MECHENG 736 Report

Otto Walker
Group 14: Celeste Allan, Luke Hynds, Otto Walker

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I Introduction

The currently available commercial prosthetic arms market is dominated by expensive, heavy, fully-actuated devices. This leads also to an increase in repair and maintenance costs. To combat this, prosthetic hands and grippers made of easily obtainable material such as PLA are being researched and designed [1]. 3D printed grippers are lightweight, cheap, and easily repairable. To add to this, underactuation of prosthetic hands with tendons for grip compliance allows for even cheaper designs and a more natural appearing hand at the expense of fine motor control. In this project, we will focus on the development of an adaptive prosthetic hand for grasping of various objects. The device will demonstrate the adaptive behavior of compliant, under-actuated grippers through a series of grasping tests. The devices should be as light-weight as possible and will be fabricated using rapid prototyping equipment and hybrid manufacturing techniques such as 3D printing and hybrid deposition manufacturing of silicon.

II Related Work

The field of underactuated 3D printed grasping devices is large, with much innovation occuring. Standout examples of this field include a paper from researchers at the University of Auckland [2] in which an underactuated anthropomorphic hand is detailed, capable of selectively locking digits to allow for more advanced grasping techniques. A second paper also from the University of auckland showcasing lockable differential mechanisms [3]. Authors from the institution of mechanical engineers [4] detail guidelines for design of prosthetic hands.

III Design

The gripper was designed to be anthropomorphic, with five fingers and a palm. Each finger had two phalanges, and the fingers were arranged in a three-two orientation on each side of the palm, with two fingers opposing for pinching motions and three interlocking. The whiffletree was located below the palm, in the support structure, and the motor below that, fastened to the base plate. The information on the design is split into three parts, those of finger design, palm & structure design, and whiffletree design.

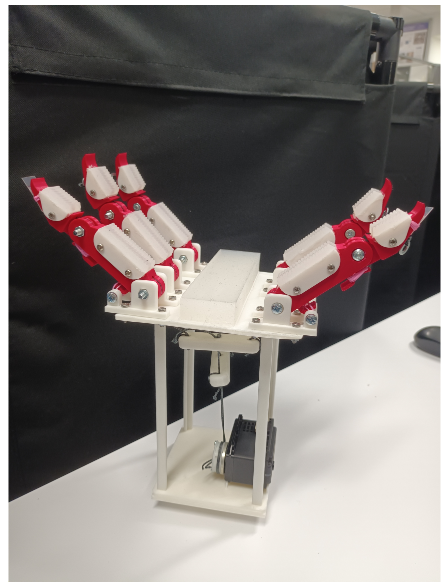


Figure 1: Fully assembled final design.

III.I Finger Design

The two parts of the fingers are connected to each other and the base mount by pivot-pivot joints, due to the tendency of flexure joints to move out of plane when under heavier loads. Each phalanx has a silicon pad and attachment points for rubber bands. The fingertip has both a solid fingernail and a pliable one.

III.I.I Fingertip Design

The main purpose of the fingertip is to pick up flat objects from a surface, and as such has a hard,

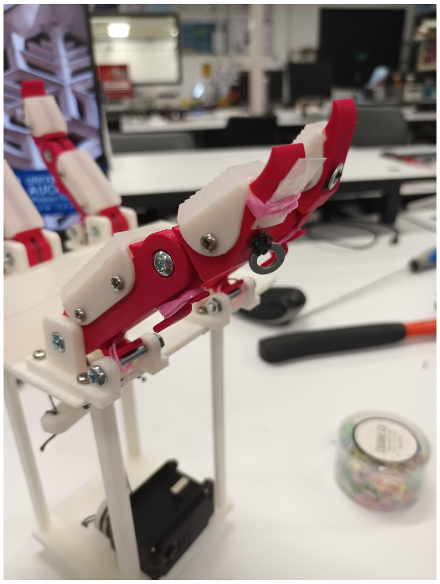


Figure 2: Fingertip, showing both hard and pliable fingernails.

pointed "fingernail". However, during initial testing, it was found that the 3D printed fingernail that was part of the distal phalanx did not have enough leverage on some objects to achieve a stable grip. To this end, a second, thinner and more flexible, fingernail was attached on the outside of the two pinching fingers. This was achieved using shaped pieces of polypropylene sheet, attached by way of rubber bands around the sheet and the finger to allow for more flexibility. To further increase the holding power of the fingertip, small pieces of waste silicon were placed between the hard fingernail and the flexible one.

III.I.II Phalanges Design

The final design of the finger had two phalanges, proximal and distal, each with a detachable silicon grip pad, and each actuated by a cord routed through them from the motor. The cord was terminated at the fingertip by tying around a washer, as shown in 2. The cord route was designed to be as far from the axis of rotation of the joints as possible, to increase finger strength. It was also designed as a groove rather than the simpler tubular shape, so as to be able to print without support material inside and to keep in place in areas where not fully enclosed. The fingers were also kept in tension using rubber bands between the distal and proximal phalanges, and the proximal phalanx and the base mount. This allowed control over which fingers closed faster or slower, and enabled the gripper to automatically return to the open state after use. The rubber band count between proximal and distal was altered between the pinching and the interlocking fingers to ensure the pinching fingers fingernails were in a useful position when grasping objects while the interlocking fingers were able to more naturally wrap around objects by increasing the count for the pinching fingers. There was also a disparity between the rubber band count of the proximal and the base mount joint, where the interlocking fingers had fewer rubber bands so as to close faster and avoid any unwanted interaction with the surface while the pinching fingers grasped small objects.

Distal Phalanx The distal phalanx was designed to be smaller than the proximal, to further imitate the human hand, and also included the fingertip, as detailed above. The silicon pad was attached to the phalanx by way of a fitted insert and held in by a single bolt through the whole assembly.

Proximal Phalanx The proximal phalanx was longer than the distal, and as such had a larger silicon pad, with two bolts to hold it in. It was also larger, as that was where most of the gripping force would come from and the increased force required higher strength so as not to break.

III.I.III Silicon Grip Design

The silicon grips were, as mentioned above, detachable, and had been formed from two separate pieces of 3D printed material; the base and the mold. This was done because during initial silicon testing, issues were found with a single piece used as both base an mold, where it was both hard to apply releasing spray to the mold area, and hard to after remove the mold from the base. The bases were made detachable in anticipation of further iterations being required for the fingers, although this did not happen. The base consisted of a simple dovetail to stop the silicon sliding out, and to allow ease of pouring of silicon. The mold was made with a ridged surface, to give the silicon more grip after casting.

III.II Palm & Structure Design

The palm and structure went through multiple iterations, where initially a simple press fit technique was used, with the palm, base, and dovetail joint were connected by way of four support poles. The final design included a joined base and dovetail joint, a smaller palm, and two support pieces instead of four, however larger and with struts between and notches to arrest torsional movement.

III.II.I Finger & Silicon Placement on Palm

The fingers were placed so that, when fully curled around the water bottle, which had the largest radius of the objects required to be grasped, the fingertips of the pinching fingers barely touched. This allowed full exertion of the gripping force on the water bottle, which was also the heaviest. The palm dimensions were also designed for this.

III.II.II Structural Elements Design

The base structure is composed of two support pieces, each composed of two poles with struts between them, connecting to the palm, a flat piece with a silicon block attached to the top and holes for finger base mounts, and the base, consisting of a motor mount on one side and a robotic arm compliant dovetail on the other.

III.II.III Assembly Choices

The holes for fitting the pole structure into the palm and base were made in an L shape, with 0.1mm tolerance to allow for a press fit for strength. The poles are forced into the holes, and stop when the holes reach a step in the pole perimeter. This is to stop compression of the structure during whiffletree use. The poles have no safeguard against structure expansion save for the press fit, due to the whiffletree mechanism holding the parts in tension.

III.III Whiffletree Design

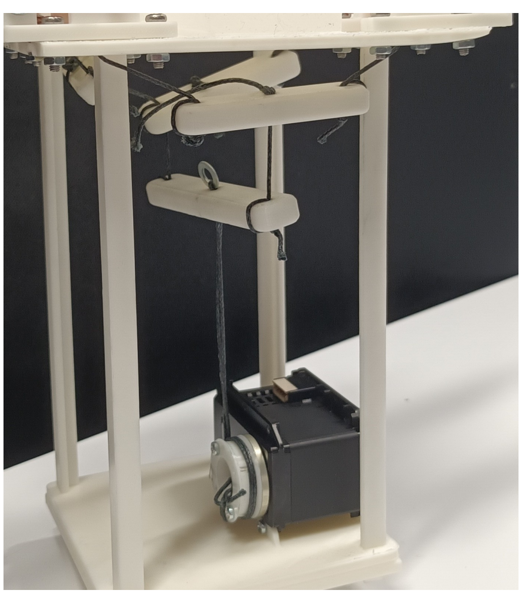


Figure 3: Assembled whiffletree

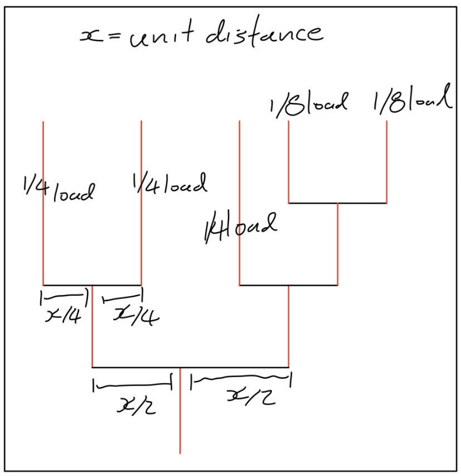
While there are other options for the conveyance of power from the motor to the individual digits, such as a system of gears, the whiffletree has multiple advantages in its ability to not only distribute force evenly, but compensate when inconsistent forces are applied to each link. This is an invaluable trait when designing an apparatus to grasp objects that are often non-uniform.

III.III.I Whiffletree Theory

A basic whiffletree consists of a spreader bar, attached on either end to a load, with a force acting in the middle of the bar. This is to distribute the force evenly between the two loads. Where the whiffletree becomes useful in the field of underactuated robotics is that when one load is stuck or otherwise unable to be moved by the force, the other load can still be acted on through the spreader bar itself tilting. As detailed above, the chosen hand design employed five fingers, and as such the motor power had to be distributed five ways. This required cascaded whiffletrees, as while multiple loads can be attached to a spreader bar, employing a technique where each load is positioned circularly around the central force, the costs in power and compactness compound after three or four simultaneous loads. It was determined that the motor power should not be distributed equally, however, as two of the fingers were designed for pinching and required more force when closing than the others, whose main use was stabilising the larger objects. To this end, multiple designs for different force distributions were drawn up, as detailed in figure 4. These designs all showed equal forces distributed to each side of the palm, but differed in how best to distribute the force within each subset of fingers. The design with an equal load to the three non-pinching fingers was decided upon for the final assembly due to the knowledge that many of the items would not be long enough to utilise the final finger and as such would be interacting only with four fingers, while the objects that were long enough would be less prone to adverse effects from the force imbalance due to the higher stability.

III.III.II Spreader Bar Design

The spreader bars themselves were created in two different sizes, 60mm and 80mm. The bars featured a hole at each end, equidistant from the edges at 7.5mm, and a hole in the middle. The cord was attached to the holes by the method of looping through the hole twice, then tying a knot. The diameter of the cord, and the diameter of the hole, meant that this arrangement could withstand considerable force without pulling loose. Previous iterations included a triangle-shaped bar where the cord could be tied around prongs located inside the triangle, similar to multiple examples in literature such as [2]. However, this was believed to lack the strength necessary to perform the required tasks due to the method required to print the pieces wherein the layers were tangential to the direction of the force. The bars were deemed not to require housings to ensure minimal out of plane movement inside the whiffletree, as the entire assembly was constantly under tension from the rubber bands attached to the digits. This also avoided any additional friction that would be introduced from housings.



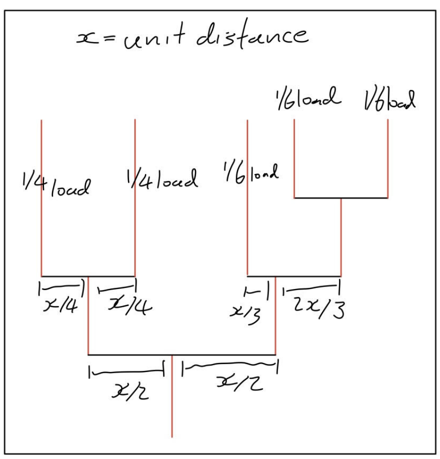


Figure 4: (a) Whiffletree design with equal forces on each side of palm. (b) Whiffletree design with equal forces on each non-pinching finger.

III.III.III Material Choices

The spreader bars were printed out of PLA due to it's unparalleled use as a prototyping material, and the cord sourced from high tensile fishing line. The PLA required knowledge of design techniques and 3D printer settings to fully utilise its strength, however the fishing line was used because it was supplied and recommended by the project organisers. The bars were printed in the same orientation they were to be used so as to not have issues with layer directions, and the infill amount was X %. While the fishing line was tied around metallic objects to increase strength at termination points in other parts of the build, the robust shape of the bars as well as the option to wrap the cord fully around the bar meant that was not necessary in the whiffletree.

IV Results

The gripper was put through a series of tests, and the results measured.

IV.I Tests

IV.I.I Grasping Test

To prove its use as a functional gripper, the hand was required to grasp and hold seven different objects. These ranged from very small, where they had to be levered off the table, to very large, where the main issue would be the motor overloading. The following table details the objects, as well as the ability of the gripper to grasp them.

Table 1: Grasping test results

Object	Grasped
M3 Washer	Yes
I.D. Card	Yes
Egg	Yes
Chain	Yes
Wrench	No
Hammer	Yes
Water Bottle	Yes

IV.I.II Strength Test

The gripper was required to test grip strength using a dynamometer, to find the strongest gripper. The maximum grip strength of the gripper was 40.39 Newtons, roughly one tenth of the average human hand maximum grip strength.

IV.I.III Weight Requirement

A weight check was required, where the gripper had to be underweight to qualify. This is related to the brief of designing for human use, where a gripper could not be heavy to the point of being hard to lift. As the gripper was designed as an anthropomorphic five-fingered hand, the weight requirement was to be under 600 grams without the motor. The gripper passed this test.

IV.II Test Conclusions

Overall, the gripper performed adequately, failing only on one object due to motor overloading. It passed the weight requirement, and scored lower than was possible on the grip strength test due to a lack of any motor power increasing methods such as gearing or pulleys.

V Conclusions & Future Directions

In conclusion, the gripper would be an adequate low-cost, easily manufactured and repaired human hand replacement prosthetic. While it lacks in certain areas, with more development it could be used satisfactorily by amputees or other in need parties. Possible areas of future improvement include some kind of system for increasing motor power,

References

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