I-RIM

PhD Course in

ROBOTICS AND INTELLIGENT MACHINES

Curriculum: Robotics and Intelligent Machines for Agrifood

Research themes

The main goal of the Agrifood curriculum is to train scientists and researchers capable of working in multidisciplinary teams on topics related to state-of-the-art solutions for a modern agriculture that is resilient to climate change and able to cope with the increase in demand. Specific research areas include:

1. Automation and integration of human and artificial intelligence with mechanical capabilities to reduce fatigue and health problems related to work and interaction with chemicals, counteracting the shortage of labor in the agricultural and food sectors.

2. Intuitive and natural interfaces that allow farmers, workers and sellers to manage robots without advanced training.

3. Precision agriculture to provide sufficient agricultural goods to the growing population with clean, climate neutral, sustainable and responsible techniques.

4. Greater stability and safety of robots in physical interaction with humans and the environment, in the production and sale of agri-food products.

5. Robotic systems capable of carrying out manipulations and locomotion in air, water and on various types of land in the cultivation, collection and transport of agri-food products.

The ideal candidates are students with a Master (or equivalent/higher) STEM (Science, Technology, Engineering, and Mathematics) degree and possibly a specific background in Robotics.

The students will perform their research project at the hosting institution (as described in the research project sheet). Interested applicants are encouraged to contact the tutors and/or the Unit's PI for clarifications before submitting their application.

International applications are encouraged and applicants will receive logistic support with visa issues, relocation, etc.

1. Virtual and Physical Prototyping of Sensorized Compliant Grippers

Curriculum: Agrifood

Hosting Institution
University of Genova

Department:
DIME – Dipartimento di Ingegneria Meccanica, Energetica, Gestionale e dei Trasporti
DITEN - Dipartimento di Ingegneria Navale, Elettrica, Elettronica e delle Telecomunicazioni

Tutors:
Prof. Giovanni Berselli
Prof. Maurizio Valle

Description:
Virtual and Physical Prototyping of compliant and sensorized robotic grippers for application in agrifood industry.

Requirements:
Applicants are expected to work in the framework of the Horizon Europe Project INTELLIMAN. The candidate is expected to design novel compliant grippers. Required skills:

- Engineering Software: SOLIDWORKS, CATIA, ANSYS, ANSYS MAXWELL, COMSOL MULTI-PHYSICS, ARDUINO IDE
- Mathematical Software: MATLAB, SIMULINK

References:

- Bilancia, P., Baggetta, M., Hao, G., Berselli, G. "A variable section beams based Bi-BCM formulation for the kinetostatic analysis of cross-axis flexural pivots" (2021) International, Journal of Mechanical Sciences, 205, art. no. 106587.
- Alameh, M., Abbass, Y., Ibrahim, A., Moser, G., Valle, M. "Touch Modality Classification Using Recurrent Neural Networks" (2021) IEEE Sensors Journal, 21 (8), art. no. 9340346, pp. 9983-9993.

Number of positions available:

1

Main Research Site
University of Genova (refer in particular to www.gberselli.info and http://www.cosmiclab.diten.unige.it/)

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Funding Scheme: This doctorate grant is co-funded by the proponent research institutions and by the Italian Ministry of Research, under law D.M. 351/2022 (PNRR).

2. Fresh food handling – Univ. Campania Luigi Vanvitelli

Curriculum: Agrifood

Hosting Institution
Università degli Studi della Campania "Luigi Vanvitelli"

Department:
Dipartimento di Ingegneria

Tutors:
Prof. Salvatore Pirozzi

Description:

Introduction
A key challenge in intelligent robotics is to create robots capable of directly interacting with the world around them to achieve their goals. On the other hand, robot manipulation is central to achieve the promise of robotics, since the definition of robot requires that it has actuators that it can use to change the world. Inspired by the fact that human hand is the most sensible, flexible and controllable part of our body, the main objective of this research activity is to develop intelligent sensing technologies to be integrated in both commercial and innovative grippers, aiming at generating smart and affordable solutions for robotic manipulation. Differently from the devices available on the market, we aims to develop and integrate innovative sensory equipment, data interpretation algorithms based on machine learning and data fusion approaches and different control modalities directly on-board the gripper fingers and its case. The resulting smart gripper will provide capabilities for the manipulation of objects with different features (e.g., deformability, fragility, stiffness, shape). Most of the commercial grippers are based on pneumatic actuation, and electric ones are usually characterized by a limited mobility. Moreover, the only sensor information usually available is the jaws aperture, and the jaws (or fingers) can't be controlled independently. The only affordable contact sensors are usually simple pressure pads providing only approximate contact information. Control modalities available in commercial grippers are usually limited to finger aperture control, fact that prevents the implementation of force-controlled grasping particularly suitable in case of unknown, soft or fragile objects. There are no commercial solutions with advanced control systems or data interpretation approaches integrated on-board and already available for the application development.

Main application field: fresh food manipulation
Grocery picking process has high complexity and is fast-moving in nature. Considering that distributors for the consumer market fulfills an average of 330,000 orders per week, any automated system designed for this task must be capable of picking a vast range of differently shaped objects, since common distributors catalogue includes more than 50,000 SKUs (stock keeping units), in any orientation, when stored in a crate with many other objects. Therefore, there is a need for something more complex than a typical industrial pick and place solution would allow for. Current solutions are conceptually simple and are conceived for a single product, and adaptation to different products is often not possible. Our research activities aim at embedding in commercial grippers and robotic hands the required sensitivity and manipulation capabilities to manipulate fruit and vegetables without causing damage to the product surface and adapting the grasp to any possible variant in terms of size, shape, weight and surface properties. The main challenges are related to:

picking from a dense environment understating relationship between objects and detecting feasibility; pack with a certain orientation depending on the task requirements; learn grasping strategies from limited trials leveraging on data and tasks interpretation; reduce the damage to delicate fruits and vegetables imposed during grasp.

Research topics

Sensing Technologies for Smart Grippers. Force, tactile and vision are exploited by researchers in order to improve robot autonomy to perform complex manipulation tasks. Despite the high number of prototypes, sensors to measure contact forces are not widespread in manufacturing applications because of the high cost of these sensors and the complex and cumbersome conditioning electronics hampering the integration of the whole robotic system. The force/tactile sensor developed by UCLV in the REMODEL project overcomes these limitations. The advantages in using tactile sensors are that it can recognize object features (e.g., shape, stiffness, center of mass, friction) and it can be used to implement control strategies for fine manipulation and precision grasping. In the REMODEL project, both tactile and proximity sensors have been successfully integrated within a stand-alone sensorized finger for parallel grippers. To tackle fresh food manipulation task one of the objectives is to improve the sensing system for commercial electric gripper by integrating in the same device vision with illumination system, tactile, proximity and inertial sensors (IMU).

Data Fusion for Intelligent Sensing System. Vision data are often used in robotic manipulation, but this approach may fail in case of complex backgrounds or occlusions. Tactile sensors enables alternative approaches: the combination of tactile data and machine learning enables the use of touch sensing solutions to daily-life applications. Integration of vision and tactile data for object recognition is an active research topic. In our research activities we intend to use all available sensor data to train machine-learning based model able to estimate and/or reconstruct physical and geometrical features for the object to manipulate, e.g., shape, stiffness, fragility, pose. Solutions exploiting single modal sensors (e.g., only tactile data and/or only vision data and/or only proximity data) will be firstly exploited. Then, multi-modal sensor fusion approaches will be evaluated by combining all available data, to test advanced solutions for a better estimation of the more complex features. For example: the combination of proximity and vision could be exploited for a more precise localization of the object; the combination of tactile and vision data could be useful in the object shape estimation in presence of uncertainties; the tactile sensors with accelerometers could be used to prevent slippage

Grasping and Manipulation. Robotic grasping envisages two main approaches: definition of proper contact points and reachability validation by a given gripper, providing practical solutions for simple grippers but not for complex ones (e.g. anthropomorphic hands); generating random positions around the object, closing the fingers to obtain a grasp, enabling grasp synthesis for anthropomorphic hands. Both approaches can be extended to multi-gripper grasping, particularly to bimanual grasps with human-like constrains. Other variations of the grasping problem are due to the available knowledge of the object (e.g., geometric model, shape, stiffness, center of mass, friction) that generates specific grasping conditions. Object manipulation in robotics has two common meanings: a) relocation of objects by grasping and moving them to another position, a broad field of research involving grasping, motion planning, arm synchronization and imitation of human movements; b) movement of objects with respect to the gripper using the fingers, also called in-hand or dexterous manipulation, involving topics like tactile sensing, object and object properties recognition, strategies for the finger motion planning and control of the sole grasp force using external constraints. Different control modalities, such as visual control, impedance/force control, slipping avoidance and short-range obstacle avoidance will be

evaluated to be directly implemented on the gripper electronics, exploiting the feedback provided by the sensors mounted on the fingers and on the gripper itself. Manipulation of deformable objects and moving it from a starting to a goal will be tackled by resorting to these multimodal sensor-based control. The multi-sensorized gripper will also allow to perform dexterous operations by resorting to the so-called extrinsic dexterity concept, including in-hand maneuvers like the object pivoting and the gripper pivoting.

Notes

The PhD student will take part to all our research activities mainly distributed in different European and National research projects. Within these project experiences with academic and industrial partners will be defined in accordance with the training periods provided at external Italian and foreign locations.

Requirements:

We are looking for a highly motivated, creative, and ambitious student, who can work well in a team as well as independently and quickly acquire knowledge in new topics. The ideal candidate should fulfill, at least partially, the following requirements:

- Successfully completed scientific university degree in Computer Science, Robotics, Automatic Controls, Electronics, Mechatronics Engineering, or other closely-related discipline with outstanding results,
- Experience in sensor development, electronics, including opto-electronics, mechatronic design,
- Excellent knowledge and experience in robotics and manipulation,
- Experience in additive manufacturing of materials, PCB design,
- Familiar with Matlab, Python, C++, CAD softwares and Finite Element Methods
- Experience in composing academic writing pieces (manuscripts, reviews, etc.)

References:

1. Cirillo, et al., Tactile Sensors for Parallel Grippers: Design and Characterization. Sensors, MDPI, 21, 1915, 2021.
2. Damian, D. D., et al., Artificial tactile sensing of position and slip speed by exploiting geometrical features, IEEE/ASME Trans. on Mechatronics, 20(1), 2015.
3. Cirillo, et al., Proximity Sensor for Thin Wire Recognition and Manipulation. Machines, MDPI, 9, 188, 2021.
4. Cirillo, et al., Tactile Sensor Data Interpretation for Estimation of Wire Features. Electronics, MDPI, 10, 1458,2021
5. De Gregorio, D. et al., Integration of robotic vision and tactile sensing for wire-terminal insertion tasks, IEEE T-ASE, 16(2), 2019.
6. M. T. Francomano, D. Accoto, and E. Guglielmelli, —Artificial sense of slip—a review, IEEE Sensors J., 13(7), 2013.
7. Costanzo M., et al.. Two-Fingered In-Hand Object Handling Based on Force/Tactile Feedback. IEEE T-RO, 36.1, 157-173, 2020.

Number of positions available:

1

Main Research Site

Dipartimento di Ingegneria, Via Roma 29, 81031 – Aversa (CE), Italy

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Funding Scheme: This doctorate grant is co-funded by the proponent research institutions and by the Italian Ministry of Research, under law D.M. 351/2022 (PNRR).

3. Automation of poultry and pig farms always having animal welfare as the goal – Univ. Catania

Curriculum: Agrifood

Hosting Institution
Università degli Studi di Catania

Department:
Dipartimento di Ingegneria Civile e Architettura

Tutor(s):
Prof. Rosario Sinatra

Description:
Even in the agro-industrial sector there is great difficulty in hiring skilled labor, that is personnel who have adequate skills in managing the plants but above all a knowledge that allows them to manage animals correctly to safeguard their well-being. Due to the scarcity of trained personnel for the management of the farms, today the breeders are trying to make the farms more and more automatic to make them operational if not with very little use of specialized personnel. The crucial function in every farm has always been to correctly manage the feeding of animals based on their weight to size ratio. In the past, the breeder saw his own cattle and based on his experience he dosed the amount of feed to be provided for proper growth.
This is the challenge that the doctorate will have to face. He will have to design a plant that is able to analyze the weight of the animals and then dose the feed they need.
Specifically, the focus is on 2 different types of intensive farming: chickens and pigs. Pigs are reared inside stalls where 5 to 10 animals are contained. The automatic system must be able to evaluate the weight with optical systems, then provide adequate food for each individual pig, delivering the consistent quantity for each individual animal.
Always with a view to animal welfare, the farm management system will have to manage the movement of the animals and the cleaning of the boxes, then at the end of the cycle transport the animals to the loading vehicles, weigh them individually and provide a report showing the growth

The doctorate will have to design all automatic breeding control systems:

- The automatic breeding control system
- The data management and archiving system
- The data visualization system
- The vision system for the definition of the weight / size of the animal
- The logic of control and management of feed distribution
- The control system for the automatic cleaning of the boxes
- Automation for the final weighing of animals

He will also have to interface with the group of mechanical engineers to ensure that the mechanical needs of the automatic system coincide with the planned automations.

Poultry farms have the same peculiarities.
The fundamental difference is that food is provided to groups of animals.
In this case the weight / size evaluation system will have to detect the characteristics of several

animals and define an average need.
From a functional point of view, however, the automations, although different, must perform the same tasks:

- Evaluate the weight and size of the animals
- Manage power
- Clean the boxes
- At the end of the cycle, convey the animals to the transport vehicles
- Weigh the animals and prepare growth reports

Therefore, the objectives of the doctorate will also be the same and therefore the design of the control systems of industrial farming, the management, storage and vision of the characteristic data of the animals and therefore the design of the control systems of each individual automation.

Requirements:
Knowledge of mechatronics, software programming and the most up-to-date industrial automation systems are required.

References:

- Bolton, William. Mechatronics: electronic control systems in mechanical and electrical engineering. Pearson Education, 2018
- Lyshevski, Sergey Edward. Mechatronics and Control of Electromechanical Systems, CRC Press, 2020

Company name and link (for industrial projects):

Hypertec Solution S.r.l. (https://hypertec.it/)

Number of positions available:

1

Main Research Site
Sede Hypertec Solution di Catania

Contacts:

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Funding Scheme: These industrial doctorate grants are co-funded by the proponent research institution, company and by the Italian Ministry of Research, under law D.M. 352/2022.

4. Design of poultry and pig farms always having animal welfare as the goal – Univ. Catania

Curriculum: Agrifood

Hosting Institution
Università degli Studi di Catania

Department:
Dipartimento di Ingegneria Civile e Architettura

Tutor:
Prof. Alessandro Cammarata

Description:

Even in the agro-industrial sector there is great difficulty in hiring skilled labor, that is personnel who have adequate skills in managing the plants but above all a knowledge that allows them to manage animals correctly to safeguard their well-being. Due to the scarcity of trained personnel for the management of the farms, today the breeders are trying to make the farms more and more automatic to make them operational if not with very little use of specialized personnel. The crucial function in every farm has always been to correctly manage the feeding of animals based on their weight to size ratio. In the past, the breeder saw his own cattle and based on his experience he dosed the amount of feed to be provided for proper growth.

This is the challenge that the doctorate will have to face. He will have to design a plant that is able to analyze the weight of the animals and then dose the feed they need.

Specifically, the focus is on 2 different types of intensive farming: chickens and pigs. Pigs are reared inside stalls where 5 to 10 animals are contained. The automatic system must be able to evaluate the weight with optical systems, then provide adequate food for each individual pig, delivering the consistent quantity for each individual animal.

Always with a view to animal welfare, the farm management system will have to manage the movement of the animals and the cleaning of the boxes, then at the end of the cycle transport the animals to the loading vehicles, weigh them individually and provide a report showing the growth.

The doctorate will have to design the new breeding and in detail:

- The shape and distribution of the boxes

- The shape and automation of the feeding systems of each animal

- Automatic box cleaning systems

- Weighing systems at the end of the cycle

He will also have to interface with the group of electronic engineers and provide support for the mechanical design of the vision systems necessary for the evaluation of the growth (weight and size) of the animals.

Poultry farms have the same peculiarities. The fundamental difference is that food is provided to groups of animals. In this case the weight to size ratio evaluation system will have to detect the characteristics of several animals and define an average need.

From a functional point of view, however, the automations, although different, must perform the same tasks:

- Evaluate the weight and size of the animals

- Manage power

- Clean the boxes

- At the end of the cycle, convey the animals to the transport vehicles

- Weigh the animals and prepare growth reports

Therefore, the objectives of the doctorate will also be the same and therefore the design of the boxes, the feed distribution systems, the cleaning and weighing systems for the animals.

Requirements:
Applicants are expected to have knowledge on mechanical engineering and design, on industrial technical design and the CAD/CAE software.

References:

- Raeymaekers, B. (2022). Design of Mechanical Elements: A Concise Introduction to Mechanical Design Considerations and Calculations. John Wiley & Sons.
- Grous, A. (2018). Applied Mechanical Design. John Wiley & Sons.
- Chang, K. H. (2014). Design theory and methods using CAD/CAE: The computer aided engineering design series. Academic Press.
- Chang, K. H. (2013). Product manufacturing and cost estimating using CAD/CAE: the computer aided engineering design series. Academic Press.
- Chang, K. H. (2014). Product design modeling using CAD/CAE: the computer aided engineering design series. Academic Press.

Company name and link (for industrial projects):

Hypertec Solution S.r.l. (https://hypertec.it/)

Number of positions available:

1

Main Research Site
Hypertec Solution site in Catania

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Funding Scheme: These industrial doctorate grants are co-funded by the proponent research institution, company and by the Italian Ministry of Research, under law D.M. 352/2022.

5. Autonomous Robotics for mountain agriculture – Univ. Trento

Curriculum: Agrifood

Hosting Institution
Università degli Studi di Trento

Department:
Dipartimento di Ingegneria Industriale

Tutors:
Daniele Fontanelli, Marco Roveri, Luigi Palopoli

Description:
Agriculture in mountainous environments is well known for the high quality of the produces. As an example, some of the best-known agricultural production of the autonomous Province of Trento come from mountainous areas.
Common traits of this type of activity are: 1. They take place in harsh environmental conditions (e.g., very steep slopes) that hinder the use of standard agricultural machinery, 2. The type of plants that are typically grown in these areas are very delicate and need to be manipulated with care, 3. The changing environmental conditions (e.g., due to global warming) are increasing the level of difficulty of this activity. 4. The areas reserved to mountain agriculture are usually within or in close proximity to National/regional parks and protected areas.
A significant result of these factors is that mountain agriculture is currently a human-intensive production with a marginal application of automation technologies. As a consequence, despite the high quality of the produce, the economic returns of mountain agriculture are limited and this important segment of the economy has constantly shrunk in the past years. The adverse effects of this trend are manifold: entire regions are losing their population, and rewilding of the areas is so chaotic that it further paradoxically increases the vulnerability of the environment.
The intended solution to this problem is based on teams of autonomous terrestrial vehicles. These devices are multi-purpose. They cooperate strictly with humans (e.g., to move heavy tools and loads across difficult-to-reach fields with heavy slopes) and monitor produce growing factors. Furthermore, they can move autonomously for additional monitoring and control missions (e.g., to ensure a real-time control of pests through the daily inspection of flypaper traps deployed at different locations in the field). Importantly, these robots can be connected in a network and can operate as shared assets for groups of farmers, and they can also serve as a sensing platform to collect environmental data during their missions and store them in the facility owned by government institutions (e.g., the regional government or the park authority) by using an open-data format.

Requirements:
The PhD program will concern the development of a robotic platform specifically tailored to mountain agriculture applications. Specifically, the student will study: 1. Locomotion and navigation solutions to move across difficult terrains, 2. Multisensory solutions for localisation and mapping, 3. Coordination and supervision policies for multi-agent operations with specific regard on data collection missions mandated by government institutions, 4. Human robot collaboration for the execution of shared tasks.

To fulfil the ambitious goals of the agenda, the student will exploit the vast body of prior research developed in the UNITN group on localisation [1], multiagent navigation [2], motion

planning [3], human robot interaction [4,5] and planning and scheduling [6].

References:

[1] Shamsfakhr, F., Antonucci, A., Palopoli, L., Macii, D. and Fontanelli, D., 2022. Indoor Localisation Uncertainty Control based on Wireless Ranging for Robots Path Planning. IEEE Transactions on Instrumentation and Measurement.
[2] Boldrer, M., Bevilacqua, P., Palopoli, L. and Fontanelli, D., 2021. Graph Connectivity Control of a Mobile Robot Network With Mixed Dynamic Multi-Tasks. IEEE Robotics and Automation Letters, 6(2), pp.1934-1941.
[3] Bevilacqua, P., Frego, M., Fontanelli, D. and Palopoli, L., 2018. Reactive planning for assistive robots. IEEE Robotics and Automation Letters, 3(2), pp.1276-1283.
[4] Boldrer, M., Antonucci, A., Bevilacqua, P., Palopoli, L. and Fontanelli, D., 2022. Multi-agent navigation in human-shared environments: A safe and socially-aware approach. Robotics and Autonomous Systems, 149, p.103979.
[5] Antonucci, A., Papini, G.P.R., Bevilacqua, P., Palopoli, L. and Fontanelli, D., 2021. Efficient Prediction of Human Motion for Real-Time Robotics Applications With Physics-Inspired Neural Networks. IEEE Access, 10, pp.144-157.
[6] Andrea Traldi, Francesco Bruschetti, Marco Robol, Marco Roveri, Paolo Giorgini: Real-Time BDI Agents: a model and its implementation. CoRR abs/2205.00979 (2022)

Number of positions available:

1

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Funding Scheme: This doctorate grant is co-funded by the proponent research institutions and by the Italian Ministry of Research, under law D.M. 351/2022 (PA)