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
  \[ M(q) \cdot \ddot{q} + C(q) \cdot \dot{q} + g(q) + \tau = \tau_u + \tau_c \]
• \( \tau \): reaction forces due to the constraints
• \( c(q, t) \): loop closing constraints

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
\[ \dot{x} = N(x) + H(x) \cdot u = f(x), \]
\[ y = C \cdot x \]
input controller \( u = K \cdot x \), where \( K \) is a constant gain matrix.

estimation of the lambda system states
\[ \dot{\hat{x}} = f(\hat{x}) + L \cdot ( \hat{y} - y ), \]
\[ \dot{\hat{y}} = C \cdot \hat{x} \]
estimation errors can be written as
\[ e = \hat{x} - x \]
this error converges asymptotically to zero.

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.

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