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PROPOSITION DE STAGE EN COURS D'ETUDES

Référence : **DTIS-2025-40**
(à rappeler dans toute correspondance)

Lieu : Palaiseau

Département/Dir./Serv. : DTIS/IGNC

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Responsable(s) du stage : Ioannis SARRAS

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DESCRIPTION DU STAGE

Thématique(s) : Identification et Commande des Systèmes

Type de stage : ☒ Fin d'études bac+5 ☒ Master 2 ☐ Bac+2 à bac+4 ☐ Autres

Intitulé : Nonlinear longitudinal control for a general model of a hypersonic vehicle

Hypersonic vehicles are in the centre of developments for future space (e.g. Moon-to-Earth, Orbit-to-Earth) and civil transportations (in the spirit of the Concorde). Although such vehicles have been studied in the past (e.g. SSTO, re-entry capsules), new vehicle designs and their corresponding subsystems are more complex and require functioning under stringent constraints and specifications. These are particularly oriented in enhancing passenger comfort and safety. In order to guarantee increased performances despite this plethora of constraints as well as model uncertainties (e.g. aerodynamic, aero-elasticity) and perturbations (e.g. wind-gusts), it is imperative to develop innovative control algorithms.

Nonlinear control designs are particularly adapted to aerospace systems as they can naturally handle model nonlinearities and uncertainties in the whole flight domain. Especially, the technique of Nonlinear Dynamic Inversion (NDI) has been widely used [1],[2] since it allows, when possible, to transform the system dynamics in an almost linear form and without neglecting the nonlinear terms.

Recently, a more application-oriented version of NDI, termed Incremental NDI (INDI), has shown to be effective for the control design in aerospace applications [3-6] by reformulating NDI in terms of available sensors and incremental control inputs. This alternative design provides increased robustness to uncertainties in the aerodynamic model and allows for a simpler control synthesis.

However, the current INDI solutions do not naturally account for eventual safety (state or output) constraints. A successful approach to incorporate safety constraints is through artificial potential functions (navigation, barrier). One particular type of such functions is a Barrier-Lyapunov function (BLF) [7-8] that is a form of Lyapunov function that is used to ensure that the system converges to the desired trajectory/equilibrium while making sure that the system does not enter a particular unsafe region.

The objective of this internship is to first study the application of NDI and INDI controllers to the longitudinal model of a generalized hypersonic vehicle, called the General Hypersonic Aerodynamic Example (GHAME) [9], and evaluate the performances of the corresponding closed-loop systems. At a second phase, the intern will study the modification of NDI/INDI using BLFs to incorporate certain state constraints.

The internship will proceed as follows: Bibliographical survey on NDI and INDI, application of NDI and INDI to aerospace applications, modelling and simulation of the GHAME vehicle, analytical NDI and INDI control design and numerical validation for the GHAME vehicle, bibliography on Barrier-Lyapunov functions, BLF-based NDI and INDI design for the GHAME vehicle, synthesis of a report.

This internship is co-advised by Profs Spilios Theodoulis, Erik-Jan van Kampen and Coen de Visser of TU Delft.

REFERENCES

[1] Stevens, B., Lewis, F., and Johnson, E. (2015). Aircraft Control and Simulation: Dynamics, Controls Design, and Autonomous Systems. Wiley.

[2] Khalil, H. (2002). Nonlinear Systems, Third edition, Pearson Education, Prentice Hall.

[3] Sieberling, S., Chu,Q.P., & Mulder, J.A. (2010). Robust flight control using incremental nonlinear dynamic inversion and angular acceleration prediction. Journal of Guidance, Control, and Dynamics, 33, 1732–1742.

[4] Pollack, T. and van Kampen, E. (2023) Robust Stability and Performance Analysis of Incremental Dynamic-Inversion-Based Flight Control Laws. Journal of Guidance, Control, and Dynamics, 46:9, 1785-1798.

[5] Grondman, F., Looye, G., Kuchar, R., Chu, Q. P., and van Kampen, E. (2018). Design and Flight Testing of Incremental Nonlinear Dynamic Inversion-based Control Laws for a Passenger Aircraft. 2018 AIAA Guidance, Navigation, and Control Conference, Kissimmee, FL, USA.

[6] Matamoros, I., and de Visser, C. C. (2018). Incremental Nonlinear Control Allocation for a Tailless Aircraft with Innovative Control Effectors. 2018 AIAA Guidance, Navigation, and Control Conference, Kissimmee, FL, USA.

[7] K. P. Tee, S. S. Ge, and E. H. Tay, "Barrier Lyapunov functions for the control of output-constrained nonlinear systems," Automatica, vol. 45, no. 4, pp. 918–927, 2009.

[8] E. Restrepo-Ochoa, "Coordination control of autonomous robotic multi-agent systems under constraints," Ph.D. dissertation, University Paris-Saclay, Gif sur Yvette, France, 2021, https://tel.archivesouvertes.fr/tel-03537341.

[9] Zipfel, P. H. (2017). Modeling and Simulation of Aerospace Vehicle Dynamics, Third Edition, AIAA Education Series.

Est-il possible d'envisager un travail en binôme ? Non

Méthodes à mettre en oeuvre :

☒ Recherche théorique	☐ Travail de synthèse
☒ Recherche appliquée	☒ Travail de documentation
☐ Recherche expérimentale	☐ Participation à une réalisation

Possibilité de prolongation en thèse : Oui

Durée du stage : Minimum : 5 mois Maximum : 6 mois

Période souhaitée : February-July

PROFIL DU STAGIAIRE

Connaissances et niveau requis :	Ecoles ou établissements souhaités :
Automatic control, Nonlinear systems, Flight mechanics, MATLAB/Simulink	Engineering school or Master in Automatic Control and/or Flight Dynamics