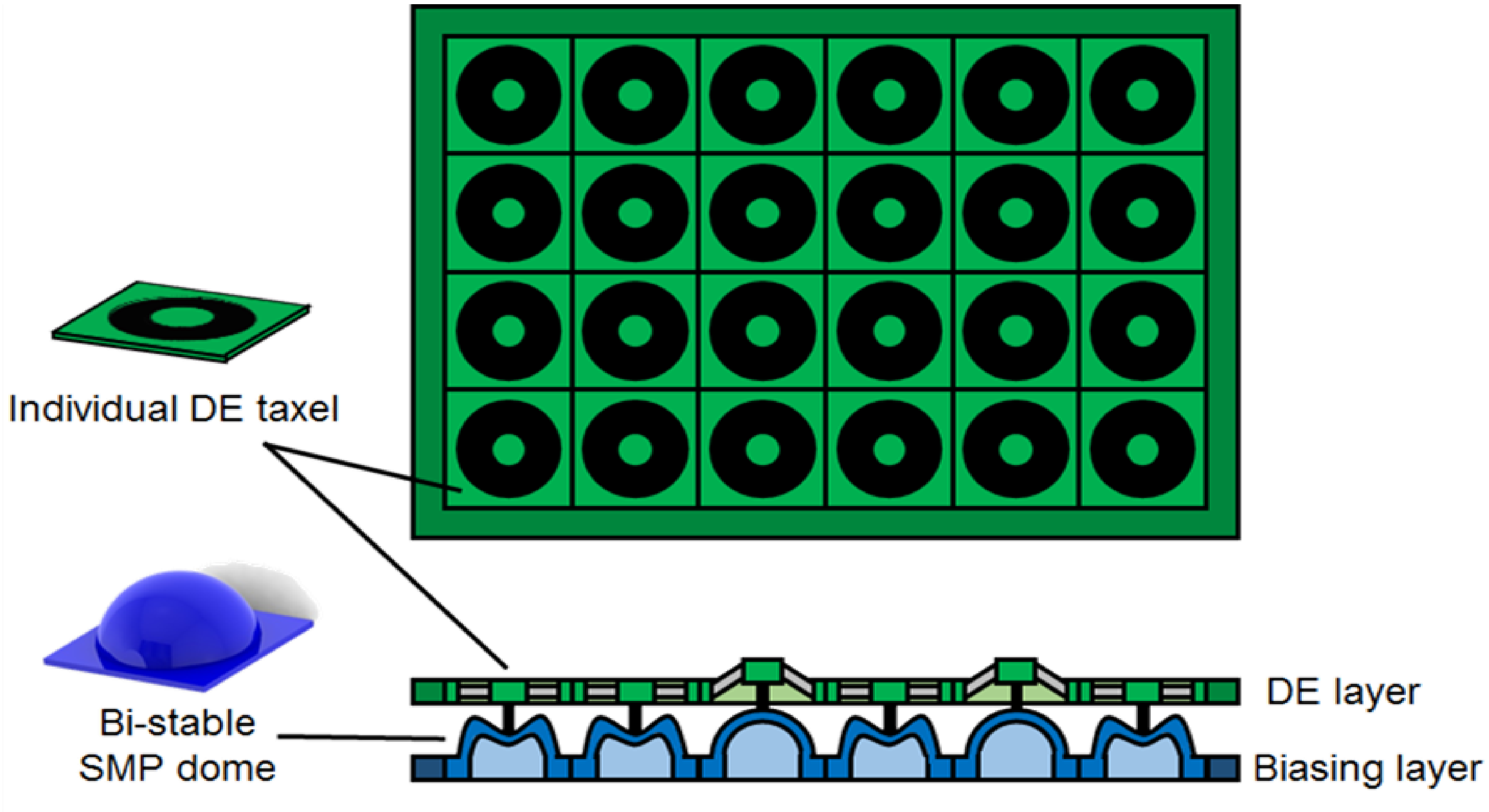
DECMAS - Dielectric Elastomer Membranes for Cooperative Micro-Actuator/Sensor Concepts



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KOMMMA A DFG PRIORITY PROGRAMME

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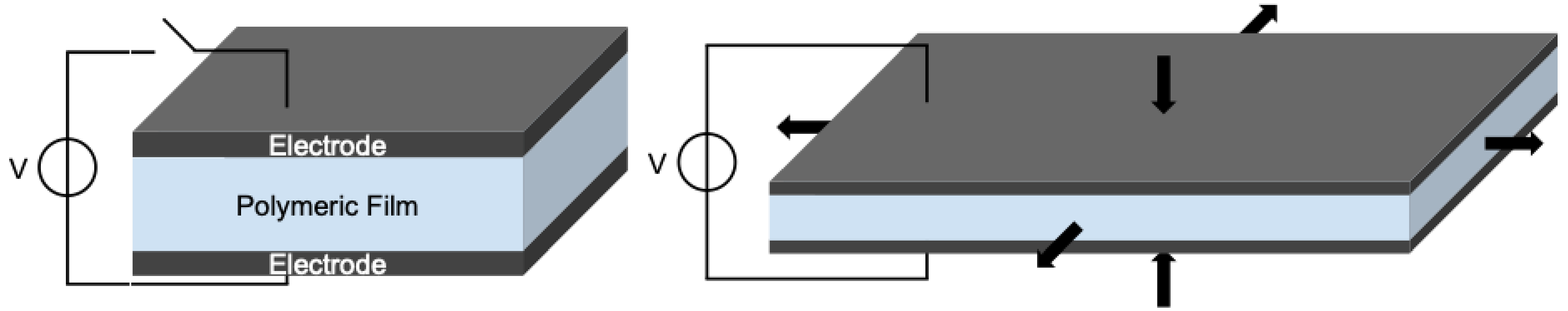
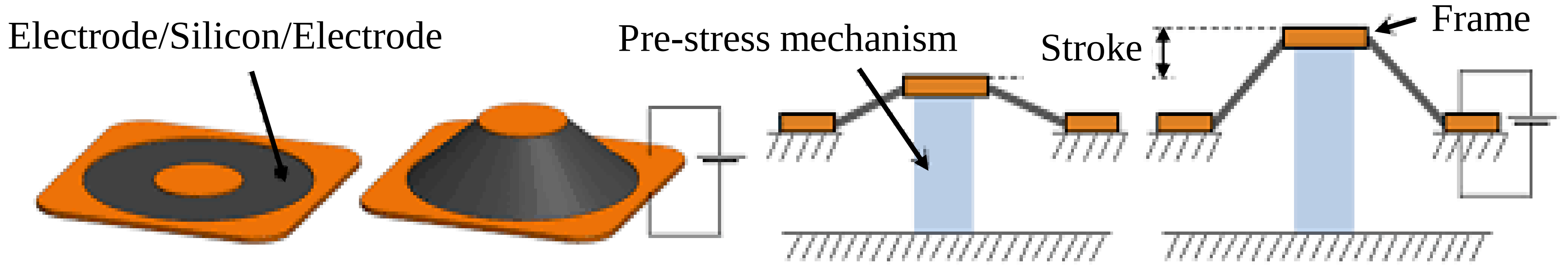
Dielectric elastomer: overview

Advantages:

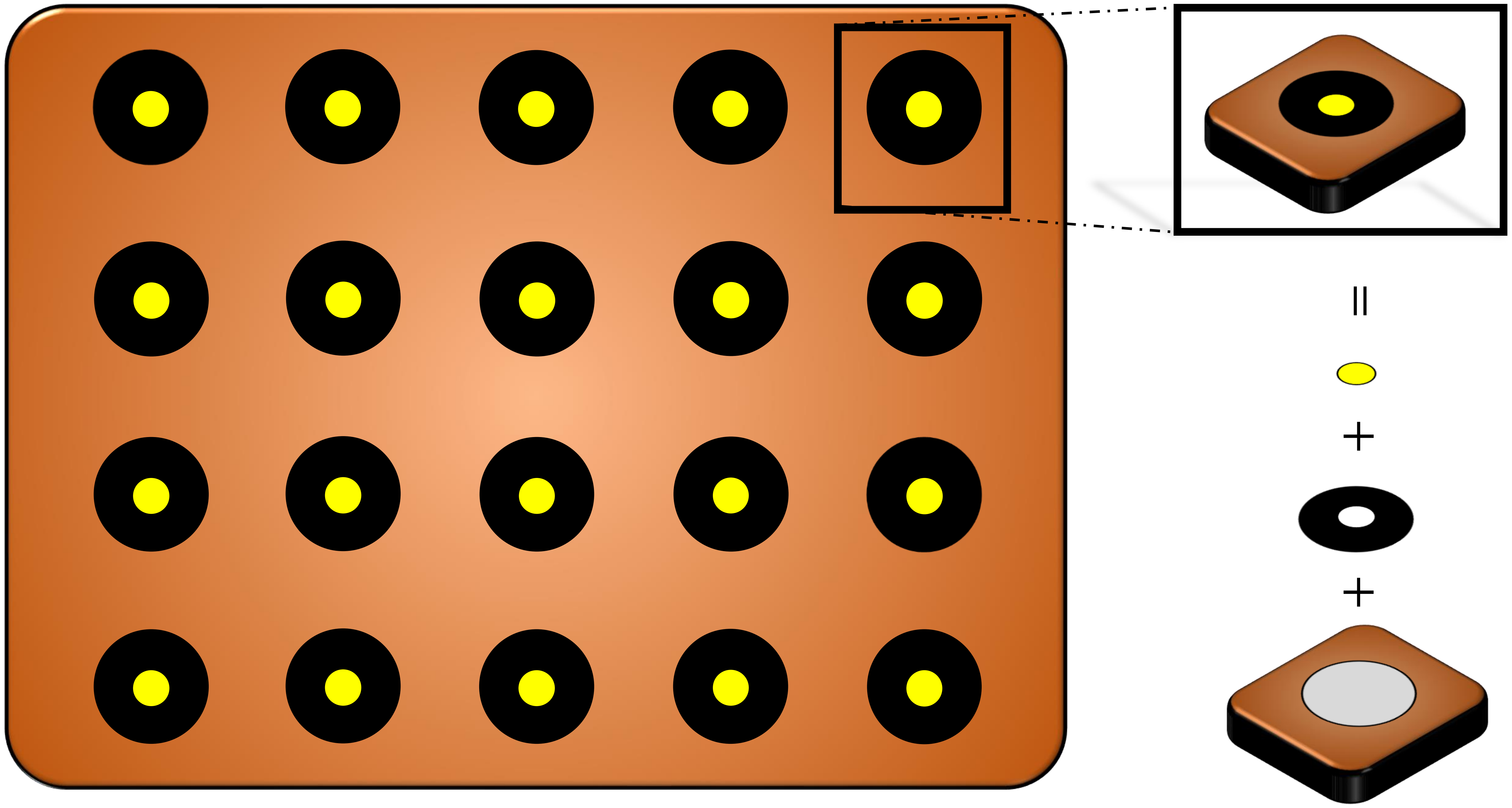
- high deformation
- lightweight
- mechanical flexibility
- energy efficiency
- low production costs
- self-sensing
- great variety of different construction designs



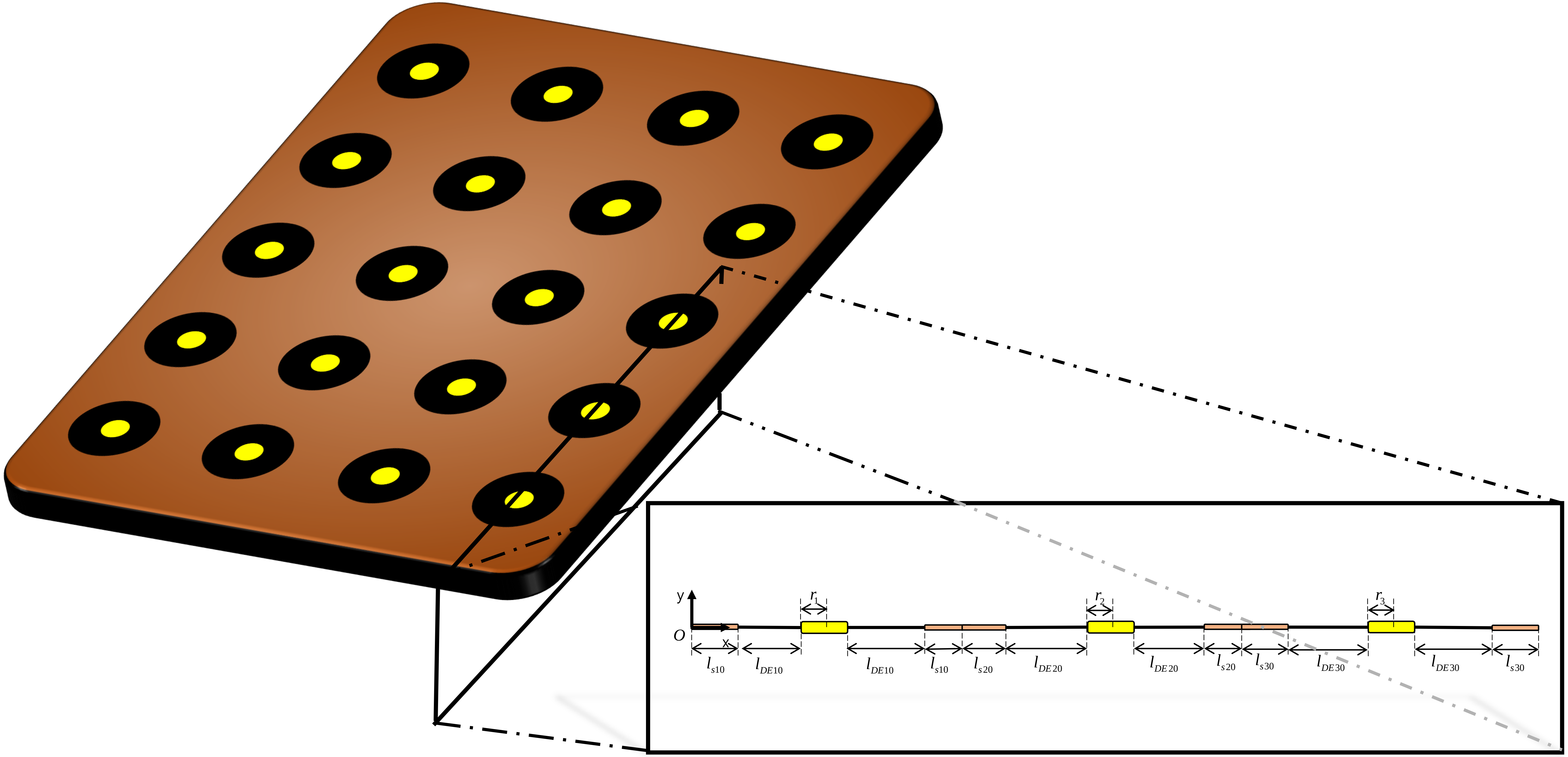


KOMMMA

KOMMMA - Cooperative Multistage Multistable Microactuator Systems

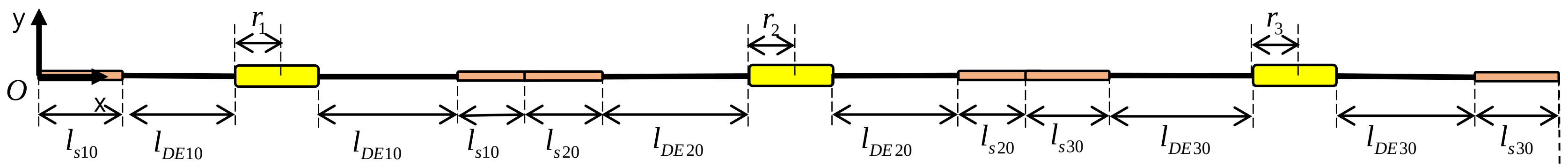


Cross-sectional view



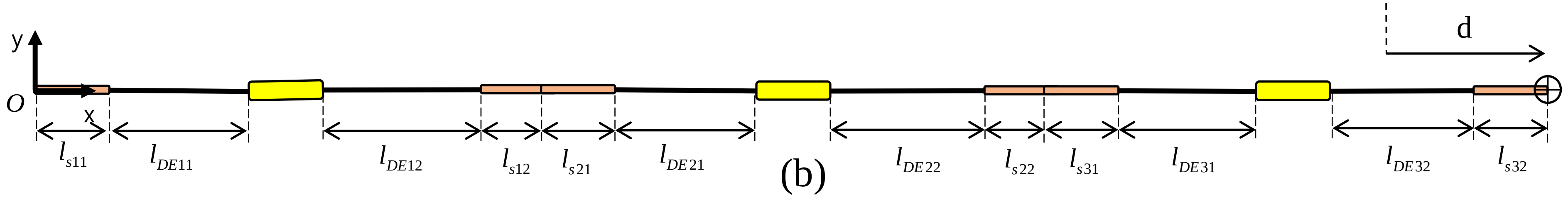
Steps for simulation

a) The membrane is initially flat



(a)

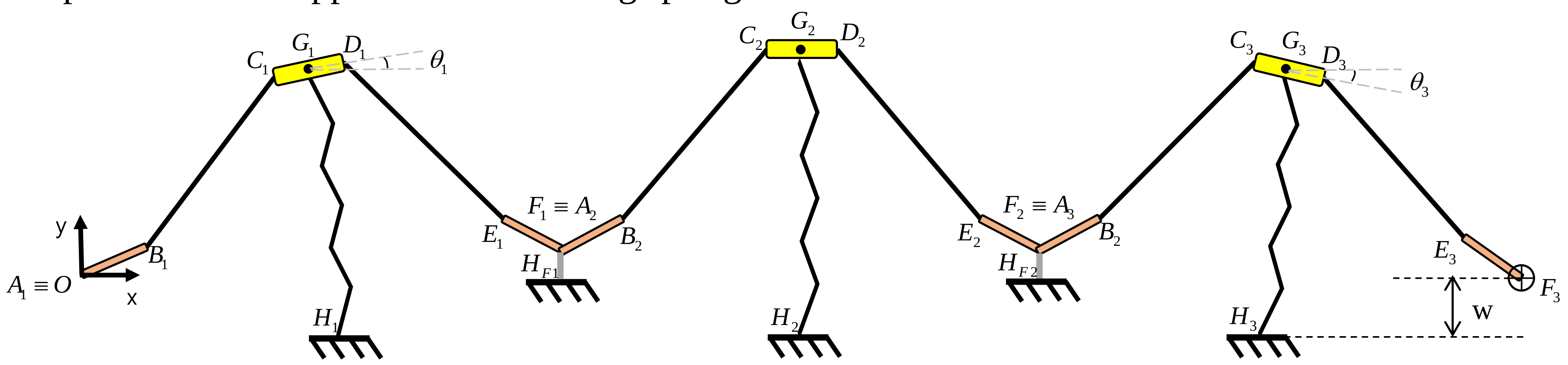
b) An in-plane pre-stretch is applied to the flat membrane



(b)

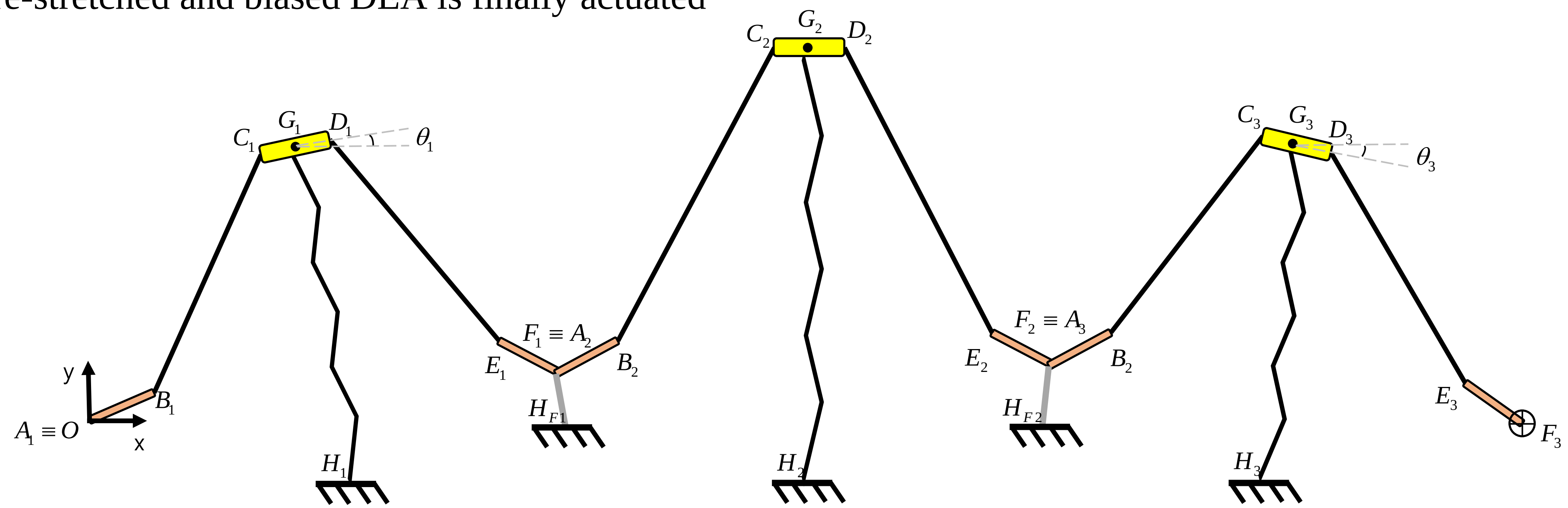
Steps for simulation

c) An out-of-plane force is supplied via the biasing springs



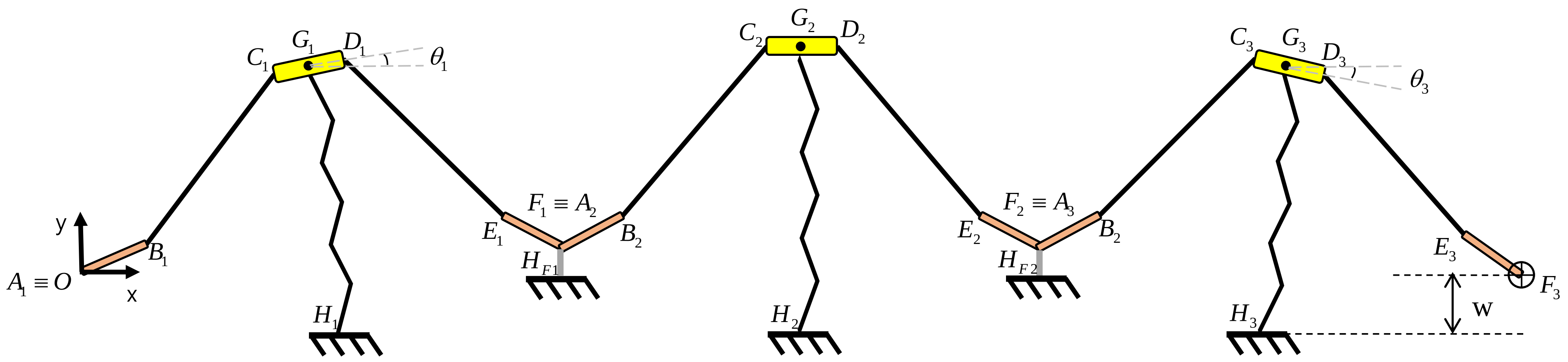
(c)

d) The pre-stretched and biased DEA is finally actuated



(d)

Methods: system configuration



Vector q of generalized variables:

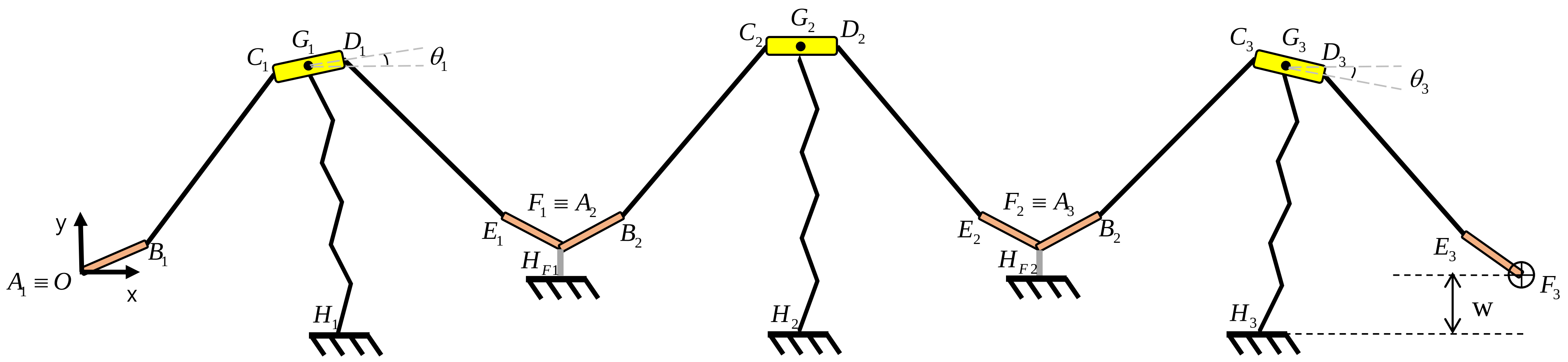
$$q = \left[B_{1x}\ B_{2x}\ B_{3x}\ B_{1y}\ B_{2y}\ B_{3y}\ G_{1x}\ G_{2x}\ G_{3x}\ G_{1y}\ G_{2y}\ G_{3y}\ \theta_1\ \theta_2\ \theta_3\ E_{1x}\ E_{2x}\ E_{3x}\ E_{1y}\ E_{2y}\ E_{3y}\ F_{1x}\ F_{2x}\ F_{1y}\ F_{2y} \right]^T.$$

Coordinates of the remaining points:

$$A_1 = (0,0),$$
$$A_i(q) = \left(F_{ix}, F_{iy}\right),\ \ i = 2,3,$$
$$C_i(q) = \left(G_{ix} - r_i \cos\theta_i, G_{iy} - r_i \sin\theta_i\right),\ \ i = 1,2,3,$$
$$D_i(q) = \left(G_{ix} + r_i \cos\theta_i, G_{iy} + r_i \sin\theta_i\right),\ \ i = 1,2,3,$$
$$F_3 = \left(\sum_i^3 2l_{Si0} + \sum_i^3 2l_{DEi0} + \sum_i^3 2r_i + d, 0\right).$$

System modeling

For the prediction of the quasi-static performance, only the characterization of the potential energy is relevant.



Potential energy of:

- rigid frames $\mathcal{V}_{RF}$
- DE membranes $\mathcal{V}_{DE}$
- silicone membranes $\mathcal{V}_S$
- biasing springs $\mathcal{V}_B$
- frame stiffness elements $\mathcal{V}_F$

$\xrightarrow{\sum}$

$$\mathcal{V}(q) = \mathcal{V}_{RF}(q) + \mathcal{V}_{DE}(q) + \mathcal{V}_S(q) + \mathcal{V}_B(q) + \mathcal{V}_F(q).$$

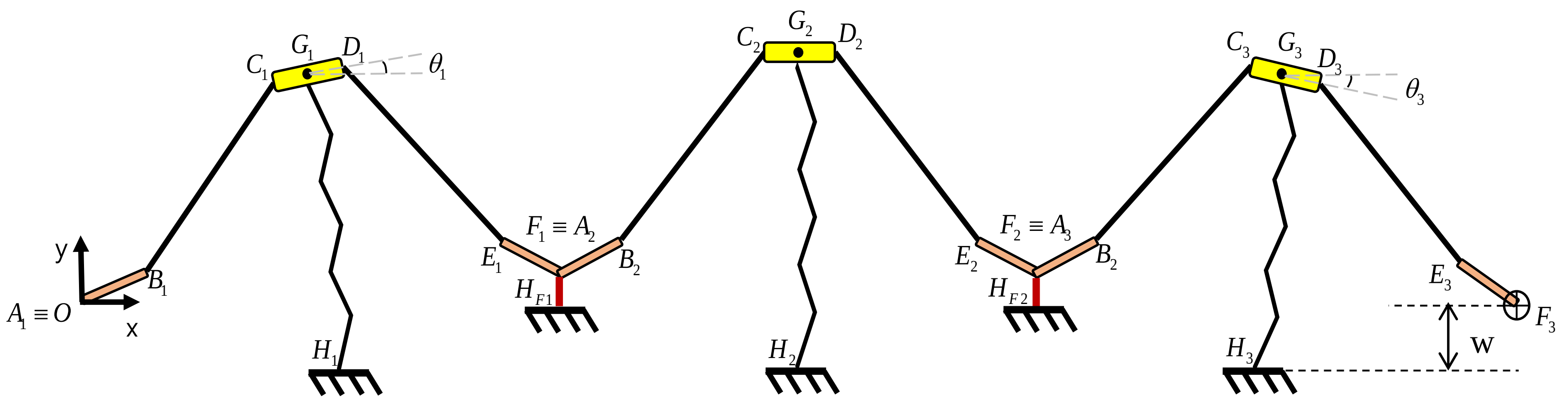
The constitutive equations of the system can be computed by solving the following equilibrium condition

$$\frac{\partial \mathcal{V}(q)}{\partial q} = 0.$$

First parametric study

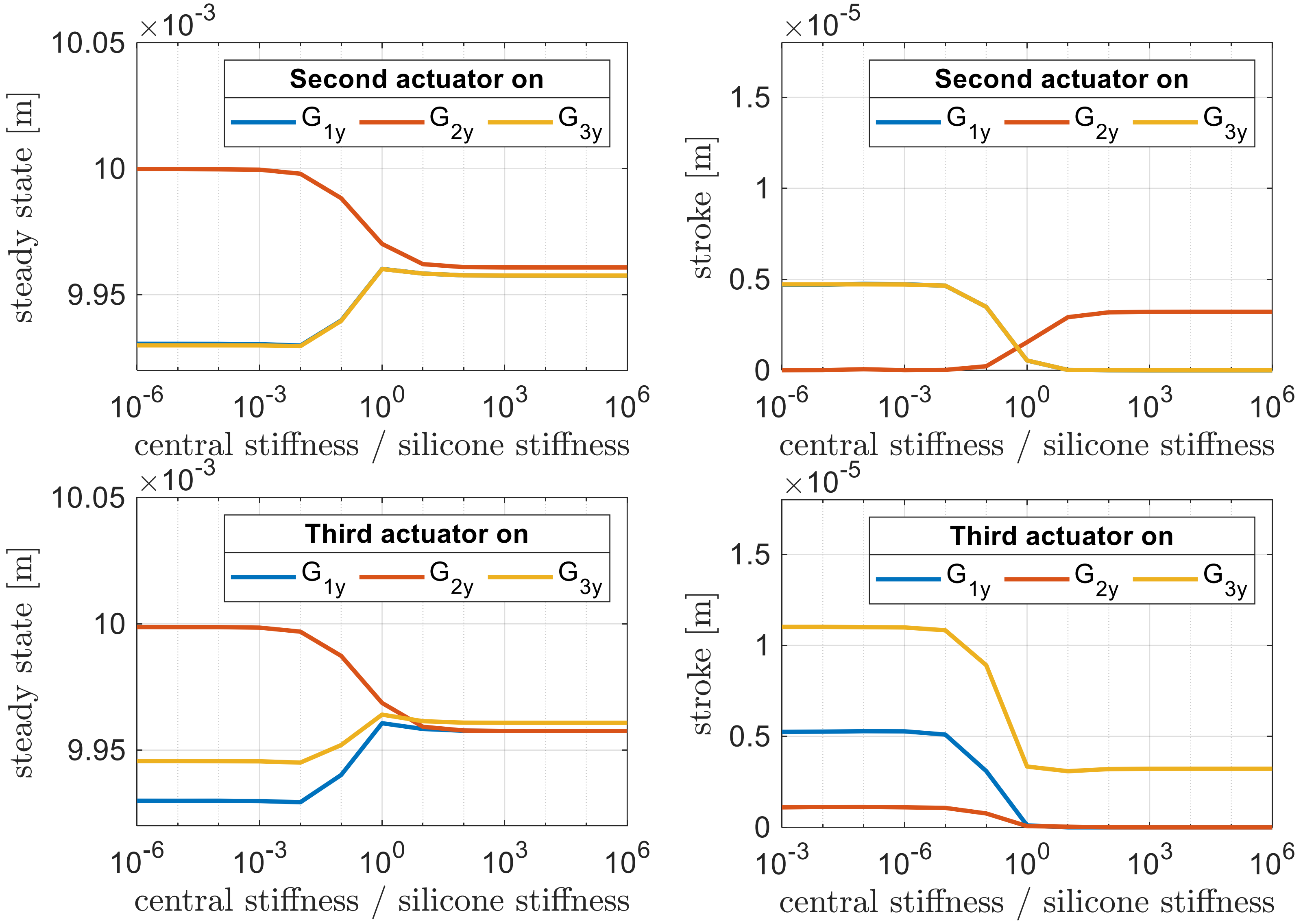
Simulations are conducted by keeping all parameters constant at nominal value listed below and changing only one of them ■ :

d = 0.01 m	k_{DEi}, $i \in \{1, 2, 3\}$ = 19.6 kN/m
w = - 0.01 m	k_{Si}, $i \in \{1, 2, 3\}$ = 19.6 kN/m
r_i, $i \in \{1, 2, 3\}$ = 0.0025 m	k_{Bi}, $i \in \{1, 2, 3\}$ = 10 MN/m
m_{DEi}, $i \in \{1, 2, 3\}$ = 0.0118 g	k_{Fi}, $i \in \{1, 2\}$ = 0 N/m
m_{Si}, $i \in \{1, 2, 3\}$ = 0.028g	d_{i0}, $i \in \{1, 2, 3\}$ = 0.02 m
m_{RFi}, $i \in \{1, 2, 3\}$ = 10 g	l_{DEi0}, $i \in \{1, 2, 3\}$ = 0.01 m
	l_{Si0}, $i \in \{1, 2, 3\}$ = 0.01 m



■ α = [10^{-6}, ..., 10^{6}]: ratio between the stiffness of the elastic element placed in the centre between two DE membranes (k_F) and the silicone stiffness (ks);

First parametric study

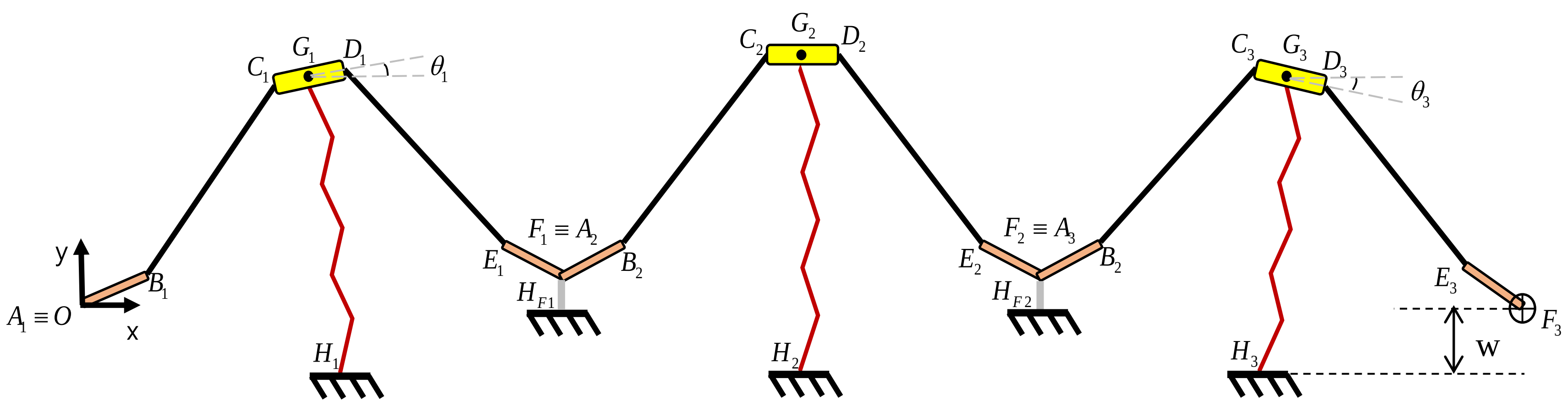


- For high k_{Fi} values the stroke of non-actuated membranes is zero, while a coupling effect is observed for low k_{Fi} values. This indicates that the softer the central elastic element, the greater the influence that the actuation of one DEA has on the other two.

Second parametric study

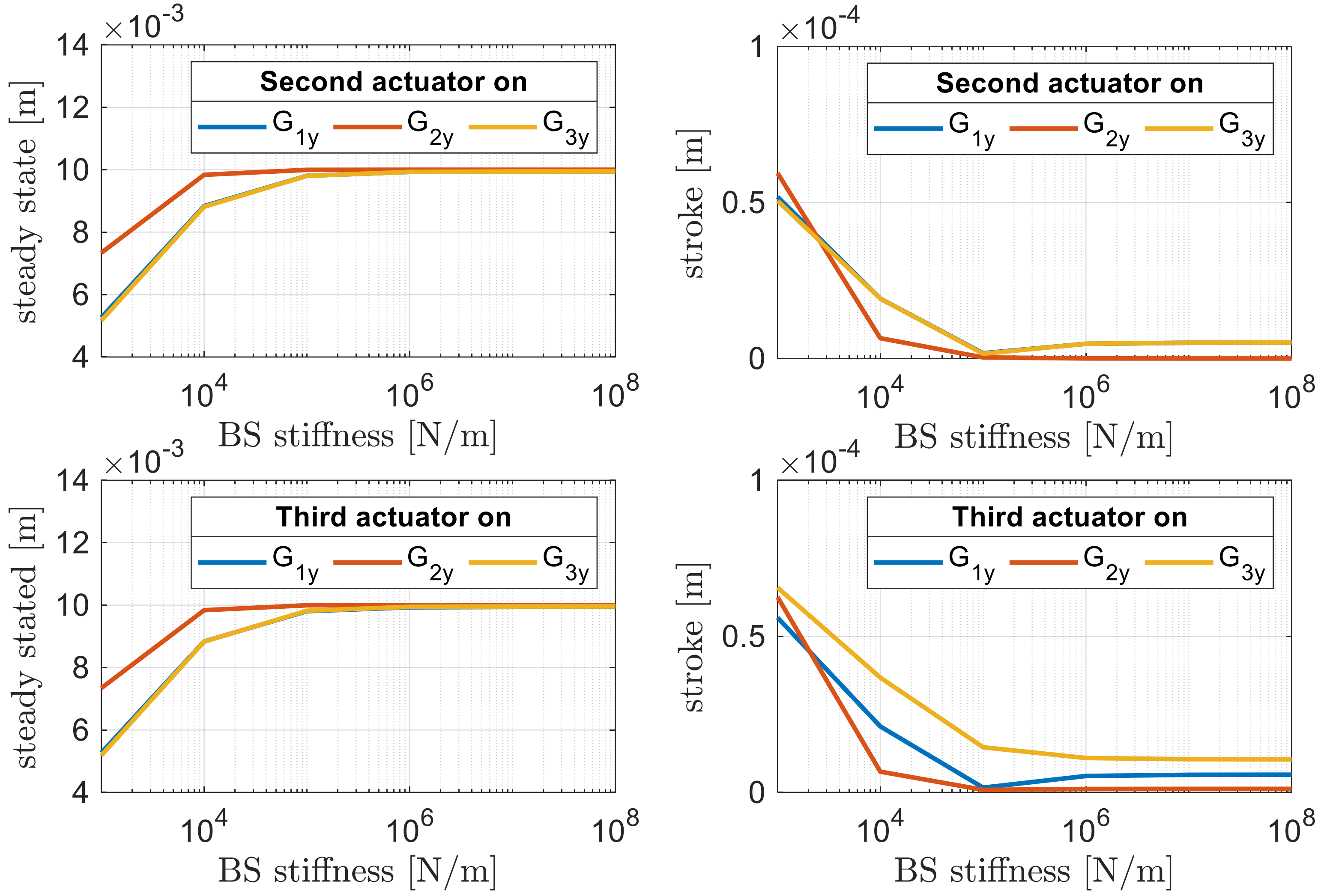
Simulations are conducted by keeping all parameters constant at nominal value listed below and changing only one of them ■ :

d = 0.01 m	k_{DEi}, i∈ {1, 2, 3} = 19.6 kN/m
w = - 0.01 m	k_{Si}, i∈ {1, 2, 3} = 19.6 kN/m
r_i, i∈ {1, 2, 3} = 0.0025 m	k_{Bi}, i∈ {1, 2, 3} = 10 MN/m
m_{DEi}, i∈ {1, 2, 3} = 0.0118 g	k_{Fi}, i∈ {1, 2} = 0 N/m
m_{Si}, i∈ {1, 2, 3} = 0.028g	d_{i0}, i∈ {1, 2, 3} = 0.02 m
m_{RFi}, i∈ {1, 2, 3} = 10 g	l_{DEi0}, i∈ {1, 2, 3} = 0.01 m
	l_{Si0}, i∈ {1, 2, 3} = 0.01 m



■ $k_{Bi} = [10^3, ..., 10^8]$: stiffness of the biasing system;

Second parametric study

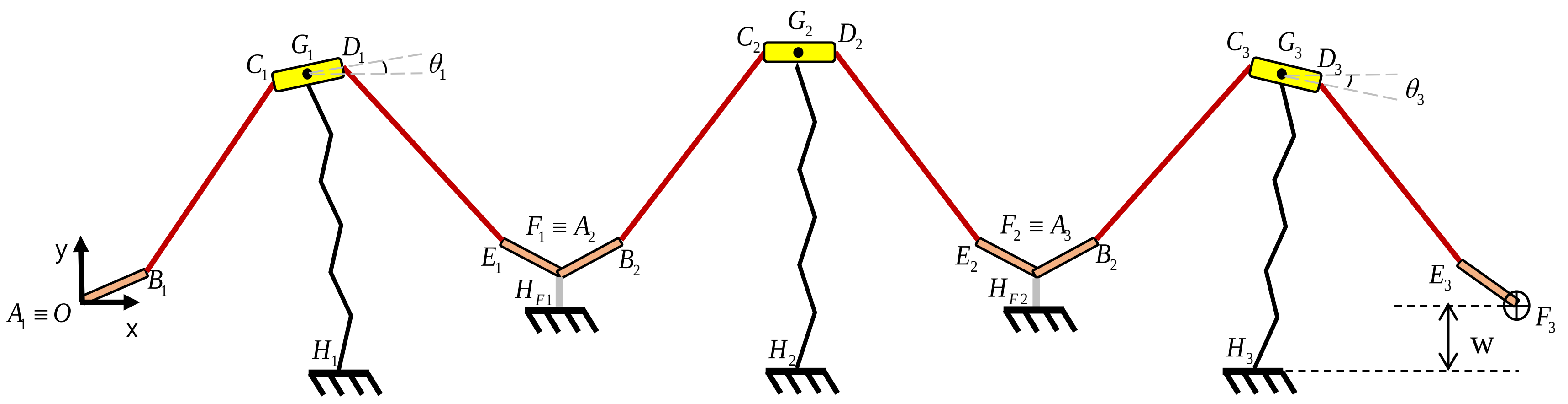


- Due to singular configuration (i.e., a quasi-flat DEA membrane which prevents an in-plane Maxwell stress to be transmitted out-of-plane), the effect of the actuation of the second DEA is more strongly affected than the remaining ones;
- Increasing the stiffness of the biasing system leads to larger steady-state values, but at the same time to a zero stroke .

Second parametric study

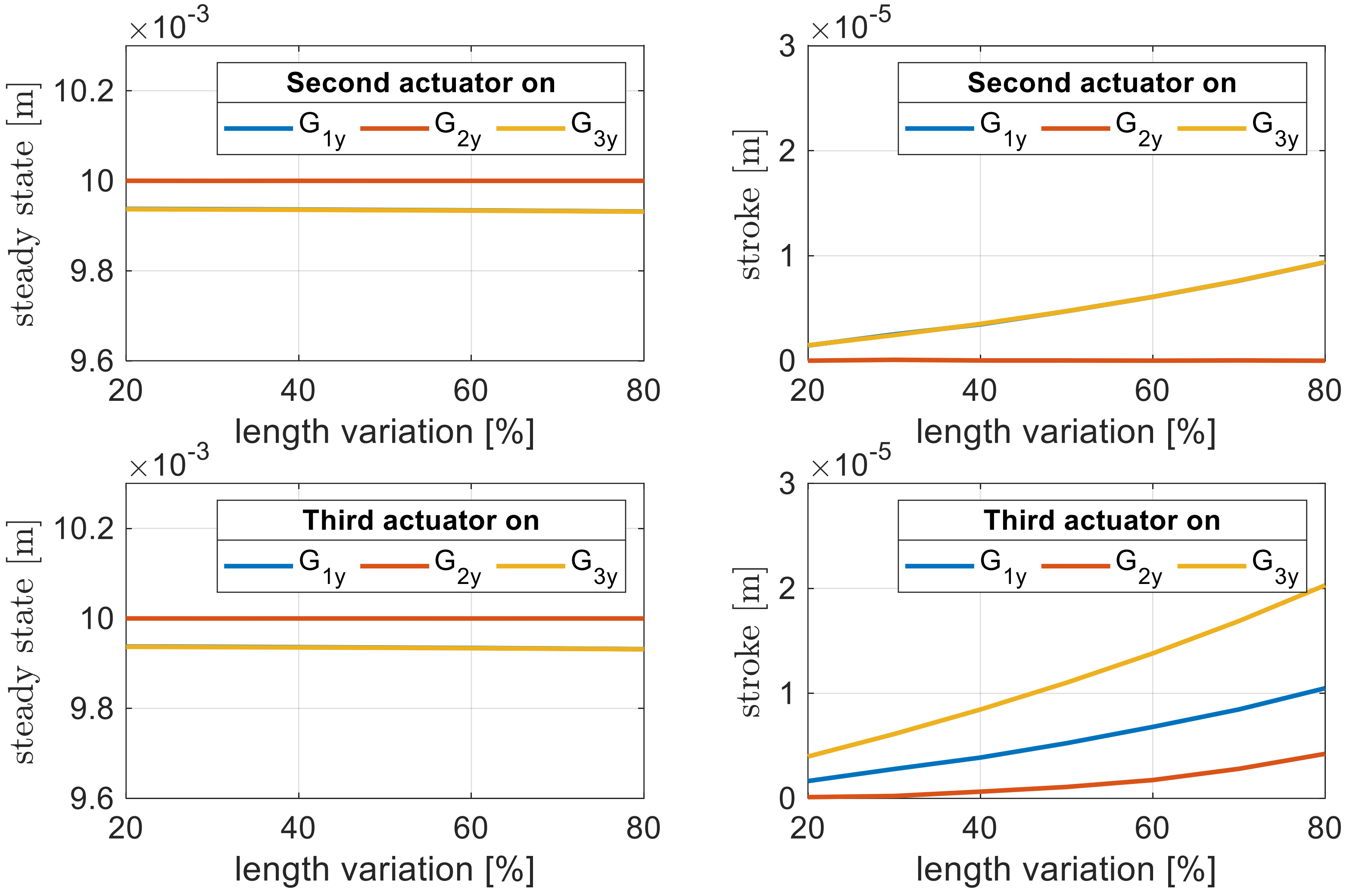
Simulations are conducted by keeping all parameters constant at nominal value listed below and changing only one of them ■ :

d = 0.01 m	k_{DEi}, i∈ {1, 2, 3} = 19.6 kN/m
w = - 0.01 m	k_{Si}, i∈ {1, 2, 3} = 19.6 kN/m
r_i, i∈ {1, 2, 3} = 0.0025 m	k_{Bi}, i∈ {1, 2, 3} = 10 MN/m
m_{DEi}, i∈ {1, 2, 3} = 0.0118 g	k_{Fi}, i∈ {1, 2} = 0 N/m
m_{Si}, i∈ {1, 2, 3} = 0.028g	d_{i0}, i∈ {1, 2, 3} = 0.02 m
m_{RFi}, i∈ {1, 2, 3} = 10 g	l_{DEi0}, i∈ {1, 2, 3} = 0.01 m
	l_{Si0}, i∈ {1, 2, 3} = 0.01 m



■ μ = [20%, ..., 80%]: percentage variation of the DE length (l_{DEi0}) relative to the sum of the DE and silicone lengths ($3\ l_{DEi0} + 3\ l_{Si0}$) ;

Third parametric study



- As the relative amount of DE increases, the stroke increases as well. This is expected, since the greater the portion of the membrane softened induced by the applied voltage, the greater the expected stroke.

Conclusions

The developed model is useful to accurately understand how the system parameters (i.e., geometry, bias force) affect the mutual electro-mechanical coupling among the many DEA taxels during actuation. The provided investigation showed that:

- The softer the connection between DEA taxels and rigid frame, the higher the influences between the actuators.
- Softer biasing springs and wider DE/passive silicone ratios have an overall positive effect of the actuation stroke.

The obtained results can then be used to guide the design and manufacturing of future DEA array systems. It will be possible to identify the optimal geometric combination of values that allows reaching the stroke and a desired configuration, without neglecting the electro-mechanical coupling effects that an actuator has on its neighbors.

Thanks for your attention