2024 I-RIM Conference
October 25-27, Rome, Italy
ISBN: 9788894580556
10.5281/zenodo.14731176

Tendon Routing Can Improve the Dexterity of Soft-Rigid Robotic Fingers

Manish Shukla
Department of Information Engineering, Science and Mathematics.
University of Siena
Siena, Italy
m.shukla@student.unisi.it

Domenico Prattichizzo
Department of Information Engineering, Science and Mathematics.
University of Siena
Siena, Italy
dprattichizzo@unisi.it

Gionata Salvietti
Department of Information Engineering, Science and Mathematics.
University of Siena
Siena, Italy
gionata.salvietti@unisi.it

***Abstract*—Soft-rigid structures have recently gained popularity due to their ease of fabrication, especially with rapid prototyping technologies. By incorporating tendon-driven actuation, these structures enable the generation of significant grasping forces while offering high adaptability to objects with varying shapes. This combination of rigid and deformable components opens new possibilities in the design of robotic systems, providing both strength and flexibility in applications that require versatile manipulation.**

In this abstract, we present our recent improvements in actuation of soft-rigid robotic finger. The improvements involve changing the geometry of tendon channels and addition of another tendon for also performing hyper-extension of the finger tips which allowed us to achieve human like pinch grasp.

***Index Terms*—tendon, soft-rigid, robotic finger, gripper**

I. Introduction

Soft-rigid structures took inspiration from our body limbs where rigid link, represented by the bones, are complemented by soft articulated joints that thanks to a tendon driven actuation can achieve a remarkable passive adaptability and active dexterity. A good example are our hands that are well equipped to grasp almost any shape with the same unique structure of soft cutaneous and sub-cutaneous tissues wrapped around rigid bones. To replicate the similar functionality many actuation systems are developed among which are pneumatic robotic fingers [1] and tendon or wire driven fingers [2] & [3]. They employed different materials like silicone to attain the "softness" on the surface, that makes the contact with gripped object compliant. The rigid part is mainly to provide a passive anchorage for the soft parts for controlling the actuation in a desired manner.

Our research group has exploited those concepts to develop several devices including a supernumerary extra finger, called the Robotics Sixth-Finger [4]–[6]. This device can be worn on the paretic forearm of post-stroke patients who lost the activity of the hand. A similar mechanical structure has been utilised to design a collaborative gripper, called CoGripper [7]. In this device the adaptability of the structure has been exploited both to guarantee a safe interaction with the user and to easily grasp objects with different shapes. After almost a decade of user study, observations and practice in both the devices, we recognized some areas of improvement which we describe in this work. Section II describes the improvements in the two devices in subsections II-A and II-B. Then we discuss our findings with these changes and conclude the extended abstract with our future perspective.

We acknowledge the support of the European Union by the NextGeneration EU project ECS00000017 THE, Spoke 9 and by the Horizon Europe project HARIA (GA 101070292). The content of this publication is the sole responsibility of the authors. The European Commission or its services cannot be held responsible for any use that maybe made of the information it contains.

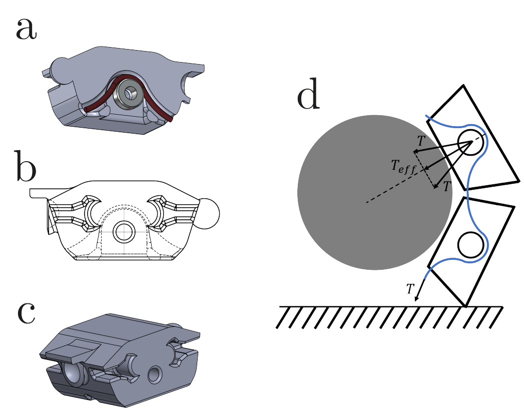

Fig. 1. New concept of a module to enhance grasping in robotic sixth-finger. (a) Isometric section view to show curvature of tendon route. (b) and (c) show different views of new module to demonstrate geometry. (d) shows a force body diagram of engagement of two respective modules

II. New Approaches of Using Tendons

During the usage of soft-rigid structures both for the Robotic Sixth Finger and the CoGripper we observed some problems with the tendon actuation that led us to find a new approach to use the same single tendon actuation but in a more optimal manner. The respective concepts that were developed are discussed in the following subsections II-A and II-B.

A. Enhancement of Supernumerary Robotic Sixth-Finger

We recognized a consequential problem with straight channel modules used in the robotic sixth finger where the modules were prone to slipping-off of the circular objects with radius of curvature more than 25mm. We produced a design to route the tendons with curves to optimise the use of the actuation effort carried by the tendons. The Fig. 1 shows the new design and concept for the finger modules.

As shown in the Fig. 1-(d), we were able to get a net effort towards the grasped object normal to the contact surface. In this manner, the slipping-off was found to be reduced. Additional to this, we found that this change distributed the efforts of the tendon towards the proximal side of the fingers as well. The friction generated due to the curvature is needed when the finger is straight to induce bending at the proximal joint, however, the channels are made wide so that they do not remain in contact after the joints bend more than 15°.

B. Enhancement of Pinch Grasp Capabilities of a Gripper

The CoGripper worked well for a long time for holding objects with almost all sizes. Anyhow, we noticed that though we could grasp small objects with "tip to tip" pinching, the grip was not stable. Therefore, we targeted to grasp objects having "thin" form factors such as a scalpel or a nail with improved stability. To solve this trouble we took inspiration from human pinching. The Fig. 2 shows an addition of extensor tendons attached to the tips of the fingers.

As the flexor tendon passes through every module, consequently actuating them simultaneously which does not allow a passive hyper-extension of the finger tips. Hence we added another pair of tendons on the back side of the finger tips to overpower the flexor tendons and routed them in such a way that only the finger tips are extended without affecting the flexion of other joints which is needed for closing the grip. The Fig. 2 shows half actuation of extensor tendons which is not enough to produce hyper-extension good enough for a pinch grasp, hence, proving our hypothesis. Therefore, by full actuation of extensor tendons we were able to achieve a proper pinch grasp.

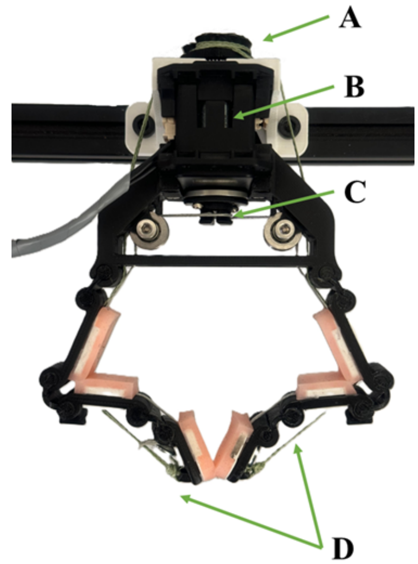

Fig. 2. Demonstration of pinch grasp using extensor tendons (half actuation) **D**. **A** is passive extensor pulley, **B** is the motor for flexion control and **C** is the flexor pulley.

III. Discussions and Conclusions

Soft-rigid structures bridge the gap between robustness and controllability when it comes to tasks such as grasping. Also, mechanically lighter form-factor of the soft-rigid robotic fingers are an advantage as they require lesser actuators which is a benefit from control systems perspective.

We have given more importance to the combination of under-actuation and robustness. For which we have considered improving the simple structure of robotic Sixth-Finger with introducing geometrical changes within the modules that proved to be effective in increasing the grasping ability of the finger as a whole. The test results have encouraged us to move forward and test the new design with stroke patients. This pilot study will establish the improvements in experimental terms.

On the other hand, adding another degree of actuation to hyper-extend the finger tips in order to perform a pinch grasp has been a step forward towards improving the robustness of the grippers which are targeted for collaborative tasks. The pinch grasp along with the power grasp combined can benefit the user to perform tasks involving another helping hand, as an example, a scrub-nurse robot utilising this gripper can reduce stress on their human counterparts.

In future we aim to combine the aforesaid improvements together to make an easy to control system capable of performing tasks with more agility and stability.

Acknowledgment

We acknowledge the support of the European Union by the NextGeneration EU project ECS00000017 THE, Spoke 9 and by the Horizon Europe project HARIA (GA 101070292). The content of this publication is the sole responsibility of the authors. The European Commission or its services cannot be held responsible for any use that maybe made of the information it contains.

References

[1] R. S. Jo and E. Ngu, "Parametric study of soft pneumatic robot grippers through finite element analysis," *IAES International Journal of Robotics and Automation*, vol. 13, no. 1, pp. 19–30, 2024.

[2] C. Gosselin, F. Pelletier, and T. Laliberte, "An anthropomorphic underactuated robotic hand with 15 dofs and a single actuator," in *Robotics and Automation, 2008. ICRA 2008. IEEE International Conference on*, pp. 749 –754, may 2008.

[3] C. Melchiorri and G. Vassura, "Mechanical and control features of the university of bologna hand version 2," in *Intelligent Robots and Systems, 1992., Proceedings of the 1992 lEEE/RSJ International Conference on*, vol. 1, pp. 187–193, Jul 1992.

[4] D. Prattichizzo, M. Malvezzi, I. Hussain, and G. Salvietti, "The sixth-finger: a modular extra-finger to enhance human hand capabilities," in *Proc. IEEE Int. Symp. in Robot and Human Interactive Communication*, (Edinburgh, United Kingdom), 2014.

[5] G. Salvietti, I. Hussain, D. Cioncoloni, S. Taddei, S. Rossi, and D. Prattichizzo, "Compensating hand function in chronic stroke patients through the Robotic Sixth Finger," *Transaction on Neural System and Rehabilitation Engineering*, vol. 25, no. 2, pp. 142–150, 2017.

[6] I. Hussain, G. Salvietti, G. Spagnoletti, and D. Prattichizzo, "The Soft-SixthFinger: a wearable EMG controlled robotic extra-finger for grasp compensation in chronic stroke patients," *IEEE Robotics and Automation Letters*, vol. 1, no. 2, pp. 1000–1006, 2016.

[7] G. Salvietti, Z. Iqbal, I. Hussain, D. Prattichizzo, and M. Malvezzi, "The co-gripper: a wireless cooperative gripper for safe human robot interaction," in *2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 4576–4581, IEEE, 2018.