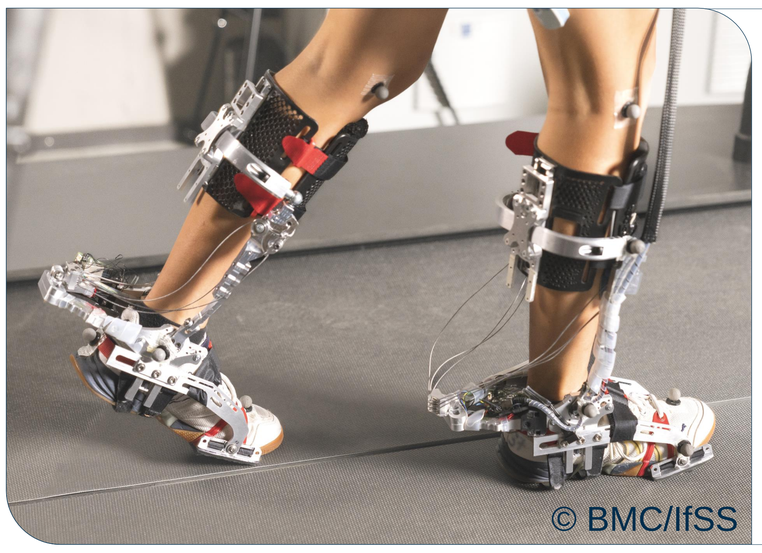
Mapping Encoder Values to Ankle Angles in a 3 DoF Parallel Ankle Exoskeleton

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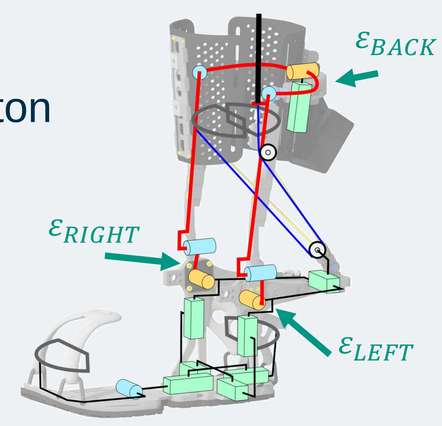


Motivation

- Can angular sensors in a 3-DoF parallel ankle exoskeleton accurately estimate ankle joint angles?
- Accurate joint angles enable **real-time control** of assistive devices → no external sensors needed
- **Parallel kinematics** of the exoskeleton **complicates direct mapping** of encoder data to joint motion → modeling is essential

Methods

- 3 DoF ankle exoskeleton with a **parallel structure** and **3 angular sensors**[1]



[1]Dežman et al., *ICRA*, 2024

User study (n = 2)

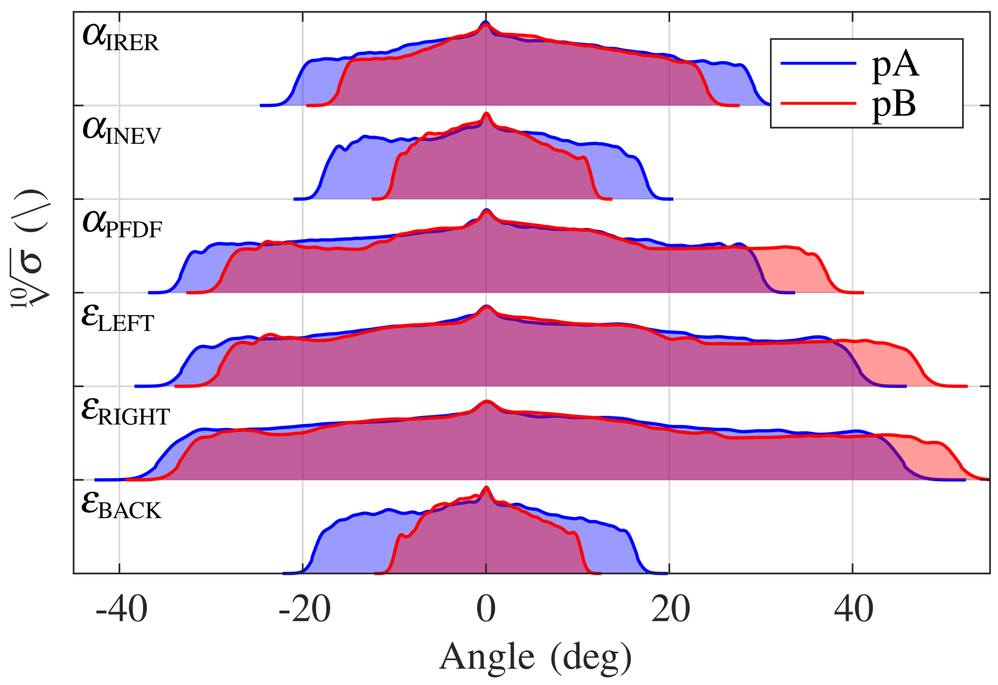
- Tasks: level walking, figure-eight walking, stair ascent/descent
- Data: exoskeleton encoder and motion capture (ground truth)
- **Mathematical model** using plane fitting to estimate joint angles from encoder data

$$f_i(x, y) = P_1 x + P_2 y + P_3$$

Analysis

Range of Motion

- ROM comparison of exoskeleton angular measurements (ε_{RIGHT}, ε_{LEFT}, ε_{BACK}) and ankle joint angles (α_{PFDF}, α_{INEV}, α_{IRER})
- Notable observation is the interparticipant variation (different RoM of pA and pB)



Model Quality

- Plane fitting applied separately for each ankle rotation (PF/DF, IN/EV, IR/ER) and error reported as RMSE (°) and normalized RMSE (% of range of motion)
- Personalized model trained on individual participants (pA, pB)
- Generalized model trained on combined participants (pAB)

TABLE III: RoM Normalized RMSE values

Partic.	f_{CPFDF} nRMSE (%)	f_{CPFDF} RoM (deg)	$f_{\alpha INEV}$ nRMSE (%)	$f_{\alpha INEV}$ RoM (deg)	$f_{\alpha IRER}$ nRMSE (%)	$f_{\alpha IRER}$ RoM (deg)	Models
pA	4.84[1]	60.8	4.29[1]	33.4	3.88[1]	47.6	pA personalized
	4.86[2]	60.8	4.35[2]	33.4	3.97[2]	47.6	pAB applied to pA
pB	3.39[1]	63.3	4.83[1]	20.3	3.52[1]	37.6	pB personalized
	3.46[2]	63.3	4.91[2]	20.3	3.64[2]	37.6	pAB applied to pB
pAB	3.73	67.9	3.61	33.4	3.78	47.6	pAB generalized

Conclusion

- Encoder-based models show promise for estimating ankle angles in parallel exoskeletons
- Accuracy is limited by **alignment**, **compliance**, and individual **variability**
- Future work should refine models with more data, parameters, and machine learning

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Carl Zeiss Stiftung

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Robotics Institute Germany

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