BioRob Arm: Antagonistic Series Elastic Actuation for Inherent Safe Human-Robot Interaction

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I. Motivation and Requirements

When using robotic arms in the vicinity of humans or for direct human robot interaction (HRI), the major issues are intrinsical safety, backdrivability and robust impedance control. Actuators with (variable) impedance are seen as a key to meet these requirements. [1]

Particularly in small and medium enterprises there are many applications that are still not automated, because current robotic systems do not meet the high safety requirements when cooperating with humans and lack the capability to be quickly adapted to frequently changing production conditions. These requirements can be met with a lightweight robot arm with mechanical compliance. Inherent safety requires low cartesian impedance with infinite bandwith at the contact point. That implies low mechanical joint stiffness, which constraints performance in terms of high force and position control bandwith. [2] In safe HRI application in which high end effector velocities are allowed, loads must be low enough in order to limit the kinetic energy and reflected inertia of the arm must be minimized.

II. BioRob Arm Design

The design of a BioRob joint is shown in Figure 1. Each joint is actuated by a DC motor which is coupled to the joint by antagonistic, elastic pulleys with progressive angle-torque characteristics. Rotational encoders are placed at the motor and at the actuated joint such that the angular difference can be measured. By placing the motors near the base, as can be seen in Figure 2, the inertia of the system can be drastically reduced. As a result, low-power motors with lower reflected inertia can be used. Four main compliant axes seem to be sufficient to guarantee low cartesian impedance, so that additional joints for orientation of the endeffector can be rigid. More details of the design are discussed in [3] and [4].

III. BioRob Arm Properties and Implementation

In contrast to series elastic actuators [5], play and backlash can be reduced by pretension in the equilibrium position. In addition, angular sensors in the joints enable higher position accuracy and the motor placement near the base leads to a energy-efficient and safe lightweight design with reduced link and reflected motor inertia. By using a progressive spring characteristic, the joint becomes stiffer when accelerating and decelerating, having a positive effect on the performance. The joint torque measurement, however, is less accurate than in SEAs, because an inverse model of the spring characteristic is needed. Still, the advantage of robust impedance control is preserved.

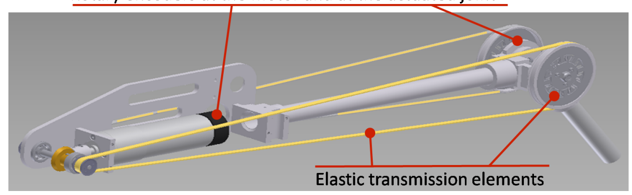

Fig. 1. Design of a single, antagonistically actuated, compliant joint.

The reduction of the motor and link inertia J_m and J has a positive effect on the natural frequencies of the motor-spring-actuation system ω_m and the joint-spring system ω_j:

$$\omega_m = \sqrt{\frac{k_S}{z^2 \cdot J_m}} \quad ; \quad \omega_j = \sqrt{\frac{mgl}{J} + \frac{k_S}{J}} \quad , \qquad (1)$$

with gearbox reduction z, link length l and spring stiffness k_S. Because of the reduced inertia, the performance bandwidth remains high enough even if a relatively low spring stiffness k_S is chosen for higher joint torque resolution measurement, which depends on the difference between motor and joint angle $(\theta - q)$. The joint torque sensing can be used for impedance control to make the arm softer in case of manually guided teach-in or collision handling.

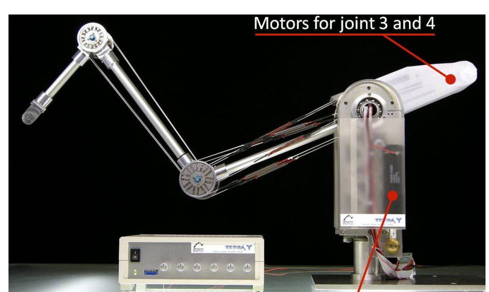

Fig. 2. BioRob arm with 4 compliant joints.

A BioRob arm with four compliant joints was manufactured and successfully tested to perform pick & place tasks with loads up to 0.3 kg at a speed not far below the speed of a human arm and an absolute accuracy of 1mm. Manually guided teach-in enables a quick programming of the arm.

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The energy consumption for this application does not exceed 15 W. Videos are available online at `www.biorob.de`.

To foster discussion about pros and cons of the proposed approach, a BioRob arm will be brought to the meeting for demonstrations and hands-on experience of the participants.

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