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3-DOF planar manipulator utilizing compliant joints with variable stiffness

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On the way to more productive manufacturing, principle of human-robot collaboration is often mentioned. Compared to heavy industrial robots, which perform their tasks behind safety fences, requirements for collaborative robots (cobots) differ. They should be small, light and powerful enough to help humans but not to hurt them. In other words, their design is mainly determined by current safety standards. Overview of safety measures used in industrial plants is presented in [2]. One of the drawbacks of cobots in today's design is their payload. Due to higher inertia of heavy load, they are not allowed to carry too much. One option, how to deal with this fact, is incorporating intrinsic compliant systems into their structure, to prevent potential collision damage. Such a system could be a variable impedance actuator, which allows controlling its position and stiffness simultaneously. Reviews on their types and design could be found in e.g. [4, 5]. Our goal is therefore to study and develop structures with intrinsic safety, which comply with safety standards and are able to assist during collaborative human-robot production tasks.

Firstly in presented work, one type of a variable stiffness actuator was adopted, namely VSA-II (Fig. 1 left) described in [3]. It consists of two motors in antagonistic setup and nonlinear transmission connecting each motor to the controlled link. The nonlinear transmission is made of 4-bar mechanism (Fig. 1 right) with specific dimensions, which makes the relationship between motor input angle θ and output angle β nonlinear and thus the stiffness seen at O is nonlinear too.

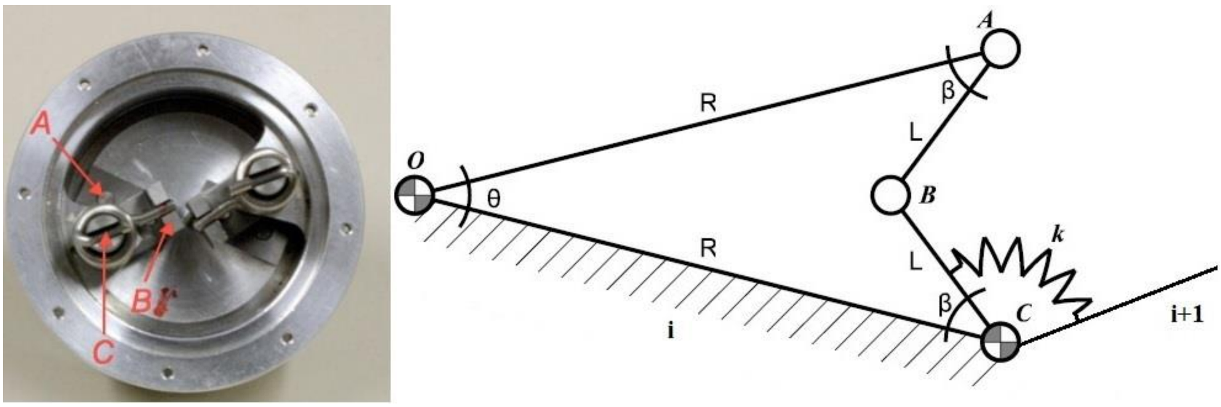

Fig. 1. VSA-II prototype (left) and 4-bar mechanism (right) used as nonlinear spring (modified from [4, 5])

Based on description in [3] simulation model of VSA-II connected to the output shaft was created and simple PD control scheme was used to control shaft position and it´s stiffness. First simulation was performed under simplifying assumptions, where no load torque and gravity is considered and steady state equilibrium is assumed, which permit us to define shaft position as motors mean position. Fig. 2 shows results of these simulations, where trajectory of the output shaft is seen on the left and tracking of angle corresponding to output stiffness could be seen in the right picture.

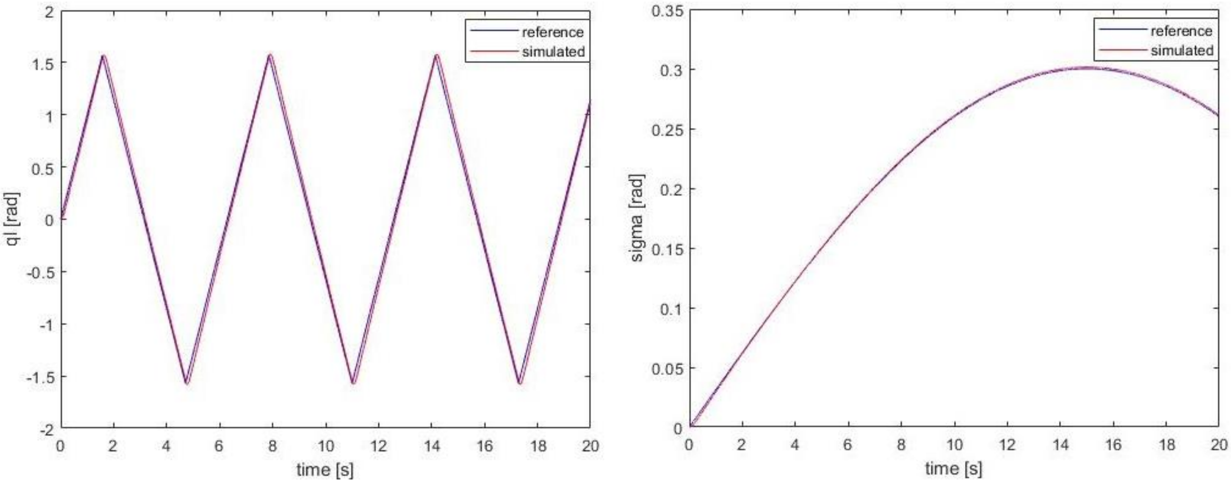

Fig. 2. Position (left) and angle corresponding to stiffness (right) tracking by 1-DOF rod controlled by VSA-II using PD regulator

As mentioned above this model was simplified, which in fact means that the dynamics of the link was ignored. Therefore next simulations with presence of load torque external disturbances and gravity for the output shaft were performed. Increased complexity of the system and especially the control algorithms were observed. The principles of state feedback linearization or feedback linearization (as mentioned in [1]) seem to be the promising solution.

Finally, the model of planar manipulator arm with three revolute joints equipped with one VSA-II in each joint was created. Four-bar mechanism is attached on link i with output shaft $i+1$connected to revolute pair C and linear spring with stiffness k, as described in Fig. 1 (right). The whole structure with 9-DOF together with efficient control scheme is studied with emphasis to the precise end-effector position tracking, stiffness adjusting and undesirable collision effect reduction.

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