NAU
NORTHERN ARIZONA UNIVERSITY

College of Engineering, Informatics, and Applied Sciences

Biomechanical Model of a Finger Fabricated Using Torsional Artificial Muscles

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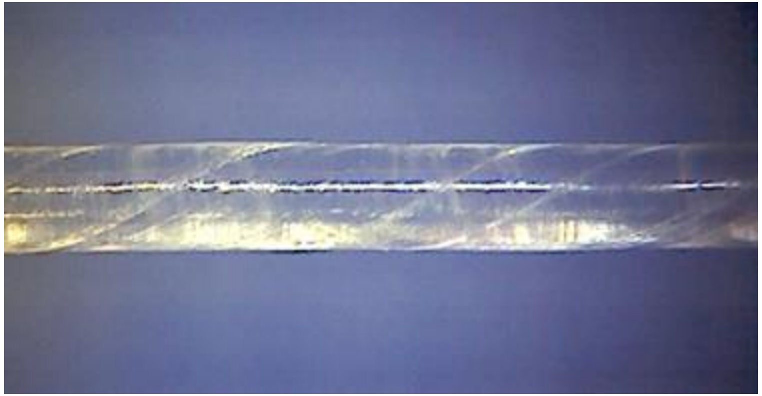
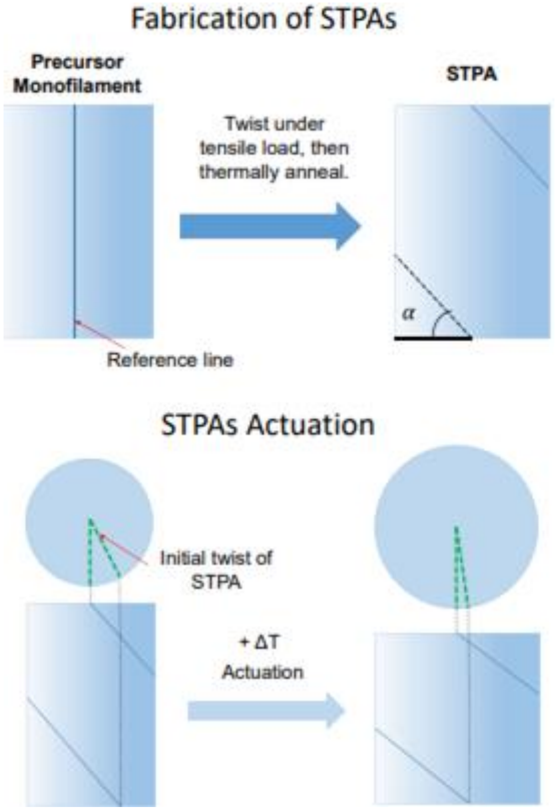
STPA vs TPA



STPA

- Straight twisted polymer actuators (STPAs)
  - Twisted Polymer monofilament
    - Nylon fishing line
  - Thin, light, cheap!

- The mechanism of untwisting actuation
  - Linear actuator
  - Untwisting due to an asymmetric thermal expansion
  - Radial expansion & axial contraction

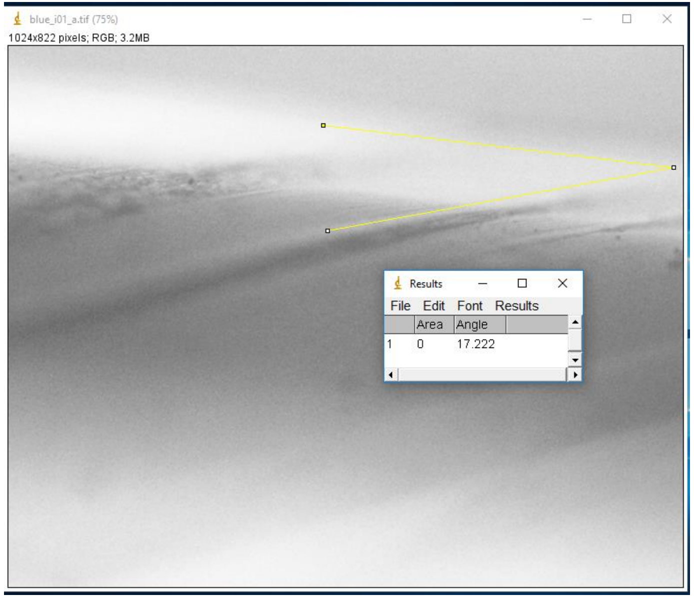


Reference	Type of Torsional Actuator	Activation Mechanism	Specific gravity	Free torsion (º/mm)	Torque normalized by cross sectional. $(\mathrm{N/mm})$	Magnitude of activation.
Jardine et al. 1996	SMA	Temperature	6.5	0.18	(100 – 200)	~ (0 – 100)ºC
Baghani et al. 2014	SMP Shape Memory Polymers	Temperature	1.12	~1.8	~ 1	~ (0 – 62)ºC
Fang et al. 2011	EAPs Ion-based actuation	Electricity	1.12	0.01	Unknown	~ (100 – 200) V/µm
Sanan et al. 2013	PAMs (Antagonistic Torsion Shape Actuators)	Pneumatic (Pressure)	0.315	0.287	~ (0 –1.43)	~ (50 – 90) kPa
Sanan et al. 2013	PAMs (Peano Actuators)	Pneumatic (Pressure)	0.315	0.315	~ (0 – 0.7)	~ (50 – 90) kPa
Foroughi et al. 2011 Suh et. al, 2016. Chun et. Al. 2013	CNT	Temperature	1.6	~ (15 – 80)	~ (0.5 – 1.8)	~ (0 – 90)ºC
Shafer et al. 2016 Shafer et al. 2017	STPA	Temperature	1.12	~12.7	~ (0 – 119)	~ (0 – 90)ºC

Fabrication

Annealing at 120°C for
20 minutes and cooled down
to room temperature

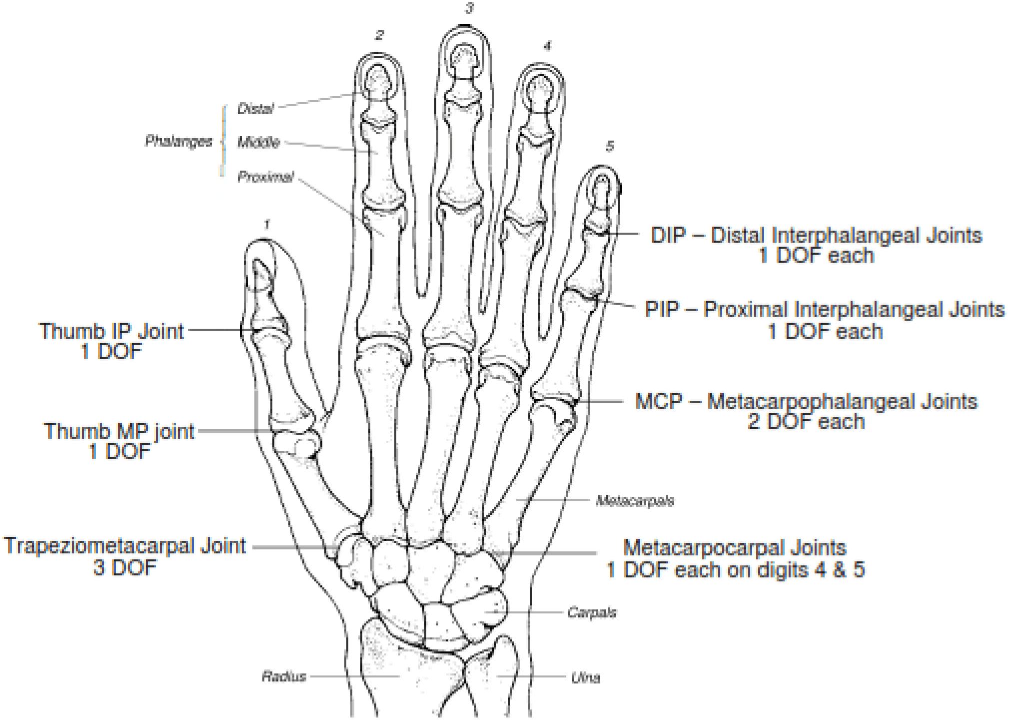
Microscope Images



INTRODUCTION

- Human Hand
  - A very sophisticated means for physical and social interaction
  - 23 DoFs for the hand and 6 for the Wrist

- Hand loss
  - Around 541,000 Americans (Ziegler-Graham et al., 2008)
  - A devastating damage
  - Limiting the capability of performing ADLs



INTRODUCTION

- Hand prosthesis
  - Passive prostheses
    - Cosmetic or functional prostheses
  - Active prostheses
    - Externally powered

- Engineering Challenges in the development of prosthetic devices
  - Size and weight of the replaced hand (Cordella et al., 2016)
  - Control of prosthesis that notably affects functionality (Gonzales & Castellini, 2013; Wininger et al., 2008)

i-Limb

Michelangelo

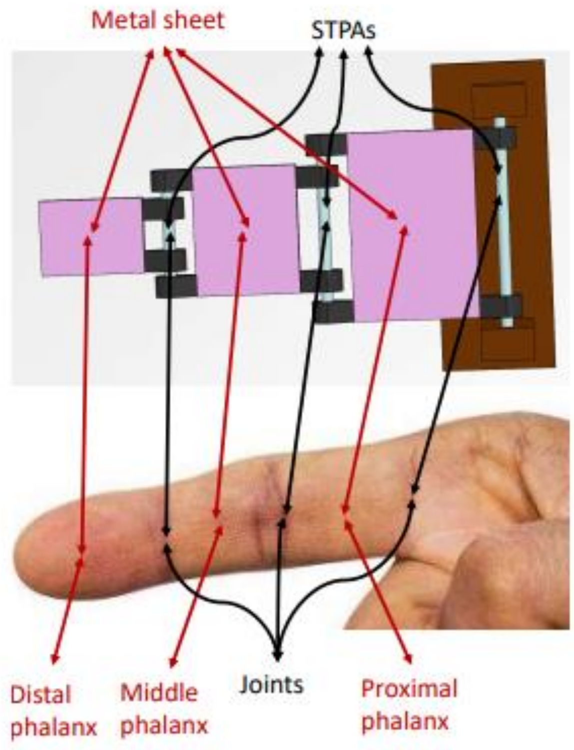
INTRODUCTION

Our Question

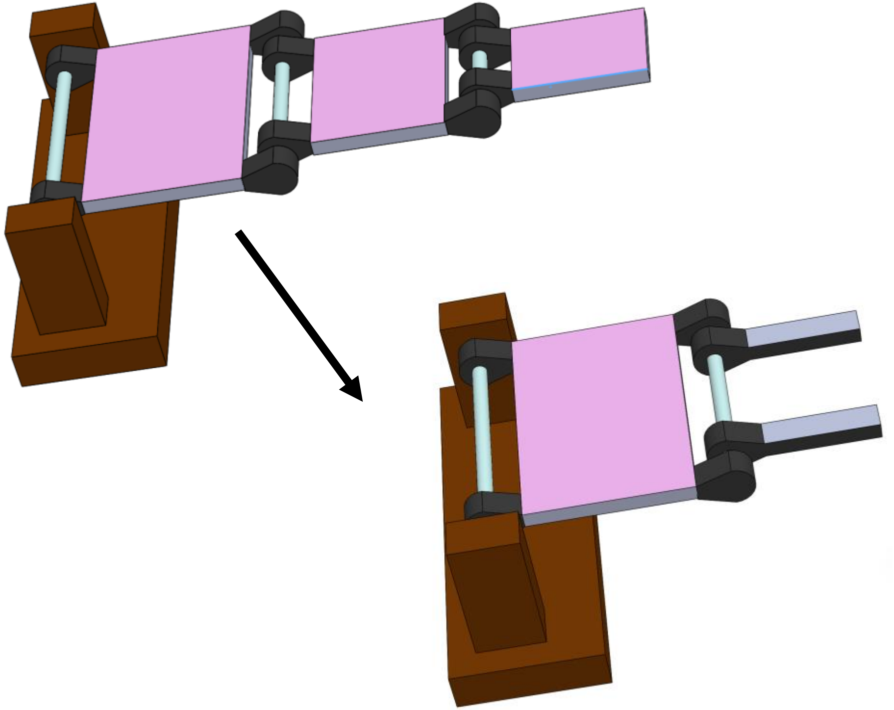
“Can a finger model made of STPAs be a candidate to substitute a human finger?”

- Light weight and cheap!!!

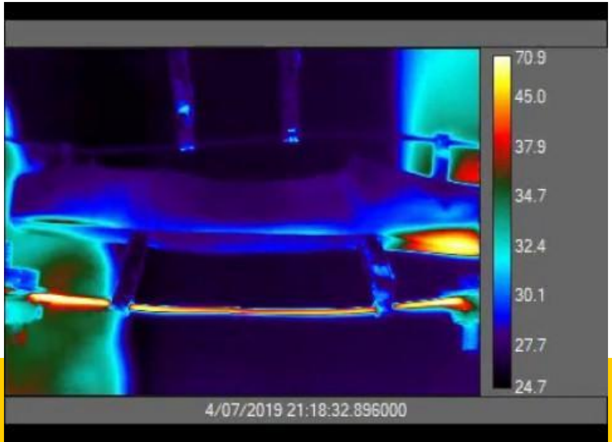
- In this study, as the first step
  - The relationship between the temperature and the joint angle
  - The relationship between the temperature and the joint torque

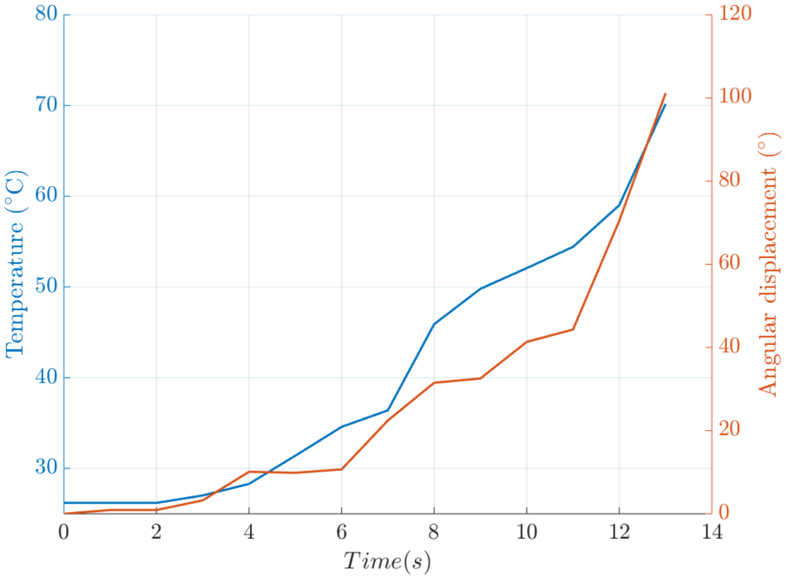


SolidWorks Model. Problem Statement



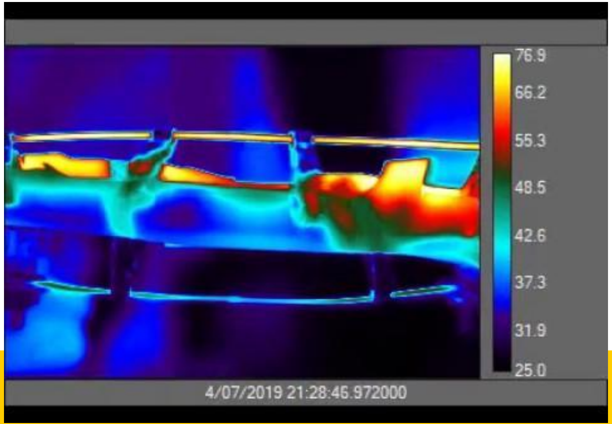
Experimental Results. Lower Torsional Actuator Joint

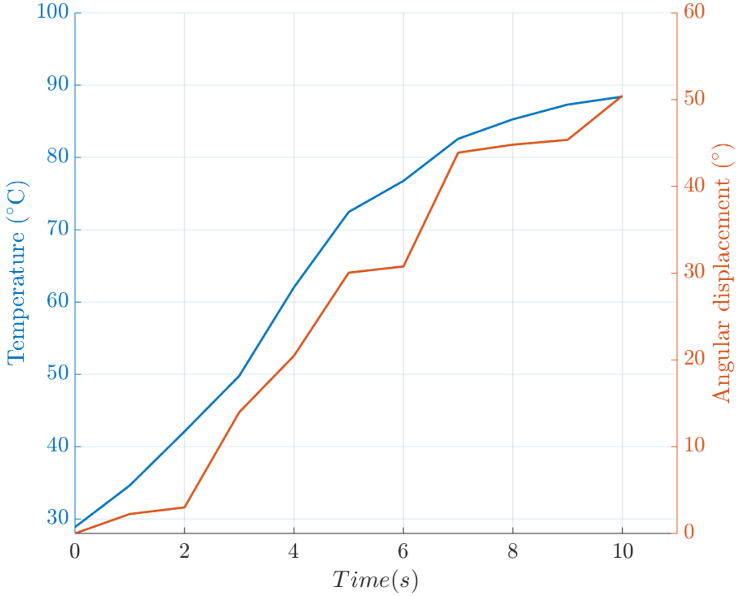




Angular displacement and temperature vs. time of the Lower Torsional Actuator Joint.

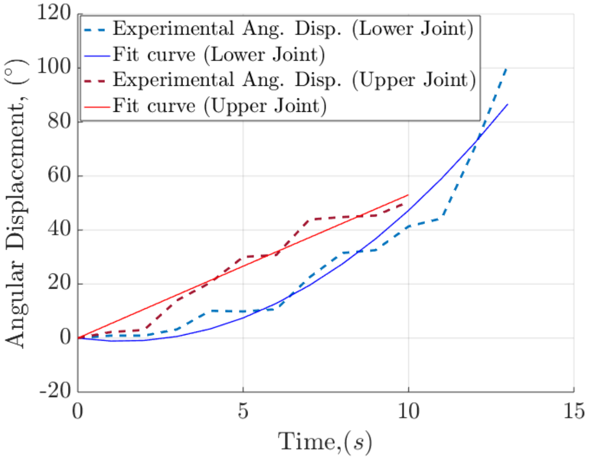
Experimental Results. Upper Torsional Actuator Joint





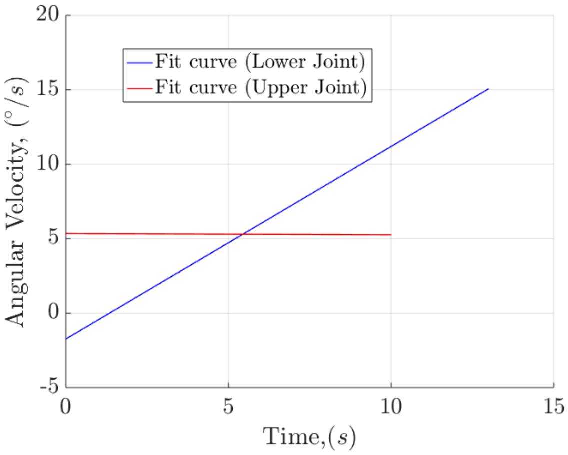
Angular displacement and temperature vs. time of the Upper Torsional Actuator Joint.

Angular Displacement, Velocity, and Acceleration for the Lower and Upper Joint



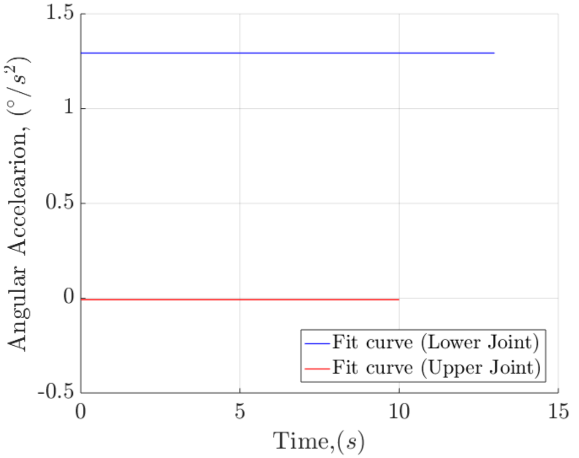
Angular displacement vs. time of the upper and lower Torsional actuator joint along with curves fit.

$$\Delta\theta_{LJ} = 0.6467t^2 - 1.7408t$$
$$\Delta\theta_{UJ} = -0.004t^2 + 5.3438t$$



Angular velocity vs. time of the upper and lower torsional actuator joint.

$$\omega_{LJ} = 1.2934t - 1.7408$$
$$\omega_{UJ} = -0.004t + 5.3438$$



Angular acceleration vs. time of the upper and lower torsional actuator joint.

$$\alpha_{LJ} = 1.2934$$
$$\alpha_{UJ} = -0.004$$

Dynamic Analysis

$$\sum M_0 = I\,\alpha$$

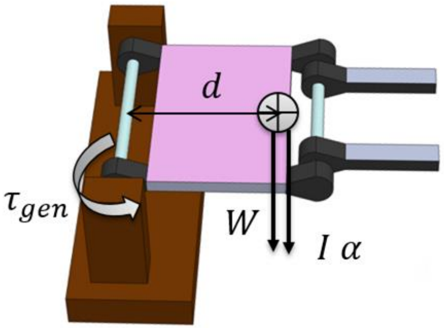
$$\tau_{gen} + \tau_{grav} = I\,\alpha$$

$$\tau_{gen} = I\,\alpha - \tau_{grav} = I\,\alpha - Wd$$

Matlab code

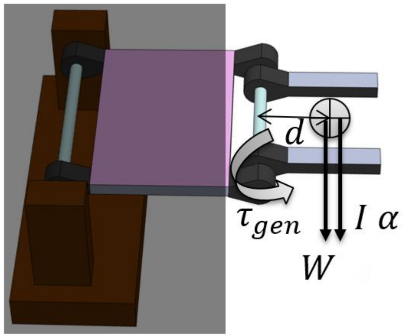
```
%Analytical model for the Lower Joint

deltathetamodelUJ = -0.004*(timeUJ.^2)+5.3438*(timeUJ)
omegaUJ = -0.008*(timeUJ)+5.3438;
alphaUJ = -0.008;
alphaUJ(1:length(timeUJ),1) = alphaUJ

Tau_genUJ = -0.0008*9.81*0.006*abs(cosd(comangleUJ))

PowerUJ = omegaUJ.*Tau_genUJ
```

Lower Torsional Actuator



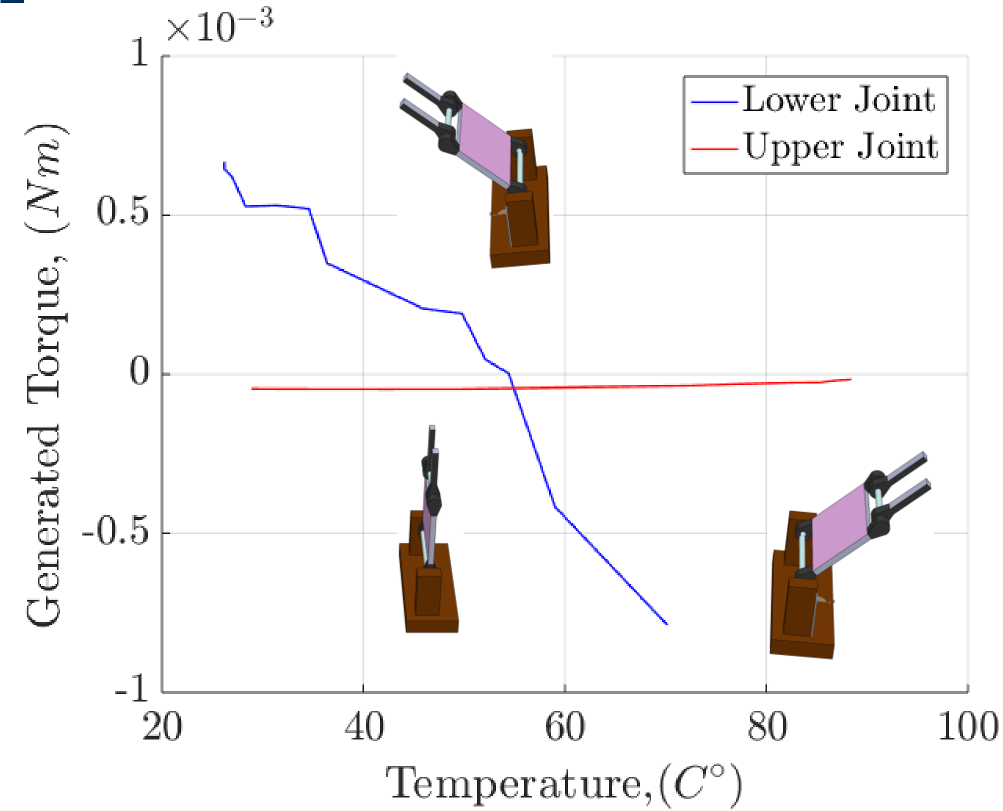
Lower Joint	
Input	Value
I	$6 \times 10^{-8}\ kgm^2$
m	$5\ grams$
α	$1.29\ °/s^2$
d	$22\ mm$

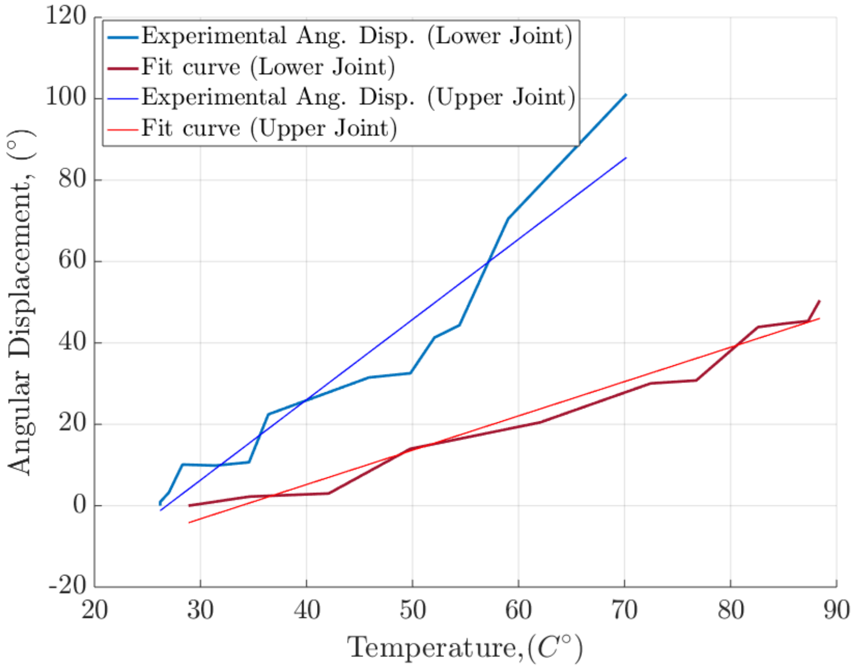
Upper Torsional Actuator



Upper Joint	
Input	Value
I	$1.72 \times 10^{-8}\ kgm^2$
m	$0.8\ grams$
α	$-0.004\ °/s^2$
d	$6\ mm$

Torque and displacement as a function of temperature





$$\Delta\theta_{LJ} = 1.9735T - 52.92$$

$$\Delta\theta_{UJ} = 0.8431T - 28.526$$

Conclusions

- STPA is a suitable candidate material for artificial fingers

- Specific Torque generated by STPA is 19.3 kNm/m3 which is in the same order of magnitude as that of a real human finger under blocked torque conditions (95.5 kNm/m3) [5]

- Further research is needed to (among other things) increase the total torque generated.

References

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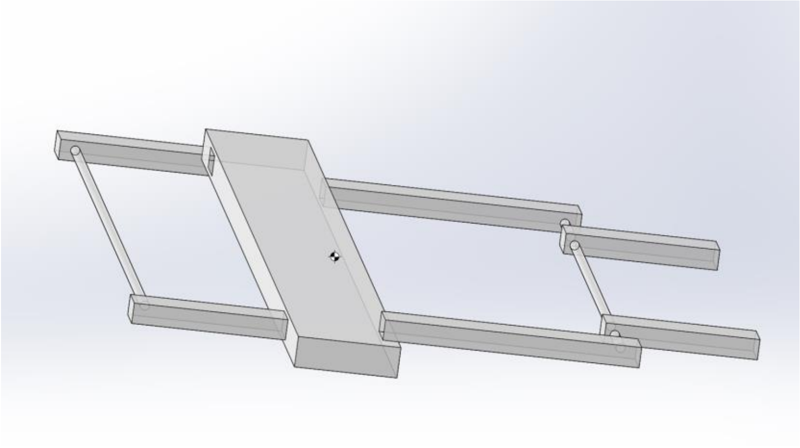
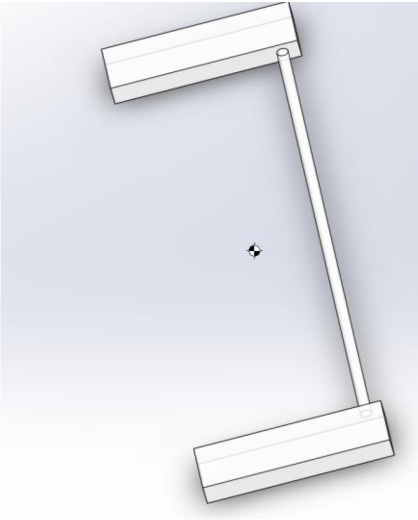
DEMO

Questions?

Back-up slides





Flexor Digitorum Superficialis:

- **Origin:** medial epicondyle of humerus, and proximal ulna & radius
- **Insertion:** middle phalanges of 2 – 5 digits
- **Action:** flexes digits 2-5 and flexes hand

Extensor Digitorum

- **Origin:** lateral epicondyle of humerus
- **Insertion:** middle & distal phalanges of 2–5 digits
- **Action:** extends digits 2-5 and flexes hand