3D Printed Robotic Hand

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Dexterous robotic hands are changing the way robots and humans interact and use common tools. Unfortunately, the complexity of the joints and actuations drive up the manufacturing cost. Some cutting edge and commercially available rapid prototyping machines now have the ability to print multiple materials and even combine these materials in the same job. A 3D model of a robotic hand was designed using Creo Parametric 2.0. Combining "hard" and "soft" materials, the model was printed on the Object Connex350 3D printer with the purpose of resembling as much as possible the human appearance and mobility of a real hand while needing no assembly. After printing the prototype, strings where installed as actuators to test mobility. Based on printing materials, the manufacturing cost of the hand was $167, significantly lower than other robotic hands without the actuators since they have more complex assembly processes.

Nomenclature

CAD = Computer Aided Design
CMC = Carpometacarpal (joint)
DIP = Interphalangeal distal (joint)
HRS = Human Robotics Systems
IP = Interphalangeal (joint)
KSC = Kennedy Space Center
MCP = Metacarpophalangeal (joint)
NASA = National Aeronautics and Space Administration
PIP = Interphalangeal proximal (joint)
STL = derivate from STereoLithography, is a file format

I. Introductions

In future space exploration human and robotic interaction will be essential. NASA's Human Robotics Systems (HRS) project is dedicated to develop technology to assist human in space exploration. This technology includes robot assistance, mobile robots, and vehicles that improve mission safety, efficiency, and productivity. Robots can support by arriving before the crew, during, working alongside the crew and after. Many times robots are needed to perform a certain task that requires human skillfulness, but are risky, repetitive or demand more strength. Trying to fulfill this need, robotic hands are becoming more sophisticated, with closer resemblance to human dexterity. Unfortunately, the complexity of the joints and actuations rapidly increase the manufacturing cost.

However, prototyping machines, commonly named 3D printers, can help lower the cost of manufacturing robotic hands. The before mentioned, uses an additive process to make solid objects practically any shape by laying successive layers of material. This prototyping technology is distinct from traditional machining techniques, which rely on subtractive processes, like cutting or drilling. The successive layers of material that the 3D printers print, are

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based on cross-sectional layers interpreted from a Computer Aided Design (CAD) model of the object which is going to be printed as shown in Fig. 1.

Some cutting edge and commercially available rapid prototyping machines now have the ability to print multiple materials and even combine these materials in the same job. 3D printers have the ability to leave gaps or insert "support material", that would be removed later, between multiple parts of an object, allowing for the printer to be able to replicate interlocking parts.

It was suggested as part of a KSC Kickstart Proposal to use this technology to produce a robotic hand at low cost. As previously mentioned, this project used the 3D printer Object Connex350 to produce a robotic hand that would need little or no assembly.

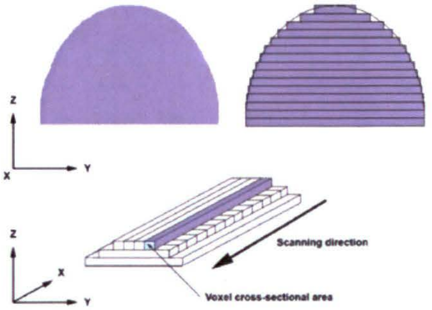

Figure 1. Cross-sectional area from CAD interpreted by 3D printer

II. Hardware

The 3D printer used, Object Connex350, has a resolution of 16 micrometers and an accuracy of 20-85 micrometers for features below 50 millimeters, making it able to print complex models. It uses PolyJet 3D printing technology, which jets layers of liquid photopolymer onto a build tray and then cures them with UV light. The Connex350 has the ability to print multiple materials and combine them at different ratios in the same print. VeroWhitePlus resin, a rigid material, was used to print out the "bones". TangoBlackPlus resin, a Rubber-like material, was used to print out the "skin" because of its soft and compliant properties. The Connex350 also jets gel-like support material specially designed to uphold overhangs and complicated geometries. It does this, by filling the gaps between joints, filling holes, and serving as base for upper layers of material, while printing. After printing, the support material is easily removed.

III. CAD Model

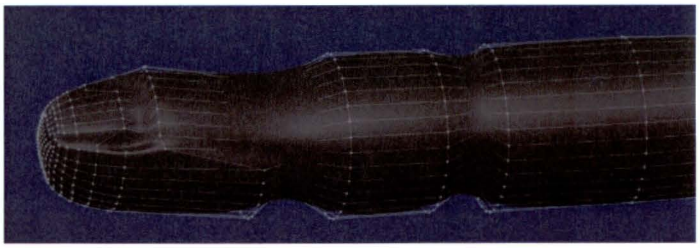

Figure 2. Mesh of finger skin with Freestyle tool

A. Software

The CAD model of the robotic hand was designed in Creo Parametric 2.0. Creo's Freestyle feature was used to create multiple meshes to model the skin around the fingers for more realistic look as shown in Fig. 2. In order to send it to the 3D printer the CAD model needs to be converted to a STL file. The term STL comes from STereoLithography, the original 3D printing method which employs a vat of liquid ultraviolet curable photopolymer "resin" and an ultraviolet laser to build parts layers one at a time.

B. Skeleton

The bones where modeled around a sketch. The sketch that served as reference for the skeleton was based on the average size of a human hand. The skeleton includes for the index, middle, ring and pinky fingers: the distal phalanges, the intermediate phalanges, and proximal phalanges. For this design the index, middle, ring and pinky fingers' metacarpals and the carpals bones where not modeled, instead the space where they are supposed to be placed was replaced by a base part, this can be appreciated comparing Fig. 3 and Fig. 4. The thumb included the distal phalange, proximal phalange and metacarpal bones. The distal phalange and proximal phalange can be easily observed on the normal hand thumb, while the metacarpal would usually pass as a part of the palm that does not move, nevertheless is indispensable for thumbs mobility. Later, this skeleton was adjusted multiple times to give fingers a more realistic alignment of the fingers and mobility.

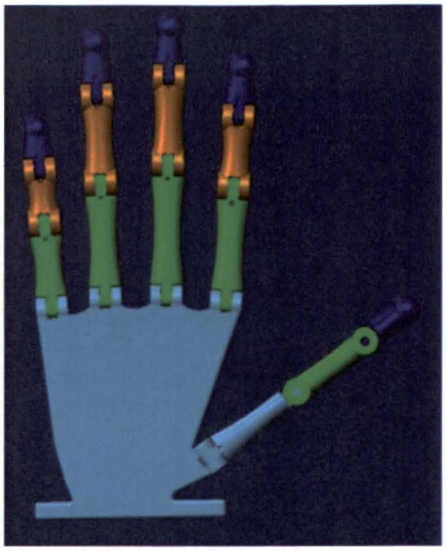

Figure 3. Skeleton of robotic hand

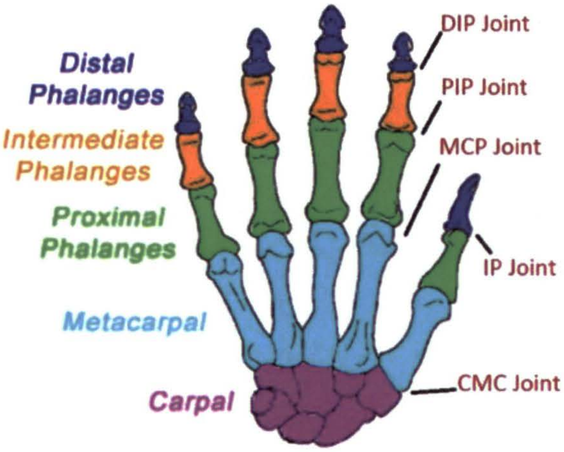

Figure 4. Skeleton of normal hand

C. Motion

The average range motion for joints was taken into consideration with some modifications for this design. For model and actuation simplicity at this stage adduction (draw or pull, body part toward the mid-axis of the body) and abduction (pull body part away from the mid-axis of the body) were not considered, only the flexion and extension motion were taken into account for the joints. The index, middle, ring and pinky fingers share the same range of motion while the thumb has a different kind of motion. The range of motion in degrees used, are showed in Table 1.

Table 1

Values for Range of Motion of Joints

Joint	Motion	Range normal hand* (°)	Range robotic hand (°)
MCP joints	Abduction	0–25	0
	Adduction	20–0	0
	Flexion	0–90	0-90
	Extension	0–30	0-30
PIP joints of fingers	Flexion	0–120	0-90
	Extension	120–0	0
DIP joints of fingers	Flexion	0–80	0-90
	Extension	80–0	0
MCP joint of thumb	Abduction	0–50	0
	Adduction	40–0	0
	Flexion	0–70	0-90
	Extension	60–0	0
	Flexion	0–90	0-90

IP joint of thumb	Extension	90–0	0

*Ranges are for people of all ages. Age-specific ranges have not been established; however, values are typically lower in fully functional elderly people than in younger people.

IV. Multiple Designs

Multiple designs where considered for the CAD of the robotic hand, with different kind of: joints, clearance and skin, after various prints to improve the model.

A. Joints

In order to need little or no assembly and take advantage of the capabilities of the Object Connex350, a joint that allow for interlocking parts and resemble finger mobility was desired. The first joint considered was sphere-like. It allow for flexion and extension but with an undesirable twisting. To resolve the problem mention before a cylindrical type joint was designed. This allowed for free flexion and extension without the undesirable twisting.

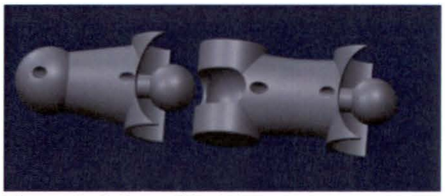

Figure 5. Sphere-like joint

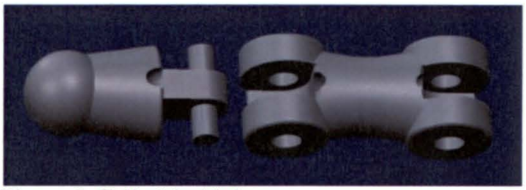

Figure 6. Cylindrical joint

B. Cables

At the stage of this project, spectra cables were used as the actuators. Holes across the bones where created to pass the cables as showed in Figure 7 and Figure 8. These cables where used to test mobility.

Figure 7. Finger with cable

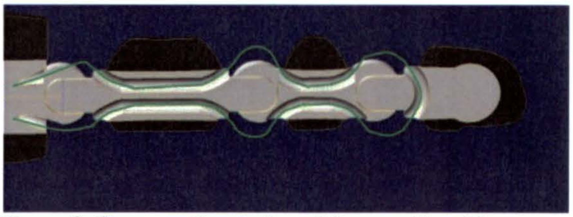

Figure 8. Cross-sectional view of finger with cables

C. Skin

As mention before, the skin was modeled using the Freestyle feature. The skin was required to look realistic but to allow free motion of the joints. It was also required, that it allowed the removal of the support material and gave access to the holes which the cables where going to pass through.

The first design covered the whole bones and the palm but had a slice through the side, so it could be peeled, to allow the support material to be removed, as showed in figure 9. After printing the first prototype of a finger, it proved to be a problem to remove the support material and also showed tearing at the area of major bending.

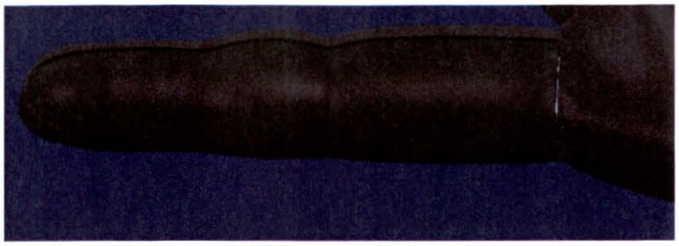

Figure 9. Slice on the side skin design

A second design was the skin and the finger printed as separate parts that would be slid together afterwards. This allowed for the easy cleaning of the support material. This design is shown in Fig. 10. However, this design did not work as expected due the poor resilience of the rubber-like material and the resistance it offered against flexion.

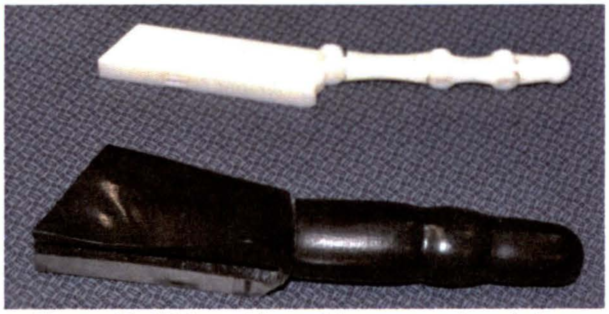

Figure 10. Sliding skin and bones together design

The third design of the skin had no skin around the joints, looked less realistic but allowed easy mobility, access to the cable holes and cleaning, this design is showed in Fig. 11.

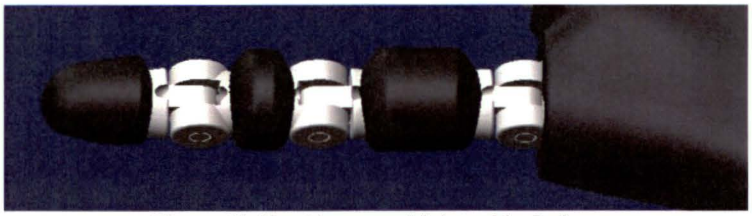

Figure 11. No-skin around joints skin design

D. Clearance

The clearance between the parts had to be adjusted to find an optimal design. At very small clearances several of the joints were fused together and could not be moved, while others moved freely. This is due to overspray and tolerance limitations of the 3-D printer. Later, more clearance was tried, which allowed the parts to move freely and to print the robotic hand as a whole part, needing no assembly.

V. Future

Modifications will be made to the thumb's CMC joint to add more freedom of movement. Also, more testing will be done, to further test mobility and the strength of the robotic hand. Future possibilities to the 3D printed robotic hand are to have more degrees of freedom to include adduction and abduction motion. Other options are to add more sophisticated actuators, like air muscles and sensors.

VI. Conclusion

The hand was successfully printed as whole needing no assembly, excepting the actuators (cables), little labor hours were invested, mostly into cleaning. The manufacturing cost of the hand, base on printing materials was $167. This cost is considerably lower than other robotic hands without the actuators, due to the more complicated assembly process and hours of labor needed, like machining. It opens possibilities for a future of lower cost robotic hands.

Figure 12. Robotic Hand CAD

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