10/3/2015

Prosthetic Hand Project

Abstract:

The Biomechanics research team from Vanier College is collaborating with a team of McGill University engineering students to provide a better understanding of the fundamentals of principles of biomechanics and their real life applications. This is implemented by experimental and theoretical studies, leading finally to the design of a prosthetic hand prototype. This research is aiming to provide a cheaper alternative to the robotic prosthetics offered in the market.

Vanier are responsible for calculating biomechanics physical parameters like force, speed, angular speed, torque, stress and strain on joints and bones of the hand, while McGill's team will focus on the design and development of a prototype.

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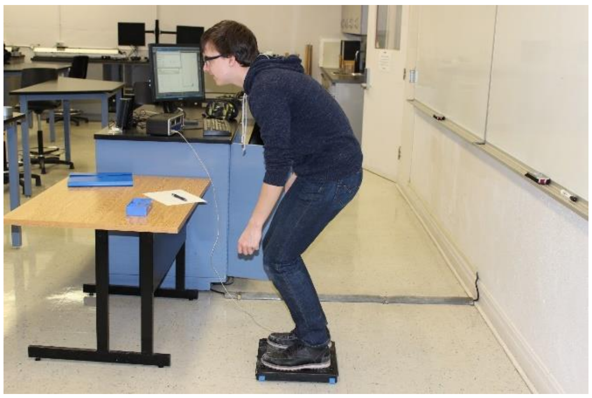
Contents

1. Introduction

Students from the Vanier Student Research Centre's (VSRC) bio-mechanics project teamed up with McGill University engineering students to design and produce a 3D-printed robotic hand that could be used as a cheaper alternative to existing prosthetic limbs. While the engineering students are be responsible for the actual design of the artificial hand, the bio-mechanics team conducts experiments and research in order to determine the physical limits of the human hand, such as the velocity of the fingers, maximum force, torque, power, stress and strain, all while applying mechanical concepts learned during class or through active learning. The results gathered from these experiments are actually used to choose the appropriate materials and components (motors, actuators, plastic, etc.) for the robotic hand in order for it to emulate an actual human hand while still keeping the cost of production down.



An example of the use of a Force Platform: Measuring the force generated by a person jumping

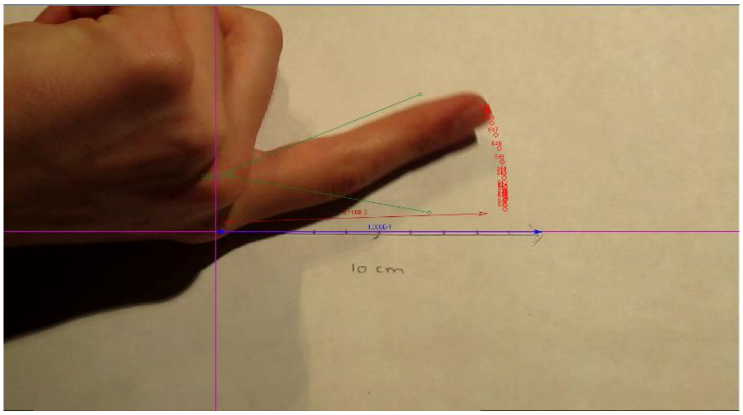
Some students also chose to study the physical limitations of the human body in general, but as of yet, research and experiments in this area will not be presented at the March Science Fair.

2. Results and Analysis

Two sets of experiments were conducted in order to determine the specifications of the actuators that would have to be used to move the fingers of the robotic hand: One to determine the maximum velocity of each finger, their angular velocity and their number of revolutions per minute (rpm); Another to determine the maximum force sustained or exerted by each finger, the corresponding torque and the power required to move the finger.

I. Motion Analysis (Finger Velocity)

To calculate the maximum velocity at which the actuators would have to operate, we had to determine the maximum velocity at which human fingers could open and close. We filmed ourselves moving each finger individually; once slowly and once fast. We imported the footage into *Tracker*, a free video analysis and modelling tool. Using its built-in tracking tools, we were able to generate position-time graphs for both the x and y axes. Analyzing the graphs, which can be found in the Appendix, we were able to find the maximum slope (instantaneous velocity) for each and calculate the magnitude of the maximum velocity vector $\mathbf{v_{max}}$. From this velocity and from the measured lengths of our fingers, we were able to calculate the angular velocity $\boldsymbol{\omega}$ and the revolutions per minute **rpm**, using the following formulas:



Screenshot from Tracker

$$v_{max} = \sqrt{(v_x max)^2 + (v_y max)^2}$$

$$\omega = \frac{v_{max}}{R}$$

$$\omega \frac{rad}{s} \frac{1\,rev}{2\pi\,rad} \frac{60\,s}{1\,min} = rpm$$

From these, we were able to obtain the results shown in **Table 1**.

Finger	v_x max (m/s)	v_y max (m/s)	v max (m/s)	Radius (m)	ω (rad/s)	rpm
Thumb	0.00527	0.0360	0.0364	0.116	0.314	3.00
Index	0.0608	0.124	0.138	0,0963	1.484	14.2
Middle	0.0626	0.0744	0.0972	0.107	0.908	8.67
Ring	0.0467	0.140	0.148	0.0631	2.35	22.4
Pinky	0.166	0.133	0.213	0.0811	2.63	25.11

Table 1: Results from the slow motion of the fingers

Because of the difficulty in analyzing the motion of fast-moving fingers, the time taken for the slow motion was compared to the time taken for the fast motion and the velocities were recalculated using a multiplier. The results are shown in **Table 2**.

Finger	$\Delta t_{slow\text{-}motion}$ (s)	$\Delta t_{fast\text{-}motion}$ (s)	Multiplier	ω (rad/s)	rpm
Thumb	1.468	0.170	8.64	2.71	23.4
Index	1.001	0.100	10.0	14.8	142
Middle	1.435	0.240	5.98	5.43	51.8
Ring	0.633	0.160	3.96	9.306	88.7
Pinky	0.634	0.170	3.73	9.81	93.7

Table 2: Results from the fast motion of the fingers

To find the multiplying factor, the angular velocity and the revolutions per minute, we used the following formulas:

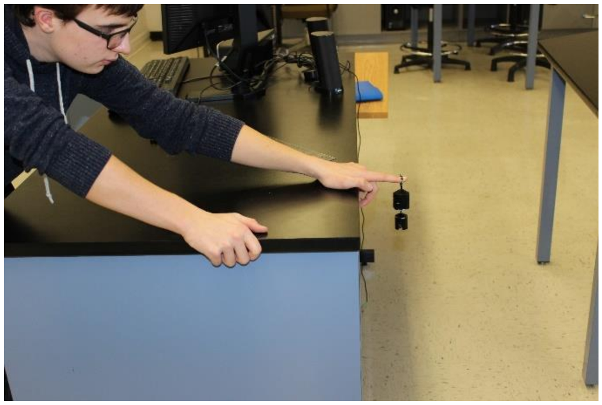
$$multiplier = \frac{\Delta t_{slow-motion}}{\Delta t_{fast-motion}}$$

$$\omega_{fast} = \omega_{slow} \cdot multiplier$$

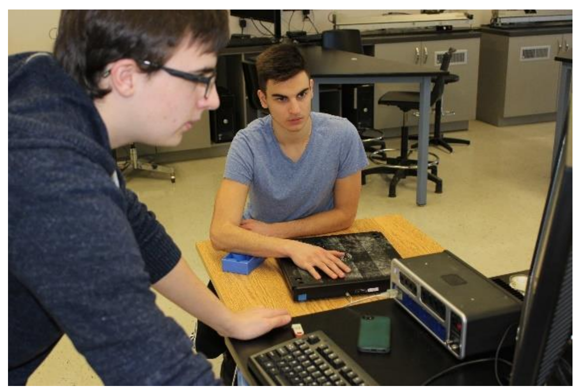
$$rpm_{fast} = rpm_{slow} \cdot multiplier$$

II. Forces (Torque and Power)

To calculate the torque and power that the actuators would have to supply in order to move the fingers, we had to determine the maximum force that a finger could either exert or sustain.


Masses hanging from a finger

Originally, we decided to find these forces by hanging masses from our fingers until we could no longer lift them. We would then calculate the gravitational force from these masses. However, we soon realized that our fingers would quickly get tired from the weight of the masses, which would lead to incorrect results.


Use of a PASCO platform to record force data

To increase the accuracy of our results, we decided to instead use PASCO force platforms connected to a computer and software which would monitor the forces applied to the platform. We pushed each finger down against the force platform and recorded the maximum force we could exert. Then, using the following formulas, we were able to calculate the results shown in **Table 3**:

$$\tau = F \cdot R \cdot \sin\theta, \theta = 90\,deg$$
$$P = \tau \cdot \omega$$

Where **τ** is the torque and **P** is the power that must be generated by the actuator.

Finger	Force (N)	Radius (m)	Torque (N●m)	ω (rad/s)	Power (W)
Thumb	30	0.116	3.48	0.314	1.09
Index	25	0,0963	2.41	1.484	3.58
Middle	22	0.107	2.35	0.908	2.13
Ring	15	0.0631	0.947	2.35	2.23
Pinky	12	0.0811	0.973	2.63	2.56

Table 3: Torques and powers required for the actuators

III. Stress and Strain

"When a [material] is subjected to a load (force), it is distorted or deformed, no matter how strong the [material] or light the load. If the load is small, the distortion will probably disappear when the load is removed. The intensity, or degree, of distortion is known as *strain*." (Engineers Edge)

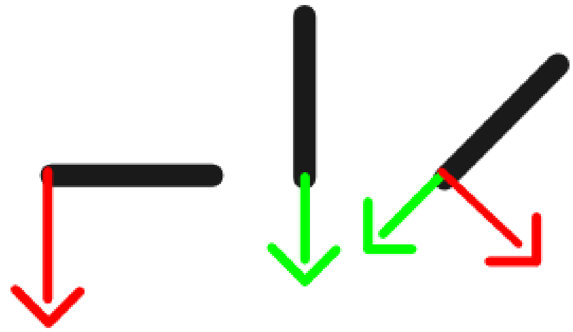
To ensure that the robotic hand can sustain the forces it will potentially be subjected to, we have to make sure the materials it is made of are strong enough. This means that the motors and actuators used must provide enough power and torque, but it also means that the plastic piece involved have to hold together.

The stress involved with the robotic hand's fingers are essentially of two types: compressional and shear. When the finger is horizontal, shear stress is at its maximum. When the finger is vertical, compression stress is greatest. Therefore, the maximum stress occurs when the finger is at a 45 degree angle, where both types of stress are involved (see **Figure 1**). Moreover, the formulas for calculating stress are quite simple:

$$S_{compression} = \frac{F \cdot \cos\theta}{A}$$

$$S_{shear} = \frac{F \cdot \sin\theta}{A}$$

Where **F** is the force applied, **θ** is the angle between the force and the finger and **A** is the cross-sectional area of the finger.



From these simple formulas, we were able to calculate the stress in all fingers at different positions (**Tables 4, 5, 6**).

Figure 1: Stress in the finger: Red is shear and green is compression

Finger	Area (m^2)	Force (N)	Compression stress (N/m^2)	Shear stress (N/m^2)
Thumb	5.31×10^{-4}	30	0	56 497
Index	4.91×10^{-4}	25	0	50 916
Middle	3.46×10^{-4}	22	0	63 583
Ring	3.46×10^{-4}	15	0	43 352
Pinkie	2.84×10^{-4}	12	0	42 253

Table 4: Stress in a horizontal finger

Finger	Area (m^2)	Force (N)	Compression stress (N/m^2)	Shear stress (N/m^2)
Thumb	5.31×10^{-4}	30	56 497	0
Index	4.91×10^{-4}	25	50 916	0
Middle	3.46×10^{-4}	22	63 583	0
Ring	3.46×10^{-4}	15	43 352	0
Pinkie	2.84×10^{-4}	12	42 253	0

Table 5: Stress in a vertical finger

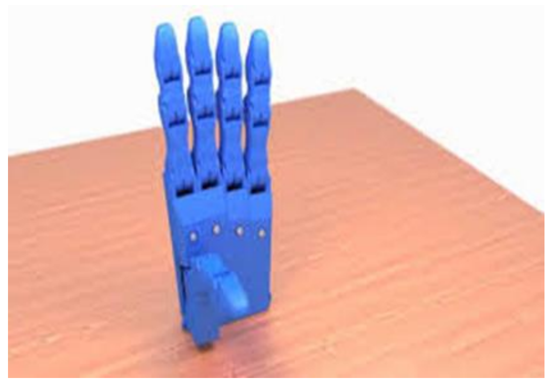
Finger	Area (m^2)	Force (N)	Compression stress (N/m^2)	Shear stress (N/m^2)
Thumb	5.31×10^{-4}	30	39 949	39 949
Index	4.91×10^{-4}	25	36 003	36 003
Middle	3.46×10^{-4}	22	44 960	44 960
Ring	3.46×10^{-4}	15	30 654	30 654
Pinkie	2.84×10^{-4}	12	29 877	29 877

IV. The Design of a Prototype

After 40 days of conceptual design and brainstorms, a solid image of the design started to form.

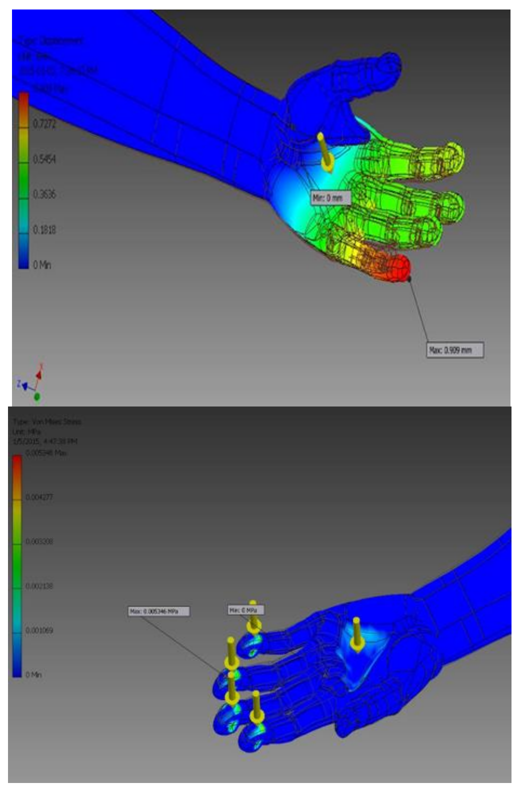
Main components:

1) Body: a 3D printed prosthetic hand seemed to be the most feasible and cheapest design, making use of the advancements made in the field of additive manufacturing will allow us to print a fully functional prosthetic hand frame.



A rendered image of the full hand assembly in Blender

Material: ABS (Acrylonitrile butadiene styrene) plastic with yield strength of 44.8 MPa proved to be the best choice after experiments carried out by the biomechanics group as well as FEA (finite element analysis) simulations.



FEA (Von Mises)

2) Driving mechanism:

Driving mechanism: 4 DC gear motors connected to a spool of steel wires that enables the fingers to bend smoothly. The thumb is driven by a micro servo motor that takes care of thumb's 90 degree rotation.

3) Logical control: Logical Control: Two possible control designs were adopted, one of them was further developed which is the use of Arduino microcontroller due to its simplicity and reliability. The algorithm developed was just for testing, not feasible for a real prototype as it relies on analog commands inputted by a set of push buttons, whereas a more realistic control system will need EMG (electromyographical) signals captured directly from the user's skin. The code for the testing algorithm can be found in the appendix.

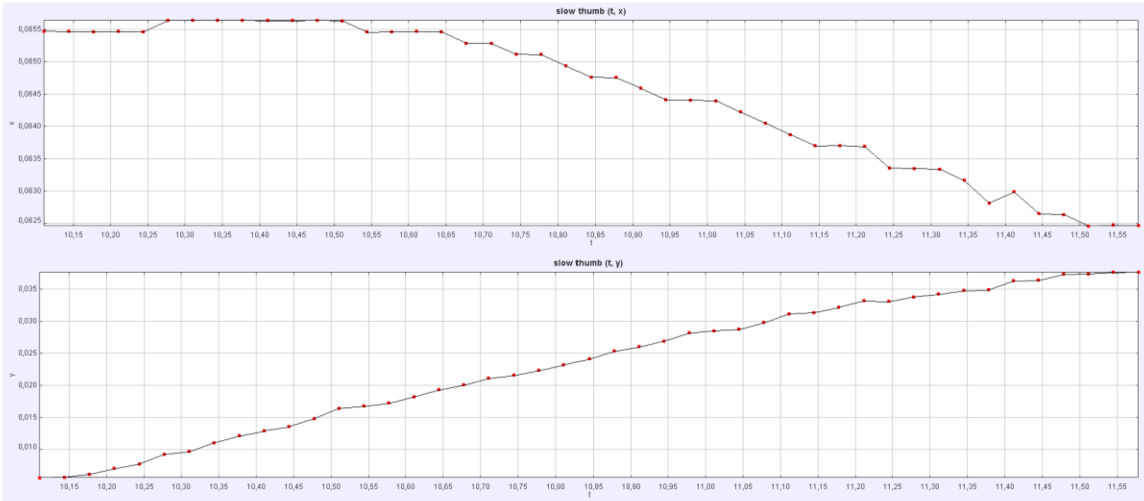
   An optimized control system will make use of the Myo armband to develop a complete user-friendly interface that can manipulate and move the hand using the Myo armband, since this mechanism wasn't developed further due to time constraints, the concept of Myo control will be presented and demoed during the since fair.

The final design parts as well as the BOM (bill of materials) can be found in the appendix.

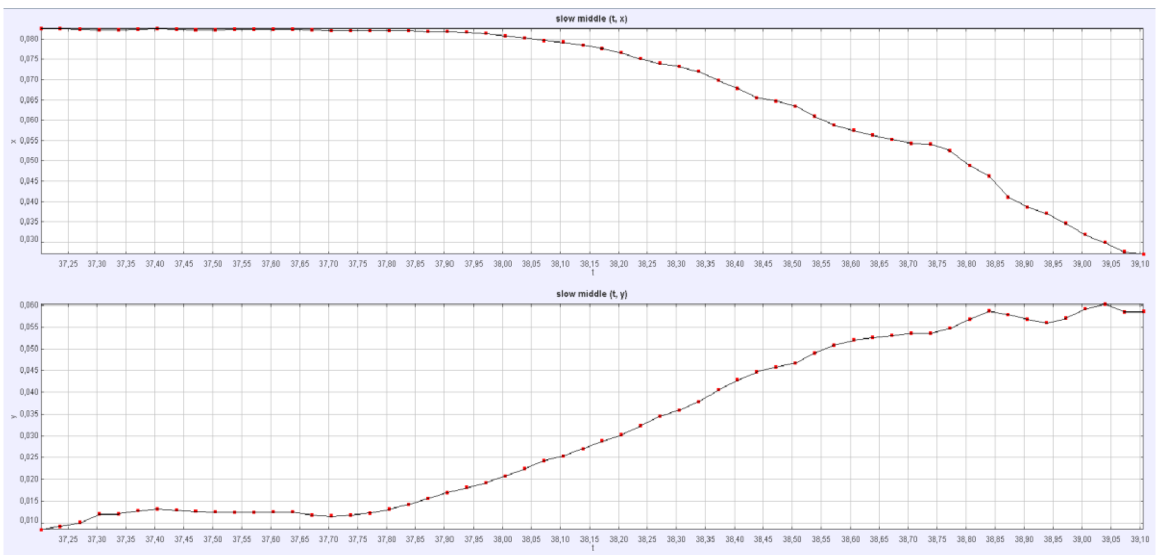
3. Conclusion

In summary, the cooperation between students from the Vanier Student Research Centre's biomechanics project and engineering students from McGill University lead to the research and calculations necessary for determining the physical limitations of the human hand so that a design could be elaborated. Although the prosthetic hand itself is not yet built due to the cost of materials and accessories (we worked on a very tight budget), it remains one of the goals of the project. Moreover, experiments and research will continue to be carried out in order to determine the physical limitations of the human body as a whole.

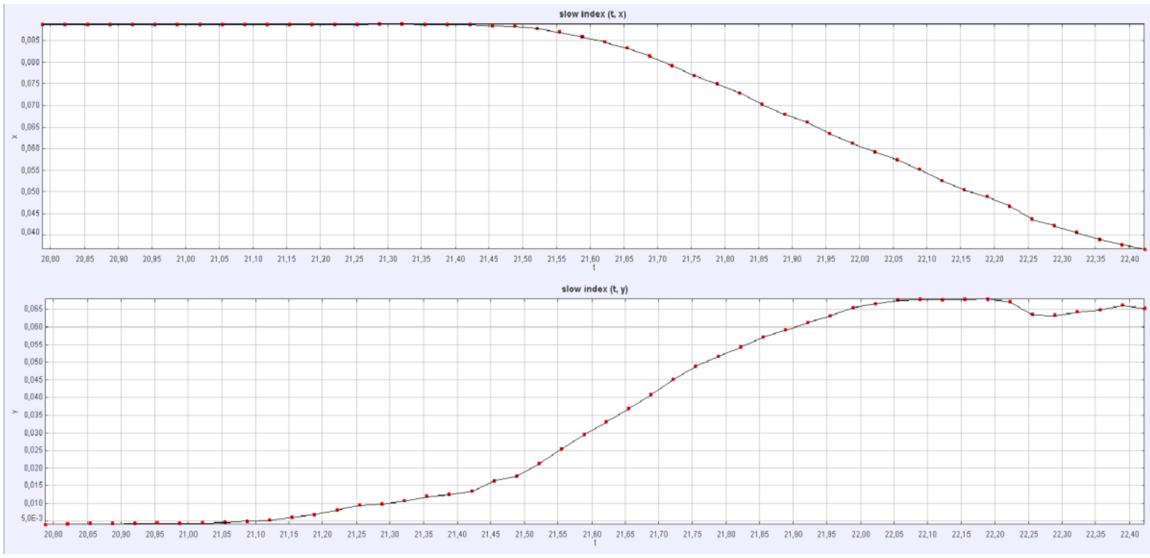
4. Appendix



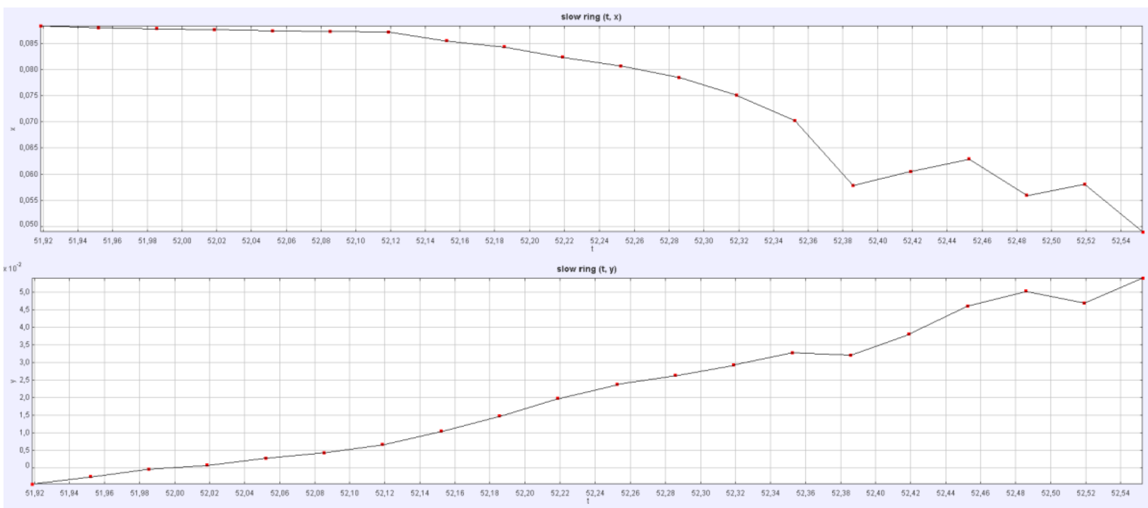
Motion analysis of the thumb in slow motion



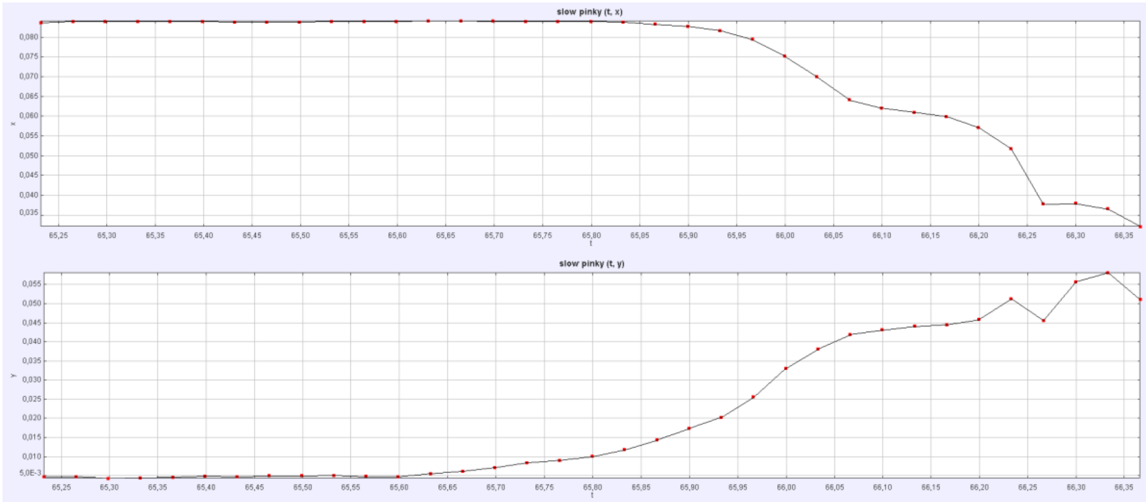
Motion analysis of the index in slow motion



Motion analysis of the middle finger in slow motion



Motion analysis of the ring finger in slow motion



Motion analysis of the pinky in slow motion

Arduino code

```
const int

PWM_A   = 3,      //Speed

DIR_A   = 12,      //Direction

BRAKE_A = 9,      //Brake

SNS_A   = A0,      //Current Sense

PWM_B   = 11,

DIR_B   = 13,

BRAKE_B = 8,

SNS_B   = A1,

PWM_C   = 2,

DIR_C   = 7,

BRAKE_C = 5,

SNS_C   = A2,

PWM_D   = 6,

DIR_D   = 10,

BRAKE_D = 4,

SNS_D   = A3,
```

```
DI0     = 18,      //Digital Inputs      18 and 19 for Seeduino 58 and
59 for Mega
DI1     = 19;
//Variable definition
int state = 1;    //Hand state, 0 = Open 1 = Closed.
boolean STOP_A = 0;
boolean STOP_B = 0;
boolean STOP_C = 0;
boolean STOP_D = 0;
int Threshold = 50;    //0 to 57
int Speed = 255;
void setup(){
  Serial.begin(9600);        //Serial for debugging
  pinMode(DI0, INPUT);
  pinMode(DI1, INPUT);
  pinMode(BRAKE_A, OUTPUT);  // Brake pin on channel A
  pinMode(DIR_A, OUTPUT);    // Direction pin on channel A
  pinMode(BRAKE_B, OUTPUT);
  pinMode(DIR_B, OUTPUT);
  pinMode(BRAKE_C, OUTPUT);
  pinMode(DIR_C, OUTPUT);
  pinMode(BRAKE_D, OUTPUT);
  pinMode(DIR_D, OUTPUT);
}
void loop(){
  Serial.print(digitalRead(DI0));    //DEBUG
  Serial.print("    ");
  Serial.print(STOP_A);
  Serial.println(STOP_B);
  if(digitalRead(DI0) == HIGH){        //If Open button is pressed...
```

```
    if(state == 0){                  //If hand is open, move thumb 
position
    thumbmove();
    }
    else{
    Serial.println("opening");      //DEBUG
    openclose(1);                  //call Open/Close subroutine to Open
    }
  }
  if(digitalRead(DI1) == HIGH){        //If close button is pressed, 
close
    Serial.println("closing");    //DEBUG
    openclose(0);                  //call Open/Close subroutine to 
Close
   }
}
void openclose(boolean function){
   digitalWrite(BRAKE_A, LOW);    //Disable brakes
   digitalWrite(BRAKE_B, LOW);
   digitalWrite(BRAKE_C, LOW);
   digitalWrite(BRAKE_D, LOW);
   delay(100);
   digitalWrite(DIR_A, function);  //Set direction
   digitalWrite(DIR_B, function);
   digitalWrite(DIR_C, function);
   digitalWrite(DIR_D, function);
   analogWrite(PWM_A, Speed);     // Set the speed of the motors, 255 
is the maximum value
   analogWrite(PWM_B, Speed);
   analogWrite(PWM_C, Speed);
   analogWrite(PWM_D, Speed);
```

```
   delay(20);                    //Delay for current spike
   while(STOP_A == 0 || STOP_B == 0 || STOP_C == 0 || STOP_D == 0){
//Continue until all motors have stopped
     if(analogRead(SNS_A)>=Threshold){
       digitalWrite(PWM_A, 0);
       digitalWrite(BRAKE_A, HIGH);
       STOP_A = 1;
       Serial.println("stopped");    //DEBUG
     }
     if(analogRead(SNS_B)>=Threshold){
       digitalWrite(PWM_B, 0);
       digitalWrite(BRAKE_B, HIGH);
       STOP_B = 1;
     }
     if(analogRead(SNS_C)>=Threshold){
       digitalWrite(PWM_C, 0);
       digitalWrite(BRAKE_C, HIGH);
       STOP_C = 1;
     }
     if(analogRead(SNS_D)>=Threshold){
       digitalWrite(PWM_D, 0);
       digitalWrite(BRAKE_D, HIGH);
       STOP_D = 1;
     }
   }
   STOP_A = 0;              //Reset stop values
   STOP_B = 0;
   STOP_C = 0;
   STOP_D = 0;
}
```

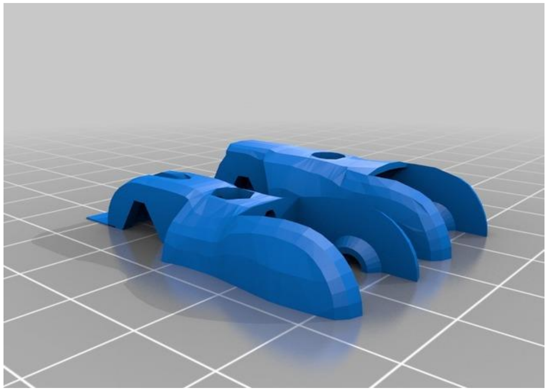
```
void thumbmove(){

}
```

Bill of materials

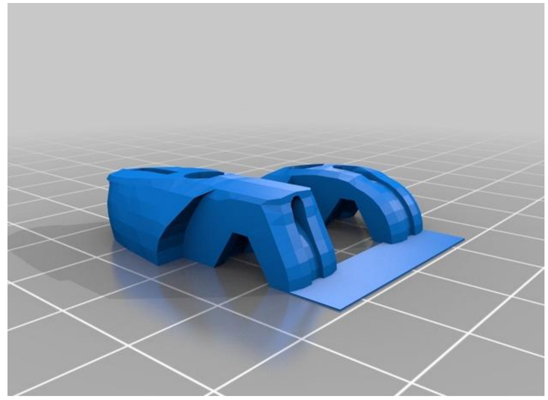
Component	Specifications	Qty
Ball bearing	10mm Outer Diameter, 3mm Inner Diameter, 4mm Width	14
Flat Head M2 bolt	M2, 6mm Length	14
Gearbox Motor Combo	16mm Diameter, 3mm shaft diameter, 50mm total length, 120rpm Nominal Output Speed,	5
9g Micro Servo	Standard 9g Mirco servo. Slow movement and high torque is best but any should work.	1
Cross Head M2 bolt	M2, 6mm Length	20
M2 grub screw	M2, 3mm length	6
M2 nut	M2	30
Grooved Ball bearing	12mm Outside diameter, 9.5mm groove diameter, 3mm Inner diameter, 4mm width	10
Spring	20mm length, 2N/mm Rate, 4.5mm Outside diameter	10
Steel cable	0.7mm diameter, nylon coated	5
M3 bolt	45mm length	4
M3 nut	M3	4
ABS plastic	Can use PLA or ABS, PLA works best for the body of the hand and ABS for the fingers.	0.25
12mm Steel Dowel Pin	3mm Diameter, 12mm length, Parallel	9
14mm Steel Dowel Pin	3mm Diameter, 14mm length, Parallel	10
6mm Steel Dowel Pin	3mm Diameter, 6mm length, Parallel	10
Copper Double Ferrules	0.8mm Double Ferrules for 0.72mm cables	10
Nylon Collar	M3, 3.1mm Inside Diameter, 4.0mm + 6.2mm Outside Diameter, 3mm+1mm length	1

Rendered images of the final design

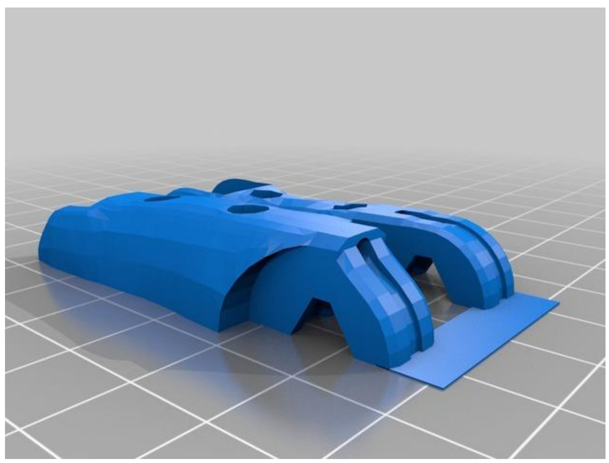
Finger sections



A finger's middle section

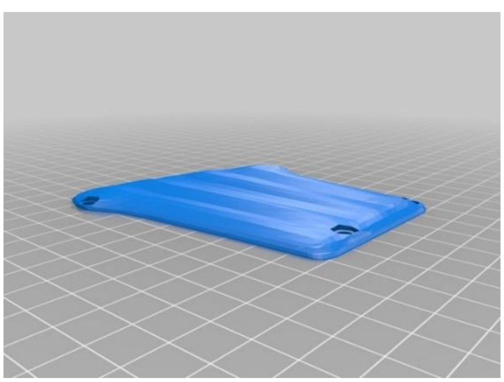


A fingertip

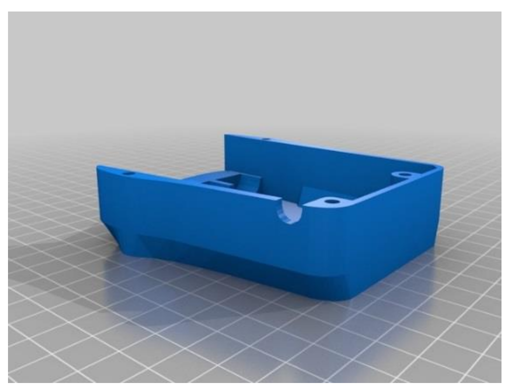


A finger's lower section

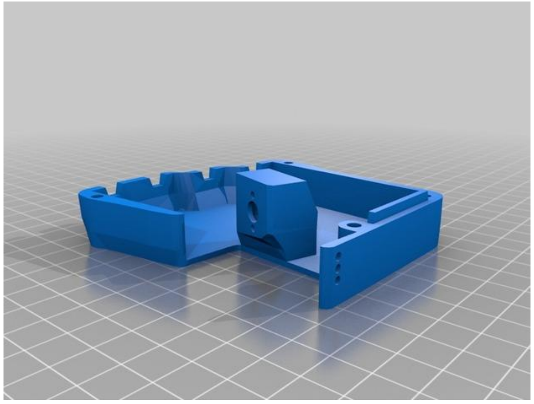
Hand cover



The cover of a palm

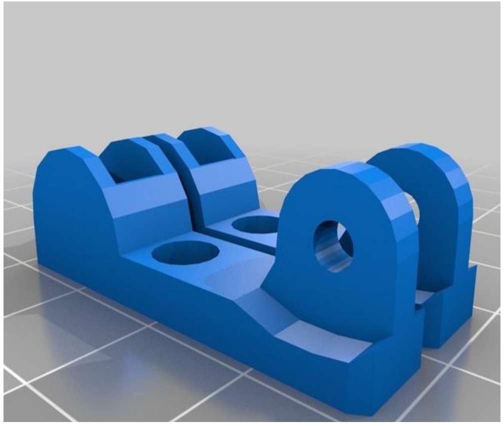


The cavity of a palm

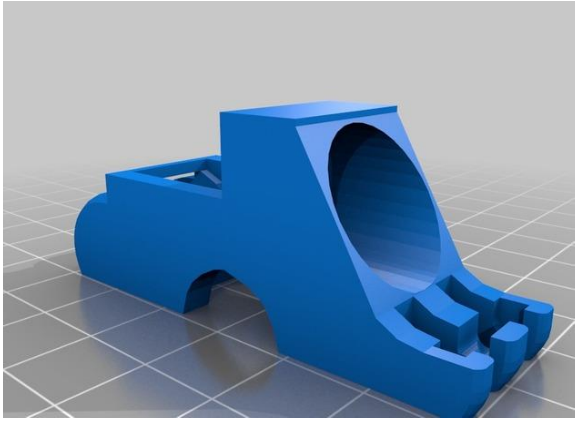


Trimetric view of the palm cavity

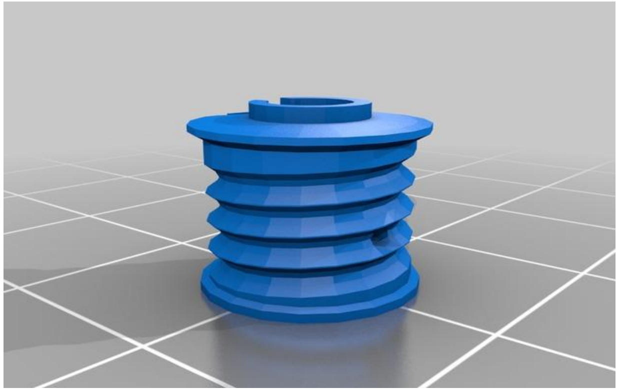
Drive system



A motor-finger connection

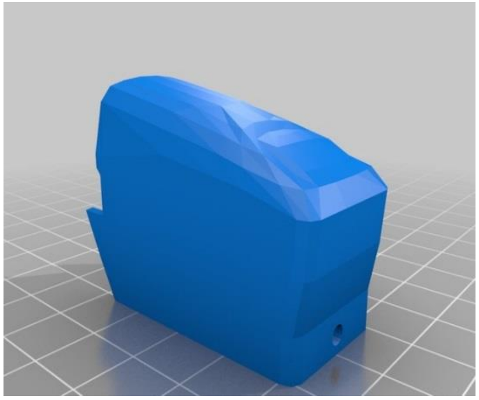


A motor housing

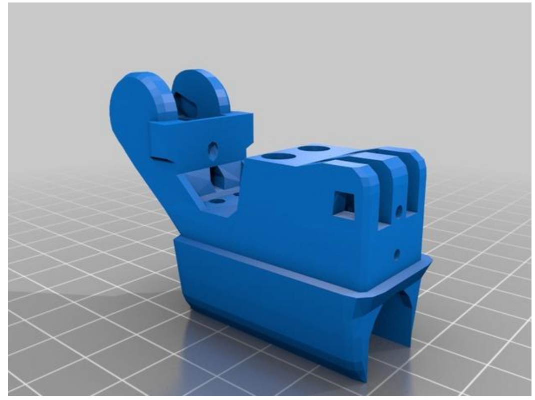


Spool

<u>Thumb</u>

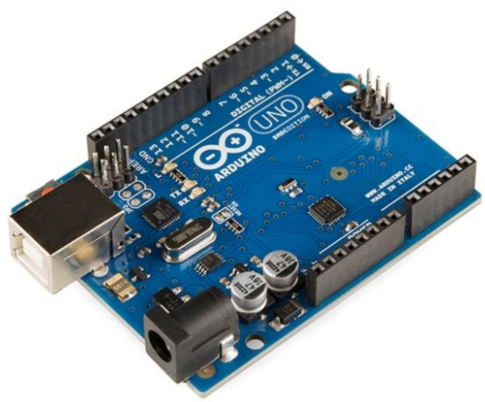


Thumb (servo) cover



Servo housing

Microcontroller interface



Arduino microcontroller. Source : [http://upload.wikimedia.org/wikipedia/commons/3/38/Arduino_Uno_-_R3.jpg]

Myo armband. Source : [http://cdn1.tnwcdn.com/wp-content/blogs.dir/1/files/2013/07/black_myo_top.jpg]

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