Multiscale Statistical Identification of Skin Nonlinear Characteristics in the Time Domain

Parnian Hemmati, Serge Dos Santos,

Jean-Christophe Pittet

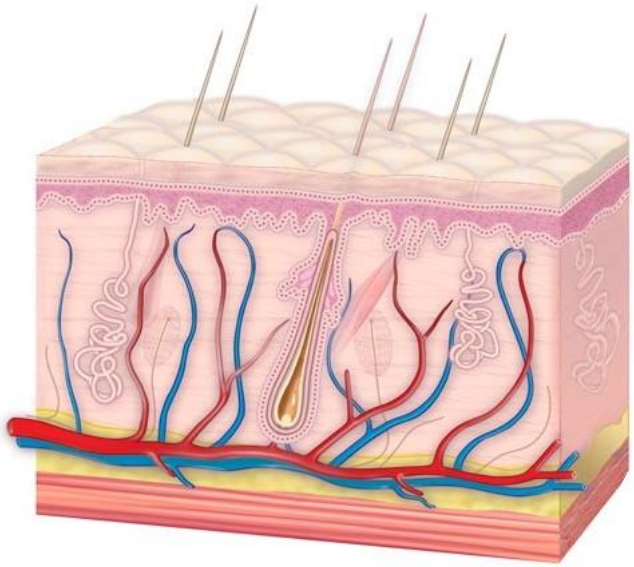
Presenter Parnian Hemmati

INSA Centre Val de Loire, Blois, France

Sharif University of Technology, Tehran, Iran

The study of skin

- Skin: anisotropic, nonlinear and viscoelastic [1]
- Memory effects and aging process[2]
- Not many *in vivo* studies, porcine skin as a model for human skin[3]



Previous Studies

	Authors	Year	Purpose	Outcome
1	Shull et al. [4]	2010	Nonlinearities of skin and its influence on user perception of rotational skin stretch	Human skin characteristics in case of rotational force and how the movements are distinguishable by the subject
2	Remache et al. [5]	2018	Defining mechanical properties of porcine skin	The hysteresis loop and the characteristics of the skin under cyclic stretching and stress loading
3	Bose et al.[6]	2022	Mechanics of collagen at different scales as one of the main components of skin	The mechanical properties of collagenous tissues and its variation range

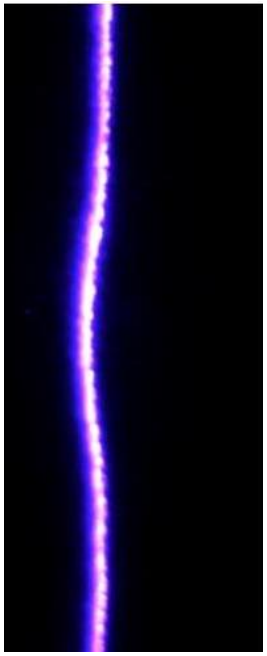
Purposes

- Study and extract the mechanical properties of skin
- Validate the results using Finite Element Method and simulation software
- Study the skin properties variation on a group of subjects after performing physical activities

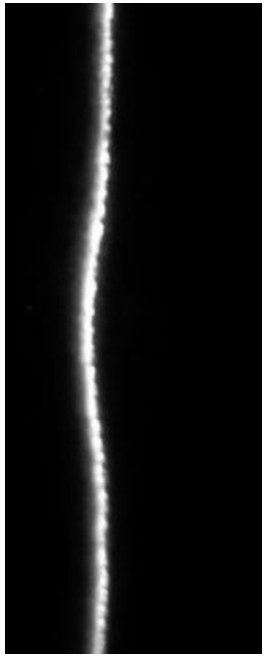
Test Setup and Subject

- Compressor, air blower, camera, laser for tracking the skin surface
- 23 year old, Female, Caucasian, left forearm
- Five different pressure groups, each three times

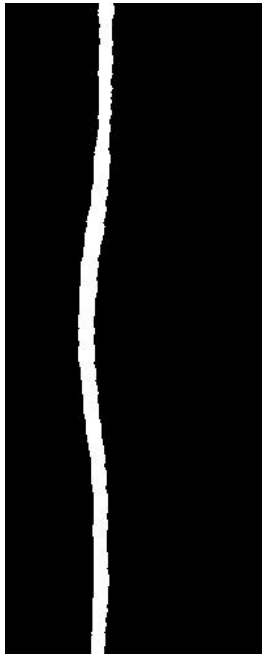
Processing the device output



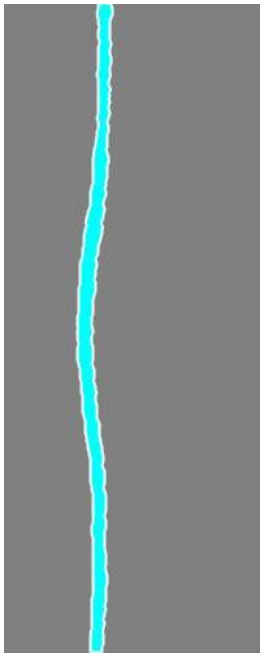
Frame extraction from video



Rgb2gray grayscale



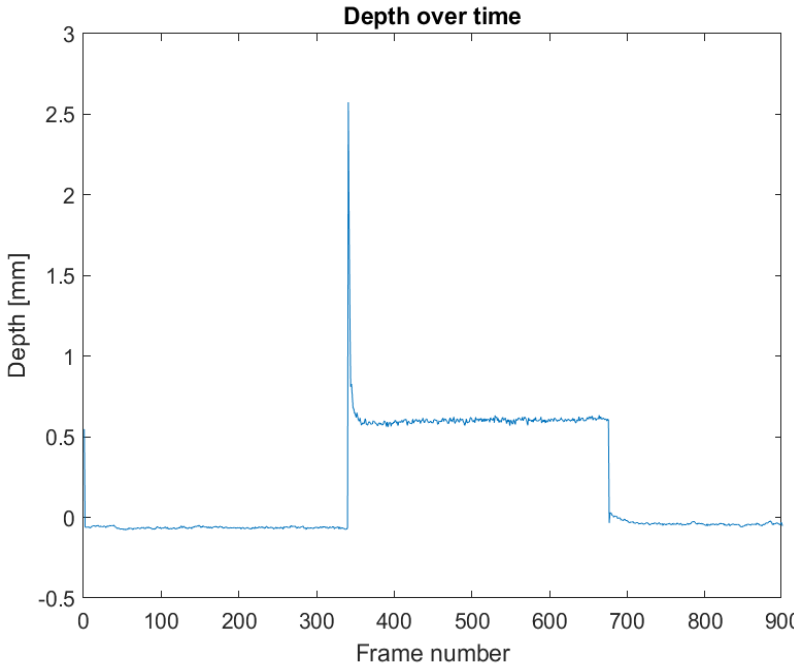
Imbinarize Binary Image

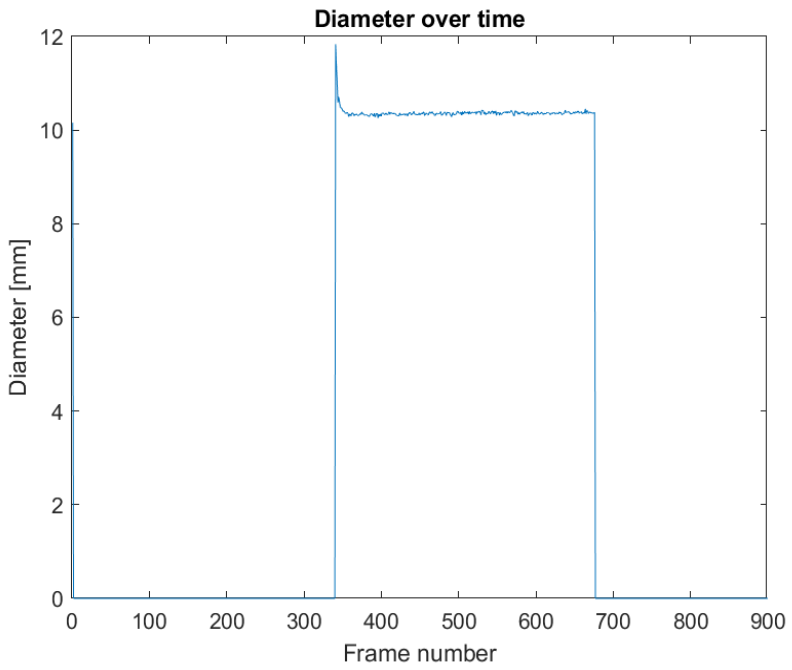


bwboundaries Matric of Boundary elements

Processing the device output

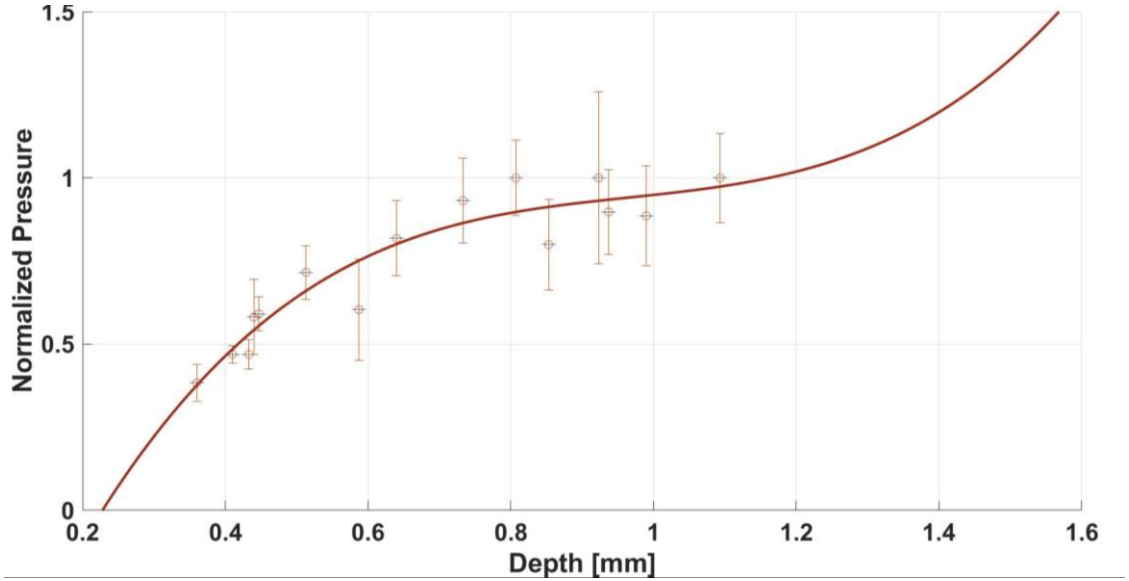
- Two dimensional, compressive and tangential force





Nonlinear behavior of the skin

- Viscoelastic Signature



$$f_{(x)} = p_1 x^3 + p_2 x^2 + p_3 x + p_4$$

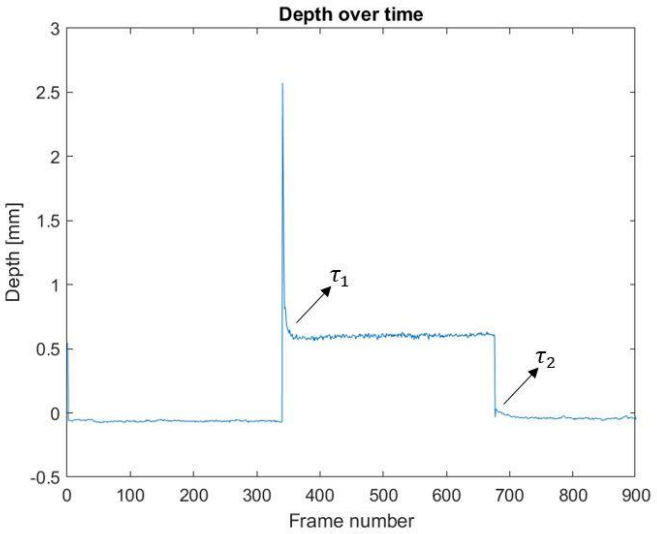
p_1	p_2	p_3	p_4	R^2
1.93	-5.59	5.621	-1.013	0.91

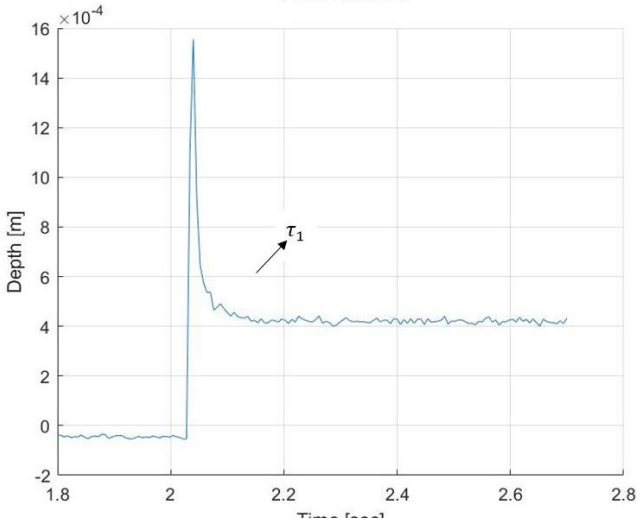
Nonlinear behavior of the skin

- Relaxation Rate

$$y = ae^{\frac{-(t-t_0)}{\tau}}$$

	1	2
a	15.56×10^{-4}	3.53×10^{-4}
t_0	2.04	4.04
τ	0.014 ± 0.002	0.006 ± 0.002

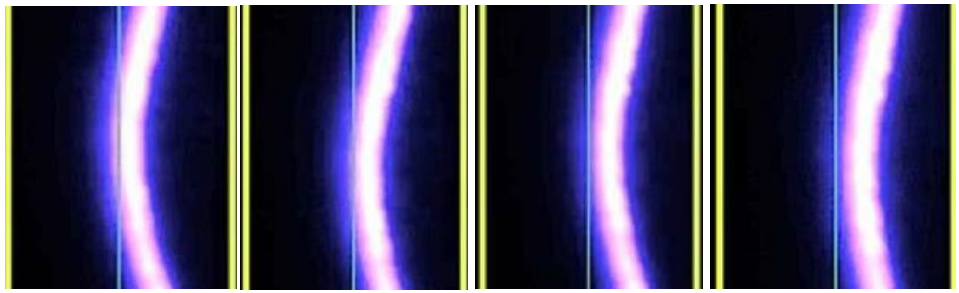


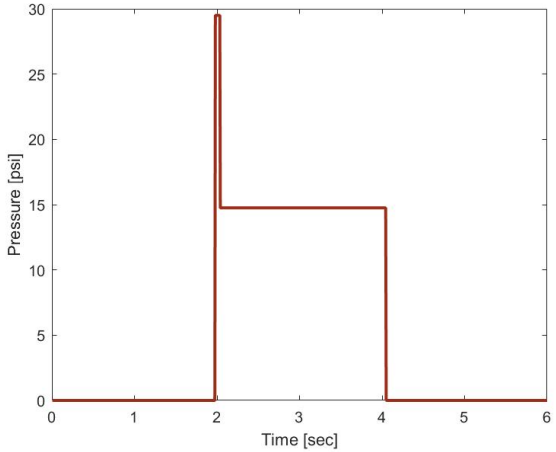


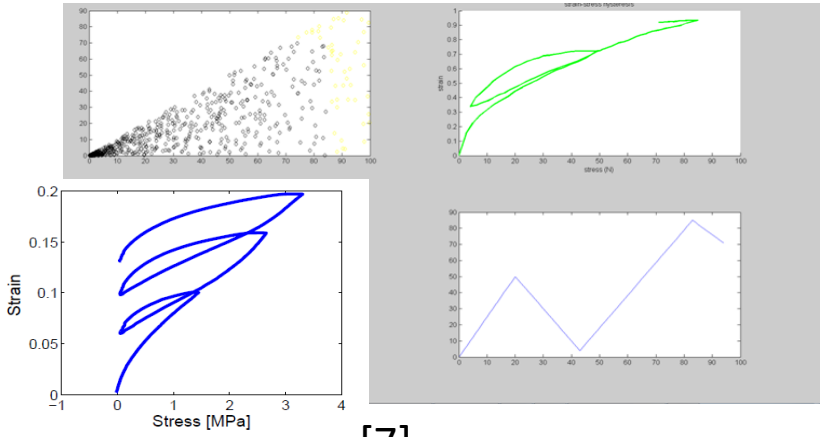
Nonlinear behavior of the skin

- Hysteresis

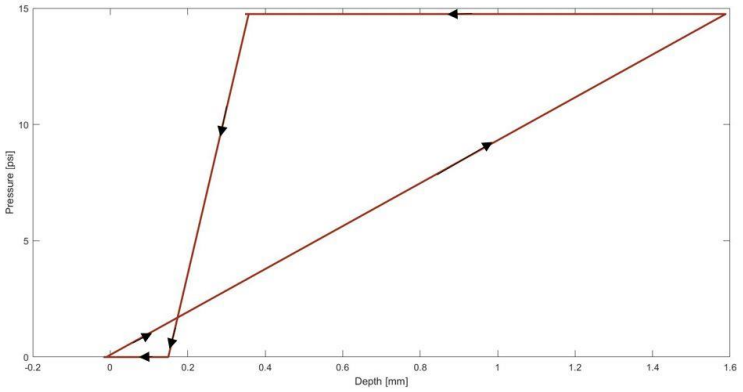
  Under cyclic loading-unloading







[7]



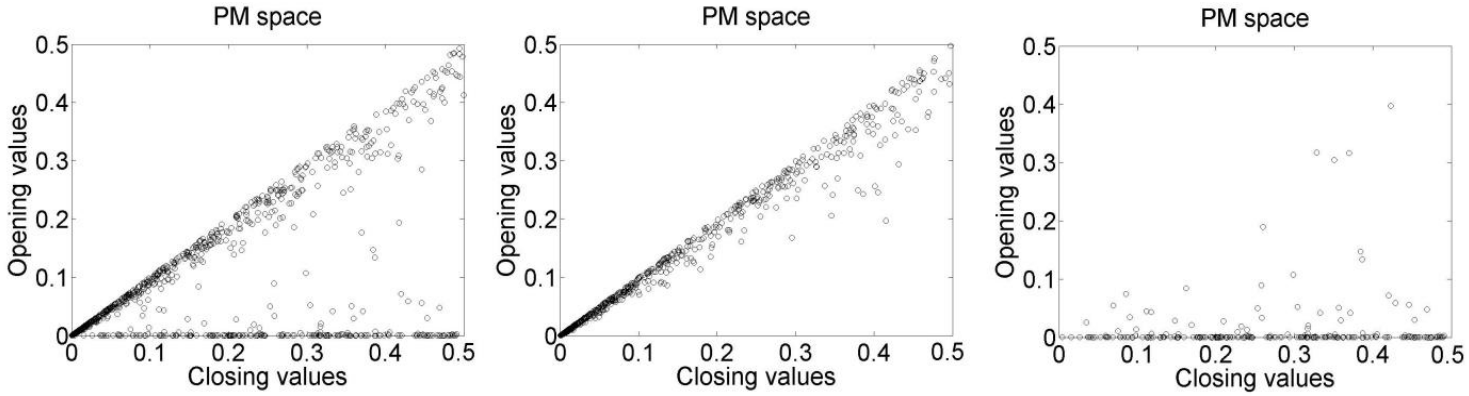
Nonlinear behavior of the skin

➢ PM Space [8]

Hysteron as elastic particle

$$k = \begin{cases} 1, & \text{if } \exists t^* : u(t^*) > P_c \\ & \text{and } \forall \tau \in (t^*, t), u(\tau) \in (P_o, P_c), \\ -1, & \text{if } \exists t^* : u(t^*) < P_o \\ & \text{and } \forall \tau \in (t^*, t), u(\tau) \in (P_o, P_c). \end{cases} \qquad \hat{\gamma}_{P_c,P_o}(u(t)) = \begin{cases} -1, & u(t) \le P_o, \\ 1, & u(t) \ge P_c, \\ k, & u(t) \in (P_o, P_c), \end{cases}$$

$$y(t) = \int\int_{P_o \le P_c} \mu(P_c, P_o)\, \hat{\gamma}_{P_c,P_o}(u(t))\, \mathrm{d}P_c\, \mathrm{d}P_o,$$

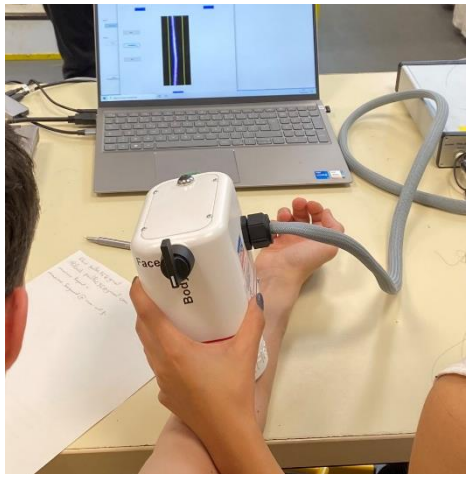


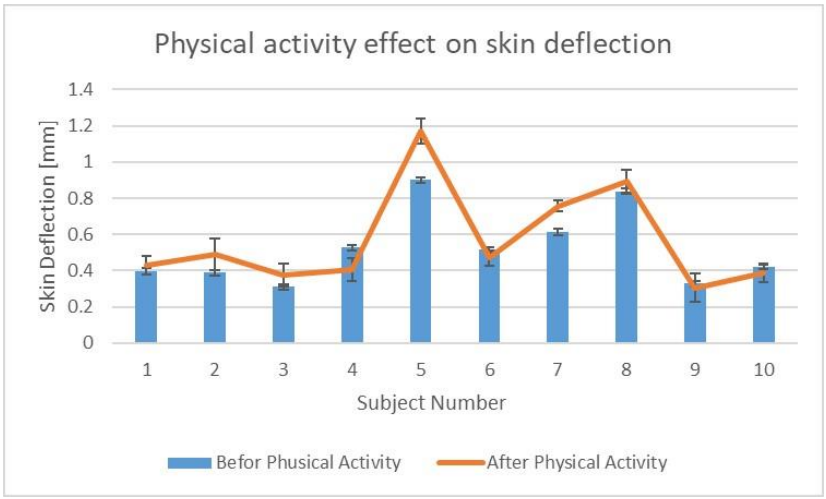
(a) PM space of porcine skin (b) Component Guyer 1 (c) Component Guyer 2

[8]

A Case Study

- 10 subjects before and after physical activity
- Change in the humidity percentage while an enhancement in blood circulation
- An Overall increase trend, the exceptional subjects did more sports and hence more adapted



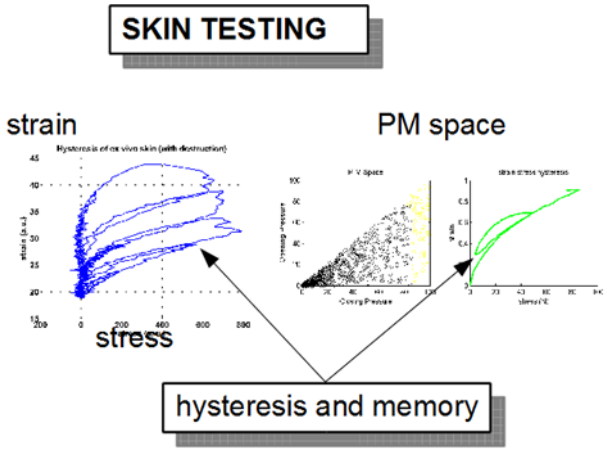


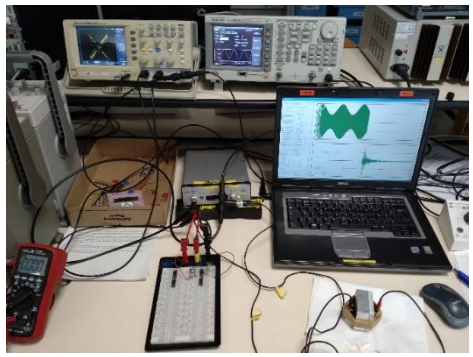
Conclusion and Future Perspective

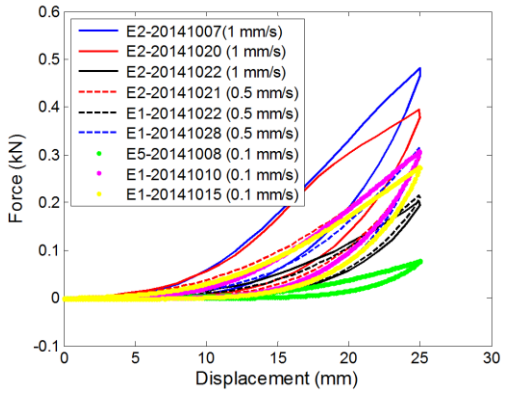
- The extraction of skin's mechanical properties including nonlinearity and relaxing time
- An *in vivo* case study showing the physical activity causes an overall increasing trend for deflection
- Validate the model using FEM simulation software
- Experimental studies on a more expanded sample of subjects concerning the hysteresis behavior and developing the final statistical model

Future Perspective

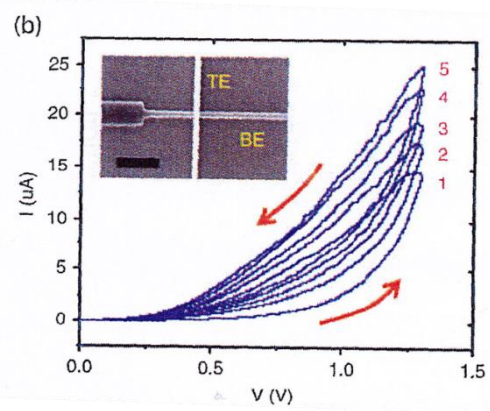
- Aging, memory, nonlinearity and hysteresis networks







Plasticity and memory properties



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