Mechatronics and robotics in the Next Generation EU projects at University of Udine and Free University of Bolzano

Lorenzo Scalera[1], Renato Vidoni[2], and Alessandro Gasparetto[1]

[1] Polytechnic Department of Engineering and Architecture, University of Udine, Udine, Italy,
lorenzo.scalera@uniud.it, alessandro.gasparetto@uniud.it

[2] Faculty of Engineering, Free University of Bozen-Bolzano, Bolzano, Italy,
renato.vidoni@unibz.it

In this paper we present the role of mechatronics and industrial robotics in the projects funded by the Italian National Recovery and Resilience Plan (PNRR) at University of Udine and Free University of Bolzano in northeastern Italy. The Italian PNRR is part of the Next Generation EU plan, launched by the European Union in response to the COVID-19 pandemic, aiming at promoting strategic investments in digitalization and innovation, ecological transition, and social inclusion. The projects presented in this paper include the Interconnected Nord-Est Innovation (iNEST) Ecosystem, and the Agritech National Center. The activities of the robotics research groups within the iNEST Ecosystem mainly include dynamic modelling and trajectory planning for energy efficiency and safe human-robot collaboration, and design of Digital Twin solutions for efficient simulations and modelling of mechatronic and robotic systems. Furthermore, the Agritech project foresees the development and implementation of mobile robotic systems for monitoring and mapping agricultural fields, as for instance vineyards, as well as the sustainable applications of robotics and mechatronics to forestry management.

1. Introduction

Italy has a rich history of research and innovation in mechatronics and robotics, with numerous universities and research centers contributing to cutting-edge advancements in these fields. In the last decades, the Italian scientific community has played a key role in developing both theoretical and applied robotics, impacting areas such as industrial automation, medical robotics, and artificial intelligence. The excellence of Italy in this field is proven, not only by the publications of Italian roboticists, but also by the increasing interest of industrial and service companies for robotic solutions, proposed by scientists, that are engineered and employed in automatic plants.

In recent years, robotics research has been significantly fostered by the Next Generation EU, which prioritizes innovation and technological advancement. The Next Generation EU plan was introduced by the European Union to help Member States to recover from the economic and social impacts of the COVID-19 pandemic [1]. The Italian National Recovery and Resilience Plan (PNRR) is part of the Next Generation EU program and focuses on driving growth through key areas such as digitalization and innovation, ecological transition, and social inclusion [2]. Within this framework, robotics plays a crucial role in boosting innovation and productivity, particularly in sectors like manufacturing, agriculture, healthcare, and sustainable energy, contributing to a more resilient and technologically advanced economy [3].

The Italian PNRR has a total value of 194.4 billion euros. Part of these funds has been allocated to large consortia, where universities, public institutions, and private companies collaborate on research projects across various sectors. These projects are mainly related to the Green and Digital Transition, which are the most important pillars of the Next Generation EU. Additionally, the Italian Ministry of University and Research has utilized PNRR funds to support numerous scientific initiatives. Many researchers from the Italian robotics community are involved in these consortia or participate in projects funded by the plan.

In this context, the research groups of University of Udine (UniUD) and Free University of Bolzano (UniBZ) in northeastern Italy take part at the Interconnected Nord-Est Innovation (iNEST) Ecosystem [4], and the National Center for the Development of New Agricultural Technologies (Agritech) [5]. The iNEST Ecosystem is a project aimed at extending the benefits of digitalization to key sectors in northeastern Italy. On the other hand, the Agritech National Center focuses on leveraging advanced technologies to promote the sustainable development of agri-food production. The robotics research groups within the iNEST Ecosystem primarily focus on dynamic modelling and trajectory planning aimed at enhancing energy efficiency and ensuring safe human-robot collaboration. They also work on developing Digital Twin solutions for efficient simulation and modelling of mechatronic and industrial robotic systems. In addition, the Agritech project involves designing and deploying mobile robotic systems for monitoring and mapping agricultural areas, such as vineyards. Furthermore, sustainable applications of robotics and mechatronics in forestry are also designed and implemented within the Agritech context.

This paper presents the research activities in industrial robotics and mechatronics within the Next Generation EU projects at UniUD and UniBZ, highlighting the applications that mainly benefit from the introduction of advanced technologies and automation. The iNEST and the Agritech projects are described and analyzed in detail, focusing on the contributions of mechatronics and robotics to innovation in various sectors, from industrial automation to sustainable agriculture. These projects highlight the active involvement of the Italian scientific community in the research fields of mechatronics and robotics, showcasing expertise in areas such as industrial robotics, including collaborative and mobile robotics, as well as agricultural robotics.

The paper is structured as follows: Sect. 2 describes the Interconnected Nord-Est Innovation Ecosystem, including a summary of the activities carried out on the topics of trajectory planning for energy efficiency, collaborative robotics, and kinematic and dynamic modelling towards Digital Twin solutions. Section 3 illustrates the Agritech National Center, covering the research activities of mobile robotics for monitoring and mapping in agriculture and the development of sustainable mechatronics solutions for agro-forestry applications. Finally, Sect. 4 concludes the paper and draws the future developments of mechatronics and robotics within these projects funded by the Next Generation EU.

2. The Interconnected Nord-Est Innovation Ecosystem

The Interconnected Nord-Est Innovation Ecosystem is a new model of innovation ecosystem. Innovation ecosystems are networks of public and private universities, public research institutions, local public entities, and other highly qualified and internationally recognized public and private organizations. They focus on technological specialization areas that align with the industrial and research strengths of their respective regions, promoting and strengthening collaboration between the research system, the production system, and local institutions. Innovation ecosystems enhance research outcomes, facilitate technology transfer, and accelerate the digital transformation of production processes within companies, all with a focus on economic and environmental sustainability and social impact on the territory.

The iNEST Ecosystem is one of 11 funded projects that align with the Smart Specialization Strategies of northeastern Italy, reflecting the industrial and research objectives of the Triveneto macro-region. This area, which encompasses the regions of Friuli Venezia Giulia and Veneto, as well as the two Autonomous Provinces of Trento and Bolzano, boasts a diverse range of specialties, spanning from industry to agri-food.

iNEST is financed by the Ministry of University and Research as part of the investments specified in the PNRR. The research and innovation program of iNEST is structured in one hub and nine spokes, engaging 24 partners, including all universities in northeastern Italy and leading research and technology transfer organizations in this macro-region. From 2022 to the end of 2025, the iNEST work plan oversees a budget of approximately 110 million euros, with more than 40 of them integrated in a cascade funding mechanism and in the related open calls addressed to the involvement of companies in the innovation process.

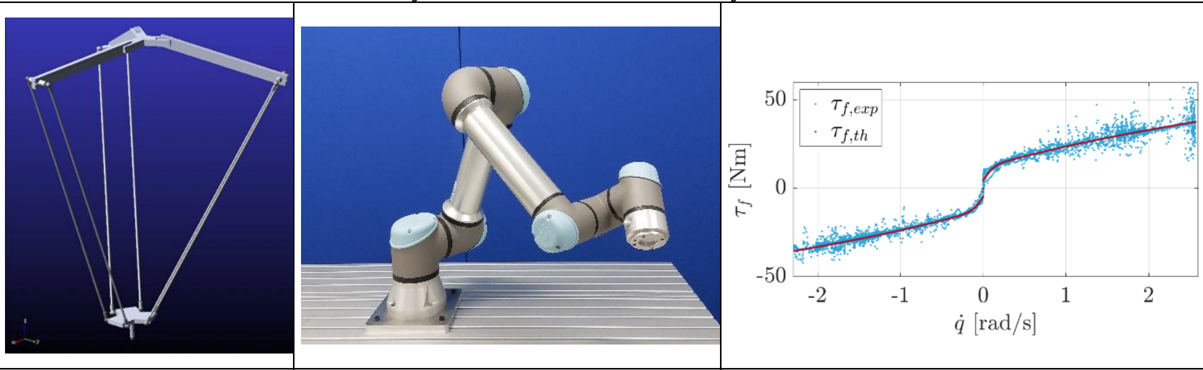
The robotics research groups at University of Udine and Free University of Bolzano, particularly with the Mechatronics and Robotics Lab [6] and the Smart Mini Factory Lab [7], are actively engaged in the Research Topic 2 “Smart Manufacturing, Mechatronics, and Robotics” within the Spoke 3, which focuses on “Green and Digital Transition for Advanced Manufacturing Technology”. The research activities of these two research groups concentrate on dynamic modelling and trajectory planning for energy efficiency in mechatronic and robotic systems, applications in industrial collaborative robotics, as well as on Digital Twin solutions. These topics are described in detail in the following.

2.1. *Trajectory planning for energy efficiency*

Energy efficiency is crucial in robotic systems, as it significantly influences both their environmental impact and operational costs. Evaluating energy efficiency strategies requires assessing their effectiveness and quantifying their effects on robotic systems. The first activity on the topic of trajectory planning for energy efficiency is focused on the dynamic modelling and energy efficiency optimization in parallel robots. The focus of this activity is the development and validation of a dynamic model of a 3-degree-of-freedom (DOF) parallel robot (Fig. 1(a)), and the optimization of its trajectories to enhance energy efficiency for industry-relevant tasks [8]. The proposed strategy leverages the task placement, the execution time, and the length of the robot lower arms to minimize energy consumption during a predefined high-speed pick-and-place operation. To assess the energy consumption of the actuators, kinematic, dynamic, and electro-mechanical mathematical models, along with an equivalent multibody model of the parallel robot, are implemented.

A second activity related to energy efficiency is the electro-mechanical modelling and identification of the UR5 e-series robot by Universal Robots with 6-DOFs (Fig. 1(b)) [9]. This task focuses on modelling the UR5e robot by identifying its dynamic and electrical parameters. Using the identified robot model, it becomes possible to compute and optimize the robot energy consumption during predefined trajectories. The proposed model is based on data collected from the robot controller during experimental tests, applying model identification techniques, and considering the technical specifications provided by the manufacturers of the manipulator, motors, and gearbox. This entire process does not require any additional sensors, allowing it to be easily replicated with a standard manipulator and applied to other robots within the same family.

To further refine the dynamic model of the UR5e robot described in [9], we also perform an experimental analysis and comparison of several friction models applied to that manipulator [10]. This activity involves comparing different friction models using data obtained from the robot real-time interface. The primary goal is to thoroughly assess the performance of each friction model, evaluating its effectiveness in accurately representing the robot dynamics. We initially examine both static and dynamic friction formulations to assess their capacity to account for various friction effects and the factors that influence the friction behavior. Then, a set of selected friction models are experimentally compared to evaluate their effectiveness in predicting friction effects in the UR5e robot (Fig. 1(c)). The results from extensive experiments demonstrate that most of the friction models considered perform well in predicting friction torque and in estimating the robot energy consumption when applied together with a comprehensive dynamic formulation.



(a) The multibody model of the Delta robot with 3 DOFs.	(b) The robot UR5e with 6 DOFs.	(c) Example of experimental and theoretical joint friction torques over joint velocity.

Figura 1: Research activities on energy efficiency.

2.2. *Industrial collaborative robotics*

The emerging scenarios of collaborative robotics and human-robot interaction require advanced strategies for planning robot trajectories [11]. These strategies have to ensure smoothness, safety, and fluency while the robot performs a task alongside a human operator.

The research activity on industrial collaborative robotics within the iNEST Ecosystem of UniUD focuses on developing a strategy for planning robot stopping trajectories [12], based on the speed and separation monitoring (SSM) paradigm described by the technical specification ISO/TS 15066 [13]. In the proposed approach, a supervisory controller constantly monitors the distance between the bounding volumes surrounding both the human operator and the robot, preventing potential collisions by calculating the robot stop time and engaging a stop trajectory when needed (Fig. 2). Experimental results indicate that the dynamical scaling of the robot safety zones in real-time significantly enhances the fluency of human-robot collaboration, demonstrating notable statistical differences compared to alternative approaches.

The approach presented in [12] is then extended to the case in which the robot dynamic is uncertain or inaccurate [14]. In this case, the uncertain robot dynamics is considered using interval arithmetic to ensure compliance with the joint torques limits even in case of imperfect knowledge of the dynamic model parameters. The effectiveness of the proposed approach is validated using a Franka Emika Panda arm, a commercially available manipulator with seven degrees of freedom. The results confirm the validity of the approach and provide insights into the impact of dynamic variations on human-robot collaboration.

Within the same topic, to further enhance productivity of a collaborative task, the combination of SSM and the Power and Force Limiting (PFL) modalities has been proposed in literature but relying on some conservative assumptions that limit its potentialities. To overcome these limitations, the approach is extended by UniBZ [15] and its effectiveness is validated through numerical experiments showing an improvement in terms of productivity, fluency of the operation and in usage of the robot, without affecting the safety of the collaborative tasks.

A further activity at UniBZ starts from the recognition that a critical gap persists in adapting robotic behavior to intuitively align with human operators' cognitive states and situational awareness limiting the potential of human-robot collaboration in complex industrial environments. A novel algorithm which dynamically modulates the trajectory of a manipulator according to the human focus towards the robot is presented and preliminary results supporting the goodness of the novel approach are introduced and discussed [16].

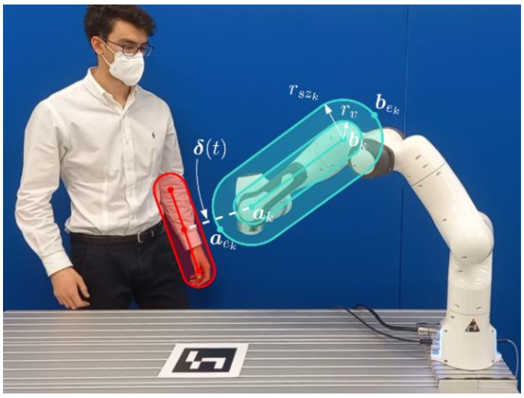
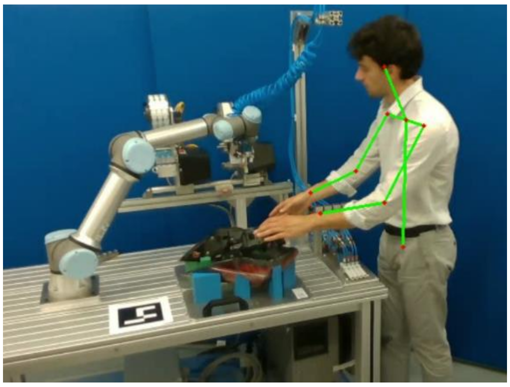
	
(a) Example of bounding volumes surrounding a link of a human operator and a link of the Franka Emika robot.	(b) Example of collaborative robotics workstation. The green segments indicate the skeleton of the human operator tracked by an RGB-D camera.

Figura 2: Research activity on industrial collaborative robotics.

2.3. Kinematic and dynamic modelling towards Digital Twin solutions

The establishment of DTs to model physical systems and exploit their advantages for prediction, control and optimal task and motion planning is becoming increasingly important for the global scientific community. As a result, DTs are experiencing continual development and improvement, indicating a noteworthy ongoing trend [17]. As broadly known, a DT serves as a precise replica of a physical entity, facilitating real-time information exchange with its physical counterpart, and vice versa, clearly distinguishing it from a Digital Model (DM), where all information is fed manually. Regarding the evolution of DMs into their corresponding DTs, still some work needs to be done. The research activities conducted by UniBZ have the scope of highlighting potentialities and limitations of kinematic and dynamic modeling towards the creation of DT. This is currently being conducted and applied on simple available mechatronic systems at the Smart Mini Factory (SMF) laboratory of UniBZ, such as the one addressed in [17], and at Progress Machines and Automation (PMA, Brixen) in [18]. To improve the capabilities of the DM towards DT solutions, two main topics are addressed: (i) introduce flexibility to the multi-body systems while keeping the DM sufficiently light to allow a DT application; (ii) introduce the energy consumption evaluate of plant machines and possibly optimize it in the DT layer.

3. The Agritech National Center

The National Center for the Development of New Agricultural Technologies (Agritech) focuses on leveraging innovative and advanced technologies to foster the sustainable development of agri-food production. Its primary goals include promoting adaptation to climate change, minimizing the environmental impact of the agri-food sector, enhancing the development of marginal areas, and ensuring safety, traceability, and security of supply chains.

The project is valued at approximately 350 million euros, with 320 million funded by the National Recovery and Resilience Plan. The Agritech National Center involves the participation of 28 universities, 18 companies, and 5 research centers throughout Italy. The Center is organized in hub and spokes, with the University of Naples Federico II responsible for the national hub and 9 different spokes. The main feature of the Agritech research program is indeed its structural organization, which reflects the high level of integration among a wide variety of participating research institutions and companies. The project develops over 36 months from 01/09/2022 to 31/08/2025.

In the Agritech project, the research groups in robotics at University of Udine and at Free University of Bolzano are involved in the Work Package 4.2 named “Smart-climate and resilient agriculture and forestry: from sustainable products to the bioeconomy”, and in the Task 4.2.2 titled “Advanced monitoring techniques and novel management practices for saving soil and water, optimizing carbon balance, and maximizing the efficiency of used resources and mitigating impacts”. The aims of the task are to test different agronomic management solutions in different living-labs to improve water efficiency and fertilizer use, optimize phyto-sanitary defense and increase the carbon stock, especially in the soil with particular attention to micro-biological aspects.

In this context, the contributions of the mechatronics and robotics research groups are focused on mobile robotics for mapping and monitoring the agricultural fields, with particular focus to vineyards, and on the development and prototyping of an autonomous mobile robotic system for three-dimensional (3D) canopy monitoring, acquisition of vegetation indexes, as well as properties and gas exchanges from the soil. Furthermore, sustainable mechatronics solutions for agro-forestry applications are also designed and implemented. The challenges of mobile robotics for mapping and monitoring in agriculture, and the development of mechatronics solutions for the forestry environments are described in the following.

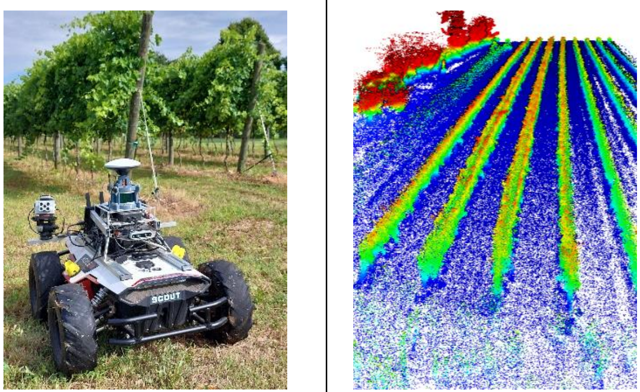
3.1. *Mobile robotics for mapping and monitoring in agriculture*

Automated monitoring of the soil-plant-atmosphere continuum at high spatial and temporal resolution is critical to transform current cropping systems through more informed farmer decision-making and enabling researchers to answer key scientific questions for our agricultural systems. The past two decades have seen, particularly regarding crop, soil, and microclimate monitoring, a steady development of IoT applications in agriculture, as well as the development and use of autonomous and robotic systems with strong computational and logic capabilities. Robotics can provide significant benefits not only in terms of crop production and optimization of the use of resources (e.g., water, fertilizers), but also in reducing the use of chemical pesticides, improving sustainability and climate performance through a more results-oriented model based on the use of up-to-date data and analysis.

For these reasons, the deployment of autonomous robotic solutions, together with advanced monitoring techniques, becomes important in the context of resilient and sustainable agriculture. Indeed, robotic solutions can acquire data from crops and plants at close range and from different viewpoints, are less weather dependent than aerial platforms, are not subject to strict legislative regulations, and have a higher sensor payload than unmanned aerial vehicles (UAVs) [19].

The first activity carried out within the Agritech National Center is related to the development of a novel approach for analyzing the effects of water regime on grapevine canopy status, using robotics for enhanced monitoring and mapping [20]. Data collected from an UAV and a ground mobile robot (Fig. 3(a)) are used to capture multispectral images and compute multiple vegetation indexes, as well as to generate a 3D reconstruction of the canopy (Fig. 3(b)). To reconstruct the 3D point cloud of the plants, an approach based on Simultaneous Localization and Mapping (SLAM) is adopted. Then, data on volume, surface and projected area of the plants are obtained from the 3D point cloud. Unlike previous studies, sixty vegetation indexes are computed with precision using the projected area of the vineyard point cloud as a mask. Extensive experimental tests on repeated plots of Pinot gris vines, carried out in one of the vineyards of the University of Udine, reveal a strong positive correlation between water potential and vegetation indexes such as GDVI, PVI, and TGI. Additionally, both canopy volume and the area projected on the ground are influenced by water status, reflecting the stem and pre-dawn water potential measurements. The results demonstrate the feasibility of the proposed strategy and highlight the potential of robotic technologies in advancing precision viticulture.

To further improve the capabilities of the mobile platform in vineyards, a navigation strategy is developed to allow the robot to autonomously move in agricultural environments, and particularly along vineyard rows. The proposed approach is based on a SLAM algorithm that combines multiple odometry sources, along with global and local path planners to guide the robot through the vineyard. The approach requires the user to input the GNSS coordinates of the starting and ending points of the vineyard rows, and is based on data from a LiDAR sensor, an IMU, a GNSS, and wheel odometry for localization and obstacle avoidance. The robot is then guided to move back and forth along each row before transitioning to the next. The navigation method is tested using a Scout 2.0 mobile robot in both open outdoor environments and an actual vineyard. Experimental results demonstrate the robot capability to repeatedly follow paths and its robustness during extensive autonomous surveys.



(a) The Scout 2.0 mobile robot equipped with sensors for vineyard monitoring and 3D mapping.	(b) Example of the reconstruction of the 3D point cloud of a vineyard.

Figura 3: Research activity on mobile robotics for sustainable agriculture.

3.2. Sustainable mechatronics solutions for agro-forestry applications

In an effort to reduce harmful greenhouse gas emissions and to lower operating and maintenance costs, hybridization and electrification gain traction both in on-road and off-road machinery traction applications. Inner the activities of the FiRST, Field Robotics South-Tirol Lab of UniBZ [21], the focus is on the hybridization or electrification of mechatronic systems for forestry operations such as tower-yarders and self-propelled carriages. Analytical models have been developed to study the energy household of the entire transport process in any cableway configuration, with the objective of proposing a complete and safe technical solution for hybrid self-propelled mechatronic carriages optimized to achieve maximum performance and efficiency, and thus minimum fuel consumption and emissions. The models continue to be validated with the prototype of a hybrid self-propelled carriage by Leitalpin Ltd (Fig. 4(a)), obtaining actual performance data of a series hybrid drivetrain in a forestry application via a specifically set-up cableway for demonstration and testing purposes [22]. In addition, a continuous skyline force monitoring system for within the carriage has been developed to boost the safety of such modern cableway installations [23]. The concept has been demonstrated via a small-scale carriage and cableway setup and will be implemented in the true-size hybrid self-propelled carriage currently under testing. A parallel activity focuses on sustainable forest management in spruce stands through a spruce-tree pruning robotic system. After an earlier design and prototyping project, in this project, an additional step regarding the conceptualization and design of an automatic spruce pruning robotic system is done (Fig. 4(b)).

(a) Hybrid self-propelled carriage by Leitalpin Ltd | (b) Spruce-Robot prototype

Figura 4: Research activity on Sustainable mechatronic solutions for agro-forestry applications.

4. Conclusions

In this paper, we discussed the role of mechatronics and robotics in the projects established by the Italian National Recovery and Resilience Plan (PNRR) at the University of Udine and the Free University of Bolzano in the Triveneto macro-region of northeastern Italy. This paper illustrated two projects: the Interconnected Nord-Est Innovation (iNEST) Ecosystem, and the Agritech National Center. The robotics research groups within the iNEST Ecosystem primarily work on dynamic modelling and trajectory planning for energy efficiency and safe human-robot collaboration, as well as the design of Digital Twin solutions. Furthermore, the Agritech project promotes the sustainable applications of robotics and mechatronics to forestry management, as well as the development and deployment of mobile robotic systems for mapping and monitoring agricultural fields, such as vineyards.

Future developments of the iNEST Ecosystem will include the design of advanced strategies for energy efficiency, also leveraging the redundancy of industrial robotic systems, as well as the implementation of more refined collision-avoidance approaches and Digital Twin solutions. Future works within the Agritech National Center will focus on the improvement of the autonomous navigation algorithm for mobile robots, the acquisition of further information on the plants' health status at a close range and the experimental evaluation of mechatronic and robotic solutions for forestry-related tasks.

5. Acknowledgments

This work was developed within the Laboratory for Big Data, IoT, Cyber Security (LABIC) funded by Friuli Venezia Giulia region, and the Laboratory for Artificial Intelligence for Human- Robot Collaboration (AI4HRC) funded by Fondazione Friuli. This study was carried out within the Agritech National Research Center and received funding from the European Union Next-Generation EU (Piano Nazionale di Ripresa e Resilienza (PNRR) – Mission 4 Component 2, Investment 1.4 - D.D. 1032 17/06/2022, CN00000022), and within the Interconnected Nord-Est Innovation Ecosystem (iNEST) and received funding from the European Union Next-Generation EU

(Piano Nazionale di Ripresa e Resilienza (PNRR) – Mission 4.2, Investment 1.5 – D.D. 1058 23/06/2022, ECS 00000043). This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

6. References

[1] Next Generation EU. https://next-generation-eu.europa.eu/index_en (2020).

[2] Italia Domani. The National Recovery and Resilience Plan. https://www.italiadomani.gov.it/content/sogei-ng/it/en/home.html (2022).

[3] Boschetti, G., Carbone, G., Ceccarelli, M., Gasparetto, A., Scalera, L., Vidoni, R. (2024). Italian Robotics in 2024: Projects Supported by the National Recovery and Resilience Plan. In *IFToMM Asian Conference on Mechanism and Machine Science* (pp. 170-177). Cham: Springer Nature Switzerland.

[4] Interconnected Nord-Est Innovation Ecosystem (iNEST): Planning of activities. https://www.consorzioinest.it (2022)

[5] Agritech: National Center for Technology in Agriculture. https://agritechcenter.it (2022).

[6] Mechatronics and Robotics Laboratory. University of Udine. https://mec-rob-lab.uniud.it/ (2024).

[7] Gualtieri, L., Rojas, R., Carabin, G., Palomba, I., Rauch, E., Vidoni, R., and Matt., D. T. Advanced Automation for SMEs in the I4.0 Revolution: Engineering Education and Employees Training in the Smart Mini Factory Laboratory. In IEEE Int. Conf. on Ind. Eng. and Eng. Manag., 2018.

[8] Fabris, G., Scalera, L., Gasparetto, A. (2024). Dynamic modelling and energy-efficiency optimization in a 3-DOF parallel robot. *The International Journal of Advanced Manufacturing Technology*, *132*(5), 2677-2699.

[9] Clochiatti, E., Scalera, L., Boscariol, P., Gasparetto, A. (2024). Electro-mechanical modeling and identification of the UR5 e-series robot. *Robotica*, 1-23.

[10] Fabris, G., Scalera, L., Boscariol, P., Gasparetto, A. (2024). Experimental analysis and comparison of friction models applied to the UR5e robot. In *IFToMM Symposium on Mechanism Design for Robotics* (pp. 125-133). Cham: Springer Nature Switzerland.

[11] Vicentini, F. (2021). Collaborative robotics: a survey. *Journal of Mechanical Design*, *143*(4), 040802.

[12] Scalera, L., Lozer, F., Giusti, A., Gasparetto, A. (2024). An experimental evaluation of robot-stopping approaches for improving fluency in collaborative robotics. *Robotica*, *42*(5), 1386-1402.

[13] ISO Standard, "ISO/TS 15066: 2016: Robots and Robotic Devices–Collaborative Robots," In: International Organization for Standardization, (Geneva, Switzerland, 2016).

[14] Scalera, L., Nainer, C., Giusti, A., Gasparetto, A. (2024). Robust safety zones for manipulators with uncertain dynamics in collaborative robotics. *International Journal of Computer Integrated Manufacturing*, *37*(7), 887-899.

[15] Manzardo, M., Vidoni, R., "On the improvement of the combination of Power and Force Limiting and Speed and Separation Monitoring for an effective Human Robot Collaboration", 6th International Conference on Industry 4.0 and Smart Manufacturing, Prague, 2024

[16] Manzardo, M., Ciaghi, D., Gualtieri, L., Morandini, S., Fraboni, F., Pierantoni, L., Vidoni, R., "Human-Robot Adaptive Collaboration through Eye-Tracking", IEEE CASE, Bari, 2024

[17] Nezzi, C., Fink, S., Rauch, E., Vidoni, R., "Digital Twin-Oriented Kinematic Modelling of a Large-Sized Mesh Welding Plant for Productivity Evaluation: a Company Case Study" (2024) Mechanisms and Machine Science, 166 MMS, pp. 424-432.

[18] Nezzi, C., De Marchi, C., Rauch, E., Vidoni, R., "Multibody Model, Simulation and Validation of Rail-Guided Shuttles for a Digital Twin-Enabled Demonstrator", Proceedings of the ASME 2024 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference IDETC/CIE2024, August 25-28, 2024, Washington D.C., District of Columbia, Maryland.

[19] Tiozzo Fasiolo, T., Scalera, L., Maset, E., Gasparetto, A. (2023). Towards autonomous mapping in agriculture: A review of supportive technologies for ground robotics. *Robotics and Autonomous Systems*, 104514.

[20] Tiozzo Fasiolo, D., Pichierri, A., Sivilotti, P., Scalera, L. (2023). An analysis of the effects of water regime on grapevine canopy status using a UAV and a mobile robot. *Smart Agricultural Technology*, *6*, 100344.

[21] FiRST, Field Robotics South-Tirol Lab of Free University of Bolzano-Bozen, https://firstlab.projects.unibz.it

[22] Leitner, S., Vidoni, R., Performance and Efficiency Study of a Hybrid Self-propelled Cable Logging Carriage – Preliminary Results (2024) Mechanisms and Machine Science, 164 MMS, pp. 171-182.

[23] Leitner, S., Carabin, G., Spinelli, R., Renzi, M., Vidoni, R., Skyline force estimation and limitation during cable yarding: A novel technical solution for within the carriage (2024) Measurement: Journal of the International Measurement Confederation, 235, art. no. 114931.