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Amoozandeh Nobaveh, Ali; Radaelli, Giuseppe; Herder, Just L.

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A Design Tool for Passive Wrist Support

Ali Amoozandeh Nobaveh, Giuseppe Radaelli, Just L. Herder

***Abstract*— A design tool for passive wrist support using compliant spatial beams as gravity balancer is presented. The aim of this assistive device is to reduce required effort for pronation-supination and flexion-extension by 70% to help patients with muscular weakness keeping their hand's posture and doing daily tasks, while the forearm is rested. To reach this goal, a setup with three connection points to the user's hand, and two optimized spatial beams as elastic gravity compensators, are developed. The overall shape and cross-sectional dimensions of the compliant beams are attained using an optimization technique. The objective is reaching a desired endpoint kinetostatic behaviour which is determined based on the hand's weight and available muscular forces. A design case is presented to show the ability of the method, and the final errors from the desired behaviour are clarified. In the end, possible further applications of the design tool are discussed.**

I. INTRODUCTION

A plain wrist support can help people who are suffering from muscular weakness [1] by keeping their hand in a normal posture and avoid further damages to the body tissues due to hanging of the hand. The majority of mentioned people have control on their muscles, but are not able to provide sufficient muscular power to keep the desired postures, e.g., patients with Duchenne muscular dystrophy (DMD). Previously there were only fixed orthoses available for those people. However, with recent developments, there exist active and passive assistive devices to help them control their hand's posture to some extent [2]. Among those, passive devices which mainly work based on reducing required effort by static balancing of the hand's weight are more widespread as they are lighter and cheaper. In the case of using compliant mechanism instead of conventional linkages in the mentioned passive devices, they could be even more flexible and slender.

The goal of this paper is to present a design tool for a flexible passive wrist support using spatial compliant beams which work as elastic elements for gravity balancing to keep the normal posture of hand and facilitate movement of the wrist in a limited range of motion while the forearm is rested horizontally. This design tool can provide tunable sizing and kinetostatic characterization for gravity balancing based on different user requirements, by using the elastic deformation of optimized spatial compliant beams [3].

The paper is structured as follows. In section II, the design of the wrist support and its functional requirements are described together with the details of the spatial beam optimizer. In section III the results are shown for a case, and discussion is given on them. In the end, the conclusion and possible future applications are discussed in section IV.

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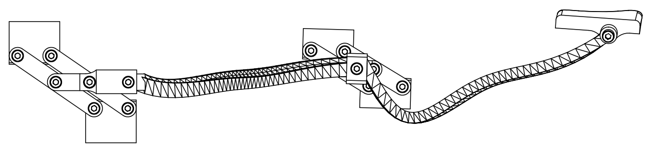
Ali Amoozandeh Nobaveh, Giuseppe Radaelli, and Just L. Herder are with Precision and Microsystems Engineering Dept., Delft University of Technology, Delft, The Netherlands (corresponding author: A.AmoozandehNobaveh@tudelft.nl).



(a)

(b)

Fig. 1. (a) Designed wrist support, (b) 3D printed prototype

II. METHODS

A. Proposed design

The wrist support is designed to have three interfaces with the hand, two on the upper and lower forearm and one under the palmar side of the hand. These three points are connected from the outer side of the hand with two slender compliant beams which are shaped by the optimization process based on defined requirements. The hand and lower forearm supination, while they are rested horizontally, are balanced by the first beam connecting the upper and lower forearm interfaces to provide the required moment by elastic deformation. The required wrist extension balancing force is provided by the elastic bending of the second beam between the lower forearm and palmar side of the hand. The requirements for passive balancing beams are set to reach $30^{\circ} \pm 25^{\circ}$ for the wrist pronation-supination and $0^{\circ} \pm 40^{\circ}$ for the hand flexion-extension with 70% less muscular effort. The resulted beams could have different shapes in restricted design area and base on dissimilar requirements of users.

Fig. 1 shows the resulted beams and the wrist support interfaces. The hand interfaces are made based on the parallelogram mechanism, which leads to easier wearing and size adaptability of the device, as well as keeping the beams aligned with the user's hand.

B. Beam shape optimization

The developed optimization process uses the general shape of the beams and their cross-sectional properties to reach the design requirements. Concerning the general shape of the beam, the coordinates of six control points along the beam together with the cross-sectional orientations on those points are subjected to the optimization to form the B-spline of the beam spine shape. Regarding cross-sectional optimization, an I-shaped cross-section is selected for the beam, since it is a commercial section and changing its parameters enables a large variety of section properties for the optimizer. All dimensional parameters of the mentioned section are subjected to the optimization. The endpoint stiffnesses in this process are derived from a self-developed finite element solver using geometrically non-linear co-rotational beam elements introduced by Battini [4] with Euler-Bernoulli beam model. Concerning the optimization process the *Multi Start*, using the *fmincon* from the Matlab® *optimization toolbox* is used and subjected to the bounds to form the beam inside the required design space.

III. Results & Discussion

The resulted connection beams could have varying shapes and cross-sections based on different user requirements. Here we present results based on requirements of an average human size [5]. Fig. 2 shows the wrist beam (top) and forearm beam (bottom) deflections from undeformed shape (transparent) to deformed shape, under three different loadings. The orange beams shows shapes loaded by the users hand's weight when wearing the device for keeping the hand in a normal posture without any muscular effort. The purple beams shows shapes when users provide 30% of the hand's weight in order to do wrist extension (top) and supination (bottom). Finally, the yellow beams show wrist flexion (top) and pronation (bottom) again with 30% effort in opposite direction. The resulted deflection angles for pronation-supination and flexion-extension are showed in Table. I. It is important to note that those angels are measured from the rest posture without any muscular effort while wearing the device. The device keeps the hand in 32.4° (supination) and 3.1° (extension) as normal posture. Comparing the resulting angles from Table I with the desired angles mentioned in Section II, the average of all errors is 5.9%. Reaching this error from these slender compliant beams in the such extensive range of motion, shows the ability of the method to replace the conventional passive assistive wrist supports with this flexible and light design. Also it shows the potential of the method to handle more complicated requirements of other assistive devices.

IV. Conclusion

This paper presents a design tool for a passive wrist support using optimized compliant beams as weight compensator to keep the normal hand's posture and enable the wrist movement in an extensive working range with 30% of required muscular forces. The effectiveness of this method has been shown by exploring resulting angles in pronation-supination and flexion-extension. Such design requirements and flexibility are not easily achievable with passive conventional mechanisms and existing compliant mechanisms design methods, which shows the capacity of this approach to handle more complex demands for passive assistive devices.

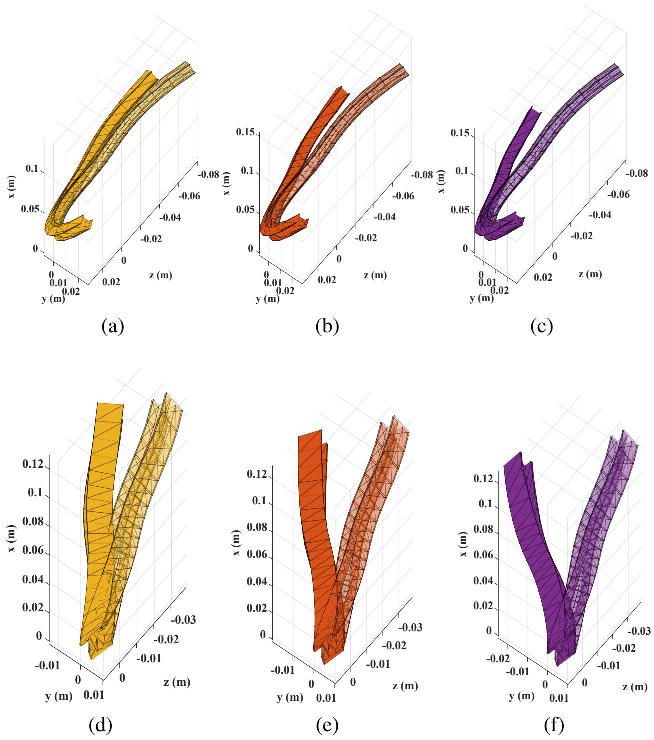


Fig. 2. Deflection of the beams from initial form (transparent) to final form, (a) wrist beam under -30% force, (b) wrist beam in neutral position under hand's weight, (c) wrist beam under +30% force, (d) forearm beam under -30% force, (e) forearm beam in neutral position under hand's weight, (f) forearm beam under +30% force.

TABLE I
DETERMINED ANGLES

Force	Supination(+) Pronation(-)	Extension(+) Flexion(-)
+30%	$-24.2°$	$-42.5°$
-30%	$-23.1°$	$+39.0°$
Avg. error	5.57%	4.29%

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