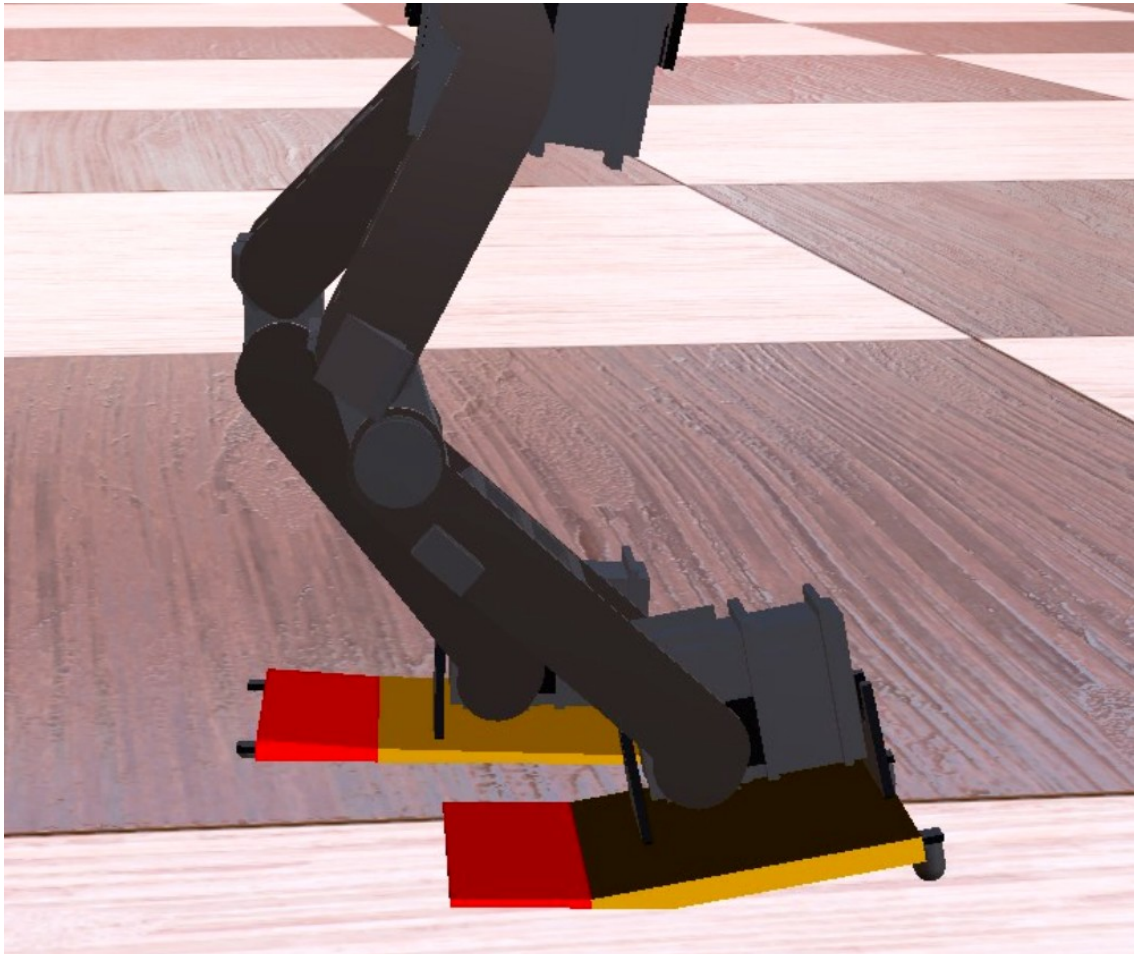
Final Presentation

Bipedal Walking With Passive Toe-Joints through Quintic Splines with Parameter Optimization

Bachelor Thesis
By Lieven Petersen



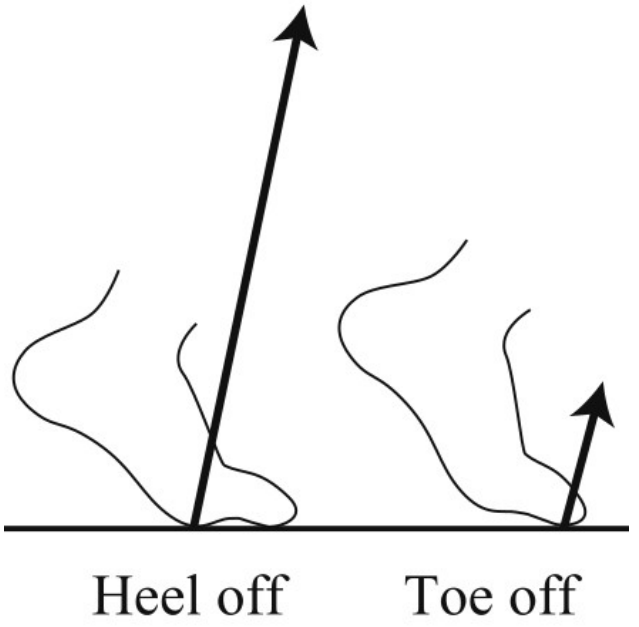
Contents

- Motivation
- Related work
- Baseline
- Approach
- Results
- Discussion & Conclusion

Motivation

Toe Joint Benefits

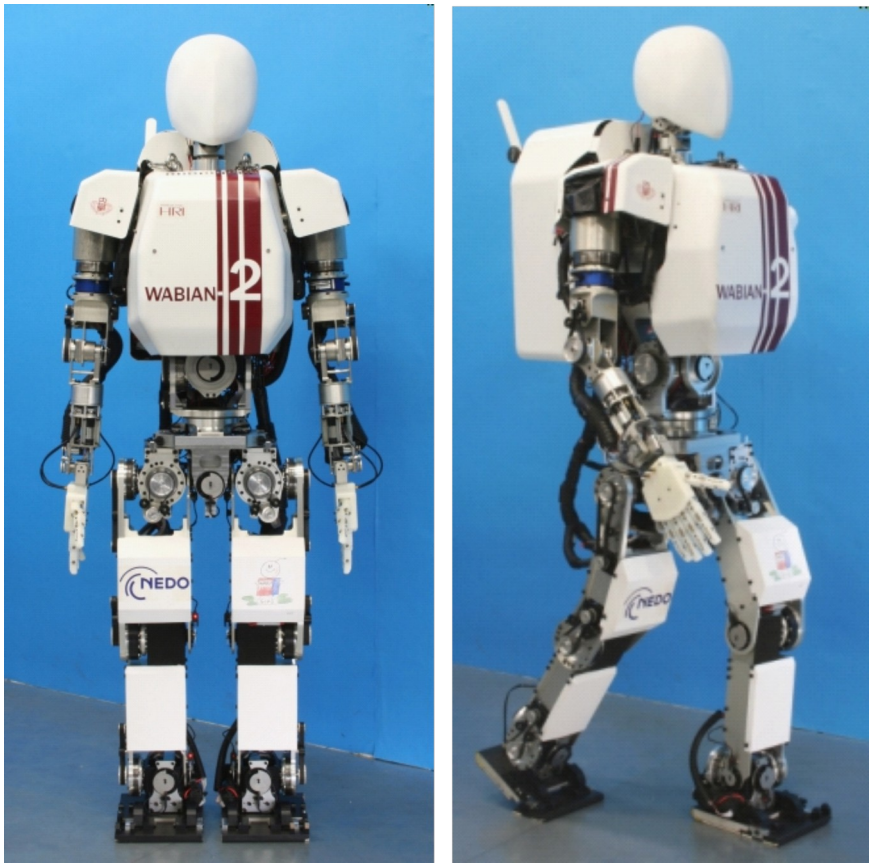
- Reduced ankle movement
- Increased Range
- Propels step
- Longer ground contact
- energy efficiency



[Yamamoto19]

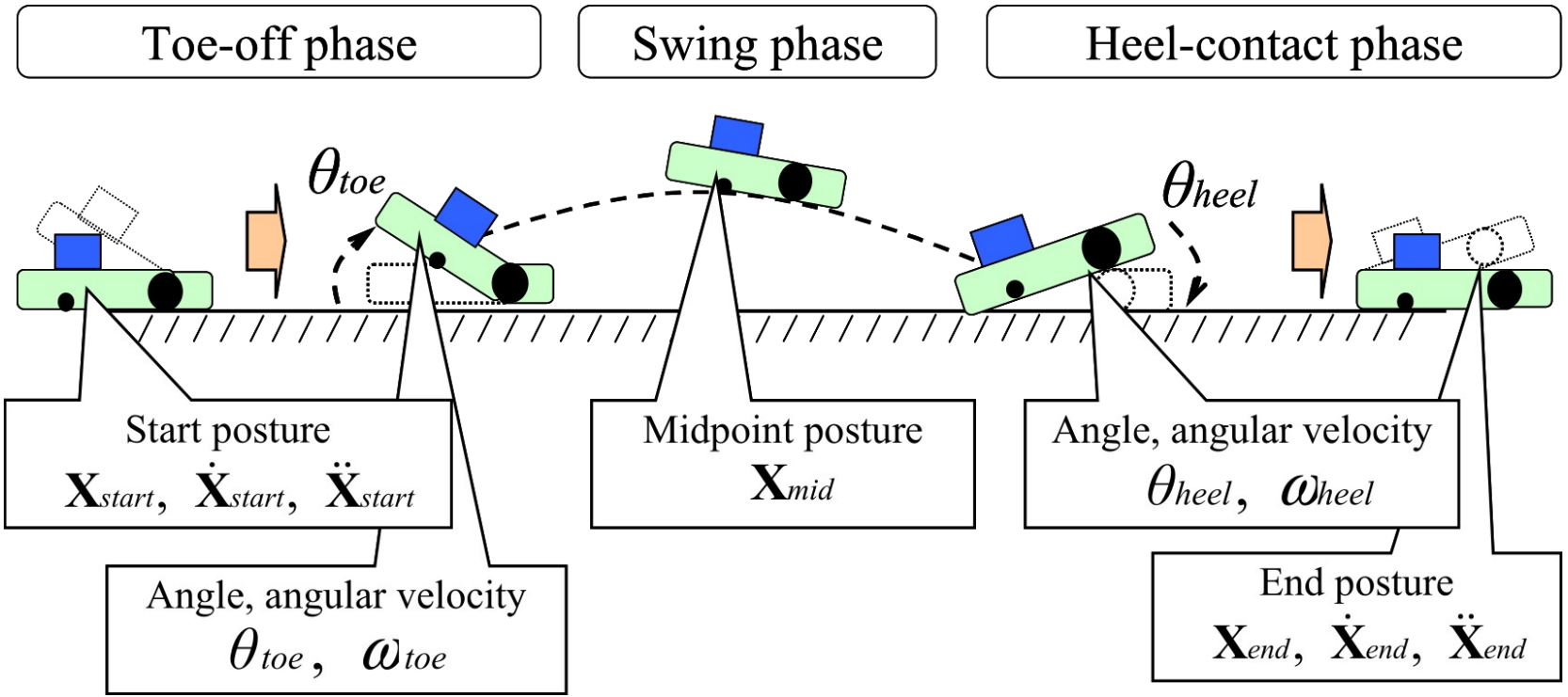
Related Work

Wabian-2R



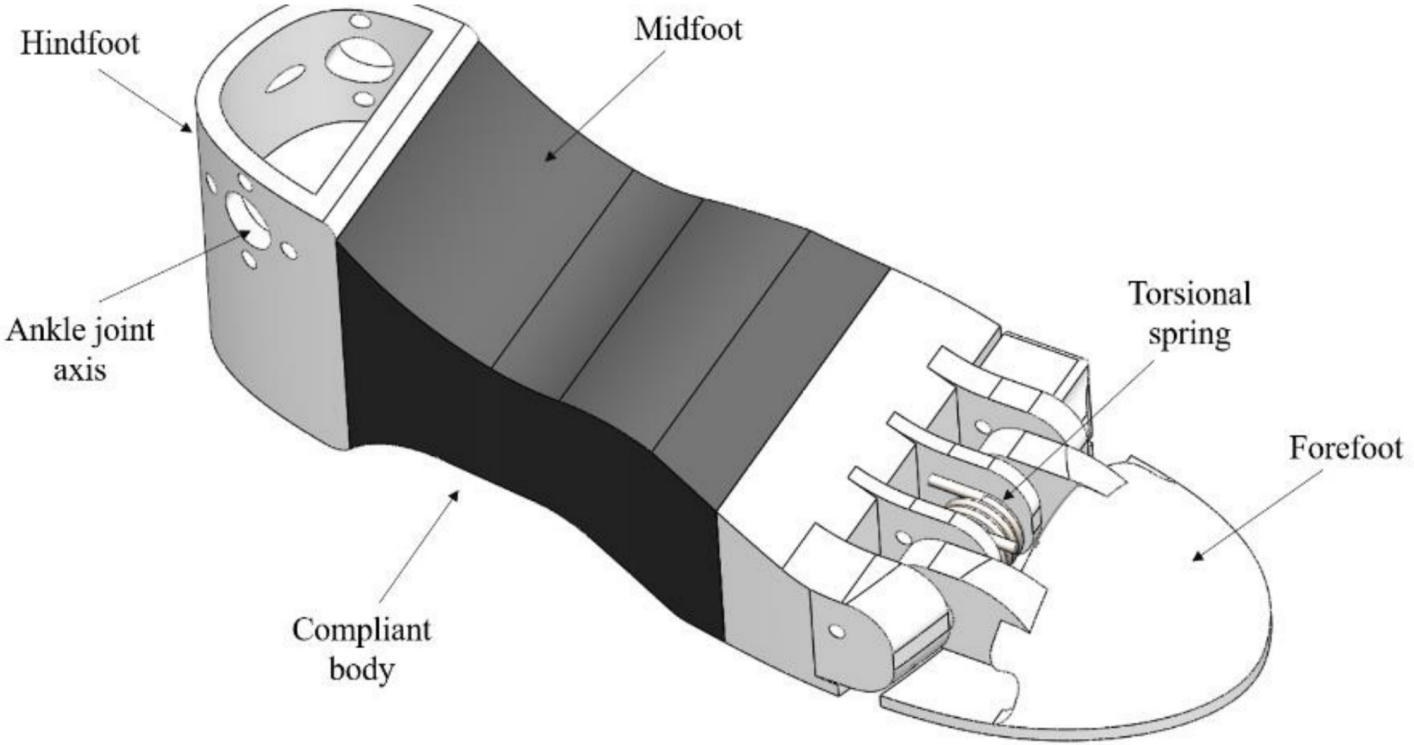
[Ogura08]

Toe-off & Heel-contact



[Ogura08]

Compliant Foot



[Russo21]

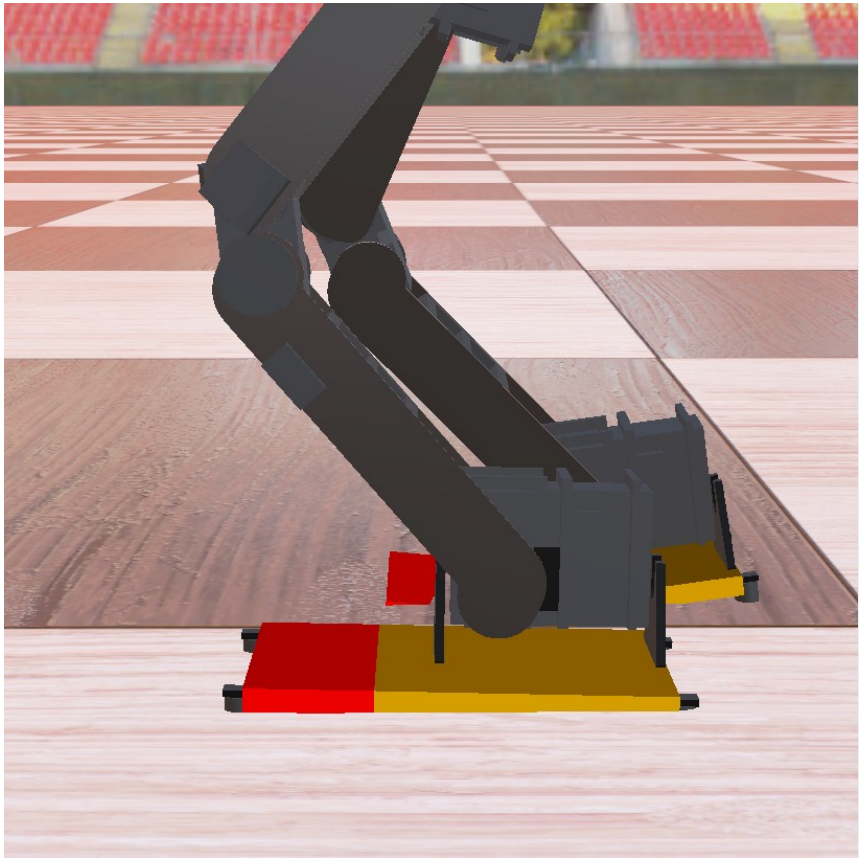
Baseline

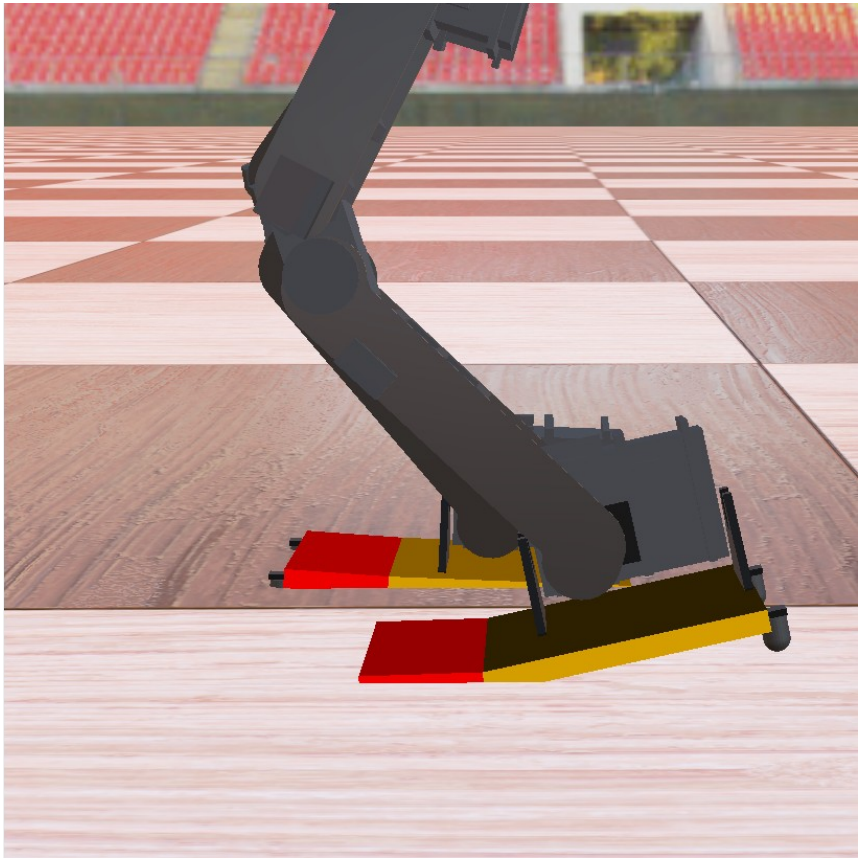
Baseline walk controller

- Parameterized Quintic Splines
- Interpolate poses of flying-foot and torso
- Given command velocity
- Optimize parameters
- Open loop

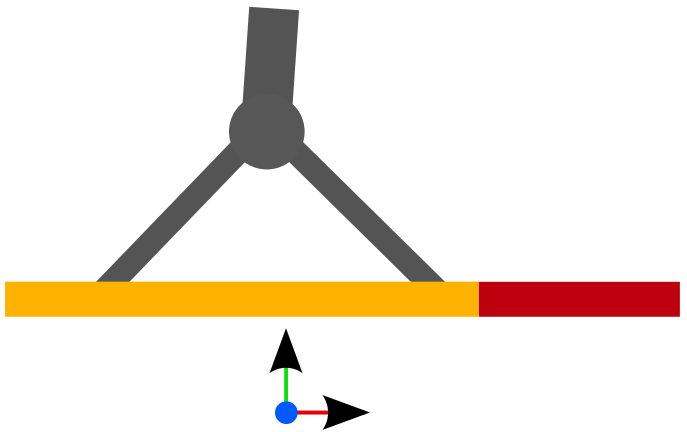
Approach

Model Changes

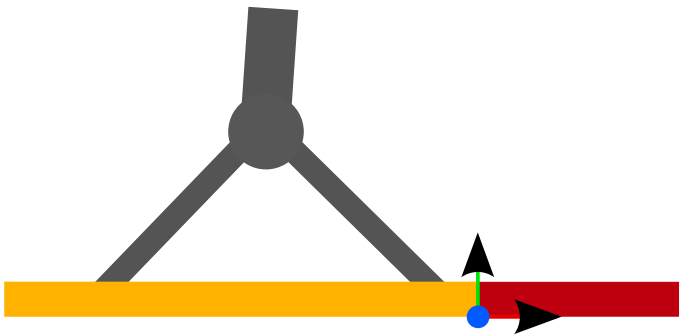




Foot Reference Frame

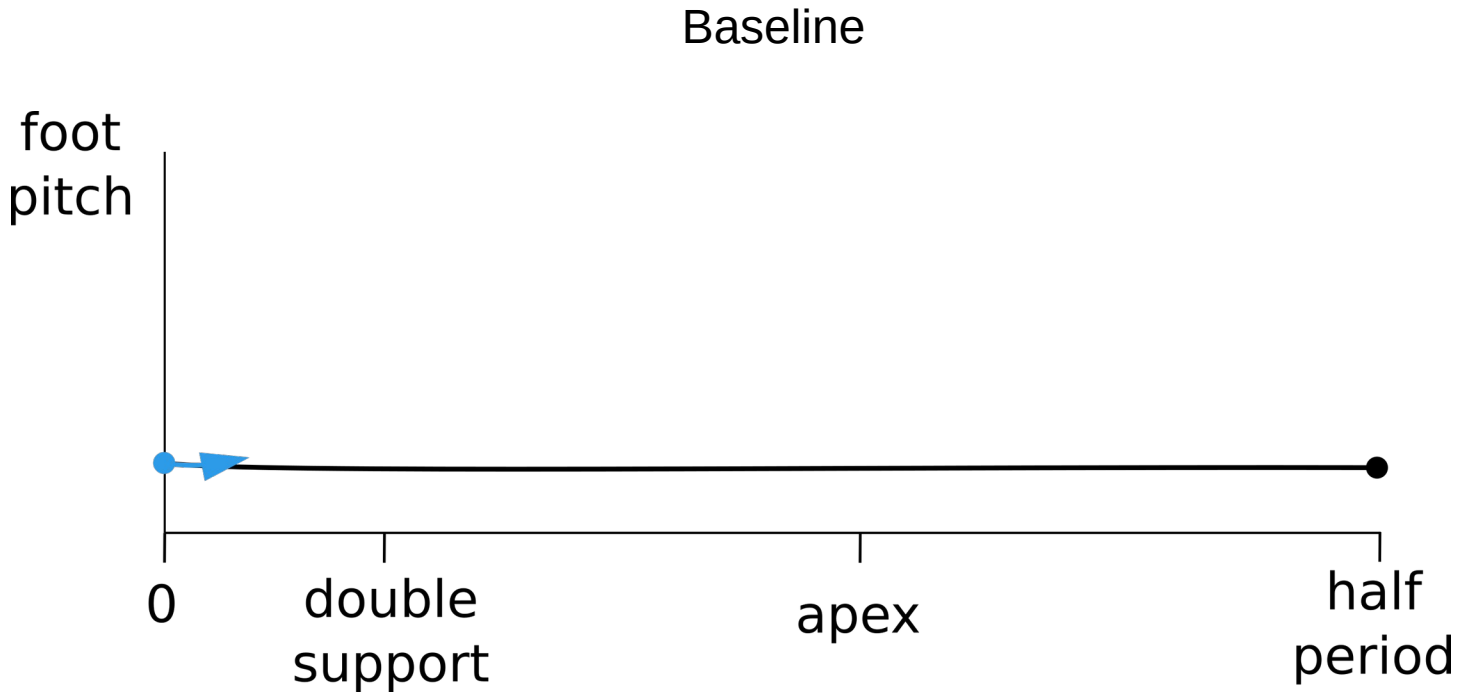


Baseline



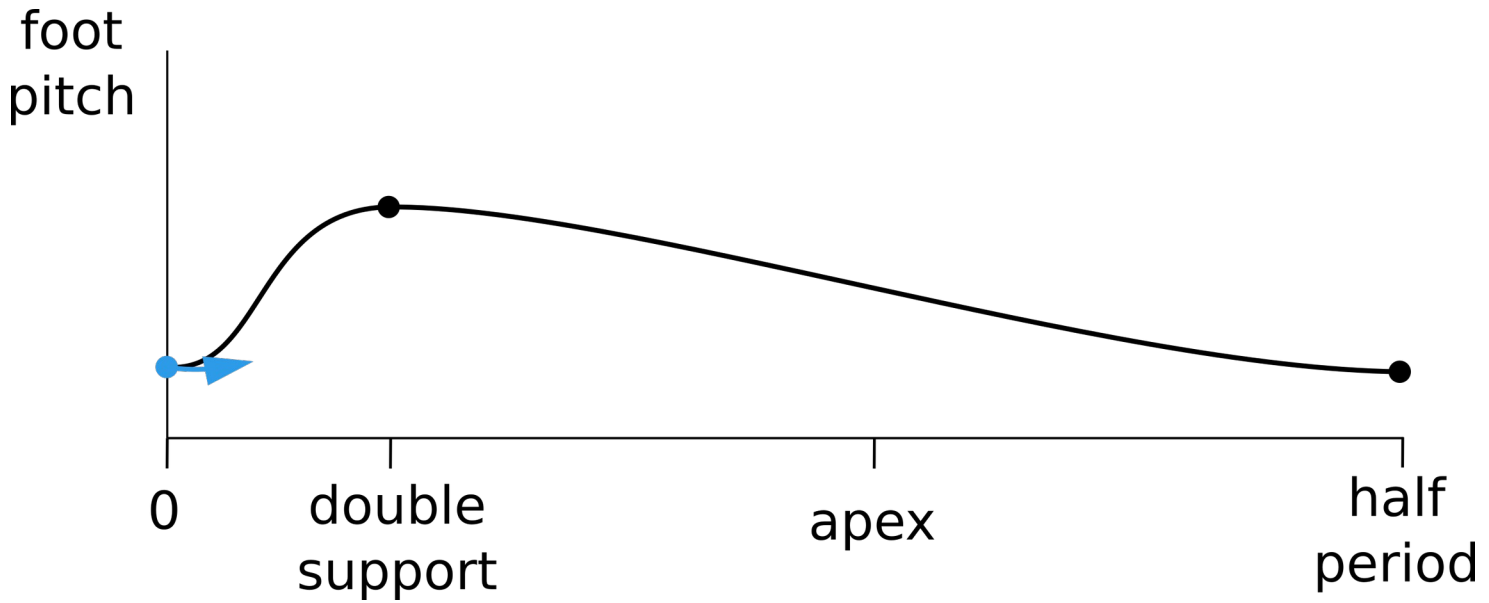
Changed

Foot Pitch



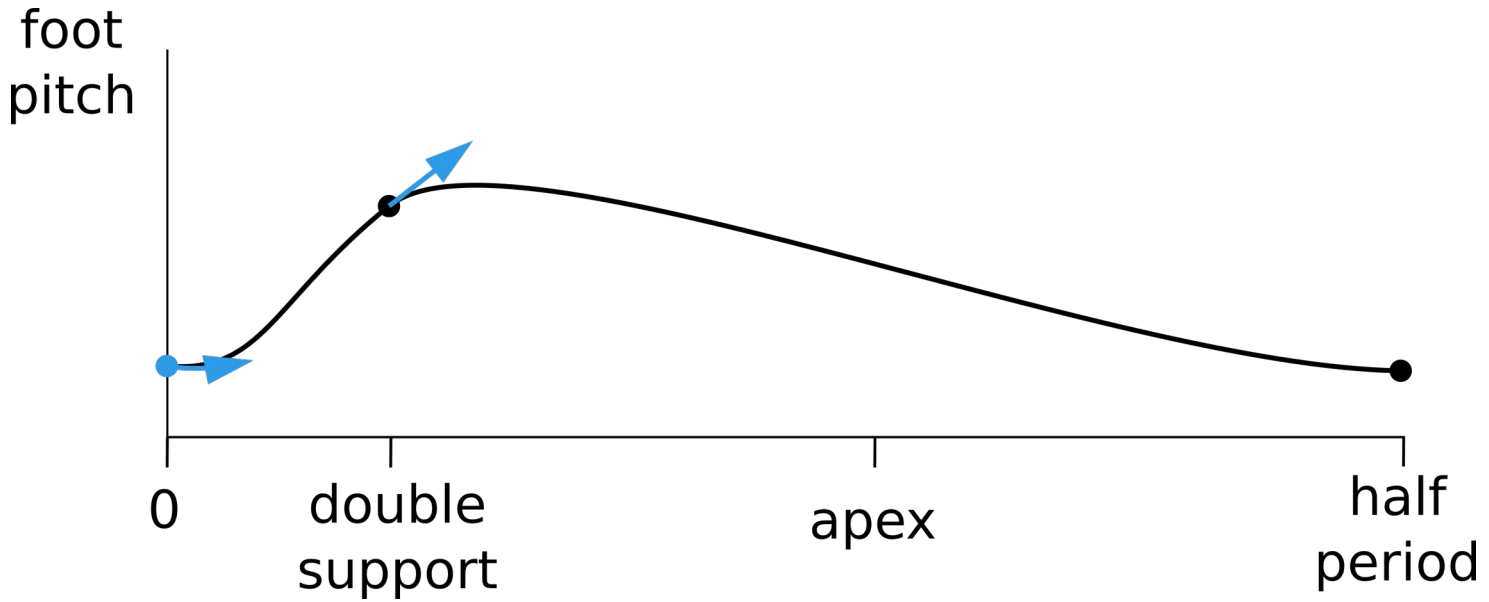
Foot Pitch

1st Iteration

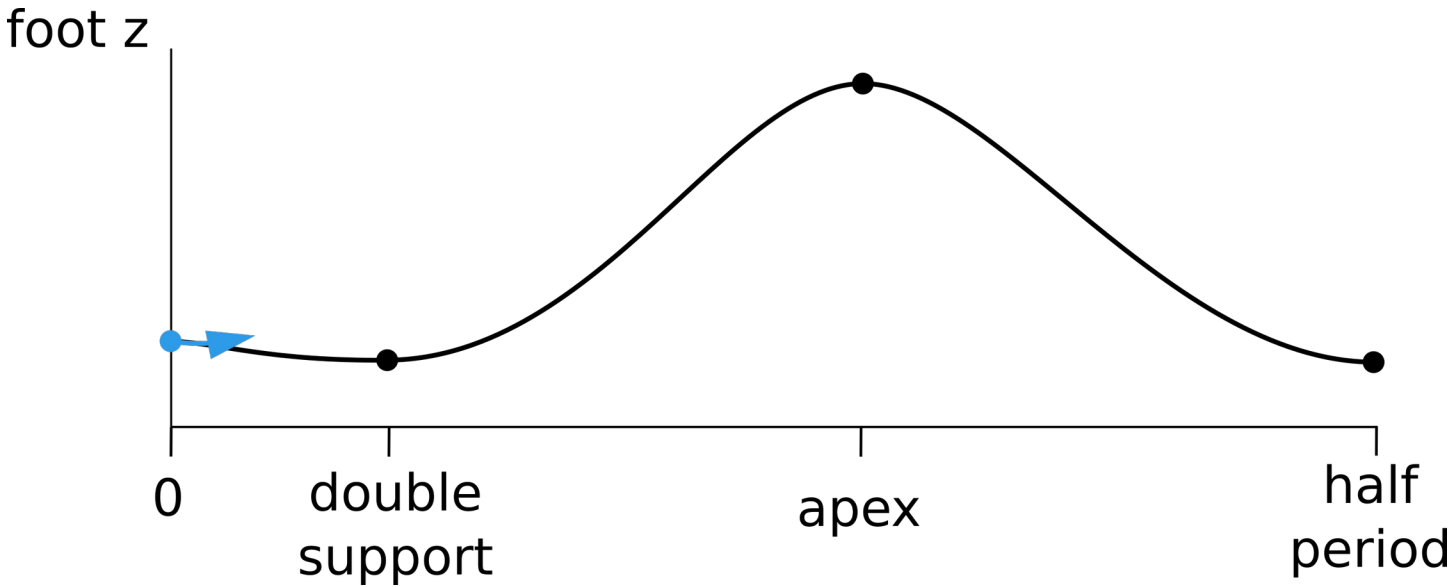


Foot Pitch

Final – 2 new parameters



Foot Height



Parameter optimization

- Black Box optimization
- Set possible parameter ranges
- Conduct trial to evaluate parameters

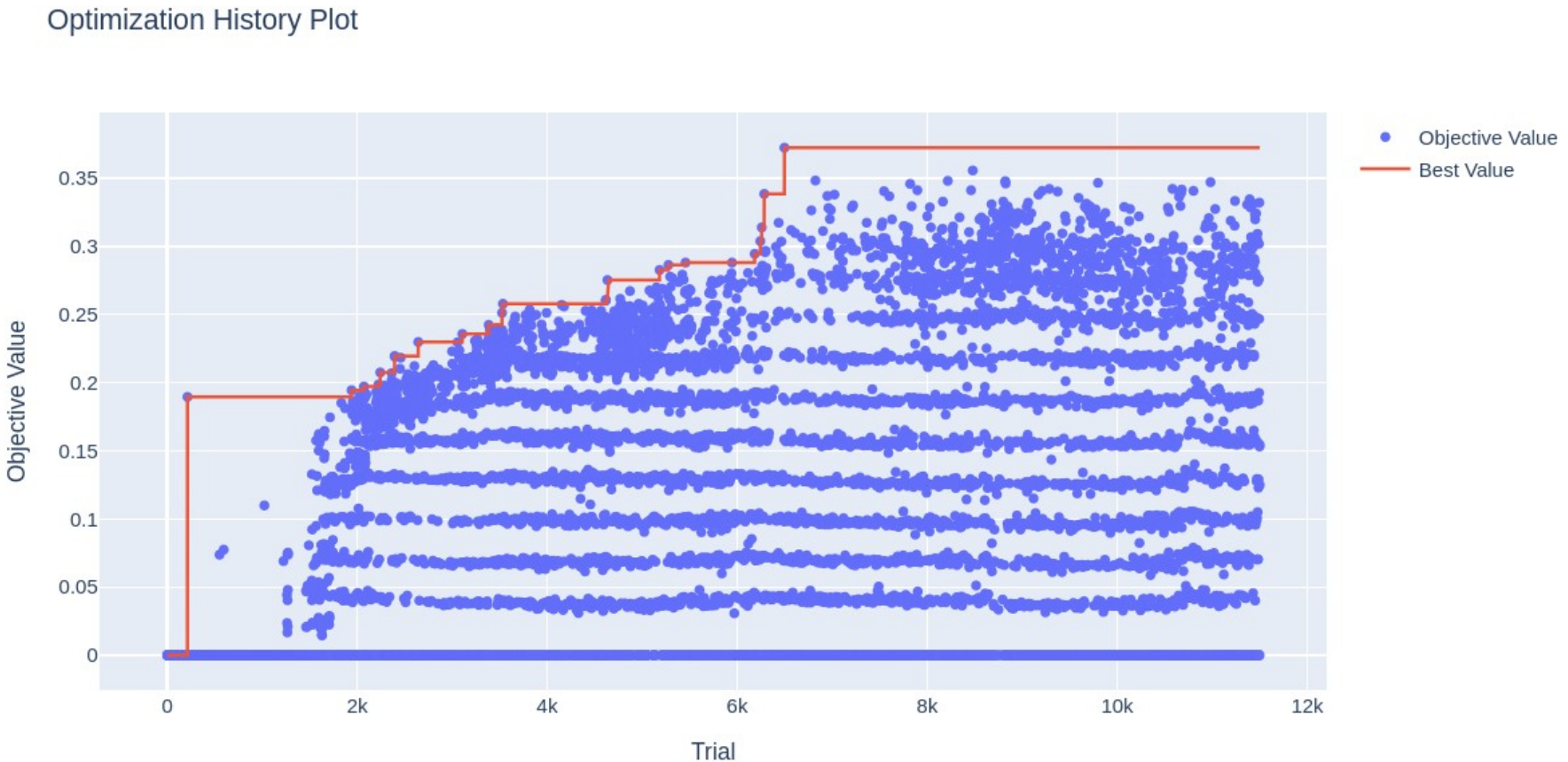
Trial

- Only walk forward

Trial

- Only walk forward
- Routine:
  - Walk for 10 seconds
  - Stand for 2 seconds
  - Repeat at increasing speed
- Objective: highest speed without fall

Final Parameter Set

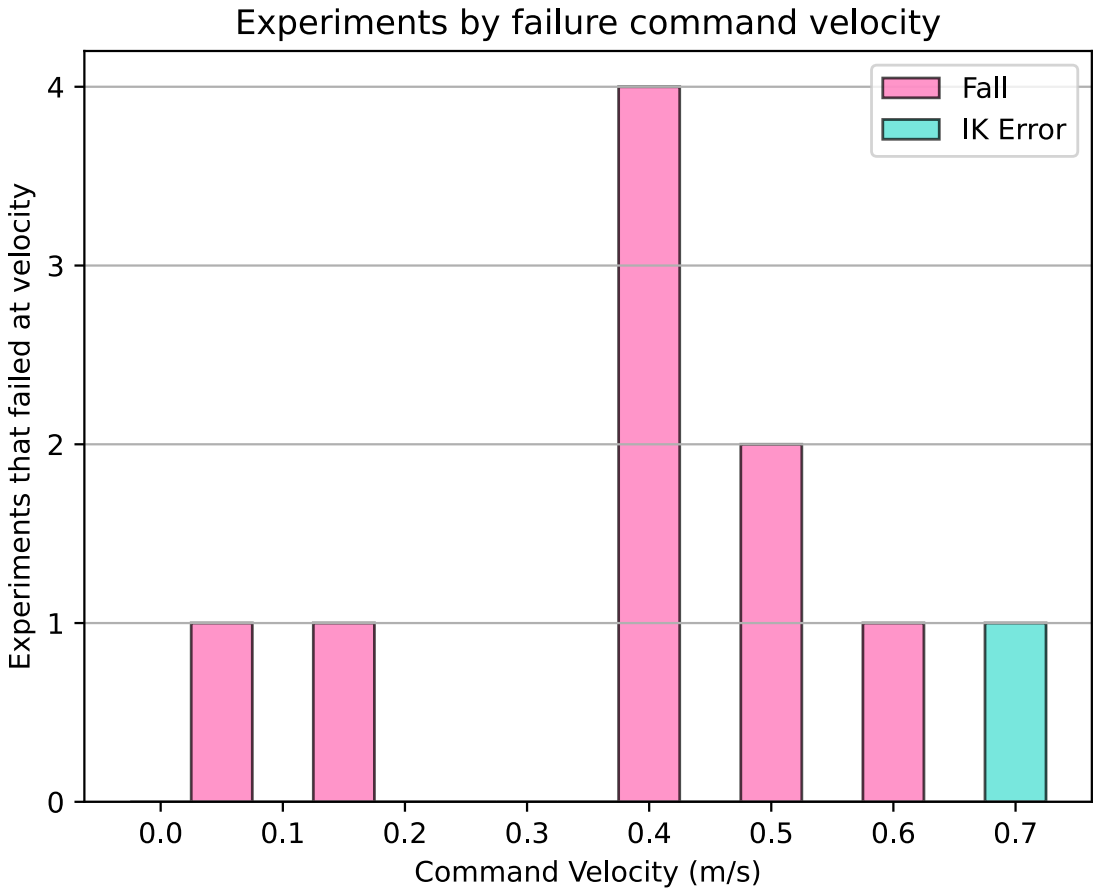


Final Parameter Set

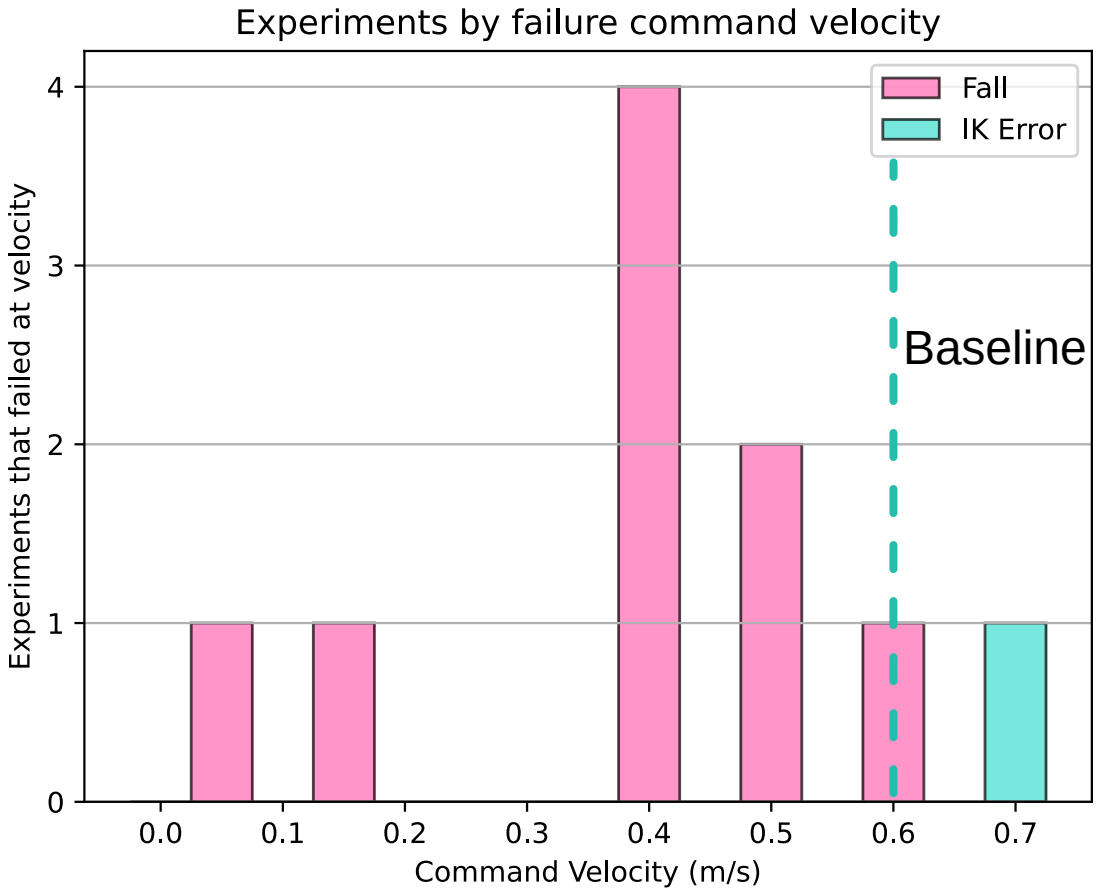
- Lower walk frequency of 1.5 Hz
- Higher double support ratio
- Forced foot pitch

Results

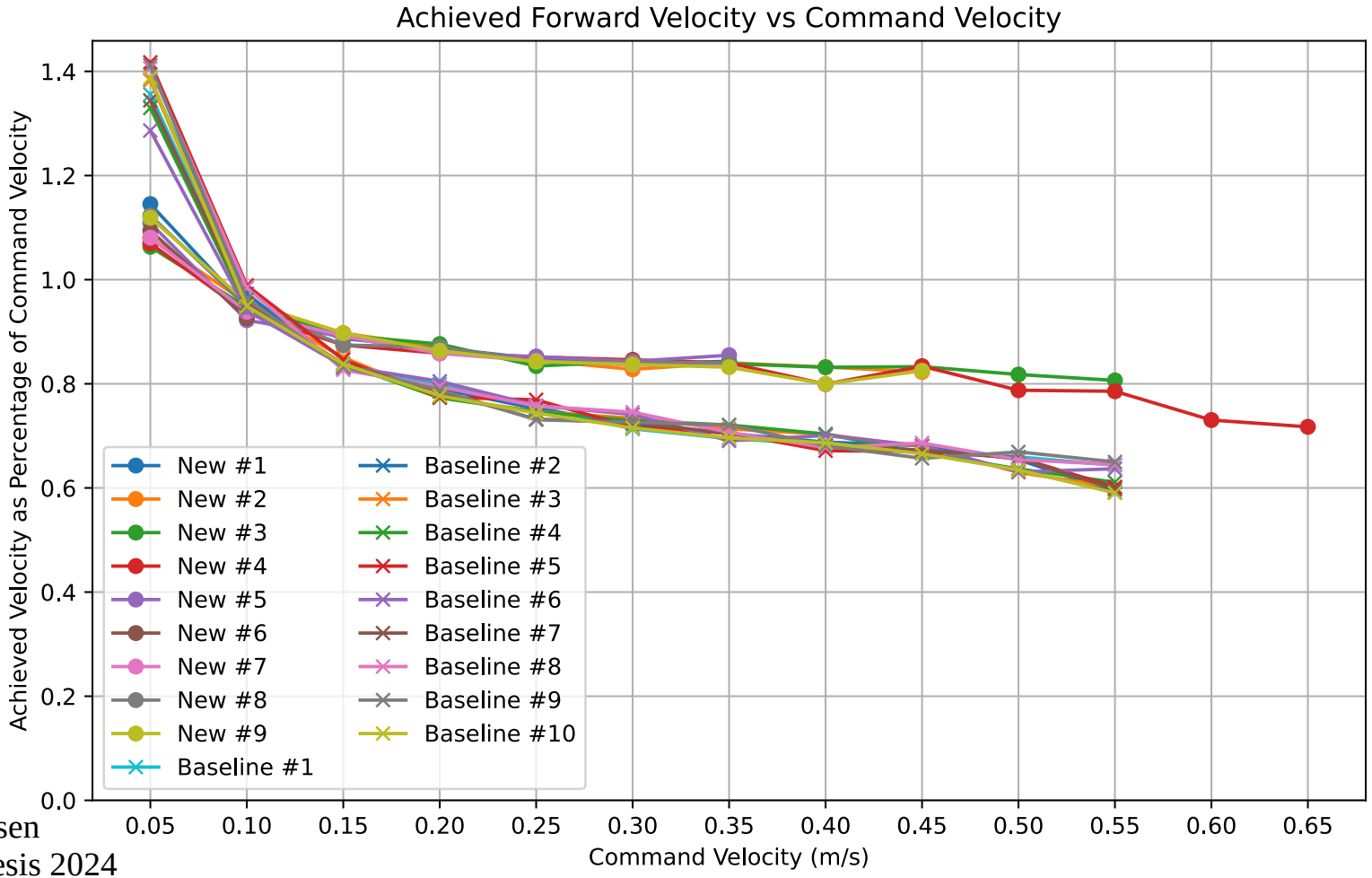
Walk Reliability



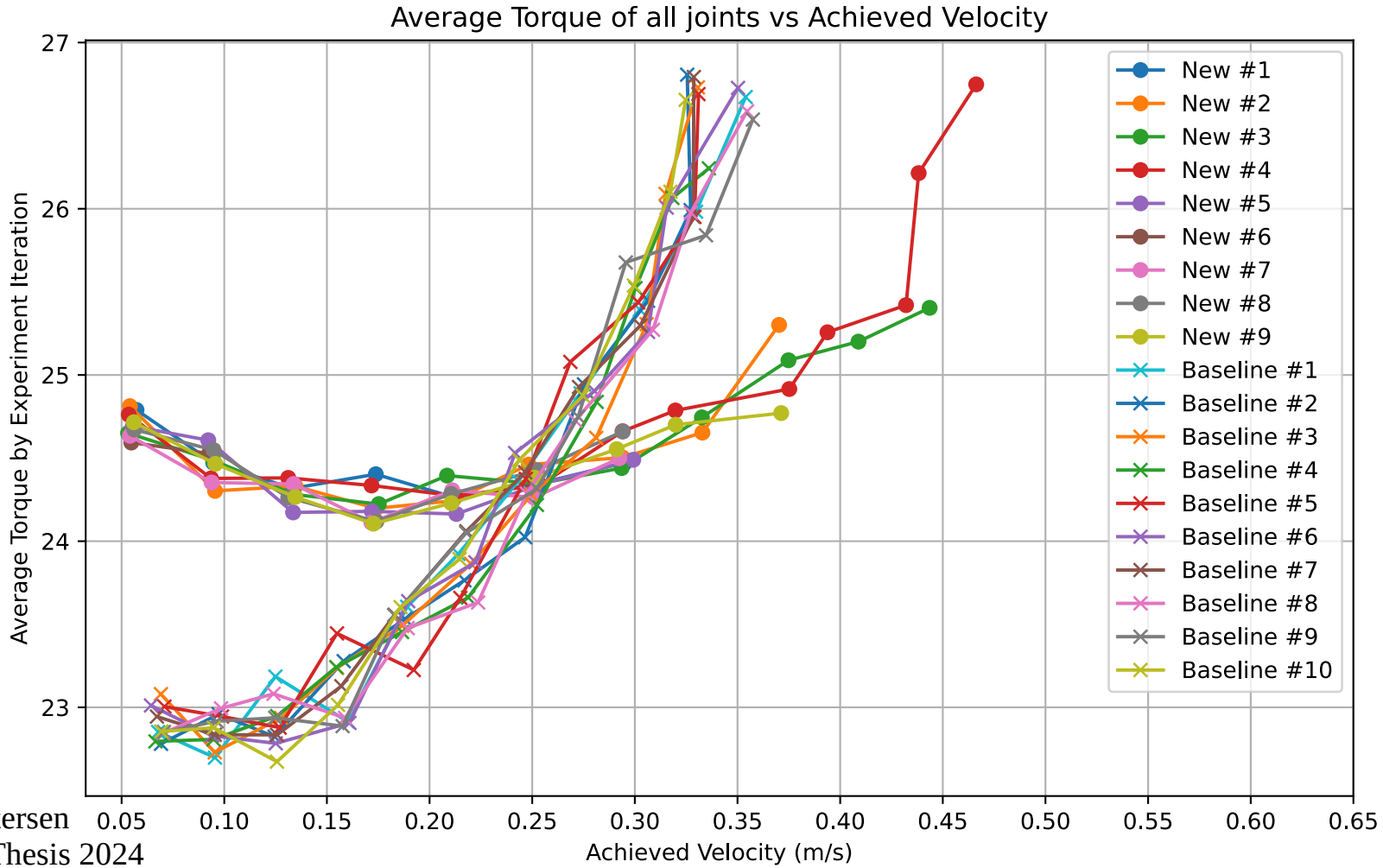
Walk Reliability



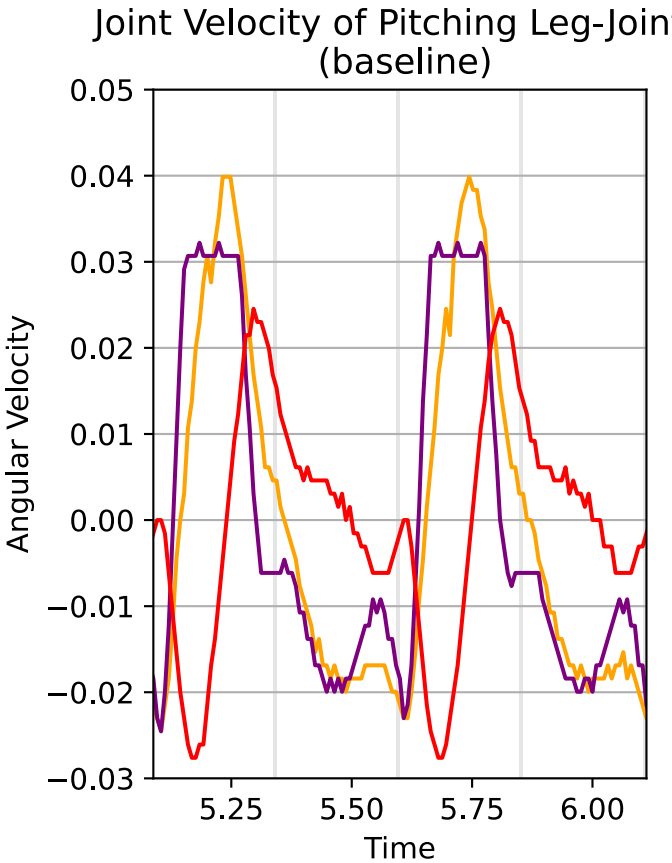
Achieved Velocity

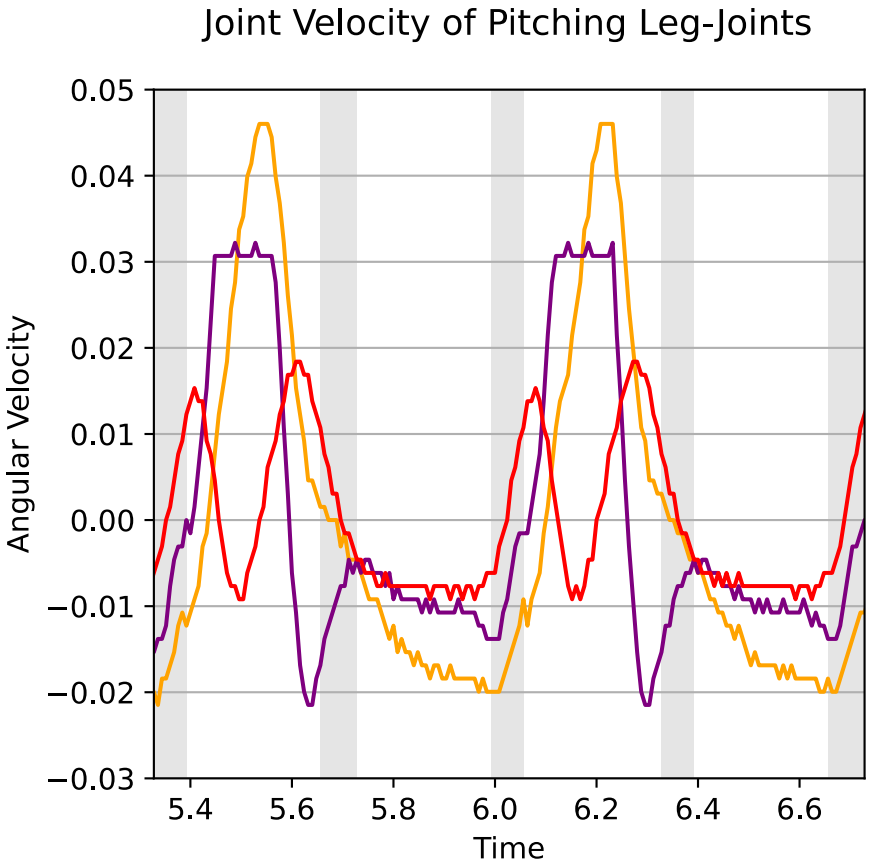


Energy Consumption



Pitching Leg-Joints





Discussion

Discussion

To what degree can a toe-off motion be realized in Cartesian coordinates?

Conclusion

Conclusion

- Less energy at higher speeds
- Reduced ankle movement
- Increased foot’s range

Conclusion

- Less energy at higher speeds
- Reduced ankle movement
- Increased foot’s range
- Poorly adapted to slow speeds
- Requires additional stabilization

Future work

- Adjust to different speeds
- Closed loop stabilization
- Heel-contact movement

Sources

[Ogura08] Y. Ogura, et al., “Human-like walking with knee stretched, heel-contact and toe-off motion by a humanoid robot,” in 2006 IEEE/RSJ International Conference on Intelligent Robots and Systems, 2006, pp. 3976-3981.

[Yamamoto19] K. Yamamoto, “Human-Like Toe Joint Mechanism”. Dordrecht: Springer Netherlands, 2019, pp. 435-456. [Online]. Available: https://doi.org/10.1007/978-94-007-6046-2_82

[Bestmann23] M. Bestmann and J. Zhang, ”Bipedal walking on humanoid robots through parameter optimization”, in RoboCup 2022: Robot World Cup XXV, A. Eguchi et al., Eds. Cham: Springer International Publishing, 2023, pp. 164-176.

[Russo21] M. Russo et al. ”A bioinspired humanoid foot mechanism”, Applied Sciences, vol. 11, no. 4, 2021. [Online]. Available: Https://www.mdpi.com/2076-3417/11/4/1686

Additional slides

Walk Parameter Ranges

Parameter	Min	Max	Fixed
step frequency			1.5
double support ratio	0.0	0.5	
foot distance	0.15	0.25	
foot pitch angle	0.3	1.0	
foot pitch velocity	5.0	10.0	
foot rise	0.05	0.10	
torso height	0.37	0.41	
torso phase offset	−0.5	0.5	
torso lateral swing ratio	0.0	1.0	
torso rise	0.0	0.02	
torso x offset	−0.02	0.02	
torso y offset	−0.02	0.02	
torso pitch	−0.5	0.5	
torso pitch proportional to v_{cmd_x}	−1.0	1.0	
torso pitch proportional to v_{cmd_yaw}			0.0

Walk Parameter Sets

Parameter	Baseline	Evaluation
step frequency	1.963	1.500
double support ratio	0.026	0.200
foot distance	0.179	0.158
foot pitch angle	-	0.334
foot pitch velocity	-	5.875
foot rise	0.081	0.077
torso height	0.394	0.373
torso phase offset	-0.151	0.101
torso lateral swing ratio	0.154	0.057
torso rise	0.015	0.008
torso x offset	0.008	0.001
torso y offset	0.003	-0.000
torso pitch	0.105	-0.183
torso pitch proportional to v_{cmd_x}	-0.186	0.890
torso pitch proportional to v_{cmd_yaw}	-0.457	0.000

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Optimization Studies

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 0) test_0904_test_7_to_3_ratio_0_7_spring
 1) 0924_test_7_to_3_ratio_2_0_spring_fixed_pitch
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 3) 0926_test_7_to_3_ratio_2_0_spring_fixed_pitch_fwd_only
 4) 1016_test_7_to_3_ratio_2_0_spring_linear_pitch_fwd_only
 5) 1021_test_7_to_3_ratio_3_0_spring_linear_pitch_fwd_only
 6) 1023_test_7_to_3_ratio_5_0_spring_linear_pitch_fwd_only
 7) 1024_test_7_to_3_ratio_4_0_spring_linear_pitch_fwd_only
 8) 1027_test_7_to_3_ratio_4_0_spring_linear_pitch_5_15_fwd_only
 9) 1028_test_7_to_3_ratio_4_0_spring_linear_pitch_3_15_constrained
10) ignore_me
11) 1106_test_7_to_3_ratio_4_0_spring_linear_pitch_3_15_constrained_doubleM
12) 1112_test_7_to_3_ratio_4_0_spring_linear_pitch_3_15_pitch_acc
13) 1112_#2_test_7_to_3_ratio_4_0_spring_linear_pitch_3_15_pitch_acc
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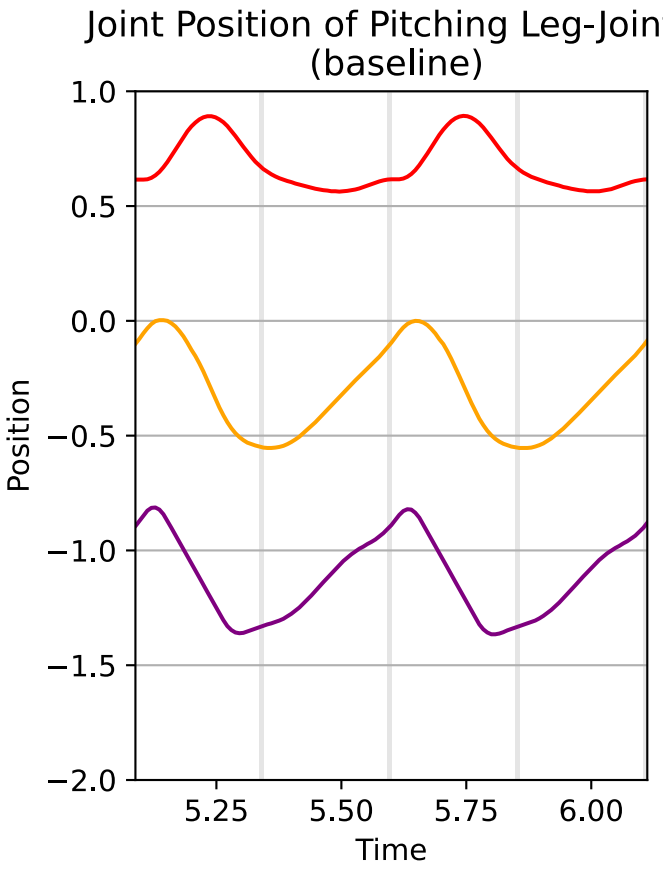
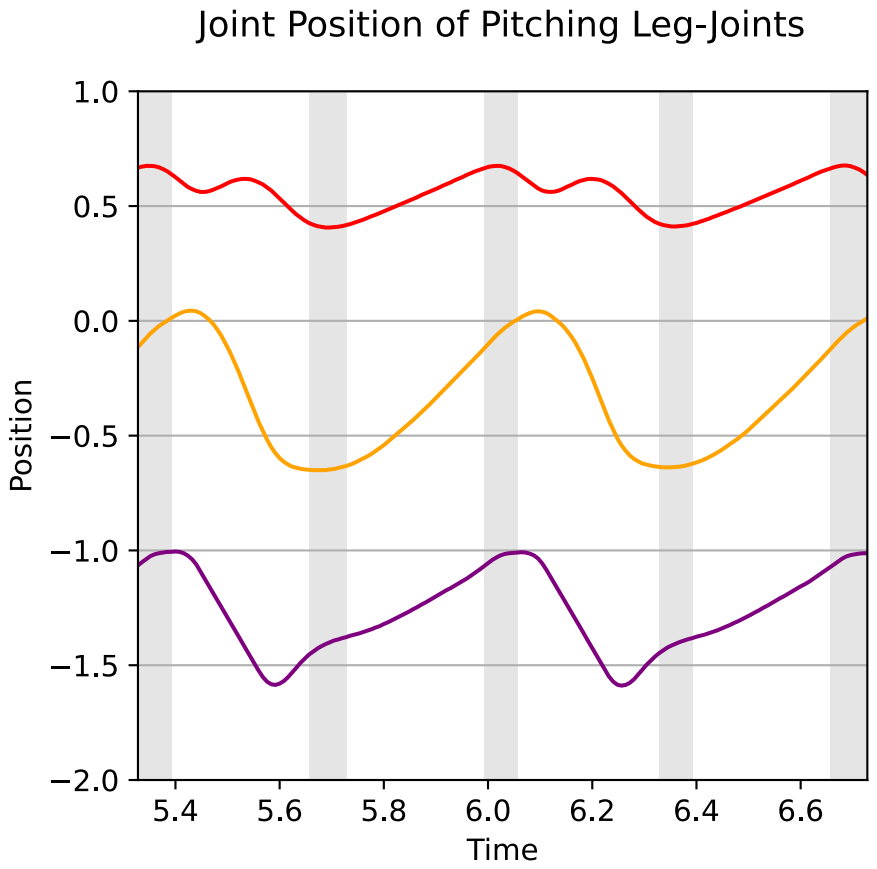
Pitching Leg-Joints





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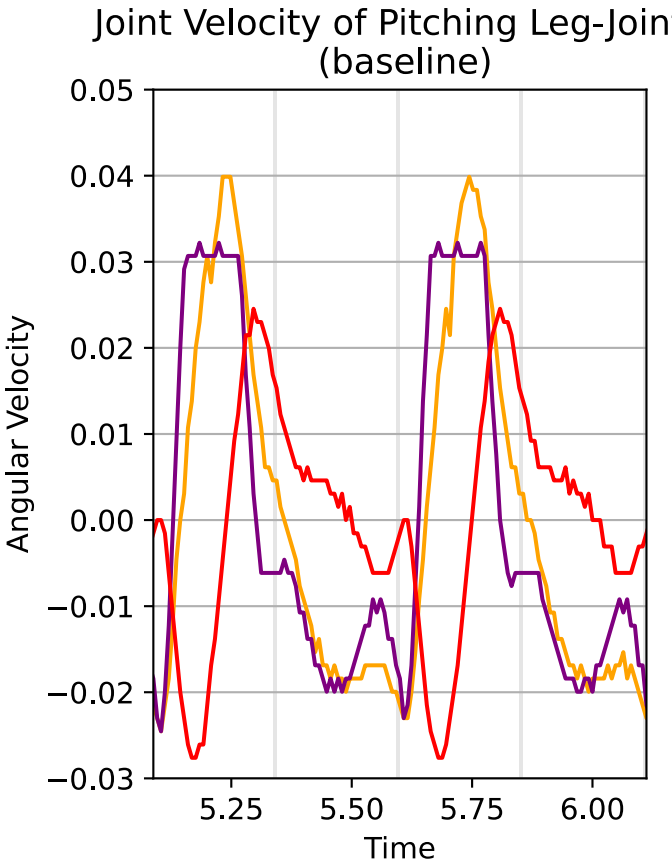

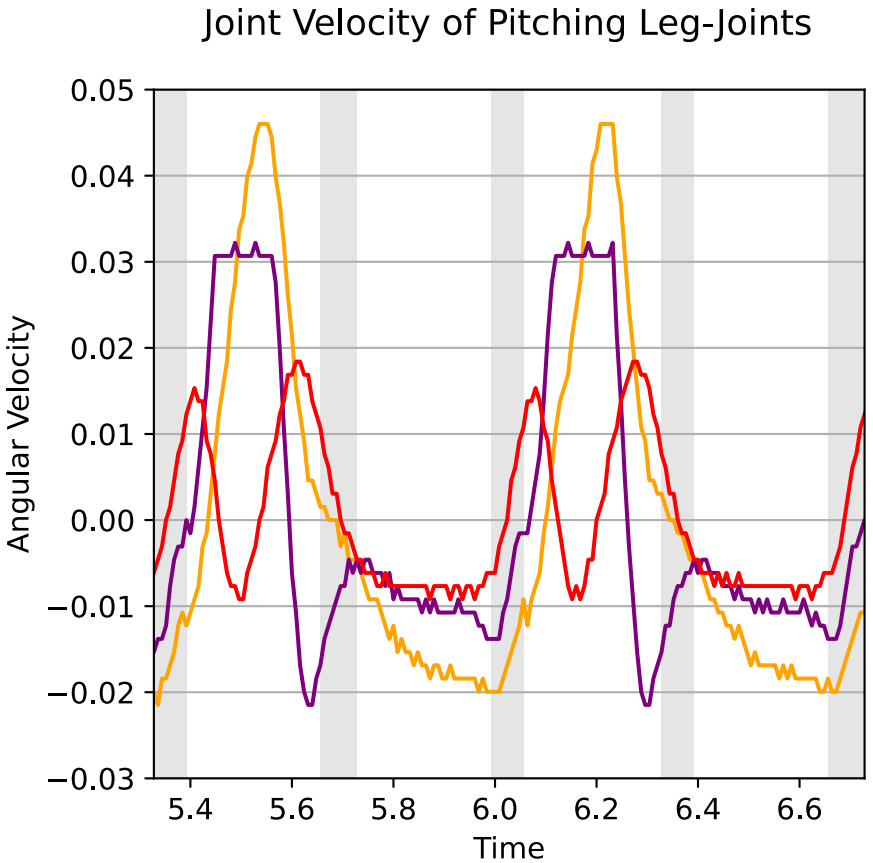

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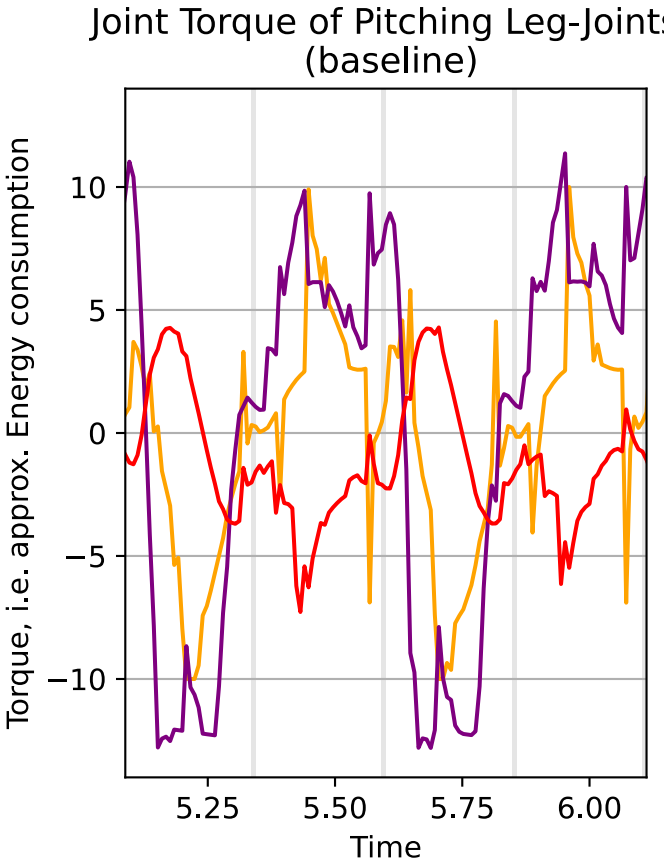
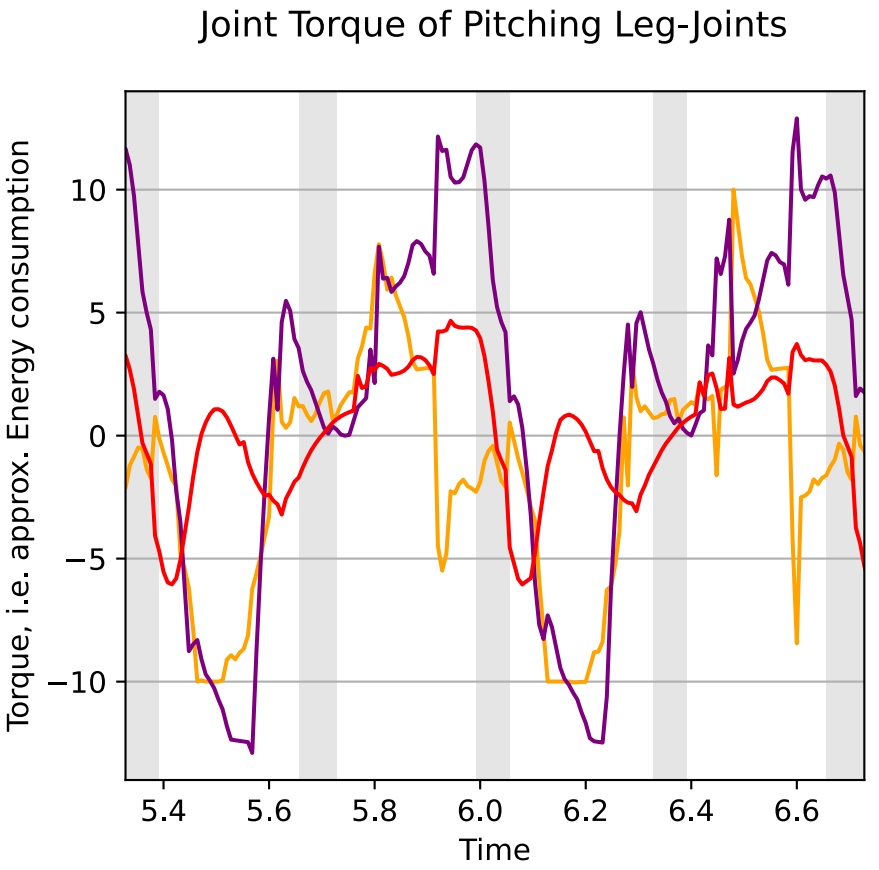
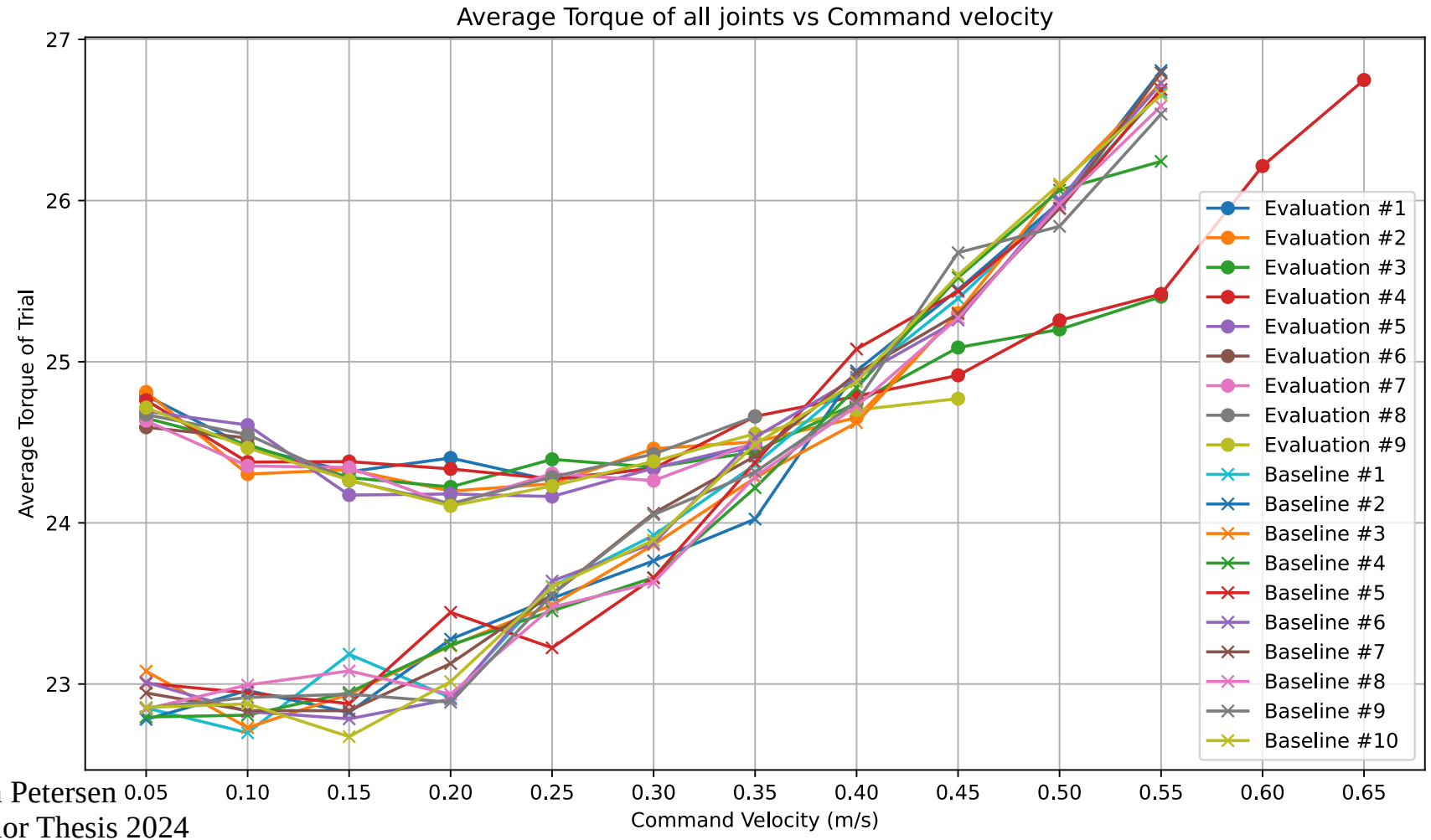
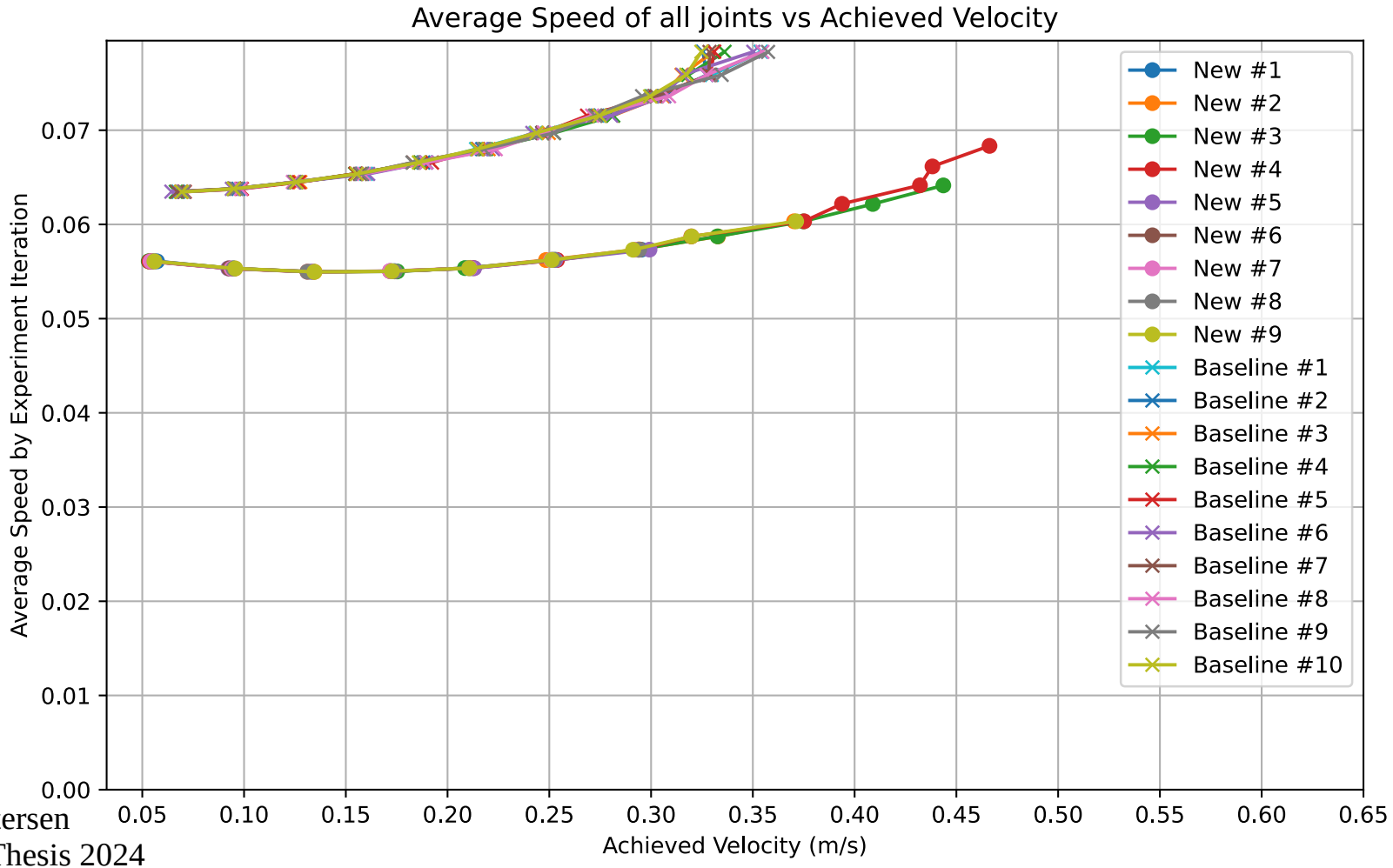




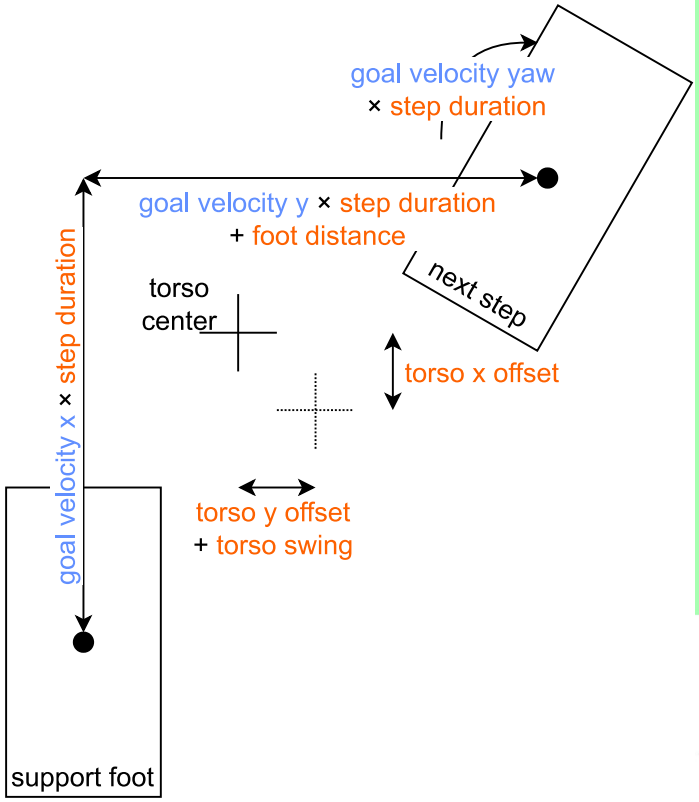
Energy Consumption

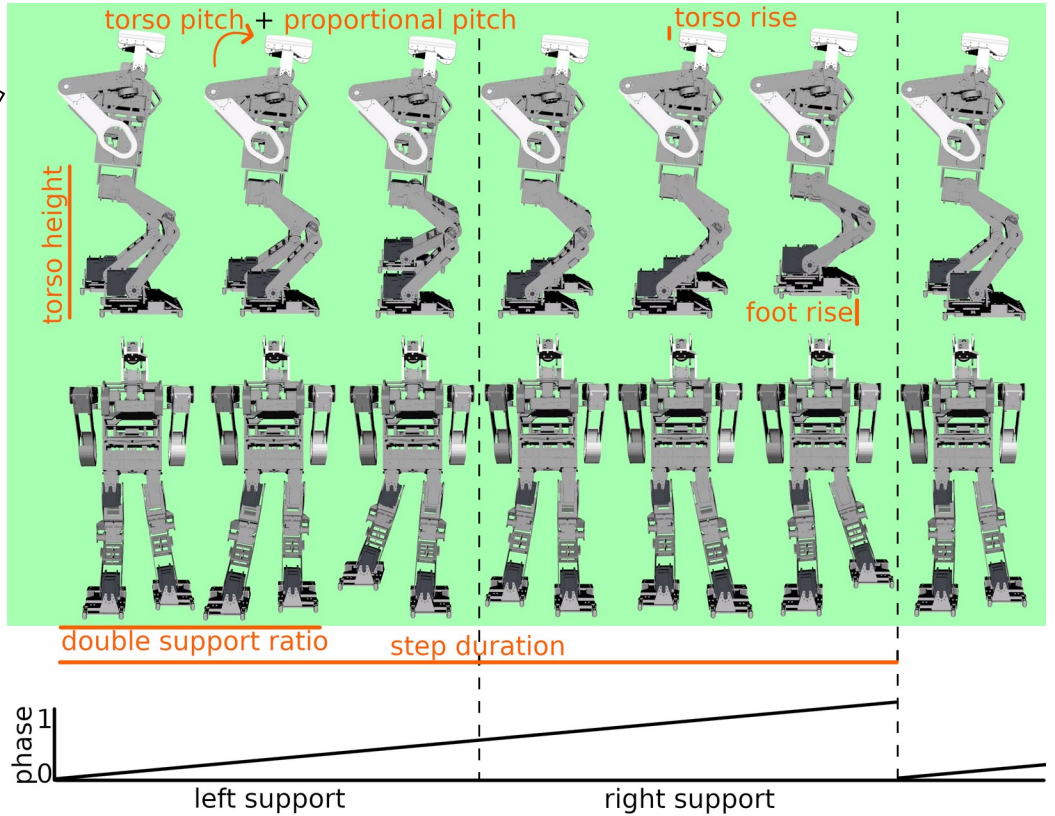


Average Speed



Walk Parameters





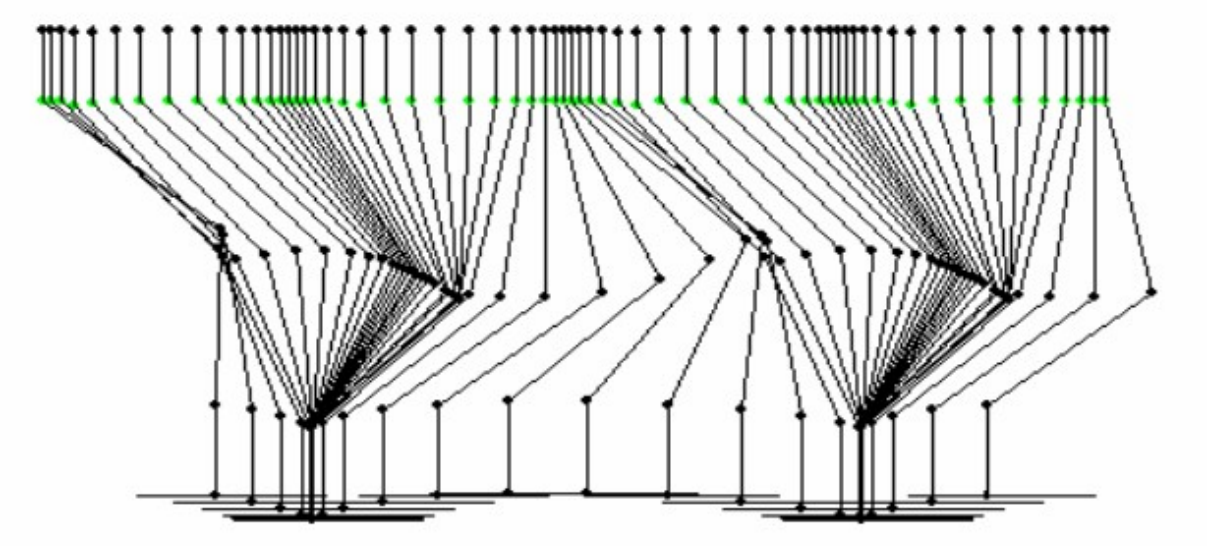
[Bestmann23]

Windlass Mechanism

- Variable Stiffness
- Shock absorption

[Hashimoto10, Yamamoto19]

Level Feet



a) Conventional walking

[Ogura08]