Position: **Doctoral Candidate #6 (DC 6)**
Project: **Network architecture for transfer learning of local properties to a large map for adaptation of robot behaviour**
Host Institution: INRAE TSCF unit - France
PhD programme: PhD doctoral school engineering science (SPI) at the Clermont-Auvergne University

Research project description

Real time environmental adaption of agricultural robots using a unified world representation based on landscape-scale data fusion

Agricultural robotics is central to the shift toward precision farming, which focuses on sustainable, efficient practices [1, 2]. These robots can reduce the environmental impact of farming, enhancing both productivity and conservation. However, they face significant challenges when deployed in dynamic, unstructured environments, including variable terrain, changing weather, and the need for real-time adaptability. As agricultural robots must operate in diverse and complex field conditions, it is crucial to integrate data from both local and landscape-scale sources to guide navigation and task execution.

The key challenge is improving robots' ability to navigate and adapt to varied terrains, considering factors such as soil moisture, traction conditions, and topography. This proposal focuses on the fusion of local data—acquired from on-board sensors—and landscape-scale environmental data from UAVs, satellites, and weather stations. By combining these data sources, robots can develop a comprehensive understanding of their environment, which enhances task accuracy and decision-making in autonomous agricultural operations.

The research will develop a framework for integrating multi-modal sensor data from various sources. Drones and satellites provide aerial perspectives [3, 4], while ground-based sensors capture localized environmental conditions such as soil moisture and temperature. These data will be combined into semantic maps that classify different areas of the field, allowing robots to make informed decisions about task planning and adaptation. The robot will use this information to navigate, managing obstacles and assess the suitability of the environment for specific tasks, ensuring safe and efficient execution.

In addition, the thesis will address the integration of landscape-scale data, such as weather forecasts [5] and topographic maps, to complement the local data from the robot. The objective is to allow robots adapting in real time to environmental changes, adjusting navigation parameters or control algorithms accordingly. For example, a robot might alter its path or delay an operation if soil moisture is too high, preventing potential damage to crops or equipment. A core challenge of this research is the development of machine learning models that can effectively process and integrate data from these diverse sensor systems. Deep Learning techniques will be explored to handle the spatial, spectral, and temporal dimensions of the data.

Finally, the effectiveness of this multi-sensor framework will be validated through experimental field trials. These tests will evaluate how well robots can navigate, plan tasks, and adapt to environmental changes in real-world agricultural settings and tasks to be achieved. By integrating both local and landscape-scale data, the robots will demonstrate enhanced autonomy and decision-making capabilities, facilitating the transition to a more sustainable and data-driven farming model.

Objectives:

Data Type Selection for Agricultural Tasks

The first step in creating integrated maps is to identify the types of data relevant to agricultural tasks. This includes visual data such as RGB and multispectral images, structural data from LiDAR-generated 3D models, and thermal data. Soil parameters from ground sensors, including moisture and temperature, are also crucial. Additionally, topographic information, typically from digital elevation models (DEMs), helps to understand terrain features. Weather data, such as temperature, rainfall, and wind forecasts, plays a critical role in predicting field conditions, thus influencing the planning and execution of agricultural tasks. This stage will assess the suitability of these data types for the experimental validation of agricultural tasks.

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Multi-Source Data Acquisition and Synchronization

Data acquisition is the process of gathering information from various sources to ensure comprehensive spatial and temporal coverage [6]. Ground robots collect high-resolution, localized data through sensors like LiDAR and cameras, while drones capture field-wide imaging at regular intervals. Satellites, including those from the Copernicus and Sentinel programs, offer regional-scale imagery and environmental data [7]. Weather data is sourced from external APIs, providing real-time updates on field conditions. Synchronizing these different data sources through automated pipelines is essential, with georeferencing and calibration steps ensuring the data's accuracy for integration and use in subsequent analysis.

Developing a Unified Sensor Fusion Framework

This objective focuses on developing algorithms and software to combine various data sources into a unified framework for agricultural task planning. Deep Learning techniques will be employed for sensor fusion, allowing the integration of data from different modalities such as visual, LiDAR, and thermal [8]. Fusion strategies will include Early Fusion (feature-level integration), Late Fusion (decision-level integration), and Hybrid Fusion, which combines aspects of both approaches [9]. A key challenge is balancing the quality of data fusion with computational efficiency, especially when handling large datasets in real-time.

Environmental Ontology Development for Task Automation

Ontology creation is aimed at defining relationships between elements in the agricultural environment, such as crops, weeds, and soil conditions. This structured representation will guide robot behaviors, linking specific environmental factors to automated actions. For instance, detecting weeds could trigger a weeding implement, or identifying wet soil might delay an operation to avoid damage. This action aims to create a comprehensive environmental model that informs robotic decision-making and enhances task efficiency. By leveraging this ontology, robots will be able to make more informed decisions based on the specific context of their environment.

Semantic Mapping for Context-Aware Task Planning

Semantic maps categorize environmental elements into meaningful classes, enhancing the robot's understanding of the field [10]. This objective involves developing algorithms for automatically generating these maps, utilizing machine learning and computer vision techniques. The semantic maps will then be used for task planning, such as determining optimal paths for operations like spraying, seeding, or weeding. The task planning algorithms will prioritize areas that need immediate attention, such as those with high weed density, while avoiding obstacles.

Real-Time Dynamic Adaptation

In agricultural robotics, offline data are often inadequate for managing the dynamic nature of farming environments. This objective involves integrating systems that allow for using real-time data from robot sensors and environmental monitoring systems. Models will be developed to adapt to changes such as new obstacles, varying soil conditions, or crop growth stages. The real-time data will enable robots to maintain accurate environmental representations, supporting real-time navigation and decision-making. This is crucial for enabling autonomous robots to adjust their operations in response to environmental shifts during task execution.

Adaptation of Control Parameters for Task Optimization

In agricultural tasks, real-time adaptation of control parameters is essential for ensuring safe and efficient task execution. This objective focuses on developing systems that allow robots to adjust variables like trajectory, speed, or tool configurations based on the semantic map and real-time environmental data. For example, when encountering soft soil, a robot might reduce speed and modify its path to maintain stability. Such adaptive behaviors are critical in ensuring optimal performance in varying field conditions. The system will be experimentally validated during real agricultural tasks to ensure that it functions effectively in real-world scenarios, optimizing performance and safety.

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Expected Results

- Identify and evaluate the types of data required for safe and efficient planning of agricultural robotics tasks.
- Design and implement a framework for data fusion, using Deep Learning techniques to combine various data modalities, including onboard sensors and landscape-level information.
- Build dynamic mapping systems capable of adapting in real-time to environmental changes, providing the robot with up-to-date terrain and environmental information.
- Create an ontology to define environmental relationships.
- Validate the proposed frameworks and algorithms through real-world experimental trials in diverse agricultural settings.
- Publish results in international conferences and high-impact journals, contributing to the field of agricultural robotics and multi-sensor data fusion.

Keywords: ***agricultural robotics; multi-sensor fusion; deep learning; robot perception; task planning; adaptive control.***

References

[1] Lenain, Roland, et al. Agricultural robotics: part of the new deal?: FIRA 2020 conclusions. éditions Quae, 2021.
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[5] Heron, Sam, Frédéric Labrosse, and Patricia Shaw. "Utilising Weather and Terrain Data to Improve Autonomous Navigation." UKRAS22 Conference "Robotics for Unconstrained Environments" Proceedings. UK-RAS Network, 2022.
[6] Ghamisi, Pedram, et al. "Multisource and multitemporal data fusion in remote sensing: A comprehensive review of the state of the art." *IEEE Geoscience and Remote Sensing Magazine* 7.1 (2019): 6-39.
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[8] Pawłowski, Maciej, Anna Wróblewska, and Sylwia Sysko-Romańczuk. "Effective techniques for multimodal data fusion: A comparative analysis." *Sensors* 23.5 (2023): 2381.
[9] Tang, Qin, Jing Liang, and Fangqi Zhu. "A comparative review on multi-modal sensors fusion based on deep learning." *Signal Processing* (2023): 109165.
[10] 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.

Secondments

The secondments planned for this research project are at:

- IPC-ESAC (in Portugal): dataset collection and trials/validation on real agricultural conditions (Living Lab)
- Critical Software S.A. (in Portugal): investigation of transfer learning and large-scale map processing; evaluation on changing terrain maps.

Desirable skills, qualifications and specific requirements

- Your application should respect the AIGreenBots general requirements and eligibility criteria. These include that the candidate must not have resided or carried out his/her main activity (work, studies, etc.) in France for more than twelve months in the three years immediately prior to the call deadline.
- You should have a MEng/MSc degree, or equivalent, in computer science, robotics, mathematics, physics, or related fields.
- Strong programming skills (preferably in Python).
- Some practical experience on robotics and machine learning.
- Proficiency in the English language, as well as good communication skills, both oral and written.
- Motivation, sense of responsibility, autonomy and problem-solving skills are highly desirable.

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Benefits

- Competitive salary - living allowance (gross - "salaire brut"): approximately 34 000 €/year.
- Mobility allowance (gross, if applicable): 427 €/month.
- Family allowance (gross, if applicable): 469 €/month.
- Research, training and networking costs covered: Registration and attendance at international conferences.

How to apply

Please send the following documents to Dr. Riccardo Bertoglio by email at riccardo.bertoglio@inrae.fr:

- A detailed CV (including your publications and/or projects with links to online material like public repositories, articles, etc.).
- A cover letter explaining your interest in the project and your relevant skills.
- Academic transcripts.
- Any other relevant documents (Master's thesis, portfolio, etc.).

Deadline: 15 March 2025, 23:59 Central European Time.

Additional information

Supervisors of this PhD project: Dr. Lenain Roland, Bertoglio Riccardo, Laconte Johann.

Location: INRAE TSCF unit, Clermont-Ferrand (France).

Host institution and living conditions: INRAE is one of the most prestigious research institutions in the world, focusing on agronomy, agriculture, and the environment. The institute employs 10,000 people and operates across France. The TSCF unit at INRAE is dedicated to developing new technologies for agriculture, with a particular focus on agricultural and environmental robotics. Located in Clermont-Ferrand, in central France, this unit consists of 35 permanent researchers and is equipped with facilities for developing mobile robots, especially for off-road applications. The unit has a fleet of eight robots, equipped with sensors, designed for various purposes and ranging in size from 10 kg to 6 tons. These robots feature either skid-steering or Ackermann steering configurations. The laboratory also has 80 hectares of experimental fields, along with facilities for assessing robot efficiency. For the past 15 years, the TSCF team has been actively working on robotics for agriculture, developing numerous algorithms to control robots in dynamic and changing environments. Their work includes applications such as trajectory following, pedestrian tracking, and edge following.

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