INSTITUT FÜR RISIKO UND ZUVERLÄSSIGKEIT

Leibniz Universität Hannover

Efficient and Interpretable System Identification in Civil Engineering Using Data-Driven Methods

Effiziente und interpretierbare Systemidentifikation im Bauingenieurwesen mittels datengesteuerten Methoden

Type of thesis
Interdisciplinary Project (12 CP)
or Master thesis (24 CP)

Prerequisites
18 CP from compulsory moduls
60 CP (only master thesis)

Notes
The thesis can be written in either German or English.

Contact
Lukas Fritsch

Email: fritsch
@irz.uni-hannover.de

May 13, 2025

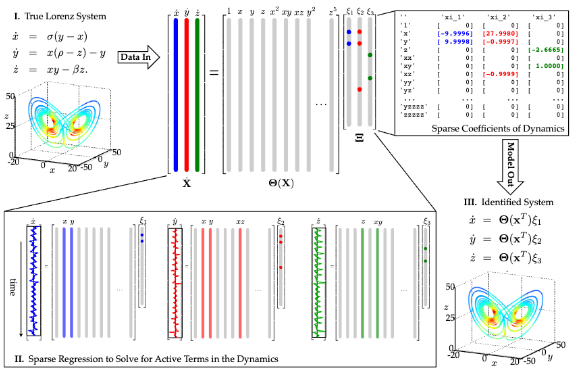

Abbildung 1: System identification with SINDy [1]

Nonlinear dynamic systems play a critical role in civil engineering, especially in the analysis and prediction of structural behavior under complex loading conditions. Precise modeling of such systems is essential to ensure the safety and longevity of constructions. However, traditional methods of system identification often reach their limits in capturing complex nonlinear relationships. In this context, the method of *Sparse Identification of Nonlinear Dynamics* (SINDy; see [1, 2]) offers a promising alternative. SINDy not only identifies precise models of nonlinear dynamics with a minimal number of parameters, but also aligns with the principles of explainable AI, providing interpretable models that offer insights into the underlying physical processes of complex systems.

The aim of this thesis is to comprehensively examine SINDy and evaluate its potential for use in civil engineering. This includes a detailed literature review of the method itself, as well as practical application in various examples. The thesis aims to demonstrate the usefulness of SINDy for efficient modeling and prediction of nonlinear systems in the field of civil engineering.

Objectives

- Conduct a comprehensive literature review on nonlinear dynamic systems and system identification in civil engineering. The focus will be on the fundamentals of the SINDy method, its underlying mathematical concepts, and practical applications. Additionally, extensions of SINDy, such as Bayesian SINDy [3], RK4-SINDy [4], and PhI-SINDy [5], should be introduced. For a master's thesis, one of these additional methods is to be examined in detail.
- Implement the numerical investigations using, for example, Julia, Python, or Matlab. The basic functionalities should be implemented independently on a simple example (a 1D nonlinear oscillator, e.g., [1, Section 4.1]). In a master's thesis, one of the additional methods, previously mentioned, is also to be implemented.
- Apply the method to a more complex example from civil engineering, such as an FEM model of a bridge or a structure. The results should be compared with those of traditional methods for system identification. Existing software packages may be used, such as the Julia package `DataDrivenDiffEq.jl`.
- Conduct a critical analysis of the results and evaluate the appropriateness of SINDy and its extensions in comparison to traditional methods.

Bibliography (Selection)

[1] Steven L. Brunton, Joshua L. Proctor, and J. Nathan Kutz. "Discovering Governing Equations from Data: Sparse Identification of Nonlinear Dynamical Systems". In: *Proc. Natl. Acad. Sci. U.S.A.* 113.15 (Apr. 2016). DOI: `10.1073/pnas.1517384113`.

[2] Steven L. Brunton and J. Nathan Kutz. *Data-Driven Science and Engineering: Machine Learning, Dynamical Systems, and Control.* Second. Cambridge University Press, May 2022. DOI: `10.1017/9781009089517`.

[3] Seth M. Hirsh, David A. Barajas-Solano, and J. Nathan Kutz. "Sparsifying Priors for Bayesian Uncertainty Quantification in Model Discovery". In: *Royal Society Open Science* 9.2 (Feb. 2022). DOI: `10.1098/rsos.211823`.

[4] Pawan Goyal and Peter Benner. "Discovery of Nonlinear Dynamical Systems Using a Runge-Kutta Inspired Dictionary-based Sparse Regression Approach". In: *Proc. R. Soc. A.* 478.2262 (June 2022). DOI: `10.1098/rspa.2021.0883`.

[5] Christos Lathourakis and Alice Cicirello. "Physics Enhanced Sparse Identification of Dynamical Systems with Discontinuous Nonlinearities". In: *Nonlinear Dyn* 112.13 (July 2024). DOI: `10.1007/s11071-024-09652-2`.

Institute for Risk and Reliability
Callinstraße 34
30167 Hannover
www.irz.uni-hannover.de

Head Office:
Tel. +49 511 762 0
Fax +49 511 762 3456
www.uni-hannover.de