Design of a High Gain Observer for a Very Flexible Parallel Robot

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Motivation

- flexible multibody dynamics modeling
- nonlinear observer design for a very flexible manipulator to estimate full states and the end-effector position
- nonlinear actuator control of an underactuated robot based on the drivers position and velocity
- experiments with a nonlinear observer on the lambda robot

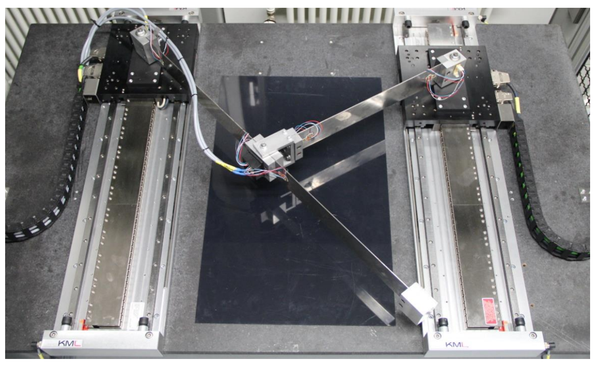
System Modeling

- equations of motion of the multibody system

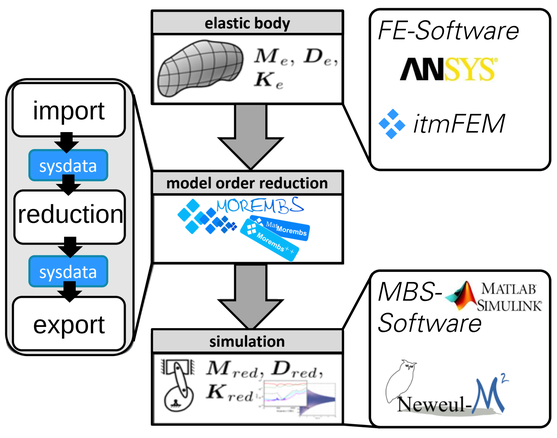
$$\boldsymbol{M}(\boldsymbol{q})\cdot\ddot{\boldsymbol{q}}+\boldsymbol{k}(\boldsymbol{q},\dot{\boldsymbol{q}},t)=\boldsymbol{g}(\boldsymbol{q},\dot{\boldsymbol{q}},t)+\boldsymbol{B}(\boldsymbol{q})\cdot\boldsymbol{u}+\boldsymbol{C}^T(\boldsymbol{q})\cdot\boldsymbol{\lambda}$$
$$\boldsymbol{c}(\boldsymbol{q},t)=\boldsymbol{0}$$

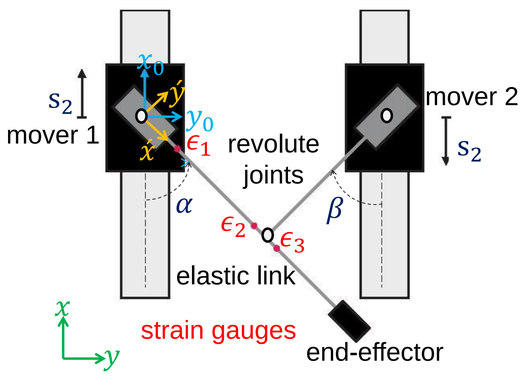
- $\boldsymbol{\lambda}$: reaction forces due to the constraints
- $\boldsymbol{c}(\boldsymbol{q},t)$: loop closing constraints

servo drives with very high bandwidth in the current loop



linear direct drives (permanent magnet synchronous motors)





Nonlinear Observer

There is no direct feedback of the end-effector position and all states of the nonlinear system. In order to estimate them, a nonlinear observer is designed.

nonlinear dynamic of the lambda robot

$$\dot{\boldsymbol{x}}=\boldsymbol{g}(\boldsymbol{x})+\boldsymbol{H}(\boldsymbol{x})\cdot\boldsymbol{u}=\boldsymbol{f}(\boldsymbol{x}),$$
$$\boldsymbol{y}=\boldsymbol{C}\cdot\boldsymbol{x}$$

input controller $\boldsymbol{u}=\boldsymbol{K}\boldsymbol{x}$, where $\boldsymbol{K}$ is a constant gain matrix

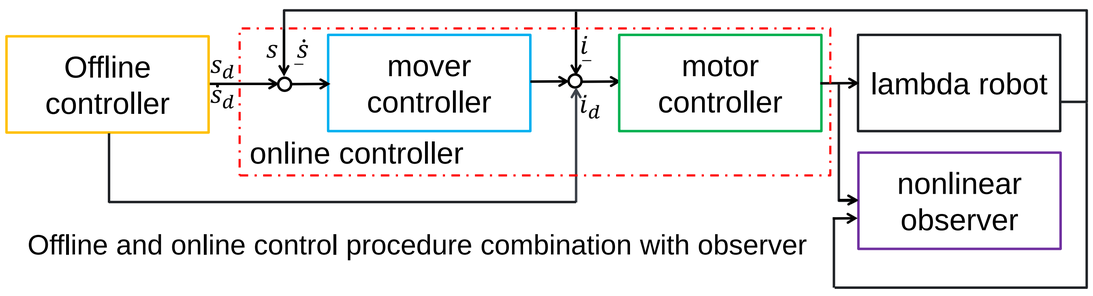
estimation of the lambda system states

$$\dot{\hat{\boldsymbol{x}}}=\boldsymbol{f}(\hat{\boldsymbol{x}})+\boldsymbol{L}(\hat{\boldsymbol{y}}-\boldsymbol{y}),$$
$$\hat{\boldsymbol{y}}=\boldsymbol{C}\cdot\hat{\boldsymbol{x}}$$

estimation error

$$\boldsymbol{e}=\boldsymbol{x}-\hat{\boldsymbol{x}}$$

this error converges asymptotically to zero



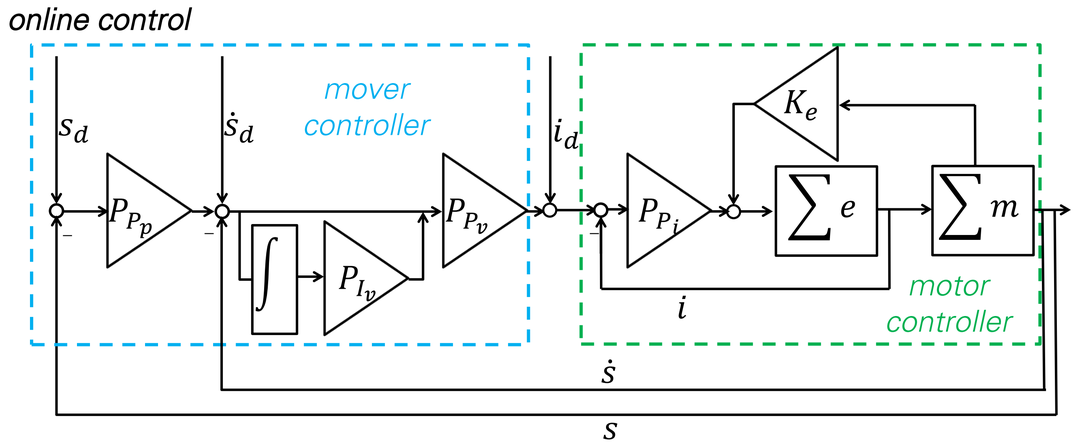
Offline and online control procedure combination with observer

System Control

offline control

- define a trajectory as a servo constraint for the system
- finding the solution by model inversion based on the stability of internal dynamics and two point boundary values with the MATLAB solver bvp5c
- result of offline control is the desired trajectory for the online tracking

online control



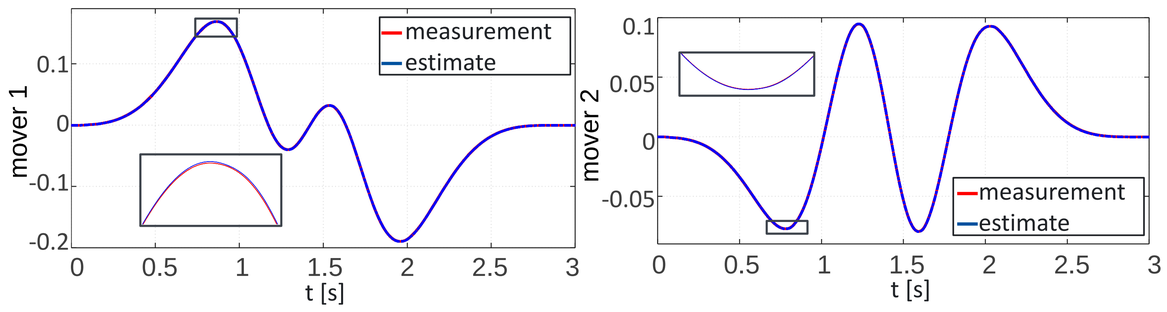
Experimental Setup

In order to validate the end-effector position, a camera is used to track the end-effector position.

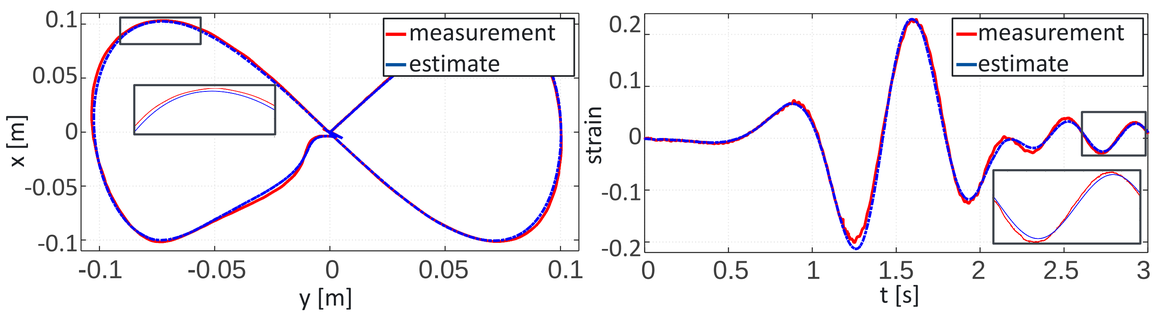
The image processing of the recorded image for the end-effector positions is accomplished offline.

Experimental Results

To estimate the end-effector position and the states of the lambda robot, the mover positions and velocities and the deformation of the flexible long link are used.



Estimated position of the movers track the measurement results



Left figure: estimated deformation tracks the strain gauge measurement results
Right figure: estimated position of the end-effector tracks recording position by camera

The experimental estimation results for the nonlinear trajectory show the designed observer estimates of the states and the end-effector positions with high accuracy.

Conclusions

- high speed trajectory tracking using a combination of the feed-forward and feedback controller
- using the deformation of the long link and position and velocity of the movers, the states and end-effector position are estimated
- a nonlinear dynamic controller shall be designed based on the observer estimation for the underactuated system

References

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[2] Primbs, J.: Survey of Nonlinear Observer Design Techniques. Penn State Notes, Vol. 1, No. 1, pp. 1–18, 1996.

[3] Khalil, H.K., Praly, L.: High-Gain Observers in Nonlinear Feed-back Control. International Journal of Robust and Nonlinear Control, Vol. 24, No. 6, pp. 993–1015, 2014.