Design and Evaluation of a Prototype Compliant Multi-Degree-Of-Freedom Robot Arm That Utilizes Force-Controllable Novel Rotational Series Elastic Actuators

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Background

The use of elastic materials to create compliant actuators - contrasting to traditional stiff actuators - opened a throughway of safe robotic interactions alongside humans, such as rehabilitating prosthetics and remote rescue missions. Specific to rotational robotic joints, the implementation of rotational series elastic actuators enable the regulation of the load's output torque through the utilization of spring deflection and Hooke's law.

Current Issues

There are many proposed and prototyped RSEA designs with some even achieving configurable stiffness. However, because of the use of linear springs, deflection range is limited due to spring buckling. Furthermore, the complexity of the majority of the said designs outweigh their practicality.

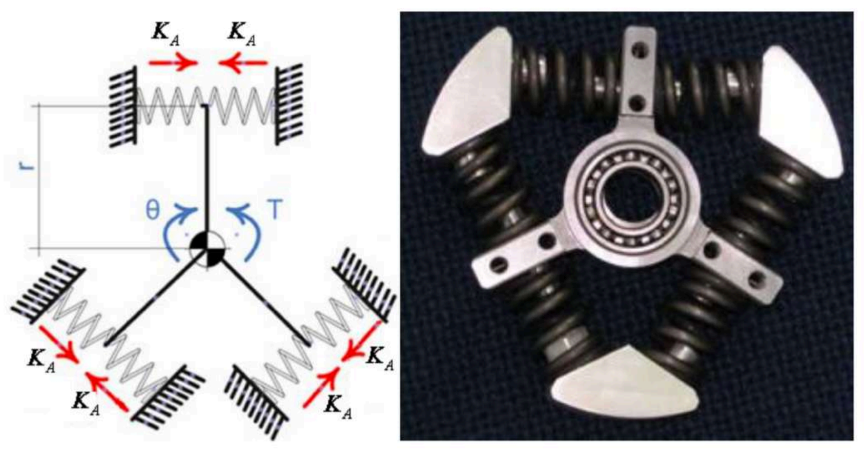


Fig. 1 Proposed design of a rotational series elastic actuator [1]

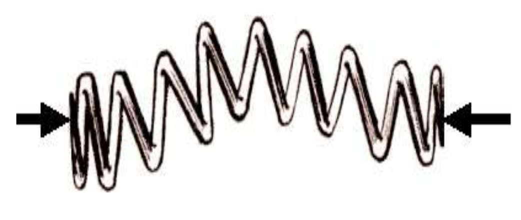


Fig. 2 Diagram of buckling of linear spring as it unnaturally compresses

Fig. 3 Inner shell

Fig. 4 Outer shell

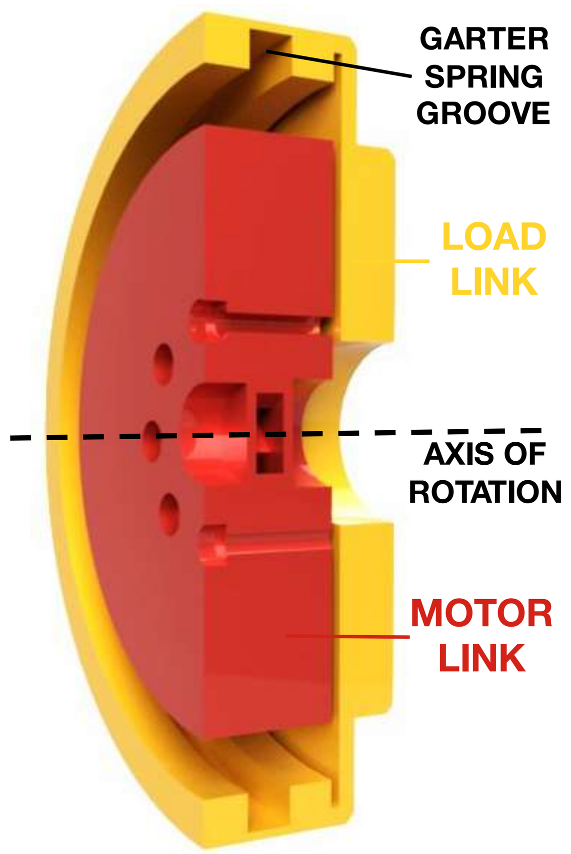


Fig. 5 RSEA cross section

Design of the novel-type rotational series elastic actuator

The approach of our RSEA's design emphasizes simplicity. It consists of two independent shells that rotates on a mutual axis. The outer shell is fixed to and rotates with the load. On the other hand, the inner cylinder that houses four steel stokes is fixed to and rotates with the stiff motor. These two components are nonetheless linked by a non-buckling garter spring, thus adding compliance and ultimate output torque control. The garter spring will allow a wider deflection range than linear compression springs; wider deflection enables better force control, shock absorption, and energy storage. Absolute encoders will read angular positions of both shells to determine the spring's deflection. This information can be processed to approximate and manipulate the load's torque.

Design of novel-type end effector hand

The hand is tendon driven, meaning it uses strings, in this case fishing lines, to control its fingers' motion. The hand is composed of three main bodies: two fingers and a base. The two fingers are able to move inwards and outwards by a string belt wrapped around their bases, and also by strings that are attached directly to the tip of the fingers. This is to both achieve position control in moving the fingers, and also to achieve
the pinching mechanism so that the hand is able to "grab" and transport objects. Series elastic actuators are implemented for force control, shock absorption, and energy storage. Magnets are used instead of linear springs to reduce mechanical wear and actuate in a novel manner. A copper pipe surrounds the magnets in this actuator and acts as the damper, which slows down the magnets' motion in case they are acted upon by a sudden force of large magnitude. With the copper pipe, magnets, and the fishing lines that act as the hand's virtual biological tendons, the hand is able to act compliant while it also is able to push as well as grab hard objects, lift them, and transport them to different positions.

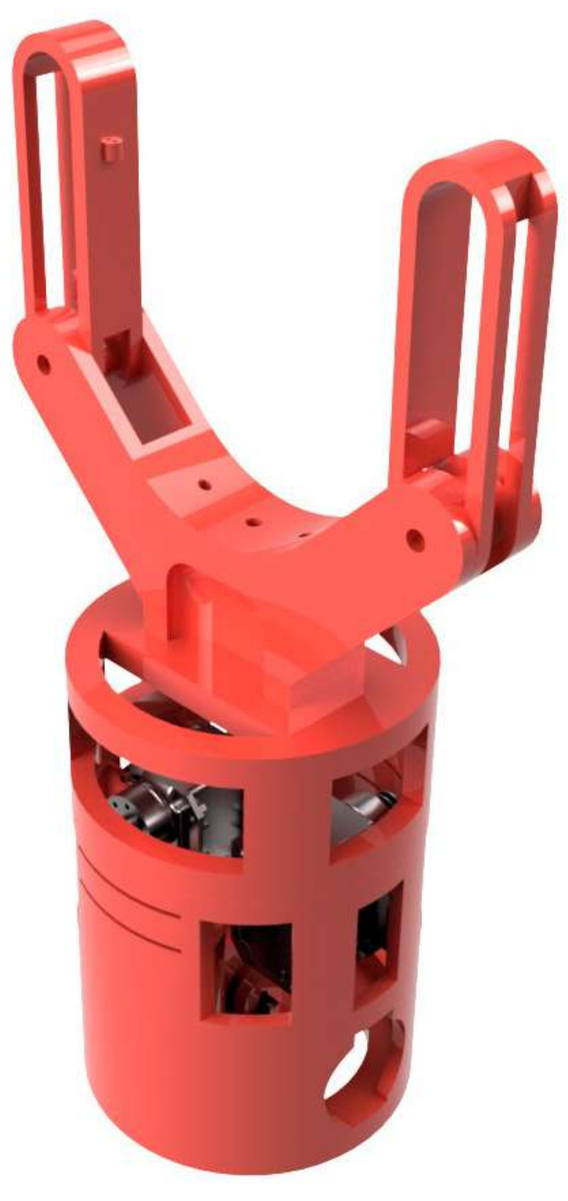


Fig. 7 Rendered assembly

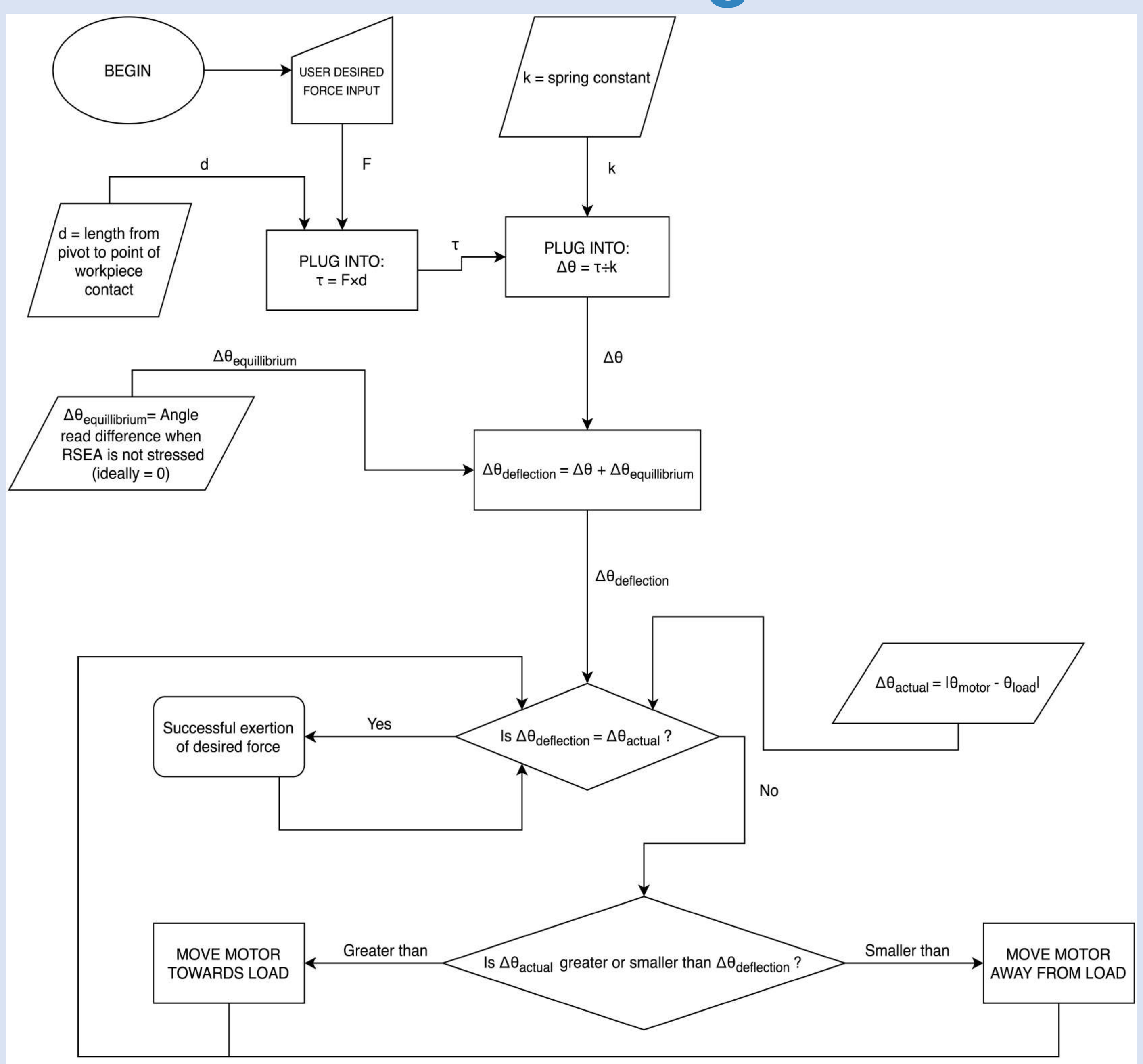
Fig. 8 Prototype assembly

Design of the robot arm's structural frame

The prototype robot arm is split into three main parts that are actuated by three Dynamixel MX-106 motors. Three degrees of freedom are achieved (pitch and yaw). For the most part, ABS plastic is used to 3-D print the structural frame; some major parts comprise of super-glued sub-parts split due to the limited space of the print palette. To facilitate stable rotational motion, ABS was refrained from use for crucial parts that can be subjected to high stress, such as stokes and shafts. Aftermarket components were purchased and integrated into the ABS parts.

Fig. 6 Arm's full assembly design

Simplified structure of the force control algorithm



A user-inputted desired force value is converted into a desired spring deflection. The motor is then prompted to move and maintain the said spring deflection. Errors are fed back and processed through simple proportional control for correction.

Resulting Prototype

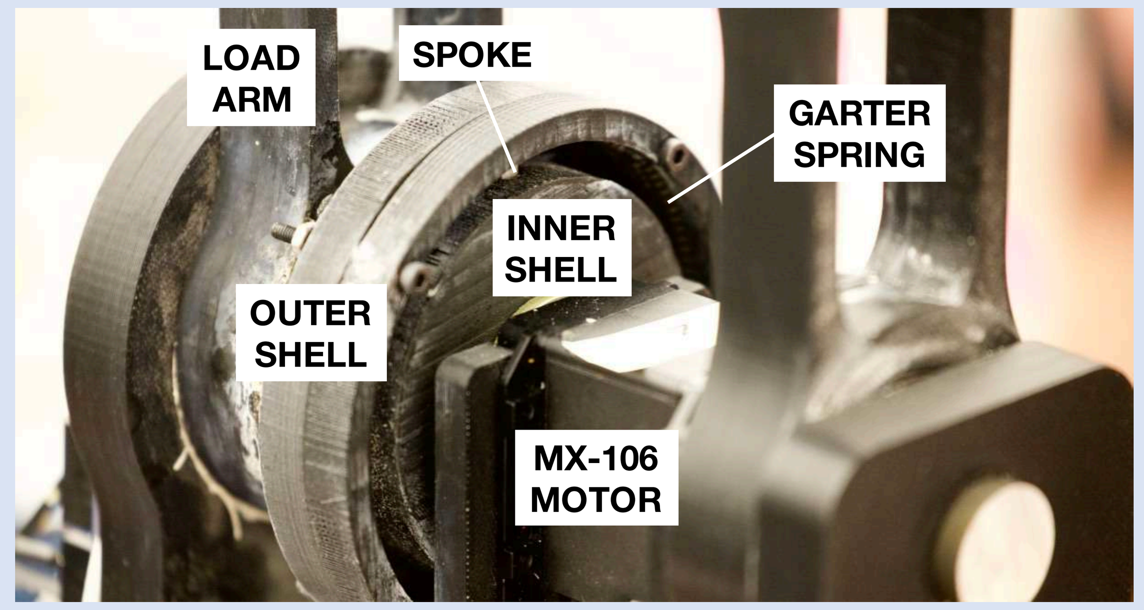


Fig. 9 Close-up of RSEA prototype assembly

Fig. 10 Prototype assembly

Compliance was achieved by the prototype arm. The Arduino controller successfully read external encoders; LabVIEW was used to integrate angular positions and determine spring deflection. Due to the nature of 3-D printing, the model had mechanical friction in the joints and ultimately moved in a rigid, unsmooth trajectory. The garter spring did not fully sit inside the groove of the RSEA due to its high stiffness and larger-than-expected size.

Conclusion and Future Advances

The prototype RSEA has potential to be practical. Further refining and prototype is intended with the goal of a final CNC-milled product that is fully functional. The practicality and simplicity of our RSEA can facilitate accessibility of safer robots through inexpensive mass production. Future designs are aimed to further minimize complexity possibly feature configurable stiffness for hybrid force and position control.

References

[1] Nikos G. Tsagarakis, Matteo Laffranchi, Bram Vanderborght, and D. G. Caldwell, "A Compact Soft Actuator Unit for Small Scale Human Friendly Robots" *ICRA*, page 4359, 2009.

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The future is optimistic.

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