How To Design Your Polymer Artificial Muscle Actuator/ Sensor?

Marwa A Eldiwiny, Eric Cattan, Christian Duriez

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I. Summary:

Nature is a source of inspiration for scientists and engineers to design new systems and solutions. To the date, science still unable to unveil the secret behind the tiny complex soft creatures. Can you imagine creating a fly, or even a worm as same as in our world, there are basic compelling questions: Do the tiny soft creatures have soft brain, how far it is intelligent?; What are the mechanisms behind their agility in locomotion or even hunting likely in chameleon. These intriguing questions still unanswerable by scientists and engineers. We have a commitment for thinking of new soft cognitive materials that have the potential to replace the passive soft materials as well as replacing the rigid micro-controllers, sensors, and batteries. The first and foremost question we have to ask ourselves as scientists and engineers, Is the soft robot is going to fulfill the safety criteria to the human being?. Researchers argue how to define the soft robot, for answering doubtful question, Rus et al [2] have answered this question clearly, that the robot can be classified as hard or soft based on the compliance of the materials. In the other side, researches identify robot that makes continuum deformation as soft robot, while Rus illustrated that not all continuum robots are soft as it is composed of rigid materials. For reaching this goal, we must have rigorous modeling of soft robotics. Miniaturized soft actuators and sensors are important for such implementation in confined environment. There is a need for new soft materials, electronic conducting polymer(ECP), this material is still complex to understand their physical behavior. Unfortunately, There is a still discrepancy in understanding and modeling of the electro-chemo-mechanical actuators/sensors, that has been highlighted in this research paper[1] and it contradicts with these following approaches [3]. The most critical point is the desired frequency of the actuation, supposing that the time of the implant insertion is $10sec$ or less, thats means in general the time of actuation and sensing must be equal or less than the time of insertion. Here is the problem if the desired frequency of the actuation is very high which is already definite, thats means that may be the time that ions takes to migrate will not be sufficient to produce displacement or force because we stop them. The fact the four samples I did shows that even at low frequencies that still have slow response(very high rise time) and from my point of view that is the most critical point in the performance. *In this research, we also handle the issue high frequency actuator and its correlation with the rise time of the electronic conducting polymer, this parameter is very crucial for designing actuator based on specific application;* ***that is means that the time of the flight of the migrating ions to produce specific force and displacement must be smaller than the desired time of the all operation*** $t_f \leq t_o$, where they are time flight and operation respectively. Recently, the researches that have been conducting on ECP, there is not a methodology for designing the actuator/sensor; this due to the fact that models developed based on data mapping or even using fitting function which end up that we cannot answer the following questions: How will be the performance of ECP if we change the geometry, thickness?, How the force is going to change if we change geometry? all these questions is not explained yet.

II. Research Objective

Our research objective is designing a miniaturized soft actuator/sensor based on ECP, through our research we found as we mentioned earlier that recent models are not capable of answering the basic questions related to the ECP behavior. The first question is what are the desired features for actuating the system?. When it comes to electro-chemo-mechanical material, it is morecomplex, as this material is orthotropic. There is a research gap where we dont have a design methodology(computer aided design); one of these gaps occurs at this following research [4], when the conducting polymer flawed to actuate the cochlea implant, thats why there is a need for practical model that could design our actuator/sensor.

III. Research Contribution

we propose a white model for explaining and answering the observed physical phenomena occurs during the experimental work. Basically in this model, we focus on the electrostatic force generated among electrons and mobile ion while it is in air configuration. The prime point in this model is computing the stress induced by mobile ions on the electronic conducting polymer surface, equations are used for estimating the stress, while F is the coulomb force of attraction and repulsion forces. Through the model *we are capable of answering these following research questions: How is the relation between the mobile ion radius and the elementary electric charge radius for generating the force?; What are the conditions of generating force: the number of the interacting elementary electric charges and mobile ions?;*

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Why the generated force saturates in the electronic conducting polymer?; What is the correlation between number of ions in the ECP and geometry variation?; To which extent do clamping unit affect in the ECP performance?; Why do the curvature in the electronic conducting polymer occurs?; What is the correlation among time travel of ions, the rise time response, the thickness, and the frequency?; How to design your polymer artificial muscle actuator based on physics engine simulator?. Now we have results related to estimating the actual young Modulus of ECP which is developed in sofa framework [1] as depicted in figure(1). The most interesting the part is the relative geometry among one mobile ion and specific numbers of electrons, so the term added to couloumb law is $N_{local} * N_{ion}$. While performing verification step, the force calculated in the same physical range of measured blocked force by Femto force sensor, while our model has a high computation, so for tackling, we are going to use model order reduction for making computation faster. The following equations can estimate the force generated by the ECP, while the clamping plays a role in the deflection profile as $F_{free} < F_P$ as the free generated force increase, while the pressurized at the clamping point, the change in the ECP geometry is negligible, so the concentration of the ions is constant, while in the free part the concetration of ions decrease as the geometry change thickness decrease, and area increase and consequently force decrease.

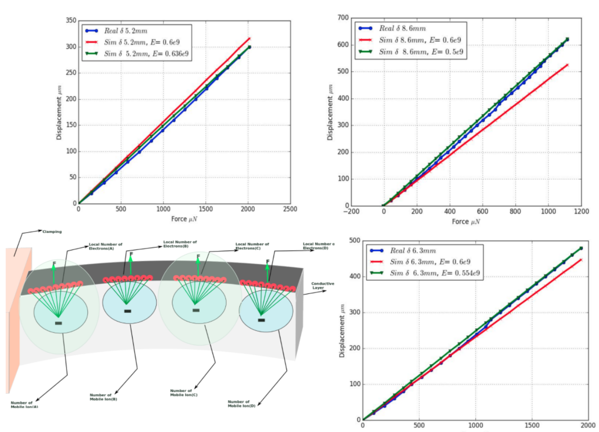

Fig. 1. The three graphs shows the results of estimating young Modulus based on Beam FEM element developed in SOFA physics engine. While the drawing of the beam shows the concept of our model that one ion could be repelled or attracted to million numbers of elementary electric charge.

$$q(t) = \frac{\int_0^T V(t)}{Z}, N_e(t) = \frac{q(t)}{e} \tag{1}$$

$$F = K\frac{q_i q_e}{r^2}, F_T(t) = \frac{q_e * q_i * K_e * N_{local}(t) * N_{ions}}{r^2} \tag{2}$$

where q_e, q_i are the charges of mobile ion and elementary electric charge.

$$F_i(t) = \frac{q_e * q_i * K_e * \int_0^T A_i(t) * \int_0^T L_i(t) * \sigma_e * \int_0^t V(t)}{r^2 * \int_0^T L_i^2(t) * e} \tag{3}$$

Where A_i is a specific area, σ_e is electric conductivity, $V(t)$ is the voltage.

$$\vec{F_i}(t) = \frac{q_e * q_i * K_e * \begin{bmatrix} e_{11} & \cdots & e_{1n} \\ e_{21} & \cdots & e_{2n} \\ \vdots & \ddots & \vdots \\ e_{n1} & \cdots & e_{nn} \end{bmatrix} \begin{bmatrix} th_2 \\ th_2 \\ \vdots \\ th_n \end{bmatrix} \cdot \begin{bmatrix} A_2 1 \\ A_2 2 \\ \vdots \\ A_n \end{bmatrix}}{\nu_i * r^2}$$

where η is the number of electron matrix layers surrounding one mobile ion; the other important term in our 3 dimensional model is the dot product between the desired th_2 and the A_2 and scalar divided by the volume of one ion ν_i so that we can know the number of the mobile ions interacting with electrons matrix. In this equation, we can compute the matrix of the electrons their rows and column relative to the mobile ion geometry.

$$F_T = \sum_0^T F_T(t) \tag{4}$$

If $N_{phi} = 0$ which is the number of ions, the new force generated equals zero, then saturation phenomena occurs.

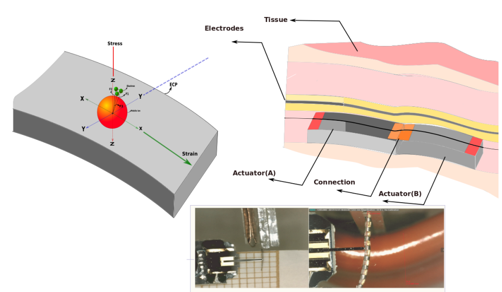

Fig. 2. The figure on the left shows the three dimensional problem, where the electrostatic force between one mobile ion and specific number of electrons related to geometry, as it illustrated the force is analysed to strain and stress. From the right, the application of using ECP as undulatory motion for actuating passive element(surgical application). The bottom figure, shows our experimental work for measuring ECP characteristics and stiffness of cochlea electrodes.

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