Pudica: A Framework For Designing Augmented Human-Flora Interaction

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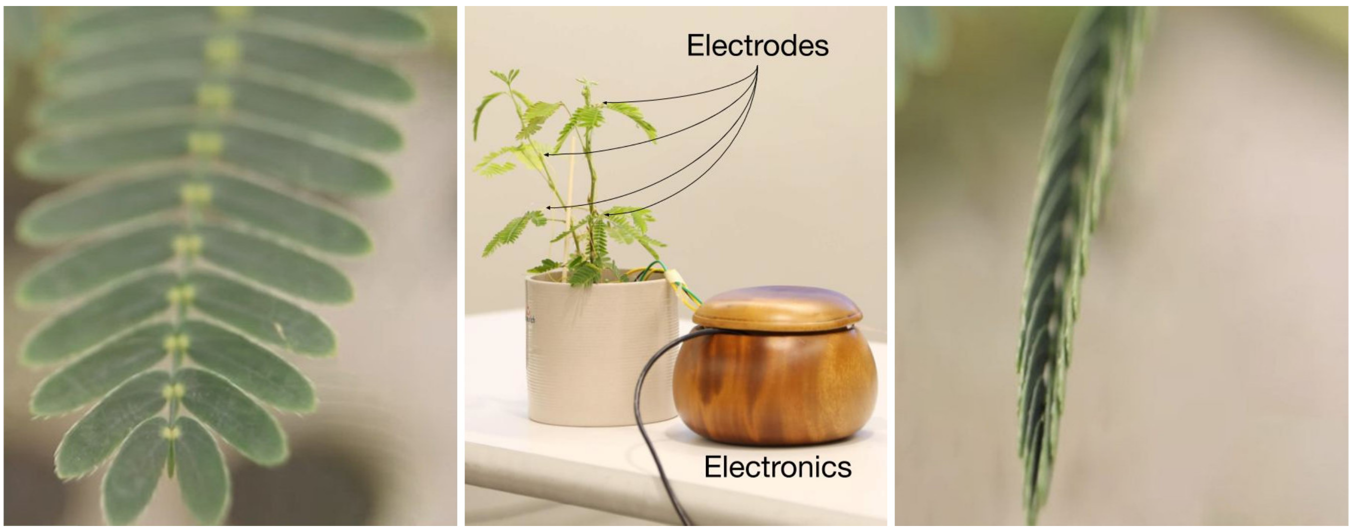

Figure 1: Thigmonastic behavior of the mimosa pudica: the leaf is originally open → electro stimulation → the leaf closes

ABSTRACT

This paper introduces and studies a design framework for designing human-flora interaction in plant-based interfaces, which could play a prominent role in a world where HCI strives to be less pollutive, more power saving, and humane. It discusses critical considerations (e.g. maintenance, reproducibility) for such interfaces, supported by a user study based on an interactive prototype. The results of our user study show that users' interest in plants varies significantly with past experience. Users may create a strong emotional bond with plants, suggesting that organic interfaces should be used for emotionally strong use cases, such as keeping in touch with loved ones or checking important data.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**.

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KEYWORDS

Shape-changing interfaces, Augmented human-flora interaction; Plant interfaces; Augmented Health and Sensing; Organic Context-Awareness.

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1 INTRODUCTION

The *aliveness* of plants lends itself to compelling and engaging emotional qualities in design. People appear more interested and caring about living plant interfaces as compared to their artificial counterparts [8]. In fact, the biophilia hypothesis proposes that people are genetically predisposed to be attracted to nature [38]. Moreover, plants have positive psychological effects on human well being, with research connecting human-plant interaction to increased happiness, reduced stress, better mental health [3], and elevated creativity [20]. Consequently, there is a strong justification for plant-based interactions for wellness treatments and therapy.

In addition, plants are highly perceptive to their environment [34] and naturally equipped for information retrieval and representation. Natural sensing abilities include thigmonasty (touch detection), chemotropy (chemical detection), gravitropy (orientation detection), hydrotropy (water detection), thermotropy (temperature detection) and the detection of infrared sources (such as humans). This data may be retrieved through chemical signals and biopotentials similar to signals from electronic circuits [20]. Moreover, many plants naturally react in a perceivable way to local information, such as by indicating the direction of the primary light source or the direction north [8]. Most people share a common expectation of plants [38]. Thus, and as proposed by Ishii et al. [14], we can build on prior understanding to create interfaces that are seamlessly integrated with the physical environment. Moreover, the situated energy, regenerative, and co-located input/output (I/O) aspects of plants give rise to unique opportunities for highly coherent, eco-friendly, and self-powered tangible interfaces capable of data physicalization [15]. Existing research in HCI has suggested the use of plant-based interfaces for applications like education [32] and visualization [9, 22, 33], and recommendations have also been made around organic interfaces in the broader sense [24–26]. However, there is still a lack of a conceptual framework specific to designing plant-based interfaces. We propose the Pudica framework - considerations for designing relevant and appropriate interfaces involving living plants. We also implement a use case involving a thigmonastic plant, *mimosa pudica* (see Figures 1), and interview 20 participants about its potential in HCI.

2 RELATED WORK

Outside HCI, human-plant manipulation has happened across cultures and throughout history. For instance, arborglyphs, or carvings made on the bark of living trees, have been documented in both indigenous Moriori and Native American communities [3, 16]. More recently, artists have also used plant-based media to create aesthetically pleasing and sometimes informative designs. Examples include using plants for distributed data collection [35], and varying light intensity to manipulate photosynthesis and chlorophyll for displaying images on grass [17].

HCI research has revealed an interesting field of interaction involving living plants. Prior work has attempted to use computer-mediated interaction with plants for: tools (including education) that support plant health and cultivation [13, 32]; visualization, entertainment, and aesthetic purposes [9, 21, 22, 33]; experiential installations [11–13, 19, 28, 29]; facilitating and improving the interaction with plants [1, 4, 23]; and companionship and mental health support [2, 18, 30]. Despite the growing collection of plant-based interface designs, there is a lack of discourse addressing *why*, *how*, and *when* plant-based interfaces could or should be used. To this end, we developed a plant-based interface, and supplemented research with interviews to develop the Pudica framework.

3 PROTOTYPE

3.1 The plant

For our "Pudica" interface, *mimosa pudica* was selected due to its thigmonastic behavior (see Figure 1), as this offers a special advantage for organic, situated I/O. Notably, the leaves (and twigs) of *mimosa pudica* can be electrically stimulated to respond as if they were touched [36]. Our framework retains the namesake of our selected plant.

It has been suggested that plants that react to touch support emotional bonding for users [1]. Other thigmonastic plants include *biophytum sensitivum, dionaea muscipula* and *oxalis rubra* [5]. Ultimately, we chose *mimosa pudica* for its availability as well as its aesthetic quality, although its nyctinastic behavior (closing leaves at night) meant that we had to carry out all tests during the day.

Past research has noted that plant displays can serve in the reification of intangible far-off effects of human behavior [3]. In our use case, visceralizing ecological data may enlighten people who typically feel detached from global climate change. Chien et al. [3] state that visually apparent effects in a local context could bring environmental issues to the user's direct attention in their immediate environment. Pudica confers plants a unique way to communicate human impacts on environmental degradation in a personal way.

Our prototype makes use of *mimosa pudica*'s natural actuating ability to display air quality over three discrete levels ('good', 'medium', 'bad'). Pudica detects a user's touch on its branch and closes more leaves to indicate poorer air quality. Currently, we access air quality data through an online API, but it could also be possible to obtain the data by monitoring plant feedback. Fig. 2 illustrates our prototype scenario. Pudica is designed to bring air pollution concerns to the forefront of consciousness, and acts as a human-plant symbiotic medium for interpreted output. It is also a model for considering other plant-based interfaces for improving human well-being, for behavioral change, or for fostering greater empathy toward plants.

3.2 Technical implementation

In our prototype, we electrically stimulated the leaves of *mimosa pudica* to close. We were inspired by bio-mimetic approaches [36] to reproduce natural signals using lightweight silver electrodes (or acupuncture needles) gently placed in the pinna and pulvinus [37] to invoke closing of the leaves (pinnules). Electrodes were placed at night before the experiment, when pinnules were closed, to avoid potentially traumatizing the plant [36]. A less invasive method to provoke leaf closure would be to stimulate the leaves with air, as demonstrated by Gentile et al [5], although this has other side effects such as decreased precision and noise generation.

For ideal electro-stimulation, we used the capacitor method [36] and adapted the capacitances to respect necessary discharge timings (impedances depend on electrodes distances). These capacitors can be charged and discharged using solid state relay or MOSFET arrays, which can be controlled by any microcontroller. As most plants can be transformed into capacitive sensors [7, 10, 29], we used off-the-shelf modules to implement touch detection. Since *mimosa pudica* plants exhibit rare thigmonastic behavior, we focused on actuation for our prototype.

A microcontroller with WiFi capabilities such as the esp8266 (e.g. http://wemos.cc) can enable Internet access for about USD2. Lower power options are also available in the affordable WiFi chip market, such as the AMW006 by Silicon Labs, which can out-perform many Bluetooth Low Energy modules (11 mA). For our use case, Internet

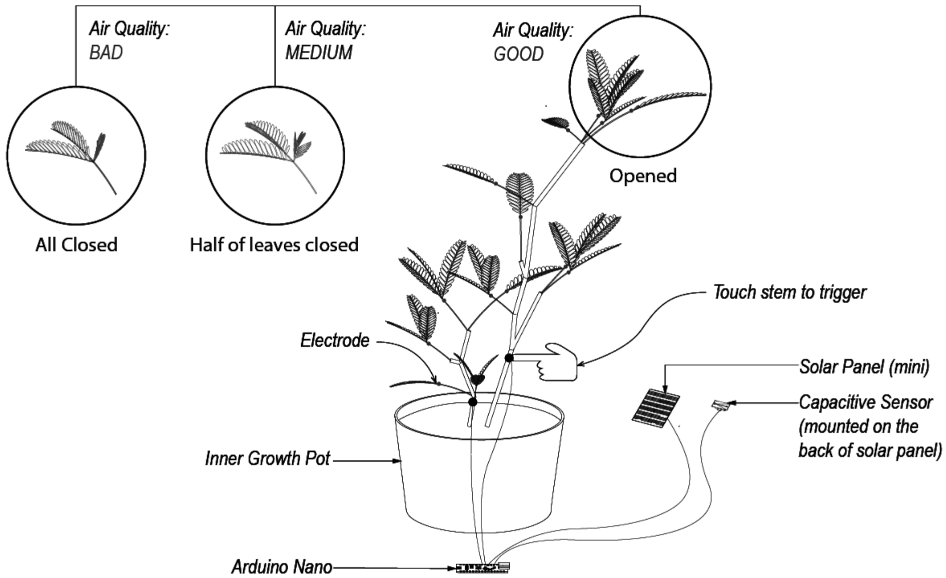

Figure 2: Example scenario where each leaf can be controlled to represent environmental data such as air quality.

access enables two key features - (1) retrieving our external IP address, which approximately locates the prototype, and (2) accessing an air quality API (e.g. http://aqicn.org).

4 USER STUDY

We conducted semi-structured interviews with 20 participants, 10 male and 10 female, between 21 and 65 years old (average being 33), with various professional backgrounds (artists, designers, researchers, carpenters, engineers, florists, students, etc). The interview comprised 4 main parts, with key elements outlined in Table 1. Through the interviews, we aimed to identify expectations as well as desirable and undesirable attributes of plant-based interfaces and the Pudica prototype. The interview was conducted in-person, and participants were encouraged to elaborate on each response. The results from our interview are interwoven into the Pudica framework, as elaborated in the next section.

5 THE PUDICA FRAMEWORK

Guided by our prototype and user study, we developed the Pudica framework, which provides I/O, usability, and other design considerations for creators to implement plant-based interfaces. In our framework, we focus on botanical I/O. This complements and actionably extends living media interface discussion by Merritt et al. [24] and the design patterns proposed by Kuribayashi et al. [20] for modelling human-plant interactions and for augmenting this with sensors and actuators.

5.1 Natural Input and Output Capabilities

To begin, we enumerate possible natural plant I/O for designers' consideration, as shown in Table 2. If needed, botanical perception can be electrically monitored using probes and analog-to-digital conversion, which is low power and can be supplied by solar cells. Designers may choose I/O combinations that cohere with their use case in order to obtain plants that fulfil these criteria, along with the considerations that follow.

The natural aspect of ideal, plant-based interfaces also bring several benefits when compared to screen-based counterparts, as summarized in Table 3

5.2 Design Considerations

5.2.1 Who will maintain the plant-based interface, and how? It may be important to the designer that their plant of choice thrives in its intended environment. Considerations would thus include the plant's lifespan, care requirements, climate resilience, and fragility upon physical interaction. There are two levels of maintenance to be considered, the first being the plant's basal needs, and the second being additional maintenance needed for the plant to function as an interface. Some interviewees shied away from plant-based interfaces due to the fear of being inadequate at plant maintenance, which would have to be addressed in any successful design. All interviewees with experience in plant-care expressed a positive affinity to having the Pudica interface around their home or work area, some justifying any additional maintenance work with the added value brought about by the interface. An analogy can be drawn to the practice of maintaining roses at the perimeter of vineyards in California. Not only do roses add beauty to the landscape, they also serve as an early warning system to mildew infestation. Notably, the natural, low-power aspects of plant-based interfaces could make them more practical over electronic interfaces in some use cases.

5.2.2 How legible does the information need to be? Visual changes in a plant may be up for subjective interpretation, though this ambiguity may be exploited by designers to invite speculation. One interviewee who had a great deal of experience interacting with

Part 1 - About plants - Imagine having plants around your home or work area. How does that make you feel?* (Why?)
Part 2 - About *mimosa* plants *(Show mimosa plant and allow participant interaction)* - Have you interacted with *Mimosa Pudica* before? (If yes, please recall your strongest memory with them.) - Imagine having mimosa plants at home or at work. How does that make you feel?* (Why?)
Part 3 - About any plant interface *(Show Table 2 listing I/O possibilities in plants)* - Describe 2-3 scenarios for plant-based interfaces. - I would interact with a plant-based interface.**
Part 4 - About our Pudica prototype *(Show Pudica prototype and introduce use case)* - In this air pollution use case, I understood the relevance of a plant-based interface.** (Why?) - I would interact with this plant.** (Why?) - In the use cases we discussed, the plant is an important aspect of the interface.** (Why?) - Imagine having Pudica Interface at home or at work. How does that make you feel?* (Why?) - From 1 (not at all) to 10 (extremely much), how much do you like this plant-based interface? (Why?)

*Options: very negative, negative, neutral, positive, very positive

**Options: strongly disagree, disagree, neutral, agree, strongly agree

Table 1: Overview of interview prompts.

Inputs	Outputs
light source direction	plant orientation
gravity or magnetic field	growth direction
motion or acoustic vibration	thigmonastic movement
temperature	thermotropic movement
time of day	nyctinastic movement
environmental compounds	compound emission
threat detection	ultrasound
duration of day	flower growth
light intensity	color change
moisture	fruit bearing

Table 2: Examples of natural plants inputs and outputs.

plants mentioned that they already receive hints about environmental changes such as humidity, dirt quality, and air pollution based on plant-health, and that a plant-based interface would be a more direct and even *moving* way to communicate with their plants.

Screens	Plants
Unnatural I/O	Organic I/O coincidence
Battery powered	Situated energy
Source of distraction	Emotional attachment
Glaring lights can be harmful	Nature promotes well-being
High cognitive load	Ambient display
Toxic, non-recyclable parts	Safely biodegradable

Table 3: Comparison of screens to plant-based interfaces.

5.2.3 How granular does the information need to be? Individual plants may not contain enough discernible variability to represent complex information, though plant multiples might. When used as sensors, networked plants may also provide greater reliability.

5.2.4 How reproducible and sensitive does the response need to be? - plant behavior is highly multi-faceted, and factors like time-of-day, temperature, wind, pests, air- or soil-quality, and seasonality may influence outcomes unpredictably. Plants of the same kind may also respond differently to the same stimuli, or present effects of unexpected sources of input. Additionally, plants like *mimosa pudica* and *drosera rotundifolia* exhibit nyctinastic movement and close their leaves at night, which would have to be designed around.

5.2.5 How fast should the interface respond? Plants tend to respond slowly to stimuli. Designers may incorporate this lag as an affective component. Some use cases can benefit from the ability of many plant-based interfaces to behave as an ambient display, or one that presents information in a subtle way.

5.2.6 Can different individuals interpret the interface? Augmented plants do not easily command the same intuition as typical ones do. Affordances [6], or usability prompts, need to be carefully considered, and input modalities have to be well tested. For instance, most plants do not naturally invite physical interaction. Moreover, user groups have to be meticulously understood, especially since groups like children are known not to value plants like adults do [31]. Similarly, the use case should be intuitively and coherently tied to the use of the plant. A majority of interviewees (70%) agreed or strongly agreed that they understood the relevance of a plant-based interface in the air pollution use case. The term "*eco-logic*" was used to describe the intuitive link between plants and air pollution, and several interviewees mentioned that the connection between plant life and air quality was *touching*. Interviewees were each asked to describe 2-3 scenarios for plant-based interfaces. This list, sorted by frequency, may contain clues about what our interviewee demographic finds acceptable and approachable for plant-based interfaces: Sensors for prediction and forewarning, including covert indicators (14 scenarios); Tools for communication between people (7 scenarios); Visualization, entertainment, and aesthetic purposes (8 scenarios); Smart home controls (6 scenarios); Experiential installation (1 scenario); Facilitating and improving the interaction with plants (1 scenario); Mental health support (1 scenario). Some of these scenarios do not necessitate complex interpretation, and the designer may choose to present information in an ambient way while users benefit from the healing properties of having plants in close proximity [3].

5.2.7 Does the plant-based interface match the user's preferences and interests? People choose plants based on taste and past experiences. This was evident in the use cases suggested by interviewees with strong emotional bonds to plants, which included getting in touch with loved ones and checking important data. In our case, interviewees who had not previously interacted with *mimosa pudica* (33%) expressed more apprehension about it as a plant-based interface, while those who had extensive exposure (e.g. interviewees who grew up in Southeast Asia) tended to be comfortable with our Pudica interface, some even expressing a strong emotional bond to the plant. Interestingly, some people who experienced *mimosa pudica* as a rampant weed felt more resistant to the idea of it as a desktop plant. Notably, our interface increased interviewees' affinity for the plant. As shown in Figure 3, a Wilcoxon signed-rank test reveals a significant difference between people's affinity for *mimosa pudica* ($M = 0.7/2$) v.s. our interface ($M = 1.25/2$, $p = .03$), suggesting that using a *mimosa pudica* plant as an interactive device supports positive interactions.

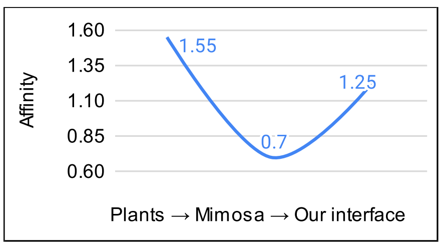

Figure 3: Average affinity for: plants in general, *mimosa pudica*, and our interface.

A selection of statements from our interviewees are presented here to provoke further discussion:

- *Plant interactivity is weird. I expect them to be dormant.*
- *The touch sensitivity is fascinating. I would touch them every time I see them.*
- *The fragile aspect of this plant is touching. It's also moving to think about how close we are to plants.*
- *There is a link between air and plants, every thing is nature related, I can sense the connection.*
- *The way we operate a display interface is so uninteresting and overused now. I think this is very fresh and can be a new paradigm as an interface. Although there may be limitation to output, the various inputs such as moisture is a critical differentiation point compared to smartphone. But I feel sorry for the plant that has to go through electrical shock.*

6 DISCUSSION AND FUTURE WORK

To create a standalone plant-based interface at the full potential of natural input and output capabilities, we envision using inherent biosensors to obtain natural input data. We may also experiment with *mimosa spegazzinii* as it is a cousin of *mimosa pudica* with better cold resilience and offers more (controllable) wind sensitivity [5]. Applications of our system will be extended in future research, along with more tests for result robustness after repeated use.

Questions still to be answered in future research include: How do people change their perception of plants and are the outcomes long-term or positive? And therefore, what are the implications for the potential of plants as an interaction medium? Are there plant-based affordances that are particularly compelling? How can affordances of sensitive plants be used for enhanced interaction between people and plants? Why do people feel more affinity for our plant-based interface than its natural counterpart, the mimosa? Is an interface that is presented as a robotic device more acceptable than a plant that has naturally-occurring robotic behavior? Could the trend in Fig. 3 be considered an "uncanny valley" effect?

One concern with various related works is that they involve plants in a somewhat arbitrary manner. Limiting water or light supplied to plants unless stocks are successfully traded [27], step counts goals are met [3], or someone recycles [8] arguably falls short of the full capacity of human-plant interaction, and may engender reactions about the inappropriate consumption of plant lives.

In a related vein, our air pollution use case also involves the conjuring artificial, imagined needs of a plant together with our interpretation of the needs and systematic manipulation of living plants for human gains.

Some may accept the use of plants to generate empathy, improve human well-being, or to raise awareness and enthusiasm about eco-themed causes. However, the question remains - what is an acceptable and appropriate use of plants? Or, as articulated by one of our interviewees and suggesting the significance of nonhuman agency, *is this what a plant would want*?

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