Improving a Flexible Robot Model Using a Nonlinear Observer

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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

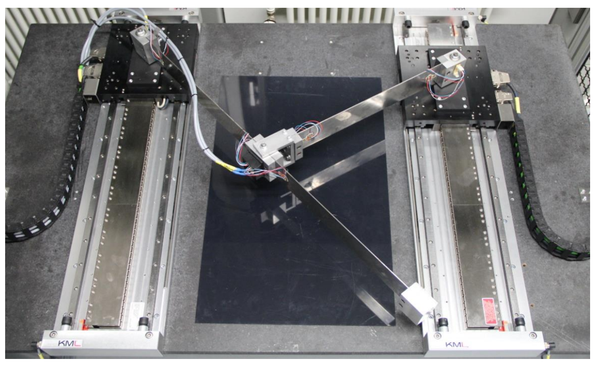
- equations of motion of the multibody system

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

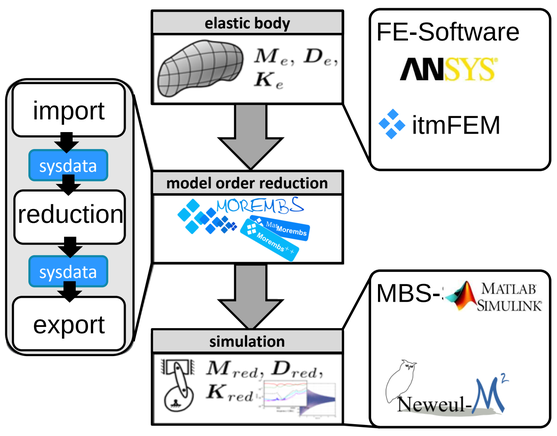
$$\boldsymbol{c}(\boldsymbol{q})=\boldsymbol{0}$$

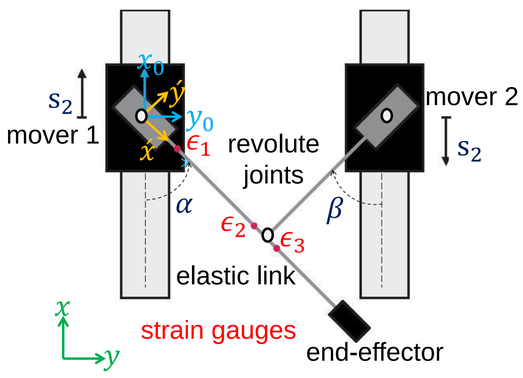
- $\boldsymbol{\lambda}$: reaction forces due to the constraints
- $\boldsymbol{c}(\boldsymbol{q},t)$: loop closing constraints

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

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

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

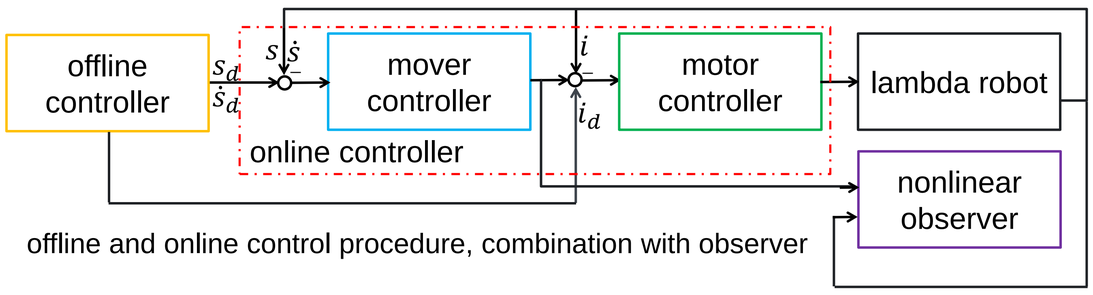
estimation of the lambda system states

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

estimation errors can be written as

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

this error converges asymptotically to zero



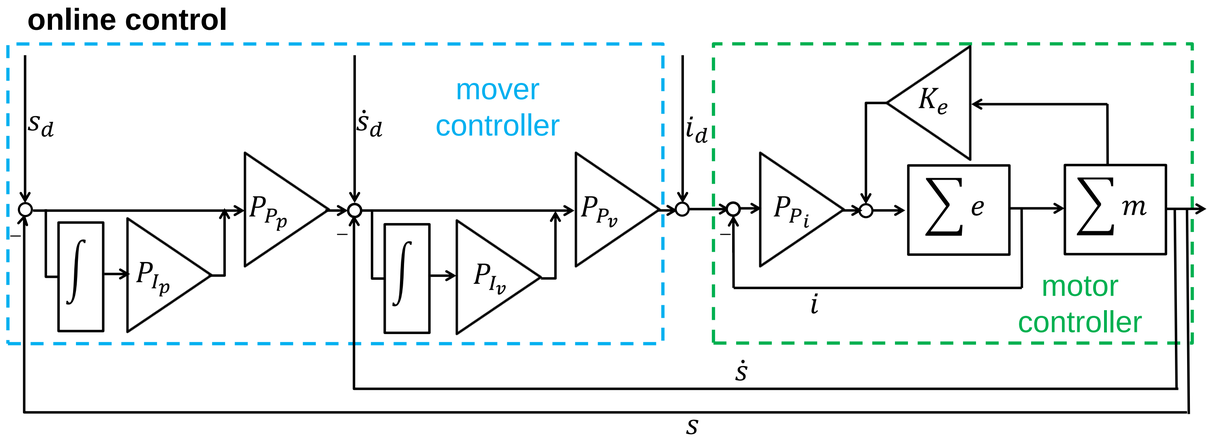
offline and online control procedure, combination with observer

System Control

offline control

- defining 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

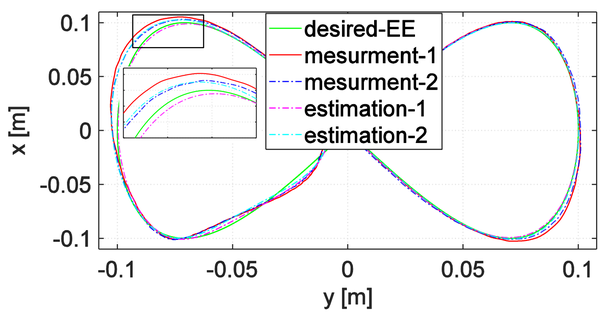
- to validate the end-effector position, a camera is used to track the end-effector position
- the image processing of the recorded movie for the end-effector positions is accomplished offline

Experimental Results

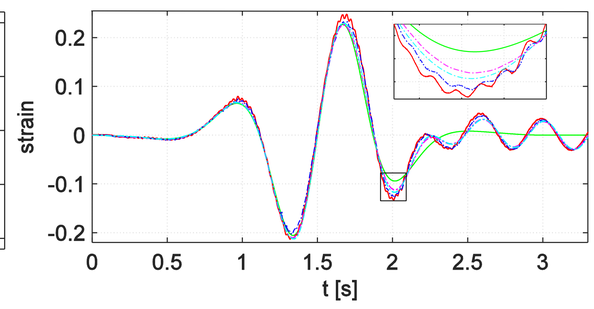
To estimate the end-effector position, the states, the mover positions and velocities and the deformation of the flexible long link are used.

Comparing the estimated results based on the existing model (estimation-1) and camera measurement of end-effector positions (measurement-1) show that the model that is used to transfer the joint space positions to work space positions does not have enough accuracy.

Therefore, the model of the flexible robot was updated based on the observation results and named model-2. The controller based on the model-2 is tested on the robot and results are measurement-2. The new observer based on the updated model designed and implement on the robot and results are estimation-2.



estimated and measured positions of the end-effector based on two models



estimated deformations and strain gauge measurements based on two models

The experimental estimation results for the nonlinear trajectory show the designed observer based on the updated model estimates 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 based on the existing model and the updated model
- the outputs of the real system are used to estimate and update the parameters of the very flexible parallel robot
- 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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