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Chapter 13

Low-Cost 3D Printed PLA Robotic Arm Prosthesis using Snap-On Joints

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ABSTRACT

This paper explains how a simpler prosthetic design could be made using PLA as 3D printing material and using a simple snap-on design for the joints. Inmoov design of the robotic hand was reengineered to reduce the overall weight, parts number, and complexity of assembly. The Initial design has limited mobility especially at the thumb because only one degree of motion is available. Autodesk Inventor Professional 2020 was used to 3D model the design. The CAD model was exported to Ansys 2020 to study the static structural on the snap-on design to ensure that the structure could endure an average human gripping force which is 30 kg. The prototype was printed on Ender 3 Pro using PLA as the filament. The weight of the printed prototype is 291 grams. The printed prototype was further analyzed with physical testing. It shows that with the new joint design the prosthesis could endure a gripping force of 35 kg without breaking. With 2 degrees of motion available on the thumb, the prosthesis has additional grip. Compare to the initial Inmoov design the part numbers were decreased by 71.7% and the total mass is also decreased by 62.5%.

Key Words: Prosthesis Arm, Snap-on, 3D Print, Polylactic Acid (PLA)

1. INTRODUCTION

According to World Health Organization (WHO), the cost of a body-powered prosthetic hand is estimated to vary from $4,000 t0 $20,00. They also stated that just 20% of people in a group of 30 million are estimated to have prosthetics or other mobility aids to suit their needs (World Health Organization, 2018). There is commercial hand prosthesis available un the market such as Vincent (Vincent Systems), iLimb and iLimb Puls (Touch Bionics), Bebionic (RSL Steeper) and Michelangelo (Otto Bock) (Ca˜nizares, Pazos, & Ben´ıtez, 2017). However, the hand prosthesis or the robotics arms are very expensive and high number of parts.

Inmoov's design has been the gold standard for 3D printed robotic prosthesis for years now. The kinematics of the design lets the user use it to grip and hold daily items. As shown in figure 1, the prosthetic uses a hole and pin joint which needs 3 parts on the joint to hold it together not including the finger. The thumb of the design only has one single degree of movement. With the high part numbers, weight and complexity of assembly are high.

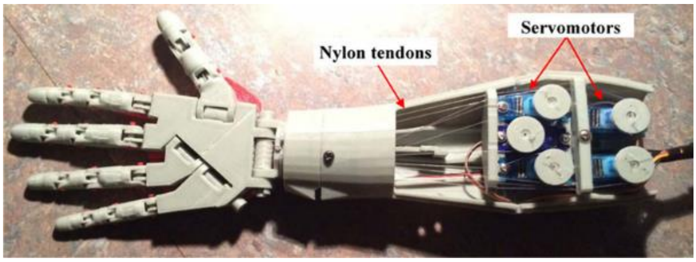


Figure 1: Inmoov open source 3D printed Prosthetic arm. (Langevin, 2012)

In this project, the joints of the prosthesis replace the hole and pin joint with a C-shaped snap-on joints. The issue to be addressed here are weight, part numbers, complexity, and limited mobility. With the new joint design the parts number, weight, and complexity of assembly can be reduced. According to Cobos, et. Al. (2008) by adding a second degree of movement on the thumb to increase the dexterity of the prosthesis as the thumb has impact on 60% of the functionality of the hand and it is used in 90% of the grip positions.

2. LITERATURE REVIEW

2.1 Inmoov Hand Design

Inmoov is an open source humanoid robot powered by Arduino microcontrollers and built out of 3D printable plastic body parts. (Langevin, 2012) Inmoov was developed and designed by a French sculptor and designer named Gaël Langevin. The hand design of this robot is being used as a platform for 3D printed prosthetics because the kinematics of the hand design is one of the closest to a normal human hand. This lets a prosthetic amputee download the file and print it in Acrylonitrile Butadiene Styrene (ABS). Figure 2 shows the assembled design of Inmoov robotic hand for the prosthetic application.

Other than Inmoov, Hero Arm, Halo arm, and Cyborg Beast in the open source 3D printing prosthetic world. However, compared to all these open source 3D printing prosthetics arms, Inmoov have the most grip variations compared to the other designs.

Figure 2: Inmoov Robotic hand design (Langevin, 2012).

2.2 Types of Human Grip

The type of human grips is mainly categorized into 2 main groups, which are: power grips and precision grips. The subcategorization of these two groups is shown in figure 3. The human "power grips" consist of the cylindrical grip, spherical grip, hook grip and lateral prehension (thumb abduction). While the "precision grips" are all from the tip-to-tip and thumb positioning for grabbing smalls object (Gelder, 2012).

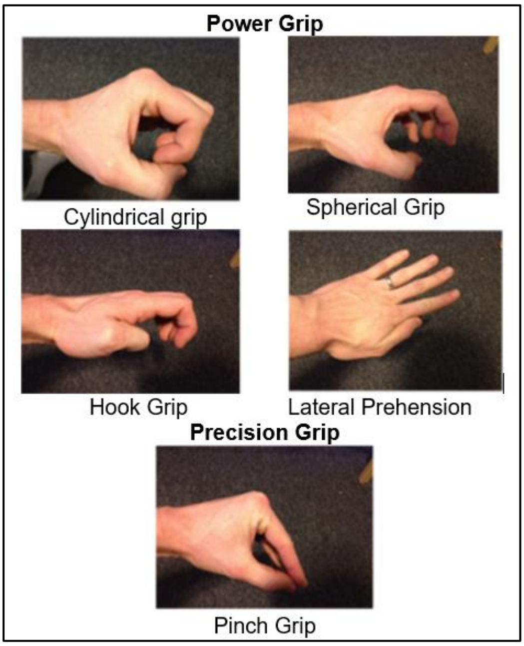


Figure 3: Types of human power grips. (Gelder, 2012)

3. METHODOLOGY

3.1 Static Structural Simulation of the joint

In this project, the 3D CAD model of the Inmoov design was reengineered using Autodesk Inventor Professional 2020. The figure 4 shows the fully assembled 3D model of the newly engineered joint (C-Shape snap joint) prototype. The upper thumb rotational axis was rotated 90° to accommodate lateral prehension grip. With using Ansys the newly engineered joints was analyzed so that the aperture of the C-Shaped on the joint could open to slip through the rod section without plastic deformation and does not break under the applied load. A bearing load of 294.1N was applied as the boundary condition at the joints as shown in figure 5.

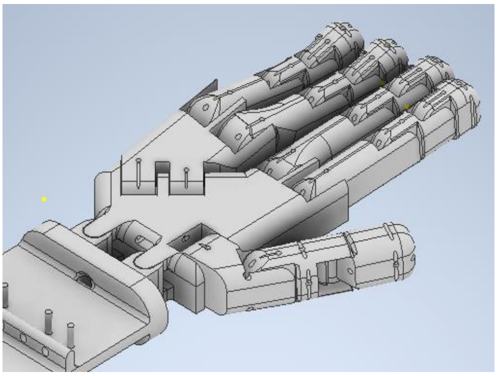


Figure 4: 3D model.

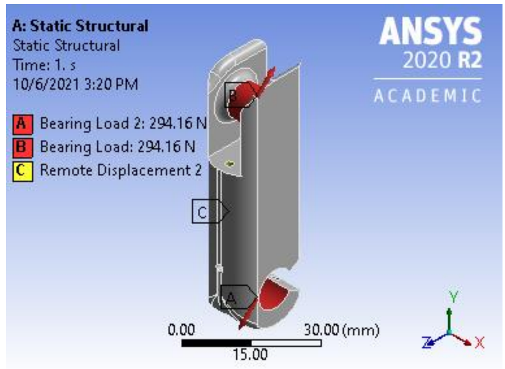


Figure 5: Ansys Boundary condition.

3.2 3D Printing

The reengineered model was printed using Ender 3 Pro 3D printer. The filament used was Polylactic Acid (PLA). The printing parameters as shown in table 1.

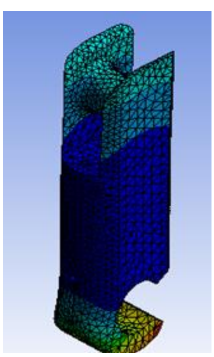
Table 1: Printing parameters.

Layer Height	Printing Speed	Bed Type	Infill	Nozzle temperature
0.2mm	50mm/s	Non-heated	20%	200°C

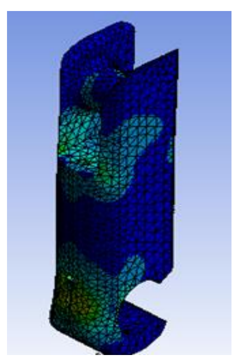
4. RESULTS AND DISCUSSION

4.1 Structural Strength at the Snap-On joint

In figure 6 shows the structural analysis at the aperture of the Snap-On joint. The maximum deformation of the C-section is 0.9mm under 30kg of load. While the maximum stress at the C-section of the joint is 52.7 MPa. The joint can sustain with the applied load without any fracture. In order to measure the gripping force of the 3D printed arm, a grip dynamometer was used as shown in figure 7. This 3D printed prototype could sustained average 35kg of gripping force without breaking which is higher than the average male gripping force which is 30kg as reported by Belter & Dollar (2011).



Maximum deformation at the C-section



(b) Maximum stress at the C-section

Figure 6: Structural Analysis

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Figure 7: Grip Test

4.2 Physical dexterity Testing

Table 2 shows Physical dexterity test results that were done on the prototype. The holding was divided into 2 types which are: vertical and horizontal hold. The prototype successfully passed all the dexterity tests.

Table 2: Dexterity Test Results.

Name of load	Weight of load (g)	Vertical hold	Horizontal hold
Water bottle	611	Success (cylindrical grip)	Success (cylindrical grip)
Deodorant (glass)	151	Success (3 finger grip)	Success (cylindrical grip)
Marker	18	Success (thumb prehension grip)	Success (cylindrical grip)
Soda Can	334	Success (cylindrical grip)	Success (cylindrical grip)
Toy ball	3	Success (spherical grip)	Success (spherical grip)
Card Holder	69	Success (thumb prehension grip)	Success (thumb prehension grip)

5. CONCLUSION

In conclusion, the addition of a second degree of movement of thumb gave the prosthesis capability to do thumb prehension grip, thus increasing the dexterity of the prosthesis. The total part number was decreased by 71.7% from 60 to 17 parts for the hand prosthesis with the Snap-On mechanism at the joint. The total weight of the 3D printed prototype is 294g and it is lighter compared to the initial design. The low part numbers and no fasteners needed ease assembly process of this reengineered Inmoov Design. Maximum gripping force that can be hold by the 3D printed prototype is 35kg without any failure.

Comparing and using the Inmoov's design as a base, the prototype prosthesis using the newly engineered joints has improved on dexterity, weight, ease of assembly, and reduction of parts number. Further studies can be done with different printing parameters and filament material.

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