A Polyurethane-based Series Elastic Actuator

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Abstract. *This article extends previous work, presenting a novel polyurethane based compliant spring system designed to be attached to a conventional robotics servo motor, turning it into a series elastic actuator (SEA). The new system is composed by only two mechanical parts: a torsional polyurethane spring and a round aluminum support for link attachment. The polyurethane spring, had its design derived from a iterative FEM-based optimization process. We present practical results using a PID controller for robust position holding.*

1. Introduction

Traditional robots usually operate at a low speed and with high torque, demanding large peak power output for short periods, accurate feedback sensing, and suitability in shape, size and mass [Wyeth 2006]. With the advances on fast and powerful controllers and precise sensors, the demand for such decoupling between a manipulator and its load can be relaxed without compromising the performance. Moreover, the demands of the field of human-robot interaction rise concern on the safety of the actuation mechanism and on its behavior towards uncertainties in the environment. A low impedance torque control scheme is usually required for stable and robust human-robot dynamic interaction [Carpino 2012]. Low impedance means that the actuator source force (torque) to the load, rather than commanding the load's position.

Real or passive compliant robot joint , which regarding to human/robot interaction it's a consensus that ensures higher levels of safety, is achieved by inserting a elastic element between the motor and load. This is typically done using mechanical springs in the design of the joints (see for instance [Guizzo 2012]).

A Series Elastic Actuator [Laranchi 2011] consists of traditional stiff servo actuator in series with a spring connected to the load, as shown in Figure 1. This topology allows the load to be partially decoupled from the motor, and the force exerted on the output of the compliant element can be evaluated by simply measuring the deflection of this component.

The device that we propose (see Figure 2) consists of a two-part component, using a modular thermoplastic polyurethane (TPU) elastomer. The material cheap, tough, easy to mill and presents rubber-like elasticity [Ashby 2014].

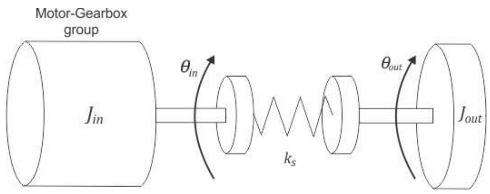

Figure 1 - Series Elastic Actuator Topology.

Figure 2 - Polyurethane spring proposed.

Our aim is toward applications on lower budget humanoid robots, providing better support for impact on the knees during walking and protecting shoulder joints during a fall. Our designed device consists of software, firmware, electronics and a mechanical accessory that can be easily attached to the popular Dynamixel MX series servo actuators, manufactured by Robotis, transforming it into a SEA. However, the general idea could be easily adapted to most servo actuators of similar “RC-servo-style" design.

2. Methodology

2.1. Design Requirements

The elastic element presented in this paper was designed aiming application on knees of humanoid robot. The SEA design ensures a symmetrical response in both directions, without saturation when exposed to the maximum torque supported by the motor. The spring consists on four ”s” shapes, with the width of 3mm. This dimension was decided after a CAD based Finite Element Analysis (see Figure 3)

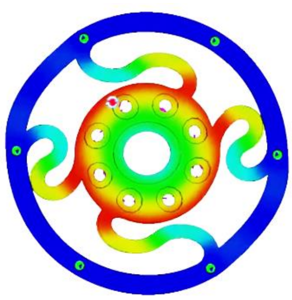

Figure 3 - Finite Element Analysis.

2.2. Manufacture and Electronics

The two mechanical parts were manufactured on an ordinary 3- axis CNC router, using a 2mm cutter. Both the polyurethane and the aluminum parts can be milled in a single operation, without the need for fixing the part in different orientations or refrigeration fluid.

In order to read the spring's angular displacement a magnet/magnetometer based circuit was designed. A radially polarized cylindrical rare earth magnet is placed on the center of the polyurethane part, and the circuit board is placed on top of the assembly so that the magnetometer chip is aligned with it. For educational purposes the electronics was designed to be Arduino compatible [Kushner 2011]. The firmware mimics Dynamixel's protocol: an id is assigned to each SEA, as if these were additional torque-disabled servo-motors, answering queries about their angular positions on the same RS485 bus.

3. Results

3.1. Obtaining the stiffness

For a linear spring, the stiffness can be described by Hook's law, given by $\tau = -k.\Delta\theta$. In order to assess the stiffness of the spring an experiment was performed, applying a known mass on the tip of the frame attached to the compliant element output, and measuring the resulting angle deflection Δθ. The rotational torque derived from the known mass can be determined by $\tau = F.l = m.g.l.\cos(\Delta\theta)$. The experiment was repeated for 20 different values of mass and the the results were plotted, as shown in Figure 4. The line which fits the data was found by linear regression, where its slope represents the inverse of the stiffness. The estimated stiffness was

$$k = 1/\ 11.33 = 0.088\ Nm/deg.$$

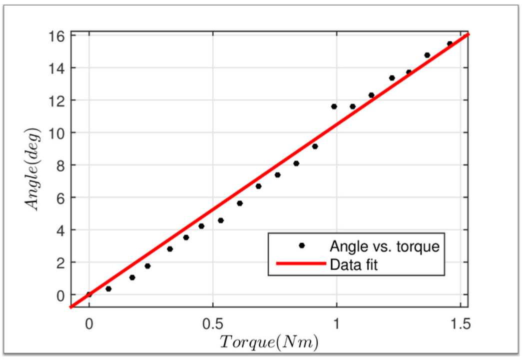

Figure 4 - Linear regression of data set plot.

3.2. Controller

A controller was designed for the system including dynamics of the servo motor and the compliant element. The goal is to keep the output at a specific setpoint even under influence of external disturbances applied to the system. The output means the total angle, that is, the angle of the servo motor plus the deflection angle of the compliant element read by the magnetometer. An opened loop system response is shown in Figure 5. This plot shows the system response without controller. On the other hand, a closed loop system response, shown in Figure 6, describes the controlled system behavior.

The real world validation was done implementing the controller in a ROS package. The MX-28R motor was fixed on a wrench and a lever arm of 88mm was attached to the SEA module, then after some time a free weight of $642.5g$ was dropped.

The closed loop system was done with a PID controller with the following gains: $Kp = 0.8$, $Ki = 3$ and $Kd = 0.025$ and a sample time of $Ts = 0.02449\ sec$.

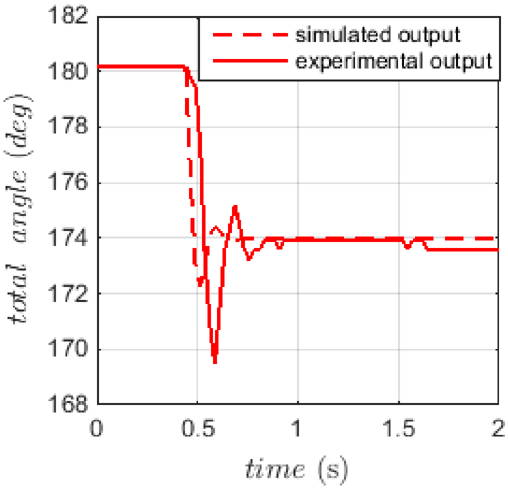

Figure 5: Opened loop response releasing weight at a specific time.

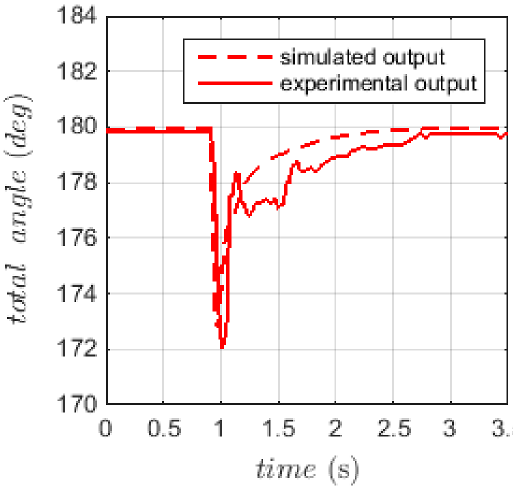

Figure 6: Closed loop response releasing weight at a specific time.

4. Discussion

This work presented a SEA upgrade solution based on an affordable module to be mounted to the output of an existing servo-motor. The two-part mechanical design was shown to be simple to manufacture, and the electronics circuit was designed around the popular Arduino platform, communicating angular displacements through the bus using the same infrastructure. We have also performed system identification and we have shown how robust position control can be achieved.

For future work the authors also want to explore the use of torque mode control, available in the Dynamixel models MX-64 and MX-106.

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