One-shot 3D Printed Underactuated Gripper*

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Abstract. Underactuated gripping mechanisms allow a wide range of objects to be grasped, with relatively simple control and input. Current 3D printed underactuated grippers are often composed of multiple parts that need assembly before use. Consolidating many of these parts allows the gripper to be manufactured more quickly for less money, and allows custom gripping devices to become more accessible. A novel one-shot printed underactuated gripping mechanism was developed, which was manufactured using HP's MJF 3D printing process. The conventional tendon lines were replaced with a band which was 3D printed as part of the gripper. Finite Element Analysis was used to model the gripper behaviour, and 3D printed prototypes were manufactured and tested, which were to grip a range of objects.

Keywords: 3D Printing · Underactuated · Gripper

1 Introduction

In the context of robot grippers, underactuation is where there are fewer sources of actuation than degrees of freedom [1], or joints. This can enable objects to be gripped with relatively simple control, as there is not a dedicated actuation device for every joint. Existing underactuated grippers usually feature rigid sections which are connected with flexible joints which act as springs [2]. A tendon line is then passed through the rigid digits, which causes the digit to bend once it is pulled [3]. Figure 1 shows tendon lines on the underside of a robotic hand [4]. As the arm casing is already 3D printed [5], if the tendon line could also be 3D printed in place, time could be saved during assembly.

2 Digit Design

Initial prototypes were manufactured on a Prusa i3 MK3S [6] which uses the FFF (Fused Filament Fabrication) 3D printing process. This process requires a support structure to be printed below hanging regions, but it is possible to 'bridge' certain straight line distances without support [7]. Figure 2 shows a basic underactuated digit design. The large blocks are the rigid sections, attached to each other by a thin flexible/compliant base. The tendon line is then printed from the end digit, through a channel in the others, to a pull tab within the main gripper body which can be attached to a linear actuator or similar. Pulling the tendon will create a bending force on the thin regions, causing the whole digit to flex. As there is only a single tendon line and actuator, this force causes

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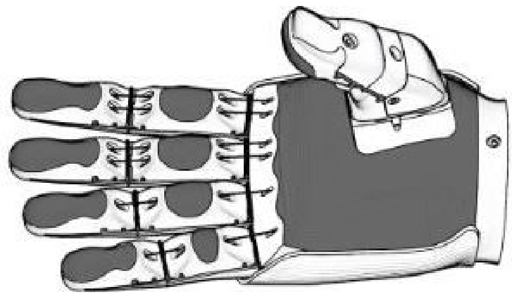


Fig. 1. Tendon Driven Hero Arm [4] Used with permission from Open Bionics

bending in the regions with the least resistance [8], allowing the gripper to conform to whatever shape it is grasping. In an FFF process, the print orientation plays a key role in the performance and manufacturability of such geometry. Due to the individual layers and lack of support, bridging can only be done parallel to the print bed. Printing digits perpendicular to the bed would be possible, but as the strength in this direction is much lower, the tendon and compliant regions would fail much more easily. In compression the tendon line can still transfer force to the tip as, even if it buckles, limited off-axis movement is possible within the digit channels. This allows the digit to bend in both directions.

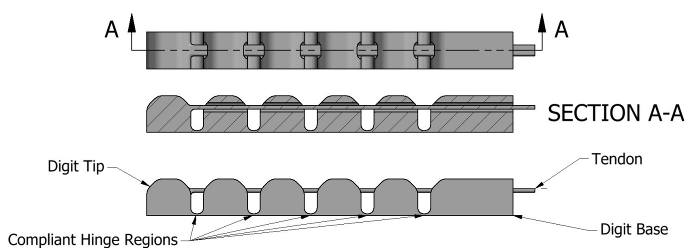


Fig. 2. Underactuated Digit

Finite Element Analysis (FEA) simulations within Ansys 2019R2 have been used to simulate the deformation of the underactuated digit to an applied load. Figure 3 shows the total deformation for a 4N load acting on the tendon. The maximum deformation is 39.6mm at an angle of 49°.

3 Digit Testing

Figure 4 shows two prototype digits, complete with integrated tendons. The left design requires the tendon to be cut at the back (rightmost) wall before it can be pulled to bend the digit, the right design was printed with two independent base sections, allowing them to be pulled apart without cutting. The compliant region thickness in these prototypes was chosen based on the first layer thickness of the FFF machine, 0.2mm in this case. This allowed the sections to flex easily, whilst still being relatively strong.

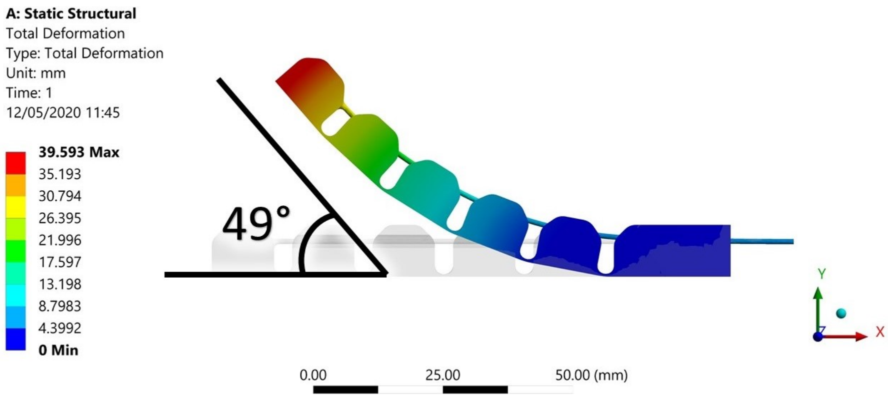


Fig. 3. Underactuated Digit Finite Element Analysis

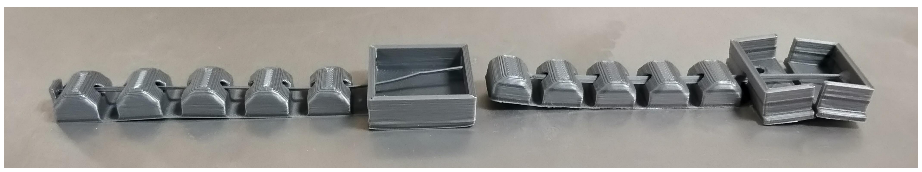


Fig. 4. Prototype FFF Digits

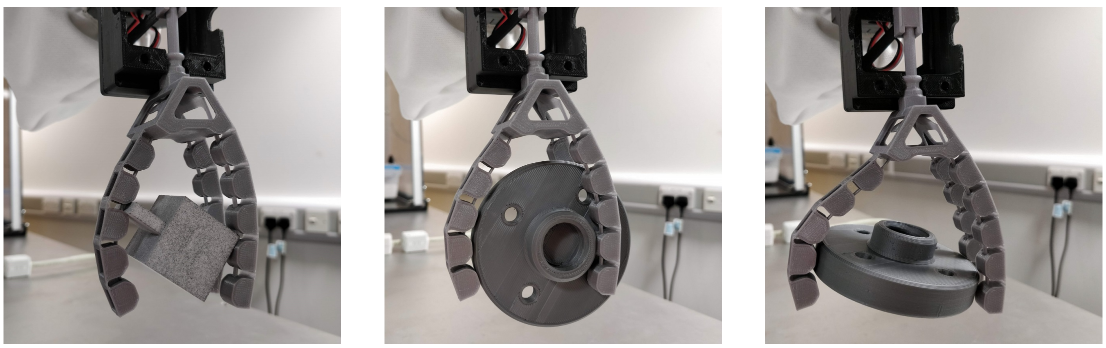
Another prototype digit was manufactured using HP's MJF (Multi Jet Fusion) process, shown in Figure 5. In this powder based process the un-fused powder provides support for the parts, removing the need for a solid support structure. This allows geometries to be printed which would be either impossible or require a complex, difficult to remove, support structure if printed using FFF. An FFF prototype with three digits has been manufactured and once connected to a linear actuator, it can be opened and closed to grasp a range of objects, as shown in Figure 6. Objects up to 200g have been sucessfully lifted using this setup. The possibility of gripping a wide range of objects is key for general purpose gripping applications such as for prosthetics, or where objects are in an unknown orientation.

4 Conclusion

3D printing tendon lines as part of the digit allows time to be saved in the assembly process, and the initial results show relatively good performance. Considerations must be taken depending on the selected manufacturing process, as support structure may be required to print the tendon line successfully. Part orientation on a FFF process is key, as the thin sections will break easily if printed perpendicular to the bed. Processes such as Multi Jet Fusion produce almost isotropic parts that can be printed in any orientation, and do not require any support structure for the tendons. The isotropic parts also more easily allow the gripping mechanism to be simulated using finite element analysis. This means different gripper configurations can be tested and the best chosen for manufacture.

(a) Bend Closed (b) Straight (c) Bend Open

Fig. 5. MJF Underactuated Digit Bend Test



(a) Object 1 (b) Object 2 Orientation 1 (c) Object 2 Orientation 2

Fig. 6. Underactuated Gripper Grip Test

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