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Master thesis - *Masterarbeit*
for
Student Name
Student No.: XXXXXXXX

Project received: XX.XX.XXXX	Workload: 720 h (24 CP)
Submission of project until: XX.XX.XXXX	Duration: 6 months
First examiner: Prof. Dr.-Ing. U. Nackenhorst	Supervisor: Dr. Jorge Urrea
Second examiner: Prof. Dr.-Ing. Vorname Nachname	

Nonlinear dynamical systems identification using kernel-based state-space models
Nichtlineare dynamische Systemidentifizierung mit Kernel-basierten Zustandsraummodellen

Many real-life systems and phenomena are nonlinear. Their behavior can often be approximated by linear models which are easy to understand and interpret. Unfortunately, linear approximations are only valid for a given input range. One remedy would be the development of a non-linear model that captures a wider range of operating conditions. However, the development of sophisticated nonlinear models capturing the real system to a good extent is a very demanding task. A better idea would be to combine an optimal linear representation of the system under study—e.g., optimal in the least square sense—and extend it adopting so-called kernel models that can "learn" the unmodeled (nonlinear) dynamics of the system given an error criterion, as follows,

$$\begin{aligned} x(t+1) &= \underbrace{A\,x(t) + B\,u(t)}_{\text{linear state-space model}} + \underbrace{E\,\zeta(x(t),u(t))}_{\text{polynomials in } x \text{ and } u} \\ y(t) &= C\,x(t) + D\,u(t) + F\,\eta(x(t),u(t)) \end{aligned}$$

Within the scope of this master thesis, some well-known kernel models widely used in Machine Learning applications should be explored, e.g., exponential, square exponential, Matern kernel with parameter 3/2 or 5/2, and compared with some polynomial approximations, e.g., Lagrange, Legendre, or Laguerre polynomials for some simple mechanical problems, e.g., two degrees of freedom spring-mass-damper system.

Required knowledge (to be covered in self-study where applicable): No specific knowledge is required. Basic knowledge in dynamical systems simulation and basic programming knowledge in Matlab or python would be an advantage, but it is not mandatory.

This project will be supervised/written in English language.

Literature:

[1] PADUART, J., LAUWERS, L., SWEVERS, J., SMOLDERS, K., SCHOUKENS, J., & PINTELON, R. (2010). Identification of nonlinear systems using polynomial nonlinear state space models. Automatica, 46(4), 647-656.

[2] FRIGOLA, R., LINDSTEN, F., SCHÖN, T. B., & RASMUSSEN, C. E. (2014). Identification of Gaussian process state-space models with particle stochastic approximation EM. IFAC Proceedings Volumes, 47(3), 4097-4102.

[1] BADDOO, P. J., HERRMANN, B., MCKEON, B. J., & BRUNTON, S. L. (2021). Kernel learning for robust dynamic mode decomposition: linear and nonlinear disambiguation optimization (LANDO). arXiv preprint arXiv:2106.01510.