Soft Robotics: Designing Robotic Actuators Made from Flexible Materials

Algorithmic Robotics and Motion Planning Course
of Prof. Dan Halperin, Semester A 2020

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Based on the Paper: "Development of Flexible Microactuator and Its Applications to Robotic Mechanisms"
by K. SUZOMORI, S. IIKURA and H. TANAKA
IEEE - International Conference on Robotics and Automation, Sacramento CA, 1991

What are Soft Robots? and how are they different?

- Robots completely made from highly compliant materials (such as rubber)
- Designed to be able to mimic smooth motions of living organisms
- The flexibility and adaptability are helping to accomplish tasks that can be hard for robots built from rigid materials
- Potential use in the fields of medicine, biology and manufacturing

Design & Build a Soft Robot

- Single flexible microactuator (FMA) is built by fiber-reinforced rubber. It will be the robot's flexible part ("finger")

- Electro-hydraulic pumps system is used to make the motion
  - Serially connected FMAs act as a miniature robot manipulator
  - Parallel connected FMAs act as "multi-fingered" robot hand

- Gentle miniature robot with no conventional "solid" links can be made by that design
- We'll go through the basic characteristics and applications of this design, and perform some analysis of its behaviour

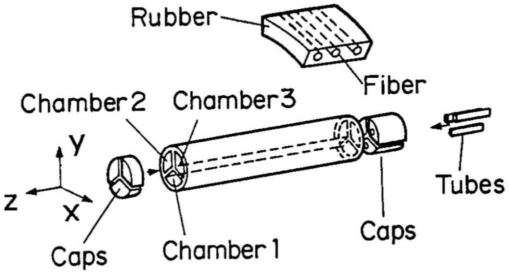
FMA Structure and Mechanism

- Rubber actuators can be divided to two types - **Shrink** & **Stretch**
  - An FMA can be regarded as a special case of the **stretch** type

- On this example, we’ll use the below structure for our FMA
- There are three internal chambers, and the internal pressure of each is controlled independently via pressure control valves

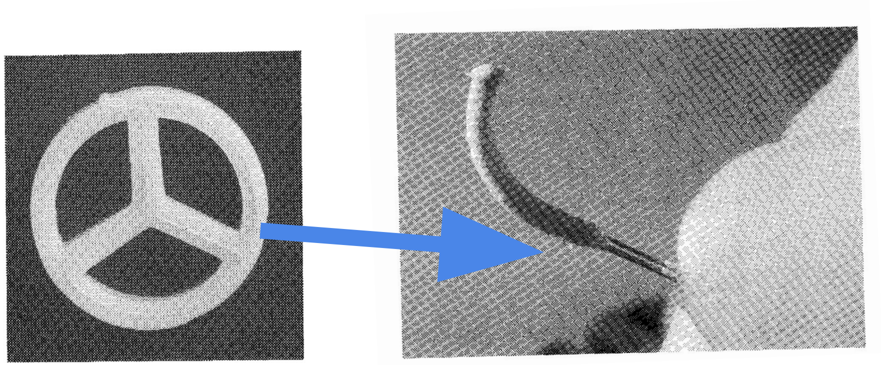
- How many degrees of freedom does such FMA has?

  3 degrees of freedom: pitch, yaw, stretch



Starting the Motion

- When the internal air pressure in the three chambers is increased equally, the FMA **stretches** in the axial direction
- When it's increased unequally (for example, only at one chamber), the FMA bends in a direction **opposite** the pressurized chamber
- We can bend the FMA in any direction by controlling the pressure level in the three chambers (thuse, having the 3 degrees of freedom)

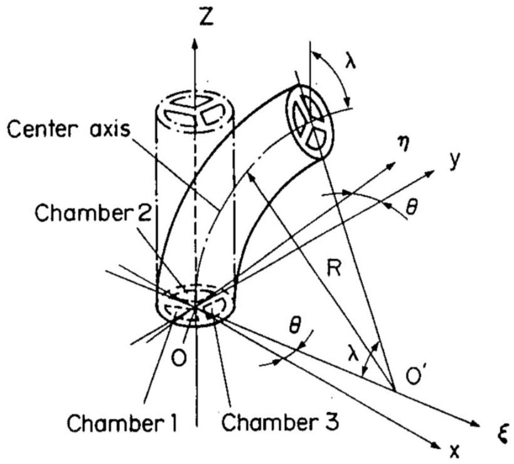


FMA Advantages over conventional actuators

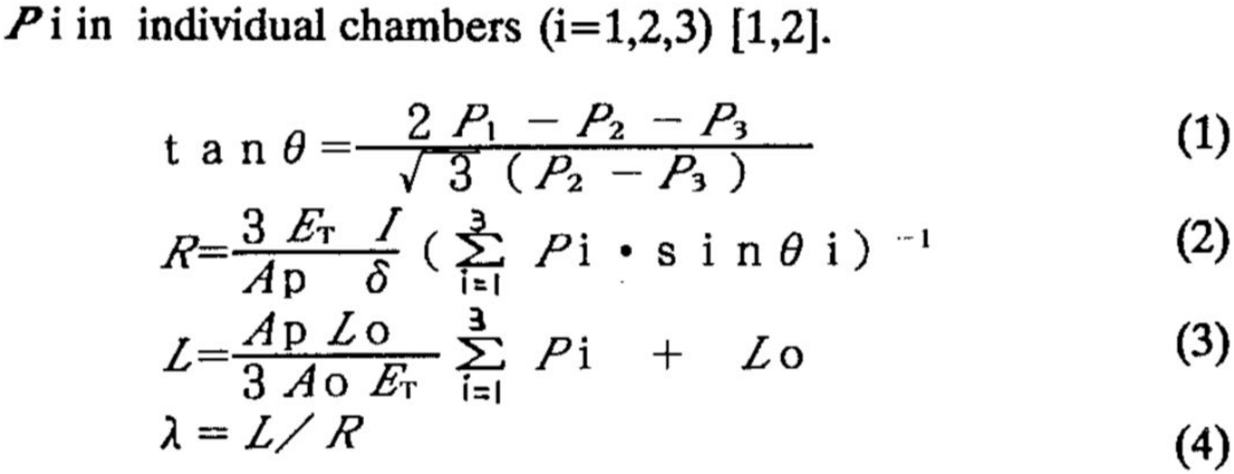
- It is easy to minimize because of its simple structure
- It has a high power density
- It has relatively many degrees of freedom - suitable for complex robotic mechanism
- It is cheap to build
- It operates smoothly and gently because of its friction

Analytical model of FMAs - Static Characteristicas

- It is assumed that the deformation of an FMA is small and that it takes the form of an “arc”
- The deformation can be described using θ, R and ƛ -
    - θ - Represents the bending direction angle
    - R - is the curvature of the center axis
    - ƛ - Is the angle between the z-axis and the tip Direction of the FMA
- By applying the infinitesimal deformation theory - θ, R and ƛ can be derived as functions of the internal pressure of every individual chamber



Analytical model of FMAs - Static Characteristicas



Pi in individual chambers (i=1,2,3) [1,2].

$$\tan\theta = \frac{2P_1 - P_2 - P_3}{\sqrt{3}\,(P_2 - P_3)} \tag{1}$$

$$R = \frac{3E_T}{A_p}\frac{I}{\delta}\left(\sum_{i=1}^{3} P_i \cdot \sin\theta_i\right)^{-1} \tag{2}$$

$$L = \frac{A_p L_o}{3A_o E_T}\sum_{i=1}^{3} P_i + L_o \tag{3}$$

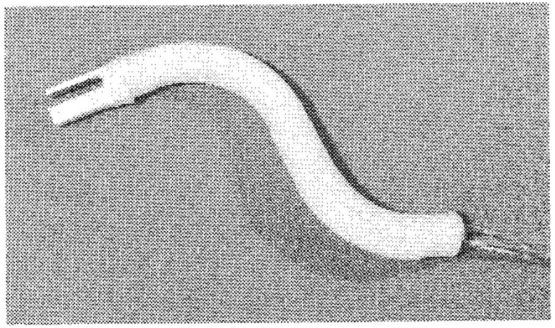
$$\lambda = L/R \tag{4}$$

Application to Miniature Robot Arm

- An FMA can be used as the arm of a miniature robot - The movements of it are suitable for that matter.
- By connecting FMAs **serially**, we can get an arm with many degrees of freedom, and “snake-like” movements.

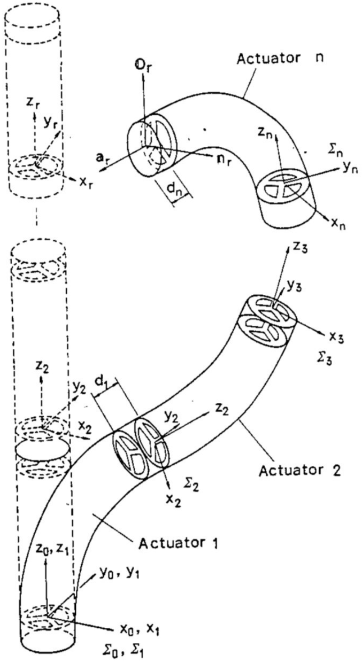
- The example has 2 FMAs and a mini gripper to hold it from the buttom
  - How many degrees of freedom does it have?

7 degrees of freedom - 3 for each FMA
and one for the gripper



Miniature Robot Arm - The General Case

- For *n* **serially** connected FMAs, we’ll have ***3n*** degrees of freedom
- The structure and angles defined as in the image



- We’ll denote the *x,y,z* coordinates to be the ones fixed to the base, and *xi, yi, zi* for the *i*-th connected FMA

- Using the above definitions (and additionals which we’ll not go through here...), we can get the transformation matrix **from coordinate *i* to *i-1***

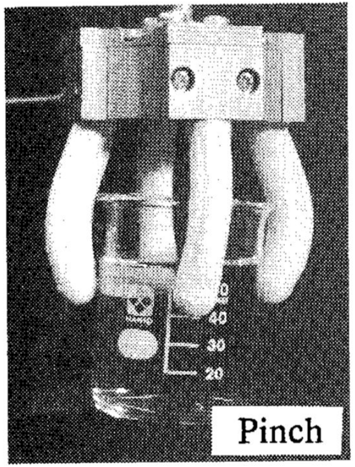
Miniature Robot Arm - The General Case

The transformation matrix:

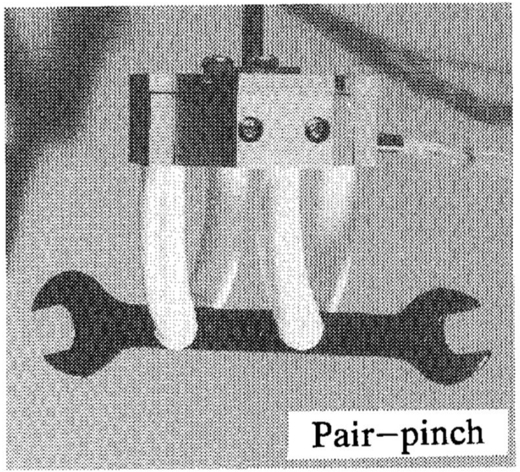
$$A_i = \begin{bmatrix} C_{\lambda i} C_{\theta i}^2 + S_{\theta i}^2 & S_{\theta i} C_{\theta i} (C_{\lambda i} - 1) & S_{\lambda i} C_{\theta i} & \{R_i (1 - C_{\lambda i}) + d_i S_{\lambda i}\} C_{\theta i} \\ S_{\theta i} C_{\theta i} (C_{\lambda i} - 1) & C_{\lambda i} S_{\theta i}^2 + C_{\theta i}^2 & S_{\lambda i} S_{\theta i} & \{R_i (1 - C_{\lambda i}) + d_i S_{\lambda i}\} S_{\theta i} \\ - S_{\lambda i} C_{\theta i} & - S_{\lambda i} S_{\theta i} & C_{\lambda i} & R_i S_{\lambda i} + d_i C_{\lambda i} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Application to Multi-Fingered Robot Hand

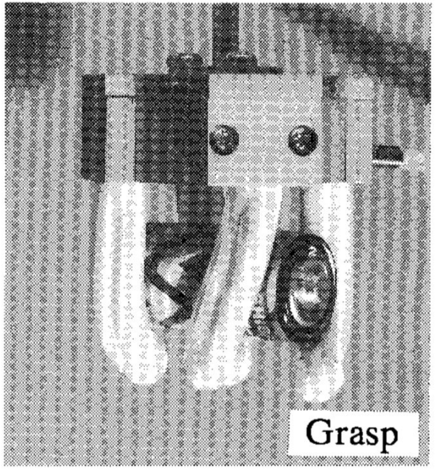
- We can see three different holding methods that were implemented as part of the prototype for four-fingered robot hand
- The prototype was made with four “fingers”, each 12mm in diameter, and had 12 degrees of freedom (3 per FMA * 4 parallelly connected)



Pinch



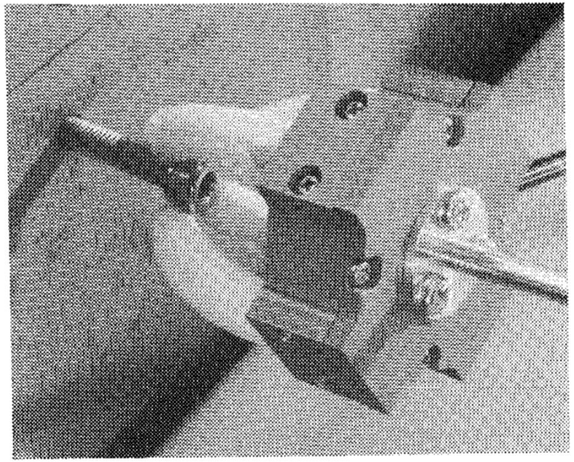
Pair–pinch



Grasp

Experiments

- The theoretical equations and results were compared with real experiments
- The figure below shows an experiment of a bolt being tightened (about 0.25rps)
- It is easy to screw in a bolt by roughly setting the position and direction of the hand because of the high compliance of the FMAs



Video

- Suzomori’s experiment (tighten a bolt)
    - https://www.youtube.com/watch?v=kHGLYRUKWeM&t=90s

Thank you!