Friedrich-Alexander-Universität
Chair of Autonomous Systems and Mechatronics | ASM

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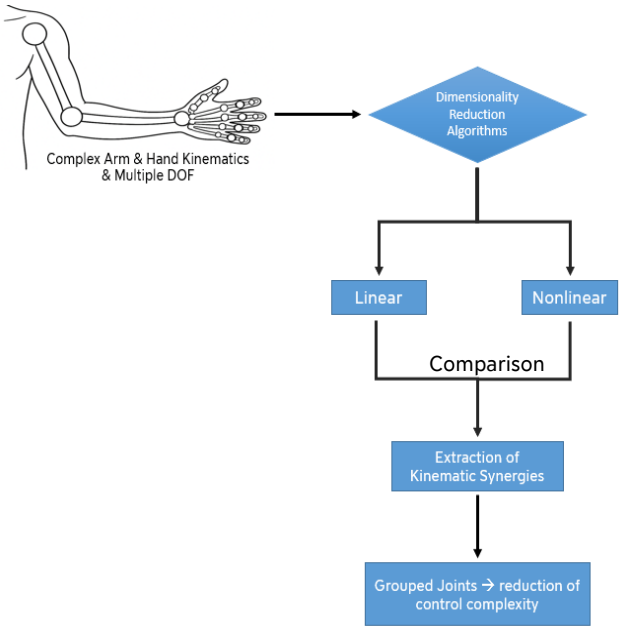
Comparing Linear and Nonlinear Methods for Extracting Upper-Limb Synergies

Vergleich linearer und nichtlinearer Methoden zur Extraktion von Oberarm-Synergien

Despite involving many joints and degrees of freedom, **human movement** is remarkably smooth, effortless and energy efficient. This is due to the fact that instead of managing each joint or muscle independently, **the central nervous system** (CNS) coordinates them in functional groups, reducing the dimensionality of motor control. These coordinated patterns, known as **motor synergies**, allow the brain to generate efficient, adaptive movement using a compact set of control signals. Understanding and modeling these synergies can potentially advance **robotic control** by optimizing joint-level complexity and improving human-likeness.



Potential Pipeline for Methods Comparison and Kinematics Synergy Extraction

This bachelor thesis focuses on **extracting, defining and comparing synergy models** (linear vs. nonlinear) from **upper limb joint kinematics** data during **Activity of Daily Living (ADL)**. The data will be provided from the **U-Limb Dataset**, a multi-modal multi-center data collection on human upper limb movements [1].

Project Goals

The student will:

- Define synergy models using U-Limb kinematic data (from University of Pisa).
- Implement and compare **linear** (PCA, NMF etc.) and **nonlinear** (Autoencoders, etc.) dimensionality reduction techniques.
- Analyze and interpret the output synergies.
- Quantify **reconstruction accuracy** of the synergies using a validation set from the same university dataset or from different center data (provided from the U-Limb dataset).
- Determine the **number of effective degrees of freedom (DOF)** effectively describe most motion variance.
- **Optional**: Evaluate model performance on **stroke patient data** (available in the dataset).

Earliest start: 01 January 2025

Supervisor: M.Sc. Maria Luna Ghanime, M.Sc. Marius Kindermann

Examiner: Prof. Dr.-Ing. habil. Philipp Beckerle

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Project Assignments

- Conduct a **literature review** on upper limb synergies and dimensionality reduction methods.
- **Segment** the provided data.
- Implement and compare **synergy extraction algorithms** (linear and nonlinear).
- Evaluate models based on **reconstruction accuracy, generalization** across tasks or subjects, **robustness** or other relevant criteria.
- **Document** key findings, algorithms used, and **recommendations** for future synergy extraction research.

Requirements

- Programming skills in **Python**.
- Understanding and first-hand experience in **machine learning** and **dimensionality reduction methods**.
- Interest in **biomechanics, robotics** and **data-driven modeling**.

References

[1] G. Averta, F. Barontini, V. Catrambone, S. Haddadin, G. Handjaras, J. P. Held, *et al.*, "U-Limb: A multi-modal, multi-center database on arm motion control in healthy and post-stroke conditions," *GigaScience*, vol. 10, no. 6, p. giab043, Jun. 2021.

[2] M. Santello u. a. "Hand synergies: Integration of robotics and neuroscience for understanding the control of biological and artificial hands". In: Physics of life reviews 17 (2016), 1–23.

[3] K. Zhao, *et al.*, "Evaluation of methods for the extraction of spatial muscle synergies," *Frontiers in Neuroscience*, vol. 16, p. 732156, 2022.

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