POLITECNICO DI MILANO

PhD in INGEGNERIA MECCANICA / MECHANICAL ENGINEERING - 41st cycle

THEMATIC Research Field: OPTIMAL CONTROL OF INTERACTING SWARMS UNDER PARTIAL OBSERVABILITY AND ENVIRONMENTAL COUPLING

Monthly net income of PhDscholarship (max 36 months)
1500.0 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	The macroscopic control of large-scale multi-agent systems through density-based models has emerged as a powerful paradigm for coordinating swarms, particularly when individual agent dynamics are either inaccessible or too complex to manage at scale. Building on this perspective, recent work has demonstrated that optimal transport theory, coupled with advection-diffusion PDE models, provides a rigorous and scalable framework for designing open-loop control strategies capable of steering agent densities toward desired spatial distributions. However, several critical limitations still constrain the practical deployment of these approaches in real-world scenarios.A fundamental challenge lies in the reliance on full knowledge of the initial and current agent density across the domain. In realistic applications - such as environmental monitoring, or crowd management - such information is typically unavailable due to sparse sensing, occlusions, and measurement noise. Furthermore, the control strategies developed so far operate largely in an open-loop setting, with control fields computed offline and without mechanisms to adapt to deviations, disturbances, or unforeseen events. This lack of feedback reduces the robustness of the control system and its ability to cope with uncertainty. Another major limitation is the limited consideration of dynamic coupling between the swarm and its environment.
Methods and techniques that will be	The proposed research will adopt a multi-level

developed and used to carry out the research	The proposed research will adopt a multi-level methodological framework that combines analytical tools from control theory and partial differential equations with modern computational and learning-based techniques. The methodological approach will be structured around three tightly coupled pillars: the development of feedback control strategies under partial observability, the modeling and control of coupled swarm–environment systems, and the use of surrogate models to enable real-time control. Each component will be addressed with a blend of theoretical analysis and numerical implementation.Validation will be pursued through the implementation of selected scenarios in high-fidelity simulation environments. Where feasible, the research will also seek collaboration with experimental partners to test specific methods on physical platforms.
Educational objectives	The proposed PhD program is designed to provide the candidate with a comprehensive and rigorous education in the theory, methods, and applications of control of distributed systems, with a specific focus on macroscopic modeling and optimal control of multi-agent systems. Over the course of the project, the candidate will develop a solid foundation in advanced mathematical modeling, control theory, optimization, and numerical methods for partial differential equations.The PhD program aims to strengthen the candidate’s scientific communication and research skills. This includes the preparation of peer-reviewed publications, participation in international conferences, and collaboration with academic and possibly industrial partners. Upon completion of the PhD, the candidate will be well prepared for academic or research-oriented careers in applied mathematics, control systems, or computational science.
Job opportunities	Upon completion of the PhD, the candidate will be well positioned for research and development roles in academia, research institutes, and the advanced industry. Potential career paths include postdoctoral research, control system design for autonomous vehicles or drones, and algorithm development for intelligent swarm coordination. The candidate’s expertise in PDE-

	constrained optimization, feedback control, and machine learning for dynamical systems will be highly valuable in sectors such as environmental monitoring, and smart infrastructure. Additionally, the interdisciplinary training will open opportunities in high-tech companies focused on AI-driven control systems, simulation technologies, and real-time decision-making under uncertainty.
Composition of the research group	0 Full Professors 2 Associated Professors 0 Assistant Professors 1 PhD Students
Name of the research directors	Prof. Gabriele Cazzulani, Prof. Andrea Manzoni

Contacts
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Additional support - Financial aid per PhD student per year (gross amount)	
Housing - Foreign Students	--
Housing - Out-of-town residents	--

Scholarship Increase for a period abroad	
Amount monthly	750.0 €
By number of months	6

Additional information: educational activity, teaching assistantship, computer availability, desk availability, any other information
Financial aid is available for all PhD candidates (purchase of study books and materials, funding for participation in courses, summer schools, workshops and conferences) for a total amount of € 6.114,50. Our candidates are strongly encouraged to spend a research period abroad, joining high-level research groups in the specific PhD research topic, selected in agreement with the Supervisor. An increase in the scholarship will be applied for periods up to 6 months (approx. 750 euro/month - net amount). Teaching assistantship: availability of funding in recognition of supporting teaching activities by the PhD candidate. There are various forms of financial aid for activities of support to the teaching practice. The PhD student is encouraged to take part in these activities, within the limits allowed by the regulations.