Modelling, control and simulation of a micro electro-mechanical actuator (MEMS) for micro-gripper operation in DNA manipulation

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***Abstract*— This project deals with the modelling, control and simulation of a micro electro-mechanical actuator for micro-mechatronical tweezers in DNA-manipulation processes.**

I. The micro-mechatronical process

The manipulation of biological molecules by using micro-mechanical and optical devices such as: magnetic tweezers [1], [2], optical tweezers [3], AFM cantilevers [4] and microfibers [5], [6], are nowadays possible thanks to the impressive technological progresses of the last years. This type of manipulation is of particular interest for the characterization of basic properties of biological molecules such as DNA molecules [7]. Silicon nanotweezers, (Figure 1).

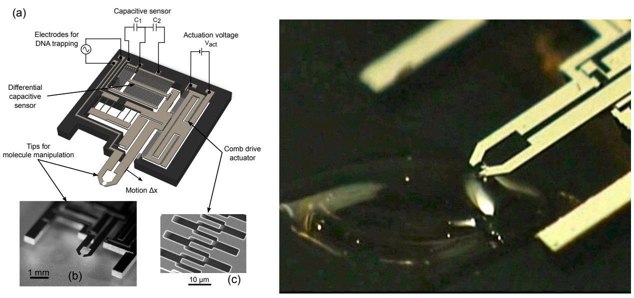

Fig. 1. Silicon nanotweezers

are used for this purpose: the principle is to trap the DNA bundle between two arm tips using dielectrophoresis and then characterize the DNA mechanical properties by using electrostatic actuation. The actuator is also used for monitoring enzymatic reactions on the DNA. The nanotweezers are so sensitive to the stiffness variation of the DNA bundle that they become flexible and as consequence, current microfabrication processes tend to reduce the thickness of the beams in order to improve the sensitivity of the actuator. This leads to control problems that may be formulated in terms of partial differential equations (PDEs).

We consider a simplified model of a flexible silicon based microgripper (Figure 2) used for DNA manipulation [8].

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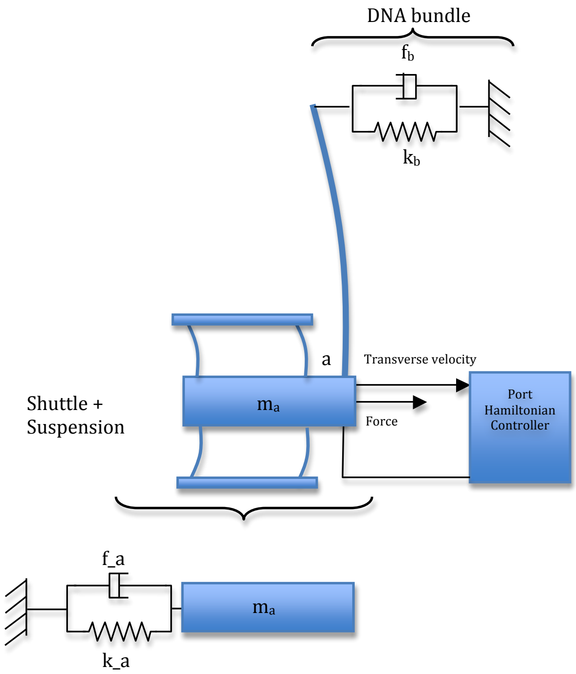

Fig. 2. DNA manipulation through port Hamiltonian control

The tweezer is made up of a *rigid* arm, clamped to a transverse suspension system. The trapped DNA bundle is approximated by a spring/damper-mass-spring/damper system attached at the tip of the tweezer. The arm is actuated by using electrostatic forces generated by a comb drive actuator, which is approximated by an external force (source term), connected to a suspension mechanism approximated by a spring/damper-mass system. For a detailed study of the modeling and stabilization of this system using infinite dimensional port-Hamiltonian framework refer to [9].

In the first part of the project we deal with the modeling, control and simulation of the **comb drive actuator**, which may be described by the MEMS shown in figure 3. The student is expected to develop the following points:

II. Modelling and control of the actuator

A. Modeling

1) For each subsystem (resistor, capacitor, spring, damper) give the set of power conjugate *effort* and *flow* variables. The closure relations are linear except for the **non-linear** capacitance which is of the form $C(q) = \frac{A\epsilon}{q}$.

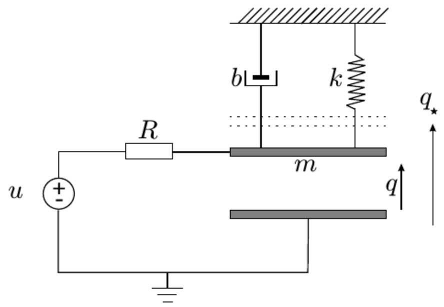

Fig. 3. MEMS actuator

2) Write down the interconnection relations linking the different subsystems.
3) Propose a port-Hamiltonian model for this system. Justify your choice by means of a physical interpretation of your model.
4) Evaluate numerically your model through numerical simulations in Matlab, Octave or Scilab.

B. Control

1) Discuss possible control strategies for the system in terms of physical interpretation and viability of implementation.
2) Propose a control law using IDA-PBC. (Hint try algebraic IDA-PBC)
3) Evaluate numerically your closed-loop system through numerical simulations in Matlab or Octave.

III. Modelling and control of the complete system

Now we consider the model of the micro-gripper.

- The **comb drive actuator** is connected to the **base of the tweezer**, i.e., the mass m of the in Figure 3 correspond to the base of the tweezer.
- the DNA-bundle is modelled as a simple spring-damper system connected to the tweezer at its tip.
- The arm of the tweezer is modelled as massless mechanical lever (the mass is included in the shuttle mass) of ratio n.

Modeling

1) Propose a port Hamiltonian model for each subsystem.
2) Write down the interconnection relations linking the subsystems.
3) Propose a port Hamiltonian formulation of the overall system

Control

1) Can the previous control law be used for stabilization in this case? How has it to be modified?
2) Propose a new control strategy suitable for the complete system.
3) Evaluate the performance of the proposed control by means of numerical simulations.

Numerical values:

m	4.10^{-8} Kg
k	1 N/m
b	3.10^{-6} N.s/m
$A\epsilon$	3.10^{-11} $F.m$
R	5 Ω
n	5

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