Chair of Applied Mechanics
Department of Mechanical Engineering
Technical University of Munich

Parameteric Sparse Identification of the Nonlinear Dynamics of a Slider-Crank Mechanism

Semester Thesis/Master's Thesis

Introduction and Problem Description

Higher, faster, and further on the one hand, but also safer and more efficient on the other hand – this trend demands a great deal of today's and future engineers. This challenging maxim in combination with economic aspects requires advanced analyses tools to master today's challenges.

Multibody system dynamics simulations are powerful tools to realistically analyse real-world, multiple-component devices in their intended operating environment. In combination with design optimization [2], such simulations are critical to reducing weight and, therefore, increasing efficiency and lowering costs of mechanical systems. However, the inherently non-linear governing equations are often (at least partially) unknown, e.g., contact and damping terms, design parameter dependencies. This problem may be addressed with data-driven approaches.

This thesis will, therefore, focus on the application of the so-called sparse identification of nonlinear dynamics (SINDy) [1] algorithm for design optimization purposes of flexible multibody dynamics systems.

Task Description

1. Literature review
2. Familiarization with SINDy on a simple academic example with synthetic data, i.e., simulated and not experimental, e.g., a one-degree-of-freedom mass-damper-spring (or cantilever) system (Fig. 1).

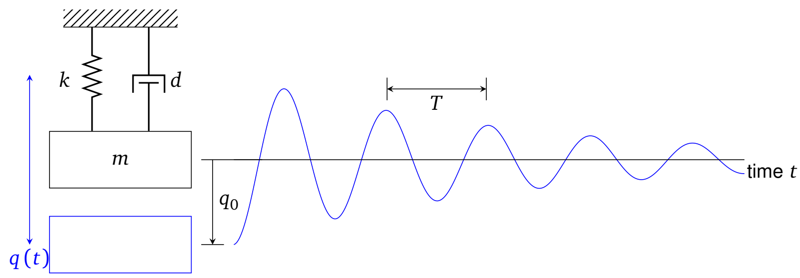

Figure 1: One-degree-of-freedom mass-damper-spring system.

3. Experimental measurements of the slider-crank mechanism test rig for multiple conrod (yellow component in Fig. 2) designs, resulting in the following data sets of a generic time-domain response $\boldsymbol{f}(t)$:

$$\begin{aligned} &\text{for design 1 } \boldsymbol{x}_1\text{: } \boldsymbol{f}_1(t) \\ &\text{for design 2 } \boldsymbol{x}_2\text{: } \boldsymbol{f}_2(t) \\ &\vdots \\ &\text{for design } n\ \boldsymbol{x}_n\text{: } \boldsymbol{f}_n(t) \end{aligned}$$

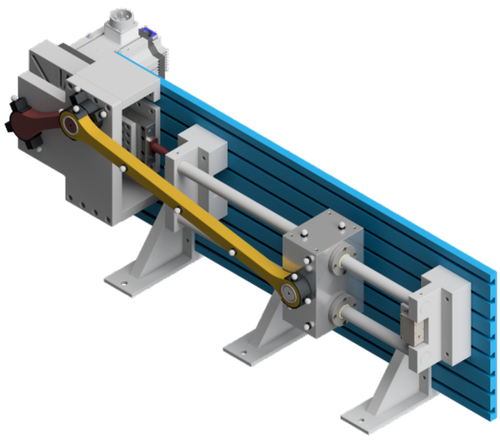

Figure 2: Slider-crank mechanism test rig.

4. Application of SINDy to identify the governing equations of the slider-crank mechanism for multiple conrod designs:

$$\text{for design 1 } \boldsymbol{x}_1\text{: } \hat{\boldsymbol{f}}_1(t) \tag{1}$$
$$\text{for design 2 } \boldsymbol{x}_2\text{: } \hat{\boldsymbol{f}}_2(t) \tag{2}$$
$$\vdots$$
$$\text{for design } n \ \boldsymbol{x}_n\text{: } \hat{\boldsymbol{f}}_n(t) \tag{3}$$

   Followed by a verification of the plausibility of the derived governing equations, and an assessment of the error and its sources.

5. Application of SINDy to identify the design-dependent governing equations, i.e., parametric governing equations, of the slider-crank mechanism:

$$\hat{\boldsymbol{f}}(t, \boldsymbol{x}) \tag{4}$$

   Followed by (i) an assessment of the number of designs needed for a proper model, (ii) a verification of the plausibility of the derived equations. An example of a design parameter to consider in the model is the conrod height/radius.

6. Bonus: Evaluation of the analytical design sensitivities of the derived parametric governing equations:

$$\frac{\mathrm{d}\hat{\boldsymbol{f}}(t, \boldsymbol{x})}{\mathrm{d}\boldsymbol{x}} \tag{5}$$

7. Documentation and written report
   - The thesis has to be written in LaTeX using the Chair of Applied Mechanics' template.
   - Computer codes and computational models must be modularly organized and thoroughly commented in order to enable their employment and further development by third-party users.
   - Technical drawings etc. have to comply with DIN/ISO norms.

Note that this project is scalable, i.e., not all points from the task description must be addressed, but the thesis can also focus on specific experimental and/or numerical subtasks, depending on the progress, interests, and strength of the student.

Requirements

- Solid background in mechanics.
- Solid MATLAB or Python programming skills.
- Interest and/or experience in some of the following topics:
  - structural dynamics
  - finite element methods
  - multibody dynamics
  - experimental dynamics
  - machine learning
  - design optimization

References

[1] S. L. Brunton, J. L. Proctor, and J. N. Kutz. Discovering governing equations from data by sparse identification of nonlinear dynamical systems. Proceedings of the National Academy of Sciences, 113(15):3932–3937, mar 2016.

[2] V. Gufler, E. Wehrle, and A. Zwölfer. A review of flexible multibody dynamics for gradient-based design optimization. Multibody System Dynamics, 53(4):379–409, oct 2021.