Multidirectional High Impact Resistant Compliant Four-bar Linkage Mechanism for a Prosthetic Hand

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Abstract— **We present the design and evaluation of multi-directional impact resistant compliant four-bar linkage mechanism for a prosthetic hand. We developed a compliant proximal interphalangeal (PIP) joint that replaces the conventional revolute pin joint of the four-bar linkage mechanism. Results from free-end and fixed-end impact test show that our design absorbs more energy on impact than the conventional four-bar linkage driven fingers with no mechanical failure.**

I. INTRODUCTION

One of the leading causes of prosthesis rejection is the lack of durability of the prosthesis in response to impacts [1]. The iHY hand [2] and the PISA/IIT Soft hand [3] have improved the impact resistance of the hand by introducing compliance, and evaluated the impact resistance through qualitative methods, such as hitting the fingers with a blunt object. However, few studies have focused on quantitatively evaluating the impact resistance of the hand. In this paper, we present the design and evaluation of a four-bar linkage driven compliant finger that makes prosthetic hand more resistant to impacts from multiple directions. We designed a compliant proximal interphalangeal (PIP) joint that replaces the conventional revolute joint of four-bar linkage mechanism which is the main site of mechanical failure. The finger consists of a 3-D printed compliant polyurethane bone covered by silicone skin, enabling grasps to easily conform to common household objects (Figure.1b). We conducted free-ended and fixed-ended impact tests in order to simulate impacts that could occur during daily prosthesis usage.

II. METHODS

We designed a monolithic finger with the compliant PIP joint. The joint achieves multidirectional compliance despite the use of four-bar linkage mechanism (Figure 1a). The joint compliance is variable, which enables the finger to handle great static load in extension direction. The compliant polyurethane (SemiFlex, NinjaTek) bone was 3-D printed (MakerBot Replicator 2X, MakerBot) and covered by silicone skin by silicone molding (Figure 1c). The output link of the mechanism consists of three layers of pre-stressed spring steel which enhances the lateral impact resistance and enables the quick recovery of the finger from impact by storing the impact energy in buckling mode. The finger is driven by DC motor (Pololu 100:1 Gearmotor HPCB 6V) with worm gear train of 20:1 reduction ratio. We conducted fixed-end and free-end impact tests with standard impact test machine (Dynatup 8250, Instron). Each test was performed by dropping a weight to the lateral, dorsal (Figure 1d), and volar aspect of the finger from varied height. The impact energy and load versus time were obtained and compared with the other specimen: compliant finger with pin joint, rigid finger with pin joint, and 1045 HR steel bar with the same geometry of the finger as a reference.

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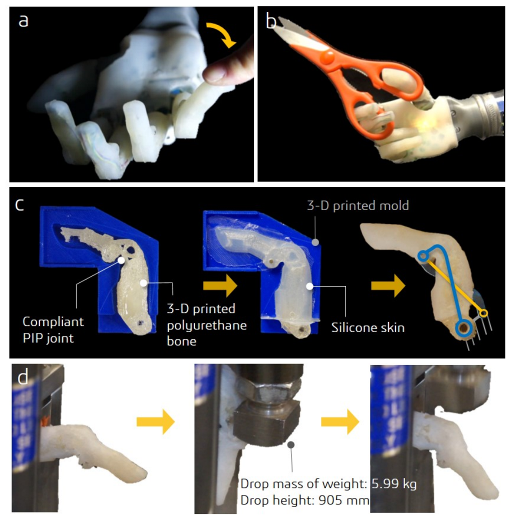

Fig. 1. (a) The compliant four-bar linkage mechanism allows the lateral compliance of the finger as well as the dorsal and volar compliance. (b) The compliance of the fingers enables grasps to easily conform to common household objects. (c) 3-D printed compliant polyurethane bone is embedded in silicone skin by silicone molding. (d) Free-end impact test on the dorsal aspect of the finger.

III. RESULTS

Our compliant finger can tolerate higher levels of impact than a non-compliant finger that also used a four-bar linkage mechanism, absorbing 10-52% more energy on impact. The compliant finger had no mechanical failure at maximum drop mass of weight (5.99 kg) and height (905 mm) while the other fingers showed the failure around the pin joint area and caused the motor and worm gear train damages.

REFERENCES

[1] F. Cordella, A. L. Ciancio, R. Sacchetti, A. Davalli, A. G. Cutti, E. Guglielmelli, and L. Zollo, Literature review on needs of upper limb prosthesis users, Front. Neurosci., vol. 10, p. 209, 2016.
[2] L. U. Odhner, L. P. Jentoft, M. R. Claffee, N. Corson, Y. Tenzer, R. R. Ma, M. Buehler, R. Kohout, R. D. Howe, and A. M. Dollar, A Compliant, Underactuated Hand for Robust Manipulation, The Int. J. Robot. Res., vol. 33, 2014, pp.736-752.
[3] M. Catalano, G. Grioli, E. Farnioli, A. Serio, C. Piazza, and A. Bicchi, Adaptive synergies for the design and control of the Pisa/IIT SoftHand, Int. J. Robot. Res., vol. 33, no. 5, pp. 768?782, 2014.