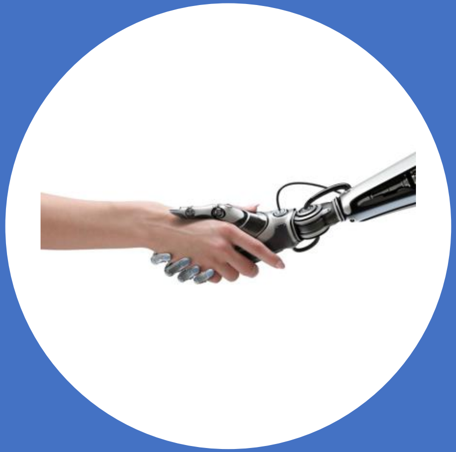


Smart Hand

By: Adrian, Abdeali, and Luc

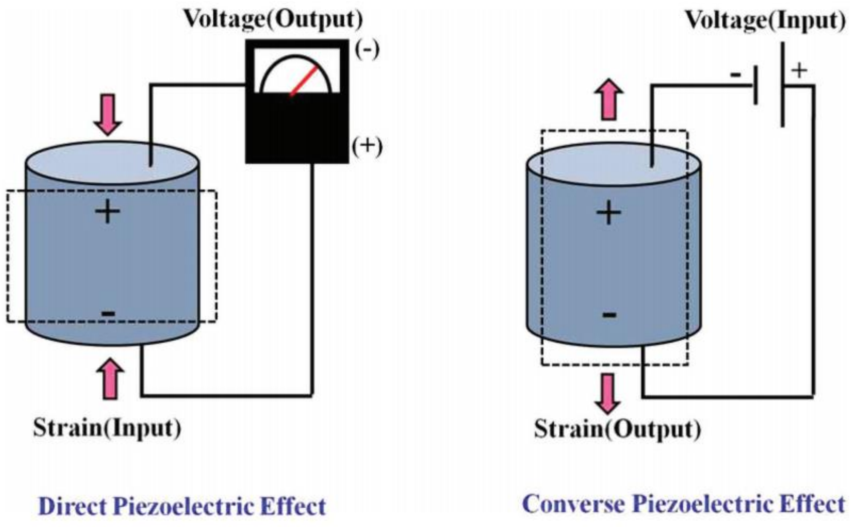
Group 1

Presentation Overview

- Introduction
- Importance of Work
- Overall Project Goal
- Literature Review:
    - Existing Commercial Solutions
    - Research into Piezoelectric Actuated Prosthetics
- Project Objectives
- Expected Analysis
- Expected Challenges
- Timeline
- Q&A

Introduction

- The Piezoelectric effect is the ability of certain materials to displace charge under mechanical stress and generate a voltage.
- The coupling between mechanical and electric field also allows for the inverse effect. An external electric field will stretch or contract the material.



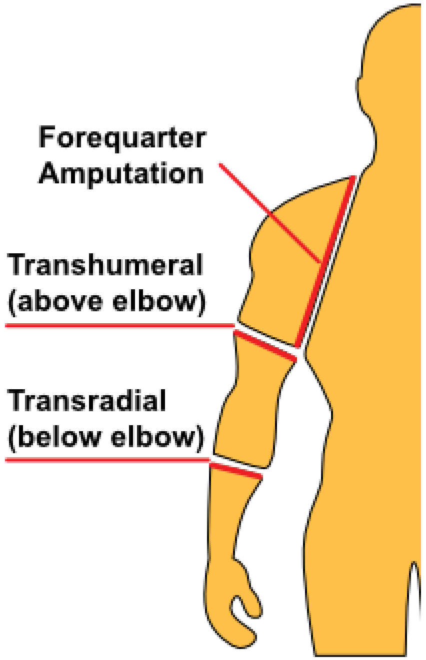
(Mishra et al.)

Introduction Cont.

- The converse Piezoelectric effect has been used to create a variety of different actuators.
- Their unique advantages over electromagnetic actuation include*:
  - Backlash-free motion
  - High force per unit area
  - Displacement accuracy
  - Response speed
- This makes them an interesting choice to be used in robotic prosthetic limbs.

*Yoichi. (2006)

Importance of Work



- The importance of robotic prosthetic devices is quite evident: 1.7 million patients with limb loss in the US.
- Upper limb loss is less common than lower extremity amputation: 41,000 patients.
- Transradial and transhumeral amputees lose complete hand function and are unable to perform activates of daily living.
- Highly dependent on prosthetics but majority only use them for cosmetic purposes.
- Functional use is often difficult due to their bulky nature: rejection rate of 34%.

(Braza, and Martin)

Importance of Work

- Living with a disability can reduce someone’s level of independence and affect their quality of life.
- Increased burden on caregivers and a reduction in their emotional and physical health.
- Far-reaching consequences warrants development of robotic limbs with life-like movement.

Overall Project Goal

- To design a simplified hypothetical prosthetic hand to leverage the unique properties of piezoelectric actuators

Existing Commercial Solutions

- Myoelectric prosthetics utilize electrical signals from intact muscles to control the actuators found in the prosthetic limb
- The limitations in their size and weight result in a need for performance trade-offs such as range of motion, gripping force, and number of actuators

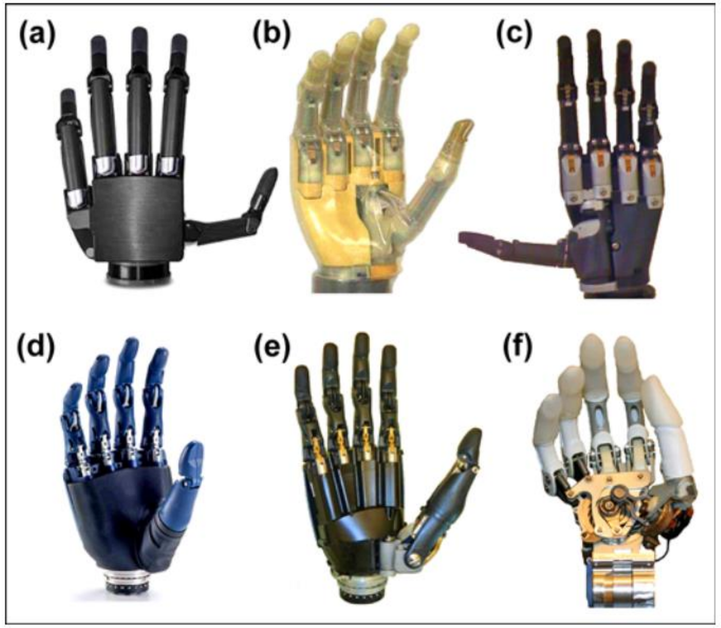


Figure 1.
(a) Vincent hand by Vincent Systems, **(b)** iLimb hand by Touch Bionics, **(c)** iLimb Pulse by Touch Bionics, **(d)** Bebionic hand by RSL Steeper, **(e)** Bebionic hand v2 by RSL Steeper, and **(f)** Michelangelo hand by Otto Bock. All hands shown without cosmetic glove.

(Belter et al., 2013)

Myoelectric Prosthetic Hand Design Guidelines

- Total weight of the prosthesis < 500 g
- Simple and robust finger kinematic designs are preferred over anatomically correct finger designs
- Maximum pinch force at the finger tip of 65 N
- Minimum grasp speed of 115 °/s
- Design should incorporate compliance in flexion (closing) direction to prevent damage from accidental impact/contact

(Belter et al., 2013)

Existing Commercial Solutions

Finger Actuation

- Often use motors with mechanical reduction via gearing to achieve rotation of finger joints
- Incorporate non-backdriveable mechanisms to allow for fingers to apply high grip force without constant current draw from battery

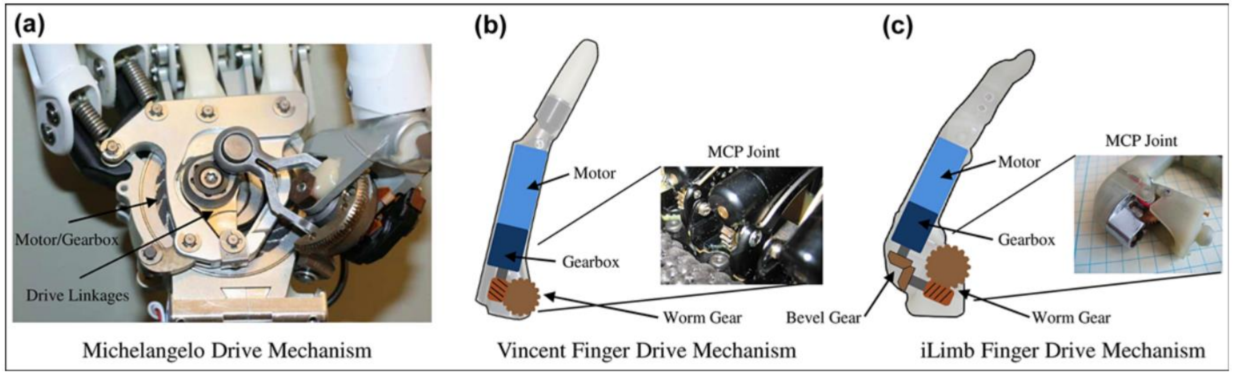


Figure 4.
(a) Drive mechanism of Michelangelo hand (Otto Bock). Center drive element controls flexion of all four fingers and thumb. Second motor (which actuates against bronze worm gear) independently controls abduction/adduction of thumb. **(b)** Vincent finger motor (Vincent Systems) is housed in proximal phalange and rotates worm against fixed worm gear to flex finger. **(c)** iLimb finger (Touch Bionics) is actuated in same manner as Vincent finger but uses set of bevel gears between motor and worm drive. MCP = metacarpal phalange.

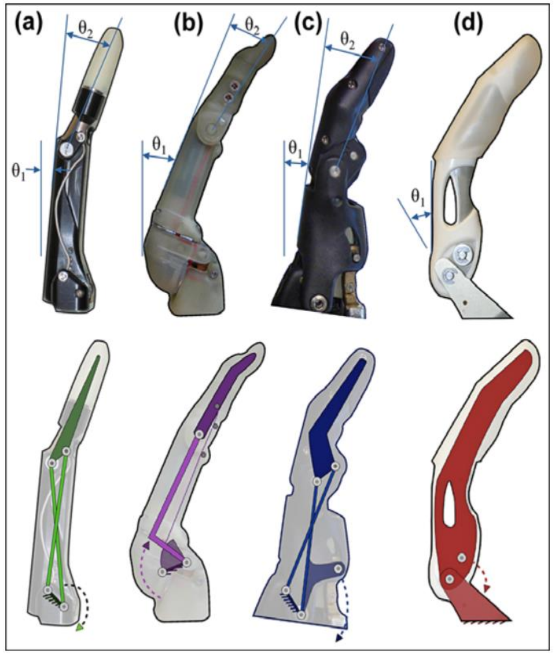


Figure 2.
Commercial finger images (top) and kinematic models of finger joint coupling mechanism (bottom). **(a)** Vincent (Vincent Systems), **(b)** iLimb and iLimb Pulse (Touch Bionics), **(c)** Bebionic v2 and Bebionic (RSL Steeper), and **(d)** Michelangelo (Otto Bock). θ_1 = angle of metacarpal phalange joint, θ_2 = angle of proximal interphalange joint.

(Belter et al., 2013)

Existing Commercial Solutions

Finger Actuation Limitations

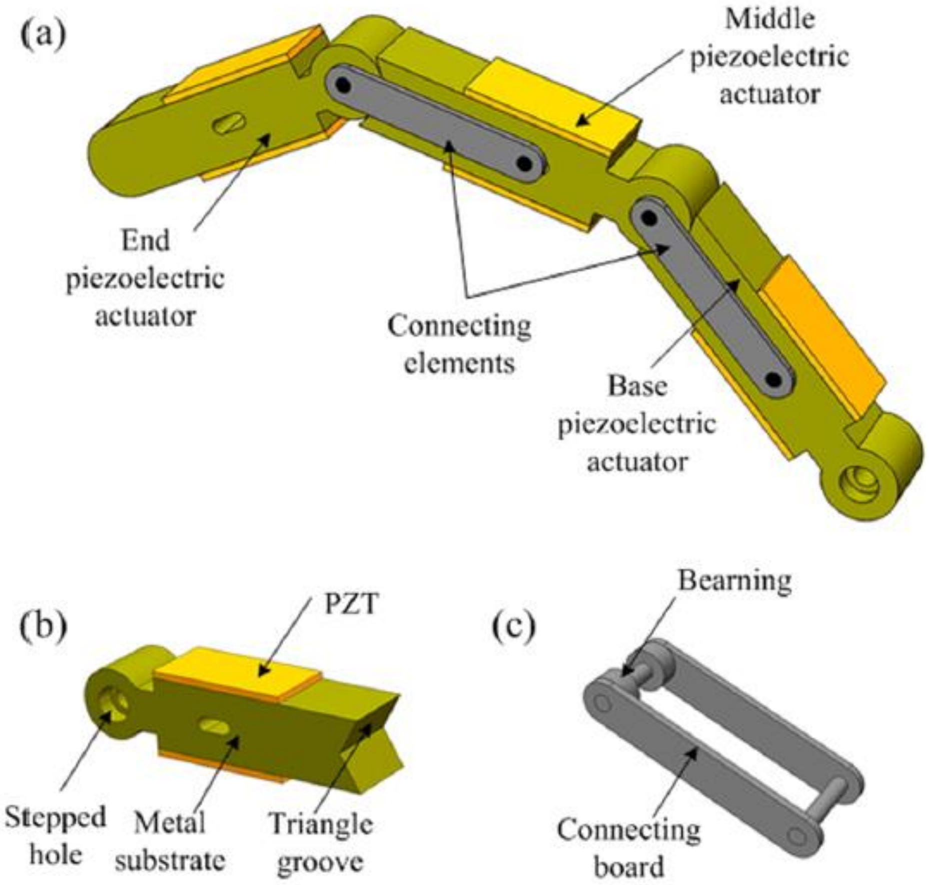
- When using traditional DC motors, the need for gearing and non-backdriveable mechanisms results in added weight and size
- This results in it being difficult to add additional DOFs (Degrees of Freedom) without greatly complicating the system
- Such systems must be designed with built-in compliance to prevent damage in the case of overloading or impact
- These systems may also be noisy to operate and the trade-offs between speed and torque may result in movement speeds that feel ”too slow” for users

(Belter et al., 2013)

Existing Piezoelectric Research

Finger Actuation

- Three piezoelectric actuators are articulating two sets of connecting elements.
- Single bronze piece sandwiched between two pieces of piezoelectric ceramic (PZT-8)
- Piezoelectric elements do not span the joint.
- First order longitudinal vibration modes of the actuators produce the relative rotation.
- Bidirectional motion is achieved by changing the temporal phase difference of excitation signals.

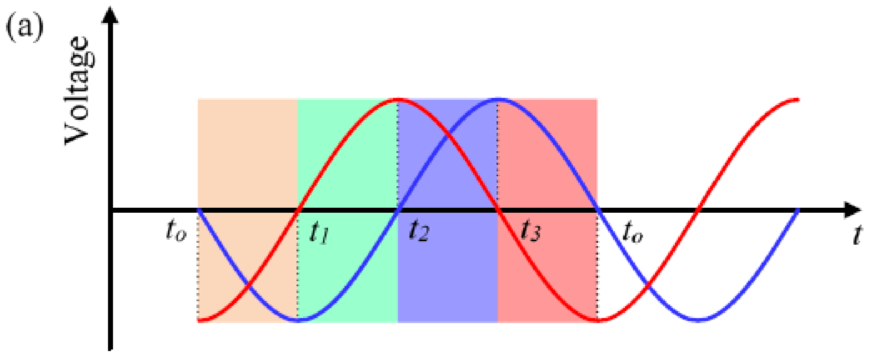


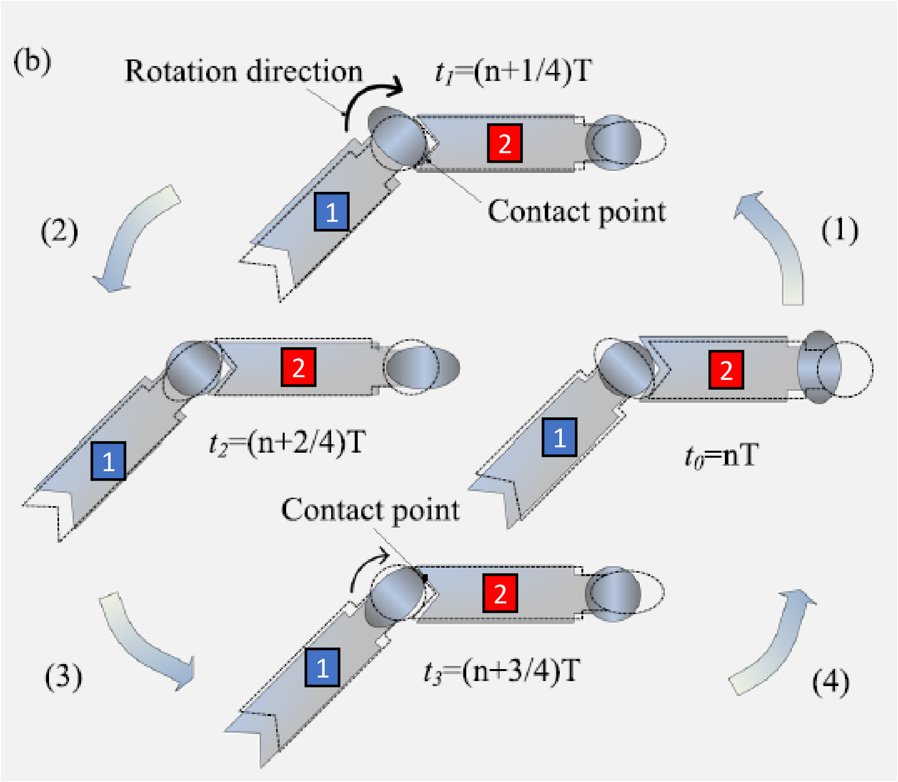
(Chen et al., 2018)

Existing Piezoelectric Research

Finger Actuation

- t(0) → actuator 1 is at equilibrium; actuator 2 is contracted.
- t(1) → actuator 1 contracts and 2 relaxes.
- Friction force at the contact point that drives rotation.
- Currently the temporal difference is $\frac{\pi}{2}$
- For counter clock-wise rotation, temporal difference should be $-\frac{\pi}{2}$





(Chen et al., 2018)

Existing Piezoelectric Research

Finger Actuation Performance

- Driven at 400 peak-to-peak voltage – 40 kHz

Size (mm)	111x10x10
Speed (rad/s)	6.6
Fingertip Force (N)	0.27
Response Time (ms)	26

(Chen et al., 2018)

Existing Piezoelectric Research

Design and Control of a Robotic Thumb Using Piezoelectric Actuators

- Designed by an undergraduate MIT student, this project undertook the development a single DOF thumb using a hybrid DC motor/PZT actuator system

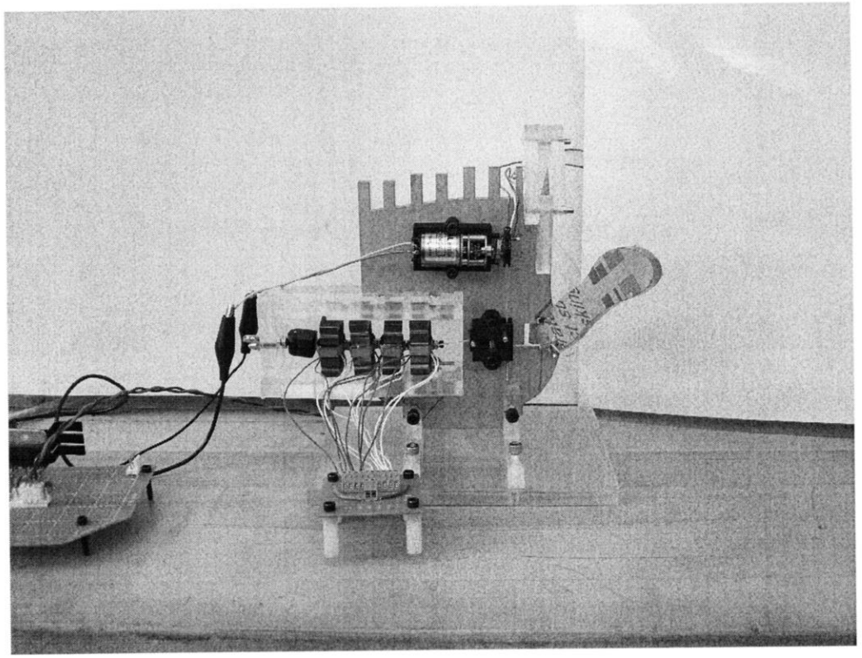


Figure 11. Front view of fully assembled hybrid DC motor/PZT actuator prototype.

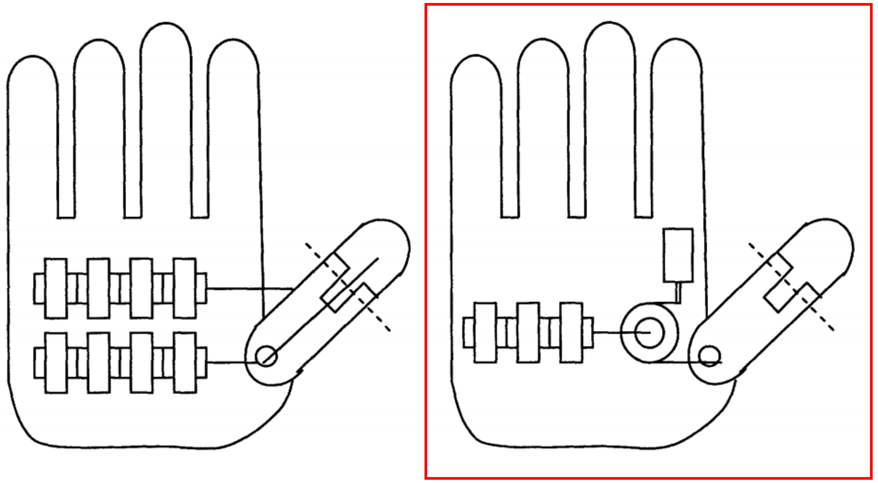


Figure 10. Potential design implementations: PZT actuator driven (left), hybrid DC motor/PZT actuator(right).

(Levinson, 2009)

Existing Piezoelectric Research

Design and Control of a Robotic Thumb Using Piezoelectric Actuators

- Aimed to achieve a 90-degree range of motion with a max pinching force of 10 N
- Implemented a "tendon" style design with DC motor used to achieve the majority of motion (0 – 90 deg) while the PZT actuator was used to achieve fine motion control (0 - 10 deg)

(Levinson, 2009)

Existing Piezoelectric Research

Design and Control of a Robotic Thumb Using Piezoelectric Actuators

- Shortcomings:
  - Limited range of motion from PZT actuators (10 degrees)
  - Selected PZT actuators had a max force output of 5 N
  - Force losses associated with routing of tendon in addition to attachment point of tendon to thumb resulted in max gripping force of only 0.35 N

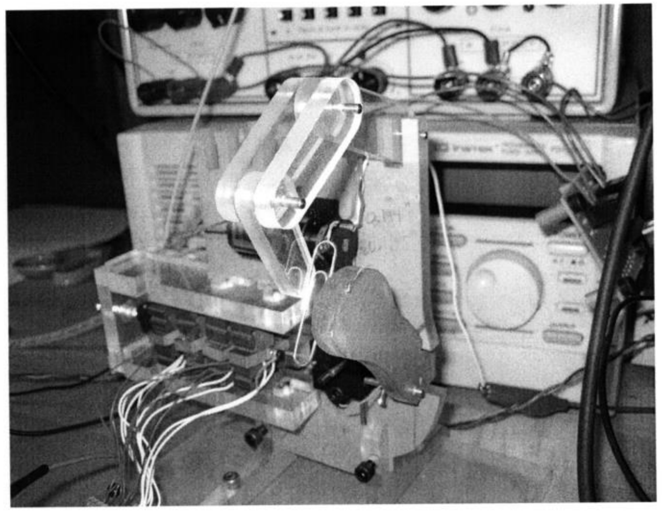
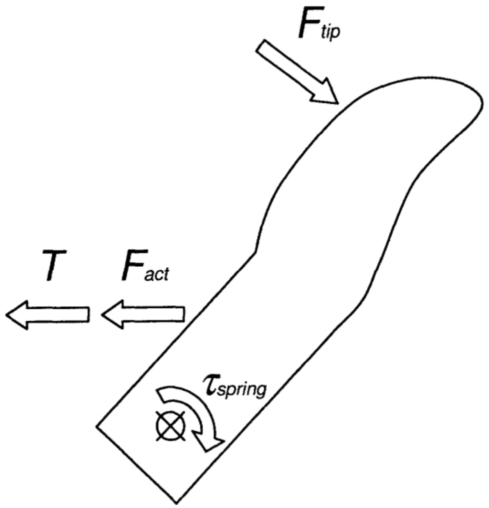


Figure 17. Thumb prototype pinching a paperclip.



(Levinson, 2009)

Objectives

Design Space Definition

- Look at anthropomorphic data sets and determine simplifications for the human hands. How many DOFs do fingers need for activities of daily living? What are their range of motions?
- How many individually articulated fingers are required? Can fingers be grouped for simplicity?
- Clamping force required for common activities.

Piezoelectric Design

- Determine the mechanism in which contraction/extension of piezo element is converted into finger motion.
- Determine the geometry of the piezo element (length, thickness, material).
- Determine the drive voltages required to achieve common motions such as grasping.

Finger Kinematics

- Linkage designs to achieve desired range of motion from each joint.

System Benchmarking

- Power consumption and required battery capacity.
- Approximate mass of system and comparison to existing solutions.

Analysis

Design Space Definition

- Determine design specifications for size, weight, range-of-motion, grip force, speed from literature

Piezoelectric Design

- Selection of piezoelectric actuator type (i.e. stack vs bimorph vs frequency leveraged)
- Design of piezo actuator to meet design specifications
    - Piezo material type
    - Geometry of piezo elements (length, thickness, material)
    - Number of actuators
    - Motion amplification

Analysis

Finger Kinematics and Hand Design

- Finger linkage design to achieve desired range of motion
- Attachment of actuators to fingers
- Packaging of components into prosthetic form factor

System Benchmarking

- Approximate expected performance of system when compared to existing solutions
  - Size
  - Weight
  - Range-of-motion
  - Grip force
  - Movement speed
  - Power consumption and required battery capacity

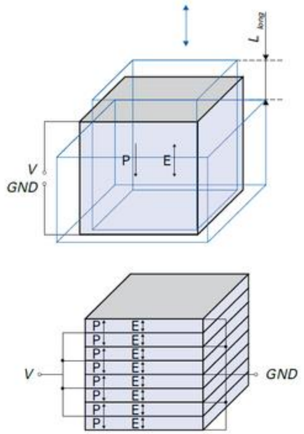
Challenges

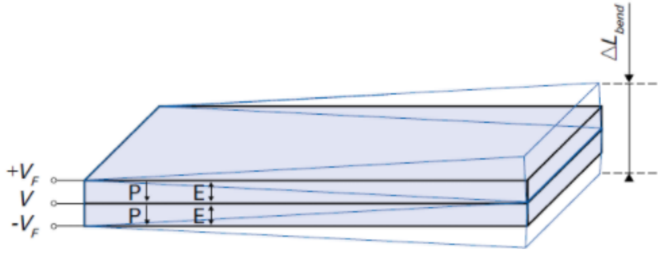
- Balance between limited displacement of piezo actuators (on the order of microns) and force output requirements
- We may find that frequency leveraged actuators are the only feasible option
  - This is a relatively advanced topic that we may need to do more research in especially with regards to modelling and design

$$\Delta L_{long} = n d_{33} V \approx 10^{-3}\ mm$$

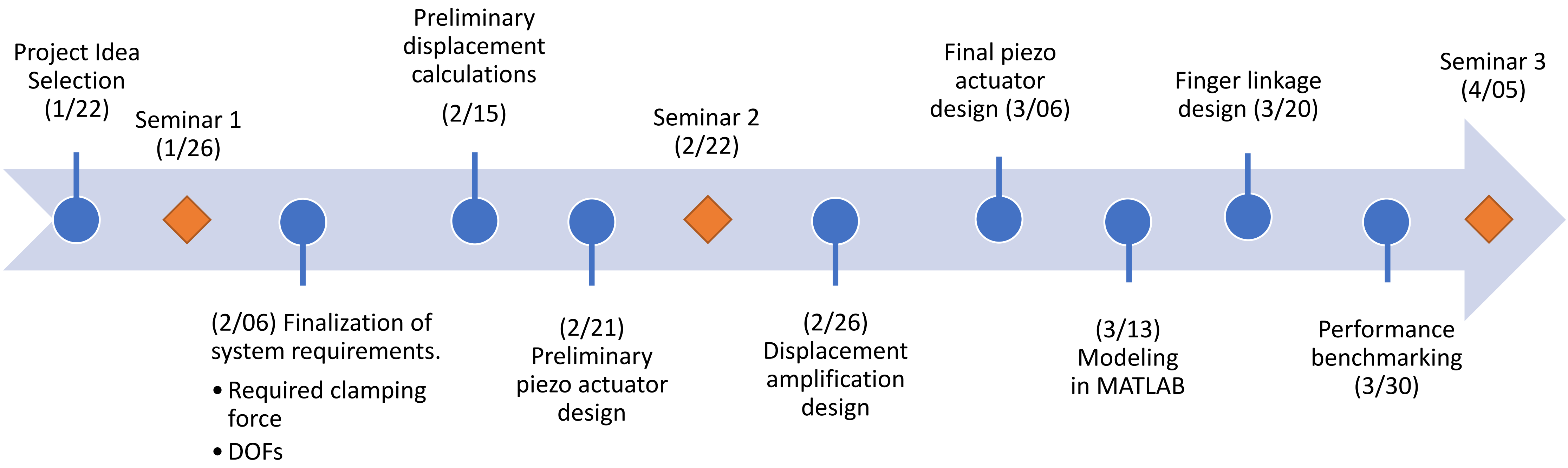
$$d_{33} = 650 \times 10^{-12} \frac{\mathrm{m}}{\mathrm{V}}$$

n = 10
V = 500





Timeline


Project Idea Selection (1/22)
Seminar 1 (1/26)
(2/06) Finalization of system requirements.
• Required clamping force
• DOFs
Preliminary displacement calculations
(2/15)
(2/21) Preliminary piezo actuator design
Seminar 2 (2/22)
(2/26) Displacement amplification design
Final piezo actuator design (3/06)
(3/13) Modeling in MATLAB
Finger linkage design (3/20)
Performance benchmarking (3/30)
Seminar 3 (4/05)

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