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Modular, Underactuated Anthropomorphic Robot Hand with Flexible Fingers and Twisted String Actuators

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Abstract. For general grasping, a strong lightweight and compact robot hand needs to be designed as a robot end effector. This paper describes the design of a 3D printed anthropomorphic robot hand that actuates flexible fingers using Twisted String Actuators (TSAs). A total of 6 of these actuators were fitted within a limited confined space, the palm of the hand. This gives the hand 6 Degrees of Freedom (DOFs) 2 in the thumb and 1 in each of the other fingers. A simple modular design was used which allows for rapid prototyping of different finger designs with respect to different requirements at low cost. In this paper, only power grasping is considered for simplicity. The hand is capable of performing both spherical and cylindrical grasps whereby the flexible nature of the fingers allows for forming around the geometry of a target object. The maximum holding load of the hand was found to be 10 kg in performance tests.

Keywords: twisted string actuators · additive manufacturing · flexible fingers · anthropomorphic robot hand

1 Introduction

From studies, tendon based transmission is one of the most commonly used actuation methods for robot hands [1]. This method of actuation is intuitive to implement and allows compact arrangements. However, the inherent compliance introduced by the flexibility of the tendons consequently requires complicated control methods for accurate position control [2]. The need of complicated control methods would be dependent on the design requirements, such as in the case of an industrial robot in car manufacturing where accurate position control is required.

In this paper, the design of a 3D printed anthropomorphic robot hand with flexible compliant fingers actuated by Twisted String Actuators (TSAs) [3] is proposed. The objective is to create an effective end effector that is cheap, light, strong, and compact. The efficacy of this hand will be defined by its performance in load carrying and its adaptability to grasp different shaped objects. This paper is structured as follows: The design considerations for the hand will be elaborated on in Section 2, Section 3 describes the tests and their results and Section 4 talks about the conclusions and future work.

2 Design Considerations

For this paper, each TSA consists of 1 Permanent Magnet DC(PMDC motor) [4] attached to 2 tendons. The motor is paired with an encoder to measure the rotations of the shaft for control. This actuation method in particular was adopted as it is relatively cheap, easy to manufacture, compact, and is capable of handling very high loads [3]. To fit the actuation system in a compact space, a total of 6 actuators were used and fitted into the palm of the hand, in particular, 2 in the thumb and 1 in each of the other fingers as shown in Fig.1 b). This results in the hand itself having 6 Degrees of Freedoms (DOFs) 2 for the thumb and 1 each for the remaining fingers. Having 2 DOFs for the thumb makes it opposable, as a result it allows the thumb to move in 2 planes of motion. This allows for more dexterous grasping to accommodate for geometrically different objects. Additionally, the hand weighs 235 g which is approximately half the weight of an average human male hand [5]

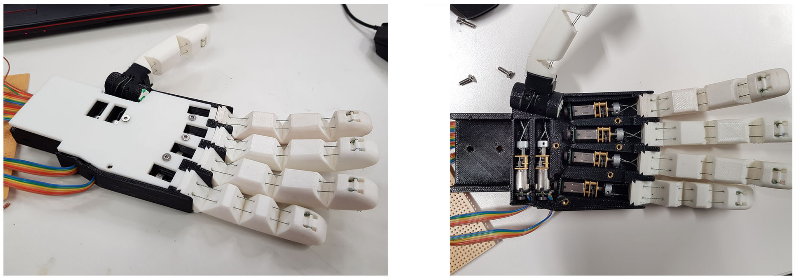

(a) (b)

Fig. 1. a) Overview of the hand b) Actuation system in the palm

A challenge of using this actuation method is the limited durability of the tendons used as opposed to their strength [6]. This is due to the fact that repetitive twisting of the tendons causes wear. From previous studies performed on different materials for TSAs, Dyneema, which is a type of Ultra High Molecular Weight Polyethylene (UHMWP), was adopted for its high durablility [6].

The hand is made of polylactic Acid (PLA) [7] which has been chosen for its durability and low cost. NinjaFlex, [8] which is a type of 3D printable flexible plastic, is used as the material for the fingers. A workpiece printed with this material is flexible at thin cross sections and stiff at thick cross sections. This allows for each finger to be 3D printed as an individual workpiece. From this, production time can be significantly reduced as compared to a standard robot finger which consists of multiple components. In addition, due to the inherent elastic nature of the material, the finger has sufficient elasticity to return to its initial shape after deformation. Therefore, antagonistic actuation is not required to fully actuate a finger, after releasing the tension from the actuators.

The hand was designed to be modular, which allows for rapid prototyping of different designs of fingers to be easily changed based on different design requirements. This is especially important for future work to allow for fingers with different inbuilt sensors to be tested without having the need to rebuild the entire hand. In addition, the compliancy of the fingers could be changed depending on their design and materials used.

3 Grasping and Load Test

Different grasps were tested with the hand on different shaped objects. Motivated to present the success of the hand design, the performance tests were carried out for power grasping in this paper. Only power grasping [9] is considered as it is simpler to implement and does not require a high amount of accuracy to implement. As shown in Fig. 2, benefiting from the opposable thumb design, the hand is capable of both cylindrical and spherical based grasping. This confirms that the compliant nature of the fingers allows the fingers to form around objects of different geometries, in particular a human brain model as shown in Fig. 2 b).

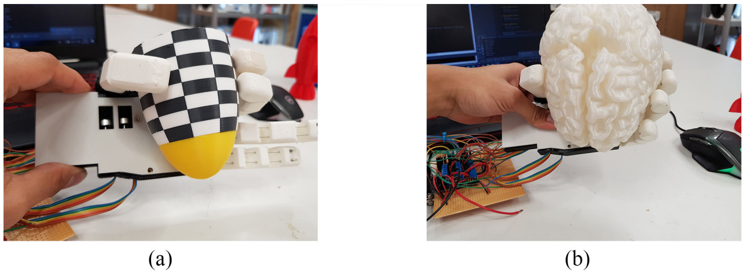
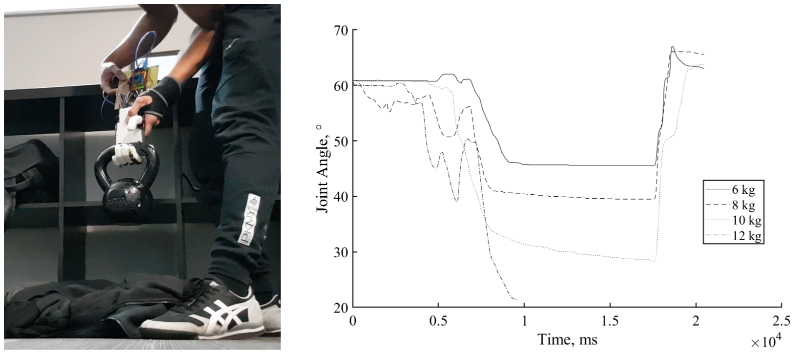

(a) (b)

Fig. 2. a) Cylindrical grasp b) Spherical grasp

To investigate the strength of the hand, varying loads were lifted by the hand until failure. Here, the measured strength refers to the maximum holding load of the hand. These tests were carried out by enclosing the fingers around the handles of kettlebells such that the TSAs have reached their limits in rotations. The hand was then lifted off the ground and held in the air for 10 seconds, before placing the kettlebell safely back on the ground as shown in Fig. 3 a).

From Fig. 3 b), the maximum holding load was found to be 10 kg. Over this weight, the fingers are unable to hold on to the handle while carrying the kettlebell. This is due to the compliancy of the finger design, primarily the flexiblity of the material.



(a) (b)

Fig. 3. a) The hand holding up a 10 kg kettleball b) Average joint angle response for differing loads

4 Conclusion

This paper presents the design of a compact and light-weight humanoid hand for potential use as an effective end effector. The design, which comprises of compliant fingers and TSA actuating mechanisms, enables power grasping of objects in various shapes and the carrying of heavy loads. The design allows for rapid manufacturing of a powerful compliant gripper at low cost. Future work will focus on the incorporation of complex control methods for more precision based pinch grasps. In addition, different finger designs that incorporate force sensing can be implemented to improve feedback control ability.

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