Studying the Mechanical Response of Petiole of Mimosa Pudica Following Exposure to DC Electrical Stimulation: An Attempt to Demonstrate through Electrical Model

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Abstract:

Acharya J. C. Bose had demonstrated through his biophysical experiments that like excitable animal tissues, the excitable plant *Mimosa pudica* exhibits characteristic response to polar electrical stimulation. He had established that under bipolar method of excitation, i.e. when the electrodes are connected to the pulvini (motor organ) of the plant, the cathodic petiole showed drooping response (mechanical response) but there was no such response at the anodic side. In recent times, similar electrophysiological experiments have also reported the ability of *Mimosa* to detect the polarity of the DC electrical stimulus. However, there exists a research gap in quantification of mechanical response of the plant under in vivo condition, following exposure to DC electrical stimulation. In light of this, in the study the mechanical response of the petiole of the sensitive plant *Mimosa pudica* was quantitatively studied using image processing in order to find out the characteristic difference in the response pattern of the plant with respect to polarity of the stimulating electrode, following exposure to DC electrical stimulus. In addition, an electrical model has also been developed based on the mechanical response pattern of the plant. The developed electrical model may be used for conceptual demonstration of the mechanical response of the plant, for educational purpose.

Keywords: Mimosa pudica, mechanical response, quantification, image processing, electrical model

1. Introduction

It is widely known that the sensitive plant *Mimosa pudica* exhibits thigmonastic or seismonatic movements in response to tactile, thermal and electrical (AC pulsatile mode) stimulation. Studies have shown that such thigmonastic movement is primarily regulated by electrical signal transduction and it is a hydroelastic and reversible process. The study of plant electrophysiology was fundamentally shaped by the pioneering work of Acharya J. C. Bose, who first demonstrated that plants possess a sophisticated sensory system comparable to excitable animal tissues. Through his rigorous biophysical experiments, Bose illustrated that the sensitive plant, *Mimosa pudica*, exhibits distinct mechanical responses to electrical stimuli. A cornerstone of his findings was the observation of polar electrical stimulation: using a bipolar excitation method, he noted that the cathodic petiole triggered a rapid drooping response (the motor organ's mechanical reaction), whereas the anodic side remained unresponsive [1].

In contemporary research, these findings have been reaffirmed. Modern electrophysiological studies continue to report the *Mimosa's* remarkable ability to detect and differentiate the polarity of Direct Current (DC) electrical stimuli [2]. This sensitivity to polarity suggests a complex internal signaling mechanism within the pulvinus, the plant's specialized motor organ. Due to the characteristic response nature of the plant to DC electrical stimulation, research based on development of equivalent circuit are on the rise because *Mimosa* is presently considered to be a suitable model organism for development of bioengineered sensors and related technologies [3]. However, despite our qualitative understanding of these phenomena, a significant research gap remains regarding the quantification of these mechanical movements. Most existing studies focus on the presence or absence of a response rather than the measurable dynamics of the petiole's movement following polar electrical stimulation.

To address this gap, the present study focuses on the quantitative analysis of the mechanical response of *Mimosa pudica* under DC electrical exposure. By utilizing image processing techniques, the study aimed at measuring the displacement and response patterns of the petiole to identify characteristic differences with respect to the electrode polarity. Furthermore, this research bridges the gap between biological observation and engineering by proposing an electrical model derived from these observed mechanical patterns.

2. Methodology

For the study, the intensity of the DC voltage was 4.58 V. The electrical model was developed using a combination of LEDs (as the response indicator) and diodes. In the study for developing the electrical circuit based on the polar electrical response of the model plant *Mimosa pudica*, the plant was stimulated with 4.58 V sing a developed DC stimulator apparatus (Fig. 1). The stimulus was applied at the two pulvini (left and right) of the plant (the main responding organ) by means of two fine coiled Cu stimulator electrodes. The polarity of the two electrodes was altered by means of the DPDT switch. The over view of the experimental set up has been illustrated in Fig. 1 and the details have been reported in a previous study conducted by Roy et al [4].

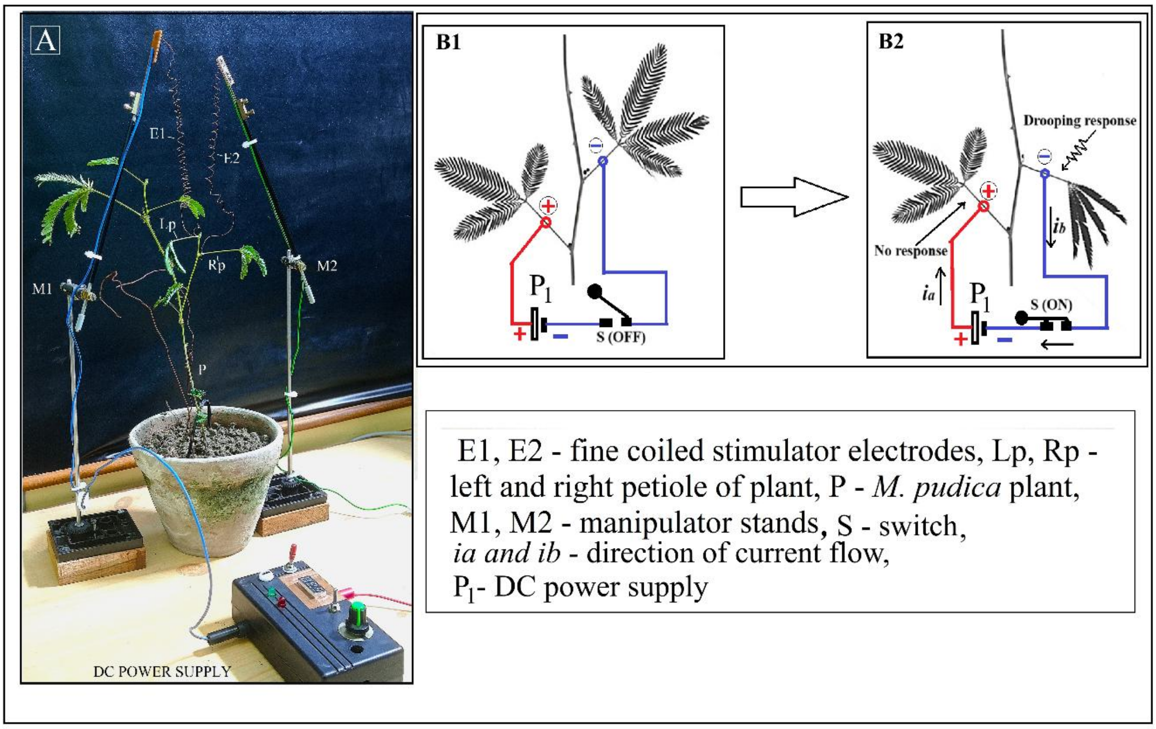

Figure 1: The whole experimental set-up: (A) Pictorial Representation of the Experimental set-up and Schematic Representation of the set-up: (B1) Before and (B2) After Stimulation

The DC power supply that was developed consisted of a Lithium ion battery (Li-ion) battery which served as the DC voltage source, a DC-DC step-up module for varying the input voltage intensity range from 3.78 V – 57.0 V through a potentiometer, a DPDT switch for altering the polarity of the electrical current during experimentation, as per the necessity, and an integrated digital display for monitoring the intensity of the DC voltage. As seen in Fig. 1, the two stimulating electrodes were placed at the left and right petioles of the plant and the electrodes were connected to the DC power supply. The polarity of the two electrodes was altered using the DPDT switch of the power supply and the response of the plant (mechanical drooping response) was noted at a constant voltage intensity of 4.58 V, each time the polarity was altered.

The developed electrical model consisted of diodes and the DC power supply. For developing the equivalent circuit, two different types of diodes were used – a) Light Emitting Diode (LEDs) and b) junction diodes (Fig. 2). In addition, some connecting wires, connectors, color coded alligator clips and breadboard were used. The circuit details of the electrical model have been presented in Fig. 7 (a and b).

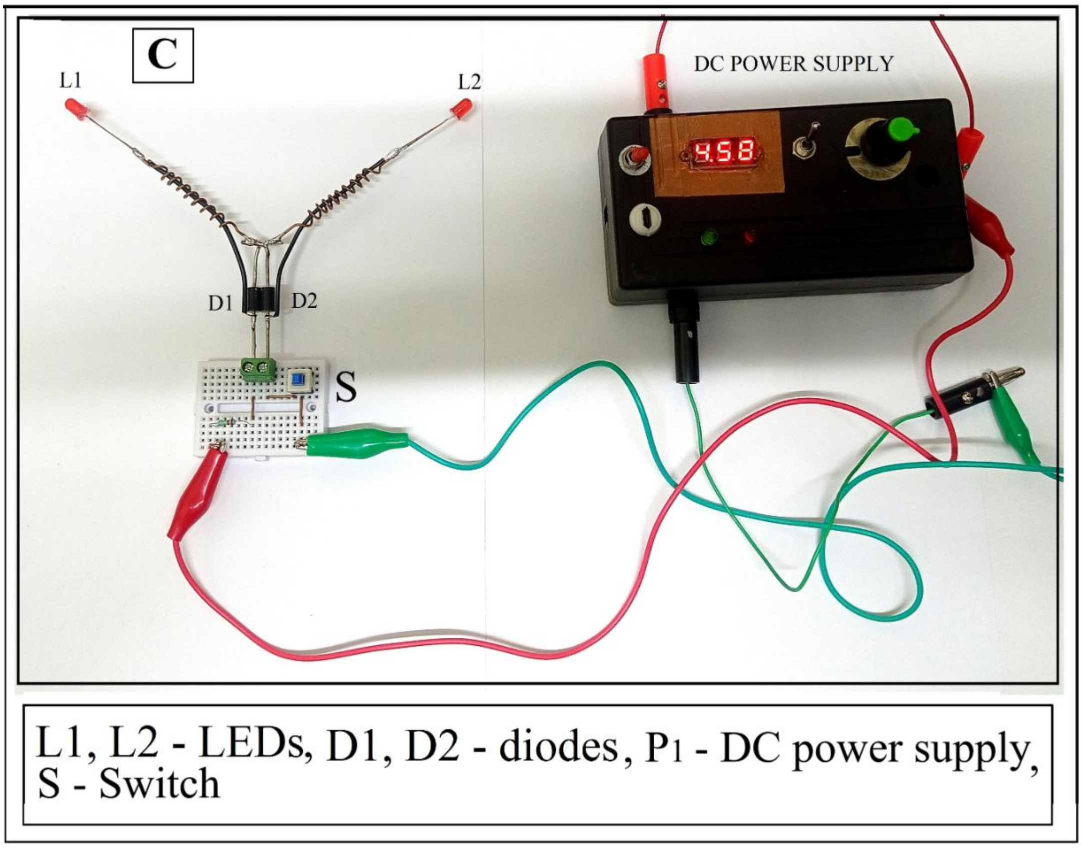

Figure 2: The Developed Electrical Model with the Developed Power Supply

Quantification and Statistical Analysis

The mechanical response of the plant was quantified in terms of difference in petiole tip position, before and after stimulation with respect to the polarity of the stimulating electrode, i.e., between cathodic side and anodic side. The response dynamics was also quantified in terms of the average velocity of the petiole drooping during the 4 s time period. The petiole tip position was tracked using the imageJ image processing software. The data was then subjected to ANOVA statistical analysis to find out any significant difference in the mean value of the petiole tip position (measured in pixels, px), before and after stimulation, between the cathodic side and anodic side.

3. Results

The mechanical response of petiole was quantitatively studied in terms of three aspects – comparison of mean value of the petiole position along Y axis before and after DC polar electrical stimulation between cathodic and anodic stimulating petiole, tracked points of the leaflet tip of the stimulating petiole (through image processing) along Y axis (px) with respect to total no. of frames (recorded at 30 fps) after anodic and cathodic stimulation and average velocity of petiole drooping during 4 s time interval through time vs displacement curve.

From the study it was found that the mean value of the petiole position along the Y axis was 360 px before stimulation and 392 px after stimulation under cathodic (negative polarity) stimulating condition. However, under anodic (positive polarity) stimulation it was found that the mean Y axis value before and after stimulation was same, i.e., 400.75 px. The mean values have been graphically presented in Fig. 3.

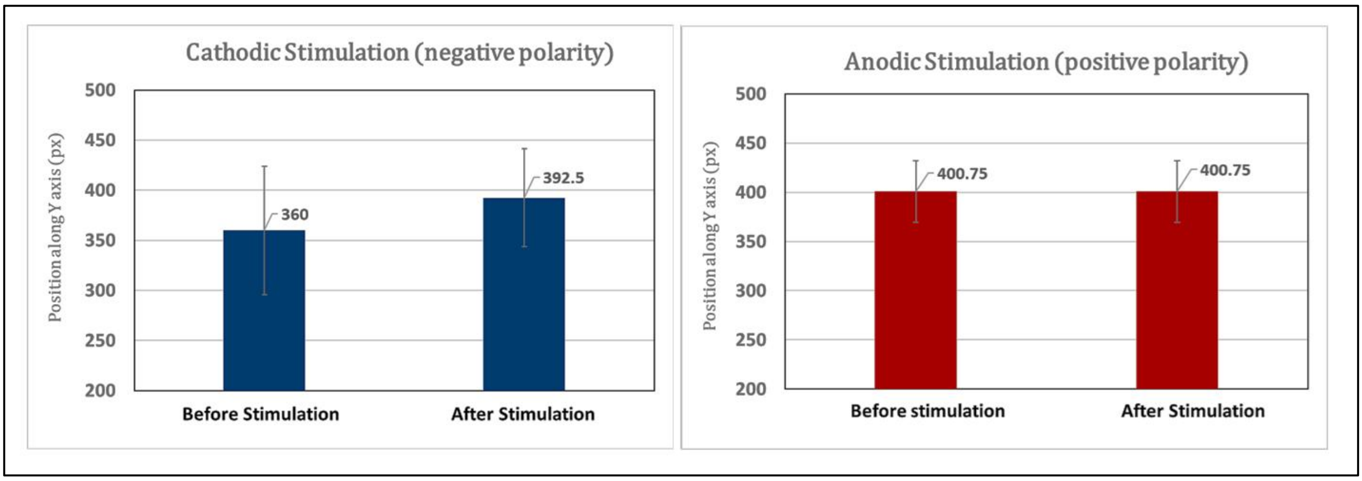

Figure 3: Graphical Representation of the Mean Y-axis value (px) of the Petiole Tip Before and After Cathodic Stimulation and Anodic Stimulation

After tracking the leaflet tip, with respect to total number of frames (frame rate being 30 fps and total duration being 4 s), using the image tracker software it was found that after cathodic stimulation there was a change in Y axis value (px) in each of the frames, thereby indicating an overall drooping of the petiole (mechanical response) during the 4 s time period (Fig. 4).

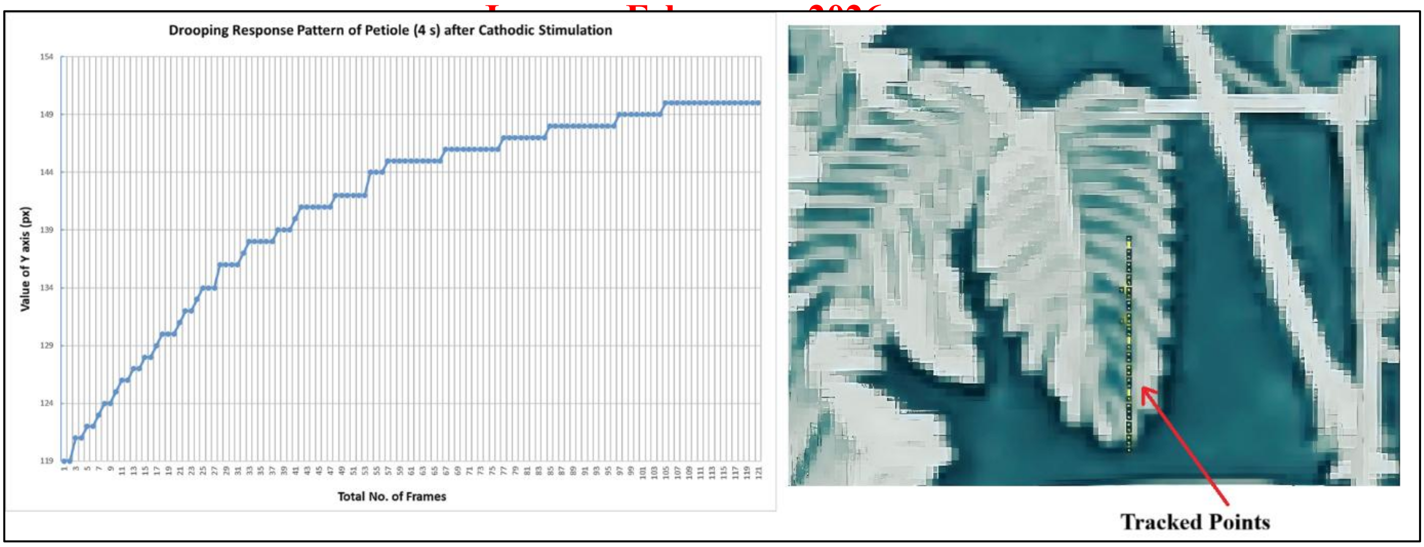

Figure 4: The Drooping Response Pattern of the Cathodic Petiole as obtained from the Tracked data points (Y-axis px values) for each of the Frames

On the contrary, after anodic stimulation no change was found in the tracked points of the Y axis value (px) in the total number of frames during the 4 s time period, instead a constant Y axis value of 175 px was found from the tracked data points, in the anodal state. The tracked points of the Y axis have been presented in the Fig. 5.

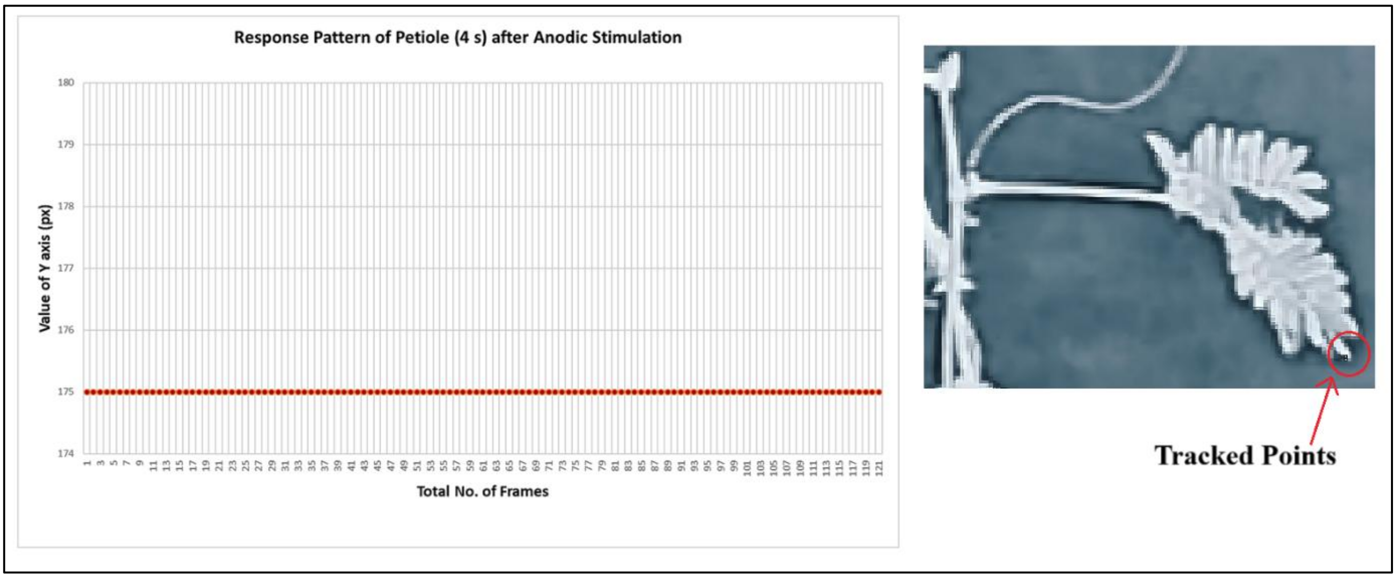

Figure 5: The Drooping Response Pattern of the Anodic Petiole as obtained from the Tracked data points (Y-axis px values) for each of the Frames

In the study, the average velocity of the petiole drooping within the 4 s time interval was also quantitatively studied. From the characteristic time-displacement curve, as seen in Fig. 6 it was found that the drooping response initially showed acceleration between 0-1 s, followed by a deceleration phase after 1 s, which continued till the rest of the period (total curve duration being 4 s).

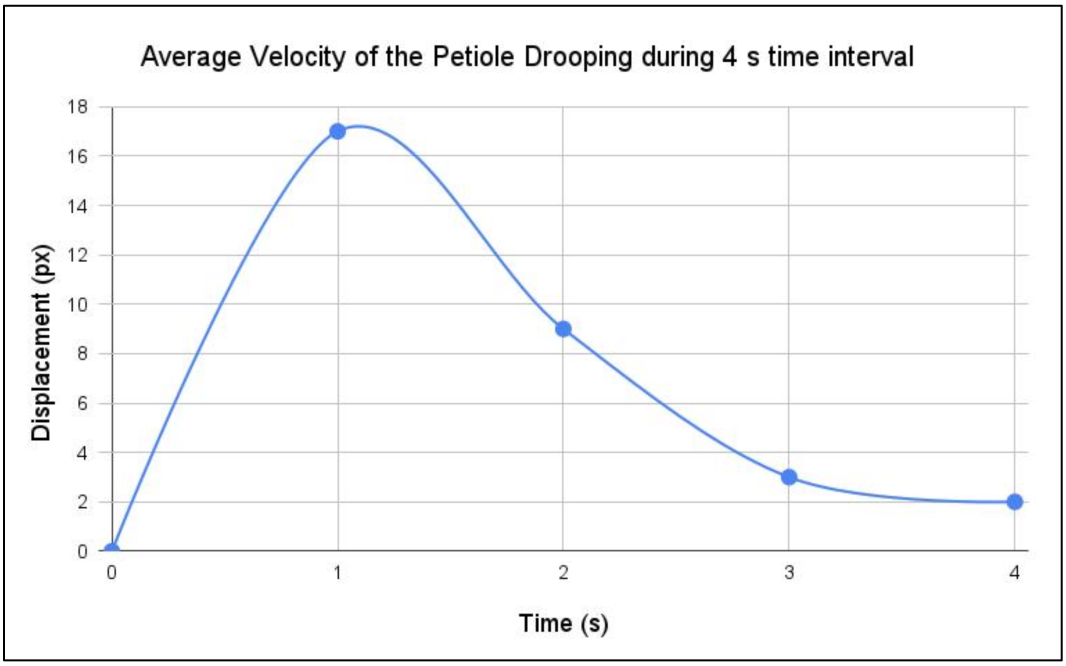

Figure 6: Figure: The Characteristic 'Time-Displacement Curve' of Mechanical Response of the Petiole of Mimosa following exposure to Cathodic Stimulation

In the study the difference value was also computed by subtracting the Y axis value (px) between initial and final petiole position. The values have been presented in Table 1. From the study it was also found that the mean difference value (px) was significantly higher (P<0.05) in the cathodic stimulation petiole in comparison to that of the anodic stimulation petiole.

Table 1: Tabular Representation of the Y-axis values of the initial and final positions of the tip of the Cathodic and Anodic Stimulation Petiole

No. of Samples	Cathodic Stimulation Petiole [(-) polarity]			Anodic Stimulation Petiole [(+) polarity]		
	Initial Position (px)	*Final Position (px)*	*Difference (px)*	*Initial Position (px)*	*Final Position (px)*	*Difference (px)*
1	268	324	56	360	360	0
2	367	394	27	414	414	0
3	414	438	24	396	396	0
4	391	414	23	433	433	0
AM ± SD			**32.5 ± 15.759** *	**AM ± SD**		**0**

*$P < 0.05$

4. **Discussion**

In the present study, the mechanical response of the petiole following exposure to polar electrical stimulation (DC) was quantitatively studied and the characteristic response of the petiole with respect to polarity of the stimulating electrode was demonstrated through development of an electrical model. The mechanical response was analysed in two phases – before-stimulation phase and after-stimulation phase. In the before-stimulation phase, the mean value of the position of the petiole tip along the Y axis (px) was computed. In the after-stimulation phase, in order to distinguish the characteristic nature of the plant response corresponding to the stimulating electrode polairty, the response was subjected to further image processing and statistical analysis. The drooping pattern was tracked for each of the frames in both, post-cathodic and post-anodic stimulated petiole, to find out the true nature of the petiole drooping. The tracked data points indicated that in the post-cathodic stimulation petiole the drooping response exhibited a stair-step nature, as observed from the Y axis value (px) at each of the frames (Fig. 4). However, in the post-anodic stimulation petiole since the petiole did not exhibit any mechanical response, a constant Y axis value of 175 px was recorded for each of the frames (Fig. 5). Moreover, upon plotting the average velocity of the drooping, it was found that the petiole exhibited a biphasic pattern, with initial accelration within 0 – 1 s followed by a decceleration, from 1 – 4 s (Fig. 6). The mean Y axis value (px) of the difference in cathodic stimulation petiole between initial (before stimulation) and final (complete drooping / 4 s after stimulation) position was computed to be significantly ($P<0.05$) higher than that of the anodic stimulation petiole (Table 1). Thus, from the study, after analysing the response dynamics of the petiole drooping it was evident that the cathodic polarity of the stimulating electrode was responsible for inducing the mechanical response following DC electrical stimulation. The response dynamics was computed by tracking the petiole movement (in px) for each of the frames from the experimental videographic data. Studies conducted in the recent past have also used similar parameters for analysing the movement of the petioles following exposure to stimuli [5].

The study also involved development of an electrical circuit that may serve as a model for demonstrating the charcteristic response of the petiole of the plant corresponding to the polarity of the stimulating electrode of the DC electrical stimulus. The electrical circuit consisted of 2 pairs of diodes – each pair (left and right side) consisted of one junction type standard silicon diode and LED (L1 [left side] and L2 [right side]). When the negative terminal of the DC power source was connected to the diode pair of the right side, only the right LED (L2) would light up (Fig. 7 (a and a1)) and when the negative terminal of the DC power source was connected to the diode pair of the left side, only the left LED (L1) would light up (Fig. 7 (b and b1)).

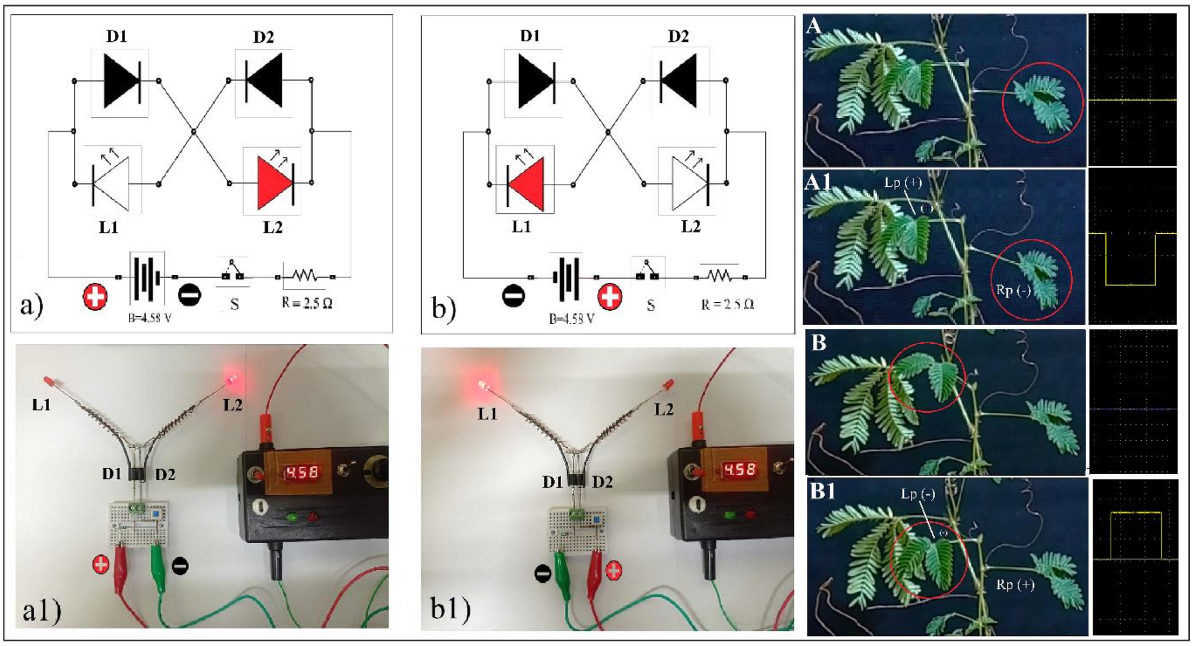

Figure 7: (a) and (b) Circuit details of the electrical model based on plant polar electrical response; (a1) and (b1) The developed electrical model under functional state based on the plant polar electrical response

Characteristic effect of anode and cathode on mechanical response of petiole at stimulating voltage intensity of 4.58 v under (A) and (B) without DC electrical stimulus, (A1) stimulation condition Rp cathodic (-) – Lp anodic (+), (B1) stimulation condition Lp cathodic (-) – Rp anodic (+)

Upon analysing the mechanical response it was found that in case of the cathodic stimulation petiole the mean difference value of the petiole position (initial vs final position of the petiole tip) was significantly higher ($P<0.05$) than that of the anodic stimulation petiole. It is known that in the excitable plant, a positive mechanical response following stimulation indicates a prominent drooping of petiole [5]. In the study, it was found that under DC voltage of intensity 4.58 V only in case of the cathodic stimulation the petiole exhibited drooping response, but in case of the anodic stimulation, no such response was observed. Therefore, it is evident why there existed a significant difference between the initial and final petiole tip position among the cathodic and anoidc petiole. It also indicates that only the cathodic stimulation was responsible for inducing excitation in the plant. Previous studies have already reported that in case of excitable animal tissues, the cathodic electrode is mainly responsible for inducing the excitation [7, 8]. It has also been reported that cathodic stimulation facilitates depolarization in comparison to anodal stimulation, through opening of pores of the voltage-gated sodium channels [9, 10]. Research on animal models have also reported that cathode is the primary electrode responsible for inducing stimulation and also cellular migration [11]. From the study it was thus, found that in the excitable plant *M. pudica* also the electrode with negative polarity (cathode) was responsible for inducing the excitation. The nature of the mechanical response of the plant was also studied using the image processing technique which could effectively track the characteristic nature of the response following exposure to DC electrical stimulus.

Conclusion

From the study, it was observed that only cathodic stimulation elicited a significant drooping response, characterized by a biphasic velocity pattern and a stair-step mechanical drooping, whereas anodic stimulation failed to induce any noticeable movement. The development of an electrical circuit model featuring diode pairs further reinforced the polarity-dependent behavior, offering a tangible representation of the plant's excitability in response to electrical cues. These findings provide a clear mechanistic insight that aligns with known principles of excitability in animal tissues, where cathodic stimulation is similarly responsible for initiating excitation. By extending this understanding into plant physiology, the study not only fills a crucial gap but also establishes a foundation for interpreting bioelectrical phenomena in excitable plants. The use of image processing techniques to track petiole motion underscores the potential of combining experimental and computational tools to unravel complex biological responses. In the near future, such findings may aid in the development of bioelectronic interfaces and novel biomimetic systems.

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References

1. Bose JC. Plant response as a means of physiological investigation. Longmans, Green and Company; 1906.
2. Khanbabaie R. A Mechanism Underlying the Electrical Polarity Detection of Sensitive Plant, Mimosa Pudica. International Journal of Engineering. 2016 Jan 1;29(1):132-6.

3. Aishan Y, Funano SI, Sato A, Ito Y, Ota N, Yalikun Y, Tanaka Y. Bio-actuated microvalve in microfluidics using sensing and actuating function of Mimosa pudica. Scientific Reports. 2022 May 23;12(1):7653.
4. Roy S, Bhattacharya B, Bal B, Haldar R, Ghosh K. A preliminary electro biophysical study on electrical polarity detection ability of the excitable plant Mimosa pudica: A probable biosensor of electrical polarity. International Journal of Microsystems and IoT. 2023;4(1):259-266.
5. Brattland, V., Austvoll, I., Ruoff, P., & Drengstig, T. (2017, May). Image processing of leaf movements in Mimosa pudica. In *Scandinavian Conference on Image Analysis* (pp. 77-87). Cham: Springer International Publishing.
6. Buti, M., Checcucci, A., Vergata, C., Renna, L., Pollastri, S., Loreto, F., ... & Martinelli, F. (2025). The transcriptional mechanism behind Mimosa pudica leaf folding in response to mechanical disturbance. *Planta*, *262*(5), 114.
7. Brocker, D. T., & Grill, W. M. (2013). Principles of electrical stimulation of neural tissue. *Handbook of clinical neurology*, *116*, 3-18.
8. Hu, Y., Feng, Z., Zheng, L., & Ye, X. (2023). Interactions between cathodic-and anodic-pulses during high-frequency stimulations with the monophasic-pulses alternating in polarity at axons—experiment and simulation studies. *Journal of Neural Engineering*, *20*(5), 056021.
9. Shin, H., Kang, M., & Lee, S. (2021). Mechanism of peripheral nerve modulation and recent applications. *International Journal of Optomechatronics*, *15*(1), 182-198.
10. Brown, B. H., Smallwood, R. H., Barber, D. C., Lawford, P. V., & Hose, D. R. (2017). *Medical physics and biomedical engineering*. CRC Press.
11. Zhao, M., Rolandi, M., & Isseroff, R. R. (2022). Bioelectric signaling: role of bioelectricity in directional cell migration in wound healing. *Cold Spring Harbor Perspectives in Biology*, *14*(10), a041236.