Stochastic Model Predictive Control for Saturated Systems : Healthcare Applications

Cotutelle PhD offer in the Laboratory of Automatic Control, Mechanics, Industrial and Human computer science (**LAMIH**) and the Graduate Program in Electrical Engineering (PPGEE) of the Federal University of Rio Grande do Sul (**UFRGS**), and in collaboration with **Gipsa-Lab**, Grenoble

PhD candidate in	Automatic control
Duration	3,5 to 4 years in total, 2 years in Brazil and 1 year and half in France
Salary	Around 1500 € net/month in France and R$ 3100 in Brazil (CAPES or CNPq scholarship)
Starting date	between August and December 2024
Location	Valenciennes (France) & Porto Alegre (Brazil)

Research context

Healthcare applications are by nature subject to various types of uncertainties, due to the inter- and intra-variability that results from the involvement of humans in this type of application. Moreover, these systems are also constrained by physical saturation. If we consider the case of an assistive robotics application [1], where a robotic orthosis is used to rehabilitate a patient's arm movement, the torques produced by the orthosis motors are saturated. If saturation limits are not taken into account in the orthosis control synthesis, the control performance is degraded and the rehabilitation may be compromised.

The context of biomedical applications is also subject to different types of uncertainty, as the models considered are characterized by parameters with a high patient dependency. An example of an application that has retained attention recentely is the dynamics of anesthesia [2-4], the latter are generally described by compartmental models, representing pharmacokinetics (PK) and pharmacodynamics (PD) that are subject to uncertainties.

Although model-related parameters are generally identified, uncertainties linked to estimation errors remain, particularly for healthcare applications. These uncertainties can affect control quality and endanger patients if they are not properly considered in control synthesis. Robust control has been widely studied through various approaches, for example those based on Lyapunov functions in [5], which consider that uncertainties are bounded. In this case, the control synthesis is based on the worst-case realization of uncertainty, which means that the results are often pessimistic and conservative, especially when additional information on uncertainty is available, for example in the form of a probability distribution.

Predictive control is known for its ability to manage the various constraints associated with physical systems. In the presence of bounded uncertainty, theoretical guarantees has been provided in the literature, for instance in [6], considering worst-case scenarios of the uncertainties affecting the dynamics. However, since robust design can lead to conservative control strategies, researchers have recently turned their attention to stochastic predictive control, in order to be able to consider uncertainties defined by probability distributions. Theoretical work is currently limited to the consideration of additive uncertainties, as in [7] and [9], and bounded parametric uncertainties, as considered in [8]. Recent results on the characterization of error covariance dynamics for linear systems affected by additive and multiplicative uncertainties [10] might be used for generating stochastically invariant sets and considering them in the predictive control design.

The control of saturated systems has been dealt with extensively in the literature, for example in [12-14], in order to guarantee the performance of controlled systems in the presence of saturation. The special case of stochastic predictive control has also been developed for systems with input saturations, for example in [11], however, given the difficulty of the general theoretical problem, several simplifications have been considered in order to be able to solve the optimization problems inherent to model predictive control. Preliminary results currently being developed show the possibility of having a saturation representation with less conservatism, which is particularly interesting in the case of stochastic predictive control.

Therefore, the main objective of this thesis is to propose a comprehensive theoretical framework of stochastic predictive control for saturated systems, considering both additive and parametric uncertainties. This framework will help to deal with various health-related applications, which are largely affected by several types of uncertainties and saturation. The project will also extend existing theoretical approaches to more general problems, demonstrating their relevance to complex systems in practice.

Main requirements

- Master degree or equivalent in Automatic Control
- Excellent background in automatic control
- Good programming skills (Matlab or Python)
- Professional English (French in not necessary)

How to apply

- Send your CV with 2 academic referees, a cover letter and your transcript of records corresponding to the last diplomas.
- Contacts : Kaouther Moussa {kaouther.moussa@uphf.fr}, Jimmy Lauber {jimmy.lauber@uphf.fr}, Joao Manoel Gomes da Silva, Jr {jmgomes@ufrgs.br} and Mirko Fiacchini {mirko.fiacchini@gipsa-lab.fr}
- Deadline : 07/05/2024

References

[1] J. Ibarra, K. Moussa and J. Lauber, “Human Torque Estimation for an LMI-based Convex Control Rehabilitation Strategy using Assistive Robots,” in American Control Conference 2024, Toronto, Canada, https ://hal.science/hal-04517410.

[2] C. Ionescu, M. :. G. M. Neckebroek and D. Copot, «An open-source patient simulator for design and evaluation of computer based multiple drug dosing,» IEEE Access, p. 8680–8694, 2021.

[3] D. Denardi Huff, M. Fiacchini, T. Dang and T. Alamo, "Optimized Coadministration of Propofol and Remifentanil During the Induction Phase of Total Intravenous Anesthesia With Statistical Validation," in IEEE Control Systems Letters, vol. 8, pp. 193-198, 2024

[4] K. Moussa, B. Aubouin-Pairault, M. Alamir and T. Dang, «Data-based Extended Moving Horizon Estimation for MISO Anesthesia Dynamics,» IEEE Control Systems Letters, pp. 3054-3059, 2023.

[5] A. Nugyen, M. Dambrine and J. Lauber, “Lyapunov-based robust control design for a class of switching non-linear systems subject to input saturation : application to engine control,” IET Control Theory & Applications, vol. 8, no. 17, pp. 1789-1802, 2014.

[6] A. Bemporad and M. Morari, “Robust model predictive control : A survey,” in Robustness in identification and control, 1999.

[7] M. Fiacchini and T. Alamo, “Probabilistic reachable and invariant sets for linear systems with correlated disturbance,” Automatica, 2021.

[8] E. Arcari, A. Iannelli, A. Carron and M. N. Zeilinger, "Stochastic MPC With Robustness to Bounded Parameteric Uncertainty," in IEEE Transactions on Automatic Control, vol. 68, no. 12, pp. 7601-7615, Dec. 2023, doi : 10.1109/TAC.2023.3294868.

[9] L. Chaouach, M. Fiacchini and T. Alamo, «Stochastic model predictive control for linear systems affected by correlated disturbances», IFAC-PapersOnLine, 2022.

[10] K. Moussa, M. Fiacchini. Covariance Stability Conditions for Linear Systems under Unbounded Additive and Parametric Uncertainties in Stochastic MPC applications. 2024. ⟨hal-04518553⟩

[11] P. Hokayem, E. Cinquemani, D. Chatterjee, F. Ramponi, and J. Lygeros, “Stochastic receding horizon control with output feedback and bounded controls,” Automatica, vol. 48, pp. 77–88, 2012.

[12] S. Tarbouriech, G. Garcia, J.M. Gomes da Silva Jr and I. Queinnec, Stability and stabilization of linear systems with saturating actuators, Springer-Verlag, London, 2011.

[13] S. Tarbouriech, C. Prieur and J. M. G. da Silva, "Stability analysis and stabilization of systems presenting nested saturations," in IEEE Transactions on Automatic Control, vol. 51, no. 8, pp. 1364-1371, Aug. 2006

[14] J. M. Gomes Da Silva and S. Tarbouriech, "Local stabilization of discrete-time linear systems with saturating controls : an LMI-based approach," in IEEE Transactions on Automatic Control, vol. 46, no. 1, pp. 119-125, Jan. 2001