, IMU, GNSS, 3D vision systems) for environment perception and vehicle status (position, orientation, safety) estimation, in order to guarantee the path following, obstacle avoidance and dynamical stability control of the vehicle. The roughness of the terrain and the vehicle-terrain interaction will be properly estimated through state-of-the-art techniques in order to control the shocks and vibrations the vehicle experiences, thus assuring vehicle stability [2]. Moreover, the Ph.D. candidate will support the product technical team on the selection and design of the transporter (e.g., wheels, half-crawler, crawler, robotic leg) and suspension system (e.g., semi-active suspension) in order to improve both the dynamical stability of the system and the performances of the onboard vision systems.
The main activity of the Ph.D. candidate will be therefore based on the study of computational methods for features extraction and data fusion of sensor measurements to support navigation control and on the development of control algorithms to command engine and suspension actuators to control position and orientations of the platform.
The research activities will be conducted in close collaboration between the Decision and Control Laboratory (http://dclab.poliba.it/) of Polytechnic of Bari and G-nous Tech Srl (https://g-nous.com/tech), which is an Italian company specialized in advanced solutions for various applications such as robotics. Furthermore, part of the research activities will be carried out at foreign institutions for at least six months.

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[1] Wijayathunga, Liyana, Alexander Rassau, and Douglas Chai. "Challenges and solutions for autonomous ground robot scene understanding and navigation in unstructured outdoor environments: A review." Applied Sciences 13.17 (2023): 9877.
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B08_PNRR630 Optimization and control strategies for power management of hybrid propulsion systems. (Polytechnic University of Bari, Dotoli/Amirante)

Research description:
Environmental concerns are pressing the industry and shipping sector to adopt energy efficiency-oriented measures to tackle greenhouse gas emissions and move to effective and environmentally friendly power systems. This implies redesigning the system configuration, the machinery, and the power management strategies. In particular, the current trend in both marine and terrestrial applications, is leading in the design of more efficient and versatile products based on the development of hybrid propulsion systems, which use internal combustion engine, electric motors, battery and fuel cell storage systems, integrating intelligent power generation strategies [1]-[2].
In this context, the proposed PhD project aims at defining a power management system capable of supervising different onboard and industrial production systems and optimizing their performance thanks to a Digital Twin, while monitoring actual states, analyzing historical states, and predicting future behaviors, to maximize the overall efficiency of assets and make immediately corrective decisions in case of unexpected deviations.
The research will be conducted in accordance with the following main activities:
1. DEFINITION OF HYBRID PROPULSION SYSTEM CONFIGURATIONS BASED ON LOAD PROFILES AND TOPOLOGIES
This activity aims at defining innovative hybrid propulsion configurations by integrating different existing energy sources based on the application topology and leveraging on the potential offered by the on-going development of battery technologies as well as hybrid drives, DC-grid solutions, shore charging, automation solution, and power-take-in (PTI) motors. The operational profile, type, and function as well as the corresponding power requirements will be considered to specify the optimal propulsion system configuration. In particular, the operational profile will identify the power demand required both for terrestrial and for navigation over different expected operation modes.
2. IMPLEMENTATION OF A DIGITAL TWIN
This activity consists of:
- defining the Digital Twin concept with the final aim of designing and modeling different hybrid propulsion architectures, including various types of physical objects corresponding to the power system components, each being simulated with the appropriate level of granularity in terms of dynamics, states, and interconnections;
- proposing a conceptual framework for designing, implementing, and supporting the entire life cycle of physical objects integrated in the power system;
- validating the conceptual framework in reference to a real hybrid propulsion solution, including all the aspects related to use of a Digital Twin in planning, monitoring, controlling, and optimizing the power system operations.
3. TEST OF A HYBRID PROPULSION ARCHITECTURE WITH CONTROLLABLE LOADS
This activity aims at testing a prototype of the above defined power management strategies for hybrid propulsion systems. The considered configurations will include the presence of common components such as combustion engine, fuel cell, battery, power converters, as well as the integration of these components in the overall system, thus enabling the assessment of technical specifications and the test of different conditions and scenarios remotely controlled by the corresponding Digital Twin framework. The prototype of the power management system will be also connected to a real propulsion testbed to enhance the effectiveness of the optimization and control strategies using real data gathered by the hardware platform.
The research activities will be conducted in collaboration between the Decision and Control Laboratory of Polytechnic of Bari and Isotta Fraschini Motori S.p.A., which is an Italian company specialized in advanced solutions for hybrid propulsion systems in marine and industrial applications. Furthermore, part of the research activities will be carried out at foreign institutions for at least six months.

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B09_PNRR630 Photonic inertial sensors for next-generation autonomous systems. (Polytechnic University of Bari, Dell'Olio)

Research description:
This PhD project aims to explore the transformative potential of photonics in Inertial Measurement Units (IMUs) for next-generation autonomous systems. Leveraging preliminary research by Prof. Francesco Dell'Olio's group, the project will investigate how photonics can significantly advance the compactness and efficiency of these systems.

The primary objectives include:

Understanding current limitations of traditional inertial sensors with a focus on Size, Weight, Power, and Cost (SWaP-C) aspects.
Exploring integrated microphotonics to overcome these limitations, enabling more compact and efficient IMUs.
Designing, fabricating, and testing a prototype photonic integrated circuit-based IMU with a target mass below 50g and volume under 30 cm^3, demonstrating navigation-grade performance.
The research will be conducted in phases: starting with a critical literature review and conceptual design, followed by theoretical studies and detailed modeling, and culminating in the fabrication and testing of prototypes in collaboration with international research institutions.

Expected outcomes include a detailed analytical report on the feasibility and impact of photonics in inertial sensors, the development of a prototype IMU meeting specific mass and volume targets, and publications in scientific journals and conferences. This project aims to revolutionize the field of inertial sensing, contributing to the advancement of autonomous systems technology.

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B10_PNRR630 Robotics, AI and predictive diagnostics solutions in rebar processing plants to increase the autonomy of processing machinery. (Università Politecnica delle Marche, Longhi)

Research description:
This research project, in collaboration with SCHNELL SpA (Pesaro, Italy), aims to develop solutions that leverage advanced artificial intelligence and predictive diagnostics methodologies to operate robotic manipulators or intelligent automation systems in order to increase the autonomy of industrial processing machines, with a focus on rebar processing. Research and results should address solutions to ensure production requirements and operation of production machines without human intervention. Algorithms and solutions should be studied on a broad spectrum, considering various approaches, such as data-driven control and analysis methods, models, machine learning, and so on. Solutions should be aimed at making processing increasingly autonomous, minimizing human operator intervention.

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B11_PNRR630 Embedding proactive safety in perception and control algorithms for collaborative automation. (University of Brescia, Visioli/Beschi)

Research description:

Predicting human motion is vital for enhancing safety and efficiency in human-robot collaboration. Motion control algorithms should natively embed safety as a constraint [1]. Function safety impacts the control design in three layers [2]: reactive safety, proactive safety, and predictive safety.

Reactive safety is a mandatory layer where robots stop, slow down, or shut down to avoid hazardous situations. It requires certified information and algorithms that follow the standard regulations and can lead to unplanned downtime.

Proactive safety aims to prevent hazardous situations in a receding horizon window based on the actual prediction, modifying the robot's behavior to avoid downtime and signaling the operators of the possible hazard.

Predictive safety uses historical data to optimize the task schedule and trajectories to eliminate risks [3].

Proactive safety requires reliable predictors to be effective. Researchers have dedicated significant efforts to developing accurate human models [4], often involving optimization and task-specific information. Observers can be used to estimate the expected human movements and confidence intervals. The prediction quality depends on many aspects:

- The human model, acting as an unknown controlled system.
- The robot model: the control algorithm that manages the robot motion depending on the actual safety mode (i.e. replanners algorithms [5]).
- The interaction model: the coupling effect between the human and the robot.
- The perception system: information obtained by sensors (images, velocity field, distances, ...) and post-postprocessing (skeletonization).

The proposed PhD project deals with designing motion control algorithms for proactive safety, and it consists of the following main activities:

- Modeling of human behavior through inverse optimal control, gaussian process, or learning technique.
- Integrating human and robot dynamical systems in UKF-based observers with the proper parameter tuning to obtain proper confidence bounds.
- Exploiting the predictions in motion replanning algorithms.
- Sensor fusion of cameras, radars, and other industrial-grade sensors.

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B12_PNRR630 Learning and Multi-agent planning, scheduling and vehicle routing for workforce management. (University of Cagliari, Prof. Mauro Franceschelli)

Research description:
The proposed PhD project aims to address large-scale multi-agent planning, scheduling and vehicle routing problems by also including elements of machine learning to improve performance and applicability of the developed methods. The main application of interest is the management and optimization of a large workforce which is required to execute geographically distributed tasks. The scenario applies to both human and robotic workers, referred to as agents.
The main objective is to develop advanced algorithms and methods, including machine learning and optimization for real-time task assignment, multi-vehicle routing and scheduling.
In the initial phase, the student will study the state of the art on the topic on learning and optimization and define large-scale optimization problems to address in collaboration also with the industry partner involved in the study. Key performance metrics and constraints to be considered for optimization will be identified.
Subsequently, methods consisting of various algorithmic solutions for offline and online distributed optimization, will be developed with the ability to adapt in real-time to changes in the schedule due to unforeseen circumstances, exploiting real-time feedback from the agents.
In the final phase, experiments will be conducted together with the industry partner.

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B13_PNRR630 Intelligent Control Techniques for Rail Construction and Maintenance Vehicle. (University of L'Aquila, De Santis)

Research description:

The railway sector represents a crucial component of global transportation infrastructure, ensuring efficient and sustainable mobility. However, the construction and maintenance of railway infrastructure require advanced solutions to improve the efficiency, safety, and sustainability of operations.

This Ph.D. project aims to develop intelligent control techniques for rail construction and maintenance vehicles, leveraging recent advances in artificial intelligence, robotics, and automation. The primary objective is to design control algorithms that enable railway vehicles to perform complex operations autonomously or semi-autonomously.

The project will focus on three key areas: path planning, adaptive control, and predictive diagnostics.

1. Path Planning: Advanced path planning algorithms will be developed to ensure that vehicles can navigate effectively in complex environments, optimizing time and resources while minimizing operational risks. This includes the ability to avoid obstacles, plan detours, and optimize routes to minimize downtime and maximize operational efficiency.

2. Adaptive Control: Model-based control techniques and machine learning methods will be explored to dynamically adapt vehicle behavior to variable environmental conditions and specific operational needs. Adaptive control systems will allow vehicles to respond in real-time to changes in track conditions, such as variations in rail geometry, adverse weather conditions, and the presence of other vehicles or workers on the line.

3. Predictive Diagnostics: A crucial part of the project is the integration of advanced monitoring systems for railway diagnostics. These systems will collect real-time data using advanced sensors mounted on maintenance vehicles, such as accelerometers, gyroscopes, cameras, and temperature and vibration sensors. Data analysis will be supported by machine learning algorithms to detect anomalies and predict failures, enabling preventive maintenance interventions. This will significantly reduce unscheduled downtime, increase the reliability of railway operations, and reduce costs associated with unexpected failures.

References:

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B14_PNRR630 Motion planning and control of autonomous systems for precision farming applications. (Università di Modena e Reggio Emilia, Giarrè/Falcone)

Research description:
According to United Nations [1] the worldwide population is expected to reach ~11 billion people by the end of the century. Such a forecast sets an unprecedented demand for, among others, food and water resources. The food demand, for at least a few decades ahead, is expected to be fulfilled by agriculture that is currently (and so will be for a while) the world's largest food industry. Agriculture, as it is now, enormously impacts the planet resources and life as it relies on chemical pesticides and fertilizers to maintain the crops fields. The chemical compounds in pesticides and fertilizers contaminate water, soil and water, contribute to lose biodiversity and, on a not-so-long-term can lead to pest resistance. Not to mention the impact of such compounds on human health.
On the other hand, the (unnecessarily) massive use of pesticides and fertilizers is often adopted to make agriculture financially sustainable for farmers. *Precision farming* technologies can contribute to balance *environmental* and *financial sustainability* in agriculture. Precision farming is a farm management approach that builds the decision-making process (e.g., watering, pesticides spraying and fertilizers application) upon observations (from on-field measurements) and a crop knowledge-base. Such technologies can effectively contribute to decrease the use of polluting pesticides and fertilizers and minimized the amount of used water.
The objective of this project is to harness the capabilities of autonomous systems to monitor crops fields and either decide, or alternatively provide support to farmers' decision, of, for example, spraying pesticides or water specific crop areas, selectively applying fertilizers thus avoiding massive use of polluting compounds. The project will adopt a combination of ground and aerial robots to collect information from the crop field ranging from parasites footprints, crop stress status from imaging spectroscopy [2]. The project results will be validated in an experimental farm by using mobile ground robots and aerial drones.

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B15_PNRR630 Production of microorganisms in bioreactors: from modelling to control systems. (University of Naples Federico II, De Lellis)

Research description:
The development of highly efficient and cost-effective industrial bioreactors requires a deep knowledge of the biological system and its optimization. Recent advancements in the study of microbial growth have identified the release and accumulation of extracellular DNA in the medium as an important limiting factor [1]. The research activity will focus on 1) the implementation of a process-based mathematical model (e.g. [2]) describing the production system and 2) the realization of a bioreactor integrating monitoring and control systems to study the microbial response to the growth environment and optimise the production.

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B16_PNRR630 Supervised autonomy: learning effectively and safely from human. (University of Padova, Falco)

Research description:
Information will be soon made available

References:
Information will be soon made available

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B17_PNRR630 AI-based VSLAM and tracking control for agricultural robots. (University of Rome "Tor Vergata", Carnevale/Galeani)

Research description:

Precision agriculture is undergoing a radical transformation thanks to the push of robotics. Autonomous guided machines are being developed at numerous research centres for the different needs in agricultural fields with the aim of decreasing the footprint of standard machines, enabling continuous and precision monitoring and actions to reduce the use of herbicides and pesticides, thus increasing the overall efficiency. A number of challenges are involved in the design of agricultural rovers and some of them are the main research topics that will be addressed during the PhD:

- Localization: sensor fusion of relative position sensors (encoders, IMU), absolute positioning systems (GPS/UWM), LiDAR and stereo/mono camera (SLAM) [1, 2]

- Guidance: development of robust vision techniques for real-time onboard implementation for autonomous driving with track and obstacle recognition and adaptive path planner based on vehicle dynamic constraints [3]

- Control framework for mobile robots using ROS2 [4]

Thanks to a CREA prototype of an innovative agricultural rover, which will be modified according to the outcome of the PhD work, experimental sessions are planned at CREA facilities to collect data and assess the effectiveness of methodological and technical choices and to produce scientific publications.

References:

[1] F. Oliva, S. Mattogno, A. Tenaglia, R. Masocco, F. Martinelli, D. Carnevale, A Trajectory Based Optimization Approach for Hybrid Observer design, 2023 62nd IEEE Conference on Decision and Control (CDC), 2023.

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B18_PNRR630 AI/Machine Learning techniques for satellite/space applications. (University of Rome "La Sapienza", Delli Priscoli/Di Giorgio/Pietrabissa)

Research description:

The PhD scholarship concerns the study, design and development of "intelligent control" methodologies, aimed at integrating appropriate Artificial Intelligence techniques (off-line/on-line supervised, unsupervised, reinforcement learning) within control systems, with two main objectives: to improve the performance of the control system by obtaining the satisfaction of specific design challenges even in contexts in which the system to be controlled is (extremely) distributed and/or difficult (or not at all) to be modelled; increase the robustness/resilience of the control system and therefore its ability to continue to guarantee, as far as possible, performance in line with the design specifications, even in the presence of disturbances/perturbations of various kinds (for example, due to faults, or physical/cyber-attacks) partially or totally unpredictable.

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B19_PNRR630 Mathematical models, machine learning, and agent-based models of individual and collective human systems that exhibit nonlinear and complex dynamics. (University of Siena, Chiara Mocenni)

Research description:
The doctoral project focuses on the psychological analysis of human behavior, particularly its pathological nature. The main objective is to develop models to support researchers in formulating therapeutic paths and control strategies. While traditio nal models rely on strict psychological procedures and manuals, this project aims to develop mathematical models that offer a complementary perspective to classical ones and propose a personalized mathematical approach for individual therapy paths. These formalized models leverage both data and formal languages, such as network approaches and control theory. The aim is to describe complex human phenomena by highlighting interactions between symptoms through dynamical systems on graphs, as well as to explore the evolution of symptom graphs over time and the spread of pathologies. Concepts like consensus and hysteresis will be exploited to answer fundamental questions about mental disorder healing and progression.

References:
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B20_PNRR630 Advanced guidance, navigation, and control algorithms for space vehicles during atmospheric entry, descent, and landing maneuvers. (Polytechnic University of Turin, Calafiore)

Research description:
Guidance, navigation and control (GNC) algorithms for spacecraft during Entry, Descent and Landing (EDL) maneuvers are crucial components for successful space missions. Such algorithms must operate autonomously and handle extreme conditions, such as high speeds, and aerodynamic and thermal stresses. The goal of the project is to develop advanced GNC algorithms for EDL that enable higher levels of autonomy, performance, and robustness than existing algorithms.
The proposed research project is closely related to relevant themes of the PNRR, such as development of innovative space technologies, space exploration, Earth observation, climate change mitigation and emission reduction, strengthening of the Italian and regional space industry, advanced training in strategic sectors and technology transfer.
The skills developed by the PhD student during the project will constitute a unique and cross-cutting combination of different knowledge in various fields, such as astrodynamics, attitude dynamics, aerodynamics, automatic controls, optimization, sensor fusion and artificial intelligence.

References:
[1] A. Nelessen et al., Mars 2020 Entry, Descent, and Landing System Overview, 2019 IEEE Aerospace Conference, Big Sky, MT, USA, 2019, pp. 1-20, doi: 10.1109/AERO.2019.8742167.
[2] M. Pagone, C. Novara, P. Martella, C. Nocerino, GNC robustness stability verification for an autonomous lander, Aerospace Science and Technology, Vol. 100, 2020.
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B21_PNRR630 Planning of trajectories in a robotic cell with multiple manipulators. (University of Verona, Fiorini/Muradore)

Research description:
Information will be soon made available

References:
Information will be soon made available

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Reference Themes “ATENEI CONVENZIONATI”

Application XL cycle - p. 17

reference ID: from C01_ACONV to C06_ACONV

C01_ACONV Model-based techniques for increasing reliability and safety of autonomous systems. (Università Politecnica delle Marche, Longhi/Freddi/Monteriù/Bonci)

Research description:

Autonomous systems represent a key enabling technology for the digital transition. For a system to reach autonomy, it must be capable of collecting and properly processing a large quantity of information, and possibly employ it to ensure its proper functioning as well as the safety of the people next to it. It is thus of utmost importance that unexpected internal problems, such as faults, can be discovered and quickly addressed before degenerating into a total system failure, which may cause both economic and human losses. For instance, an autonomous aerial vehicle experiencing a fault should be at least able to land to avoid a crash, or a faulty industrial robot should be at least able to stop before causing harm to a human operator. This may be achievable thanks to the information on the internal states of the system and on the environment in which it operates. Moreover, whenever such information is augmented by a model, fault diagnosis and fault-tolerant control techniques represent an effective way to increase the reliability and safety of the system. Starting from relevant models available in the literature, the PhD candidate will be required to investigate the state of the art on linear and nonlinear techniques for fault detection and diagnosis, as well as fault-tolerant control techniques, using both active and passive approaches. These techniques will be then validated in one or more application scenarios, which may include unmanned vehicles, mobile robots, industrial manipulators and intelligent machines in general.

References:

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C02_ACONV Control and trajectory planning for firefighting drones. (Free University of Bozen-Bolzano, von Ellenrieder)

Research description:
Owing to the effects of climate change, forest fires are becoming more intense and harder to control world-wide. If a forest fire can be detected at a very early stage, it can be extinguished more easily, while also minimizing danger/damage to the natural environment and to the health/well-being of nearby human populations. One strategy under consideration for combatting forest fires is to use special purpose aerial drones to monitor forests, detect fires during their onset, and to deliver flame retardant, and/or to provide situational awareness to first responders. From an automation standpoint, the development of aerial drones that can approach an incipient fire and drop flame retardant will require advanced trajectory planning and control techniques that permit the drone to traverse cluttered and highly unstructured forest environments, fly through the strong wind disturbances and updrafts caused by a fire, and handle large variations in the dynamics of the vehicle when its geometry (and hence aerodynamic properties) and inertia change during the firefighting mission. The PhD candidate will: explore the literature to determine control design requirements; study the most-effective guidance, navigation, and control approaches for this application; develop a kinematic/dynamic model of the drone and implement it in simulation; design and implement trajectory planning and nonlinear control algorithms in multiple complex simulation scenarios to demonstrate the anticipated perfomance of system; if time permits, perform field tests of the system on a physical platform.

References:
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C03_ACONV Smart control and optimisation of electrical smart grids. (University of Campania "Luigi Vanvitelli", Cavallo/Russo)

Research description:
To decrease greenhouse gas emissions and reduce energy demand, nations worldwide are adopting policies focused on low carbon and energy efficiency. This shift has led to a surge in the deployment of distributed generation technologies, primarily utilizing renewable energy sources and fossil fuels for co-generation applications.
The integration of intermittent, non-schedulable renewables as independent units within distribution networks poses challenges for maintaining power balance in the transmission grid. This issue can be effectively addressed by consolidating these distributed energy resources into intelligent microgrids (MGs). MGs can manage various power sources and loads collectively, providing crucial balancing services that ensure the safe operation of the power system while meeting environmental objectives. Microgrids comprise production plants, distribution networks, storage systems, and loads, all coordinated by a central controller, or a decentralized group of controllers. By grouping multiple distributed energy resources into a single entity, MGs can simplify the management and monitoring tasks for the distribution system operator. However, they necessitate flexible and reliable energy management systems to automatically schedule plants based on economic and environmental criteria.
Due to difficulties in precisely modeling large MGs, measurement data (voltages, power, etc.) can be utilized to solve the problem of maintaining power balance while minimizing operational costs. The proposed Ph.D. project focuses on designing control algorithms based on acquired data, employing a data-driven approach, while ensuring operational stability by constraining the MGs' currents and voltages within safe limits.

References:
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C04_ACONV Optimization and control of multiscale processes. (University of Genova, Sacone)

Research description:
Information will be soon made available

References:
Information will be soon made available

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C05_ACONV Optimization and control techniques for energy management systems. (University of Palermo, D'Ippolito)

Research description:

The effectiveness, efficiency and cost-effectiveness of the action of both public and private companies depends on the degree of knowledge of the complex systems that the company manages and governs. In particular, electricity distribution systems represent a fundamental aspect of a country's economy; therefore, the relative management of these systems is crucial. Regarding system modeling, hybrid dynamical systems constitute a suitable framework for representing physical systems that embed continuous, discrete, and event-based dynamics. For this reason, the Ph.D. candidate will investigate the possibility of casting the above-mentioned electrical energy distribution systems into the hybrid systems framework. This will constitute a solid methodological starting point for optimal decision policies. Subsequently, the second goal will be the design of Lyapunov-based control techniques for optimizing the efficiency of the conversion systems (power converters). In particular, by exploiting the hybrid structure of the mathematical models, Lyapunov matrix-based min-projection control laws will be applied to ensure uniform asymptotic stability of the entire system. In addition, further constraints should be included, through appropriate cost functions, to increase the system's efficiency.
Finally, the last key aspect of analysing is to exploit the flexibility enabled by different power sources (photovoltaic panels, wind farms, batteries, fuel cells, etc.) and power users because it gives chances for a synergistic approach, where a supervisory control can be designed to address the global efficiency of the system. Policy optimization techniques should be proposed for designing a power management controller for this task.
The activity will make use of the laboratories of the hosting University.

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C06_ACONV Human centered control for Cyber-Physical-Human Systems. (University of Roma Tre, Panzieri/Pascucci)

Research description:
Effective human–automation interaction (HAI) in cyber–physical–human systems (CPHS) promises enhanced safety, performance, and efficiency in various domains like transportation, healthcare, and manufacturing through shared autonomy between humans and automation. However, this vision faces significant research challenges. Mathematical modeling of human responses is complex, and current control theories often rely on oversimplified assumptions.

Decades of research highlight correlations between human behaviors and cognitive factors, recognizing their dynamic nature. However, creating mathematical models for human cognition and decision-making remains challenging. Questions about the appropriate model structure, whether relationships are linear or nonlinear, and the complexity required are still unresolved.

With suitable models, control algorithms can be designed to make autonomous systems responsive and adaptive to humans in real-time. Traditionally, humans were modeled as disturbances in control systems, but human-aware CPHS envisions active human interaction and collaboration with cyber–physical systems to achieve shared goals. Cognitive feedback can enhance decision-making capabilities and allow systems to adapt to errors and disruptions by leveraging human strengths.

The PhD project will explore such models to improve the integration of human and automation in CPHS in a control perspective.

Applicants must hold a master's degree, preferably in Engineering, with a good background in relevant areas of interest (e.g., cyber-physical human systems, human-centered design, industrial control systems, and data-driven control). Solid mathematical and coding skills are encouraged. Proficiency in both spoken and written English is required. The candidate should be highly motivated and interested in undertaking innovative and challenging research activities involving both theoretical analysis and experimental validation.

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Reference Themes “ERC”

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reference ID: from D01_ERC to D03_ERC

D01_ERC Soft and Wearable robotics powered by electro-active fluids. (Polytechnic University of Bari, Cacucciolo)

Research description:
Information will be soon made available

References:
Information will be soon made available

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Polytechnic University of Bari, Italy

Contacts:
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D02_ERC Soft and Wearable robotics powered by electro-active fluids. (Polytechnic University of Bari, Cacucciolo)

Research description:
Information will be soon made available

References:
Information will be soon made available

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D03_ERC Mechanical design of dynamically-excited soft interfaces for smart tuning of contact forces. (Polytechnic University of Bari, Papangelo)

Research description:

The possibility of quickly and finely regulating the contact forces between two surfaces has a transversal interest in various fields of engineering, with particular reference to soft robotics [1], where manipulation and gripping tasks are required. The present research proposal aims to develop methodologies capable of numerically simulating the process of gripping and releasing objects using polymeric surfaces, typically made of silicone, capable of actively regulating the contact forces [2, 3]. Preliminary literature results [4] have shown that the macroscopic adhesion force, primarily due to non-specific van der Waals interactions, can be adjusted using a vibration of appropriate amplitude and frequency capable of interacting with the contact interface determining its performance in terms of maximum adhesion force and energy necessary for detachment to occur. The researcher will therefore have to investigate the effect that the amplitude and frequency of the vibration, the surface microstructure, the material, the geometry of the indenter, the loading and unloading protocol have on the adhesive behaviour of the interface.
This PhD research proposal fits the objectives of the ERC research project ERC-2021-StG "SURFACE" (ID: 101039198), which supports this research. Therefore, the researcher will have the possibility to carry out both numerical simulation through finite or boundary element codes and validation experiments using the equipment and skills available at the TriboDynamics Lab (DMMM, PoliBa), in particular regarding the possibility of designing and fabricating polymeric micro-structured interfaces with resolution down to 200 nanometres using the Nanoscribe Photonic-Professional GT2 laser micro-fabrication system available from the TriboDynamics Lab.

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