Modelling and Control Synthesis of Flexible Robot Arm Equipped with Additional Sensors

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Abstract

Industrial robots of the serial structure would represent an interesting cost-saving and flexible alternative for machining applications, if it was possible to increase their effective stiffness and positioning accuracy. The ultimate goal is to achieve the accuracy of products machined by industrial robots comparable with the production by machine tools. The causes of inaccuracy are many. Primarily it is the compliance of the industrial robot compared with machine tool, but also the temperature deformation, geometric errors due to inaccurate calibration, backlash in gearboxes, vibration etc. The basic question is, how to increase the effective stiffness of the robot end-effector by the feedback strategies, appropriate auxiliary structures and additional sensing. The modelling and control synthesis of the flexible robot equipped with additional sensors is the topic of the paper and part of the research project supported by Czech Science Foundation. Several possible concepts of the redundant measurements of the flexible arm and its end-effector motion using additional auxiliary mechanisms and/or laser beam sensors have been analyzed by authors in [1].

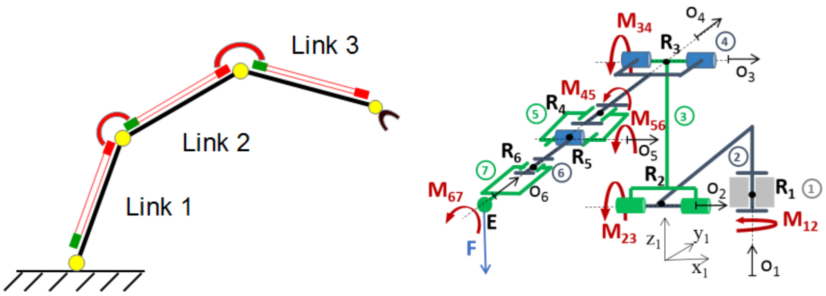

Figure 1: Considered concept of additional measurements and structure of robot model

The control law synthesis was realized on the complex mechatronical simulation multibody model (Figure 1). The model consists of the flexible robot members, flexible gearboxes, encoders on the motors and on the revolute joints, arms deformation sensors consisting of the laser emitter and the photodiodes and the models of motors and servo drives.The model of robot dynamics (1) has been assembled. The parameters of the model had to be estimated according to the material of the robot parts and their dimensions and are easily tuneable. Their adjustments will be based on the future identification experiments with the currently constructed functional model. The eigen-modes of the flexible arms have been obtained using the FEM analysis.

$$\begin{bmatrix} \boldsymbol{M}^R(\boldsymbol{q},\boldsymbol{E}) & \boldsymbol{M}^{RF}(\boldsymbol{q},\boldsymbol{E}) & \boldsymbol{0} \\ \left(\boldsymbol{M}^{RF}(\boldsymbol{q},\boldsymbol{E})\right)^T & \boldsymbol{M}^F(\boldsymbol{q},\boldsymbol{E}) & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{M}^M \end{bmatrix} \begin{bmatrix} \ddot{\boldsymbol{q}} \\ \ddot{\boldsymbol{E}} \\ \ddot{\boldsymbol{q}}_M \end{bmatrix} = \begin{bmatrix} \boldsymbol{Q}^R(\boldsymbol{q},\dot{\boldsymbol{q}},\boldsymbol{E},\dot{\boldsymbol{E}},\boldsymbol{q}_M,\dot{\boldsymbol{q}}_M) \\ \boldsymbol{Q}^F(\boldsymbol{q},\dot{\boldsymbol{q}},\boldsymbol{E},\dot{\boldsymbol{E}},\boldsymbol{q}_M,\dot{\boldsymbol{q}}_M) \\ \boldsymbol{Q}^M(\boldsymbol{q},\dot{\boldsymbol{q}},\boldsymbol{E},\dot{\boldsymbol{E}},\boldsymbol{q}_M,\dot{\boldsymbol{q}}_M) \end{bmatrix} \quad (1)$$

The symbol $\boldsymbol{M}^R$ represents the part of mass matrix related to the „rigid“ motion, $\boldsymbol{M}^F$ is the part of the mass matrix representing the „flexible“ motion and $\boldsymbol{M}^{RF}$ represents the interconnection of them. The symbol $\boldsymbol{M}^{M}$ represents the mass matrix of the rotors. The $\boldsymbol{q}_{M}$ represent the position of the motors' rotors, $\boldsymbol{E}$ the arms' deformation and $\boldsymbol{q}$ the movement of the joints. the The symbols on the right-hand side are the corresponding generalized force vectors. Both the additional measurements and the sufficiently precise mathematical model of the robot dynamic properties are intended for the robot control with higher precision.

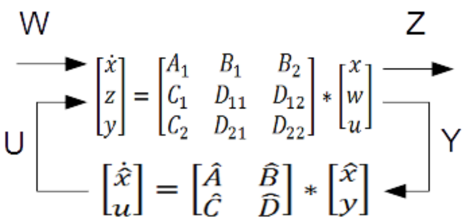

Figure 2: Scheme of the H$^{\infty}$ robust control

The aim is to achieve unique control strategies for accurate trajectory tracking in the course of motion of the end-effector. In concrete the model cascade control and H$^{\infty}$ robust control (Figure 2) synthesis have been used for this aim. Further the model predictive control is intended to use with the H$^{\infty}$ robust control [2]. Moreover the sensitivity to errors of sensor measurements and robustness with respect to model inaccuracy has been studied by simulation experiments.

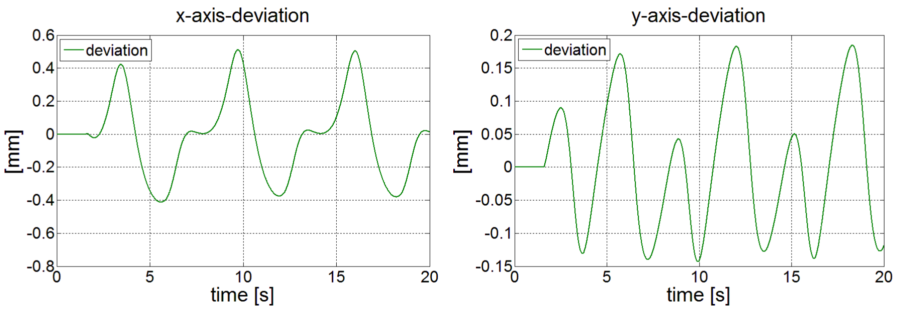

Figure 3: Deviation of the end-point

The simulation model has been tested (Figure 3) on Lemniscate of Bernoulli with maximum position change of 5mm in y-axis and 15mm in x-axis. The further development of control design will continue, the functional model will be identified in order to make the mathematical model more accurate. The final aim is to verify the increase of effective stiffness and positioning accuracy of the robotic chain equipped by redundant measurements using position feedback based control.

Acknowledgements

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References

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