Accurate Parameter Estimation for Safety-Critical Systems with Unmodeled Dynamics (Abstract Reprint)

Arnab Sarker[1], **Peter Fisher**[1], **Joseph Gaudio**[1], **Anuradha Annaswamy**[1]

[1]Massachusetts Institute of Technology, United States of America

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Abstract

Analysis and synthesis of safety-critical autonomous systems are carried out using models which are often dynamic. Two central features of these dynamic systems are parameters and unmodeled dynamics. Much of feedback control design is parametric in nature and as such, accurate and fast estimation of the parameters in the modeled part of the dynamic system is a crucial property for designing risk-aware autonomous systems. This paper addresses the use of a spectral lines-based approach for estimating parameters of the dynamic model of an autonomous system. Existing literature has treated all unmodeled components of the dynamic system as sub-Gaussian noise and proposed parameter estimation using Gaussian noise-based exogenous signals. In contrast, we allow the unmodeled part to have deterministic unmodeled dynamics, which are almost always present in physical systems, in addition to sub-Gaussian noise. In addition, we propose a deterministic construction of the exogenous signal in order to carry out parameter estimation. We introduce a new tool kit which employs the theory of spectral lines, retains the stochastic setting, and leads to non-asymptotic bounds on the parameter estimation error. Unlike the existing stochastic approach, these bounds are tunable through an optimal choice of the spectrum of the exogenous signal leading to accurate parameter estimation. We also show that this estimation is robust to unmodeled dynamics, a property that is not assured by the existing approach. Finally, we show that under ideal conditions with no deterministic unmodeled dynamics, the proposed approach can ensure a $\tilde{O}(\sqrt{T})$ Regret, matching existing literature. Experiments are provided to support all theoretical derivations, which show that the spectral lines-based approach outperforms the Gaussian noise-based method when unmodeled dynamics are present, in terms of both parameter estimation error and Regret obtained using the parameter estimates with a Linear Quadratic Regulator in feedback.

References

Sarker, A.; Fisher, P.; Gaudio, J.; and Annaswamy, A. 2023. Accurate parameter estimation for safety-critical systems with unmodeled dynamics. *Artificial Intelligence*, 316: 103857.