# Rapid Prototyping of Elbow Orthosis in Biomedical Application

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*Abstract*— **Orthosis is used to support align, prevent or correct deformities to improve functions of movable parts of the body. Elbow hyperextension happens when the elbow joint in hand is bent beyond its normal range of motion. The elbow hyperextension can be treated as different method like ice therapy, elastic bandage, physical therapy and surgery. But the treatment process has some limitation like uncomfortable and took prolong curing time. So an elbow orthosis is to be designed ergonomically for the elbow hyperextension problem. The ergonomic design of elbow orthosis, reduces the problem of uncomfortable and allows fast curing time when compare with other braces. The design is based on the personalized profile of the human hand from the 3D scanned model. The 3D modeling of orthosis is done in Solidworks. The design is verified for the failure analysis by FEA static structural analysis using solid works simulation. The weight reduction & strength stiffness objective are achieved through topology optimization. The elbow orthosis are produced by one of the Additive Manufacturing process Fused Deposition Modeling with ABS material.**

## I. Introduction

Elbow hyperextension happens when elbow joint is bent beyond its normal range of motion is shown in fig.1. This type of injury can damage the ligaments and bones of the elbow. Immediately following the injury, place a cold compress on your elbow to help reduce pain and swelling. To make a cold compress, wrap some ice or an ice pack in a cloth. Also take over-the-counter anti-inflammatory pain relievers, such as aspirin, to help ease swelling and discomfort.

Fig. 1. Hyperextension of elbow hand

Each one of the elbows is made of three joints: your humeroulnar joint, humeroradial joint and superior radioulnar joint. You’re able to flex and extend your arm because of your humeroulnar joint. This joint connects the bones of your upper arm, known as your humerus , and your forearm, known as your ulna. Your elbow is hyper extended when your humeroulnar joint bends backward and out of its natural range of motion

Orthosis is used to support align, prevent, or correct deformities to improve functions of movable parts of the body. Orthosis derived from the Greek word, ORTHO meaning straight, upright or correct.

Rapid prototyping is a group of techniques used to quickly fabricate a scale model of a physical part or assembly using three-dimensional Computer Aided Design (CAD) data. Construction of the part or assembly is usually done using 3D Printing or "Additive Manufacturing" technology.

The elbow orthosis was produced using fuse deposition modeling. The model is fabricated using real scale of (1:1) for the conceptual design.

Additive manufacturing is defined as the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies.

FDM is a filament-based technology where a temperature controlled head extrudes a thermoplastic material layer by layer onto a build platform. A support structure is created where needed and built in water – soluble material.

## II. Literature Review

A multi objective optimization approach is proposed for choosing the appropriate process, material and thickness that minimizes production cost and time and maximizes device performance [1]. Tested framework with a simulated case study to choose between traditional plaster casting and two Additive manufacturing techniques for an ankle foot orthosis.

High performance and reliable prototype was developed for the low cost production [2]. The performance was good even though the prototype using rapid prototype materials. The controller board also functions as it programmed. The development of cost-effective new mechanism of dynamic ankle-foot orthosis was successfully fabricated in this current study.

Three types of Orthoses and prostheses are reviewed and compared to the traditional plaster molding techniques [3]. A study was first conducted at the University of Michigan Orthotics and Prosthetics Center to study the quantity and revenue of Orthoses and prostheses. The laborious steps and long fabrication time of the traditional manufacturing method and the progress and benefits of AM for custom orthoses and prostheses are evident.

Ankle Foot Orthoses offer better fit, comfort and functional performance than prefabricated ones developed [4]. The 3D printing technique is ideal for fabrication of personalized AFOs. Fused deposition modeling is a 3D printing method with the desired strength and material deposition rate for custom AFO application.

Rheumatoid arthritis is an inflammatory joint disease that can lead to pain, stiffness, and deformity , often with marked involvement of the small joints of the foot and ankle foot [5].The trial indicated that these orthoses performed as well as the patients current prescribed customized devices in terms of the observed gait and subjective evaluation of fit and comfort.

Passive dynamic ankle foot orthosis that seeks to improve walking ability for persons with various neuromuscular disorders by passively (like a spring) providing variable levels of support during the stance phase of gait. Current PD-AFO manufacturing technology is either labor intensive or not well suited for the detailed refinement of PD-AFO bending stiffness characteristics [6]. This study was to explore the feasibility of using a rapid free form prototyping technique, selective laser sintering (SLS), as a PD-AFO manufacturing process.

Framework that combines a fully parameterized PD-AFO computer aided design (CAD) model and freeform fabrication to rapidly manufacture customized PD-AFO [7]. A virtual orthopedic alignment process and selection of discrete design parameters values further customize the orthosis which is fabricated via selective laser sintering.

In this paper, a new solution is given to elbow hyperextension problem. An Orthosis is designed based on the 3D scanned data of a person affecting hyperextension problem. The model is printed using Fused Deposition Modeling Technique. The weight is reduced with improved stiffness is done by Topology Optimization Techniques.

## III. Methodology

### A. Design Methodology of Orthosis

3D laser scanner was used to scan the left elbow hand. Scanned data was converted into point cloud data. Point cloud data was converted into surface modeling. The Surface modeling does not change the required boundary conditions. So the Surface modeling was converted into Solid modeling to make the required boundary conditions for orthosis. Design of Orthosis was done by using Solidworks 2018 software. Orthosis was analyzed by FEA Static Structural Analysis by using Solidworks Simulation 2018. Analysis results is not higher than the yield strength of ABS. Therefore the redesign of orthosis design was done. Topology optimization analysis is done for the orthosis to reduce the weigth of the orthosis. Reconstructed the orthosis parts based on the topology optimization analysis was also done by using Solidworks 2018. Orthosis part files are converted into STL file format for 3D printing technique such as Fused deposition modeling which is used to print the orthosis parts.

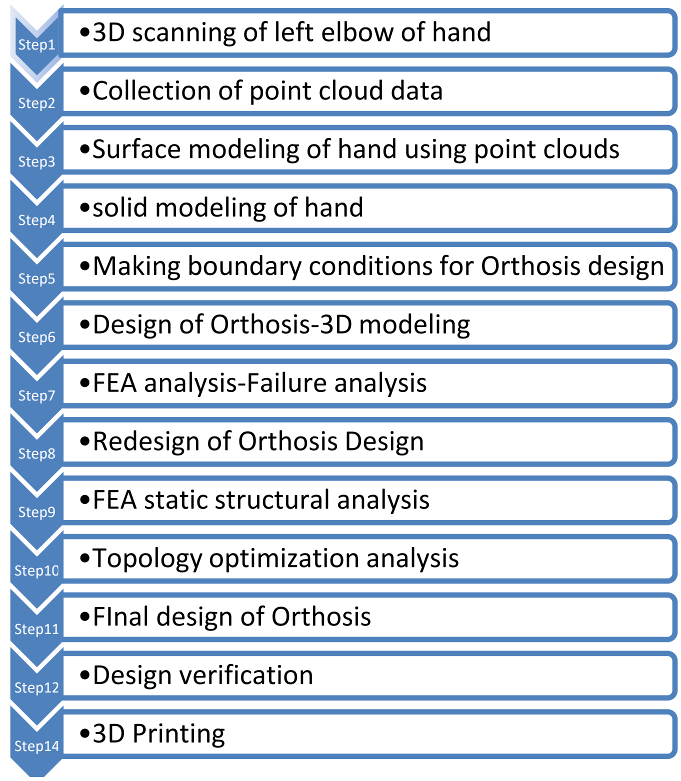


Fig. 2. Schematic Diagram of Orthosis Design Development

Fig 2 represents the schematic diagram of Orthosis Design development. 3D laser scanner is used to scan the human elbow hand. The scanning is converted into point cloud data and point cloud data converted into surface modeling. The Surface modeling does not change the required boundary conditions. So the Surface modeling is converted into solid modeling. Topology Optimization (TO) is a mathematical method that optimizes material layout within a given design space, for a given set of loads, boundary conditions and constraints with the goal of maximizing the performance of the system

### B. Material Selection

Acrylontrile butadiene styrene (ABS) is used in this project. It is a common thermoplastic polymer and it is amorphous and therefore has no true melting point.

### C. 3D Scanning

3D laser scanner is used to scan the elbow of human left hand. The scanned data is converted into point clouds data which is used to do image reconstructions.

### D. Image Reconstruction

Image Reconstruction refers to iterative algorithms used to reconstruct 2D and 3D images in certain imaging techniques. For example, in computed tomography an image must be reconstructed from projections of an object Point cloud data is converted into surface modeling. The Surface modeling does not change the required boundary conditions. So the Surface modeling is converted into solid modeling.

### *E. 3D Modeling of Orthosis Design*

Initially design of orthosis need the boundary conditions of hand profile from the scanned data. This Orthosis is an assembly of several individual parts along with screws, ratchet, springs and hinges. Upper part of the orthosis and lower part of the orthosis are connected two joints. The arm movements are controlled by using ratchet arrangement. Fig.3 shows the initial design of the elbow orthosis model which was designed by Solidworks 2018.

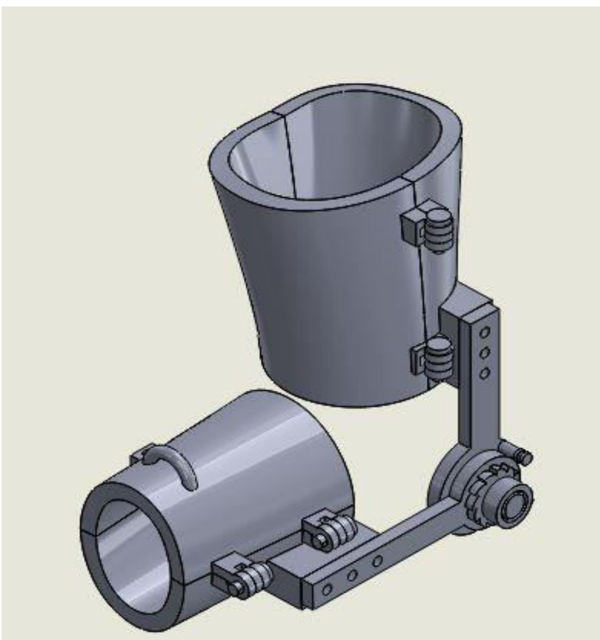

Fig. 3. Initial design of orthosis

Upper part and lower part are connected to the two joints. Orthosis parts are designed by using of solidworks 2018 software.

## IV. DESIGN CALCULATIONS

### *A .Force applied on Orthosis*

Force = Weight in N× Length of the lower hand × Centre of gravity

Weight in kg =3.5kg

Weight in N =3.5×9.81=34.335N

Length of the lower hand in meter =0.163m

Centre of gravity=9.81metre per second square

Force =34.335×0.163×9.81=54.90N

Factor of safety =2

### *B. Ratchet Wheel Design*

Ratchet Wheel

Ratchet Wheel D =Z × m [8]

Where,

Z= 12-20 (for ratchet arrester)

m= module,

$$m = 2\sqrt[3]{Mt}/Z\psi[\sigma b]$$

where,

$M_t$ –Transmitting torque

ψ- (b/m ratio,1.5 to 3)

$\sigma_b$- bending stress(300-500kgf/mm2)

Transmitted torque = (P×60000) / (2×Π×N)

= (150×60000)/ (2×Π×40)

Mt = 35809 N-mm

m = 2×1.25

m= 2.5

D= m × Z

D= 2.5 × 12

D= 30mm

## V. FEA ANALYSIS

Finite element analysis (FEA) is the modeling of products and systems in a virtual environment for the purpose of finding and solving potential (or existing) structural or performance issues. FEA is the practical application of the finite element method (FEM), which is used by engineers and scientists to mathematically model and numerically solve complex structural, fluid and multi physics problems.

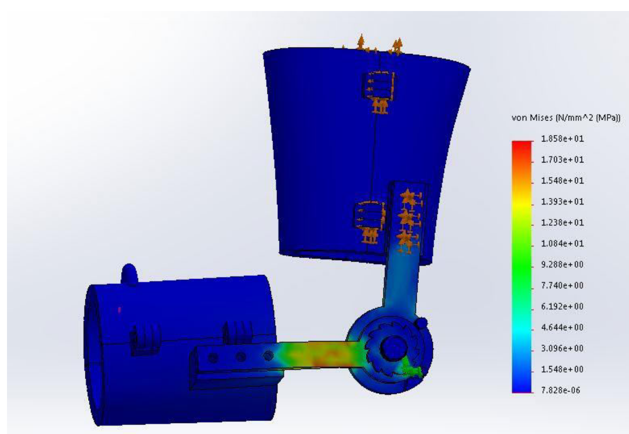


Fig. 4. Static Structural Analysis

FEA Analysis is done using Solidworks Simulation 2018. Fig.4. shows the FEA static analysis of the entire Orthosis Assembly. It is done to verify the stress acting on the orthosis model. The Upper part top surface & holes are fixed. The load is applied on the lower part. The Maximum Stress attained in the Orthosis design is 18 Mpa. The Ultimate strength and Yield Strength of the ABS material is 40 Mpa and 20 MPa. The Factor of safety considered is 2. Here the stress of the Orthosis is less than that of yield stress. Therefore design is safe. Also the maximum stress ocuurs at the lower joint which connects the upper part and the lower part. The material used for the analysis is ABS material. Fine mesh is used to make the mesh geometry.

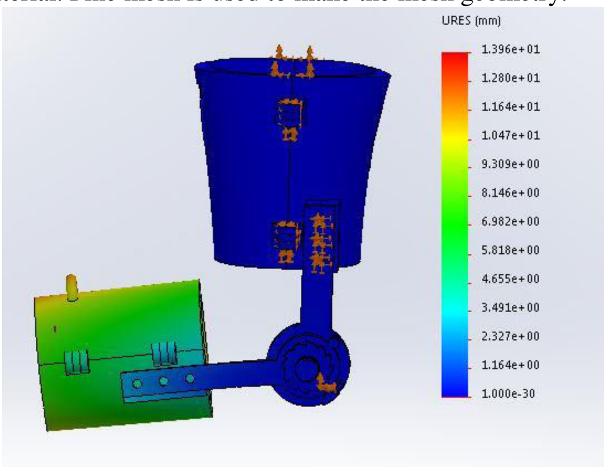


Fig. .5 Displacement of Orthosis

Fig.5. shows the displacement plot of the orthosis after the application of forces on the orthosis. The maximum displacement value is 0.1 mm.

## VI. Topology Optimization

Topology Optimization (TO) is a mathematical method that optimizes material layout within a given design space, for a given set of loads, boundary conditions and constraints with the goal of maximizing the performance of the system.

Topology optimization method solves the basic engineering problem of distributing a limited amount of material in a design space. Currently, engineers mostly use topology optimization at the concept level of a design process.

The benefits of Topology Optimization are

- Reduce the mass property& material
- Increasing the stiffness, quality
- Reduce the cost of the material

Topology Optimization was done in Solidworks Simulation 2018. Tho TO was done for all the major components of the Orthosis. The results of the TO are discussed below.

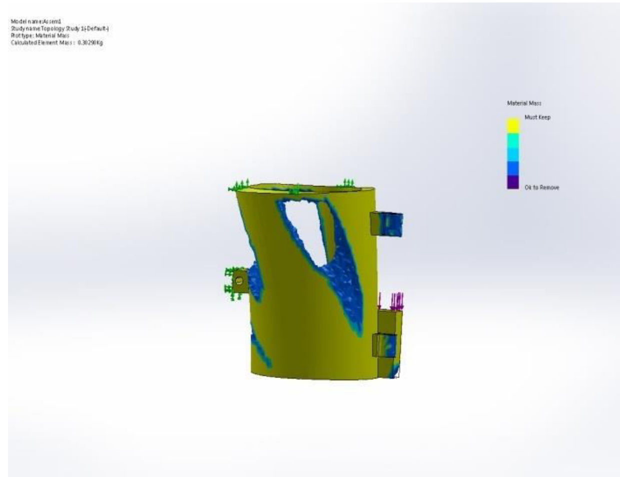

Fig. 6. Topology Optimization on upper right part

Fig.6. shows the Topology Optimization analysis of the upper right part by using solidworks simulation2018. It shows the material to be removcd and to keep within the body.

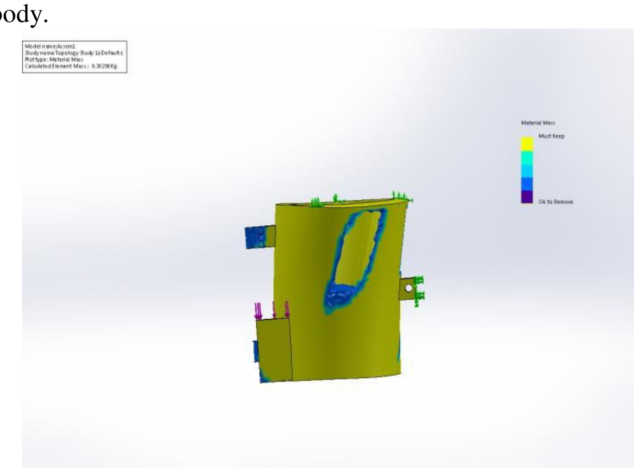

Fig. 7. Topology Optimization of Upper Left Part

Fig.7. shows the Topology optimization of analysis upper left part by using solidworks simulation 2018. The weight ratio is reduced to 30% by its actual mass.

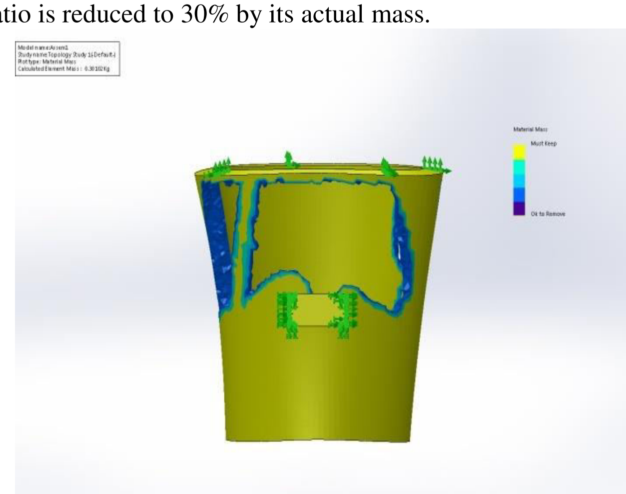

Fig. 9. Topology Optimization of Upper Part

Fig.9. shows the Topology optimization of analysis upper part by using solidworks simulation 2018.

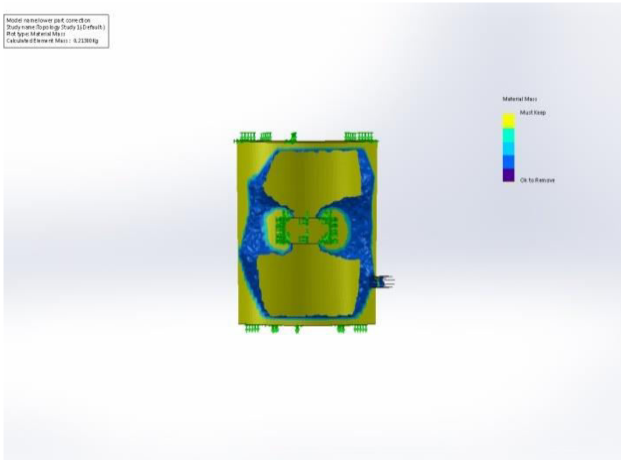

Fig. 10. Front view of the Lower Part

Fig 10 shows the Topology optimization of analysis lower part by using solidworks simulation 2018.

## VII. REDESIGN OF ORTHOSIS DESIGN

The redesign of orthosis is done based on the geometry available in the results of Topology Optimization. The design re modification is done using Solidworks 2018. The redesign is done only to reduce the mass of the orthosis with improved stiffness.

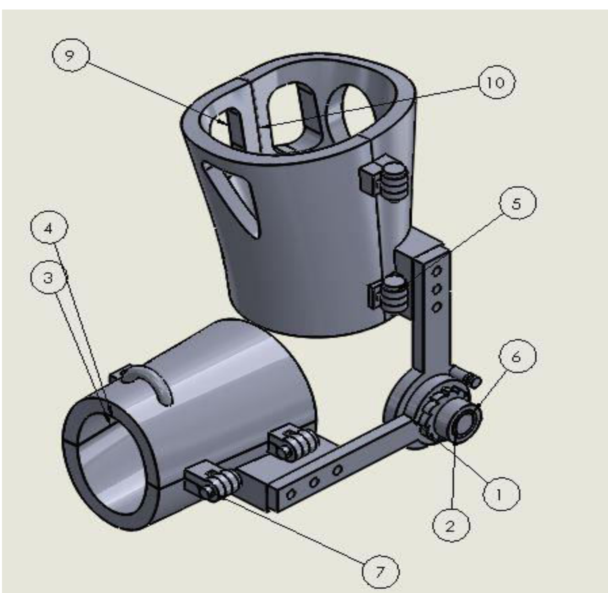


Fig. 11. Topology Optimization of Orthosis

Fig 11 shows the reconstructed design of orthosis based on the topology optimization analysis. Table.1. shows the bill of materials for the orthosis design.

Table.1. Bill of Materials

| Item no | Part name | Material | Qty |
|---|---|---|---|
| 1 | Topology optimization on upper right part | ABS | 1 |
| 2 | Topology optimization on upper left part | ABS | 1 |
| 3 | Topology optimization on lower right part | ABS | 1 |
| 4 | Topology Optimization on lower left part | ABS | 1 |
| 5 | Upper joint | ABS | 1 |
| 6 | Lower joint | ABS | 1 |
| 7 | Pawl | ABS | 1 |
| 8 | Bolt | MS | 6 |
| 9 | Nut | MS | 6 |
| 10 | Screw | MS | 6 |

The design is then fabricated by using the Fused Deposition Modeling which is one of the cheapest additive manufacturing techniques with ABS material. The design is then assembled by using various fasteners and the implanted in the human hand for elbow hyper extension problem.

Fig.12. Implementation of Elbow Orthosis

The printed orthosis and its assembly is successfully implanted in the human left hand as shown in Fig.12 to solve the elbow hyper extension problem.

## VIII. RESULTS AND DISCUSSION

The virtual and real model model simulation and analysis is done and it is mentioned in the below Table.2.

Table.2. Optimization Results

| S.No | Particulars | Mass (g) | Volume (cm$^3$) | Max stress (MPa) | Max dis (mm) | Yield strength | Safe /No |
|---|---|---|---|---|---|---|---|
| 1 | Without TO | 766.42 | 7.6 e5 | 18.56 | 13 | 20 | Y |
| 2 | With TO | 692.80 | 6.9 e5 | 19.76 | 13 | 20 | Y |

Table 4.2 shows the optimization results of the Orthosis. Before topology optimization, the mass property of the orthosis is 0.766kg. After topology optimization, the mass

property of the orthosis is 0.692kg. So, % of mass reduction is about 10%. Without topology obtained volume of 766420 and with topology obtained volume of orthosis 692799. So the designed orthosis is a complete safe design.

## IX. Conclusion

Orthosis are more comfortable to any person because of its ergonomically design and suitable for any users. The entire Orthosis is an assembly of several individual parts with screws, ratchet and hinges. It is manufactured by one of the Additive Manufacturing technique named Fused Deposition Modeling with ABS material. The Maximum Stress applied in the Orthosis design is 18 Mpa and its Ultimate strength of the ABS material is 40 Mpa. Thus it is a safer design and never undergoes any failure. Before Topology Optimization the weight of the orthosis is 0.766 kg. After the Topology Optimization the weight is reduced by 10% with improved stiffness. After topology optimization stress applied in the Orthosis is 19Mpa and it is lesser than the yield stress. Therefore the sign is safe. After Topology Optimization the weight of the orthosis is 0.692 kg The Orthosis could be worn for long period of time without causing pain and therefore the curing time is faster.

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