PlantMate: A Bidirectional Touch-Based System for Enhancing Human-Plant Empathy and Pro-Environmental Behavior

Hong Luo
Exertion Games Lab, Department of Human-Centred Computing
Monash University
Melbourne, VIC, Australia
hong.luo@monash.edu

Tuomas Kari
Natural Resources Institute Finland (Luke)
Helsinki, Finland
tuomas.kari@luke.fi

Rakesh Patibanda
Exertion Games Lab, Department of Human-Centred Computing
Monash University
Melbourne, VIC, Australia
rakesh.patibanda@monash.edu

Maria Fernanda Montoya
Exertion Games Lab, Department of Human-Centred Computing
Monash University
Melbourne, VIC, Australia
maria@exertiongameslab.org

Josh Andres
School of Cybernetics
The Australian National University
Canberra, Australian Capital Territory, Australia
josh.andres@anu.edu.au

Don Samitha Elvitigala
Exertion Games Lab, Department of Human-Centred Computing
Monash University
Melbourne, VIC, Australia
don.elvitigala@monash.edu

Florian 'Floyd' Mueller
Exertion Games Lab, Department of Human-Centred Computing
Monash University
Melbourne, VIC, Australia
floyd@exertiongameslab.org

Figure 1: PlantMate is a novel prototype in the form of a bidirectional system between humans and plants

Abstract

Enhancing the emotional connection between humans and nature is critical for fostering pro-environmental behavior, yet humans often struggle to perceive plants' responses to environmental changes. Existing systems for human-nature interaction are largely unidirectional, limiting opportunities for meaningful empathy. To address this, we present "PlantMate", a platform enabling bidirectional touch-based interaction. PlantMate translates users' touch into bioelectrical stimulation to enhance plant growth while translating a plant's electrical signals under varying environmental conditions (e.g., temperature, humidity) into electrical muscle stimulation for users. A pilot study with 12 participants revealed three key benefits: perceiving plants as interactive agents, decoding plant feedback, and redefining human-plant relationships through discernment and

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affective touch. This research highlights the potential of bidirectional human-plant systems, offering a novel approach to human-nature interaction while aiming to enable users to cultivate empathy for nature and encourage pro-environmental behavior.

CCS Concepts

• **Human-centered computing → Interaction design**.

Keywords

Human-nature interaction, Touch, Plant electrical, Electrical muscle stimulation, Pro-environmental behavior

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1 Introduction

Imagine a world where touching a plant not only calms your mind but also allows you to feel its response to the environment – a subtle, tangible connection that deepens your empathy for the natural world. Humans possess an innate affinity for nature, supported by genetic predispositions [6], and research shows that interactions with plants enhance psychological wellbeing [41], reducing stress and promoting happiness [11]. Beyond personal benefits, such connections can foster pro-environmental behaviors, essential for a sustainable future [28]. Yet, modern lifestyles often limit contact with nature, leading to missed opportunities for these benefits to occur and a diminished sense of environmental stewardship. Richard Louv's concept of Nature-Deficit Disorder (NDD) [7] emphasizes the societal consequences of human disconnection from nature, including declining environmental awareness. Fostering personal experiences that reveal our interdependence with nature can cultivate empathy and strengthen our connection to the natural world. Prior research [46] further suggests that cultivating empathy for plants can increase our willingness to engage in environmental protection [22].

The Human-Computer Interaction (HCI) field has increasingly explored the relationship between humans and nature through interactive technologies [45]. Initiatives like the NatureCHI seminar series envisioned future interactions with nature in outdoor environments [12]. Several studies have helped people reconnect with the rhythms of nature [1] and facilitated human-plant interactions through technology to highlight the essence of plant life [14] . Other research explored systems where plants act as sensors and actuators [37], serve as interfaces between humans and computers [39], or enable direct interaction with plants [31]. During these interactions, humans can perceive changes in plants' biological states [43], listen to "plant voices" [25], and engage in two-way dialogues with plants [40]. Prior research has demonstrated the potential to bridge the experiential gap between individuals and natural systems, inspiring empathy for nature while offering actionable insights to promote eco-friendly behaviors [8].

However, there is limited discussion on the role of technology in mediating these interactions and its impact on the relationship between humans and plants. We explored how touch can serve as such a bidirectional mechanism for human-plant interactions. Our initial focus is on electrical muscle stimulation (EMS), unlike previously explored electrical stimulation [27], the EMS can transform the body into both input and output [30], and provide more realistic tactile feedback [24]. To achieve this, we designed the "PlantMate" system, which uses bidirectional touch by delivering EMS to users based on plants' electrical signals, as shown in Figure 1. This design aims to enhance the benefits of interacting with plants by fostering discernment and emotional connection through touch. In a pilot study with twelve participants using PlantMate over five days, thematic analysis of interviews revealed that the system helped users perceive plants as interactive beings, understand the potential for plant feedback, and build empathy through thoughtful and affective touch. In some cases, this interaction also contributed to improved wellbeing in human-nature relationships. This paper features the following contributions and benefits:

- System Contribution: A novel prototype in the form of a bidirectional system between humans and plants. This could be valuable for NatureHCI researchers as inspiration for novel human-plant interaction systems.
- Empirical Contribution: An empirical contribution in the form of an investigation of how touch, enhanced by electrical stimulation, can strengthen the connection between humans and nature. This could be useful for researchers aiming to gain a better understanding of how technology could help people sense the dynamics of plants, foster a deeper understanding of plants as living organisms and cultivate empathy for nature.

Ultimately, this work aims to advance NatureHCI research by exploring how interactive technologies can foster meaningful connections with nature, encouraging a more integrated and appreciative coexistence with the natural world.

2 RELATED WORK

We primarily learned from four key areas of prior work:(1) conventional NatureHCI interactions, (2) electrical stimulation of plants, and (3) interfacing plant electrical activity with humans.

2.1 Conventional NatureHCI interactions

We build on the interaction framework proposed by Rasmussen et al. [32], which identifies the direct interaction model in human-plant projects. Direct interaction occurs when humans provide input directly to plants through touch, gesture, sound, or remote, networked entities. Examples include using plants as input devices for visual image programs [44], playing music [34], or participating in games [36]. These projects demonstrate how HCI researchers can make plant capabilities more explicit, enabling humans to perceive hidden physiological activities in plants. We found that direct physical contact with plants enhances human-plant interaction by offering a tangible means to perceive biological changes, reinforcing the perception of plants as living organisms. Building on this foundation, we incorporate touch as a key direct interaction mechanism in PlantMate.

2.2 Electrical stimulation of plants

Plants are highly sensitive to their environment [35], possessing innate abilities to acquire and represent information through natural sensory mechanisms such as touch detection, chemosensory perception, orientation, moisture sensing, thermosensory detection, and infrared detection. These capabilities are mediated by chemical signals and biopotentials, which function similarly to electronic circuit signals [38]. The relationship between plants and electrical stimulation has been explored since the early 1970s. J. D. Black [26] pioneered research into the effects of electrical stimulation on plant growth and development, revealing its potential to influence physiological processes. For example, high-intensity pulsed electric fields have been found to accelerate metabolic processes and photosynthesis in plant cells. These signals can be measured using extracellular and intracellular recording techniques, providing valuable insights into plant health and responses to external factors [2]. Thus, the input of electrical stimulation and the output of plant electrical activity could create an interactive loop that might enhance plant physiology while supporting their interactions with the environment.

2.3 Interfacing plant electrical activity with humans

Plants generate electrical signals in response to environmental stimuli such as light, temperature, and touch, a phenomenon that has long been studied in biological science. With advancements in related technologies, HCI research has begun leveraging these bioelectrical properties to create novel forms of interaction between humans and plants.

One of the earliest applications of plant electrical signals in interactive systems appeared in art installations. For example, prior work [29] allowed users to control the virtual growth of programmed plants on a screen by touching or moving real plants. Similarly, "Surrounded" [21] converted plant signals into sound, enabling users to "listen" to real-time plant responses. Hu et al. [18] explored the potential of plant-based interfaces, emphasizing ecological sustainability and biological integration, while "Cyborg Botany" [37] expanded the use of plants as output devices for displays. Research has also examined the psychological and emotional impact of human-plant interactions [11]. Additionally, plants can respond to human touch in "human-like" ways, such as producing sounds, which can foster empathy for plants and enhance their perception as living entities [19]. These works highlight the potential of using interfaces with plants to strengthen emotional connections between humans and the natural environment [10].

However, the bidirectional interaction between plant's electrical signals and humans, as well as its impact on fostering a deeper connection with nature, remains underexplored [46]. Building on previous research, we developed the following research question: How do we design plant-human bidirectional touch experiences to foster empathy with nature and pro-environmental behavior? Our prototype design investigates how bidirectional touch interactions between humans and plants can be facilitated through plants' bioelectric properties. This approach aims to enhance our understanding of plants as interactive entities, foster deeper emotional engagement, and promote pro-environmental behaviors.

3 PLANTMATE

Our work employed a "research through design" (RtD) approach [47] to investigate technology-mediated human-plant interactions. The PlantMate system, conceived as a speculative "physical embodiment" artifact, aims to generate new insights into the potential of fostering interactive engagement with nature. Simultaneously, it allows us, as designer-researchers, to examine the mediating role of technology in human-plant interactions. This approach enables an exploration of how our system is both shaping and shaped by the relationships and experiences it facilitates.

3.1 Hardware

The hardware setup consists of five main components, as shown in Figure 2: (1) A microcontroller (Seeeduino XIAO SAMD21[1]) embedded with a speaker (XC3744[2]) and an Electromyography (EMG) sensor[3] with electrodes. (2) A plant (heartleaf philodendron) as the central element. (3) A smartphone for system control. (4) An Electrical Muscle Stimulation (EMS) device[4] with electrodes attached to the user's forearm. (5) A humidifier and Peltier chiller[5] to simulate different environmental conditions. (6) Participants using the PlantMate system at the workshop. To ensure portability, the entire system weighs under 300 grams. The microcontroller, housed in a custom-designed 3D-printed case, divides the EMS output into one controllable channel using an Adafruit STEMMA relay[6]. We conducted durability tests, including drop and shake assessments, and evaluated battery longevity [23].

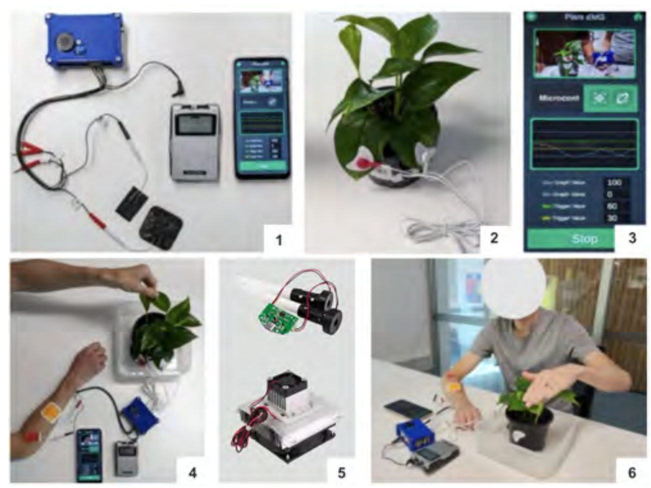

Figure 2: Hardware setup

3.2 Software

We developed a minimalist smartphone application that communicates with the microcontroller via Bluetooth. The user interface

[1]https://wiki.seeedstudio.com/Seeeduino-XIAO/
[2]https://www.jaycar.com.au/arduino-compatible-audio-amplifier-with-speaker-module/p/XC3744
[3]https://www.seeedstudio.com/Grove-EMG-Detector-p-1737.html
[4]https://66fit.com.au/products/allcare-digital-ems-unit
[5]https://core-electronics.com.au/peltier-thermo-electric-cooler-module-heatsink-assembly-12v-5a.html
[6]https://www.adafruit.com/product/4409

was designed to keep users focused on interacting with the plant rather than the screen. Key features of the application include: (1) Connecting to the microcontroller. (2) A graph screen showing the value of the measured voltage difference as a number and a line tracing. (3) Adjustable graph scales to ensure the line tracing is displayed clearly. (4) Threshold calibration for triggering the EMS device, allowing users to define whether the device activates based on an increase, decrease, or intermediate change in voltage difference.

3.3 Plant selection

A key component of the system is the plant to which the electrical components are connected. For this study, we chose a heartleaf philodendron, a popular houseplant known for its air-purifying capabilities and large leaves. These leaves provide ample space for electrode placement and human touch, enabling direct measurement of electrical signals.

4 STUDY DESIGN

The study procedure is as follows: After designing and developing the PlantMate system and conducting initial user tests, we held a half-day seminar lasting 5 hours workshop to introduce participants to the research context and demonstrate how to use the PlantMate system. Participants then engaged in hands-on interactions with the system, exploring its use with plants in an unstructured and exploratory manner. Over the five-day pilot study, participants used the system daily, recording their feelings and experimenting with connecting it to indoor plants or taking it outside to interact with outdoor plants. At the end of the study, all participants took part in semi-structured interviews.

4.1 Participants

We recruited twelve participants (five males and seven females) aged 22 to 30 years (mean = 25.83, SD = 2.79). All participants were passionate about connecting with nature and were recruited through advertisements on our lab's social media. Most had no prior experience with EMS. During the workshop, we observed how participants used PlantMate to interact with plants. After the five-day experience, we conducted 60-minute semi-structured interviews with each participant. We employed a reflective thematic analysis approach [4] to analyse the data, the twelve participants totalling 720 minutes of interview recording, which was 26 pages of transcribes. The interviews explored their experiences with PlantMate, how they engaged with the system, and its potential to promote empathy between humans and plants. Follow-up questions were based on their responses.

4.2 Operating system design

The PlantMate system operates as follows:

- Setup: The user attaches the EMG electrodes to the plant (VCC and VOUT to one leaf each and the ground electrode to the plastic pot) and connects the input jack to the EMG sensor integrated into the microcontroller. These electrodes measure the change in voltage difference between the two leaves, detecting when the user touches the plant.
- Connection: The user opens the smartphone application and connects it to the microcontroller via Bluetooth.
- Calibration: The user attaches the EMS electrodes to their forearm and calibrates the EMS intensity using a dial on the EMS device for comfort. They then set the minimum and maximum threshold limits for the voltage difference that triggers the EMS in the application.
- Interaction: If the voltage difference falls within the set range, the EMS is triggered, resulting in muscle stimulation. This creates a tangible, embodied experience, facilitating discriminative and affective touch. The EMS can even produce arm movement if the intensity is set high enough. Users can further calibrate the system by positioning the electrodes to stimulate fine- or gross-motor movements.
- Environmental conditions: Different environmental conditions were simulated using a humidifier and Peltier chiller to measure the hidden activities of the plants.

To ensure safety, all users were instructed on EMS use by an expert.

As an additional use case for our system, the pin of the firing EMS electrode can also be inserted into the plant's soil instead of the electrode situated in the forearm, while the ground electrode remains attached to the user's forearm. This configuration directs electrical stimulation into the plant's soil, potentially benefiting the plant's development [2]. This form of human-plant electrical touch stimulation brings awareness about plants as living, coexisting organisms deserving of care.

5 DISCOVERY: EMPATHY BETWEEN HUMANS AND PLANTS

In this section, we unpack the user experience through four overarching themes: a) perceiving plants as interactive agents, b) decoding the potential of plant feedback, c) the perspective of discernment and affective touch, and, d) revisiting the human-plant relationship. We then discuss limitations and future research.

5.1 Curiosity and exploration: perceiving plants as interactive agents

Participants perceived plants as interactive agents through the bidirectional touch system. P5 shared, "*I was surprised by the intermittent tactile sensation from the plants.*" P8 noted, "*It feels like plants have their language. I feel like I'm talking to them.*" This tactile experience sparked curiosity among participants. P3 remarked, "*When I touched the plants briefly and stayed longer, I wondered what the plants were responding to.*" P1 also asked, "*How will plants adapt to environmental changes in humidity and temperature?*" Participants recognized that the system revealed the plants' hidden, instantaneous signals, which are typically slow and subtle. P2 commented, "*I can now directly observe the plants' reactions. Before, I could only see changes when they bloomed or withered. It's as if time has been condensed.*"

5.2 Exploration and understanding: decoding the potential of plant feedback

As participants engaged more deeply, they explored how plant feedback related to environmental changes, touch intensity, and duration. P4 shared, "*I tested plants with different vitality, leaf sizes, and light requirements at home, and I also took the system to the park.*" P3 added, "*I took the plants outside, moving them between direct sunlight and shadow.*" While touch was the main interaction method, participants were not satisfied with repetitive touching and began exploring other ways to interact. P7 said, "*I tried talking to the plants, shouting, singing, blowing, and watering them.*" P1 also noted, "*I experimented with different actions like pressing, brushing, stroking, and flicking the plants*" P2 commented, "*I found that touch produced a stronger response from the plants than any non-tactile interaction.*"

(a)Pressing (b)Stroking (c)Watering

Figure 3: Different actions with the plant

5.3 Emotion and connection: the perspective of discernment and affective touch

The system promoted both discernment and affective touch. For discernment, participants experimented with different EMS settings. P6 observed that the frequency and duration of the EMS could be adjusted by changing the tolerance in the smartphone application. For affective touch, we found that touching a plant or its leaves typically increased the voltage difference, which activated the EMS. P5 noted that plants could "*sense*" human touch based on this voltage change. P2 added that plants could also "*touch*" the user independently if the voltage difference changed enough to trigger the EMS without any user input.

The resulting "*touch*" was described with varying adjectives depending on its intensity, frequency, and length. For example, intense and short touches were perceived as "*aggressive*" or "*angry*," while high-frequency, short touches were described as "*erratic.*" Mellow, sustained touches were perceived as "*flirty*" or "*gentle*," which participants found the most pleasurable.

5.4 Empathy and responsibility: revisiting the human-plant relationship

Participants gradually anthropomorphized plants, developing empathy for their feelings and reflecting on their behavior. P4 asked, "*Will delayed watering make the plants 'thirsty'?*" P1 commented, "*I avoid stepping on the grass because I'm not sure if it would cause the plants 'pain'.*" Participants also recognized the strong connection between plants and climate change. P6 shared, "*I think plants are bravely adapting to environmental changes,*" while P7 believed, "*Plants must be very uncomfortable, even in pain.*" Some participants saw caring for plants as an ecological responsibility. P2 said, "*I take the initiative to care for plants, like making sure the potted plants at home are healthy.*" P5 added, "*Should we provide better conditions for plants, such as improved soil and a more stable ecological environment?*" This shift seems to reflect a transformation from empathy to active responsibility.

6 DISCUSSION: A CONVERSATION THAT GROWS

Participants began as explorers, tentative yet intrigued. When P8 described, "It feels like plants have their language," they echoed a long-standing human fascination with plant sentience. Unlike prior systems that rendered plants as passive interfaces, PlantMate appeared to transform curiosity into a form of conversation. The system's real-time feedback loop—voltage shifts translated to muscle actuation—seemed to act as a kind of Rosetta Stone, decoding what P2 called the "condensed time" of plant responses. This aligns with Aspling's observations of cherry blossoms [3], but with a notable difference: here, the ephemeral nature of touch seems to become embodied, transforming fleeting interactions into tangible, felt experiences.

As participants experimented—testing varied intensities of touch, different environments, and even singing to plants—they mirrored the playful experimentation seen in "Flora Robotica" [13] and Infotropism [16]. Yet, their discoveries seemed to take on a deeper resonance. When P7 sang to a philodendron or P1 debated whether a flick or stroke elicited stronger feedback, they appeared to be negotiating what it might mean to communicate with a plant. This negotiation of communication reflects Hu et al.'s vision of sustainable HCI [18] but grounds it in the lived, often messy reality of human-plant interaction. The system's bidirectional design, which allowed plants to "touchback," seemed to turn abstract environmental signals (humidity, light) into visceral exchanges. As P5 noted, "the plants sensed me," echoing Park et al.'s findings on tactile engagement [20], but potentially adding a layer of mutuality, where the act of touching becomes a shared, reciprocal experience.

Some of the most intriguing moments arose not from data, but from metaphor. When participants described plant feedback as "flirty" or "angry," they seemed to be translating electrical signals into an emotional lexicon. This spontaneous, vivid language mirrors how "Surrounded" [21] users "heard" plant voices, but PlantMate's tactile channel might deepen the bond. A "gentle" EMS pulse could feel like a caress; an "erratic" burst, like a plea for attention. These descriptions align with theories of affective touch [15], but stretch them across species, suggesting that the system might not just map signals—it could author a shared sensory poetry, where the boundaries between human and plant sensations blur.

By the study's end, participants seemed to shift from interacting with plants to advocating for them. P5's question, "Should we provide better soil?" and P1's hesitation to step on grass might reflect a moral shift from empathy to stewardship. Like Shannon's climate-aware gardeners [33], participants began to see plants not as decor, but as kin—a perspective potentially amplified by PlantMate's ability to render environmental stress (via humidifier, and Peltier chillers) as tangible discomfort, making the abstract consequences of climate change feel immediate and personal.

PlantMate's innovation might lie in its refusal to let plants remain passive. Unlike VR or AR ecosystems, which simulate nature

[17], this system could amplify it. By framing electrical signals as dialogue [30], it seems to answer Rasmussen et al.'s call for direct interaction [32] while challenging HCI's human-centric norms [5]. When P6 marvelled at plants "bravely adapting" to climate change, they were not just attributing human traits to plants – they might have been recognizing the plants' resilience in the face of environmental challenges, fostering a deeper connection to their struggles and a sense of shared vulnerability.

In this light, PlantMate could be more than a tool – it could act as a technological mediator of kinship. It invited participants to reconsider what Louv [7] termed "Nature-Deficit Disorder" not as a lack of exposure, but as a lack of dialogue. By letting plants "speak" through touch, it could rekindle ancient reciprocity, one where empathy grows not from screens or simulations [42], but from the quiet thrill of a pulse returned – a reminder that even the smallest gestures can bridge the gap between humans and nature.

7 LIMITATIONS AND FUTURE WORK

Our exploration has several limitations that highlight opportunities for future work. EMS calibration is required during use, and each plant exhibits unique electrophysiological and bioelectric signals, which can complicate the interaction. Additionally, users have varying tolerance levels for EMS, affecting their overall experience. Future work could address these calibration challenges to improve consistency. The ambiguity of touch, while encouraging experimentation and curiosity, also led to moments of confusion. Participants sometimes questioned whether their touch was being recorded or what the plant's feedback truly meant. To address this, we intend to incorporate tools like Makey Makey [9] to improve the functional clarity and reliability of touch detection in future system iterations, ensuring a more intuitive and consistent interaction. It also remains unclear whether participants would use the system repeatedly or if the bidirectional touch with plants genuinely enhances pro-environmental behavior and encourages nature-protecting actions. While initial findings suggest a shift in empathy and ecological awareness, further research is needed to investigate such outcomes. Lastly, the slow growth cycle of plants makes it difficult to assess the long-term impact of the system. Future studies will involve long-term tracking to evaluate the system's applicability and effectiveness over time.

8 CONCLUSION

We presented "PlantMate", a novel system designed to facilitate human-plant interactions through bidirectional touch, using electrical muscle stimulation to enhance the sensory and emotional experience of connecting with plants. This work offered a technological bridge to help people appreciate plants as dynamic, responsive organisms. Our research showed how PlantMate transforms plants from passive background elements into active participants in shared sensory experiences, possibly promoting wellbeing in human-nature interactions and encouraging pro-environmental behaviors. In conclusion, PlantMate demonstrates the potential of interactive technologies to foster meaningful connections with nature, encouraging a more integrated and appreciative coexistence with the natural world.

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