Series-Parallel Elastic Actuation (SPEA) for Reduced Torque Requirements

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Traditional stiff actuators have a high reflected inertia, which do not meet the safety requirements, are bad to absorb shocks and cannot store and release energy which are for different applications required. Initiated by the introduction of the Series Elastic Actuator (SEA) by Gill A. Pratt in 1995, a wide range of Variable Impedance Actuators (VIA) are developed, for which inspiration was found in the elastic properties of biological muscle. These compliant VIA’s benefit from the inherent series elasticity since the series elastic element can store and release energy for energy efficiency and decouple the inertia from one link to another. As a result, VIA’s significantly extended the possibilities of traditional stiff actuation. However, current actuators do not yet reach the torque and power requirements for many novel applications like exoskeletons, humanoids, agile locomotion, prostheses and manipulators.

This abstract reports on the study of a novel compliant actuator: the Series-Parallel Elastic Actuator (SPEA). The difference with previous studies on parallel elastic elements in joint actuation is that the parallel springs in the SPEA are actively controlled and not passively used. Main inspiration source is again the biological muscle that consists of a large set of parallel and series muscle fibers. The difference is that not all parallel springs in the SPEA need to have their own force converter (mostly DC motor), but are tensioned by an intermittent mechanism actuated by a single motor. This abstract discusses the design and testing of a first Proof Of Concept prototype.

I. CONCEPT AND Prototype

The series-parallel elastic actuator (SPEA) consists of a bundle of parallel compliant elements, for which every compliant element can be contracted one after the other. A single spring can be in three phases: 1) In unpretensioned phase the spring is at its rest length connected to both sides of the link. 2) In pretensioned phase the spring is extended with its sides connected to both links. All forces that are exerted will not pass the motor because it is not in the force path present. 3) In the pretension phase the motor controls the length of the spring and brings it from unpretensioned phase to pretensioned phase or back. The forces that are exerted on the spring in unpretensioned phase will go through the motor. Since most of the springs are in unpretensioned or pretensioned phase and only one or a few are in pretension phase, only a portion of the total torque exerted on the link will be felt by the motor. This concept is in the prototype tested with a multilated gear that is an intermittent mechanism which translates the continuous rotation of the motor into four dephased intermittent rotary motions to pretension one after the other the parallel springs. The first Proof Of Concept is depicted in Fig. 1.

II. EXPERIMENTAL RESULTS

A comparison is made between a simulated stiff actuator model, an SEA and SPEA and compared with real measurements of the POC. In order to compare the same output stiffness and equivalent internal kinematics of the three models has been used. The experiment consists in lifting a load from the vertical to the horizontal position, while measuring required motor torque and angular position (Fig. 2). It is shown that the measurements and simulated results of the SPEA are similar and are much lower than the two other models. This clearly shows that not all the torque generated by the actuator, needs to be generated by the electrical motor. This actuation techniques need further investigation to deliver several innovative and original aspects, which will lead to remarkable advances compared to the current state of the art in robotic actuation. Improvements are making it bidirectional and with adaptable stiffness.

![Figure 1: Overview picture of the SPEA Proof Of Concept.](image1)

![Figure 2: $T_{motor}$ w.r.t. output angle $\psi$ for the three actuator models and measurements.](image2)