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CUSTOM PROSTHETIC FINGER DEVICE USING 3D PRINTABLE PA11 CF POWDER

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ABSTRACT

This article presents a study on how to prototype a finger joint exoprosthesis using different CAD software and 3D printing techniques. The article describes the measurement of morpho-anatomical parameters, the creation of a 3D model based on these parameters, and the integration of an articulation mechanism into the patient's finger. This study also outlines the process of producing the custom prosthesis prototype by using PA11 CF material, which has applications in various fields including medicine. The prosthesis was then introduced to Sinterit Studio where a G-code was generated and the layers that would be printed were visualized. This method provides insight into the process of creating a prototype using 3D printing technology and specific software applications.

KEYWORDS: custom finger prosthesis, additive manufacturing, SLS

1. Introduction

Prototyping a finger joint prosthesis can be achieved through several methods, such as measuring the morpho-anatomical parameters of the index finger and creating a 3D model based on these parameters, or 3D scanning of the patient's hands and applying a mirror CAD function to the healthy finger in order to create a symmetrical prosthesis model with an articulation mechanism that will be integrated into the patient’s finger [1].

Each 3D printing process is based on a computer-generated graphic model created by various CAD (Computer Aided Design) applications. The graphics generated in CAD are exported as a mesh, with the most common format being STL (Standard Tesselation Language), which transforms the CAD model into a triangular representation. The mesh is introduced into a slicing software (e.g., Ultimaker Cura, Sinterit Studio) where the position and the number of pieces is established. In this slicer, the introduced model is divided into individual layers, each representing a 3D printing process.

To create the exoprosthesis, a mechanism consisting of regular bodies and the appearance of an integrated human finger is required, which presents irregular geometry. Since each CAD software has limitations in terms of tools that create easier geometry, we used the following CAD software:

a. *Blender* – is an open-source application for 3D creation, modelling, manipulation, simulation, animation, and rendering. Blender allows the modeling of polygonal meshes and uses vertices (points in 3D space) which are connected by lines. In this software, we can add vertices or modify their positions in the 3D space using specific tools, and we can edit the generated graphics' faces or geometry in any desired form.

b. *Autodesk Inventor Professional 2022* – is a CAD software that provides a range of tools for 3D modeling. This software allows the user to create the 3D body, reducing the risk of incorrect data transfer if the user wants to transform the model in a 2D drawing. Inventor is known for creating mechanisms and parts in the technical field, being able to create well-defined parts based on values or complex mathematical equations.

c. *Fusion 360* – is a software offered by Autodesk also used in 3D modeling, CAD, CAM, CAE, and a PCB platform for product design and manufacturing. This software is similar to Inventor but allows faster and easier 3D modeling. The user can design without the need to create a sketch, cut, or create an object. The list of tools in Fusion 360 allows us to modify the dimensions of faces and bodies in real-time, and we can also modify meshes, metal, and

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plastic sheets. In addition, it also provides verification, testing, and FEA simulation.

d. *3D Builder* – Offered by Microsoft, is a software that allows the creation and modification of 3D files in formats such as 3MF, STL, OBJ, and PLY. It comes loaded with a wide range of 3D tools that are easy to use.

2. Experimental measurements and customized prosthesis modeling

For measuring the parameters, we used a 3D scan of a normal-sized hand from *Digital Reality Lab's* website, which we imported into Blender.

Using the mirror function, we created the second hand. For the left hand, we amputated the distal and medial phalanges of the second finger. We performed this amputation using the boolean function, creating a body with which we cut the mesh. The next step involved the "*measure*" function to measure the parameters necessary for the creation of the prosthesis. The measured parameters are presented in Table 1.

Using the data from the table below, we create a mechanism consisting of 3 parts in Autodesk Inventor Professional 2022. The mechanism is able to mimic the movements of a functional finger on a single axis. To create the parts, we started with simple 2D sketches that were transformed into 3D objects using the extrude function, along with fillet, sweep, revolve, and loft functions, which created 3 component parts that can form an articulating assembly similar to a human finger.

The 3 component parts have two circular holes that cross the parts (Figure 1); the holes have two roles: the first role is to extend the prosthesis, as an elastic band is introduced through this channel, allowing the prosthesis to return to its neutral position, where all angles between the parts are 180°. The second role is to flex the prosthesis, with the help of a high-resistance elastic wire attached to a bracelet on the patient's wrist, this can initiate the flexion of the distal phalanx, thus initiating the flexion of the entire prosthesis mechanism.

The images below show the 3 parts generated by Inventor Professional program and their assembly.

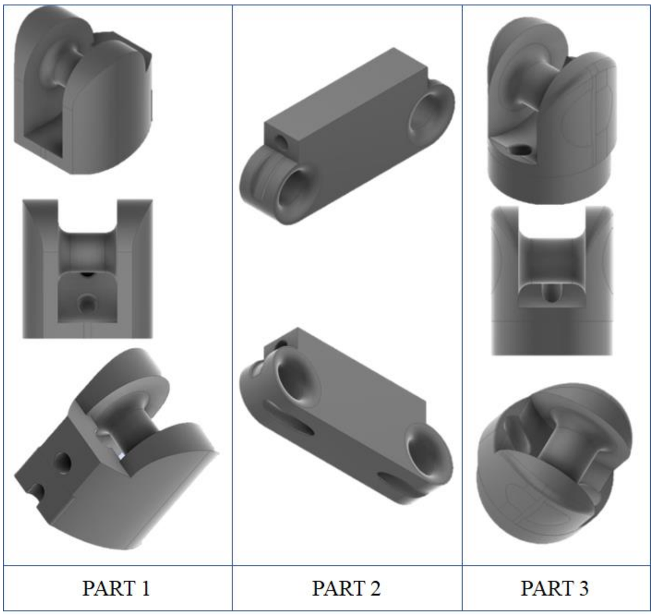

Fig. 1. *The component parts of the prosthesis assembly*

After creating the mechanism, we exported it in STL format and imported it into Blender, where the mirror function was used again to obtain the left hand. We cut off the finger that was initially amputated and used it to integrate the mechanism inside the finger. To integrate the mechanism inside the finger, we followed a few steps:

a. Positioning the assembly inside the finger, according to the measured parameters shown in Table 1.

b. Creating lines that follow the outline of the corresponding pieces of the distal-medial and proximal-median joints, and cutting the finger using the boolean function.

c. Sculpting inside the finger with the mechanism created in Inventor but for this step, it was necessary to fill the gaps in the parts to create a precise sculpting.

d. The final step involves placing the mechanism in the empty space inside the previously

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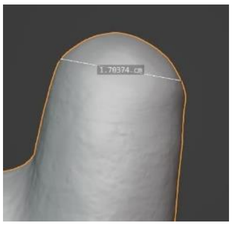
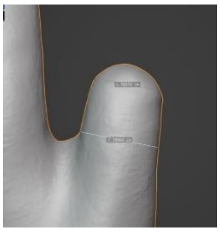
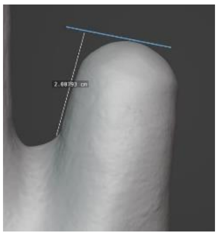
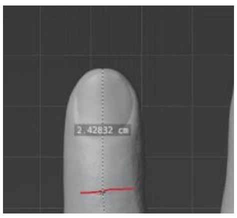
sculpted pieces. After placement, we used the "*Armature*" function, a tool that helps insert elements similar to a real skeleton, so we could articulate the component pieces precisely in the joint area where the mechanism axes are located.

Table 1. *Measurements of the parameters used to generate the prosthesis*

Parameter	**Measured Area**	**Dimensions [mm]**
Amputation top diameter		170
Amputation base diameter		216
Amputation height - side		200
Amputation height - compared to the palm		220
Medial phalanx height		260
Distal phalanx height		240

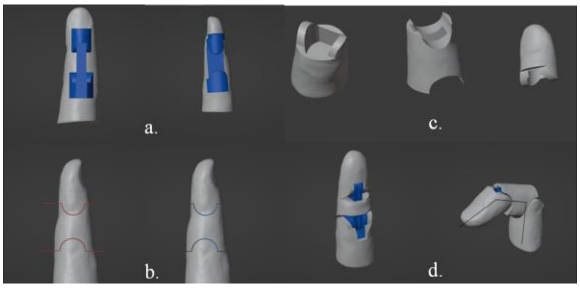


Fig. 2. *Custom finger prosthesis assembly. a. Fitting mechanism; b. Sectioning the finger; c. Creating space inside the finger for integrating the mechanism; d. Articulating the prototype using armatures*

After creating the prototype, we placed it on the hand with the amputated finger in order to make a comparison with the other hand and to observe how it fits on the mount, as shown in Figure 3.

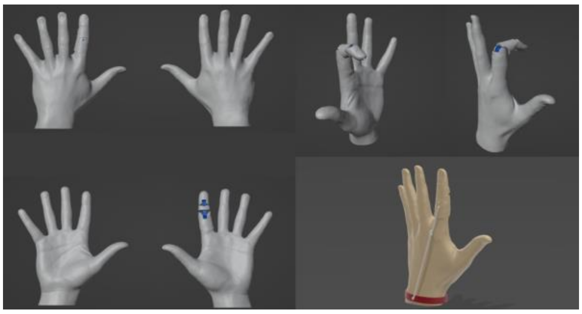


Fig. 3. *Presentation of the final virtual model of the custom prosthesis for the index finger*

3. Manufacturing method

The printing technology used for this prototype is SLS, with the help of the Sinterit Lisa Pro printer. Because is the only printing method through which mechanisms and parts containing multiple components can be printed without the need for supports and without gluing the parts together [2, 3]. Thus, assemblies can be directly printed with high precision. Compared to other printing techniques, it would have been necessary to create a prototype that would be assembled using separate components. The materials are divided into 3 categories:

a. Standard – the powders are excellent for prototyping and creating detailed objects with high resolutions.

b. Performance and special applications – these powders are used to create elements that require an extended life cycle, as well as high mechanical, chemical, and thermal resistance.

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c. Flexible – TPU and TPE powders are used to create flexible elements wherever flexibility with high mechanical properties is needed.

Among the available materials, we find: PA12 (rigid polyamide 12), PA11 (polyamide 11 with high mechanical strength and high elongation at break), PA11 ESD (polyamide 11, material from biological sources), PA11 CF (polyamide 11, the strongest and most versatile material available for SLS) [4]. Each material can be used by one or two printers in the range of those from Sinterit, with some materials only available for a specific type of printer. These materials find applications in the fields of production parts, automotive design, medical applications, tools, footwear, gaskets, and even aerospace parts.

Fig. 4. *3D printing results of the custom index finger prosthesis*

For the production of this model, we used PA11 CF (with carbon fiber) because it has applications in various fields, especially in medicine, where is used in medical equipment and prosthetics. Preparing the prototype for printing consisted of exporting it from Blender in STL format and importing the model in 3D Builder to check for imperfections that could cause printing errors, correcting the prototype, and then saving it in 3MF format. We introduced the prosthesis into Sinterit Studio, where we can position it according to the number of pieces we want to place or on which side we want the printing to start. The final 3D print results are shown in Figure 4.

4. Conclusions

The prototype developed in this study aimed to provide the patient with a method to produce a replacement for the amputated finger due to various pathological reasons and restore up to 70% of the movements of a healthy finger. This is an easy-to-create and printable prototype, which is parameterized and can be improved, such as by wrapping the prosthesis in a silicone material for better adhesion and a texture similar to that of the skin, making it moldable. Therefore, different shapes can be created that can be quite useful in the patient's activities. In the future, this prototype can be further developed, with the creation of a website where anyone can enter their measurements, and with the help of parametrization software, the prototype can be delivered with the appropriate dimensions, without the need for any CAD program intervention.

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