STUDY OF A BIOLOGICAL ACTUATOR AND SENSOR: THE MIMOSA PUDICA

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The Mimosa Pudica is an action plant that closes its leaves when given a stimulus. The plant integrates both sensing and actuating mechanisms, and the distinctive motion is about a hinge-like point, the pulvinus, making the characterization of the motion attractive. In this project, experiments were set up to measure the characteristics of the plants in the goal to estimate the possibility to produce micro-actuator based on a similar principle. The signal speed, the sensitivity, the actuator speed, the power, the torque produced by the plant were measured by using different sensors. The results showed that the torque is dependent on the diameter of the pulvinus and that actuator could reach a top angular velocity of 1 rad/s. We developed a phenomenological model to describe the behavior of the plant that could match experimental results and propose an original physical description of the mechanism inside the plant by considering a phase transition behavior instead of the classical ion channel model. Finally, the plant actuator energy density is also compared with other known micro-actuators and the possibility to use the plant as a micro-actuator is discussed.

Keywords: Mimosa Pudica; Micromechanical; sensor; actuator.
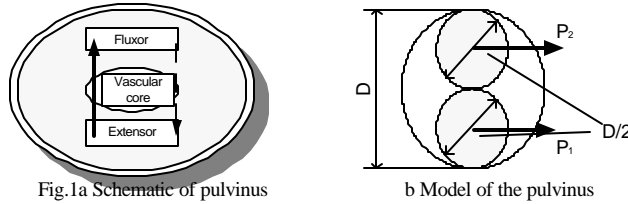
1. Introduction

The *mimosa pudica* is a plant belonging to the family of Leguminosae. This family of plant has compound leaves and pulvinus, a bulbous structure that grows on the side of the stems. It is originated from Brazil but is commonly found in the tropical zone where it is most conducive for growth. The leaves of the *mimosa pudica* when excited by a stimulus in the form of shock will be set into motion. To date, many works had been done on the transmissions of signals in the plant and the many mechanisms that are associated with the stimulations, but none had been able to explain how the plant senses [1-5]. In addition, there is also a lack of study and literature of the plant based upon a mechanical engineering viewpoint.

Hence, it will be appealing if a study on the mechanical aspects of the motion of the plant is done; and the movements of the plant along with its sensing and actuating mechanism are characterized and defined.

2.   Motion model

The mechanical motion of the plant can be described by a purely phenomenological model, as proposed by *Kagawa, et al* [6].

In Figure 1a, the schematic cross section of a typical pulvinus is shown. We assume that the petiole deflection is caused by the loss and gain of turgor pressure, also called osmotic pressure change. It is the only mechanism available to the plant for movement.

Fig.1a Schematic of pulvinus   b Model of the pulvinus

If we assume that the change in pressure between the extensor, P_1, and fluxor, P_2, is constant, and that both regions are circular, the moment can be estimated to be proportional to the cubic of the diameter of the pulvinus as:

$$M = ap\left(\frac{1}{4}\right)^3 (P_1 - P_2)D^3 \qquad (1)$$

3.   Experiments

The motion of the plant was recorded using a digital camera and the chart below shows the displacement of the petiole versus time. Upon stimulation, the petiole accelerated from rest to a maximum angular velocity of approximately 1 rad/s before finally settling down to rest at its final position after approximately 2s.
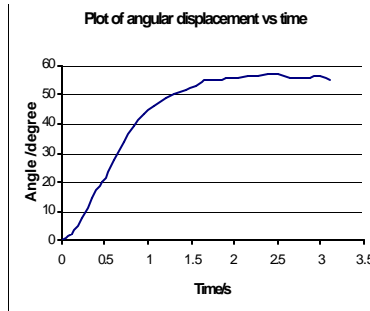

Fig.2. Plot of angular displacement vs. time.

The torque (or force) produced was measured using a micro-force sensor (Figure 3a) after a stimulus (naked flame) has been applied to the plant.

Figure 3b show the relationship between torque and pulvinus diameter, which shows a modest agreement with the equation (1) plotted as a solid curve. This result shows that the torque produced by the *mimosa pudica* depends on the diameter of the pulvinus, and most probably elevated to the third power as suggested by the model. However no defini-

tive conclusion can be reached due to the small spread of pulvinus diameter that was used in the experimentation. This limitation has two origins, on the one side the difficulty to
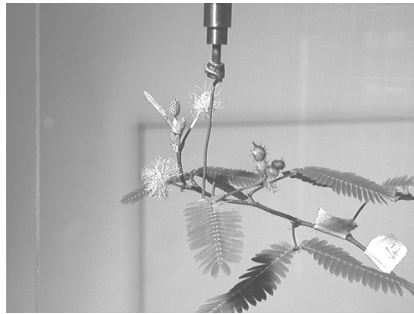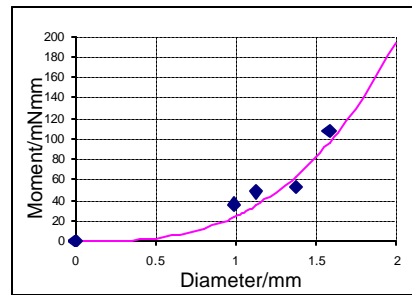

Fig.3a. Photo of petiole torque acquisition

b Plot of mean moment vs. diameter.

grow large specimen and on the other side the difficulty of the force transducers to measure the smaller torque.

4. Discussion

The motion mechanism was reported to be caused by ion pumps and channels on the surface of the motor cells [6]. However recent theory [7] debunked the existence of ions pumps and channels but instead advocated a new approach to understanding cell dynamics.

There we consider cells as a gel mixture where the transportation of ions through cells is achieved through phase transition. The phase transition expected is the physical change of polymer (i.e., protein) strains from long to short configurations and vice versa. In the long configuration, water is structured but in the short configuration, the water is dispersed and there is no order. The process is completely reversible. In the cell, once triggered by a change in the environment, the polymer, say originally in the long configuration, will contract and depolarise water. The change will propagate in the direction away from the disturbance source and through cooperativity, "a change that increases the propensity for additional change in the same direction" [7], polymer strains will continue this transition until the short state is reached.

In the plant, the phase transition change can be seen as the bulk movement of water into and out of the upper and lower motor cells of the pulvinus creating the pressure difference and the actuating torque. The cooperativity can be readily observed from the response of the plant to a stimulus. The plant is seen to react to the stimulus nearest to the source first and then closing of the leaves in a falling domino fashion.

Another interesting feature of the cell-gel theory is the source of the trigger. As long as the cells are stimulated above a threshold level, phase transition will inevitably occur. From the position of the *mimosa pudica*, the stimulus can be either mechanical stress or thermal stimulation. These stimuli impart energy into the plant and as observed, the greater the change in energy, and the faster the response from the plant.

Furthermore, the bulk transportation of water due to phase change could tie up the relationship between the sensing and actuating mechanisms. A close loop is formed whereby there is a control signal from the 'sensors' of the plant to the 'motor' of the plant. It adds further credence that the process takes around 2 seconds to complete and around 10 minutes to be restored because the restructuring process could take longer than the destructuring process due to the need to restore order in the water structure – whereas ion channel and pumps should work at the same speed in both cases.

In Table 1, we finally compare the mimosa other actuators [8].

Table 1: General Comparisons of Mimosa Pudica with Motors and Human Skeletal Muscles.

Type of Motor	Torque/Mass	Power/Mass
	Nm/kg	W/kg
Sarcos Dextrous Arm (electro hydraulic)	120	600
McGill/MIT Electromagnetic Motor	15	200
Polyacrylic Acid/polyvinyl Alcohol polymeric Actuator	17	6
NiTi Shape Memory Alloy	20	6
Human Biceps Muscle	20	50
Mimosa Pudica	6.95	6.95
Burleigh Piezoelectric Inchworm	3	0.1

If in terms of torque per unit mass, *mimosa pudica* ranks only second from bottom, its power storing capacity is comparable to shape-memory alloy that could make it an interesting device for miniature actuator, that does not need high speed.

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