The Design Philosophy for Creating a Series Elastic Actuated Wrist Assessment Exoskeleton

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***Abstract*—Robotics devices provide a compelling platform to assess recovery after neurological injury. In this paper, the design philosophy behind the creation of the series elastic (SE)-AssessWrist, a device intended for wrist biomechanical assessment, is presented. The SE-AssessWrist was designed with a modular and ease of assembly design philosophy. Further, the SE-AssessWrist embraces components spanning the spectrum of manufacturing modalities, including manual machining, CNC machining, laser cutting, water jetting, and 3D printing.**

I. Introduction

Robot-aided assessments offer the possibility for accurate, objective, repeatable, and readily implemented assessments throughout neurorehabilitation [1]. One of the challenges of implementing robotic assessments is that rehabilitation robots have not been specifically designed for assessment. In this abstract, the design of the SE-AssessWrist is discussed—a device designed intentionally for assessing wrist biomechanical features [2], [3]. The SE-AssessWrist (see Fig. 1) is a two-degree-of-freedom (DOF) series elastic actuated robotic exoskeleton that can interact and measure user wrist flexion/extension (FE) and radial/ulnar deviation (RUD). Compared with existing wrist rehabilitation devices, the SE-AssessWrist can measure complete wrist range of motion, while also being able to measure passive wrist stiffness. The desired range of motion capabilities are achieved through the use of a Bowden cable transmission that enables locating the actuators off-board the device. As a result, the device structure can be more open, and achieve a greater range of motion. Series elastic actuation is employed for its human-friendly compliance and to provide the necessary force sensing to balance the static friction from the Bowden cable transmission.

This work was supported by the National Science Foundation Graduate Research Fellowship Program under Grant No. 1450681.

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II. Design Concept to Implementation

A. Modular Design

A core aspect of the SE-AssessWrist design philosophy was the use of modular design. This concept was naturally facilitated by the serial kinematic device structure with wrist FE as the first joint in the chain and RUD second. To achieve the desired 2-DOF design, first an FE module was designed, fabricated, assembled, and tested (see Fig. 2). Before the version shown in Fig. 2, a prototype was developed primarily created from 3D printed structural components and an initial version of the elastic element. From this design reference, the actuation concept was validated, and designer experience was gained. Further, this thorough process enables incorporating lessons learned, including that the spring needed a major redesign. The initial elastic element did not contain a closed path on the outer ring, which led to creep in the connection interface at higher torques.

While initial prototypes can be beneficial, 3D printed components can have limitations, and the designer must consider these aspects when testing a prototype. A benefit of being able to test the device in simplified format, here a 1DOF module, is that it provides a testbed to evaluate control performance as well as assessment performance [2]. In some respects, this simplified structure represents the best case scenario for control and assessment, providing the designer a reference point before moving on to assemble and test multiple DOFs.

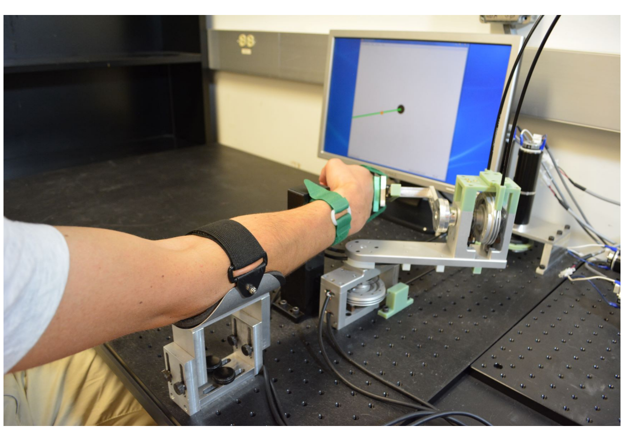

Fig. 1. A user exploring their range of motion with the SE-AssessWrist. The device can also be used to assess passive wrist stiffness over the user's range of motion.

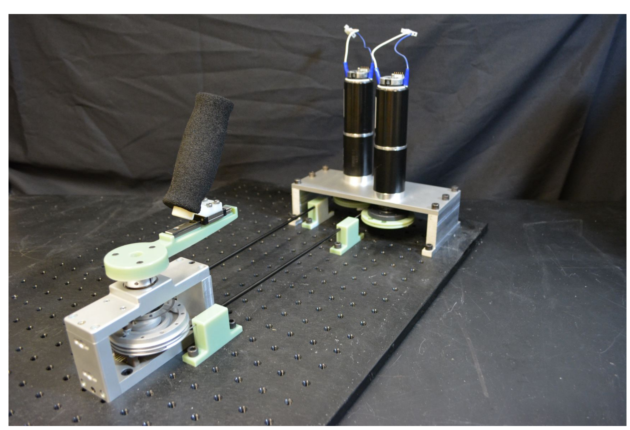

Fig. 2. Testing at the sub-system level can provide insight into the design and control of the fully assembled device. It also provides an excellent opportunity to develop control schemes.

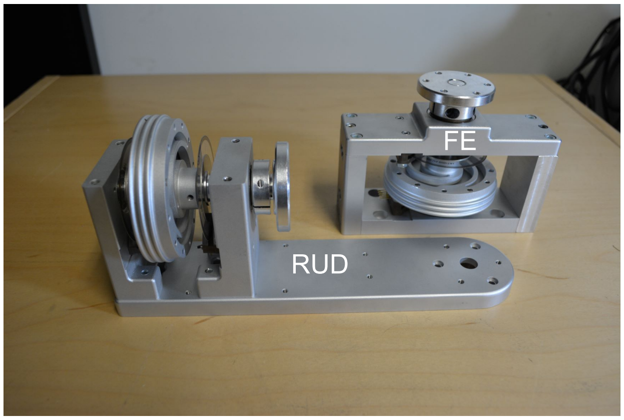

Fig. 3. The flexion/extension (FE) and radial/ulnar deviation (RUD) joints of the SE-AsessWrist were designed with modularity in mind. This modularity is necessary due to the serial kinematic structure, but is strengthened by the ease of assembly aspect. Each joint contains a structural input, an elastic element stage, and a flange-mount shaft collar output.

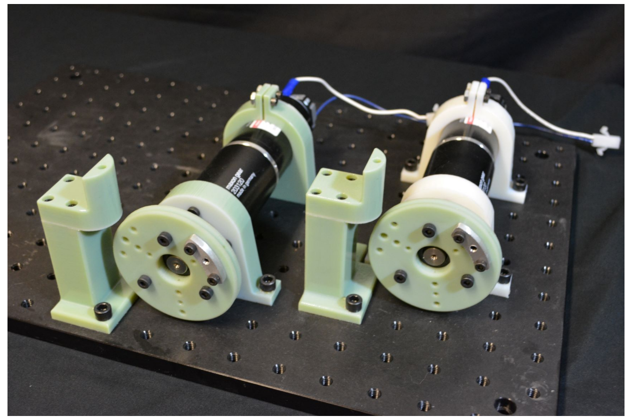

Fig. 5. The off-board RUD motors with 3D printed components and a laser cut metal piece with post-machining. Using 3D printing enabled custom components that were developed in-house. The metal component is screwed into the 3D printed motor pulleys, which have inserts for the mating screws. The aluminum piece contains a threaded hole for a set screw.

B. Ease of Assembly/Disassembly

Isolating a representative unit of the SE-AssessWrist was possible due to the modular design. In Fig. 3, the core structure of the FE and RUD joints is shown. The joints follow the same structural pattern, which facilitates the ease of assembly/disassembly desire as well. Each unit uses a flange-mount shaft collar, as the interface to the next link in the chain. Additionally, within the series elastic element structure (see Fig. 4), the shafts were machined to have a clearance fit with their corresponding bearings, while bearings were press fit into the structure. As such, each unit was easily configured to the other, and within a unit parts could be readily disassembled or assembled as a result of the minimal use of interference fits.

C. Manufacturing Selection

The SE-AssessWrist contains parts that were machined manually and CNC machined as traditionally done. But, it also contains aluminum components that were cut by water jet and laser cutting, as well as 3D printed plastic components (see Fig. 5). A key point in leveraging these different manufacturing capabilities is understanding the tolerancing limitations of each. For example, laser cut and water jet parts might not have exceptional tolerancing (especially for holes), and so should only be used for components that do not need strict tolerancing. On the other hand, 3D printed parts could be made with excellent tolerancing, but were only incorporated where structural integrity was not a concern. This all-around approach enabled using the best aspects of each approach.

Fig. 4. A series elastic unit consisting of output spring shaft, elastic element, and input pulley (below the spring). The output pulley contains its own shaft that is integrated into the custom pulley. The spring has an integrated hub for connection to its own output shaft. These monolithic concepts reduce a possible point of failure between the connection of the spring and pulley to their respective shafts.

III. Conclusions

Some of the design philosophies incorporated into the SE-AssessWrist have been presented. Through the use of a variety of manufacturing methods, ease of assembly/disassembly, and modular design strategies, a device that is easy to modify, test, and ultimately design was achieved. Future work for the device would include lightweighting components, which was not a primary concern given the desire to assess slow movements. With lightweighting and the use of less powerful DC motors, a device capable of rendering haptic environments with low-inertia might be achieved. Similarly, the device spring can be readily modified without changing the device, enabling the testing of different series elastic actuator concepts.

Acknowledgment

We thank Dr. Craig McDonald and Nick Moser for their contributions to the design of the SE-AssessWrist.

References

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