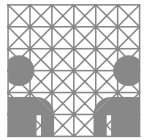

Learning Error-Corrections for Series Elastic Actuators on Humanoid Robots

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University of Hamburg
Faculty of Mathematics, Informatics and Natural Sciences
Department of Informatics

Technical Aspects of Multimodal Systems

15. November 2022

Outline

Motivation

Related Work

Approach

Evaluation

Discussion

Conclusion

Outline

Motivation
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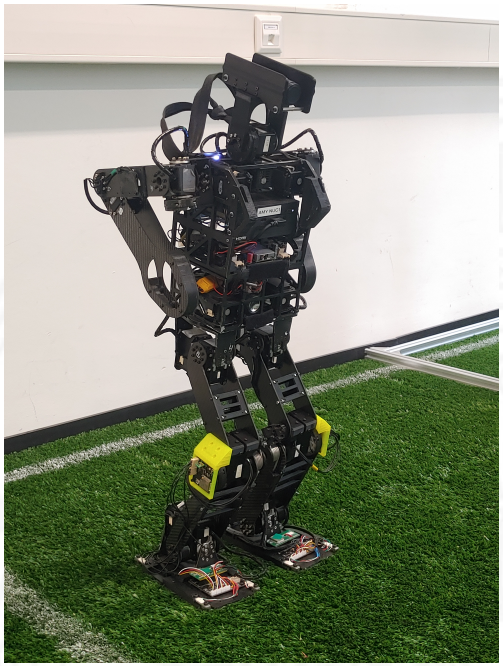
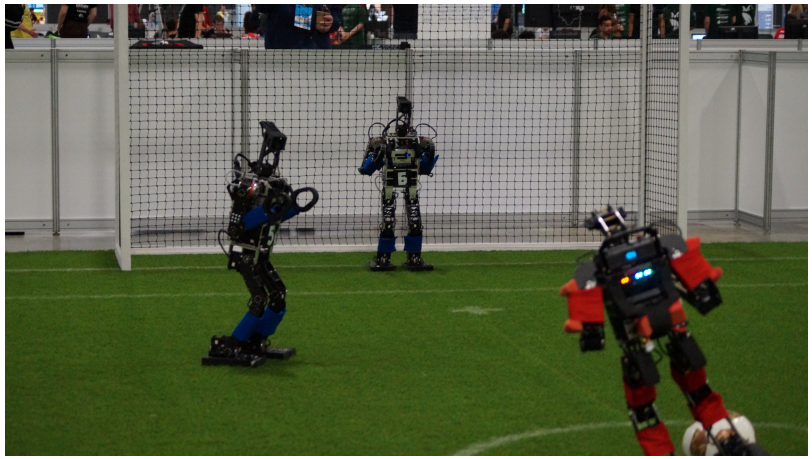
Discussion
Conclusion

Motivation

- Goal: Add compliant elements to robot knees
- Many benefits
  - Protects gearboxes and actuators
  - Reduced energy consumption
  - Human safety
- Disadvantage: Harder to control



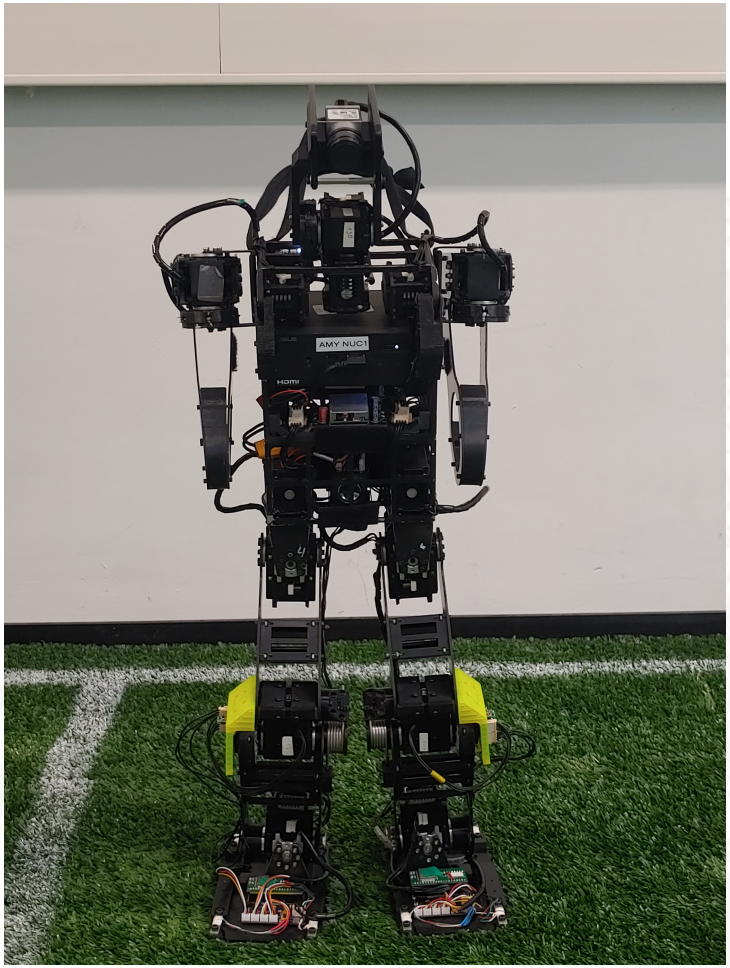
Motivation: Robocup



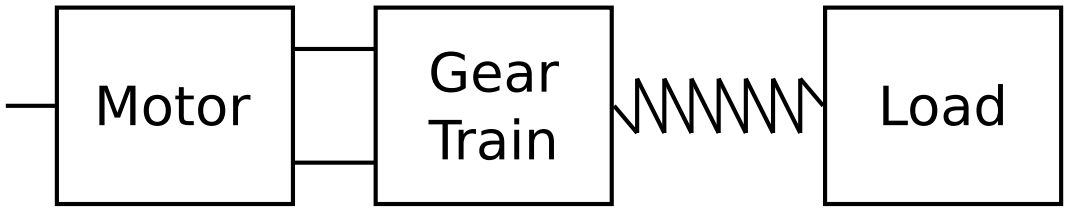
- Founded 1996
- Goal: beat human world champion by 2050
- Supports interdisciplinary research in artificial intelligence and intelligent adaptive systems
- 335 Teams, 40 Nations, 2200 Participants (WM 2019)

Motivation: Robot Platform

- Height: 80 cm
- Weight: 8 kg
- 20 Degrees of Freedom
- Sensors
  - IMU
  - Camera
  - Pressure Cells
  - Internal
- Dynamixel Actuators
- SEAs and PEAs



Series Elastic Actuators



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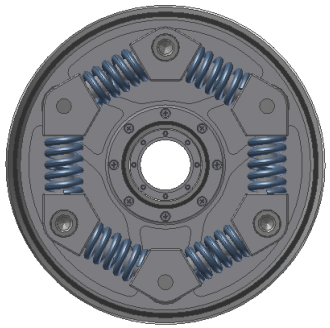
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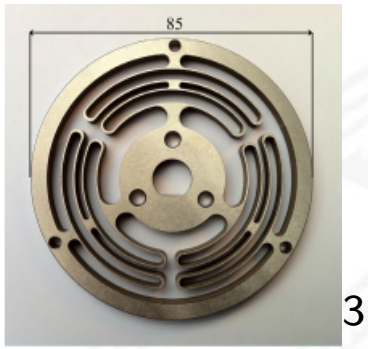

3

4

[1] Lee and Oh, "Development, analysis, and control of series elastic actuator-driven robot leg".

[2] Yu et al., "Learning the elasticity of a series-elastic actuator for accurate torque control".

[3] Sergi et al., "Design and characterization of a compact rotary series elastic actuator for knee assistance during overground walking".

[4] Martins et al., "A polyurethane-based compliant element for upgrading conventional servos into series elastic actuators".

Outline

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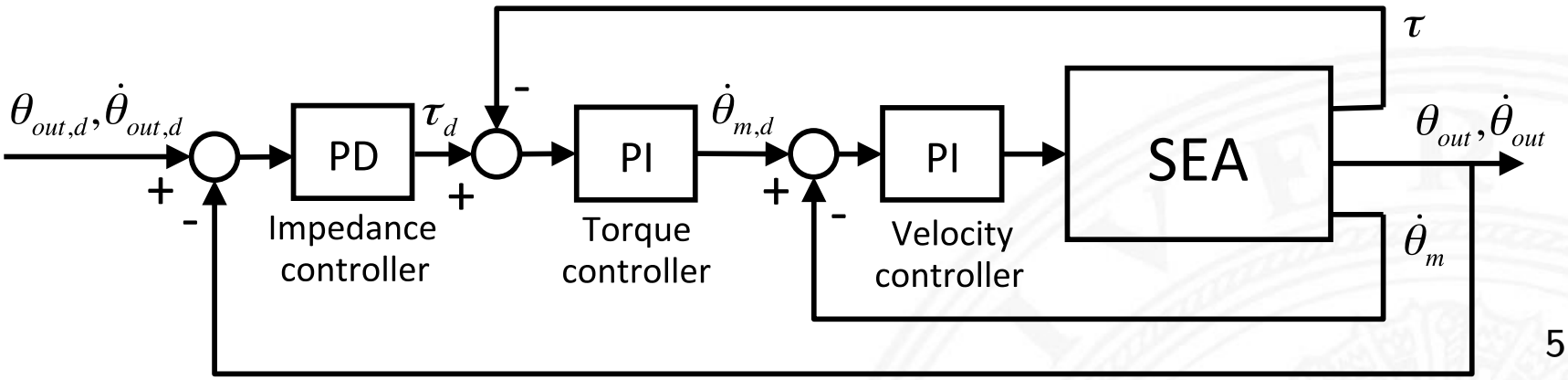
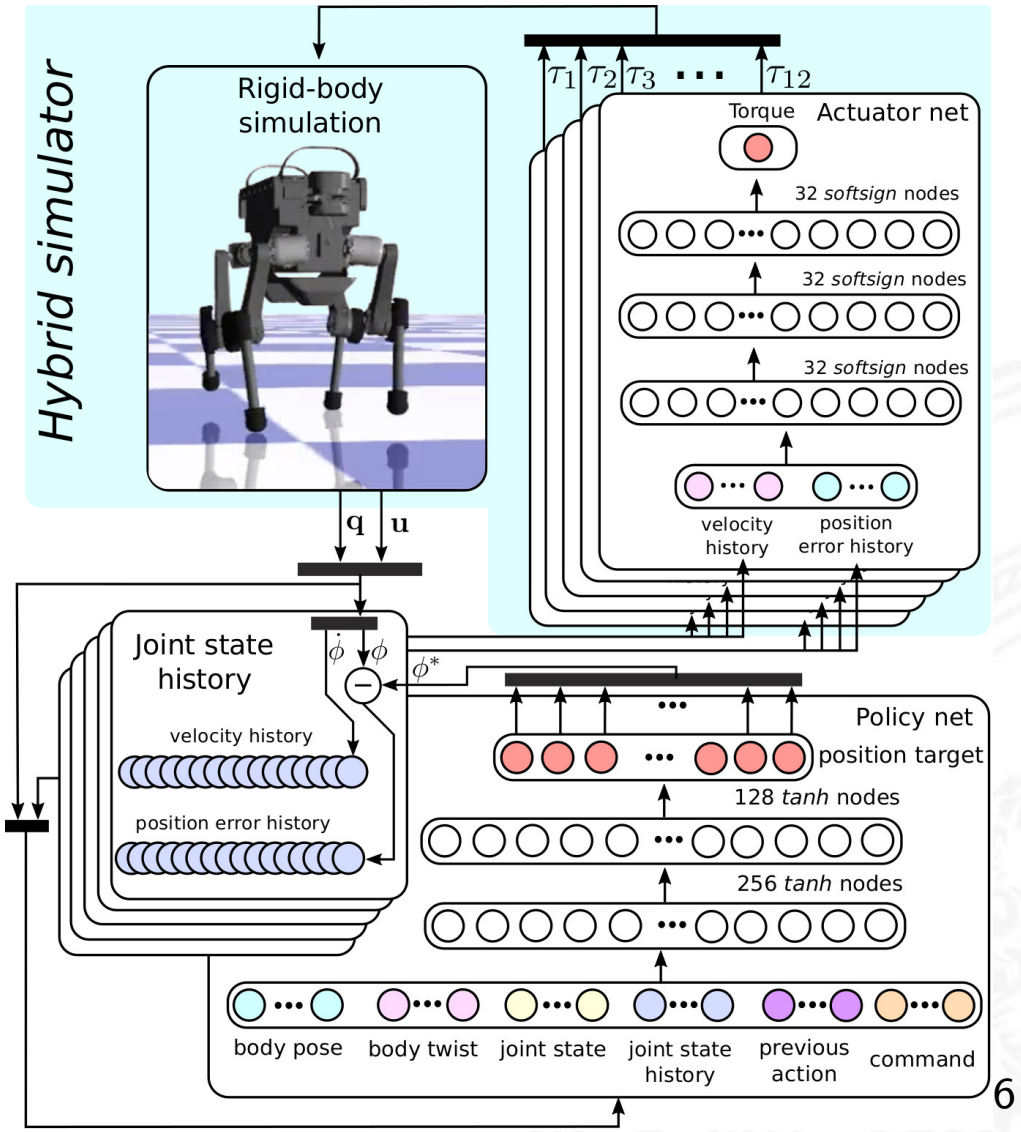
PID Controllers



[5] Sergi et al., "Design and characterization of a compact rotary series elastic actuator for knee assistance during overground walking".

Neural Networks



[6] Hwangbo et al., "Learning agile and dynamic motor skills for legged robots".

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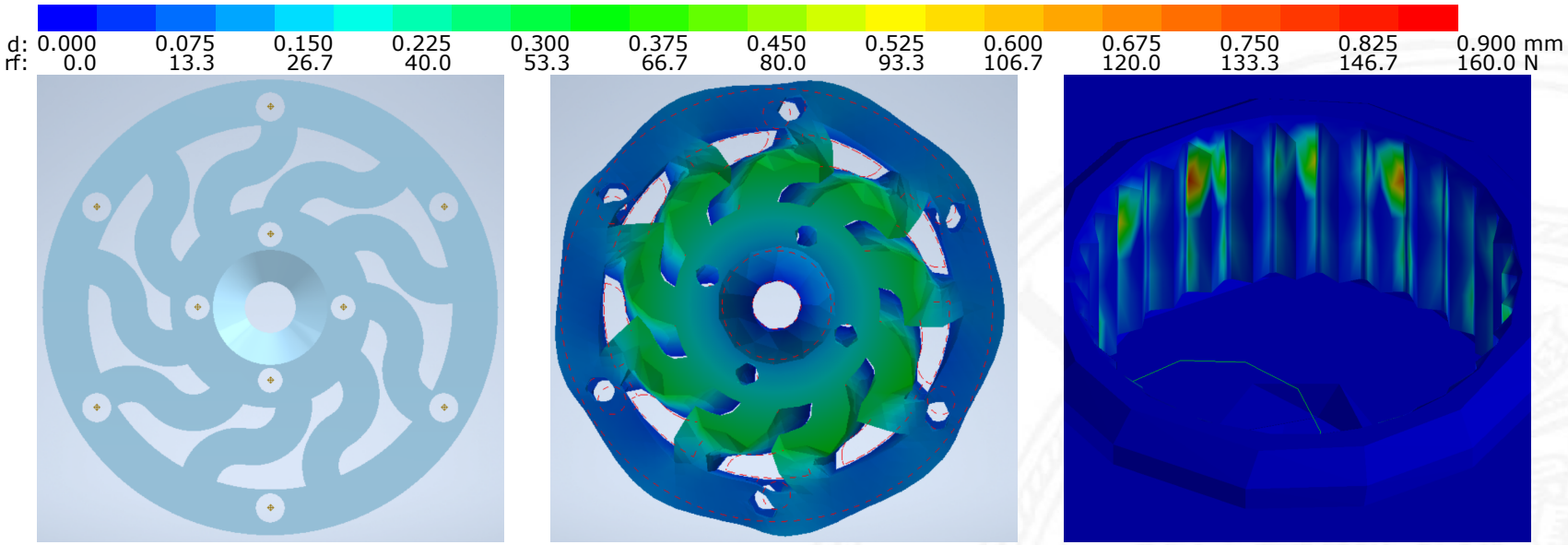
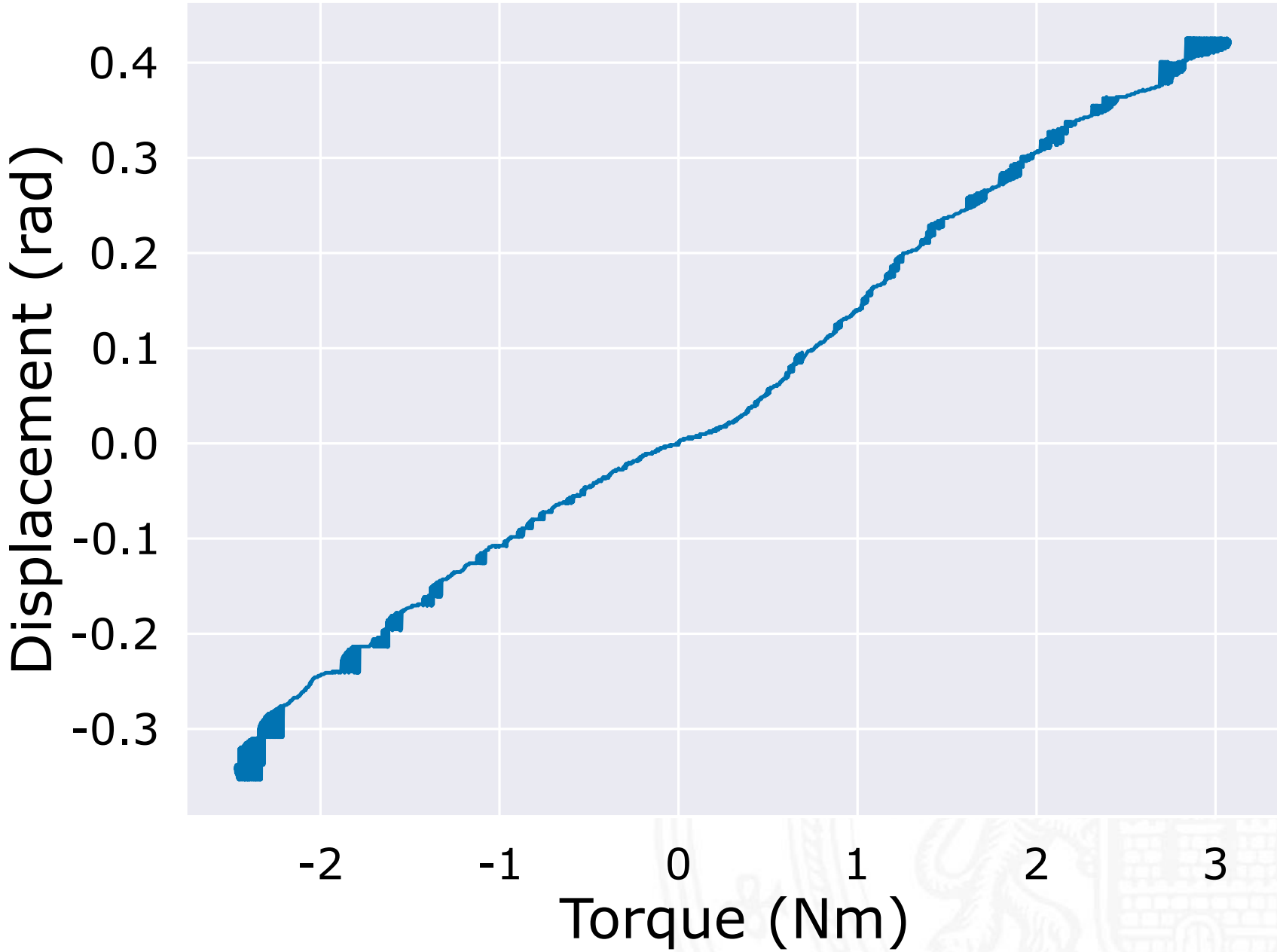
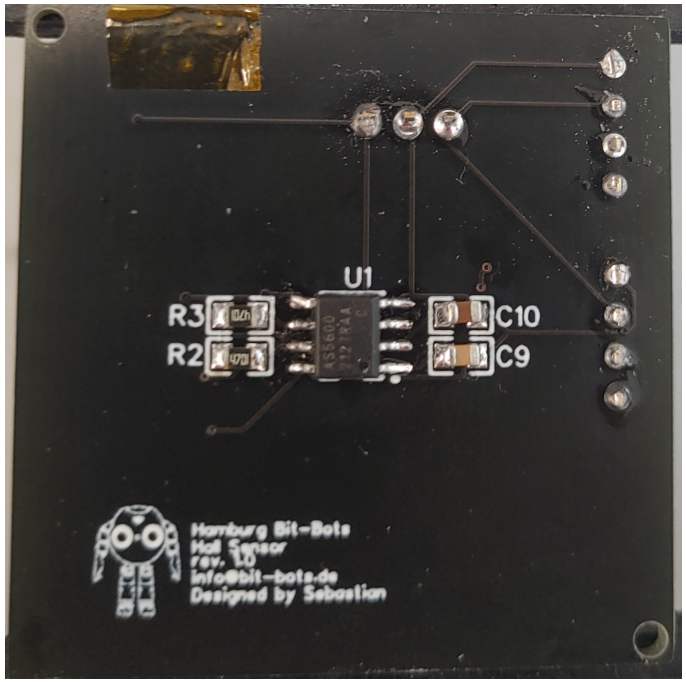
Hardware: SEA Choice

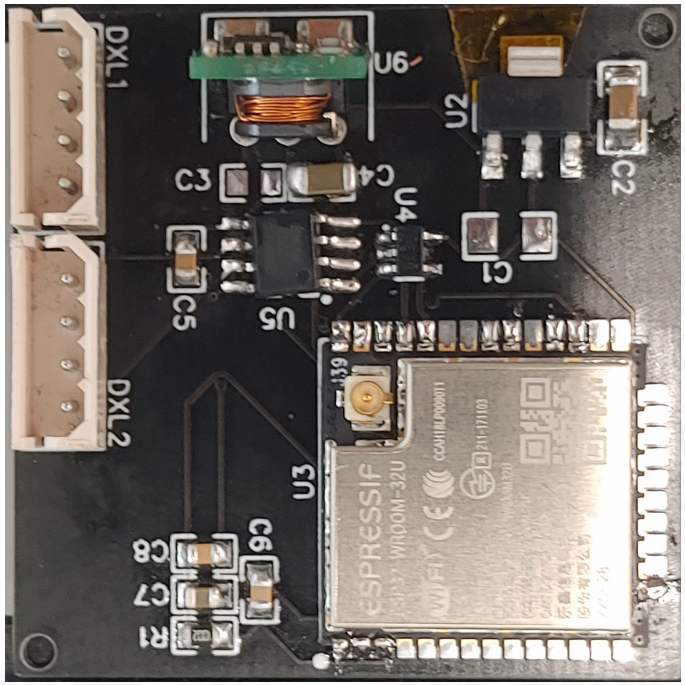


Hardware cont.: SEA Choice cont.



Hardware cont.: Hall Sensor Board





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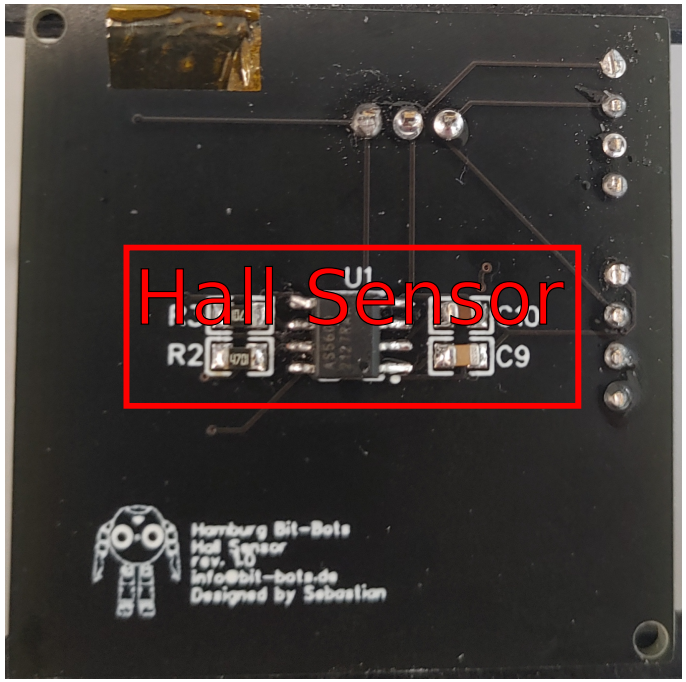
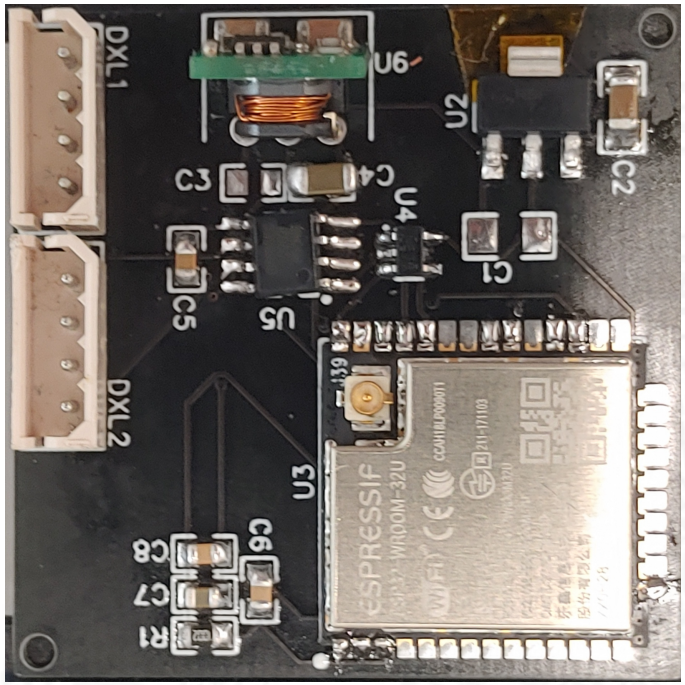
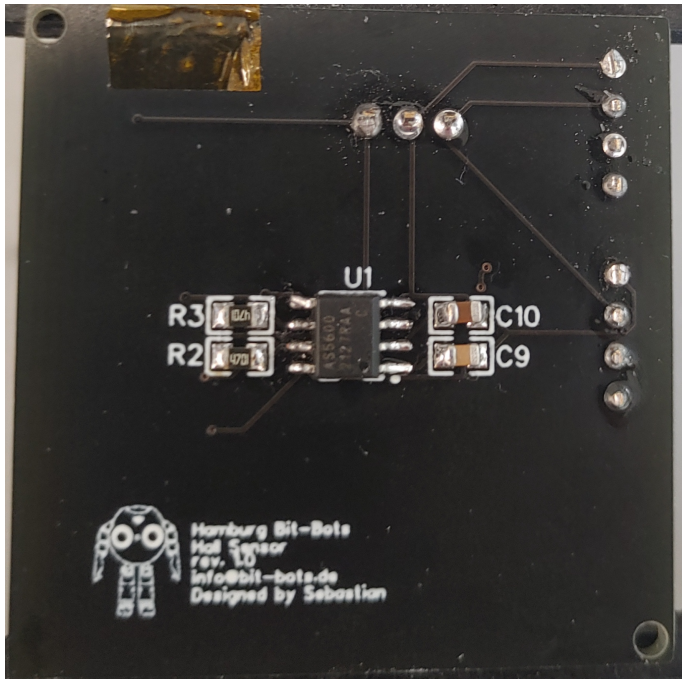
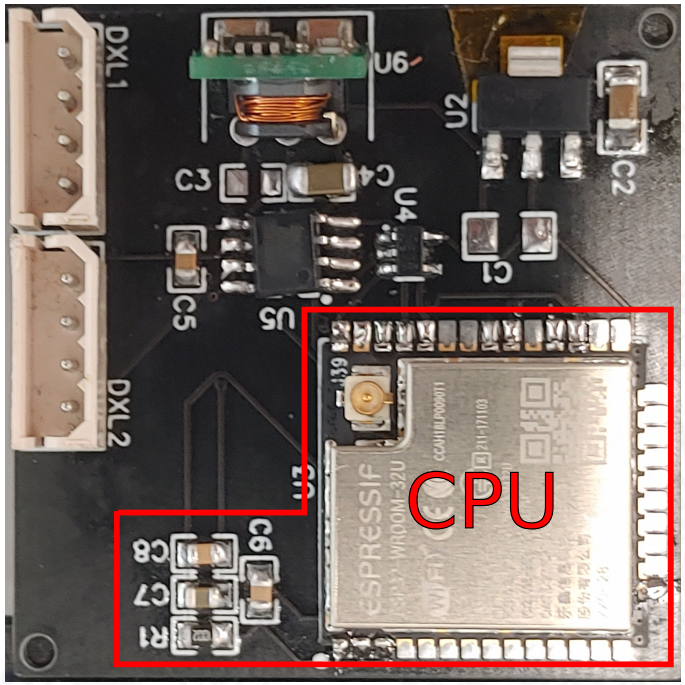




Hardware cont.: Hall Sensor Board





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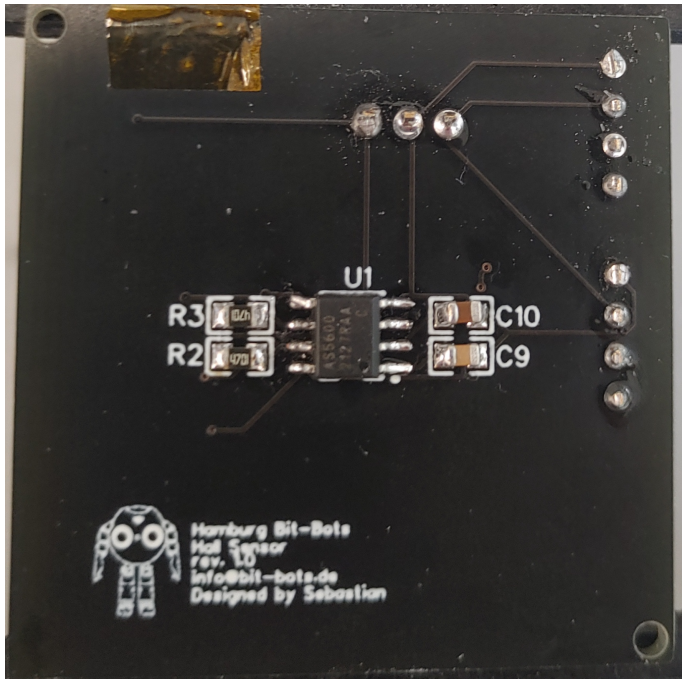

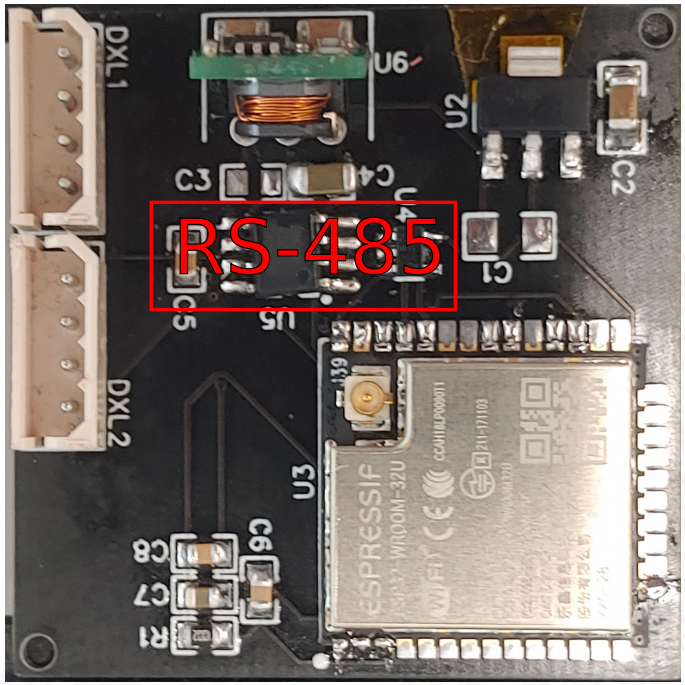

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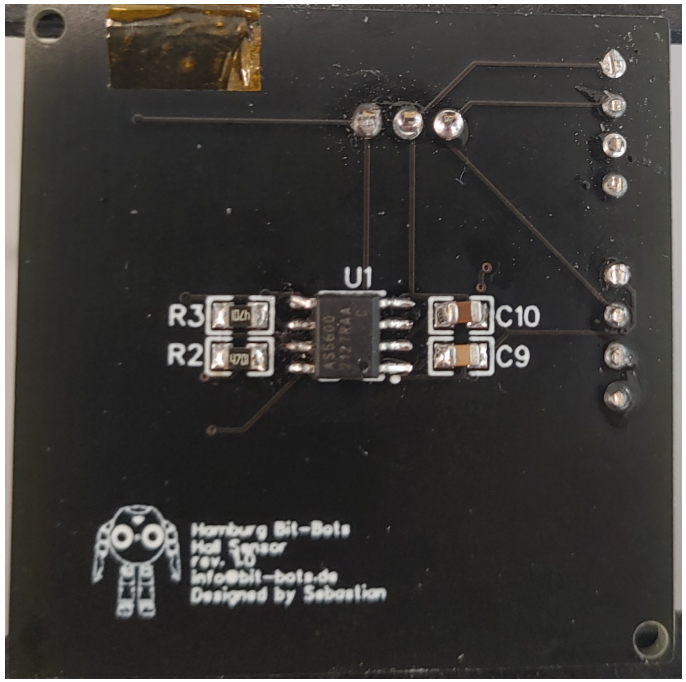
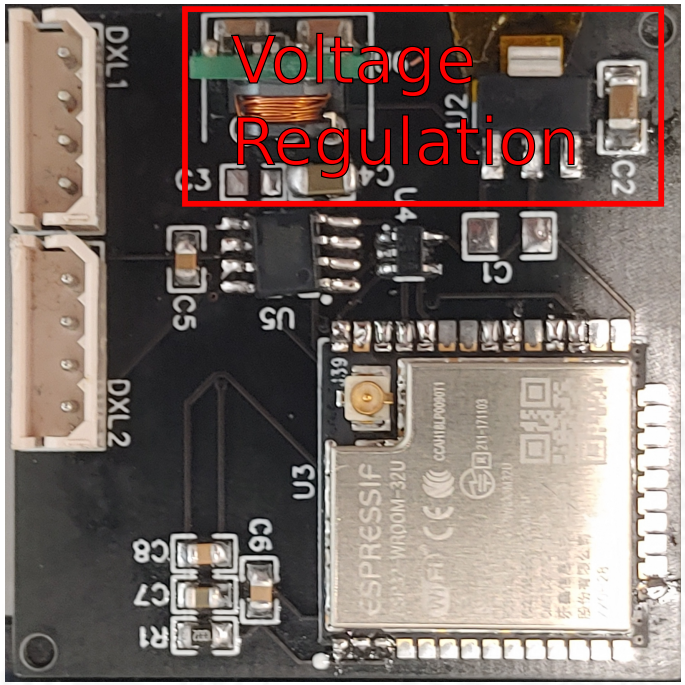
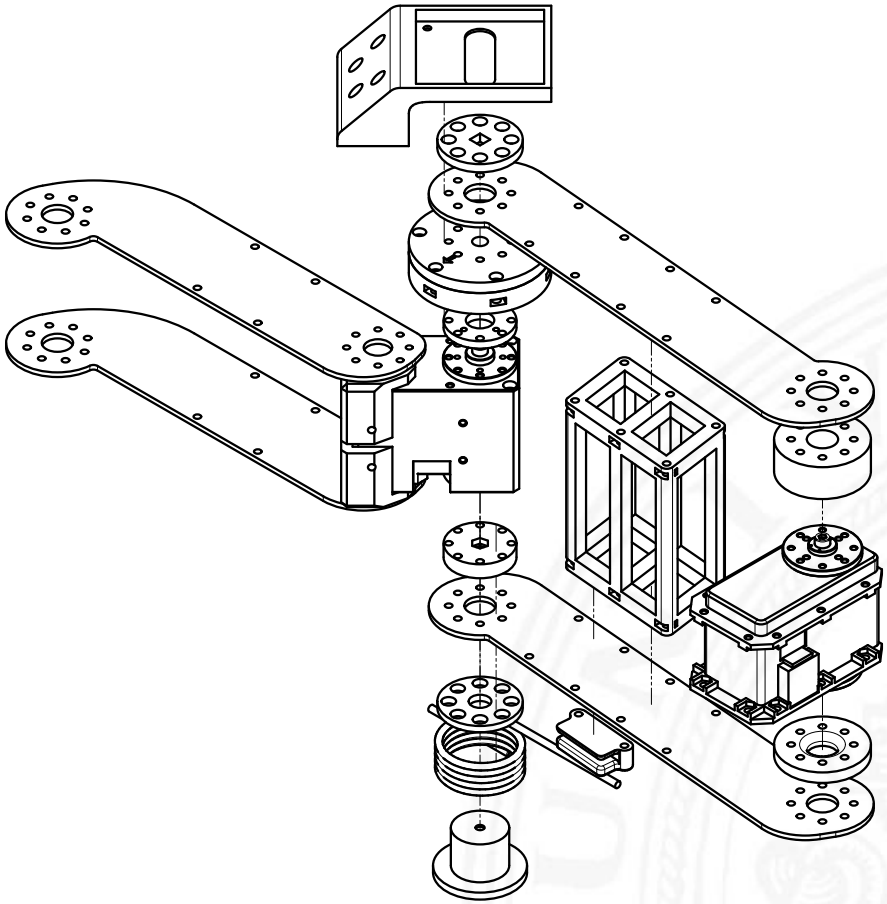
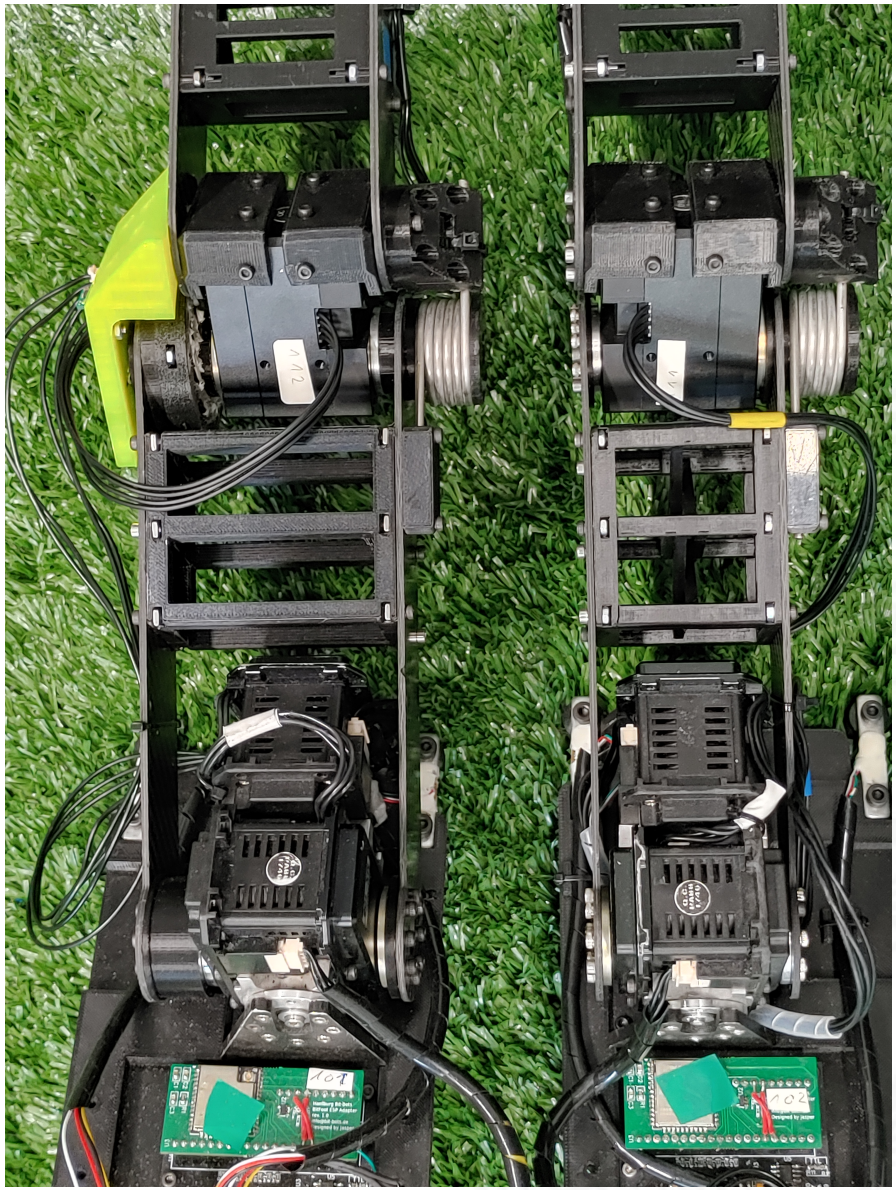




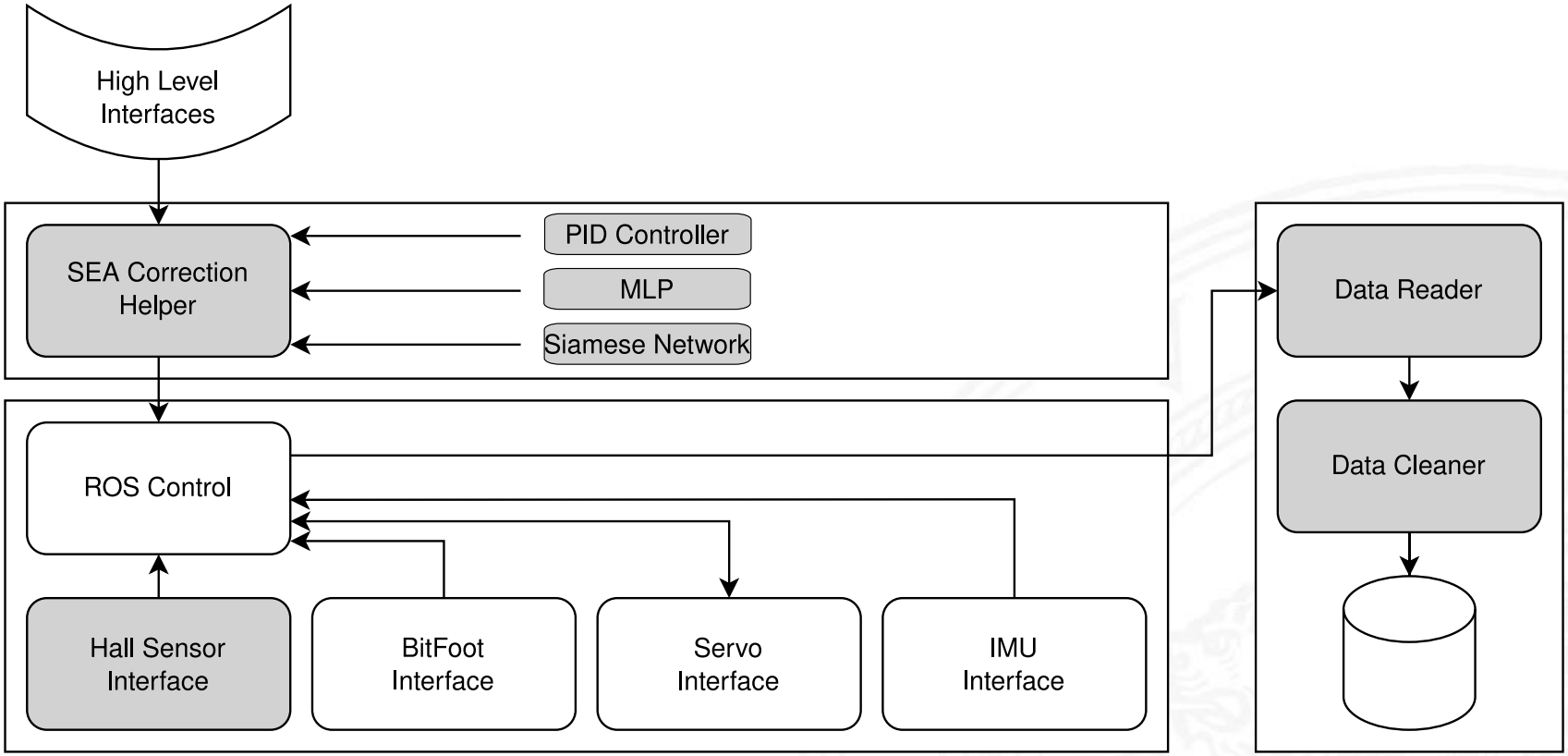
Hardware cont.: Assembly



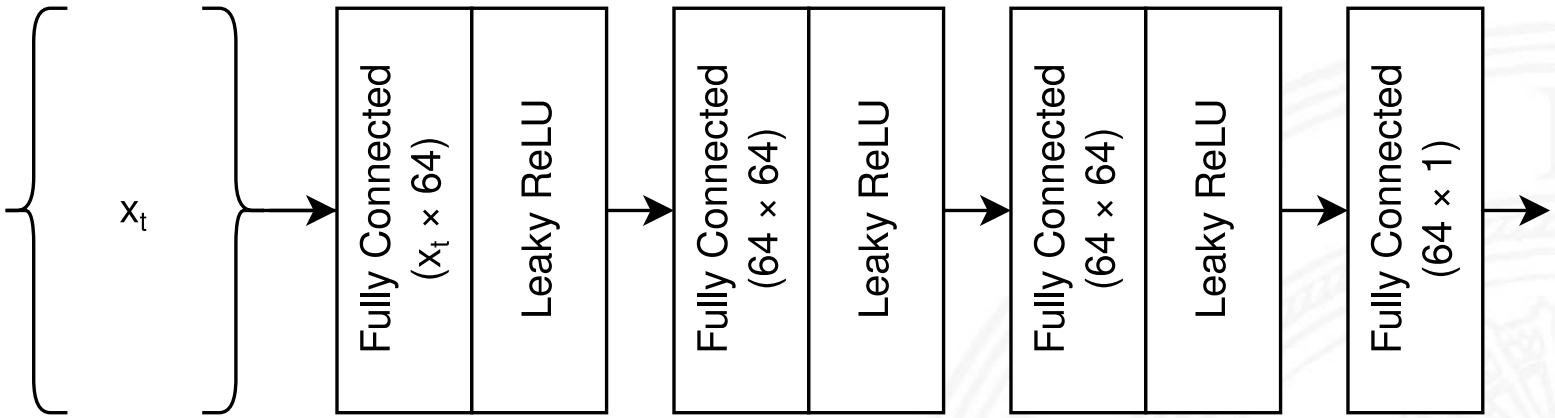
Hardware cont.: Assembly cont.



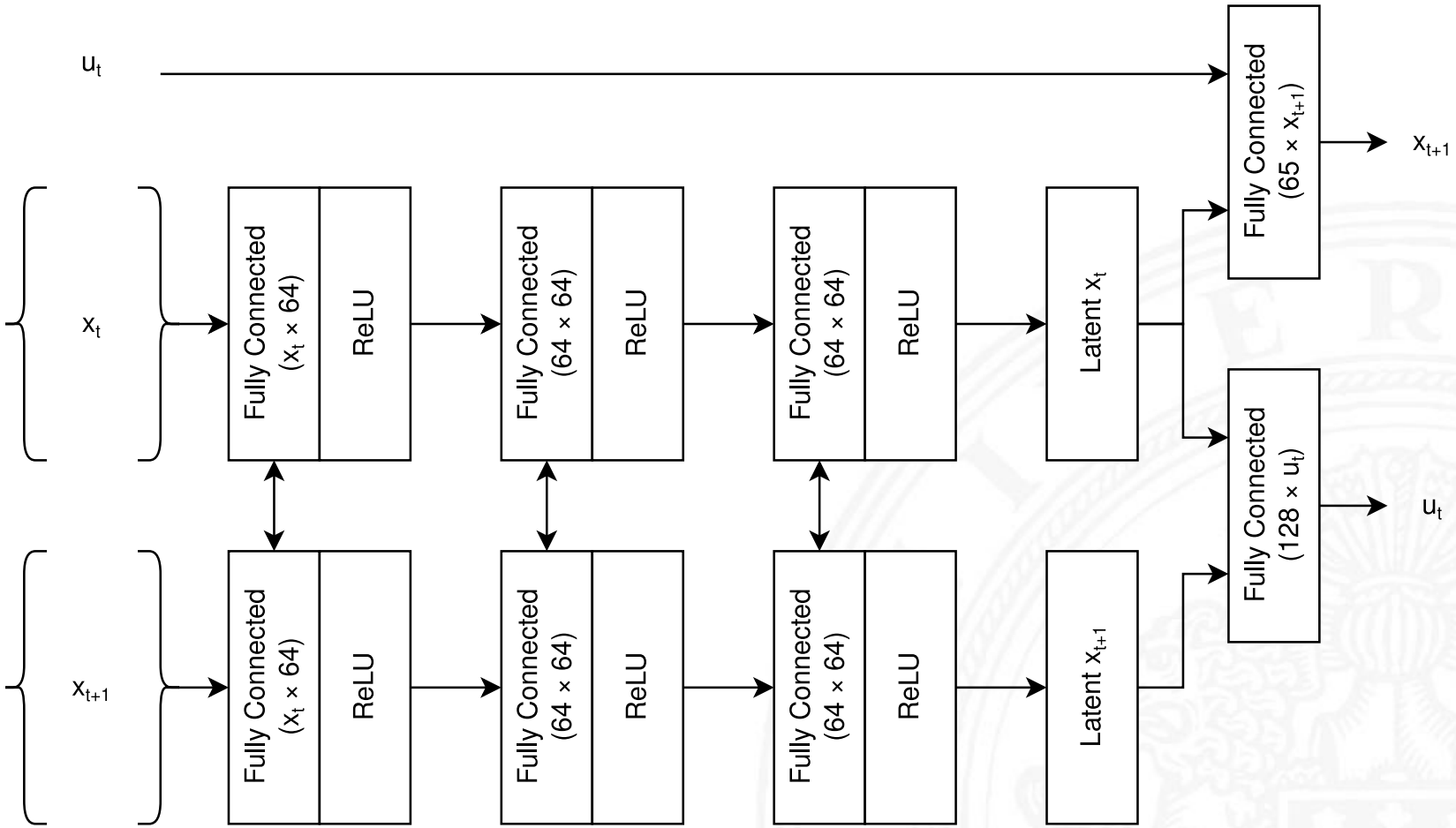
Software: Overview



Software cont.: MLP



Software cont.: Siamese Network



Outline

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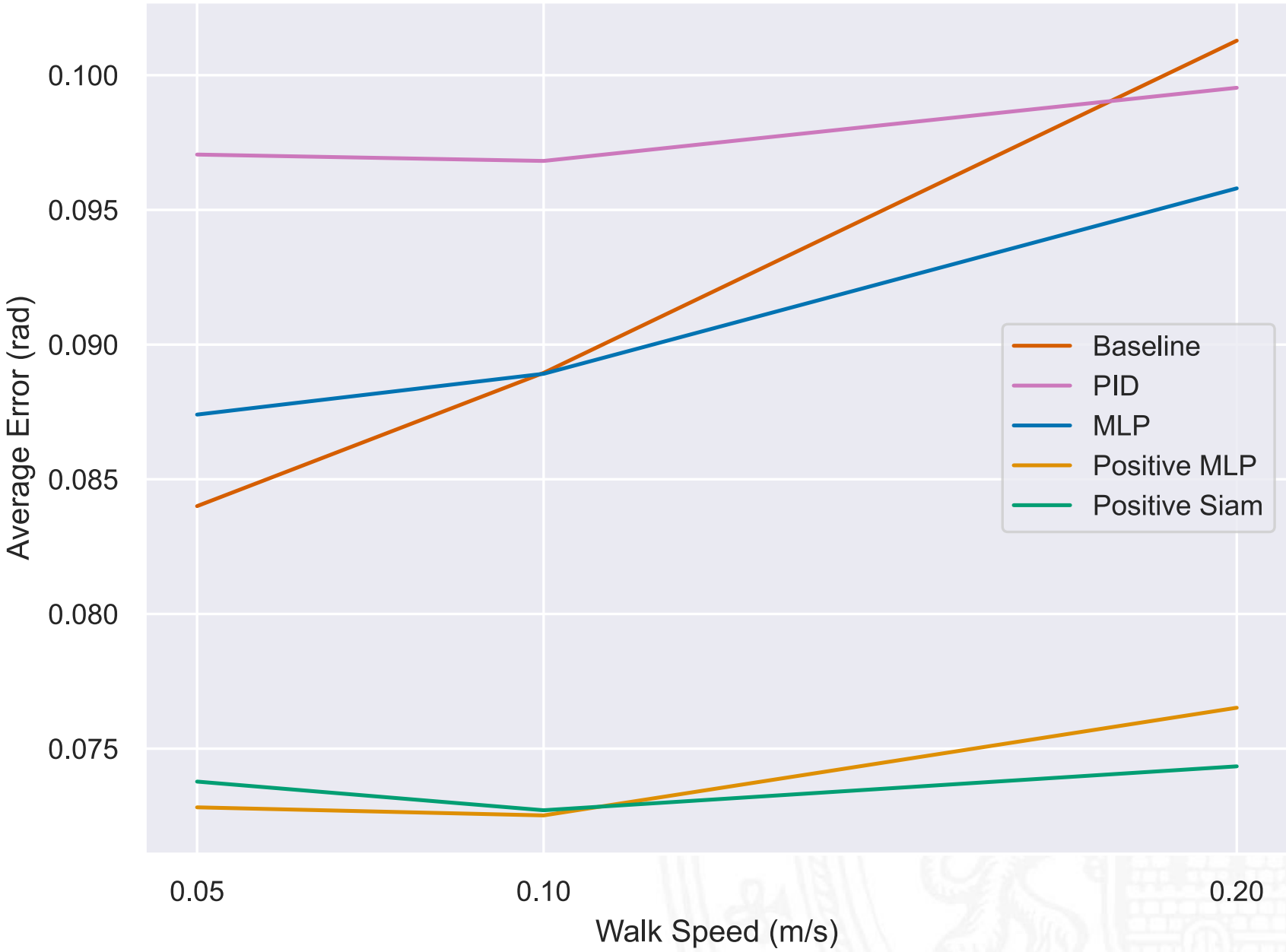
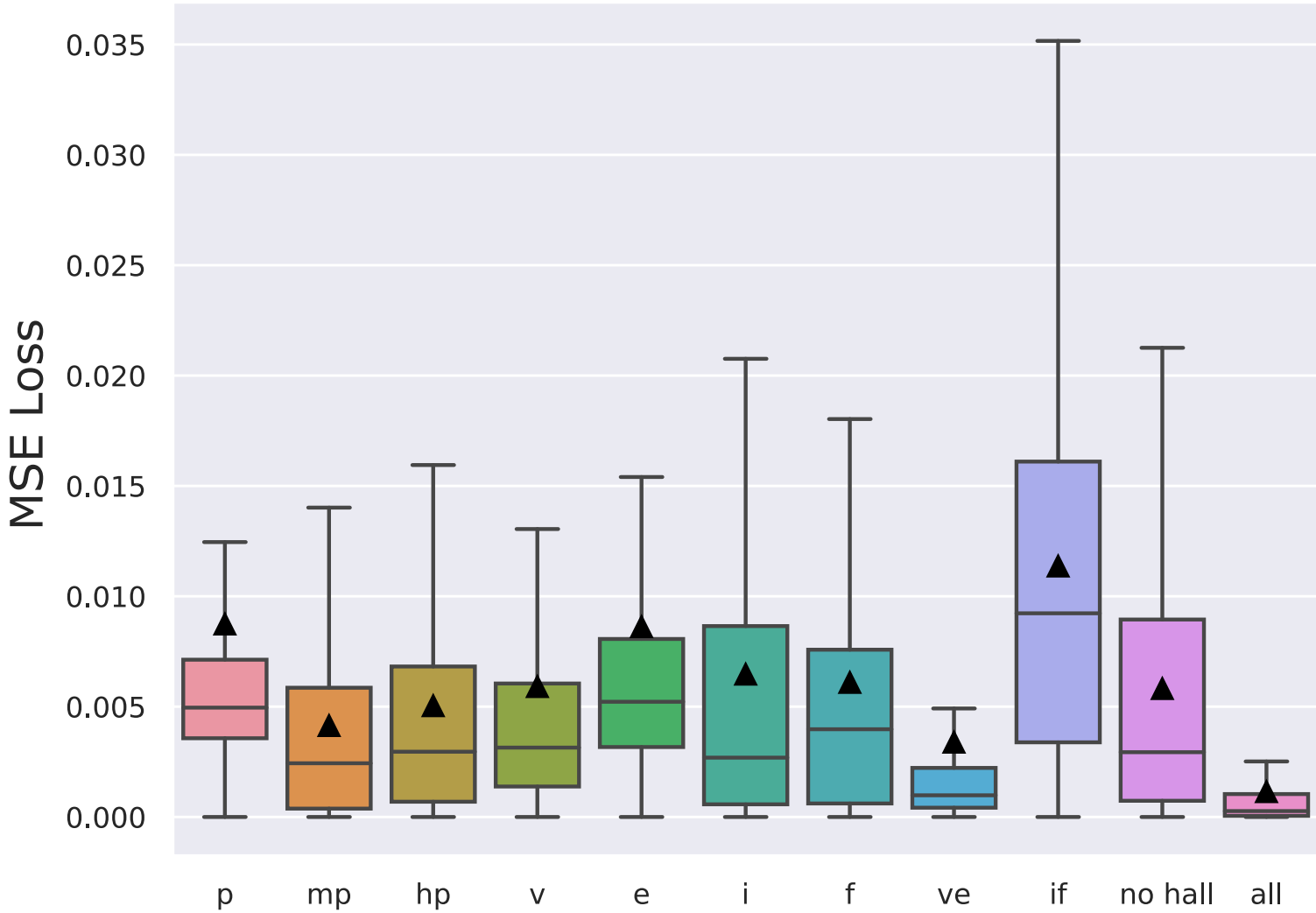
Experiment Setup

- Training parameters
  - Adam optimizer
  - Learning rate 10^{-6}
  - Batch size 32
  - 2500 epochs
- Datsets recorded on real robot walking in different directions
- Evaluation on real robot or prerecorded dataset

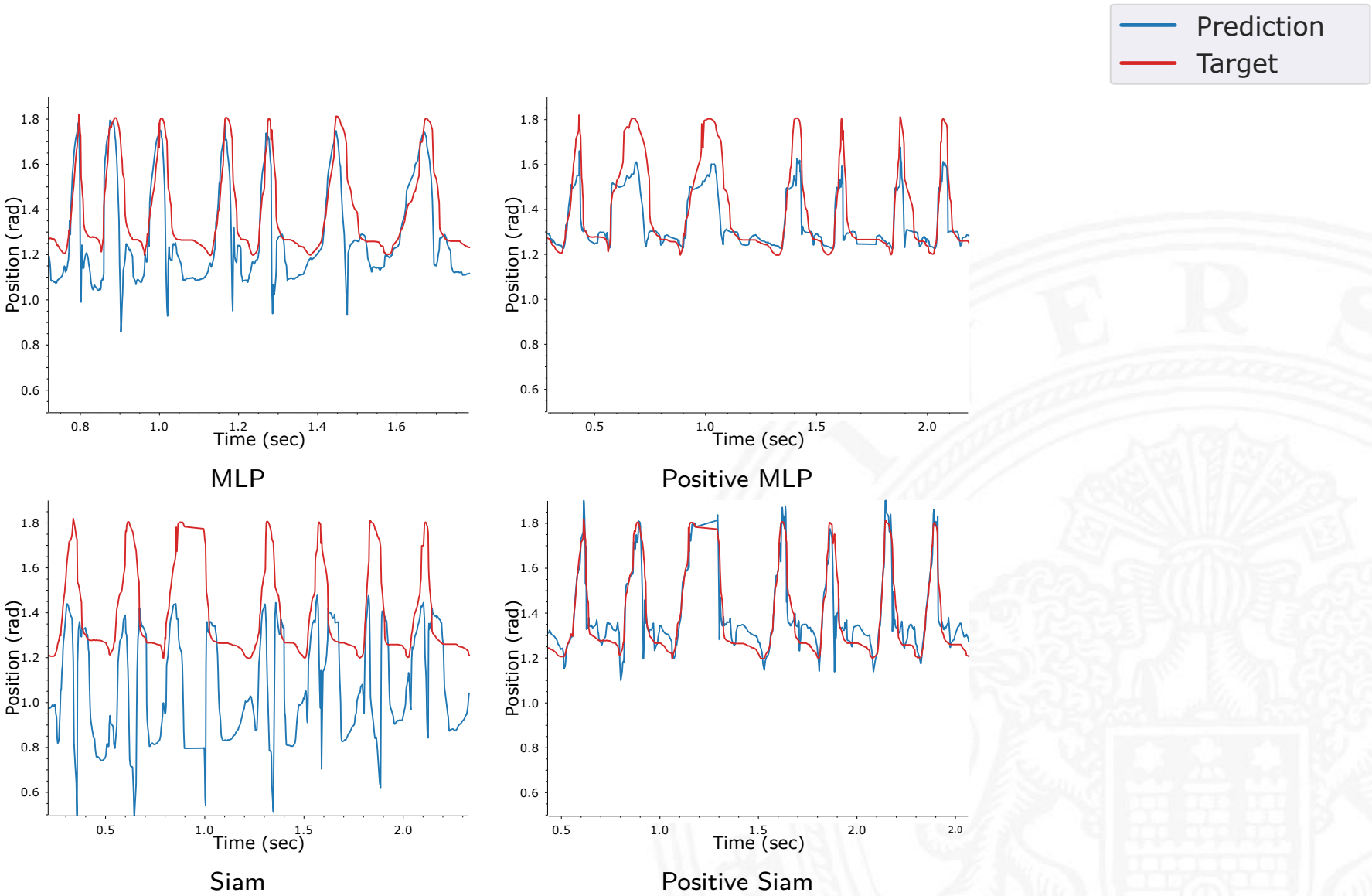
Free Hanging Robot



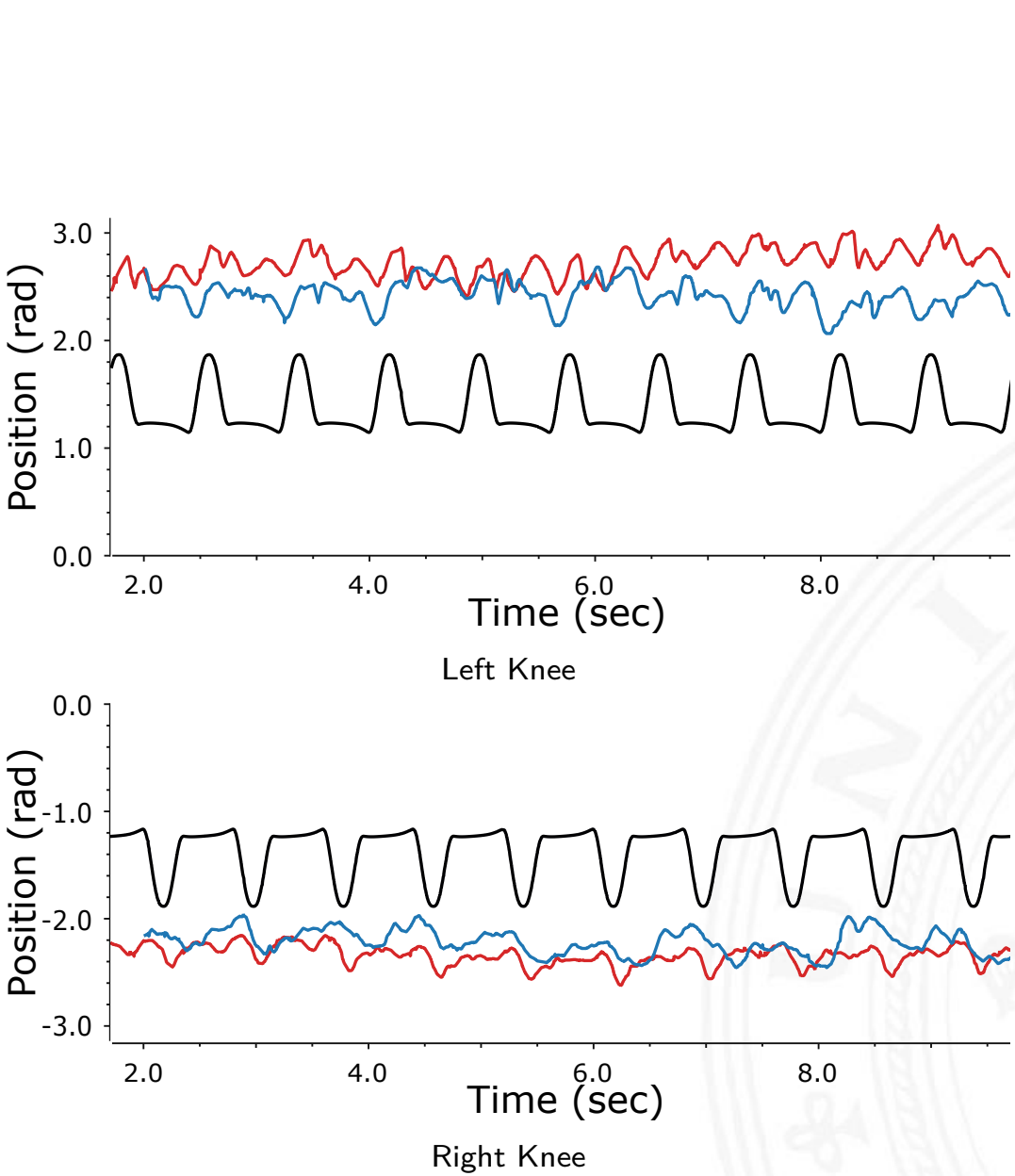
Ablation Study



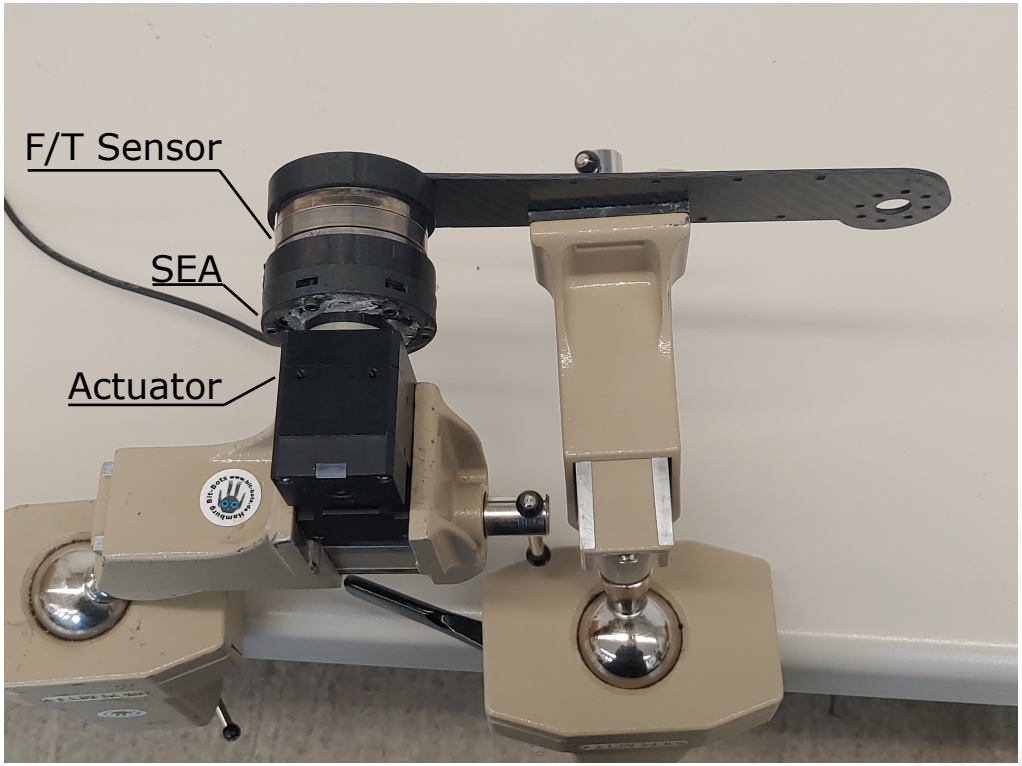
Model Types


Prediction
Target
Position (rad)
Time (sec)
MLP
Positive MLP
Siam
Positive Siam

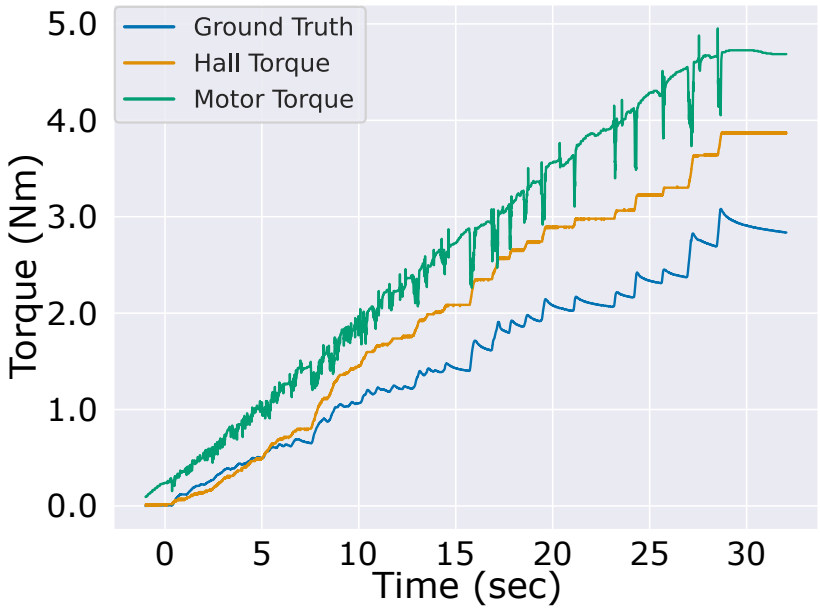
Transfer to Real World

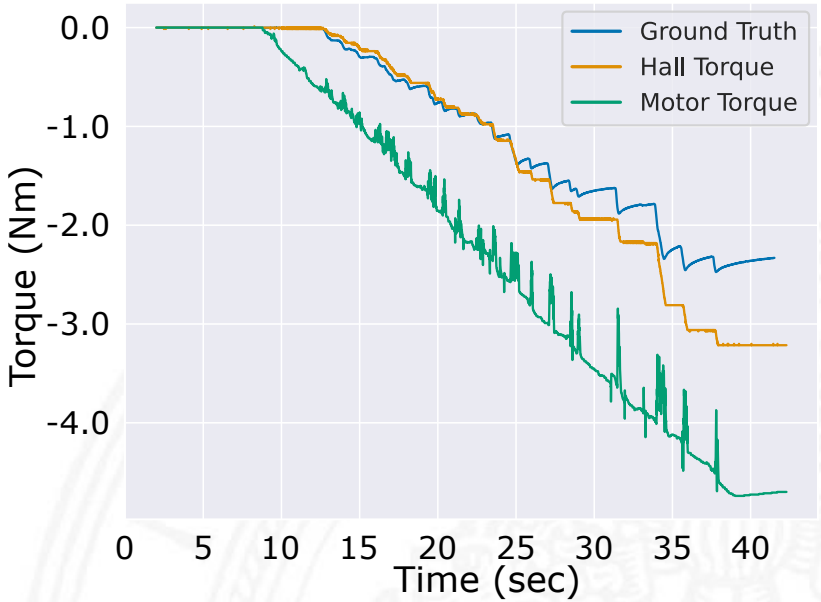


Using SEAs as Torque Sensors

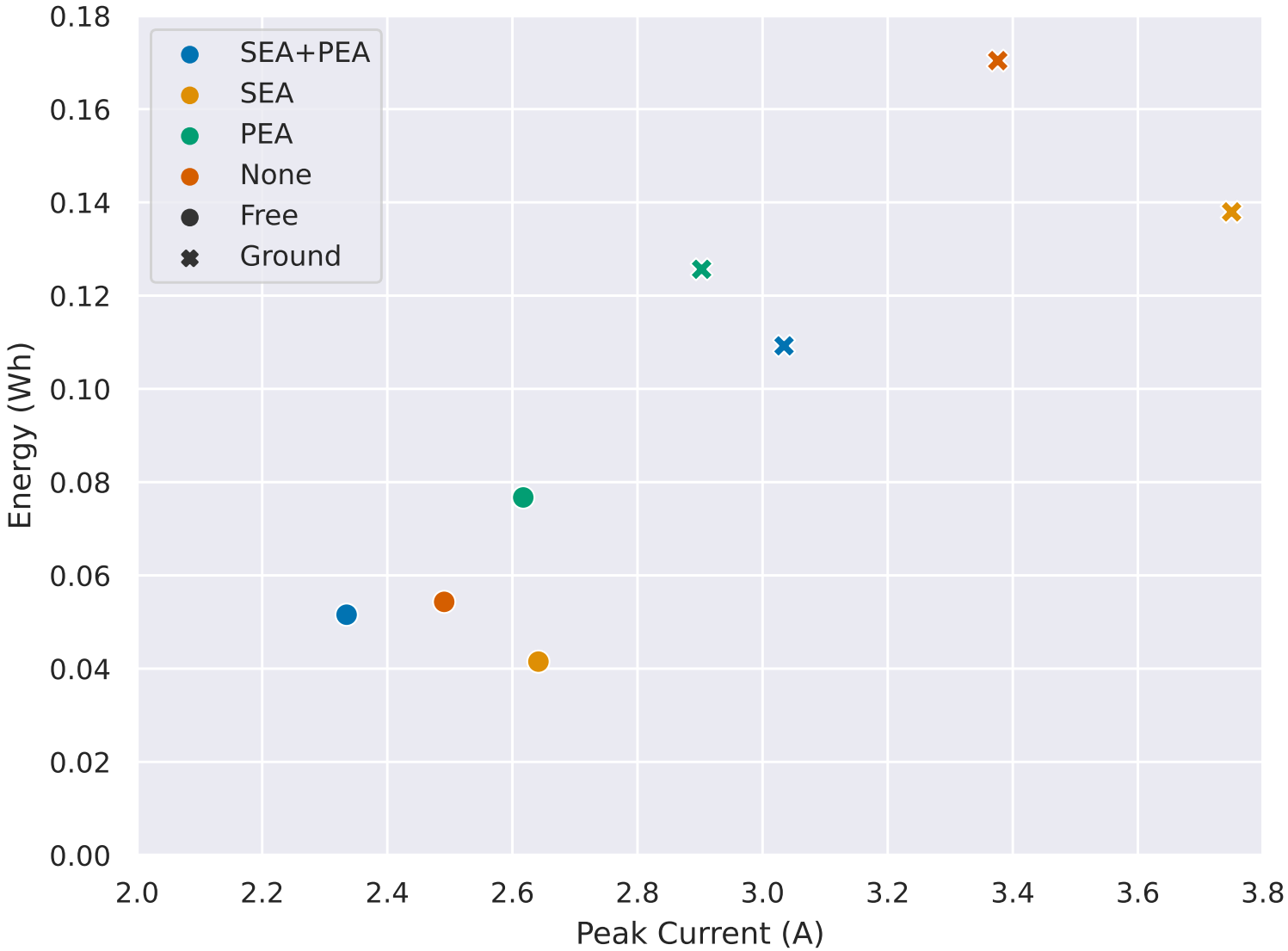


Using SEAs as Torque Sensors cont.





Energy Consumption



Outline

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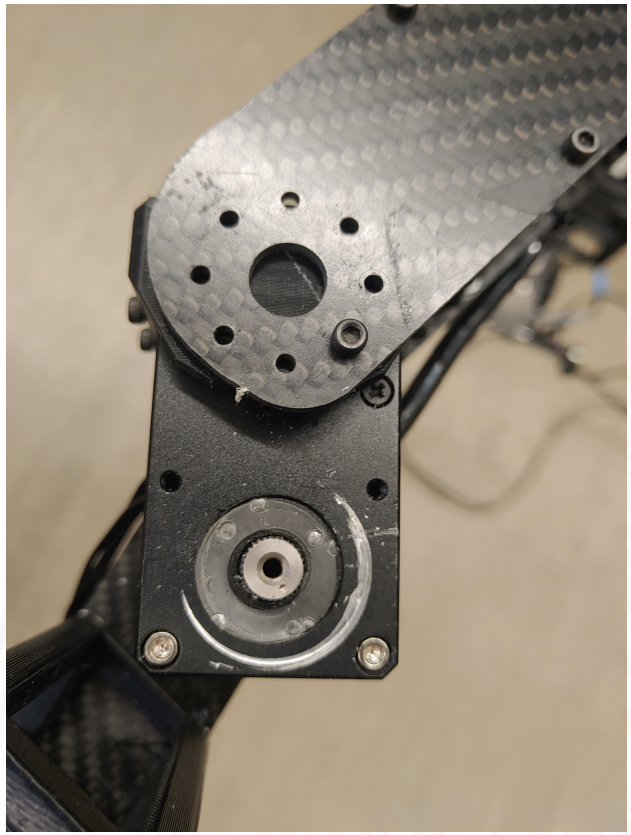
Discussion

- Overall promising results
- Hardware limitations
  - Strong shear forces
  - Spring too weak
  - Filament weakens under heat
  - Sensor inaccuracies



Discussion cont.

- Software limitations
  - Training samples only contain small errors
  - Feedback loop causes convergence towards one value

Outline

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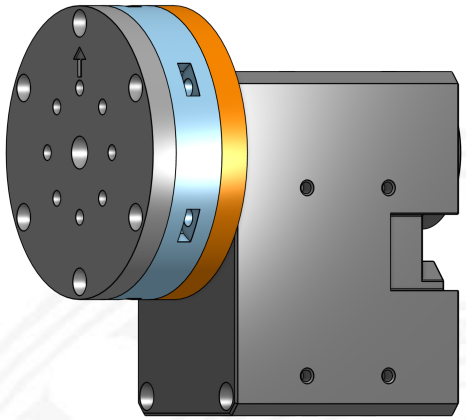
Conclusion

- Corrections achieved with this method work
- Hardware seems biggest problem right now
- Framework for evaluating new approaches
- SEAs as torque sensors
- Energy Efficiency

Future Work

- Improved Hardware
- Iterative or continuous learning
  - PyAOgmaNeo[7]



8

[7] https://ogma.ai/

[8] https://www.robotis.us/epx540-br101-set/

References

Hwangbo, Jemin et al. "Learning agile and dynamic motor skills for legged robots". In: *Science Robotics* 4.26 (2019), eaau5872.

Lee, Chan and Sehoon Oh. "Development, analysis, and control of series elastic actuator-driven robot leg". In: *Frontiers in neurorobotics* 13 (2019), p. 17.

Martins, Leandro Tomé et al. "A polyurethane-based compliant element for upgrading conventional servos into series elastic actuators". In: *IFAC-PapersOnLine* 48.19 (2015), pp. 112–117.

Sergi, Fabrizio et al. "Design and characterization of a compact rotary series elastic actuator for knee assistance during overground walking". In: *2012 4th IEEE RAS & EMBS International Conference on Biomedical Robotics and Biomechatronics (BioRob)*. IEEE. 2012, pp. 1931–1936.

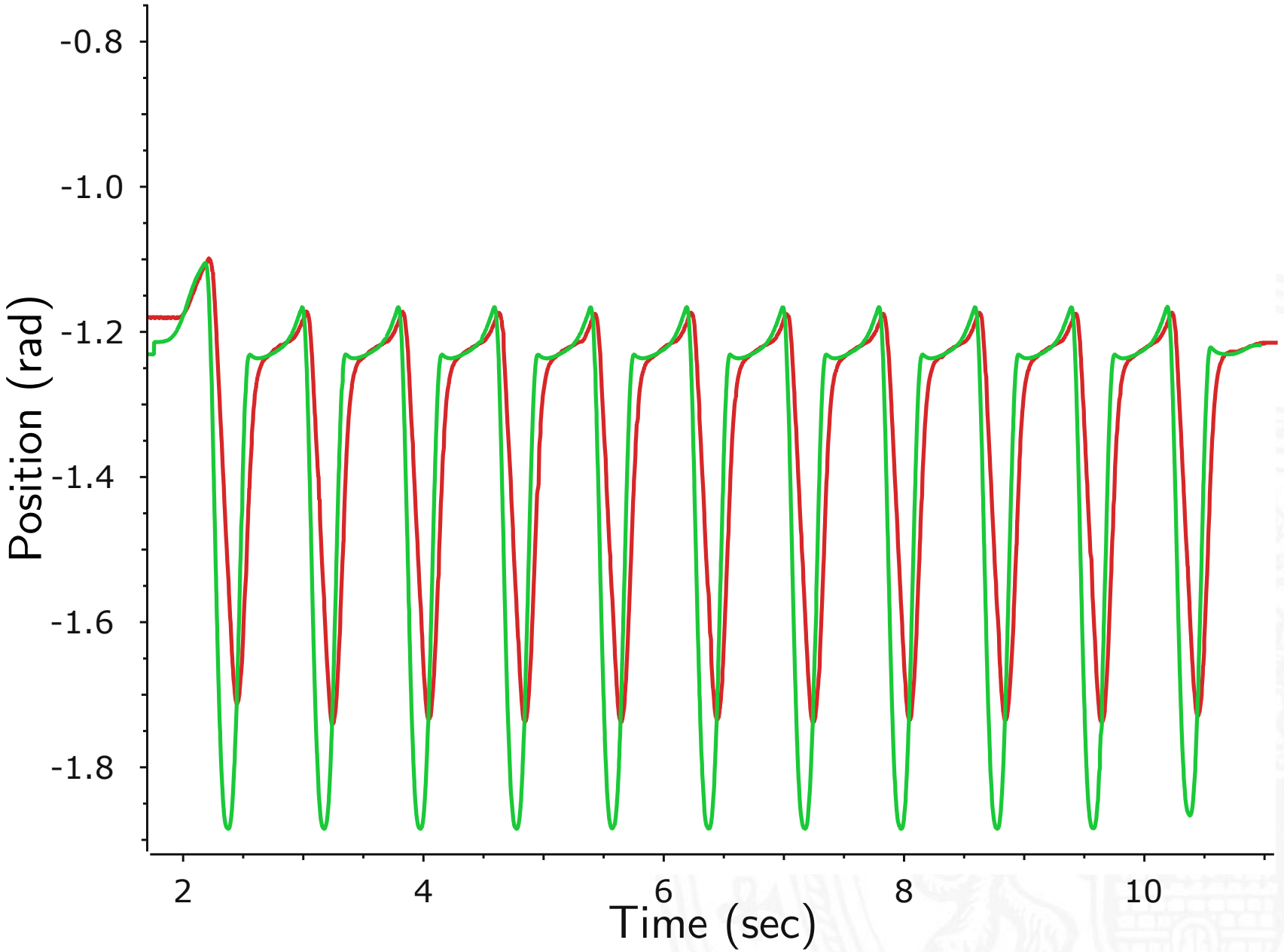
References (cont.)

Yu, Bingbin et al. "Learning the elasticity of a series-elastic actuator for accurate torque control". In: *International Conference on Industrial, Engineering and Other Applications of Applied Intelligent Systems*. Springer. 2017, pp. 543–552.

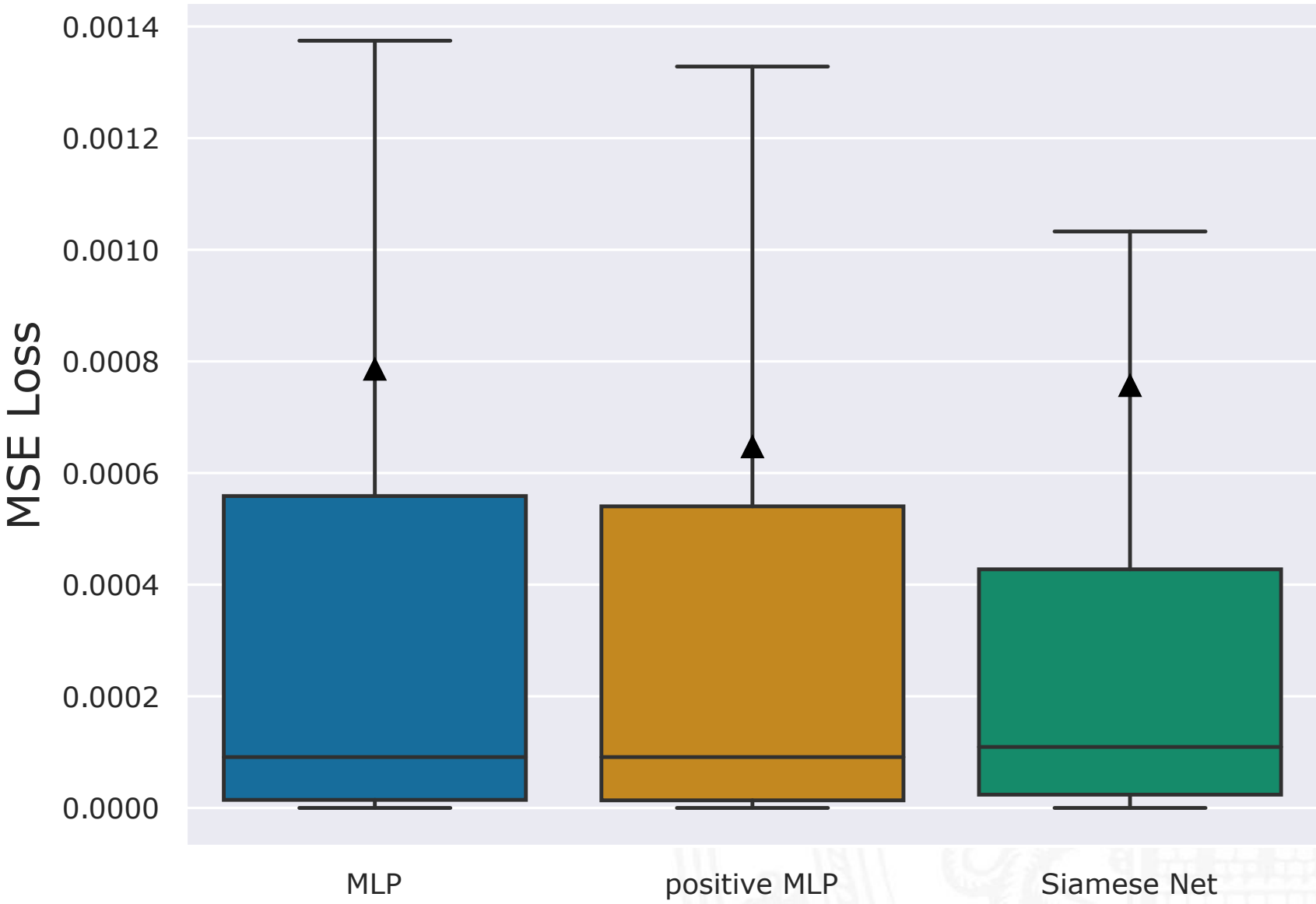
Thank you for your attention!

https://github.com/16stelter/deepSEA

Motor Position and Motor Command



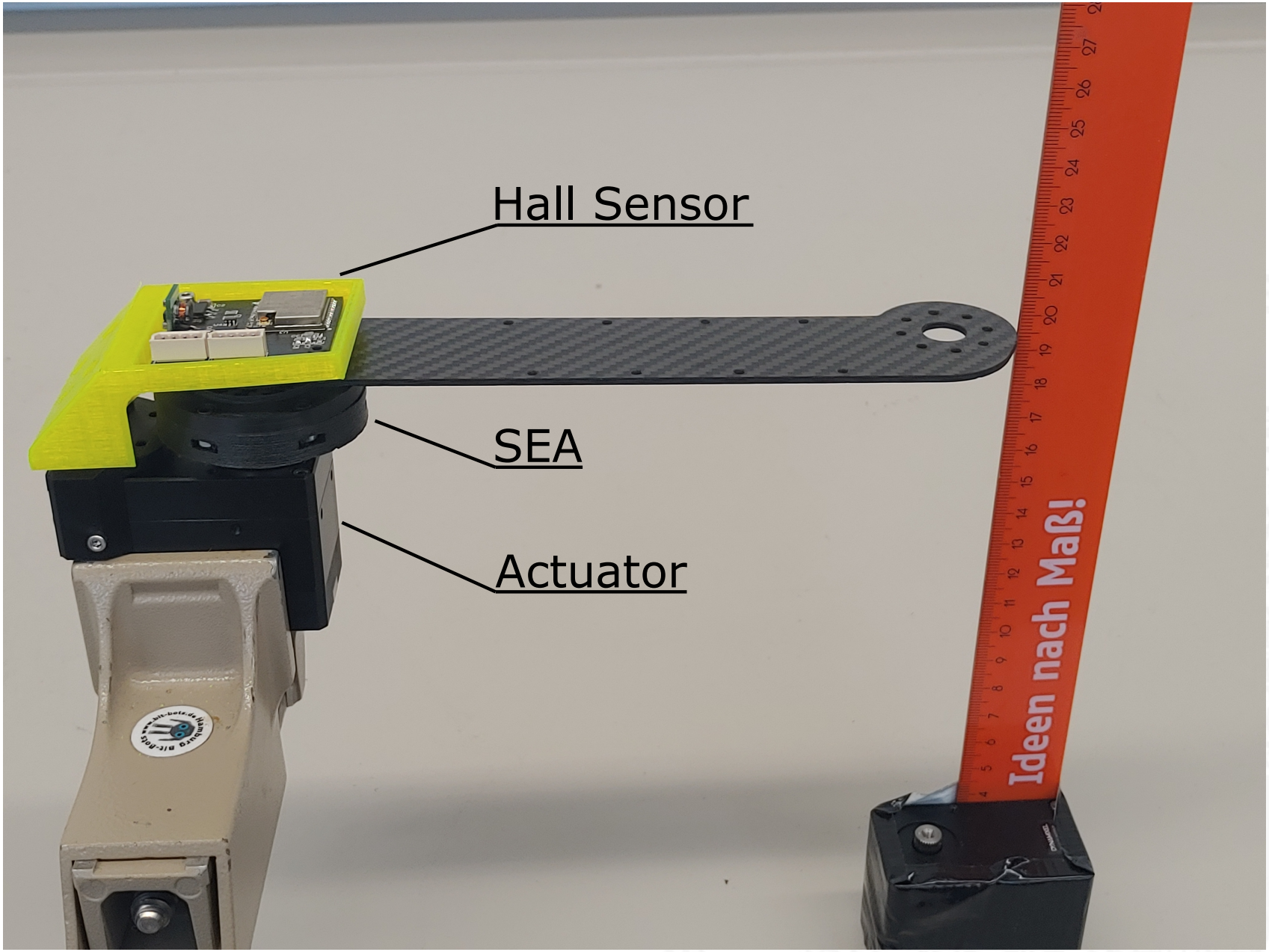
Free Hanging Robot cont.



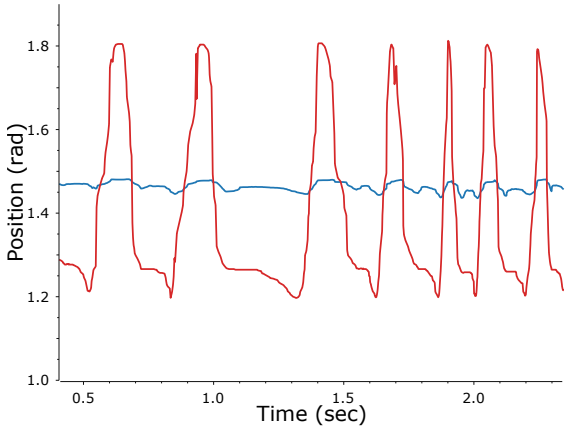
Datasets

	Unmodified	"Positive"
ID	555	555
RKnee Pos	-0.506347688	0.506347688
RHall Pos	-0.777292145	0.777292145
RKnee Vel	1.798561096	-1.798561096
RHall Vel	-1.093115501	1.093115501
RKnee Effort	0.133515464	-0.133515464
IMU	<IMU>	<IMU>
LPressure	<LPressure>	<LPressure>
RPressure	<RPressure>	<RPressure>
Timestamp	<Timestamp>	<Timestamp>

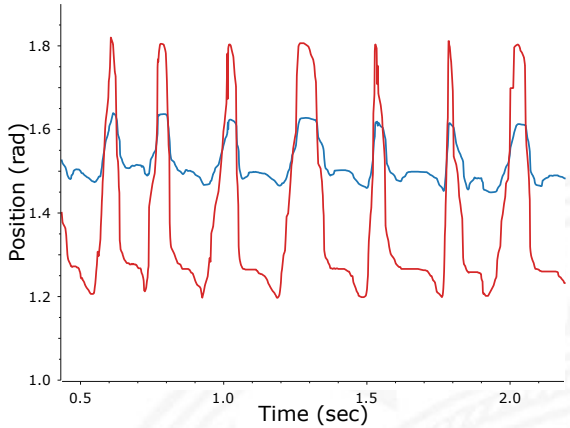
Displacement Experiment



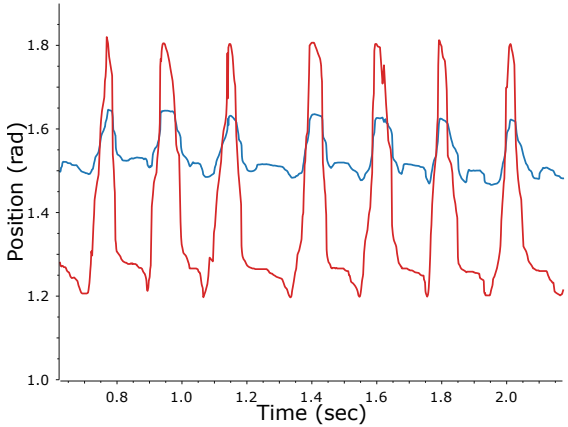
Ablation Study



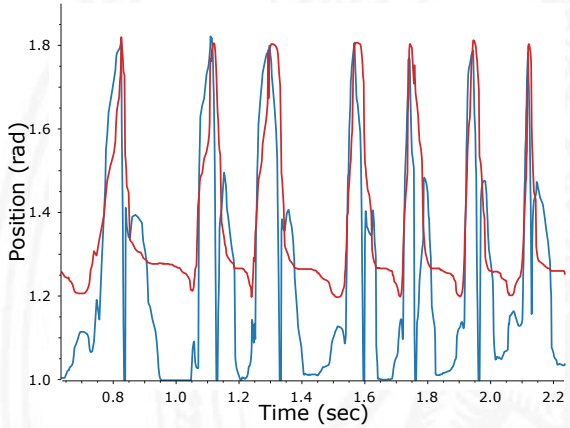
Target Only



Motor Position

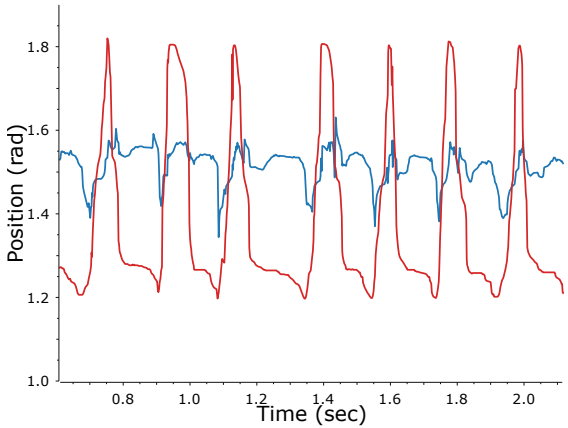


Hall + Motor Position

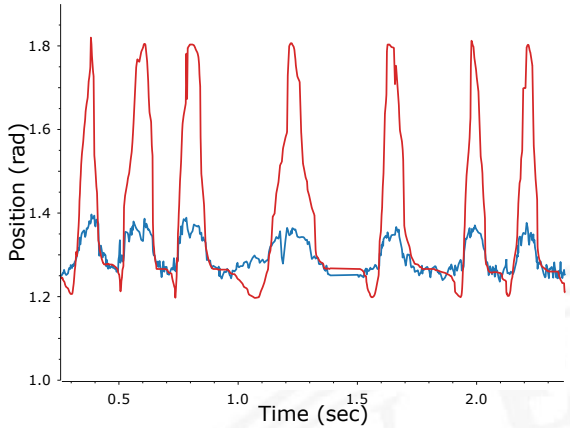


Velocity

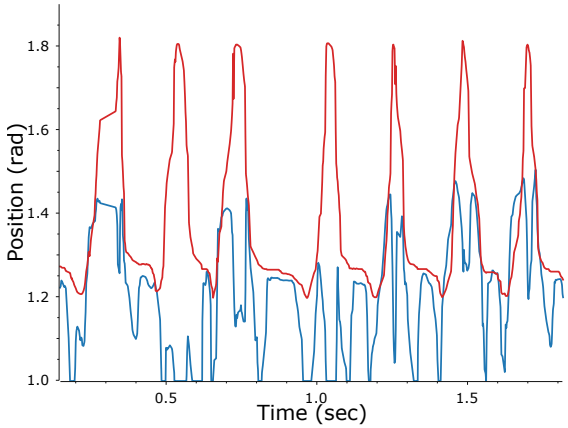
Ablation Study (cont.)



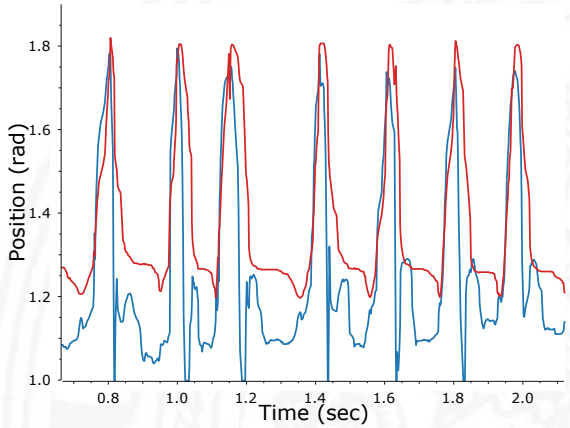
Effort



IMU

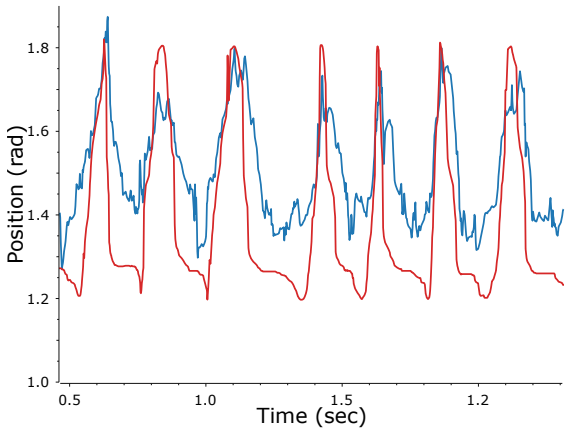


Pressure

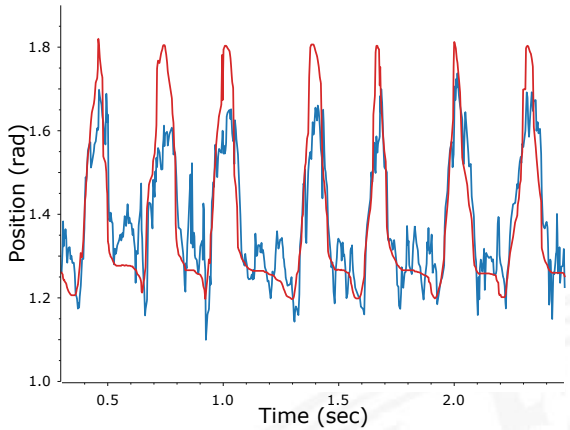


Velocity + Effort

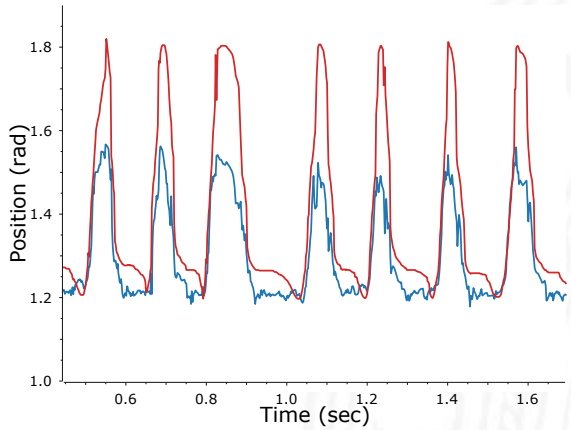
Ablation Study (cont.)



IMU + Pressure

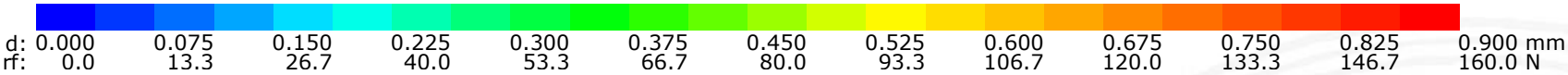


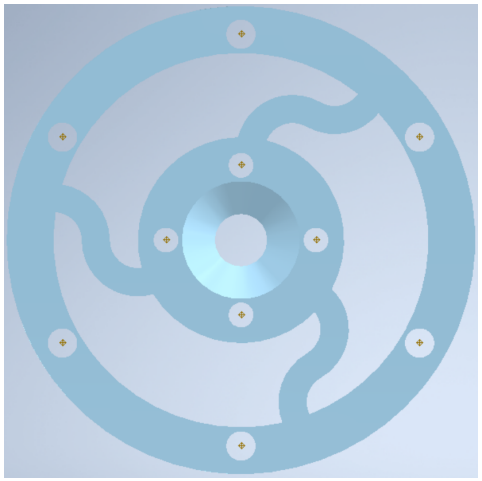
No Hall Position



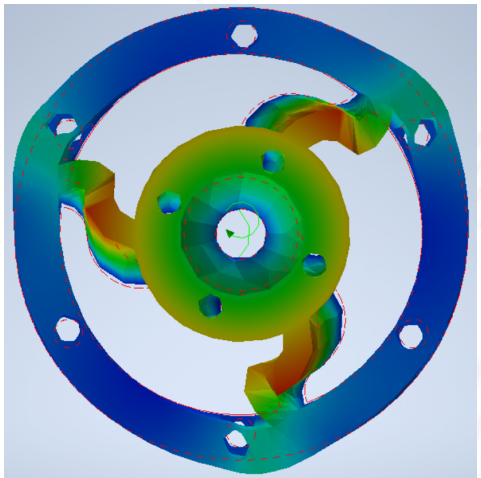
All

FEA

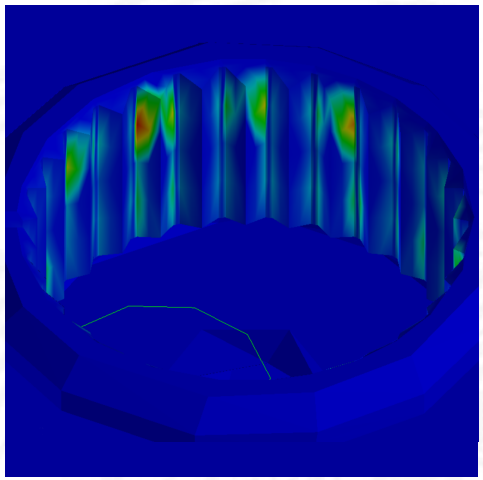




(a) 3 beams, 6 mm

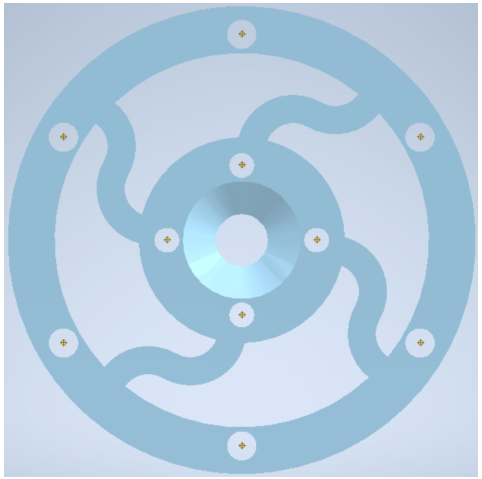


Max d: 0.859 mm

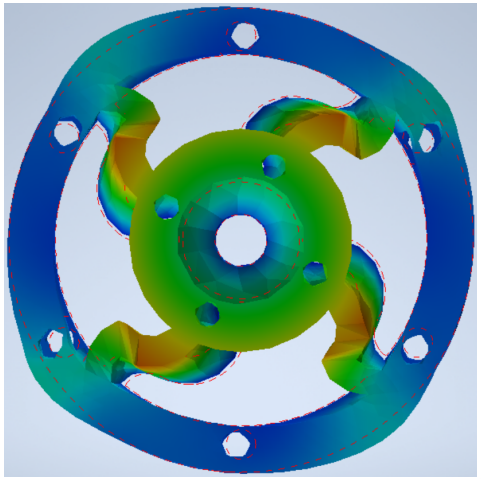


Max rf: 152.6 N

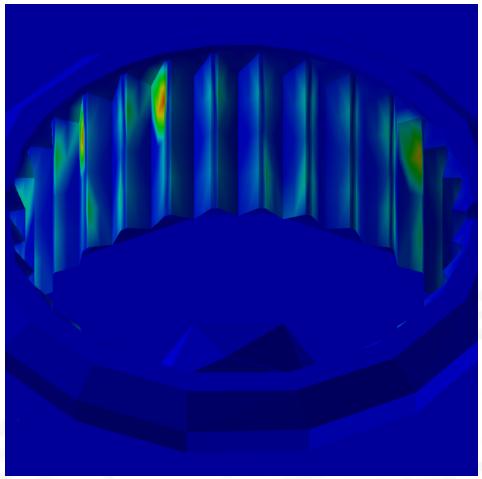
FEA (cont.)



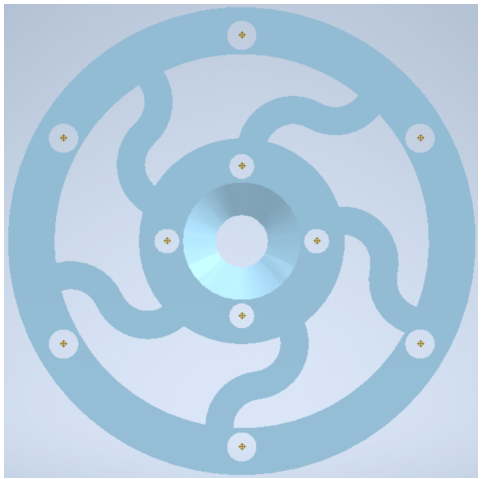
(b) 4 beams, 6 mm



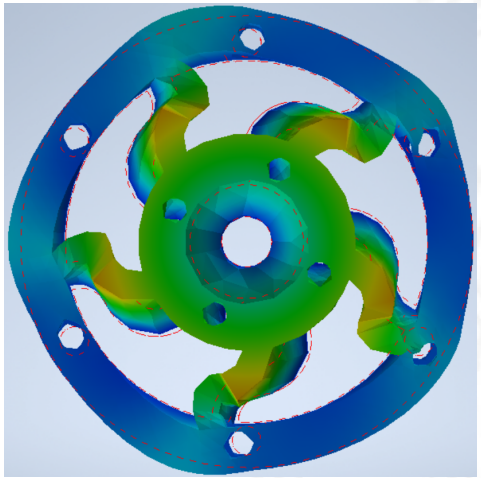
Max d: 0.745 mm



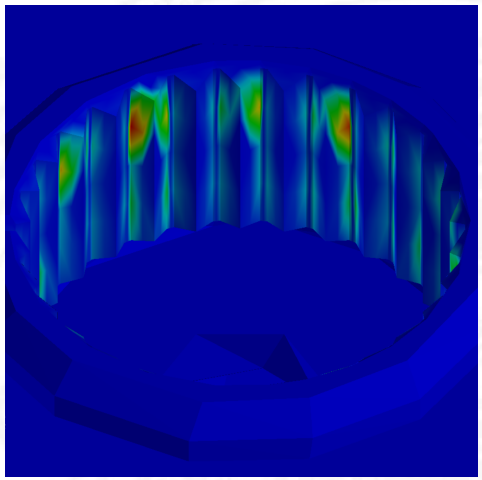
Max rf: 155.1 N



(c) 5 beams, 6 mm

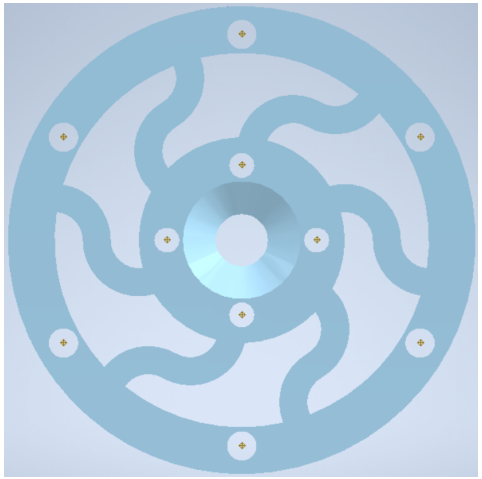


Max d: 0.652 mm

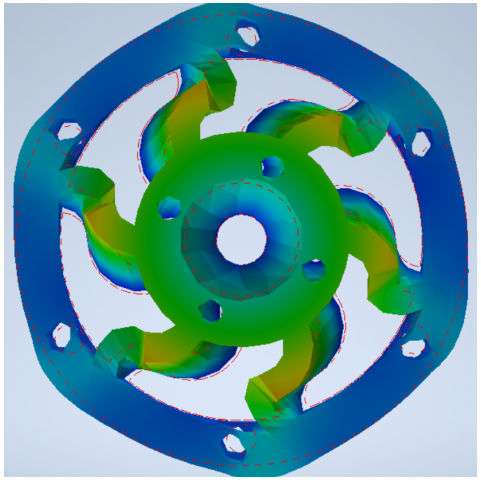


Max rf: 149.3 N

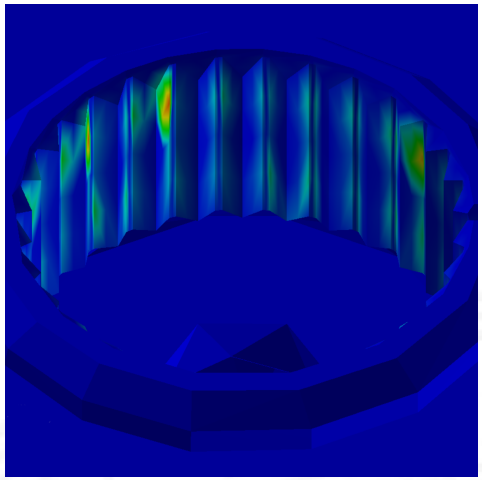
FEA (cont.)



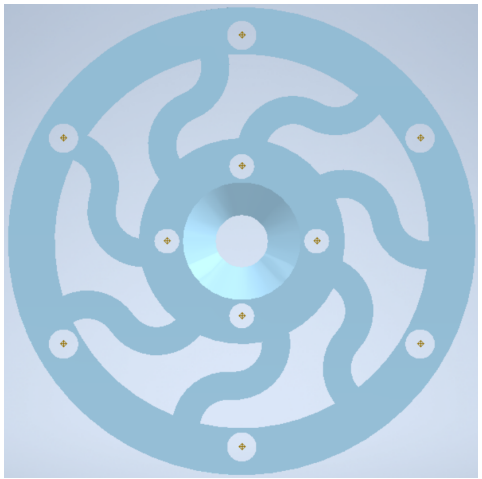
(d) 6 beams, 6 mm



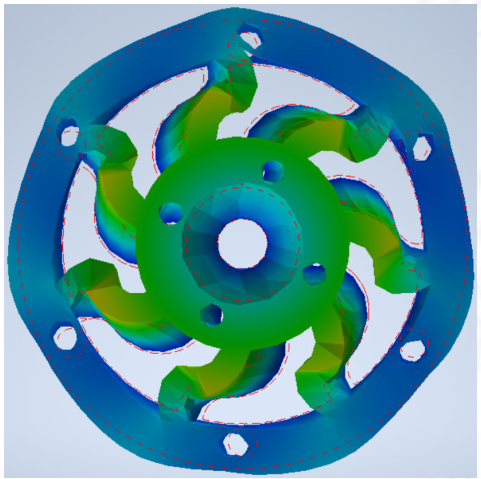
Max d: 0.607 mm



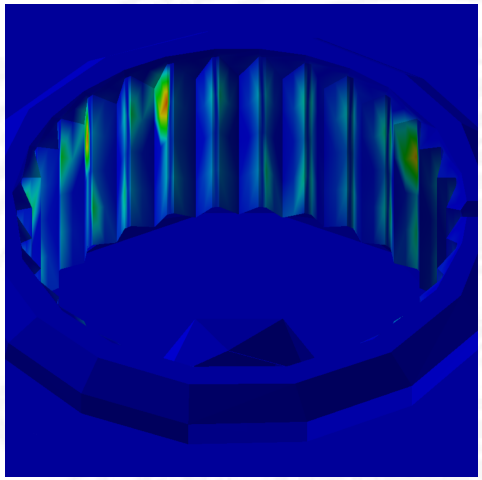
Max rf: 166.1 N



(e) 7 beams, 6 mm

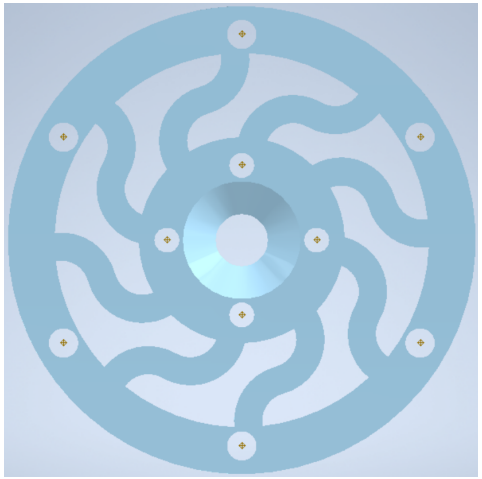


Max d: 0.554 mm

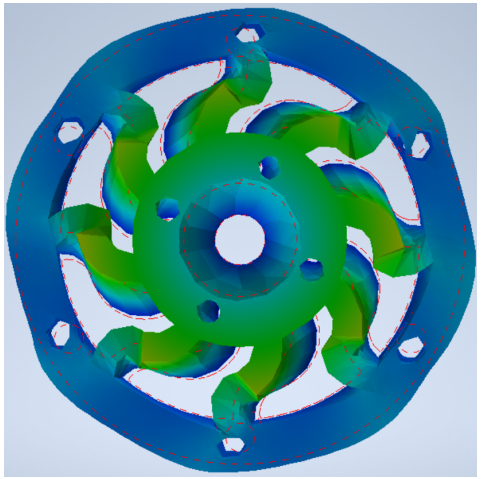


Max rf: 151.1 N

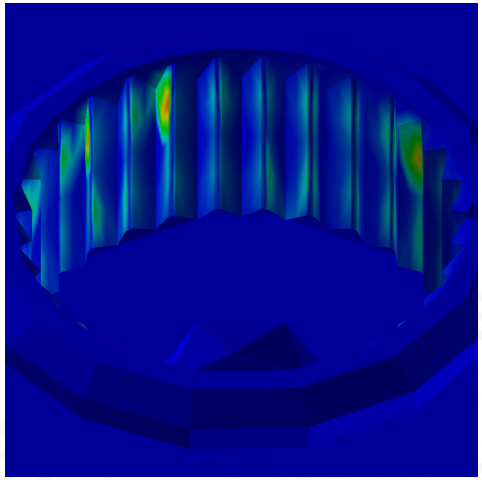
FEA (cont.)



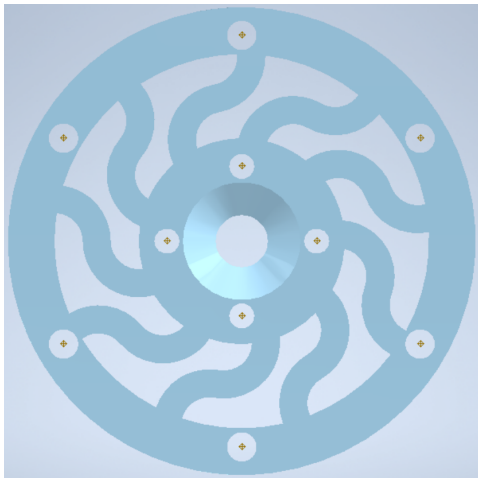
(f) 8 beams, 6 mm



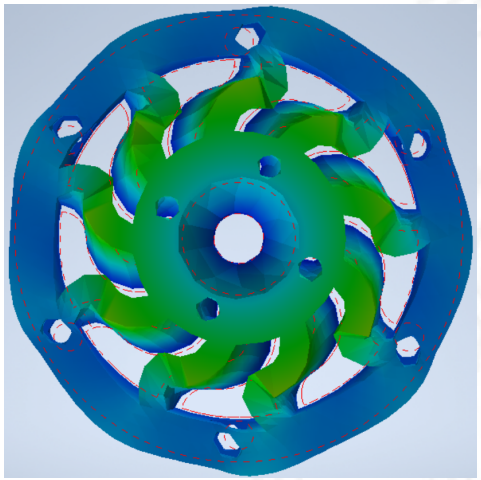
Max d: 0.511 mm



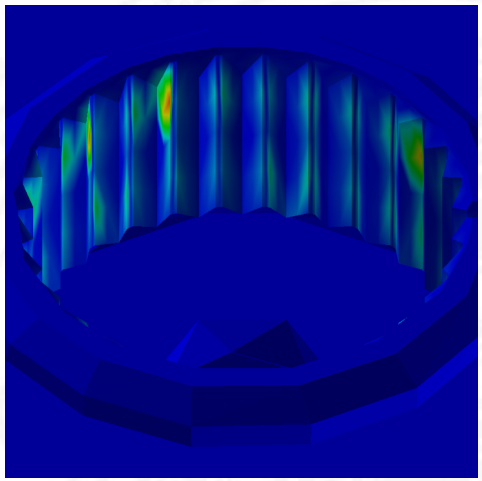
Max rf: 151.1 N



(g) 9 beams, 6 mm

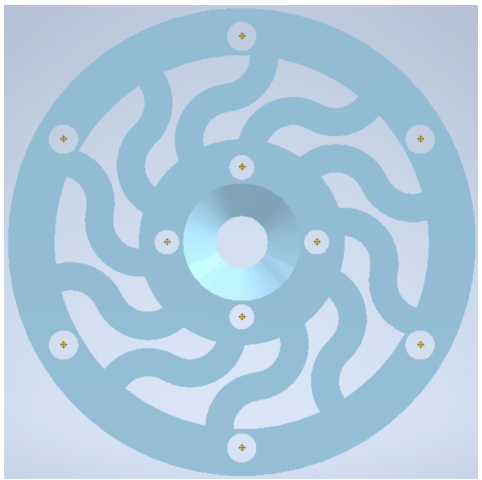


Max d: 0.471 mm

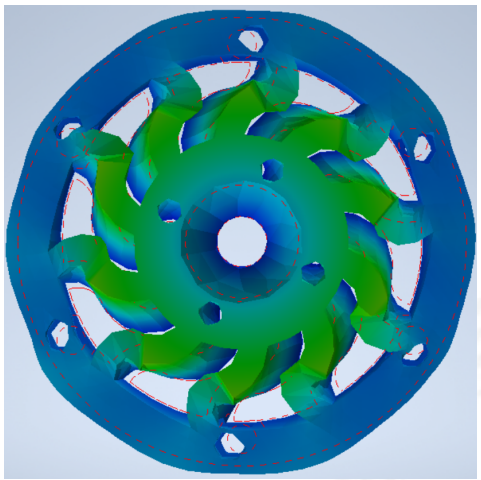


Max rf: 153.4 N

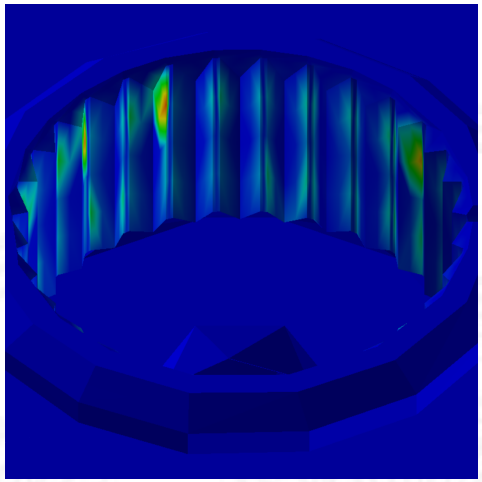
FEA (cont.)



(h) 10 beams, 6 mm



Max d: 0.461 mm



Max rf: 154.6 N