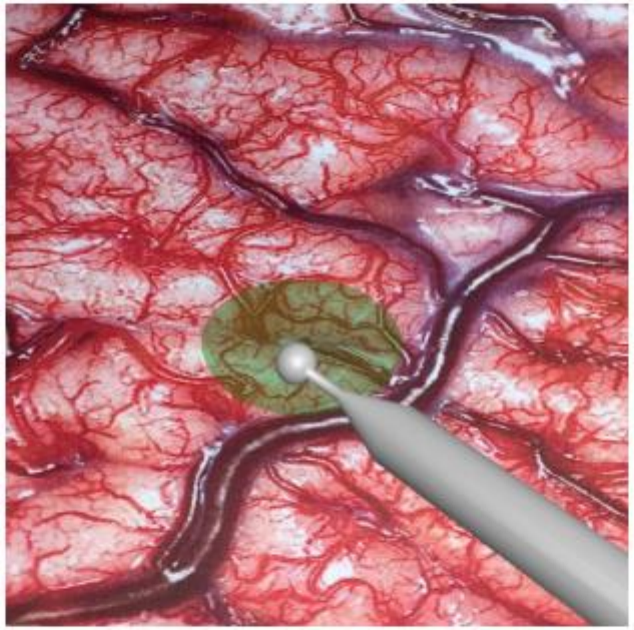
Adjustable Constant Force/Torque Mechanisms for Medical Robotics

Cheng Zhuoqi

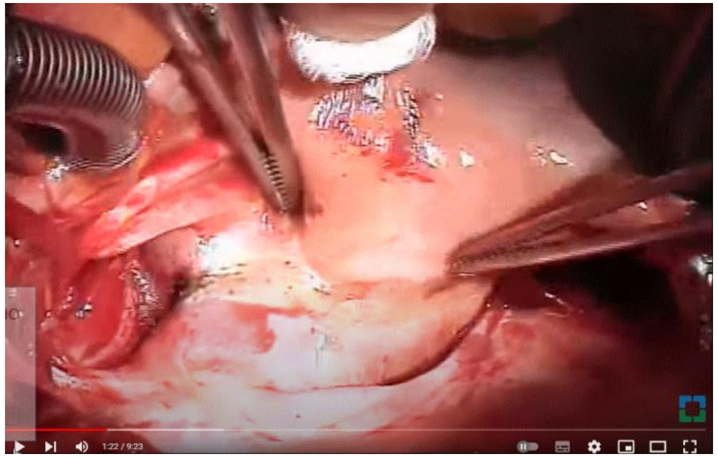
zch@mmmi.sdu.dk

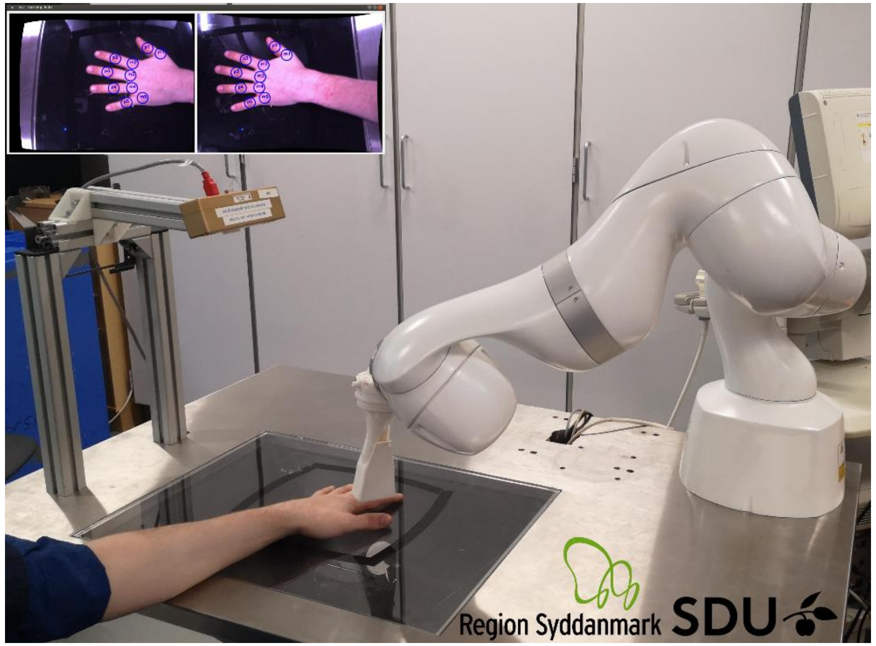
Objectives



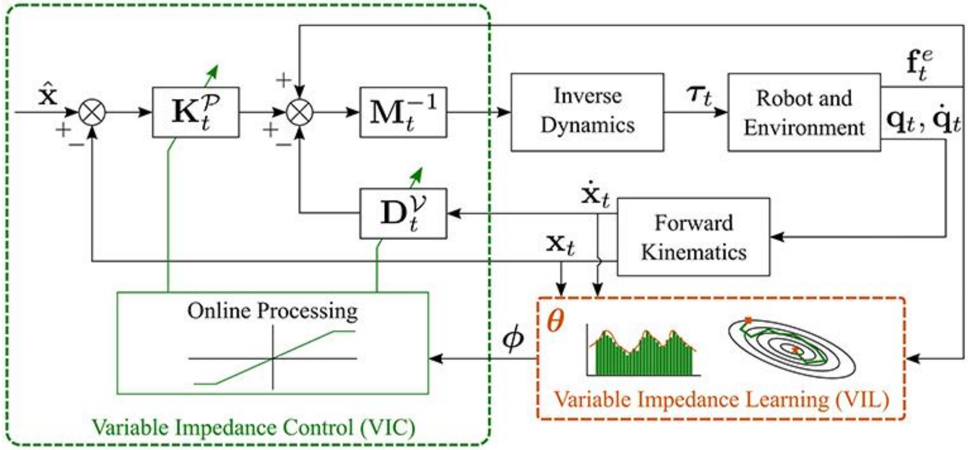
Safe tool-tissue interaction

- The exerted force must be constrained;
- The exerted force can be controlled.



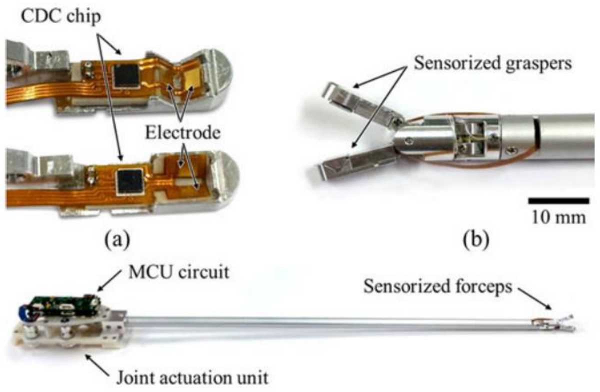


Intuitive idea: Impedance control

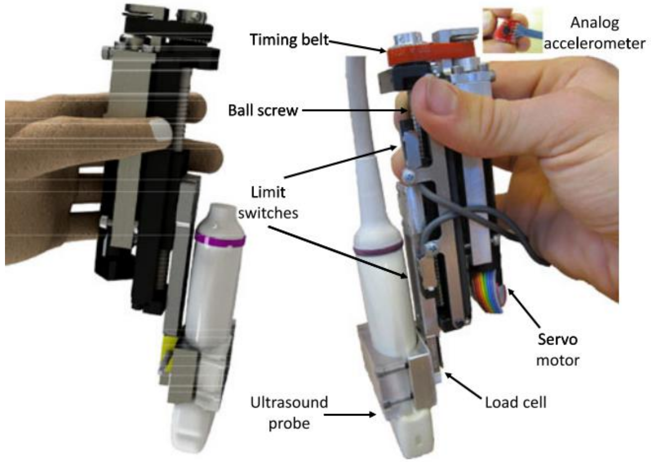


Why not?

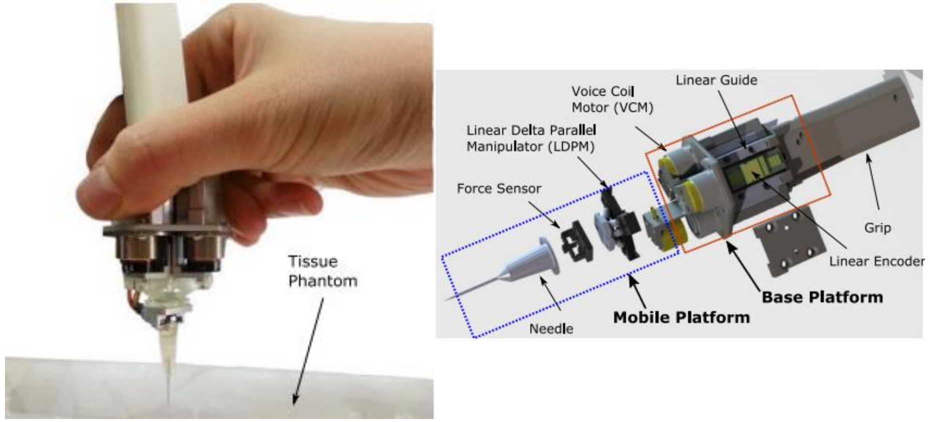
- x Sensor integration
- x High bandwidth
- x Time latency in control loop
- x Sterilization
- x Cost



Kim et al., Force Sensor Integrated Surgical Forceps for Minimally Invasive Robotic Surgery, IEEE T-RO

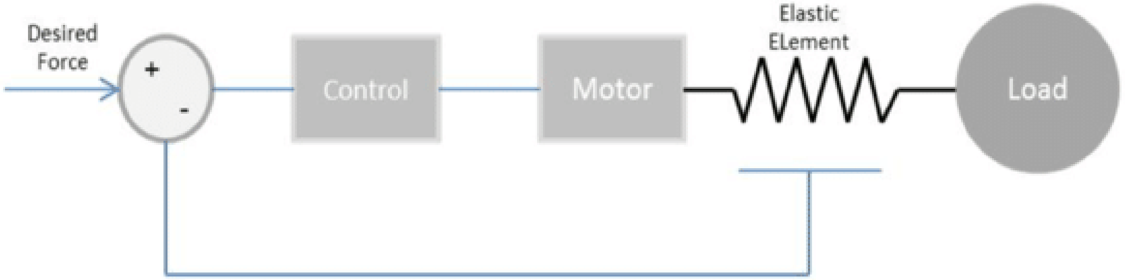


Gilbertson et al., Force and Position Control System for Freehand Ultrasound, IEEE T-RO

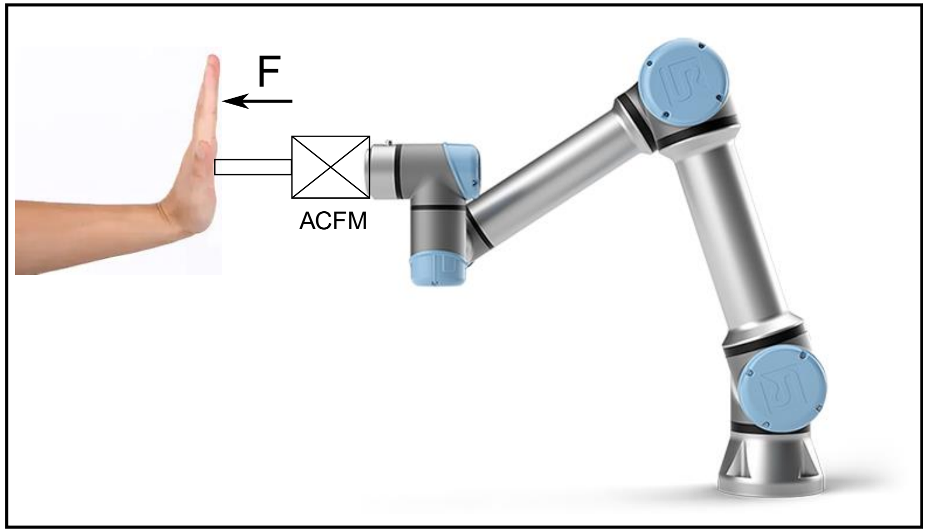


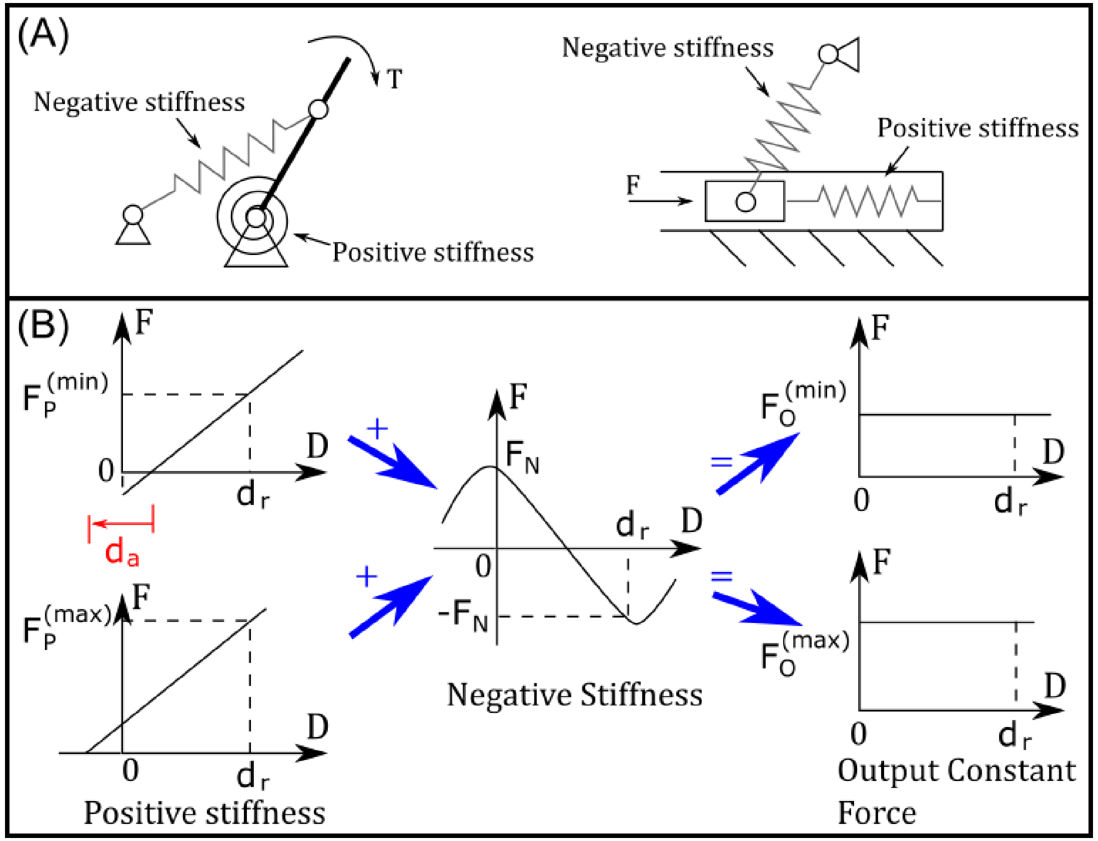
Kyeong et al., A Hand-held Micro Surgical Device for Contact Force Regulation against Involuntary Movements, EMBC

SEA: Serial Elastic Actuator



Positive constant stiffness + negative constant stiffness

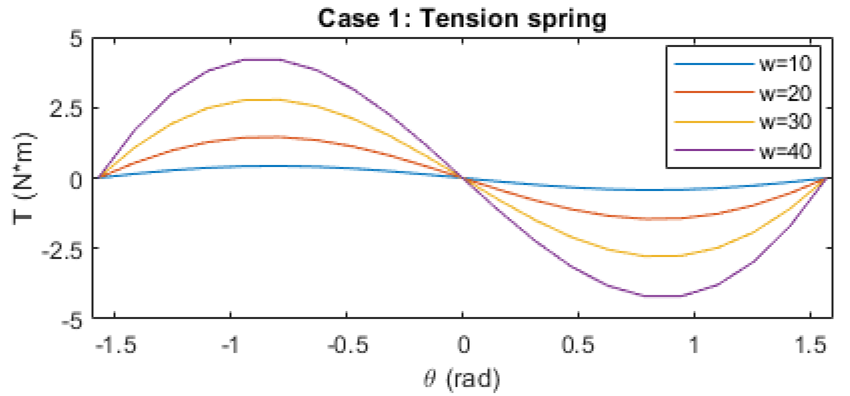


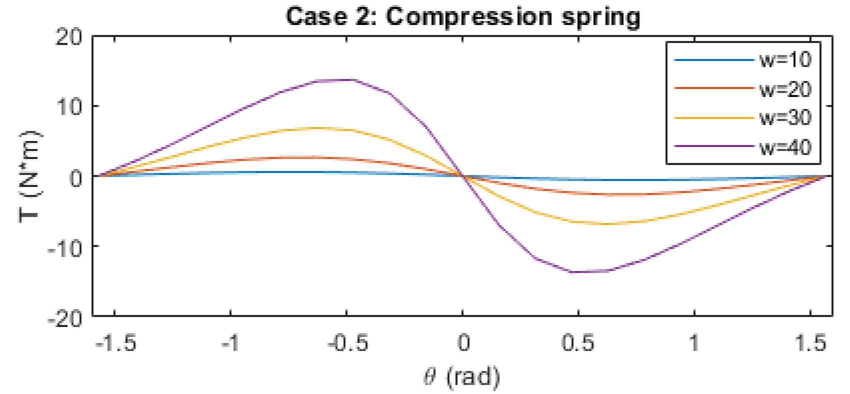


Adjustable Constant Force/Torque Mechanism

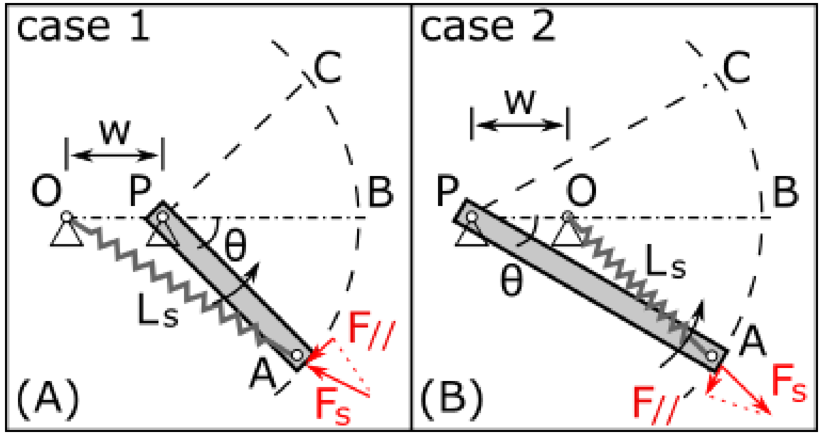
SDU

Design of negative stiffness

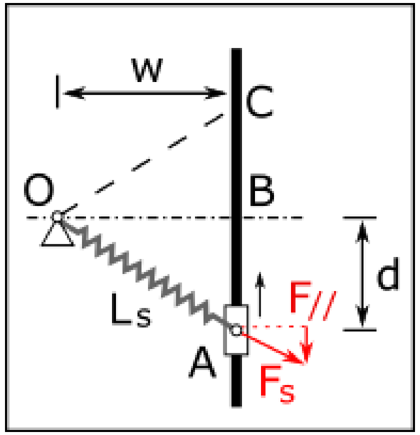


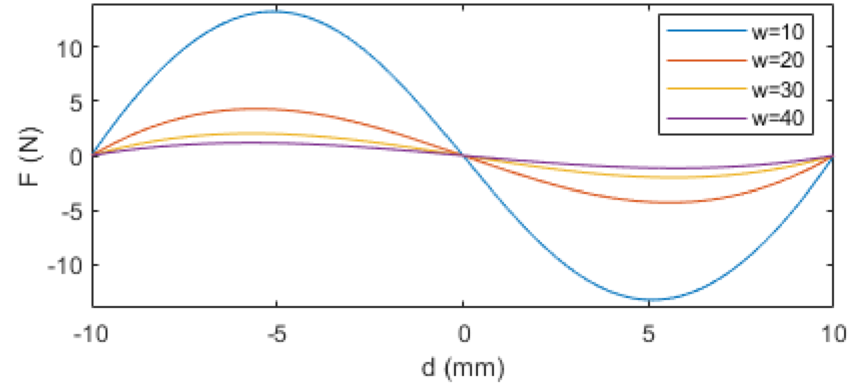


Rotational



Translational





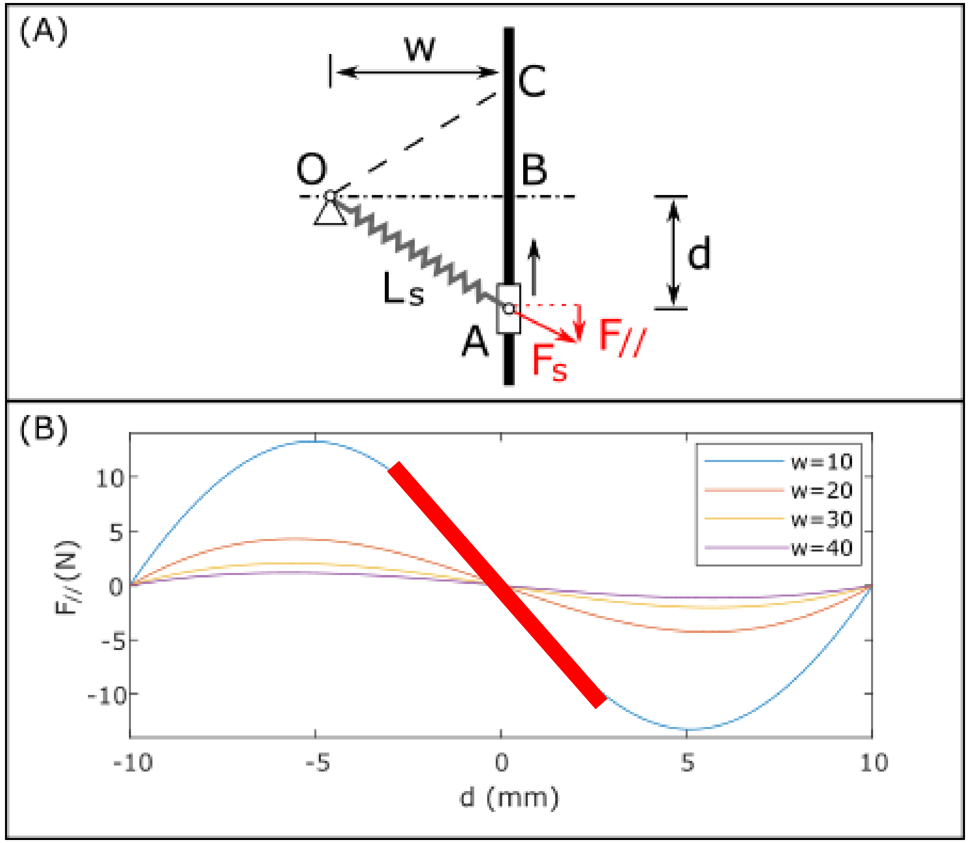
Nonlinear spring

Translational case as an example

Expected: $F = \tilde{k} d$ ($\tilde{k}$ is a constant)

So the stiffness of the spring should be nonlinear

$$k = \frac{\tilde{k}}{\left(\frac{L_s}{\sqrt{w^2 + d^2}} - 1\right)}$$

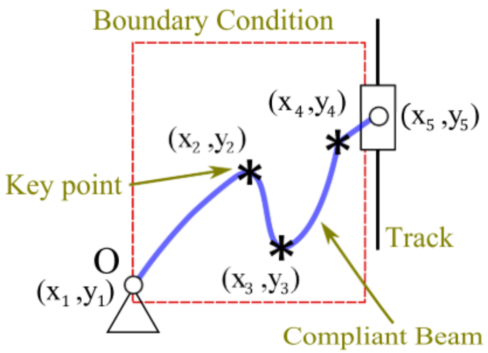


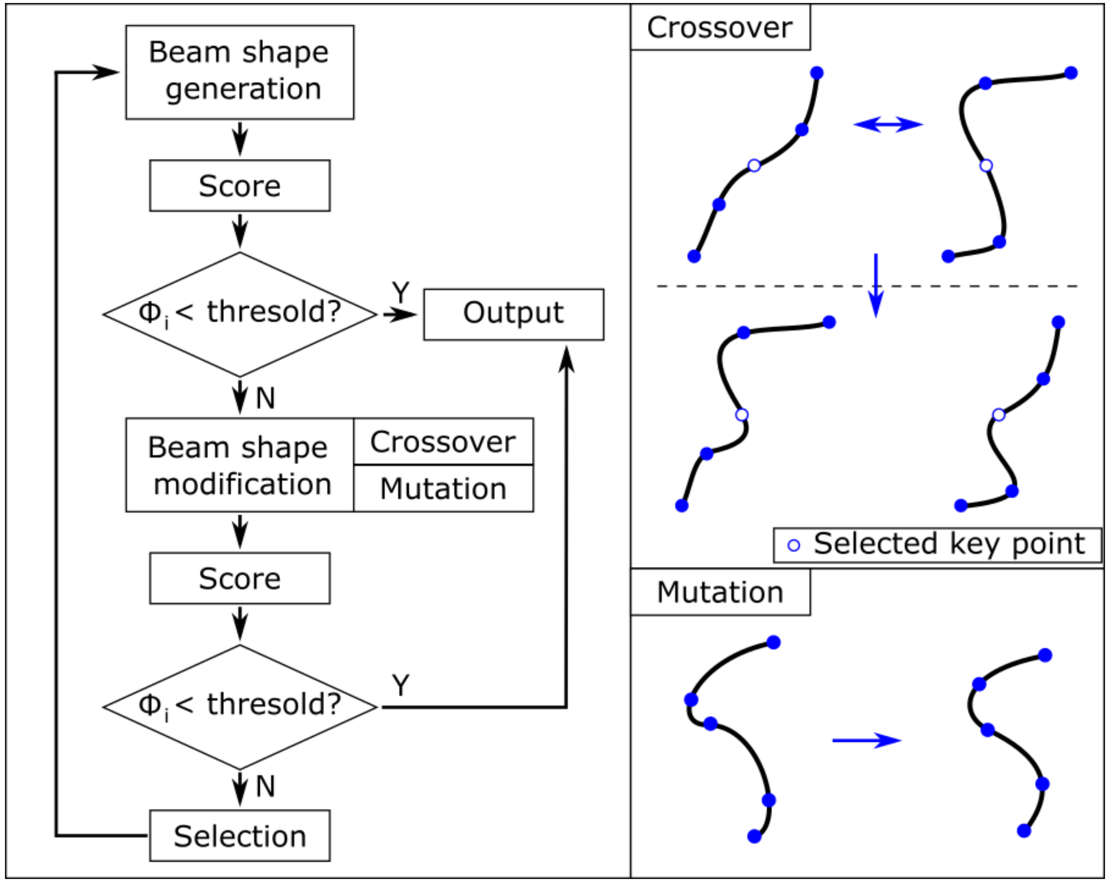
Objective:

Seeking the shape of a compliant beam which satisfies the desired stiffness function.

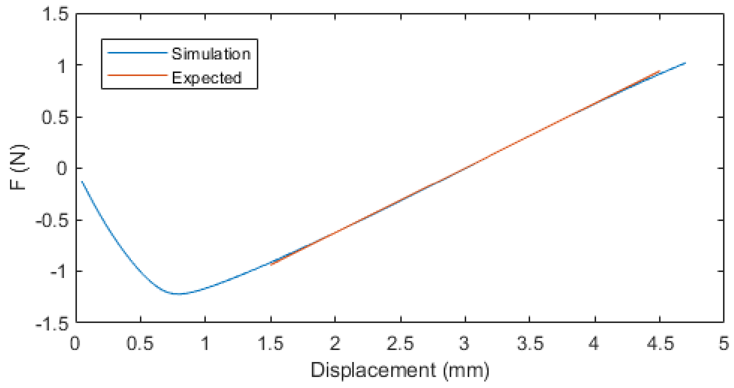
Genetic Algorithm + Finite Element Simulation

- Beam curve generation
- Score
- Crossover and mutation
- Selection





$$\text{Minimise } \Phi = e \cdot R(k, k_0) + \xi \cdot R(k, k_0)$$



$$R(k, k_0) = \frac{k_0}{k}$$

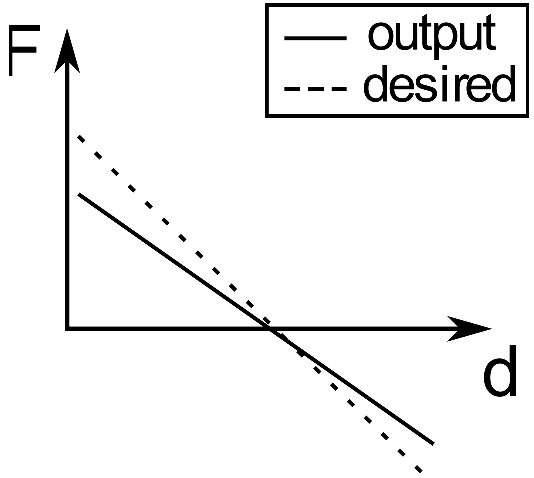
Stiffness k
Norm of residual e

Beam section area design

Objective function:

$$\text{Minimise } \Phi = e \cdot R(k, k_0) + \xi \cdot R(k, k_0)$$

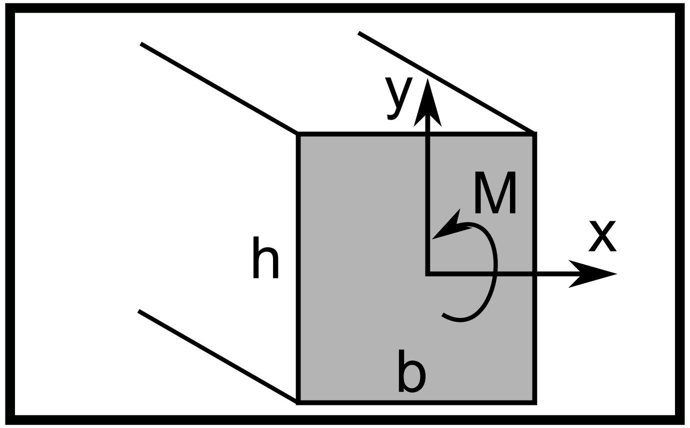
- Linearity: residual e
- Stiffness matching: $R(k, k_0) = \frac{k_0}{k}$



Then the beam section area is modified

Moment of inertia: $I = \frac{bh^3}{12}$

* Better to change b

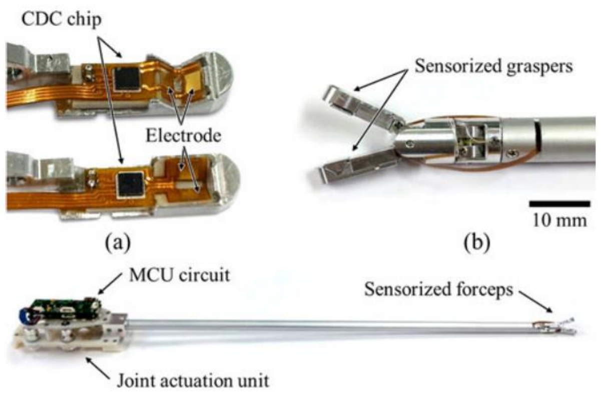


SDU

Medical application
Rotational case: Surgical forceps

Motivations:

Hard to estimate and control the grasping force



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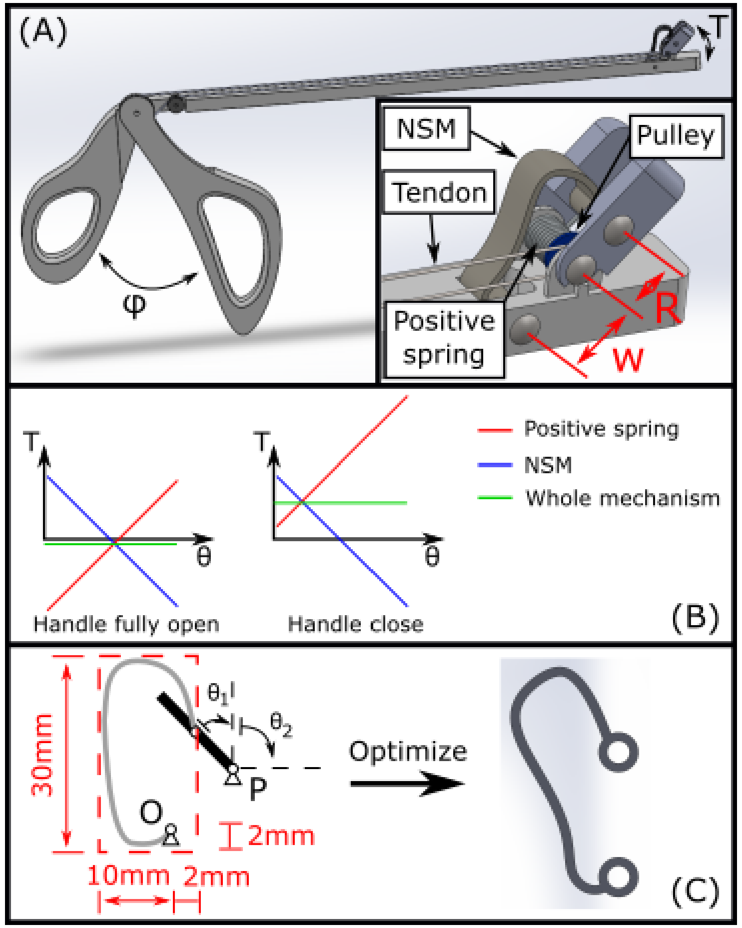

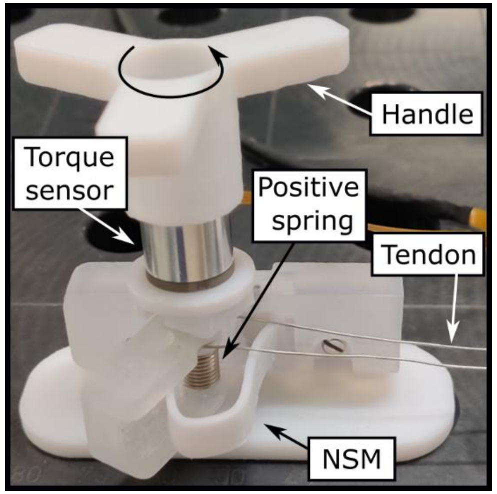

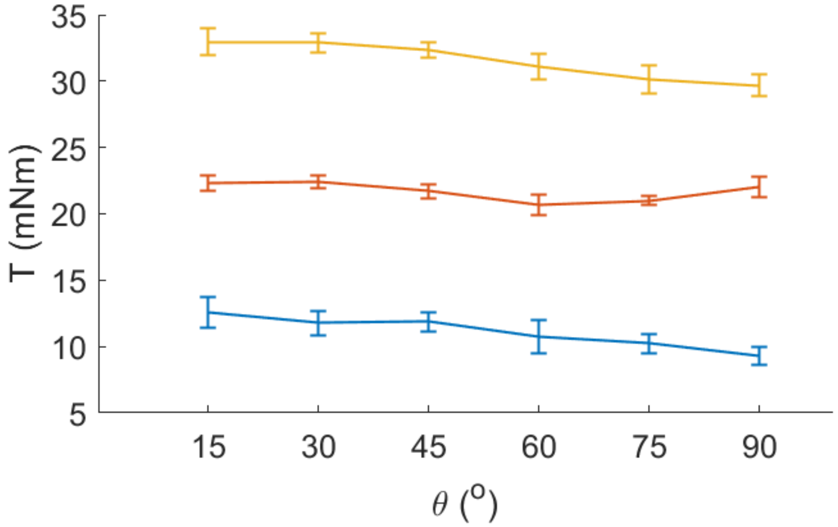

Medical application
Translational case: Ultrasound Robot

Motivations:

- The pressing force should be consistent during a robotic ultrasound scanning;
- The force can be changed online for diagnosis purpose;
- End-effector should be compliant for safety consideration.