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A Polyurethane-based Compliant Element for Upgrading Conventional Servos into Series Elastic Actuators ⋆

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Abstract: This paper presents a novel compliant spring system designed to be attached to a conventional robotics servo motor, turning it into a series elastic actuator (SEA). The 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. A magnetometer based circuit is used to measure angular displacement and communicate it through a RS485 bus protocol.

Keywords: robotics, passive compliance, modular design, series elastic actuator

1. INTRODUCTION

Traditional robot manipulators, such as the ones designed for use in controlled industrial settings, typically use very stiff joints, heavy and rigid structures and powerful actuators. These 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 rises concern on the safety of the actuation mechanism and on its behaviour towards uncertainties in the environment.

The solutions for adding compliance into the design of robot joints can be divided in two groups: (1) active (or simulated) compliance and (2) passive (or real) compliance. Simulated compliance is achieved through software, by continuously controlling the impedance of back-drivable electric motors (see for instance Jain and Kemp (2010)). Real or passive compliance is achieved by inserting a elastic element between the motor and load. This is typically done through the use of mechanical springs in the design of the joints (see for instance Guizzo and Ackerman (2012)).

A Series Elastic Actuator (Pratt and Williamson, 1995) basically consists of traditional stiff servo actuator in series with a spring connected to the load, as shown in

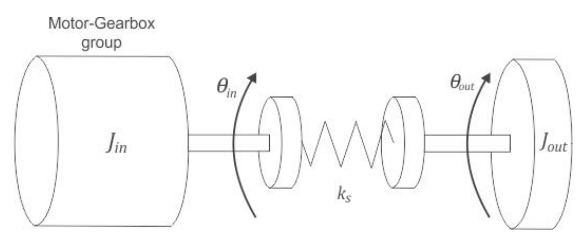

Fig. 1. Series Elastic Actuator Topology (Laffranchi et al., 2011)

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. Carpino et al. (2012) splits the existing SEAs design in two classes. The first class comprises compliant systems adopting helicoidal compression springs arranged in such a way that a centering elastic torque is produced when the joint shaft is rotated (see Fig.2-*A* presented by Tsagarakis et al. (2009) and Fig.2-*B* presented by Yoon et al. (2003)). The second class includes compliant systems employing torsional springs somehow connected to the load (see for instance Fig.2-*C* and Fig.2-*D* presented by Carpino et al. (2012) and dos Santos and Siqueira (2014), respectively).

These designs are complex and difficult to manufacture. The helicoidal spring designs usually require an elevate number of parts, and the torsional spring designs in the literature use expensive alloys that have to be milled. In both cases the resulting SEA becomes rather heavy and bulky. These springs are not suitable for the ever growing market of smaller humanoid robots or other robots

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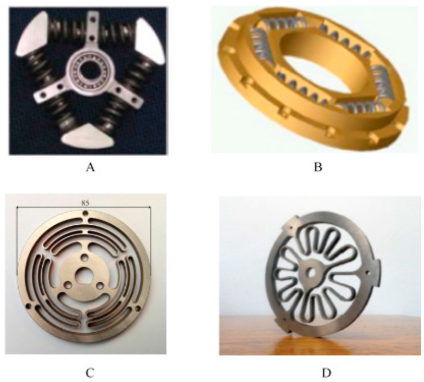

Fig. 2. Examples of existing compliant elements. Laffranchi et al. (2011)

Fig. 3. Polyurethane-based spring used in our system

based on traditional consumer servos such as the Robotis Dynamixel MX line of actuators.

In previous work (see Martins et al. (2014)) the authors of this paper have experienced with the design of a SEA module using helicoidal springs. The observed disadvantages included insertion of extra friction and non-linearities, backlash and assembly complexity. Thus, from this previous experience we came up the idea to design a new compliant element based on an alternative material, avoiding helicoidal springs and numerous other parts.

The design consists of a two-part component, using a modular polyurethane-based spring. This is an low-cost design that can be easily manufactured using a CNC router. Our aim is toward applications on lower budget humanoid robots, trying to provide a 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 fit most servo actuators of similar “RC-servo-style” design.

The remainder of this work is organized as follows: Section 2 explains the main details regarding the design as well as the modelling of the SEA. Section 3 shows some data regarding the actual construction of the device and a robot upgrade case. Section 4 presents the closing remarks and future work.

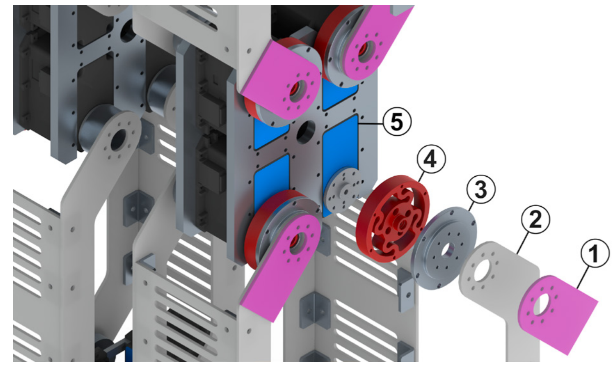

Fig. 4. Knee joint assembly with four SEA, including exploded view. The components are: (1) circuit board, (2) leg link frame, (3) attachment cover, (4) polyurethane torsional spring, (5) Dynamixel MX-106 servo actuator. Drawn by Eduardo Henrique Maciel.

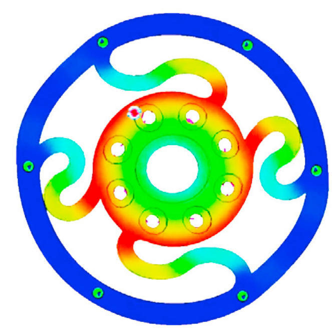

Fig. 5. Finite Element Analysis showing the maximum displacement region in red.

2. METHODOLOGY

2.1 *Design Requirements*

The elastic element presented in this paper was designed aiming the application on the knees of a humanoid robot which uses a parallel leg mechanism. This robot is being developed by the joint RoboCup team WF Wolves (Germany) & Taura Bots (Brazil) (Hannemann et al., 2014). This robot employs the Dynamixel MX-106 servo actuators manufactured by Robotis in a redundant arrangement, allowing the springs to be compressed against each other for leg rigidity modulation (see Figure 4).

The SEA design was elaborated to ensure 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 Figrue 5)

2.2 *Manufacture*

The manufacturing of the two mechanical parts was all done 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. Refrigeration fluid is not needed.