Technical University of Munich
TUM School of Engineering and Design
Chair of Applied Mechanics

Overview of Design Considerations for Data-Driven Time Stepping Schemes Applied to Non-linear Mechanical Systems

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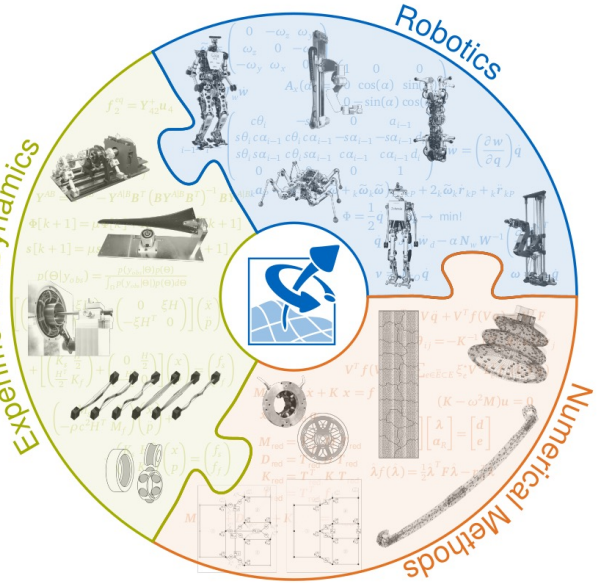
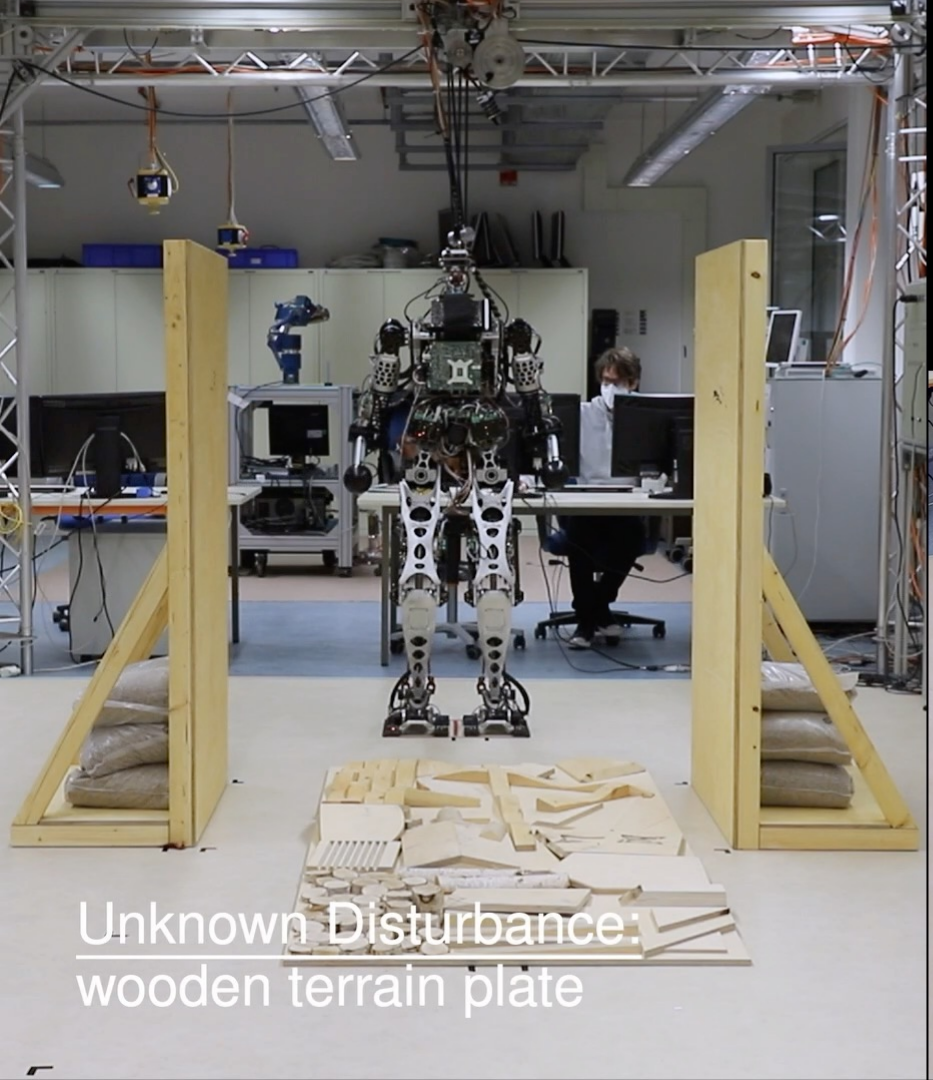
Research @ TUM- Applied Mechanics

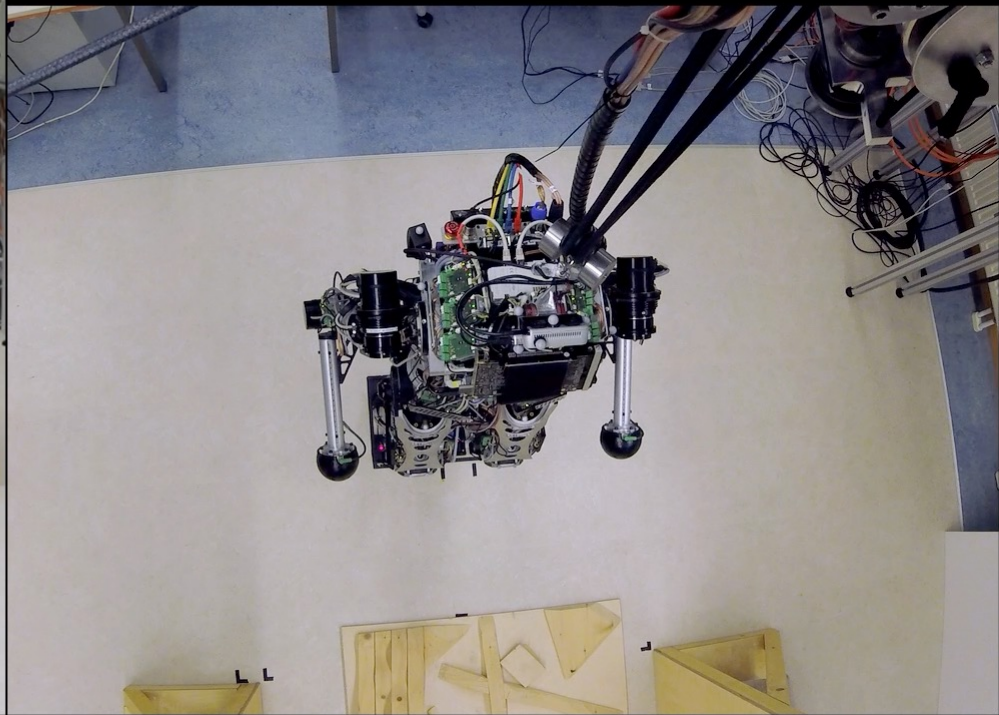


"[…] **Numerical** and **Experimental Methods** for Efficient Mechanical System Dynamics Simulations, […] Build Novel **Robotic** Systems."

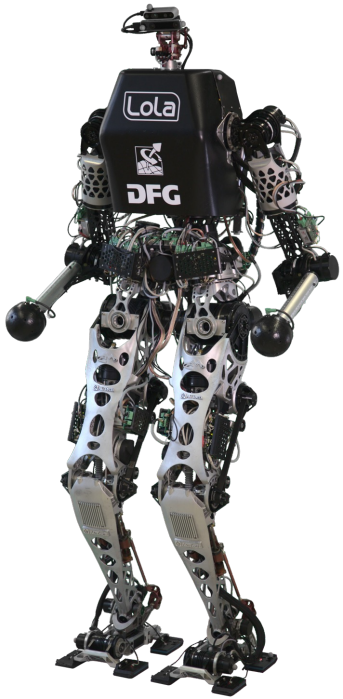
- ❑ Data-Driven Reduction & Dynamics
- ❑ Joint Dynamics
- ❑ Flexible MBS & FEM
- ❑ Humanoid Robots

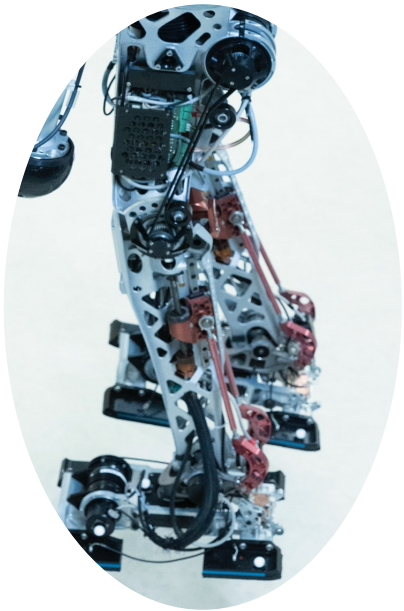


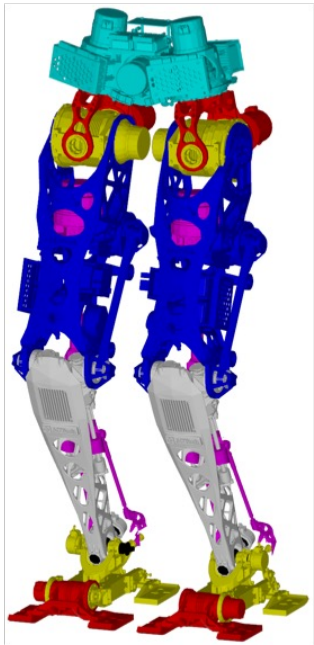
Unknown Disturbance:
wooden terrain plate



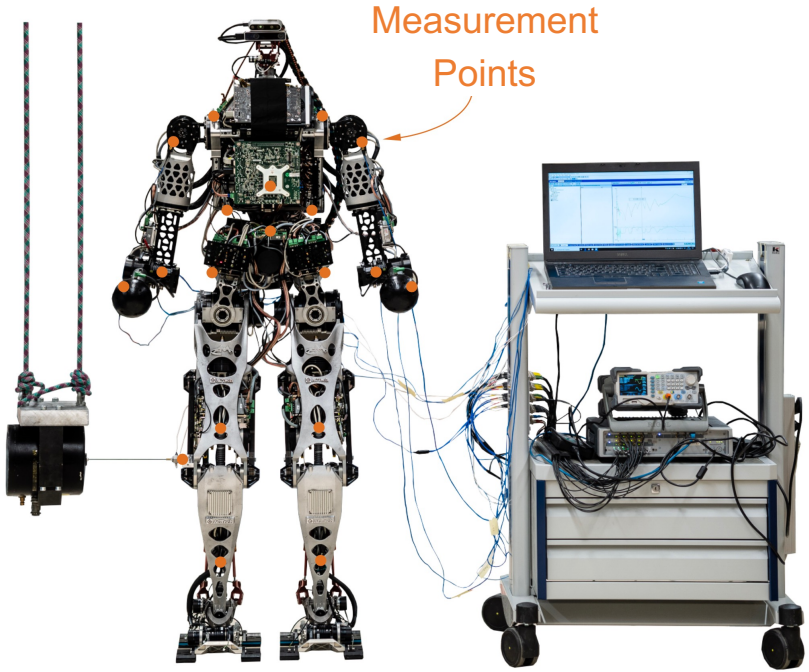
AM's Humanoid Robot *LOLA*

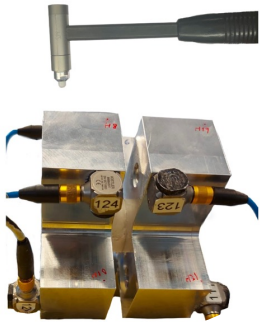


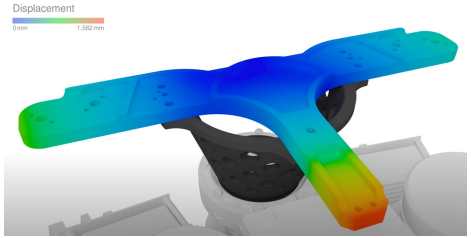




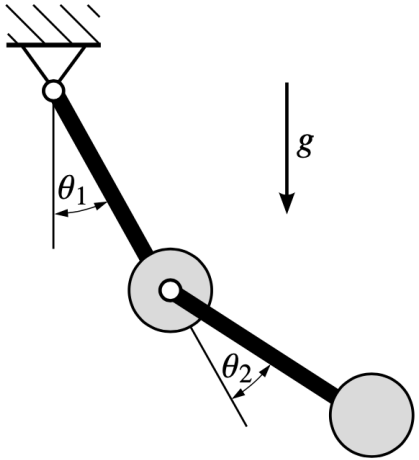
Data From Experiments & Simulations



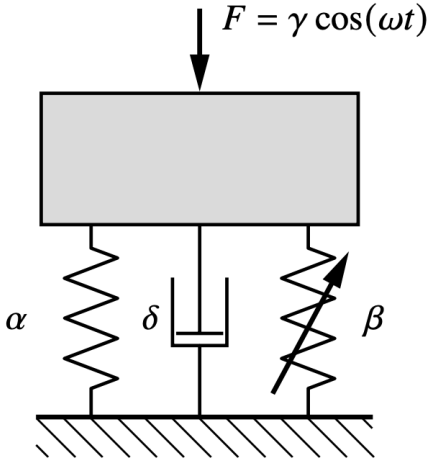




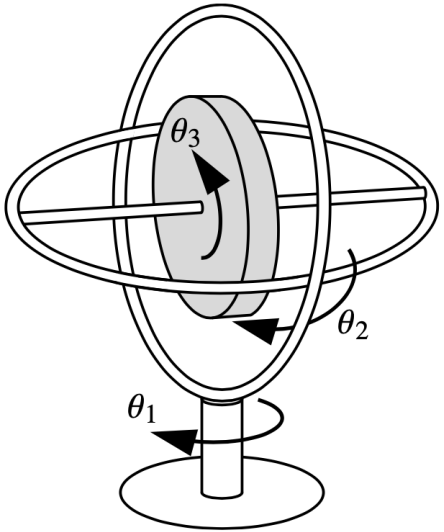
Numerical Examples



(a) Double pendulum

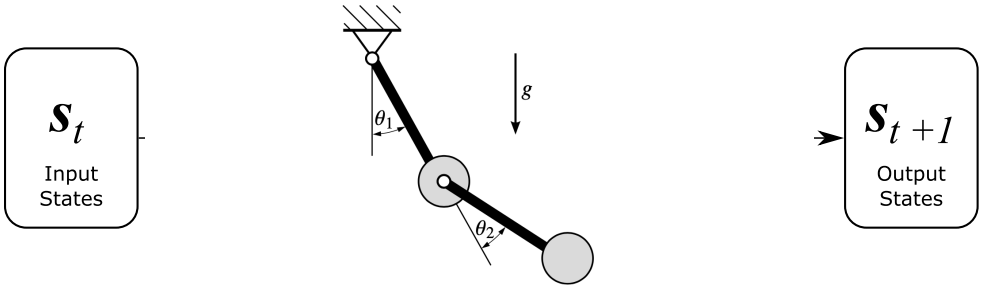


(b) Duffing oscillator

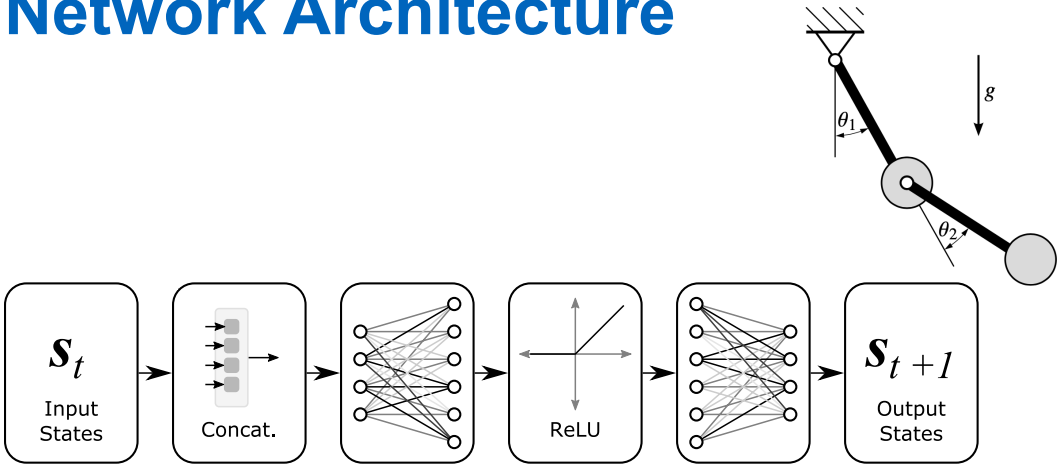


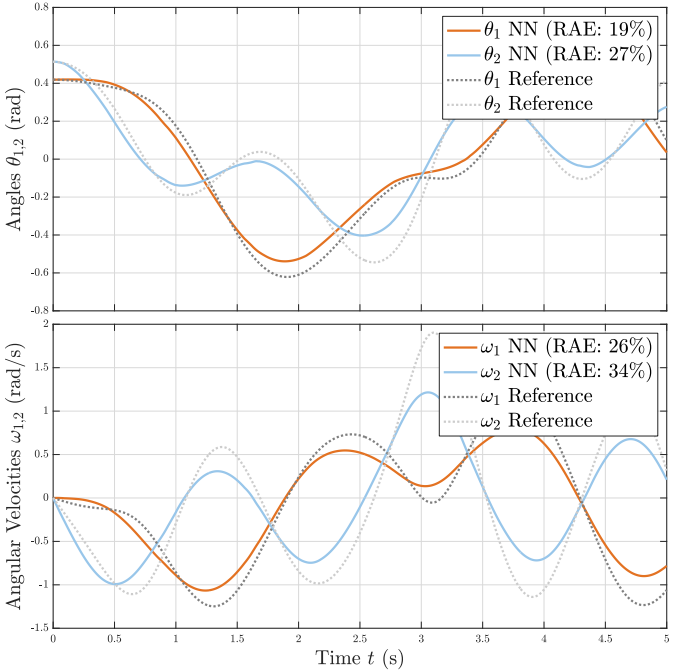
(c) 3D Gyroscope

Neural Network Goal

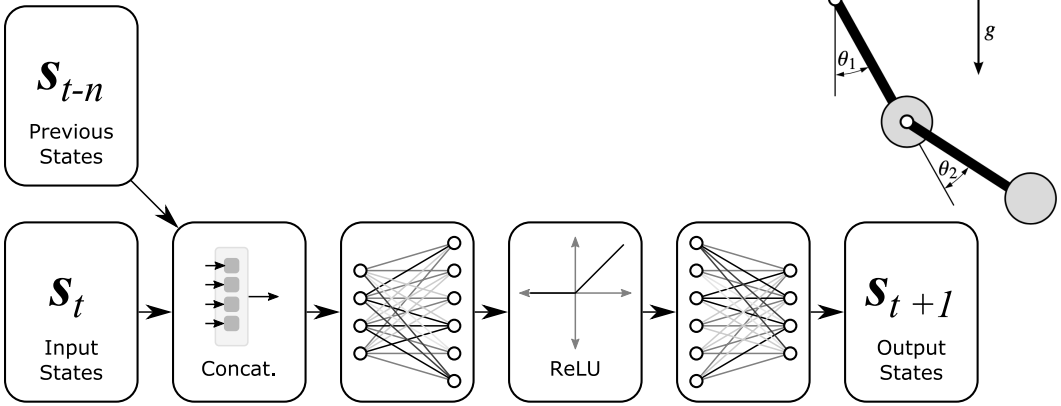


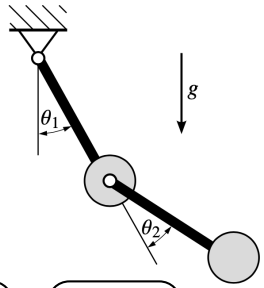
Network Architecture

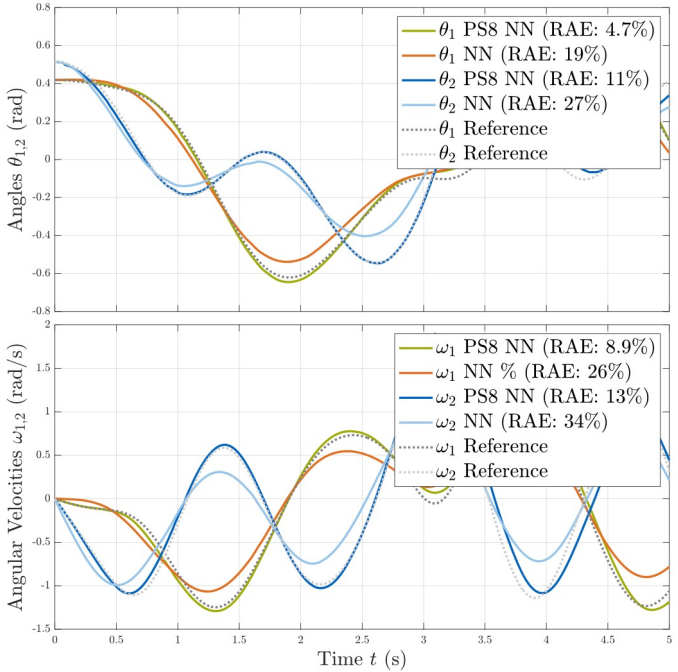




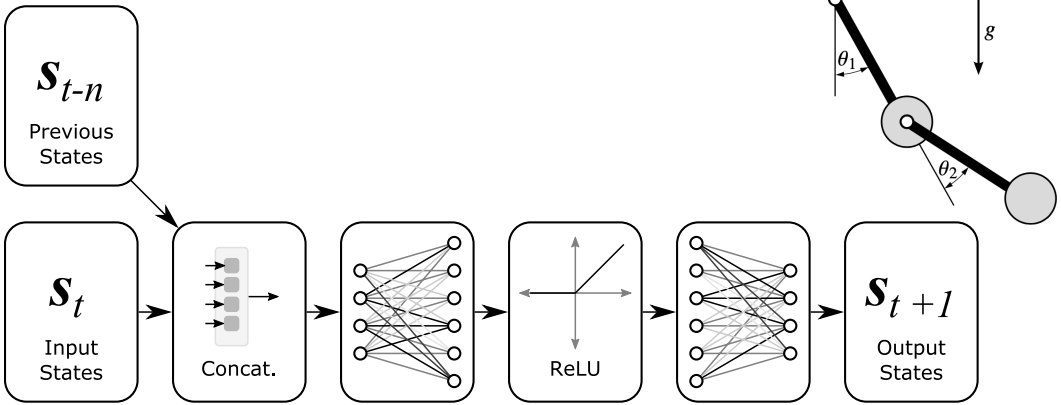
Previous States

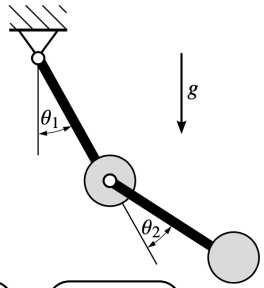






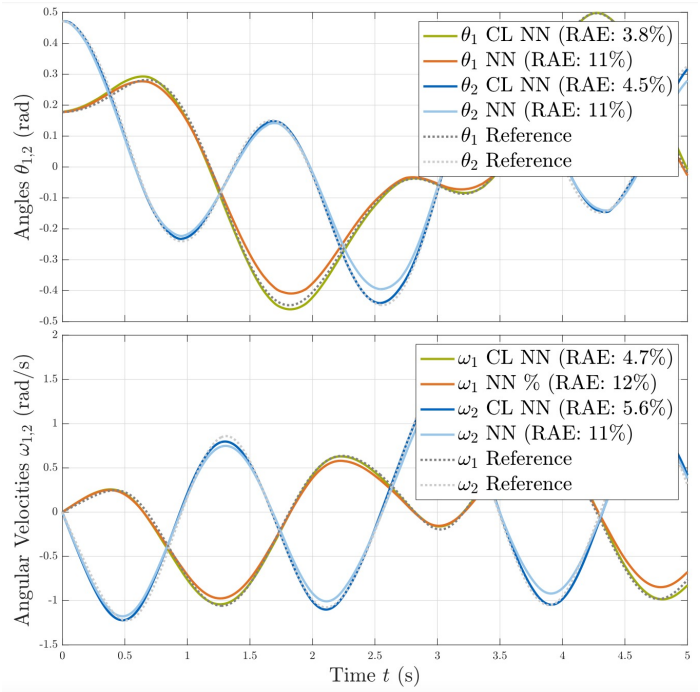
Closed Loop Training





RMSE

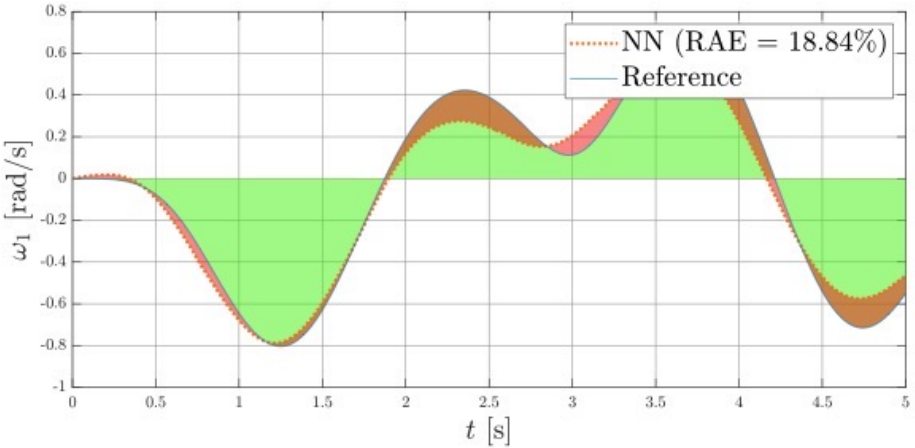
Trained with closed loop	θ_1 (rad)	θ_2 (rad)	ω_1 (rad/s)	ω_2 (rad/s)
no	0.0253	0.0327	0.0693	0.1125
yes	0.0101	0.0169	0.0311	0.0579



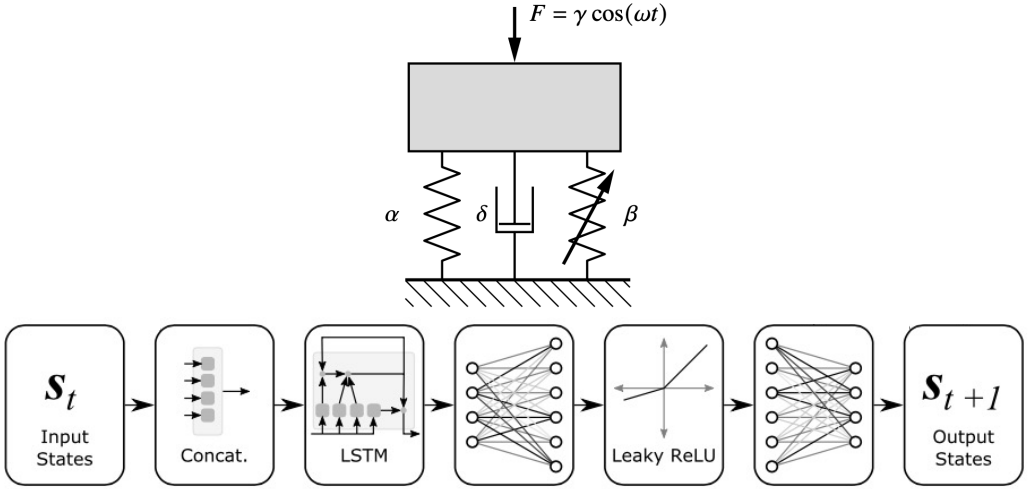
Root Mean Square Error

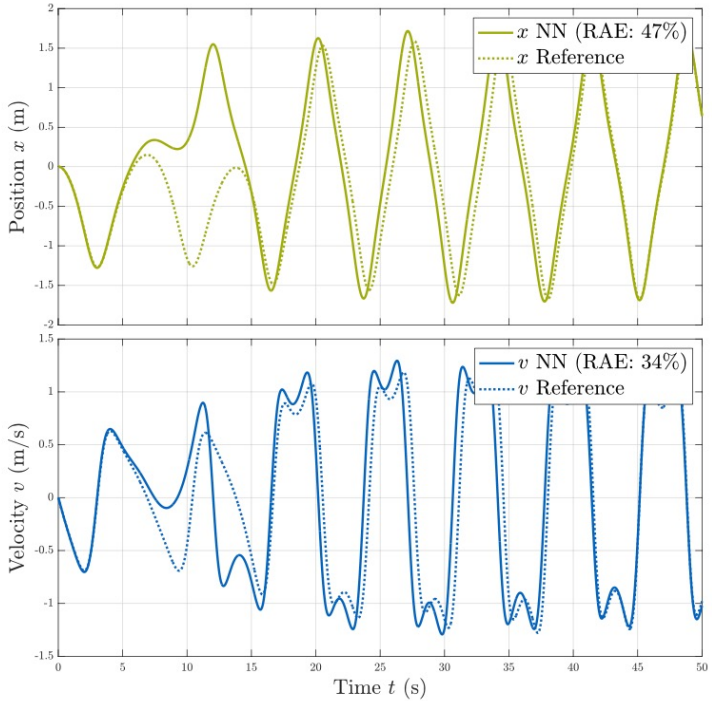
	RMSE				
Noise	θ_1 (rad)	θ_2 (rad)	ω_1 (rad/s)	ω_2 (rad/s)	REI
reference	0.0074	0.0120	0.0232	0.0420	
1%	0.0119	0.0130	0.0272	0.0449	1.2
2%	0.0133	0.0132	0.0277	0.0402	1.3
5%	0.0506	0.0343	0.0783	0.0800	3.7
10%	0.1119	0.1047	0.2353	0.3054	10.3

Relative Area Error



Analytical Integration





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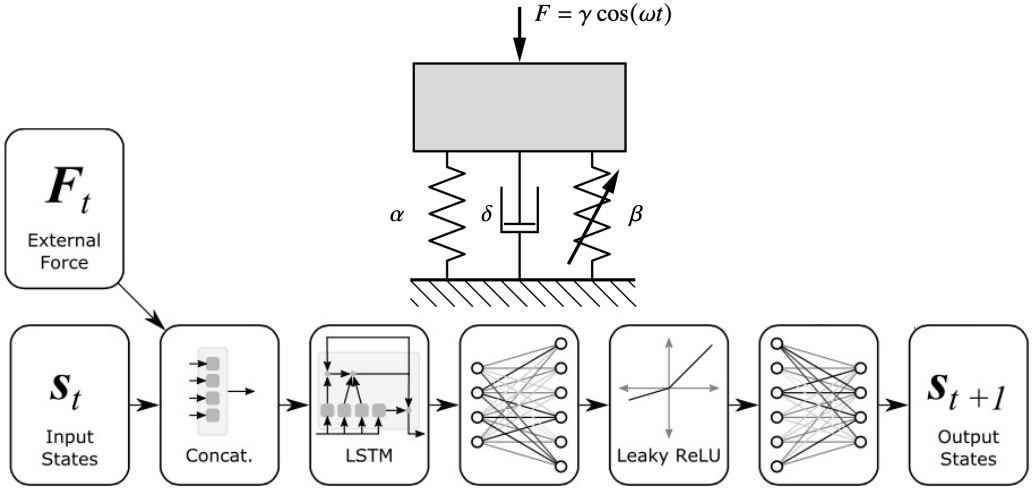

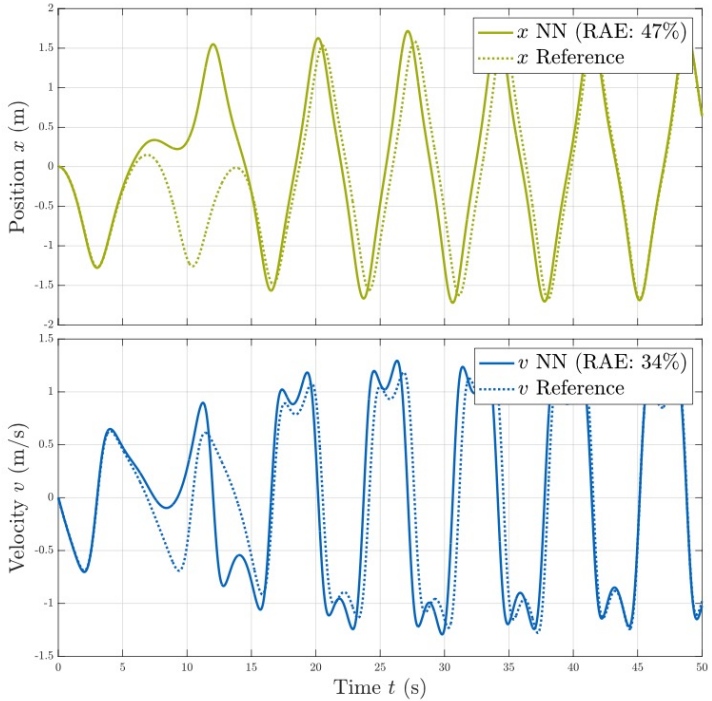

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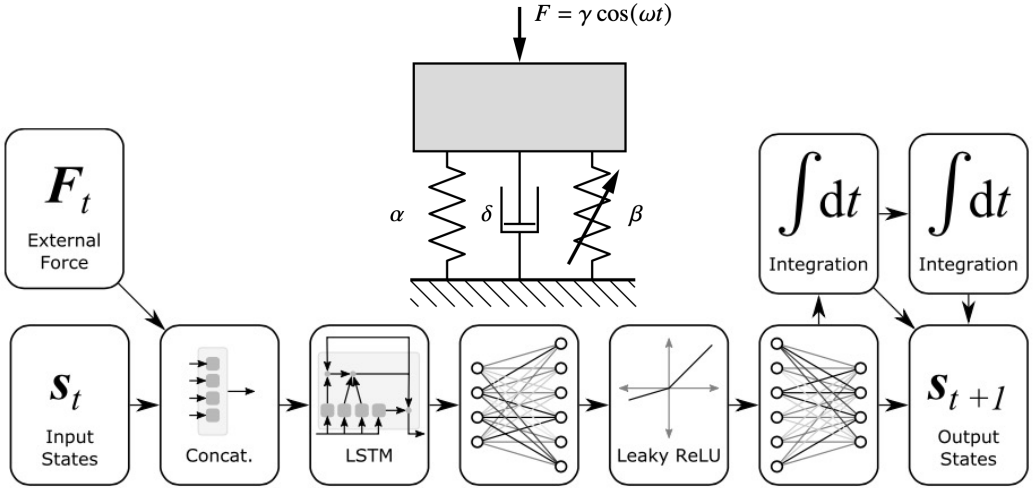
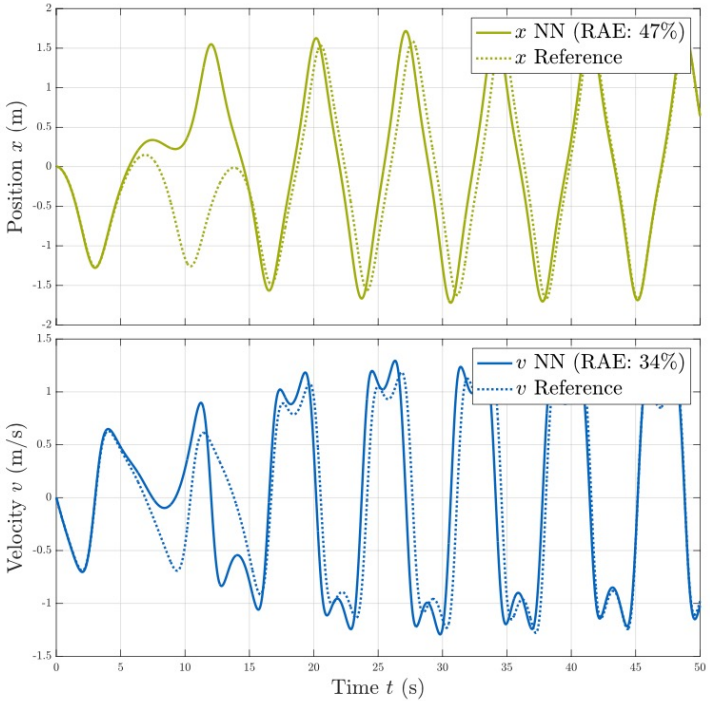
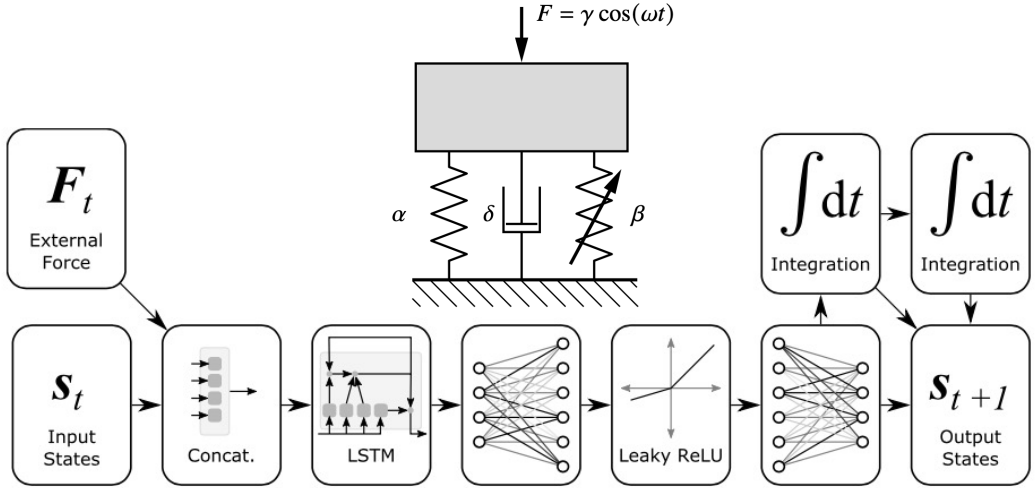


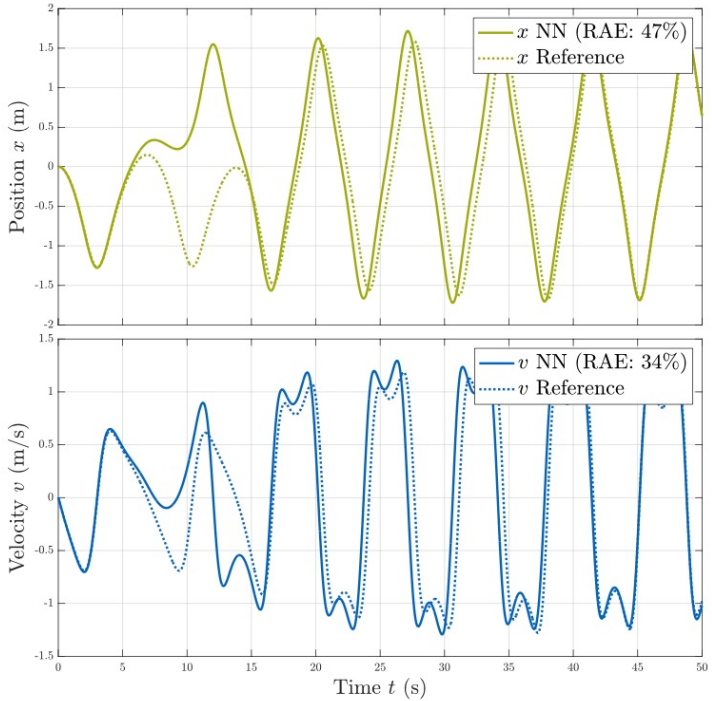


Analytical Integration

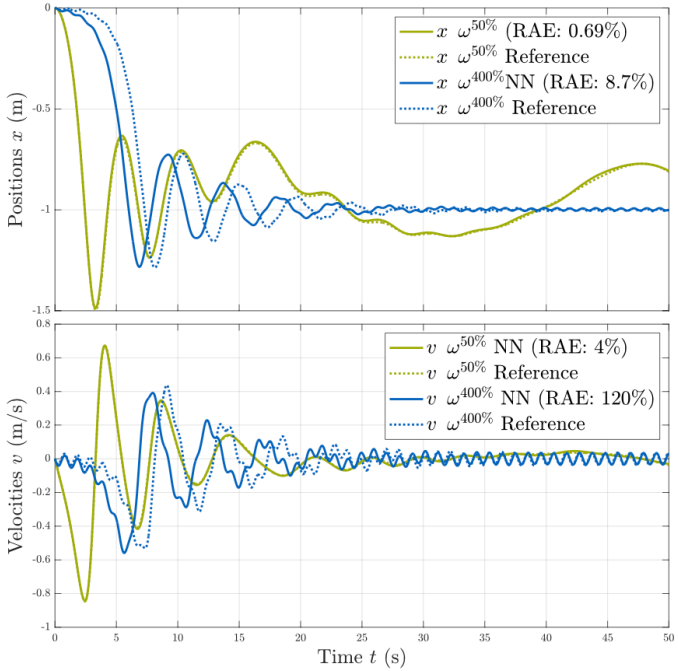


Frequency (Hz)	RMSE (m)	RMSE (m/s)
50	0.4679	0.2576
100	0.2422	0.1347
200	0.5141	0.3004

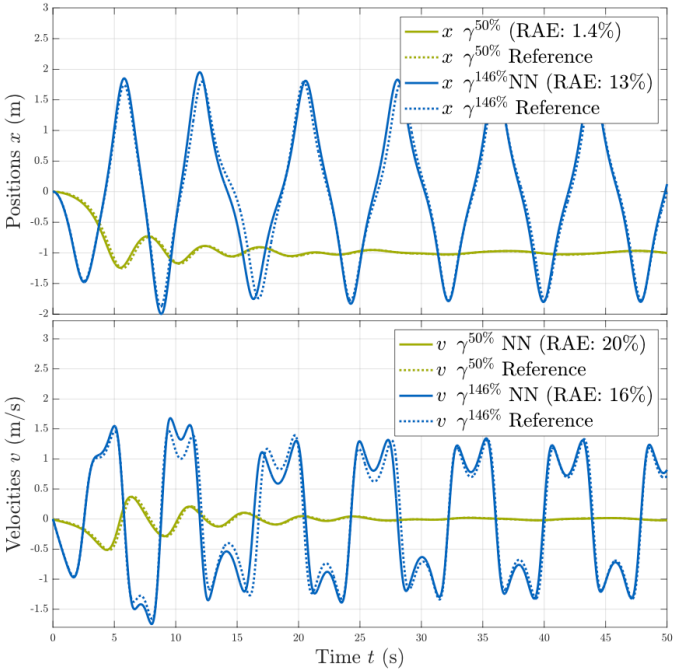
Previous Steps	RMSE (m)	RMSE (m/s)
reference	0.5046	0.2654
6	0.4096	0.2376
7	0.2462	0.1531
8	0.2422	0.1347
9	0.3469	0.1874
10	0.4219	0.2108



Extrapolation

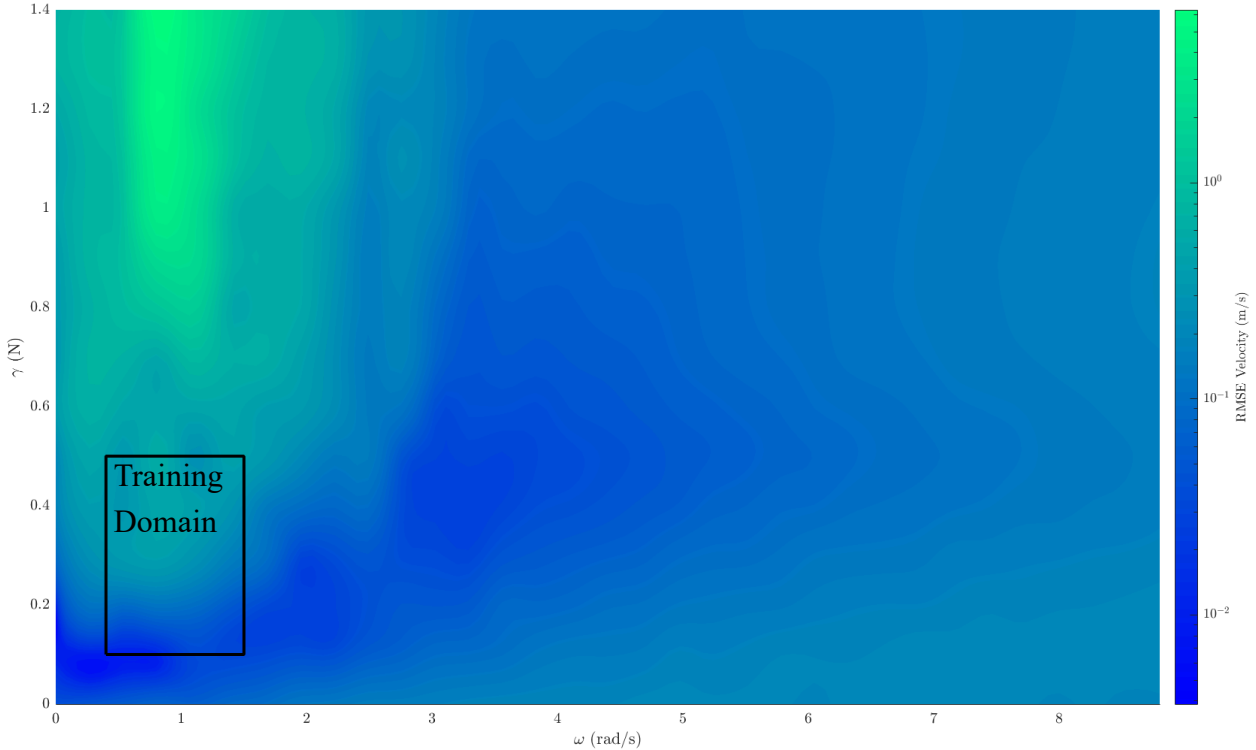


(a) Extrapolation of excitation frequency

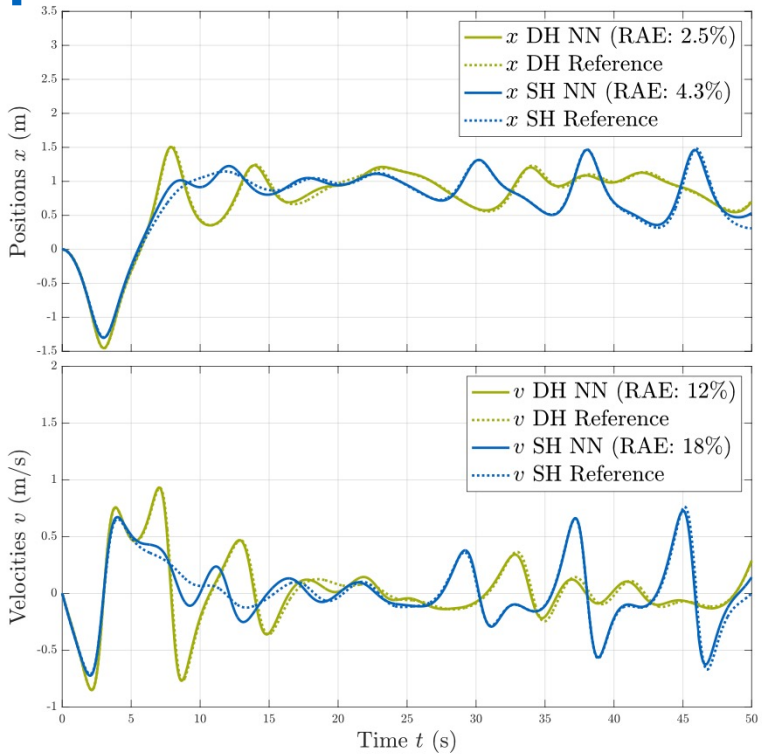


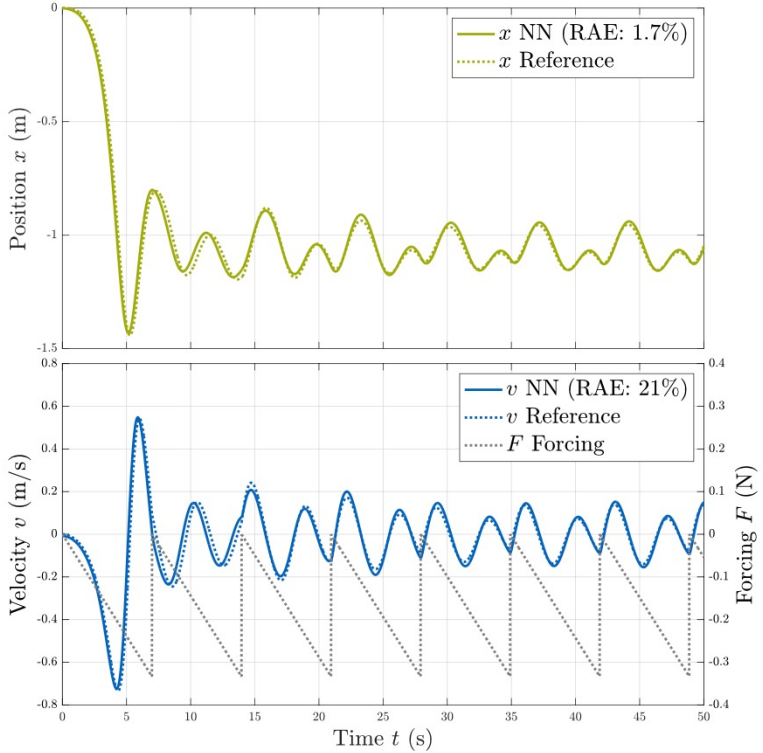
(b) Extrapolation of excitation amplitude

Extrapolation

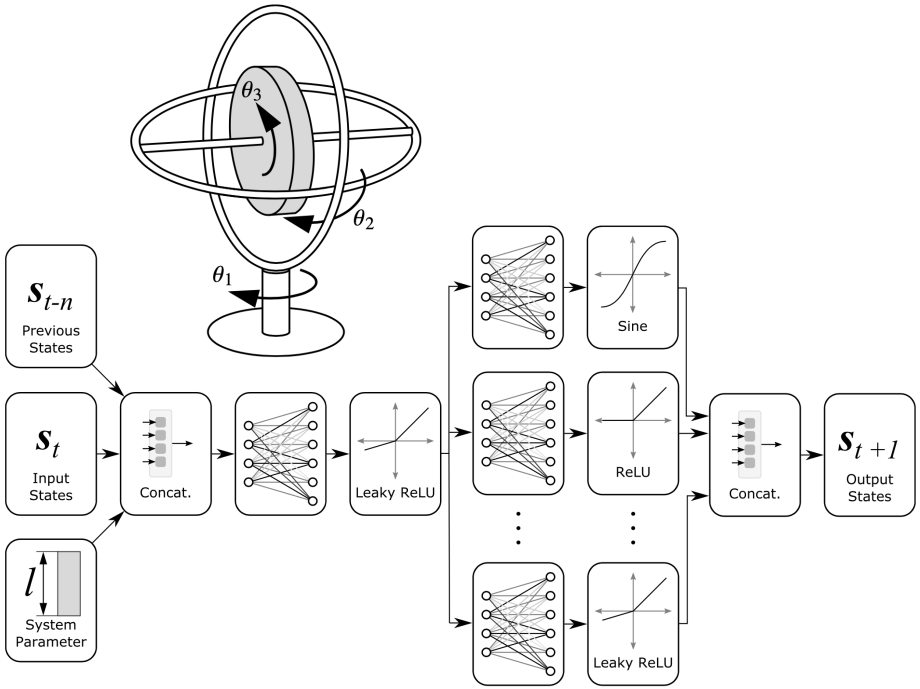


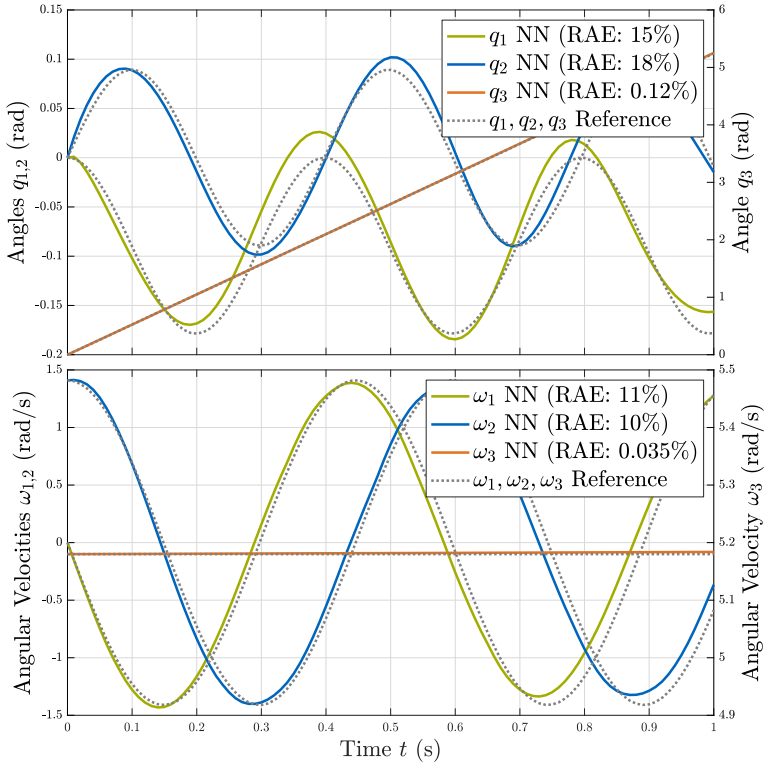
Extrapolation



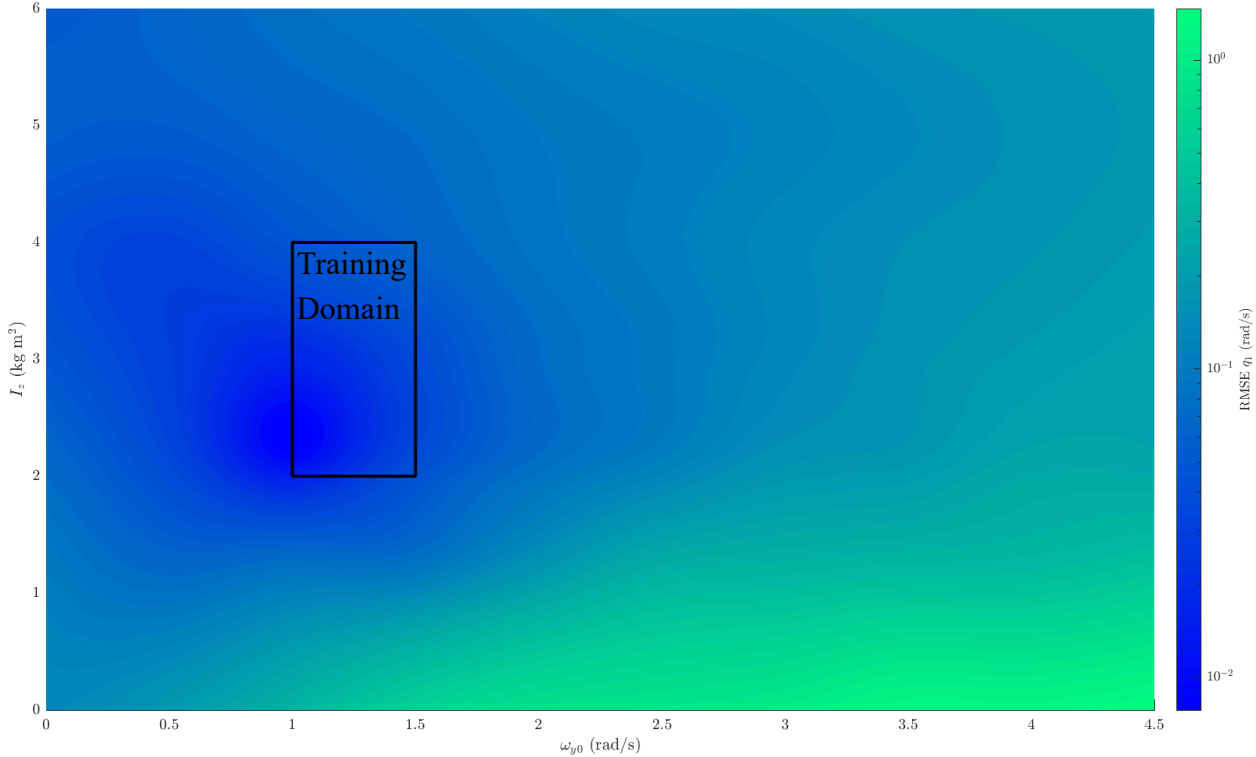


Branched Neural Network

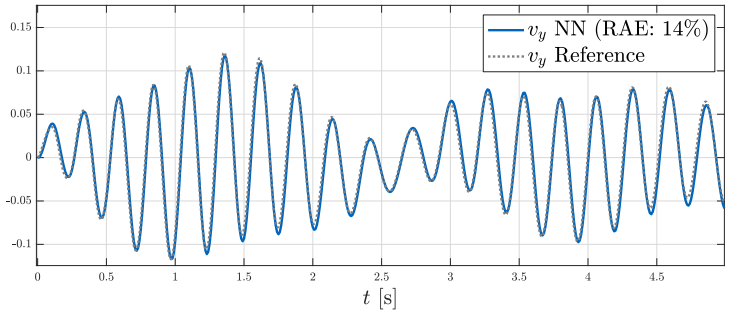




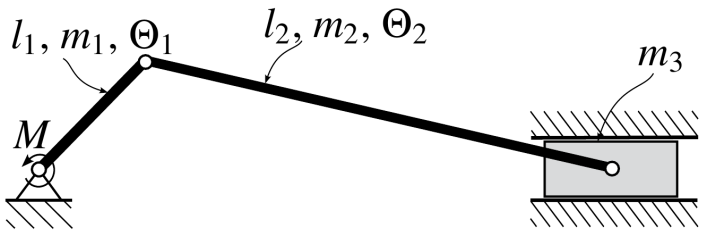
Extrapolation



Teaser:
Flexible bodies



Real-world data



Take Home Messages

- ❑ Data-driven identification of MBS dynamics is possible
- ❑ Expert understanding of neural network design is required
- ❑ Extrapolation using neural networks is feasible

https://gitlab.lrz.de/tomas.slimak/asme-idetc2023-112087

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