# Low Cost 3D-Printed Prosthetic Arms

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## Background

- Average price of a prosthetic arm ranges from $3,000 - $30,000
- In 2008, there were approximately 3 million arm amputees worldwide; 2.5 million of them are from developing countries [1]
- The most common cause of amputation in a developed country is Vascular disease. In war-torn countries like Afghanistan and Syria, it's caused by shrapnel from explosions
- Prosthetic limbs consist of three main components: the socket to house the stub, the limb, and the artificial hand/foot [2]
- Due to growth and heavy use, an average child will go through a prosthetic limb every six to twelve months [3]

## Objective

- Design and produce an inexpensive, aesthetic, and durable pediatric prosthetic arm for children in developing countries
- Find existing open-sourced designs and modify/improve them to work with my own designs and constraints [4]
- Conduct FEA and refine the drawings accordingly
- 3D print the various components and assemble the arm
- Identify channels for funding research and development, as well as future mass-production efforts
- Establish a framework for conducting future research in the field of biomechanics, as well as studying the effects that access to prostheses have on the labor markets and health

## Parameters

### Restoration Finger Forces


**Distance between force and joint=1/2 in**
**Weight of fingertip=1/32 lb**
**Restoration torque=1/2in·1/32 lb=1/64 lb·in**

**Phalange 1**
- Object Torque = (1/2in) ·(2lb) = 1 lb·in
- (1/64 lb·in)·(1 lb·in) = F·(1/4")
- Force On String: F = 4.0625 lb

**Phalange 2**
- Object Torque=(1in) ·(2lb) = 2 lb·in
- (1/64 lb·in)·(2 lb·in) = F·(1/4")
- Force On String: F = 8.0625 lb

**Phalange 3**
- Object Torque=(1.5in) ·(2lb) = 3 lb·in
- (1/64 lb·in)·(3 lb·in) = F·(1/4")
- Force On String: F = 12.0625 lb

### Motor Output

**Max Torque=1.26 N·m**
**Shaft Diameter=6.35 mm**
**Shaft Radius=3.175 mm=0.003175 m**

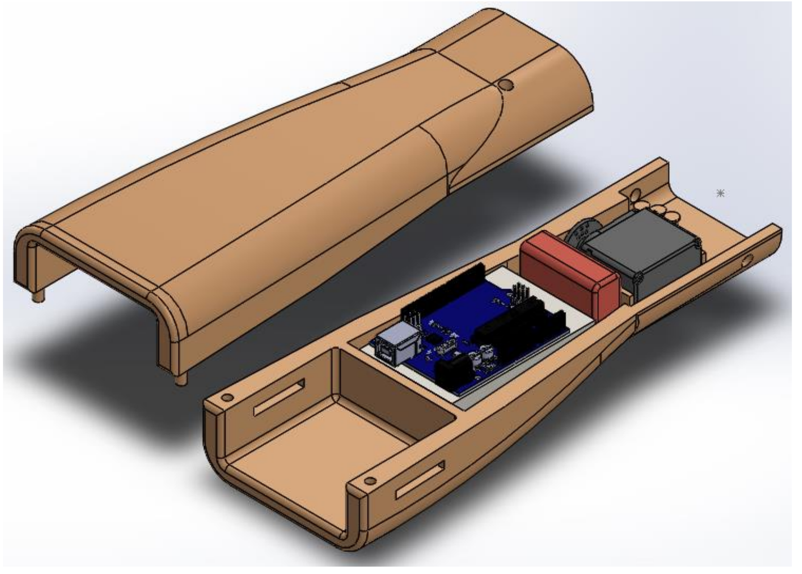
**Torque**
- Torque = 1.26 N·m/0.003175 m = 396.85 N
- Torque = 396.85 N = 89.215 lb

Rotation of the motor shaft produces a linear force of 89.215 lb. This force is transferred upon four of the fingers

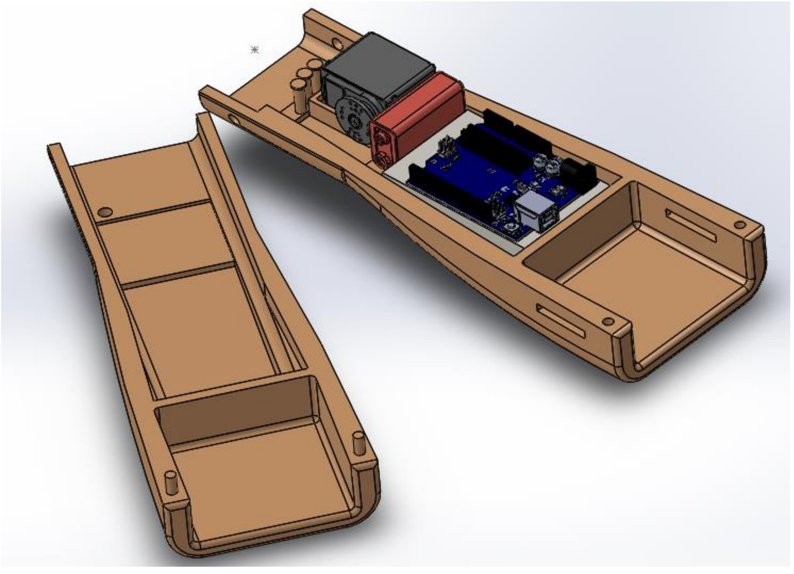
**Max Force**
- Max Force Per Finger = 22.3 lb
- FOS applied: Force Per Finger = 12 lb

**Finger Pressure**
- Approximate Finger Area = 2.8 in^2
- Finger Pressure = 12 lb/2.8 in^2 = 4.3 psi

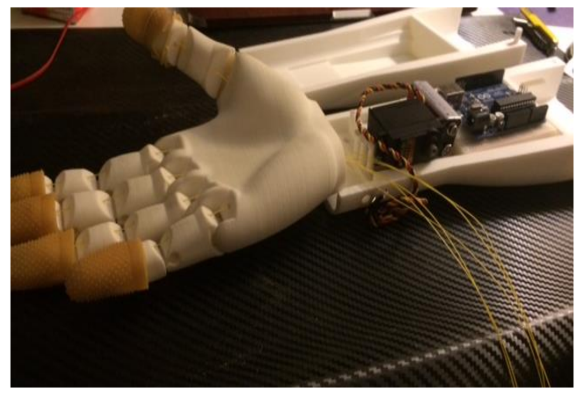
## 3D Printing



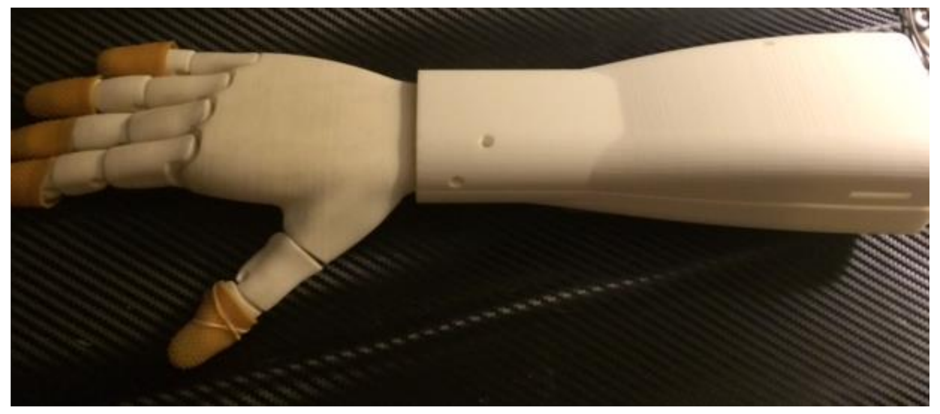
Isometric Assembly View 1



Isometric Assembly View 2

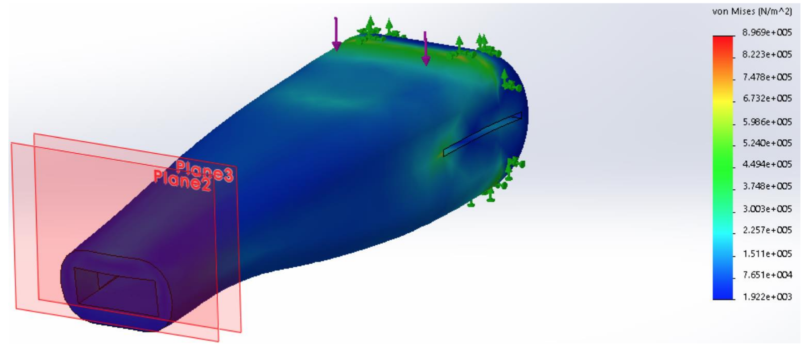


3D Printed Arm – Open

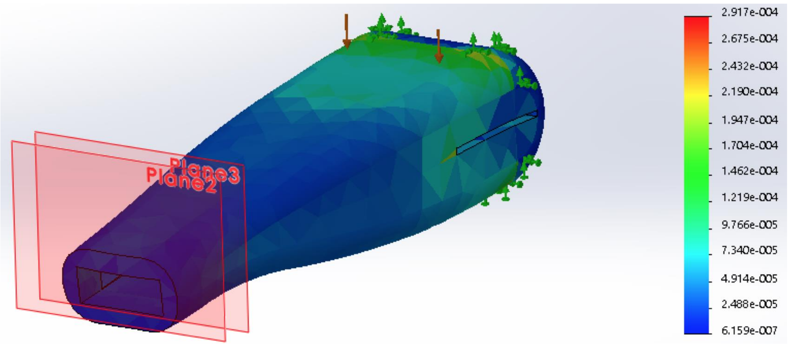


3D Printed Arm

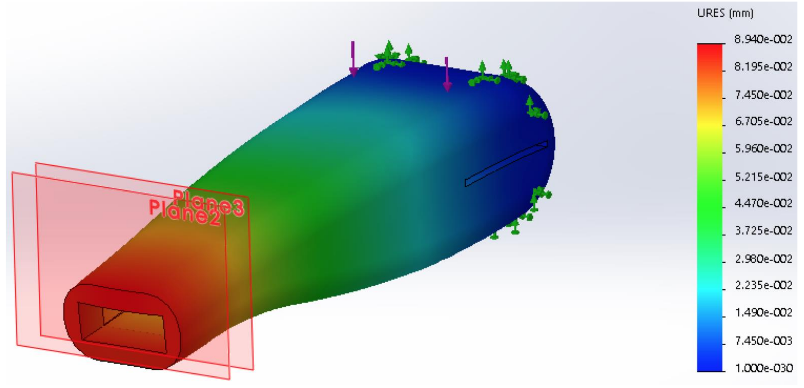
## Finite Element Analysis



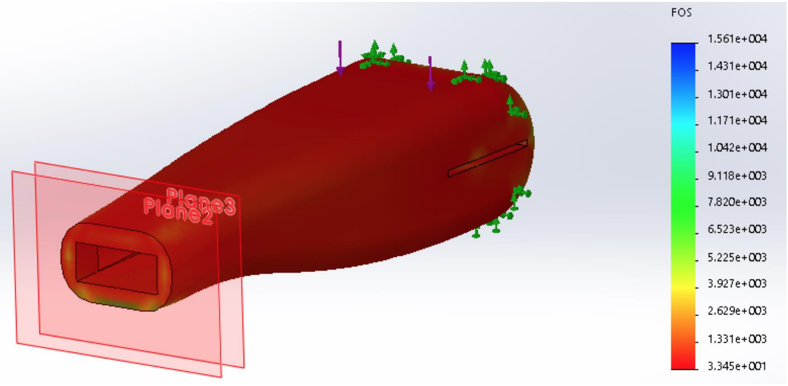
Arm Stress Analysis



Arm Strain Analysis



Arm Displacement Analysis



Arm Factor of Safety Analysis

## Results

- Standard engineering analysis conducted on the arm housing unit, where applied loads were a concern to the unit's integrity
- Fixed at the base, with an excessive 25 pound downward force applied at the end of the arm housing
- PLA and ABS plastic results are comparable under SolidWorks finite element analysis
- Stress is generally on the order of 10^4 – 10^5 Pa, while strain stays below 0.0003. These values are within the tolerant range for the modulus of elasticity and yield strength of plastic
- Plastic arm displaces a maximum of 0.0894 mm, which won't cause any deformities
- Factor of safety is well above the minimum industry standard of 2
- Standard loads won't cause damage to the plastic arm housing

## Production Method

1. Export CAD files as a .stl file and open in a 3D printing software like Makerbot Software or 3D Builder
2. Software will slice drawings into many thin, printable layers
3. 3D print the drawing files
4. Velcro-tape the breadboard, Arduino, battery, and motor to the prosthetic housing bottom (hook up the EMG sensors to the additionally required adapter for the electrical version)
5. Import code from Arduino IDE to the microcontroller
6. Slide the prosthetic housing top piece onto the bottom one, screwing them together

## Conclusions

- Max stresses typically on the order of 10^4 – 10^5 Pa, well within the range for plastic's modulus of elasticity and yield strength
- Reaction force of 25 lb load is 97.5 lb, requiring additional strap
- High strength-to-diameter braided line required for tendons
- 100% infill unnecessary and cumbersome
- At least 1 order of magnitude cheaper than industry prosthetics
- Factor of safety on-par with industry standard
- Can be printed and assembled in less than one week
- Suitable product for developed countries with access to the grid
- Larger battery required to power electronics for longer periods

## Future Work

- Improve code for the electromyography sensors to reduce noise
- Test alternative motors (particularly servos) and microcontrollers
- Print using different infill percentages to find the optimum weight and performance
- Develop a mechanical prosthetic arm for poorer countries: will use no electricity and is significantly cheaper to build
- Launch a kickstarter campaign to acquire funding in the future
- Connect with various aid organizations who have the distribution systems to disseminate the prosthetic limbs in war-torn regions

## References

1. LeBlanc, Maurice. "Give Hope – Give a Hand" – The LN-4 Prosthetic Hand. Published 11/09/2008.
2. Strait, Erin. "Prosthetics in Developing Countries." *American Academy of Orthotics and Prosthetists.* 2006.
3. Yousif, A., Sadiq, A. "The Design, Development, and Construction of an Adjustable Lower Extremity." *IOSR Journal of Engineering*. 2012.
4. "Limbitless – Creating Hope with 3D Printed Limbs." *Limbitless.* <http://limbitless-solutions.org/index.php/en/>

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