Offre n°2025-09114

PhD Position F/M PhD on Modular Model Predictive Control Architecture for Human-Robot Collaboration

Le descriptif de l’offre ci-dessous est en Anglais

Type de contrat : CDD

Niveau de diplôme exigé : Bac + 5 ou équivalent

Fonction : Doctorant

Niveau d'expérience souhaité : Jeune diplômé

A propos du centre ou de la direction fonctionnelle

The Inria center at the University of Bordeaux is one of the nine Inria centers in France and has about twenty research teams.. The Inria centre is a major and recognized player in the field of digital sciences. It is at the heart of a rich R&D and innovation ecosystem: highly innovative SMEs, large industrial groups, competitiveness clusters, research and higher education players, laboratories of excellence, technological research institute...

Contexte et atouts du poste

This PhD thesis will take place within the Auctus team at the Inria center at the University of Bordeaux.

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The Auctus team is composed of ?20 people (5 permanent researchers, 1 permanent research engineer, 4 postdocs, 4 engineers, 4 PhD students, 3 interns currently) whose core expertise ranges from robotics to cognitive sciences including biomechanics and numerical constrained optimization. This research team aims to meet the challenges of collaborative robotics for humans at work. The team’s research is divided into three scientific areas: 1) analysis and modeling of human behaviors (both from biomechanical and cognitive perspectives); 2) human-robot interaction, coupling and mediation; 3) design and control of cobotic systems. The team also has a strong background in experimental robotics which is a key ingredient to the scientific validation of robotic control concepts developed to tackle dynamic contexts, especially when humans are implied. This PhD thesis will mostly contribute to develop a novel control architecture (axis 3) but will benefit both from axes 1 and 2, considering factors influencing human motion as well as human-robot interaction modalities. Beyond the available hardware (3 Kuka IIWA, 1 Franka Panda, 1 Flexiv Rizon10s, multi-cameras Optitrack motion capture system, 1 6-Dof Omega Haptic interface from ForceDimension, 1 Hololens, 2 6-axis FT sensors, several tactile sensors …) and software resources of the team's experimental platform, the recruited PhD candidate will be benefit from the research network of the team at the regional (R4 research network, Rhoban team, ROBIOSS@Pprime), national (GDR Robtotique, ISIR, LAAS, INRS, Onera DTIS, CEA LIST, Rainbow@Inria, Hucebot@Inria, Combo@Inria, Willow@Inria, Camin@Inria,…) and international (NYU, Stanford, KAIST, IIT, TU Eindhoven, TU Munich,…) levels. Finally the PhD thesis will also benefit from the scientific context and collaborations within the COURRIER ANR project which aims at studying the role of intention signals sent by the robot in human-robot collaboration. The control framework proposed in this PhD thesis will contribute to provide the project with a generic and open control architecture dedicated to Human-Robot collaboration.

The recruited candidate will be co-advised by:

- Vincent Padois, senior research scientist at Inria, whose core scientific expertise focuses on robot control, especially in the collaborative context;
- Sébastien Kleff, postdoctoral scholar at Inria, whose core scientifc expertise lies in Model Predictive Control for robots in physical interaction.

Mission confiée

While the first industrial robots were conceived to relieve humans from strenuous and hazardous tasks, robots are now primarily seen as a means to enhance productivity - both in mass production environments and in settings that demand industrial agility. Nevertheless, humans remain, for both organizational and societal reasons, the cornerstone of industry at large. Fully replacing them is still far from being technically feasible - despite the media hype following recent advancements in artificial intelligence - and remains highly debatable from a societal model perspective. It is therefore of paramount importance to continue improving workers' health and working conditions. This is not only an ethical imperative but also an economic necessity [1], particularly in the context of a rapidly aging European workforce.

The growing ability of robots to produce both advanced motion and complex physical interaction - enabled by progress in actuation and sensing - makes them increasingly attractive as assistive systems. Yet, their capacity to effectively support humans in physically demanding tasks necessitates close human–robot collaboration (HRC), which raises several challenges. In particular, effective assistance requires the robot to adapt its behavior to the dynamic context of collaboration, such as human movement or environmental changes. Pre-planned motions or finely tuned controllers tailored to specific use-cases often lead to impasses. Recently, however, modern control techniques based on numerical optimization - such as nonlinear Model Predictive Control (MPC) [2] - have demonstrated strong potential for automating the synthesis and online execution of complex motions.

Nonetheless, applying these techniques in the context of human–robot collaboration poses several fundamental scientific challenges, particularly concerning the robot's ability to adapt and act autonomously. These challenges are closely linked to the need for systematically incorporating predictions of human and environmental motion into the control process. This is all the more complex given the stochastic nature of these motions. Overall, the central question tackled by this PhD thesis is the following: which, generic enough, control architecture would allow to handle uncertain robotic scenarios, both ensuring optimal control decision and reactivity to the environment dynamics while ensuring the respect of intrinsic and extrinsic safety constraints?

The proposed PhD thesis aims at addressing this issue through a modular control architecture centered on MPC. It is hypothesized that such an architecture is essential for equipping assistive robots with a general control framework capable of producing reactive yet optimal control decisions in uncertain environments.

Indeed, MPC and more particularly nonlinear MPC has shown great successes in synthesizing online complex motions on various robots ranging from industrial manipulators [3, 4] to quadrupeds [5, 6, 7] and humanoids [8, 9, 10]. The main advantage of MPC lies in its ability to re-optimize on the fly the robot's trajectories based on a predictive model and physical constraints. However constructing accurate predictive models of the human and the shared environment is notoriously difficult [11, 12, 13].

Concurrently, learning methods (reinforcement learning [14], learning from demonstration [15]) have led to remarkable results on real hardware thanks to their ability to learn control policies mapping high-dimensional observations to low level robot actions [16] or latent representations [17] (e.g. human model). While they allow to push robots robustly to their performance limits in complex tasks, learned policies are often task-specific and lack generalization: transferring them across different tasks (e.g. to new control objectives or physical settings) is not trivial and usually requires to re-train from scratch. Lastly, they do not naturally allow to specify operating constraints, which is critical in HRC.

In face of these challenges, we propose to investigate scenario MPC [18, 19] which extends classical MPC by planning trajectories over a set of possible future evolutions or scenarios arising from discrete or continuous uncertainty distributions. By considering structured hypotheses about the future, scenario MPC (s-MPC) may provide the robustness and flexibility required for HRC applications where, for example, the multimodality and the stochasticity of human motion prediction models needs to be accounted for. Specifically, s-MPC is expected to improve the robustness in face of uncertain human behavior and environmental changes while maintaining the advantages of MPC (online re-planning, constraint satisfaction, and interpretability).

In such a framework, higher-level semantic planning can feed s-MPC with a list of, context dependent, desirable control objectives. Given these objectives, s-MPC replans online with robustness and safety guarantees the robot control action. This control action accounts both for stochastic prediction models related to the environment dynamics (including the human) and sensor feedback allowing to update these models (e.g. through estimation). Hence the proposed architecture could directly address the shortcomings of modern ”end-to-end” policy learning by preserving model-based optimization as a central component, while allowing the use of data-driven human models.

The PhD work will start with a review of the literature in different related domains. In order to position the work in the large perspective of robot control, the candidate will focus on reviewing existing control architectures aiming at handling dynamic and constrained robotic contexts where the ability to compute the robot control input in a online fashion so as to robustly accommodate uncertain environment dynamics is central. The focus of this review of the literature will also be placed on nonlinear model predictive control approaches on the one hand and on scenario-based MPC on the other hand as they provide the cornerstone of the envisioned control approach.

Given this review of the literature, an initial version of the overall architecture including high-level task planning, low level control, perception processing, uncertain prediction models and scenario-based MPC will be delineated.

Given this architecture, the PhD work will consist in formulating the MPC problem considering, as generically as possible, the connections with its different constitutive blocks (propagation of task objectives, constraints, sensor feedback, etc.). Attention will be paid to the optimization problem’s structure in order to benefit from the framework of scenario-based MPC while maintaining a computational complexity compatible with real-time control [20].

The architecture will be instantiated and experimentally tested on a collaborative sorting task, in which a human operator and the robot must pick and place objects from a shared tray.

[1] J. de Kok, P. Vroonhof, J. Snijders, G. Roullis, M. Clarke, K. Peereboom, P. van Dorst, and I. Isusi, “Work-related msds: prevalence, costs and demographics in the eu – european risk observatory executive summary,” 2019.

[2] L. Gr¨une, J. Pannek, L. Gr¨une, and J. Pannek, Nonlinear model predictive control. Springer, 2017.

[3] S. Kleff, A. Meduri, R. Budhiraja, N. Mansard, and L. Righetti, “High-frequency nonlinear model predictive control of a manipulator,” in 2021 IEEE International Conference on Robotics and Automation (ICRA), 2021, pp. 7330–7336.

[4] A. Jordana, S. Kleff, A. Meduri, J. Carpentier, N. Mansard, and L. Righetti, “Stagewise implementations of sequential quadratic programming for model-predictive control,” Subm. IEEE TRO, 2023.

[5] M. Neunert, M. St¨auble, M. Giftthaler, C. D. Bellicoso, J. Carius, C. Gehring, M. Hutter, and J. Buchli, “Whole-body nonlinear model predictive control through contacts for quadrupeds,” IEEE Robotics and Automation Letters, vol. 3, no. 3, pp. 1458–1465, 2018.

[6] J.-P. Sleiman, F. Farshidian, M. V. Minniti, and M. Hutter, “A unified mpc framework for whole-body dynamic locomotion and manipulation,” IEEE Robotics and Automation Letters, vol. 6, no. 3, pp. 4688–4695, 2021.

[7] A. Meduri, P. Shah, J. Viereck, M. Khadiv, I. Havoutis, and L. Righetti, “Biconmp: A nonlinear model predictive control framework for whole body motion planning,” IEEE Transactions on Robotics, vol. 39, no. 2, pp. 905–922, 2023.

[8] E. Dantec, M. Naveau, P. Fernbach, N. Villa, G. Saurel, O. Stasse, M. Taix, and N. Mansard, “Whole-body model predictive control for biped locomotion on a torque-controlled humanoid robot,” in 2022 IEEE-RAS 21st International Conference on Humanoid Robots (Humanoids), 2022, pp. 638–644.

[9] I. Dadiotis, A. Laurenzi, and N. Tsagarakis, “Whole-body mpc for highly redundant legged manipulators: Experimental evaluation with a 37 dof dual-arm quadruped,” in 2023 IEEE-RAS 22nd International Conference on Humanoid Robots (Humanoids), 2023, pp. 1–8.

[10] C. Khazoom, S. Hong, M. Chignoli, E. Stanger-Jones, and S. Kim, “Tailoring solution accuracy for fast whole-body model predictive control of legged robots,” IEEE Robotics and Automation Letters, vol. 9, no. 12, pp. 11 074–11 081, 2024.

[11] P. Kratzer, M. Toussaint, and J. Mainprice, “Prediction of human full-body movements with motion optimization and recurrent neural networks,” in 2020 IEEE International Conference on Robotics and Automation (ICRA), 2020, pp. 1792–1798.

[12] Q. Li, Z. Zhang, Y. You, Y. Mu, and C. Feng, “Data driven models for human motion prediction in human-robot collaboration,” IEEE Access, vol. 8, pp. 227 690–227 702, 2020.

[13] L. Vianello, J.-B. Mouret, E. Dalin, A. Aubry, and S. Ivaldi, “Human posture prediction during physical human-robot interaction,” IEEE Robotics and Automation Letters, vol. 6, no. 3, pp. 6046–6053, 2021.

[14] A. Kumar, Z. Fu, D. Pathak, and J. Malik, “Rma: Rapid motor adaptation for legged robots,” arXiv preprint arXiv:2107.04034, 2021.

[15] T. Z. Zhao, V. Kumar, S. Levine, and C. Finn, “Learning fine-grained bimanual manipulation with low-cost hardware,” arXiv preprint arXiv:2304.13705, 2023.

[16] D. Hoeller, N. Rudin, D. Sako, and M. Hutter, “Anymal parkour: Learning agile navigation for quadrupedal robots,” Science Robotics, vol. 9, no. 88, p. eadi7566, 2024.

[17] V. Prasad, D. Koert, R. Stock-Homburg, J. Peters, and G. Chalvatzaki, “Mild: Multimodal interactive latent dynamics for learning human-robot interaction,” in 2022 IEEE-RAS 21st International Conference on Humanoid Robots (Humanoids), 2022, pp. 472–479.

[18] D. Bernardini and A. Bemporad, “Scenario-based model predictive control of stochastic constrained linear systems,” in Proceedings of the 48h IEEE Conference

on Decision and Control (CDC) held jointly with 2009 28th Chinese Control Conference, 2009, pp. 6333–6338.

[19] G. C. Calafiore and L. Fagiano, “Robust model predictive control via scenario optimization,” IEEE Transactions on Automatic Control, vol. 58, no. 1, pp. 219–224, 2013.

[20] D. Kouzoupis, “Structure-exploiting numerical methods for tree-sparse optimal control problems,” Ph.D. dissertation, Albert-Ludwigs-Universit¨at Freiburg im Breisgau, 2019.

Principales activités

- **Literature Review**: Reading and synthesizing academic papers to understand the field.
- **Conducting Research**: Making a scientific proposition, Formulating the corresponding optimal control problem, proposing solvers
- **Validating Research**: Designing experiments, collecting data, analyzing results.
- **Writing**: Producing research papers, thesis chapters, grant proposals.
- **Meetings**: Regularly meeting with advisors, collaborators, and lab groups.
- **Presenting**: Giving talks or posters at conferences, seminars, or workshops.
- **Professional Development**: Attending workshops, learning new tools or methods, networking.

Compétences

From an academic and technical point of view, the candidate should have excellent skills in:

- Robotics;
- Control theory;
- Applied Mathematics (linear algebra, optimization, numerical methods);
- C++ and Python programming;

- A knowledge of the ROS middleware and associated tools can be an asset.
  The candidate is also expected to be:
- rigorous and intellectually honest;
- curious and eager to learn;
- able of strong analytical and abstract thinking;
- independent and well-organized;
- team-oriented with good communication abilites.

Avantages

- Subsidized meals
- Partial reimbursement of public transport costs
- Leave: 7 weeks of annual leave + 10 extra days off due to RTT (statutory reduction in working hours) + possibility of exceptional leave (sick children, moving home, etc.)
- Possibility of partial teleworking and flexible organization of working hours
- Professional equipment available (videoconferencing, loan of computer equipment, etc.)
- Social, cultural and sports events and activities

Rémunération

The monthly salary will be 2200€ in 2025 and 2300€ in 2026 (before social security contributions and monthly witholding tax)

Informations générales

- **Thème/Domaine :** Robotique et environnements intelligents
- **Ville :** Talence
- **Centre Inria :** Centre Inria de l'université de Bordeaux
- **Date de prise de fonction souhaitée :** 2025-10-01
- **Durée de contrat :** 3 ans
- **Date limite pour postuler :** 2025-07-21

Contacts

- **Équipe Inria :** AUCTUS
- **Directeur de thèse :**
  Padois Vincent / vincent.padois@inria.fr

A propos d'Inria

Inria est l’institut national de recherche dédié aux sciences et technologies du numérique. Il emploie 2600 personnes. Ses 215 équipes-projets agiles, en général communes avec des partenaires académiques, impliquent plus de 3900 scientifiques pour relever les défis du numérique, souvent à l'interface d'autres disciplines. L'institut fait appel à de nombreux talents dans plus d'une quarantaine de métiers différents. 900 personnels d'appui à la recherche et à l'innovation contribuent à faire émerger et grandir des projets scientifiques ou entrepreneuriaux qui impactent le monde. Inria travaille avec de nombreuses entreprises et a accompagné la création de plus de 200 start-up. L'institut s'e?orce ainsi de répondre aux enjeux de la transformation numérique de la science, de la société et de l'économie.

Attention: Les candidatures doivent être déposées en ligne sur le site Inria. Le traitement des candidatures adressées par d'autres canaux n'est pas garanti.

Consignes pour postuler

Please apply via the jobs.inria website by sending the following documents:

- cv
- covering letter
- letter of recommendation (if applicable)
- transcripts and rankings of Master's years (or equivalent)

Sécurité défense :
Ce poste est susceptible d'être affecté dans une zone à régime restrictif (ZRR), telle que définie dans le décret n°2011-1425 relatif à la protection du potentiel scientifique et technique de la nation (PPST). L'autorisation d'accès à une zone est délivrée par le chef d'établissement, après avis ministériel favorable, tel que défini dans l'arrêté du 03 juillet 2012, relatif à la PPST. Un avis ministériel défavorable pour un poste affecté dans une ZRR aurait pour conséquence l'annulation du recrutement.

Politique de recrutement :
Dans le cadre de sa politique diversité, tous les postes Inria sont accessibles aux personnes en situation de handicap.