Université de Rennes

Direction de la Recherche et de l'Innovation

Appel à projets - Année 2025

Contrats doctoraux «Ordinaires»

ECOLE DOCTORALE : Matisse **POLE DE RECHERCHE : Mathématiques-Numérique**

Unité de recherche d'accueil

Unité de Recherche : IRISA

Equipe : TARAN

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Sujet

Titre : **Hardware Accelerations for Unmanned Aerial Vehicle Control Algorithms**

Mots clés : Hardware Acceleration, Hardware Architecture, Robotics, UAVs, Drones

Cotutelle internationale (oui/non) : non **Si oui, préciser l'établissement et le pays de rattachement** :

Descriptif (15-30 lignes) :
Contexte socioéconomique et scientifique ; Les hypothèses et questions posées ; Les grandes étapes de la thèse et démarche ; Approches méthodologiques et techniques envisagées

Robots are physical agents that interact with their physical environment. Accordingly, their sensorimotor capabilities are essential and largely determine the activities that robots can perform. In recent years, great progress has been made in sensory capabilities thanks to significant advances in machine learning and dedicated hardware. In contrast, much less progress has been made in motor skills. Examples of promising approaches in the current scientific literature are Model Predictive Control (MPC) [1] and Model Predictive Path Integral (MPPI) control [2], where control actions are optimized over a finite time horizon, considering the time evolution of robot dynamics to optimize a given cost or reward function that describes the robot motion. Such algorithms are particularly suited for **optimizing control trajectories and planning horizons in real time** due to their ability to handle dynamic environments.
From a control perspective, **planning a horizon that is as long as possible** to manage complex trajectories while considering the environment is essential. Additionally, maintaining **a high control frequency** is crucial to meet the **real-time** demands imposed by real-world physics and, if necessary, to adjust the sequence of movements. In the **resource-constrained context of small-scale UAVs**, such control algorithms are crucial as they enable **optimal trajectory generation and real-time decision-making** in complex, dynamic, and uncertain environments. However, particularly for **battery-powered UAVs**, achieving a high control frequency while planning for a long horizon is difficult due to limited computational power and energy constraints [3], and conventional GPU acceleration often requires excessive energy consumption.
In recent years, **hardware acceleration** [4] has become increasingly popular, using **dedicated platforms** such as **FPGAs** (Field Programmable Gate Arrays) and **ASICs** (Application-specific Integrated Circuits)**,** increasing energy efficiency by **orders of magnitude** [5]. However**, dedicated hardware acceleration for small-scale UAV control has not been proposed.**

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This Ph.D. thesis aims to use **algorithm-specific custom hardware acceleration** to implement **efficient real-time control for UAVs** with **long prediction horizons** and **high control frequencies**. The structure of the control algorithms is complex and sensitive to numerical errors or reduced arithmetic precision. Thus, applying a **hardware-algorithm Co-design** approach is necessary, i.e., adapting **the control algorithms to the hardware** and **designing the hardware to suit the control algorithms optimally.**

After a detailed study of UAV state-of-the-art control algorithms, the student will identify HW acceleration opportunities, such as **parallelization**, **pipelining**, and **data specialization**. The student will apply **co-design** approaches to realize efficient accelerators, utilizing the control algorithms' properties to improve the hardware while adjusting the algorithms to the hardware's characteristics. **Simulations** will be carried out to validate the proposed approaches and prepare the final **integration in the UAV platform**, which is already available to the RAINBOW team.

[1] E. F. Camacho and C. Bordons, *Model Predictive control*. in Advanced Textbooks in Control and Signal Processing. London: Springer, 2007. doi: 10.1007/978-0-85729-398-5.

[2] G. Williams, P. Drews, B. Goldfain, J. M. Rehg, and E. A. Theodorou, "Aggressive driving with model predictive path integral control," in *2016 IEEE International Conference on Robotics and Automation (ICRA)*, May 2016, pp. 1433–1440. doi: 10.1109/ICRA.2016.7487277.

[3] K. Nguyen, S. Schoedel, A. Alavilli, B. Plancher, and Z. Manchester, "TinyMPC: Model-Predictive Control on Resource-Constrained Microcontrollers," in *2024 IEEE International Conference on Robotics and Automation (ICRA)*, May 2024, pp. 1–7. doi: 10.1109/ICRA57147.2024.10610987.

[4] W. J. Dally, Y. Turakhia, and S. Han, "Domain-specific hardware accelerators," *Commun ACM*, vol. 63, no. 7, pp. 48–57, Jun. 2020, doi: 10.1145/3361682.

[5] J. L. Hennessy and D. A. Patterson, "A new golden age for computer architecture," *Commun ACM*, vol. 62, no. 2, pp. 48–60, Jan. 2019, doi: 10.1145/3282307.

➢ **Ce document est à renvoyer par la direction de l'unité de Recherche aux animateurs du Pole Recherche et à l'école Doctorale pour le 13 février 2025 au plus tard**