MODELLING AND SIMULATION OF AN UPPER HAND PROSTHETIC

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Abstract. This paper deals with the mechanical aspects that are taken into consideration while constructing a prosthetic arm. In the beginning, the design of the arm has been discussed at length. This section includes both - the part wise and the overall design made on modeling software. This is followed by explaining the movement of the arm. The parameters have been discussed in the section of the forward kinematics of the arm. The reverse engineering used in the design process is discussed. The material used has been covered towards the end. Finally, all these concepts have been put to use in a prototype developed by this team whose description is provided at the end of the paper.

1. INTRODUCTION
When an arm is lost, prosthetics play an important role in rehabilitation. An artificial arm improves the mobility of several amputees and aid in implementing daily activities. Prosthetics have evolved significantly from being fashioned from iron to wood and currently to a strong and durable lightweight material such as carbon fibre or plastics. In this paper, we have discussed about the material used in making of the prosthetic fore arm keeping in mind the importance of it being light in weight and durability for ease of use. The movements of the arm have been included in the robotics section of the paper, which comprises of forward and reverse kinematics. The dynamics section describes the effect of the subsequent movements and the possible failures the arm could encounter in real life. The final prototype is made to undergo a series of destructive and nondestructive tests to ensure durability.

2. DESIGN
The First design was based on the reverse engineering of a real hand with a digital Vernier robotics planning as well as the finite element analysis of the entire assembly and subassemblies. The bending in the x & y directions was analysed with the multiple simulations and the dimensions were iterated to get a sufficient factor of safety at the locations where the stress was concentrated.

2.1 Design of palm
Surface:
By the careful observation of the real palm contour, a replicated design was created to for the same in order to get a sufficient gripping action by the natural design curvature of the palm. This was done by merely taking the imprint of the palm over a clay and then taking the dimensions of the same using Vernier Calliper very carefully. The Figure 1 & Figure 2 shows the design of the palm contour and the wireframe design for the same. The fingers were designed such that they have a self-locking capability which constraints their motion after a certain limit in the backwards direction.
2.2 The Design of Thumb:

Figure 1. The Palm Contour & Wire Frame Structure

Figure 2. Overall Design of the hand
The Thumb is designed to have a maximum functionality with 2 degrees of freedom, which is then controlled by two motors, one having control over the bending of the upper two parts of the thumb and the other having control over the lower part for bending it transversely for reaching maximum points and thus having a bigger work volume. The figure shows the design of the thumb connected to the palm.

![Figure 3. Thumb Design.](image)

2.3 The design of Spring for reverse actuation:

The internal holes are designed to actuate the fingers with thread in the closing direction. The counter action of opening the fingers is achieved with the help of the loaded torsional springs. The simulation for determining the spring coefficient was determined with the help of SOLIDWORKS motion simulation. The Fingers were fixed under gravity along with a torsional spring torque acting on the joint to properly suspend their load.

![Figure 4. Spring Parameters Calculation](image)
2.4 The design of Internal holes for Actuation:

The curved holes are designed such that they act maximum normal force can be generated by the tension in the thread created by the motors without hindering the design strength properties and proper control over the fingers. These curved holes are designed with the considerations of their additive manufacturability, the importance of this was that such a mechanism can only be 3D printed and cannot be manufactured by any other means. The threads pass through these holes and when sufficient tension is generated by the motors, the fingers close by cancelling the reverse torque of the torsional strings.

![Figure 5. Finger Design(Index & Thumb)](image)

2.5 The Design of palm:

The palm is having the most complex design for this product. The best possible design for accommodating five rotatory motors was developed along with its strength bearing capabilities and least possible weight with sufficient factor of safety. Palm also have several internal holes for the passage of 6 threads for 5 different fingers, one for each finger and two for thumb. All these holes are not intersecting and their one end opens at the finger joint and the other at the motor head. Some curvature was given for accommodating them in the lesser space and without interference with each other.
Figure 6. Finger Design (Index & Thumb)

Each hand finger consists of two links and 1 degree of freedom. The four primary fingers are programmed to move in a way given in the image below Figure 1. The actuation of the fingers is designed in such a way that their motion is tabulated in Table 2.

Table 1. Link Lengths of the Fingers

| Sr. No. | Name of the Finger | Link 1(mm) | Link 2(mm) | Link 3(mm) |
|---------|--------------------|------------|------------|------------|
| 1.      | Thumbs             | 36         | 36         | 50         |
| 2.      | Index              | 70         | 50         |            |
| 3.      | Middle             | 76         | 55         |            |
| 4.      | Ring               | 67         | 46         |            |
| 5.      | Little             | 57         | 43         |            |

Table 2. Rotation of Joints

| Sr. No. | Simultaneous States | Joint 1(Link 1 and Link 2) | Joint 2(Link 2 and Main body) (Degrees) |
|---------|---------------------|----------------------------|----------------------------------------|
| 1.      | State               | 0                          | 0                                      |
| 2.      | State               | 30                         | 0                                      |
| 3.      | State               | 70                         | 40                                     |
| 4.      | State               | 70                         | 70                                     |
| 5.      | State               | 90                         | 90                                     |

The Figure below (Figure 2) depicts the work volume of the Thumb designed. The thumb has two degrees of freedom and is designed to grip the objects from the opposing side.
2.6 Finite Element Analysis:
Multiple Finite element Static Analysis were conducted for Multiple Combinations of the Fingers and Palm after which it was found that there was a sufficient factor of safety for the design for its stability and sustainability under the loads and a log life of fatigue.

Table 3. Mesh Information:

| Sno | Mesh Information | Solid Mesh |
|-----|------------------|------------|
| 1.  | Mesher Used:     | Standard mesh |
| 2.  | Automatic Transition: | Off |
| 3.  | Include Mesh Auto Loops: | Off |
| 4.  | Jacobian points | 4 Points |
| 5.  | Element Size | 4.86577 mm |
| 6.  | Tolerance | 0.243289 mm |
| 7.  | Mesh Quality Plot | High |
8. Total Nodes & 40971 \\
9. Total Elements & 24207 \\
10. Maximum Aspect Ratio & 33.083 \\
11. % of elements with Aspect Ratio < 3 & 83.7 \\
12. % of elements with Aspect Ratio > 10 & 0.306 \\
13. % of distorted elements (Jacobian) & 0 \\

**Figure 9.** Meshed Image

**Table 4.** Material Properties

| Model Reference | Properties |
|-----------------|------------|
|                  | Name: **Nylon 6/10** |
|                  | Model type: **Linear Elastic** |
|                  | **Isotropic** Default failure criterion: **Max von Mises Stress** |
|                  | Yield strength: 1.39043e+08 N/m² |
|                  | Tensile strength: 1.42559e+08 N/m² |
|                  | Elastic modulus: 8.3e+09 N/m² |
|                  | Poisson's ratio: 0.28 |
|                  | Mass density: 1.400 kg/m³ |
|                  | Shear modulus: 3.2e+09 N/m² |

*Figure 10. Images Depicting Various loads and Deflection due to them.*
Table 5. Parameters of the Simulation:

| Sim No | TYPE       | COMPONENTS       | FORCE (N) |
|--------|------------|------------------|-----------|
| 1      | BENDING X  | RING12+PALM      | 10        |
| 2      | BENDING X  | INDEX12+PALM     | 10        |
| 3      | BENDING X  | MIDDLE12+PALM    | 10        |
| 4      | BENDING X  | LITTLE12+PALM    | 10        |
| 5      | BENDING (+Y)| RING12+PALM      | 10        |
| 6      | BENDING (+Y)| INDEX12+PALM     | 10        |
| 7      | BENDING (+Y)| MIDDLE12+PALM    | 10        |
| 8      | BENDING (+Y)| LITTLE12+PALM    | 10        |
| 9      | BENDING (-Y)| RING12+PALM      | 10        |
| 10     | BENDING (-Y)| INDEX12+PALM     | 10        |
| 11     | BENDING (-Y)| MIDDLE12+PALM    | 10        |
| 12     | BENDING (-Y)| LITTLE12+PALM    | 10        |

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