Politecnico di Torino

MECHANICAL ENGINEERING

CRT/DIMEAS - AI-based Task Planning and Motion Control for User-Specific Human–Machine Physical Interaction

Funded By	Dipartimento DIMEAS FONDAZIONE CRT CASSA DI RISPARMIO DI TORINO [P.iva/CF:06655250014]

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Context of the research activity	Human–machine physical interaction (HMPI) plays a key role in fields such as collaborative and service robotics, wearable systems, rehabilitation, and human assistance. In these domains, humans and machines act as an integrated system, exchanging forces, motions, and intentions. Ensuring safe, efficient, and intuitive cooperation requires adaptive control and planning strategies capable of handling human variability and dynamic conditions. This research aims to integrate AI-based tools for modelling human behaviour, predicting intent, and optimizing task planning and motion control to enable personalized, intelligent, and seamless physical interaction between humans and machines.

	The physical interaction between humans and machines is a common and crucial condition encountered in several application domains, such as collaborative and cooperative industrial robotics, wearable robotics, service robotics, motor rehabilitation, biomechanical assistance, and even sports applications. In these contexts, humans and machines must operate as an integrated system, continuously exchanging actions, forces, and motion information. Depending on the task and the operational conditions, the roles of the human and the machine can dynamically alternate between those of master and slave, or merge into a shared control paradigm. Effective human–machine physical interaction (HMPI) requires systems capable of understanding human intent, adapting to individual user characteristics, and responding safely and efficiently to variable dynamics. Traditional control strategies, often based on rigid models and predefined trajectories, struggle to manage the uncertainties and nonlinearities inherent in human behaviour. Consequently, recent research has increasingly focused on integrating artificial intelligence and learning-based approaches to enhance adaptability and personalization in task planning and motion control. By enabling machines to perceive, predict, and adapt to human actions in real time, AI-driven HMPI systems promise to improve not only performance and safety but also comfort and user experience. This interdisciplinary

Objectives	research area bridges robotics, control theory, biomechanics, and machine learning, paving the way for next-generation intelligent systems that can physically collaborate with humans in a natural and intuitive manner. The main objectives of the PhD program, not necessarily following a strict chronological order, are outlined as follows: • Acquisition of background knowledge on human–machine physical interaction in various domains, including industrial collaborative and cooperative robotics, service and wearable robotics, rehabilitation, and human care applications. • Acquisition of background knowledge on generative AI methodologies for trajectory planning and motion control in robotic and mechatronic systems. • Acquisition of background knowledge on AI-based methodologies for human motion analysis, perception, and understanding. • Comprehensive literature review on physically interactive human–machine systems and on digital twinning methodologies for dynamic modelling and simulation. • Literature review on human posture and gesture control during physical interaction with machines, with a focus on related modelling and estimation approaches. • Implementation of high-fidelity simulation toolchains for multibody modelling of robotic systems (e.g., collaborative robots, wearable robots) and human body biomechanics. • Development of an integrated simulation environment for dynamic analysis of human–machine interaction as a whole multibody system, where active actuators, smart sensors, machine structures, and human body segments and articulations are modelled in a single closed loop. • Design and development of AI-based trajectory and task planning algorithms for autonomous and cooperative machine control. • Design of AI-based algorithms for modelling human gestures and behaviours in selected case studies. • Development and evaluation of human behavioural models, assessing their effects on system dynamics during representative human–machine interaction scenarios. • Design and implementation of system-in-the-loop and human-in-the-loop frameworks for experimental testing and validation in laboratory environments. • Experimental setup and testing to measure human–machine physical interaction under realistic working conditions and to assess the performance of developed AI algorithms. • Preparation and submission of high-quality review papers on the state of the art in AI-based human–machine physical interaction, and of journal and conference papers reporting ongoing research results throughout the three-year program. • Writing and submission of the final PhD thesis. During the PhD project, at least 6 months will be spent at another company or academic institution, based on joined research agreements involving the PhD program.

Skills and	The ideal candidate should possess: • A solid academic background with an MSc degree in Mechanical Engineering and/or Biomechanics. • Competence in numerical modelling and simulation tools for mechatronic and multibody systems. • Experience with model-based control techniques and related control

competencies for the development of the activity	architectures. • Experience in human body modelling and analysis of biomechanical systems. • Hands-on experience in experimental testing and validation of electro-mechanical systems. In addition, the candidate should demonstrate strong teamworking skills, problem-solving abilities, and an aptitude for working effectively within a multidisciplinary research environment.