POLITECNICO DI MILANO

PhD in MODELLI E METODI MATEMATICI PER L'INGEGNERIA / MATHEMATICAL MODELS AND METHODS IN ENGINEERING - 40th cycle

INTERDISCIPLINARY Research Field: MATHEMATICAL MODELS AND DATA INTEGRATION FOR THE DEVELOPMENT OF A VERTICAL FARMING SYSTEM DIGITAL TWIN

Monthly net income of PhDscholarship (max 36 months)
€ 1400.0 In case of a change of the welfare rates during the three-year period, the amount could be modified.

Context of the research activity	
Motivation and objectives of the research in this field	Interdisciplinary PhD Grant The PhD research will be carried out in collaboration with research groups of the PhD programme in "**INFORMATION TECHNOLOGY**". See https://www.dottorato.polimi.it/?id=422&L=1 for further information. The agricultural sector faces increasing challenges due to demographic shifts, environmental issues, and economic changes, necessitating the adoption of innovative practices to enhance efficiency, sustainability, and resilience. Climate-Smart Agriculture (CSA) refers to an approach aimed at transforming and reorienting agricultural systems to effectively support food security under the new realities of climate change. Among the techniques of CSA we have Controlled Environment Agriculture (CEA) and in particular vertical farming (VF). VF not only reduces the amount of land space needed, but enables year-round cultivation to take place, providing a sustainable and efficient method for cultivating crops in vertically stacked layers. VF offers a promising solution to the global challenge of food scarcity, by maximizing yield in limited space; the plant development is optimized through a precise control of the environmental factors throughout the entire growth cycle: • lighting: CEA systems employ LED lighting that can be adjusted in terms of intensity and spectrum to meet

	specific plant requirements and optimize the photosynthetic process; • temperature: CEA systems foster ideal metabolic rates and growth conditions by maintaining optimal temperature ranges tailored to each cultivation; • humidity and CO2: a fine-tuning of the humidity levels prevent plant stress, optimizes transpiration rates, and enhances nutrient uptake; • air flow: an optimal control of air flow prevents microclimate variations and facilitates transpiration crucial for nutrient uptake and plant cooling to prevent heat stress. This research intends to tackle some of the challenges described above by developing a *crop digital twin*, i.e., a digital counterpart of a real-life object that mirrors its behavior and state over its lifetime in a virtual space, aimed at design optimized growth control strategies. Reaching this objective entails blending numerical modeling to construct a 3D virtual model of plant behavior with field data collected via direct observations/measurements on-site. We aim to enhance such digital twin incorporating data provided by advanced tools like multispectral or hyperspectral cameras. Indeed, such devices augment the digital view of crops beyond the visible spectrum, allowing the early detection of critical factors and possible stress. Advanced machine learning (ML) and data analysis methods are envisioned as the ideal means for this enhancement.
Methods and techniques that will be developed and used to carry out the research	Creating a digital twin model for vertical farming requires a combination of highly diverse skills.This involves formalizing complex models of physical and biological processes, supplemented by data extracted through computer vision and deep learning techniques. Specifically, the project aims to undertake the following two distinct tasks: **1.** Accurate modeling of canopy behavior in 3D: the aim is to develop a 3D model which includes the crop's response to the competition among individuals and space availability, as well as variety-specific

	morphological features. This will allow the analysis of how plant structure's impact on photosynthetic efficiency, crucial for optimizing crop density conditions and spatial distribution. The goal involves several steps, including inferring the 3D canopy structure from 2D RGB images using recent advancements in machine learning, converting this structured data into 3D point clouds, and employing these point clouds to create detailed and dynamic representations of individual plant and crop models using Gaussian splatting techniques [1]. **2.** Quality analysis via hyperspectral images:hyperspectral sensing methods provide a non-invasive approach for assessing plant biochemical and morphological characteristics in agriculture. The goal is to exploit hyperspectral imaging to evaluate and compare the insights provided by conventional vegetation indices [2] (e.g., the Normalized Difference Vegetation Index (NDVI) or the Photochemical Reflectance Index (PRI)) with those derived from custom-built models using ML/DL methods. The main emphasis will be on enhancing biophysical-based crop growth models to determine the optimal lighting conditions throughout the growth cycle, with the goal of maximizing yield as well as improving plant quality and extending shelf life. [1] B. Kerbl, G. Kopanas, T. Leimkühler, G. Drettakis. 3D Gaussian Splatting for Real-Time Radiance Field Rendering" Proceedings SIGGRAPH 2023 (ACM Transactions on Graphics). [2] https://metergroup.com/education-guides/ndvi-and-pri-the-researchers-complete-guide/
Educational objectives	This research project offers the candidate a comprehensive educational experience by exploring the entire pipeline from theory to practice. The key benefits in terms of educational objectives include: · **Holistic understanding:** the candidate will blend numerical modeling with practical field data, constructing

	a 3D virtual model of plant behavior. This integration provides a deep understanding of the theoretical and practical aspects of the research. · **Interdisciplinary collaboration:** the project involves collaboration between the Department of Mathematics, the Department of Electronics, Informatics and Bioengineering and the Department of Mechanical Engineering, promoting interdisciplinary learning and teamwork. · **Hands-on experience:** access to the vertical farming lab prototype, part of the PNRR Agritech-Spoke 3 activities, will provide the candidate with practical, hands-on experience using a wide range of sensor and hyperspectral data. · **Innovation and problem-solving:** working in the state-of-the-art vertical farming lab will help the candidate develop innovative problem-solving skills and adapt to emerging technologies in agriculture. · **Professional networking:** the collaborative nature of the project will allows the candidate to build a network with professionals and researchers across different departments, enhancing their professional growth and opportunities. Overall, this project aims to equip the candidate with a robust problem-solving capacity, balancing theoretical rigor and practical experience, and preparing them for a successful career in both academic and industrial environments.
Job opportunities	The interdisciplinarity of this research project will help the candidate acquire a problem-solving capacity, balancing theoretical rigor and practical experience, rendering them ready for a “forma mentis” typical of an industrial environment.
Composition of the research group	2 Full Professors 0 Associated Professors 1 Assistant Professors 2 PhD Students
Name of the research directors	Prof. Simona Perotto, Prof. Matteo Matteucci

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Additional support - Financial aid per PhD student per year (gross amount)	
Housing - Foreign Students	--
Housing - Out-of-town residents (more than 80Km out of Milano)	--

Scholarship Increase for a period abroad	
Amount monthly	700.0 €
By number of months	6

Additional information: educational activity, teaching assistantship, computer availability, desk availability, any other information
Educational activities (purchase of study books and material, funding for participation to courses, summer schools, workshops and conferences): financial aid per PhD student per year 1st year: max 1.902,40 euros 2nd year: max 1.902,40 euros 3rd year: max 1.902,40 euros The PhD students are encouraged to take part in activities related to teaching, within the limits allowed by the regulations.1 individual PC per student +several shared PC. Access to one cluster with 32 processors and 384 GB RAM, and to several multi - processor servers.