Chair of Applied Mechanics
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Modeling of Overconstrained Parallel Mechanisms in Exudyn

Bachelor's-/Semester Thesis

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Motivation and Problem Description

An Exudyn simulation was developed to support the dimensioning of two internally parallel mechanisms for a robot shoulder joint. A static exudyn analysis provided the internal force distribution within the highly redundant parallel mechanism [1]. Since the joint model used in the simulation is highly simplified, it is necessary to assess the reliability of the resulting force predictions.
For that, the modeling of overconstrained parallel mechanisms in Exudyn should be investigated.

Exudyn

https://exudyn.readthedocs.io/en/stable/docs/RST/GettingStarted.html
"Exudyn – (flEXible mUltibody DYNamics – EXtend yoUr DYNamics)
Exudyn is a C++ based Python library for efficient simulation of flexible multibody dynamics systems. [...]
Exudyn is designed to easily set up complex multibody models, consisting of rigid and flexible bodies with joints, loads and other components. It shall enable automatized model setup and parameter variations, which are often necessary for system design but also for analysis of technical problems. The broad usability of Python allows to couple a multibody simulation with environments such as optimization, statistics, data analysis, machine learning and others."[2]

Task Description

The research question is: How can overconstrained parallel kinematic mechanisms be accurately modeled within the Exudyn framework, and which simulation parameters are most critical? For that, the working packages of the thesis are:

- Research methodologies for modeling overconstrained parallel kinematic mechanisms within the Exudyn simulation framework.
- Develop a minimal working example (MWE) simulation, ensuring the model architecture is suitable for future hardware implementation and validation.
- Perform a sensitivity analysis on parameter variations to quantify the influence of individual components on the system's global behavior. Performance metrics include internal force distribution, elastic deformation, and vibration analysis.

Requirements

- Strong proficiency in mechanics
- Ideally experience with Python, FEM, mechanical multibody simulation
- Knowing or motivation to learn Latex, citation, Git, Inkscape
- A high level of self-organization

Recommended Literature

[1] Motivation: Simulations to be validated (Section 4.3.2)
[3] Motivation: 2 DOF Joint to be validated: Quaternion Joint
[4] Motivation: 2 DOF Joint to be validated: CompactWrist
[5] Methods for Force Analysis of Overconstrained Parallel Mechanisms: A Review

References

[1] Perkhammer, M. “Parallel Joints for Humanoid Arms: Investigation of Kinematics and Actuation”. MA thesis. Technische Universität München, 2025.

[2] Gerstmayr, J. “Exudyn – a C++-Based Python Package for Flexible Multibody Systems”. In: *Multibody System Dynamics* 60.4 (Apr. 2024), pp. 533–561. ISSN: 1384-5640, 1573-272X. DOI: 10.1007/s11044-023-09937-1. URL: https://link.springer.com/10.1007/s11044-023-09937-1 (visited on 05/12/2026).

[3] Kim, Y.-J., Kim, J.-I., and Jang, W. “Quaternion Joint: Dexterous 3-DOF Joint Representing Quaternion Motion for High-Speed Safe Interaction”. In: *2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. 2018, pp. 935–942. DOI: 10.1109/IROS.2018.8594301.

[4] Klas, C. and Asfour, T. “A Compact, Lightweight and Singularity-Free Wrist Joint Mechanism for Humanoid Robots”. In: *2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. 2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). Kyoto, Japan: IEEE, Oct. 23, 2022, pp. 457–464. ISBN: 978-1-6654-7927-1. DOI: 10.1109/IROS47612.2022.9981787. URL: https://ieeexplore.ieee.org/document/9981787/ (visited on 02/12/2026).

[5] Liu, W.-L., Xu, Y.-D., Yao, J.-T., and Zhao, Y.-S. “Methods for Force Analysis of Overconstrained Parallel Mechanisms: A Review”. In: *Chinese Journal of Mechanical Engineering* 30.6 (Nov. 1, 2017), pp. 1460–1472. ISSN: 2192-8258. DOI: 10.1007/s10033-017-0199-9. URL: https://doi.org/10.1007/s10033-017-0199-9.