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Master's Thesis
Academic Year 2019

Planting Memories: Relationship Changes with Raised Plants through Physical Expression

Keio University
Graduate School of Media Design

Qingyun Lan

A Master's Thesis
submitted to Keio University Graduate School of Media Design
in partial fulfillment of the requirements for the degree of
Master of Media Design

Qingyun Lan

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Abstract of Master's Thesis of Academic Year 2019

Planting Memories: Relationship Changes with Raised Plants through Physical Expression

Category: Design

Summary

Many people raise plants in their lives, and planting can also bring back a lot of pleasure and satisfactory. However, plants are normally regarded as passive creatures, and there still exist a lot of boundaries for plant owners to understand their plants' growth.

In this research, we want to help plant owners get a better understanding of plant's growth and develop closer relationship with raised plants. Previous research shows that plants have sensing abilities, and the design methods such as 3D modeling and haptic display can help interpret the data showed in many researches. So in this project, three types of data have been collected and analyzed first, which are touching, moisture and light, and then built into the physical expression with correspondent characteristics.

Furthermore, we also help store planting memories. As each piece of 3D printed texture is based on one-week data, this is done by creating a plant's platform that is with the texture of past-one-week data for them to understand the growth during that time period, and at the same time, creating a memory album used to gather all the texture in the past in order to store all the memories.

Keywords:

Plants, Relationship, Understanding, 3D Printing, Haptics, Visualization, Memory

Keio University Graduate School of Media Design

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Chapter 1
Introduction

1.1. Background

Living with plants can be a rewarding and lifelong endeavor. To make the living environment livable, people usually choose to place a plant in their room, or to build a garden filled with different kinds of plants. At the same time, planting can bring back a lot of pleasure and satisfactory.

However, plants——including herbs, shrubs, and trees–are commonly characterized in Western thought as passive, sessile, and silent automatons lacking a brain, as accessories or backdrops to human affairs. [1] As the growth of plants is affected many factors in the living environment, such as the light condition, temperature, moisture, how to create the suitable condition that just meets plants' needs is quite important. Especially different types of plants have different living conditions. Different from animals and humans, plants lack movements and never directly communicate with people. For many plant owners, they have a lot of boundaries with their plants in their planting life, even for those have already had rich planting experience, they still feel quite hard to truly understand their plants' needs and to help the plants grow well.

1.2. Emotional Bonding with Plants

Instinctively aware of the aesthetic vibration of plants, human beings are spiritually satisfied by the planting life, and are happiest and most comfortable when living with flora. For plant owners, there exist the emotional attachment to the plants, which cannot be ignored.

Emotional attachment, the emotional bond connecting an individual with a specific target, has been identified as an important construct within the marketing domain [2], and has been widely explored in many examples such as the emotional bonding with mobile [3], to the brand extension [4], and even the public display [5]. However, for the plant owners, it also gets quite important to encourage them to form emotional attachments with plants and develop the closer relationship.

1.3. Relationship Improvement Requirements

The relationship difference between plants owners and plants has also affected by many reasons, such as plant owners' planting experience, the familiarity level with the raised plants, the degree of love for plants.

To situate this research work, we explore the design process by setting different familiarity levels between plant owners and plants, and through improving the familiarity levels in the relationship to help break the boundaries with the raised plants and develop the closeness feelings.

There are three levels set in the research(Figure 1.1): (1)Own the plants, which refers to the level that the plant owner has raised the plant in the life, but there still exist a lot of boundaries. (2)Understand about the plant's needs, which refers to the level that the plant owners start to understand the plant's growing status and can have a better control of their planting methods. (3)Develop closer relationship with the plant, which refers to the level that the plant owner not only understand the plant's growing status, but also have cultivated strong emotional attachment to the plant.

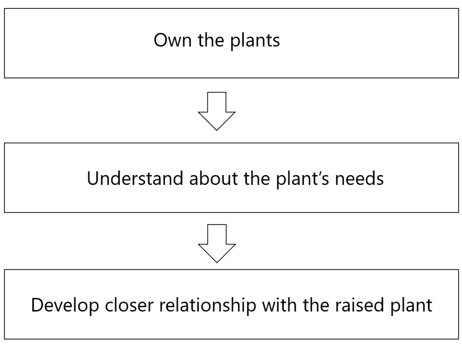


Figure 1.1 Different Familiarity Levels with Plants

1.4. Purpose of the Thesis

Increase deeper understanding of plants' growth and develop closer relationship with raised plants.

Plants' growth is responding to many factors in the living environment. Depending on the differences in the plant owners' treatments, plants grow differently. In this research, the focus is on breaking the planting boundaries and developing an intuitive expression to help plant owners understand whether their treatments just meet their plants' needs first, and then gradually build a closer relationship with raised plants during the process. This thesis goes depth into the analysis of the factors that can affect plants' growth, and then provides a possible solution to customize the effects into a design method that can be easily identified. The expression method will objectively reflect the changes in plants' growing environment by their treatment, and evaluate the growing effects on these plants. The biggest challenge in this project is to figure out these factors and then to customize generation in data translation process and simplify the understanding. Another challenge is to help plant owners store the precious memories with the plants in an intuitive expression method. Finally, this project aims to help plant owners develop a closer relationship with raised plants in their planting life.

To sum it up, this thesis provides the following contributions:

- Increasing plant owners' understanding of their plants' growth.
- Planting memory collection in an intuitive method.
- Bringing plant owners' closeness relationship with raised plants.

1.5. Thesis Structure

This thesis consists 5 chapters. Chapter 1 presents the background and states the purpose of this project. Chapter 2 focuses on the research and studies related to plants and different physical expression methods of abstract data. Chapter 3 outlines the design process followed to create the prototype and develop the product proposed. Chapter 4 describes the evolution of users' experience during the long-term user test and the steps taken to prove the concept. Finally, Chapter 5 is the conclusion of the thesis.

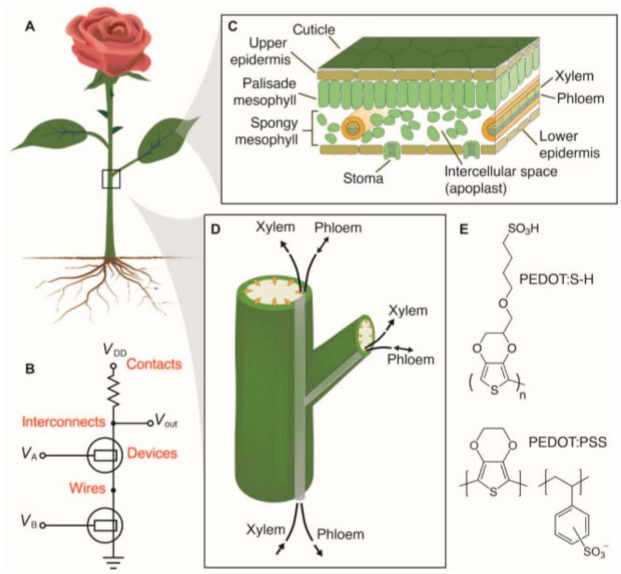
Chapter 2
Literature Review

2.1. Plants and Expression Abilities

2.1.1 Plants and Understanding Changes in History

People's understanding about plants keeps changing throughout the history. Aristotle's dogma that plants have souls but no sensation lasted through the Middle Ages and into the eighteenth century. Carl von Linné, grandfather of modem botany, declared that plants differ from animals and humans only in their lack of movement. Later, the conceit was shot down by the great nineteenth-century botanist Charles Darwin, who proved that every tendril has its power of independent movement [6]. Plants— including herbs, shrubs, and trees—are commonly characterized in Western thought as passive, sessile, and silent automatons lacking a brain, as accessories or backdrops to human affairs [1].

Whereas plants have been almost universally regarded as senseless automatons, an emerging body of research recently has showed that plants have more abilities than people expect. Plants sense many aspects of their abiotic and biotic environments and communicate and signal to remote organs and exchange information with other organisms [7]. Plants are self-powered, self-fabricating, self-regenerating and active signal networks, and plants carry highly advanced systems to sense and respond to the environment. Plants have now been found to be able to distinguish between sounds inaudible to the human ear and color wavelengths such as infrared and ultraviolet invisible to the human eye, and they are specially sensitive to X-rays and to the high frequency of television [6]. There are also research findings which prove that plants are electrically active systems. Plant's roots, stems, leaves, and vascular circuitry of higher plants are responsible for conveying the chemical signals that regulate growth and functions. These signals are transported over long distance to selectively trigger, modulate, and power processes throughout the organism [8]. Plants such as roses, consists of roots, branches, leaves, and flower similar to electrical circuits with contacts, interconnects, wires and devices(Figure 2.1). Plants generate electrical gradients or potentials in response to the changes in light, gravity, luminous intensity, osmotic pressure, wounding, chemical compounds and water potential [9].

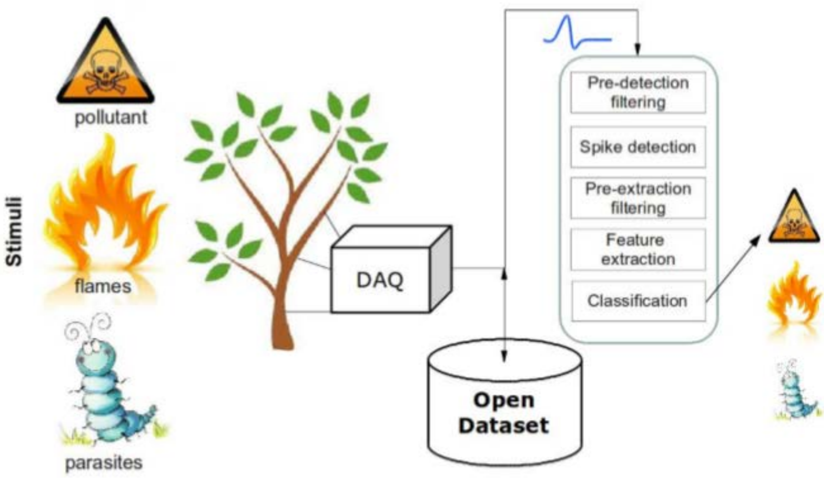


(Source: Electronic Plants 2015)

Figure 2.1 Basic Plant Physiology and Analogy to Electronics

2.1.2 Plants and the Utility of Sensing Technology

Plants can sense the environment, other living entities and regenerate, actuate or grow in response. Many of plant organisms are carrying unique sensing and expression abilities. There was once a research that implement the PLEASED(PLants Employed As Sensing Devices), which is an experimental set-up that through needle electrodes commonly employed in electromyography (EMG) to record plant's electrical activities, in order to demonstrate that plants can be effectively employed as biosensors of a new generation of pervasive and organic wireless sensor networks [10]. As plants are able of amazing sensing capabilities, there are also a lot of research that have envisioned the possibility of augmenting the capabilities of natural organisms by interfacing them to machines, and the biological functions of plants also have been proposed different views into the interactive design. For example, Cyborg Botany is a design exploration of deep integration within plants [11]. Based on plants' natural functions, plants have been augmented as a touch sensor, motion sensor, antenna and more. For example in the Elowan project, by using plant's own internal electrical signals, the plant is interfaced with a robotic extension that drives it toward light(Figure 2.3). There are other research such as Botanicus Interacticus [12], which is a technology for designing highly expressive interactive plants, both living and artificial(Figure 2.4). In the project, the swept frequency capacitive sensing technology has been used, and since the plant has a complex and dynamic electrical structure, the touch location and the gestures on plants are estimated by the plants' integrated frequencies.

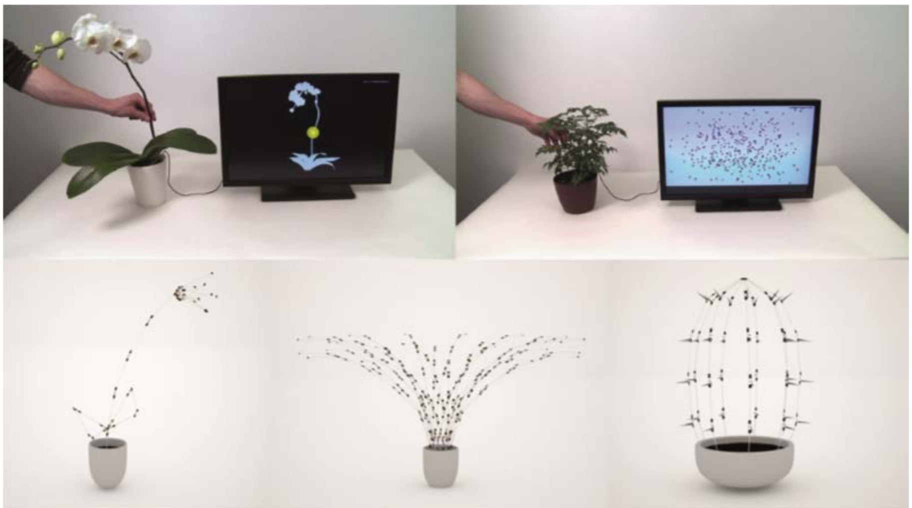


(Source: Demo Abstract: Plant as Sensing Devices)

Figure 2.2 An Exemplification of a PLEASED Experiment

(Source: Elowan- A plant-robot hybrid)

Figure 2.3 A plant-robot Hybrid



(Source: Botanicus Interacticus-Interactive Plants Technology)

Figure 2.4 Top: Precise and Playful Interaction with Living Plants; Bottom: Design of Biologically Inspired Artificial Plants

2.2. Data Changes and Physical Expression Methods

Based on the research findings in the first part, it has showed that plants are electrically active system, and grow in response to the changes in light, gravity, temperature, wounding and other environmental conditions. To present these data changes in plant's growth, in this part, different expression methods of data changes have been explored from previous research.

2.2.1 Digital Data and Artwork Explanation

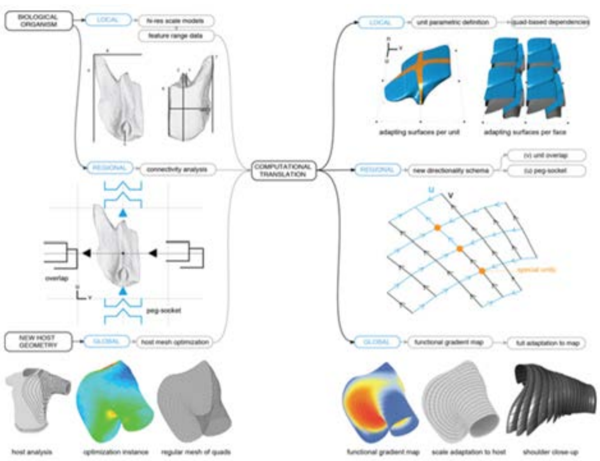
(Source: Bruises - Data We don't See)

Figure 2.5 A Coded System of Artistic Elements Underlies the Visualization of the Family's 4-month Ordeal

Graphic representation has largely improved the interpretation and understanding of complex scientific data in many cases, such as chemical field [13], or accident scenario [14]. However, not the understanding of all the data sets can be simplified with graph. Graphic formats appear to facilitate judgmental performance in some contexts, but not in others [15]. For example in one project, knowing that clinical records alone could not capture the full range of effects on the family, so art and music have been used to track the illness process, and interpret the full impact of a child's illness, which has helped a family and their friend understand and communicate their experience [16]. In the data expression, a non-linear timeline has been structured, where each one of the white petal-like elements indicates a new day. Days are grouped in sections, and in the visualization, a new group of days started with each a lab test(Figure 2.5). This data visualization has offered a holistic method for understanding the impact of a child's illness.

2.2.2 Digital Data and 3D Printing Technology

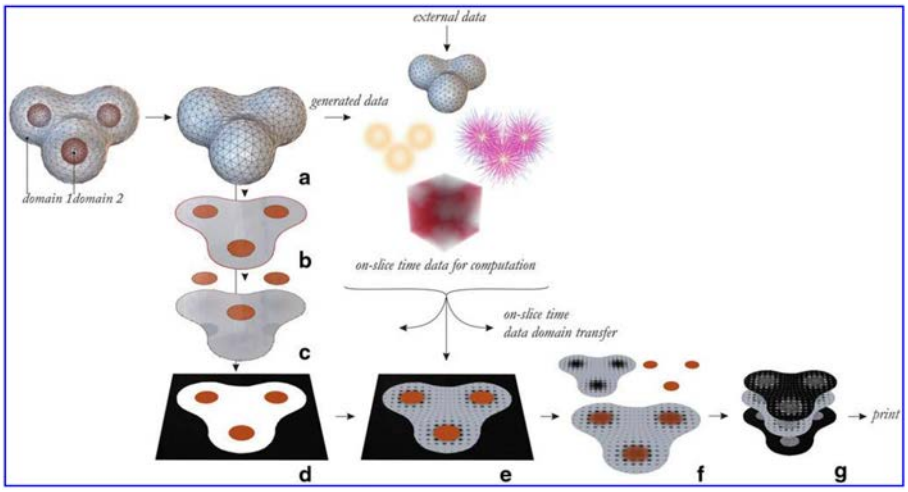
Beside visualized data expression, there are also many other design methodology to represent the data changes. Recent development in 3D printing technology have enabled the design of objects with high-resolution visualization and unprecedented levels of structural complexity, for example it is possible to fabricate customized hair-like structures on both flat and curved surfaces [17], and make objects that are comparable with traditionally manufactured items [18]. The design process in the 3D modeling software has provided more potential in the structure generation, and the prototyping process.



(Source: MetaMesh- A Hierarchical Computational Model for Design and Fabrication of Biomimetic Armored Surfaces)

Figure 2.6 Generate a Flexible Protective Surface based on an Armored Fish Exoskeleton through Hierarchical Computational Model

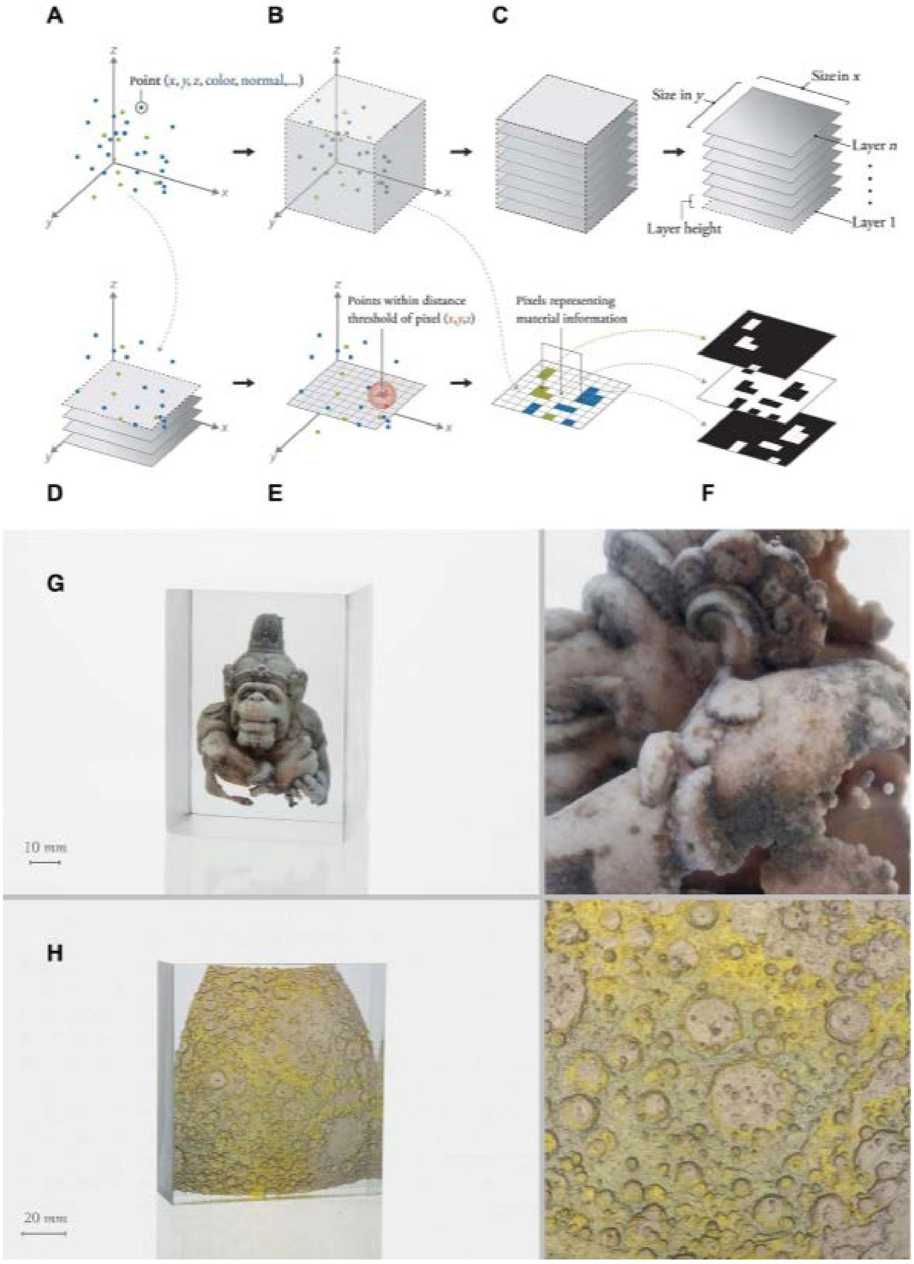
Generative design is a revolutionary new method of creating artwork, models,



(Source: Data-driven Material Modeling with Functional Advection for 3D Printing of Materially Heterogeneous Objects)

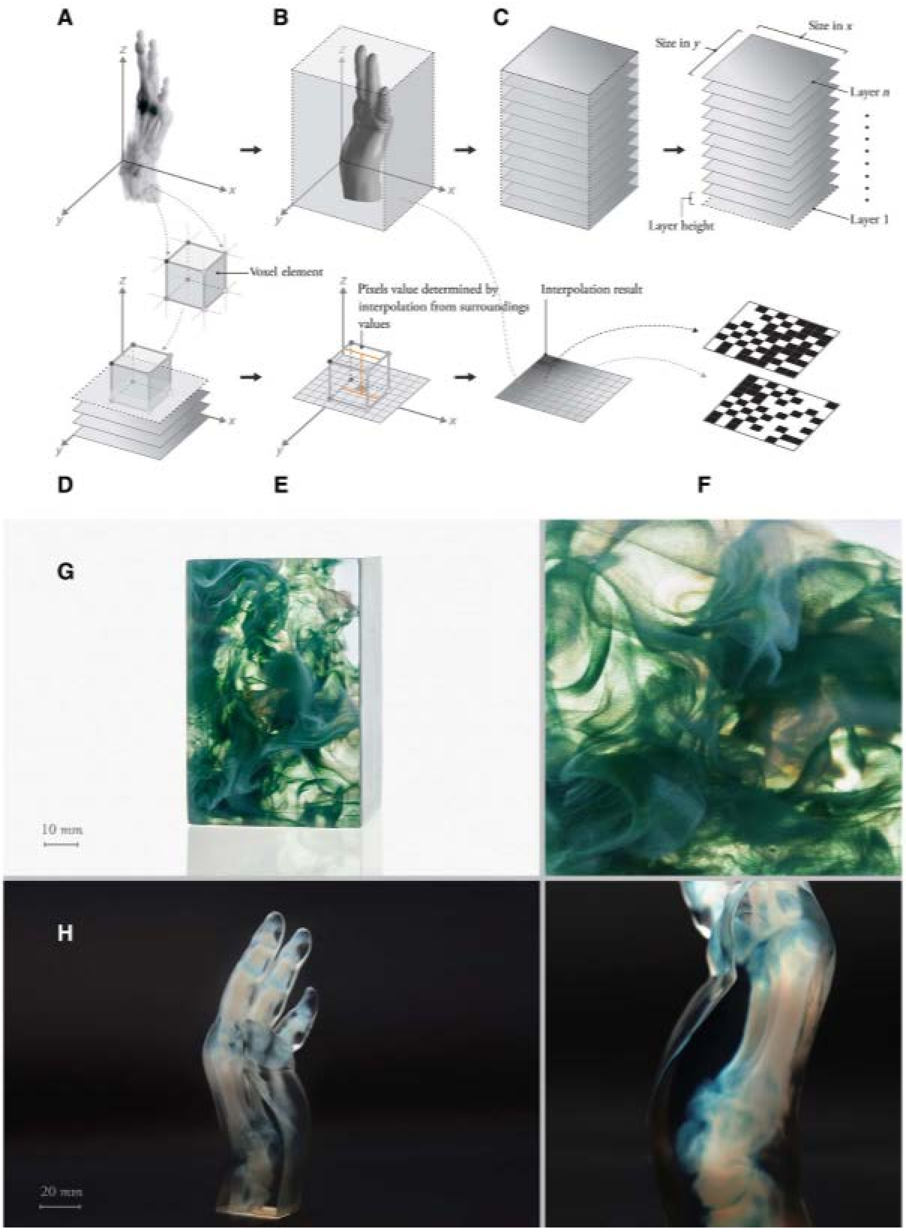
Figure 2.7 A Data-driven Computational Framework for the Production of Bitmap-printable Parts

and animations from sets of rules, or algorithms [19]. It has been widely used in 3D modeling process, which offers new modes of aesthetic experience based on the incorporation of system dynamics into the production of artifact and experience [20]. The generative methodology has offered an unconventional way of conceptualising and working in design, that can generate the complexity and present the complex and interconnected relationship between organism and environment. For example in some projects, the computational design methodology that combines scientific analytical methods and computational form finding tools is used to generate a flexible protective surface. In the project of MetaMesh [21], the hierarchical computational model has been used for design, which can adapt s segmented fish scale armor system to fit complex host surfaces(Figure 2.6). Besides, such type of 3D modeling that based on generative design has also been used in data processing, which help improve the shortcomings of 2D information displays. There is an approach that titled Data-driven Material Modeling (DdMM), which has utilized external and user-generated data sets for the evaluation of heterogeneous material distributions during slice generation, thereby



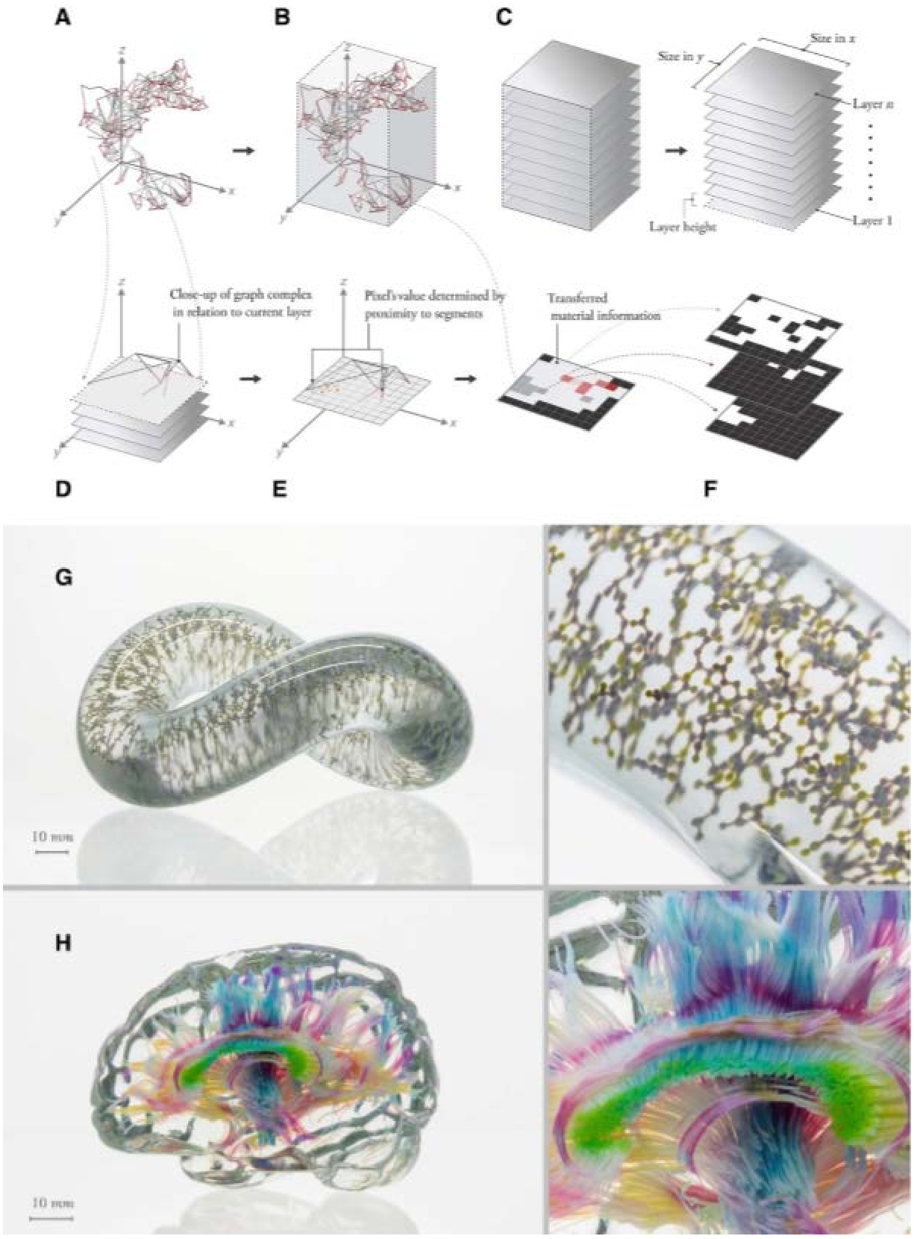
(Source: Making Data Matter - Voxel Printing for the Digital Fabrication of Data across Scales and Domains)

Figure 2.8 Point Cloud Data Processing Workflow and Representative 3D-printed models from Point Cloud Data Sets



(Source: Making Data Matter - Voxel Printing for the Digital Fabrication of Data across Scales and Domains)

Figure 2.9 Volumetric Data Processing Workflow and Representative 3D-printed models from Volumetric Data Sets



(Source: Making Data Matter - Voxel Printing for the Digital Fabrication of Data across Scales and Domains)

Figure 2.10 Curve and Graph Data Processing Workflows and Representative 3D-printed models enabling the production of voxel-matrices describing material distributions for bitmap-printing at the 3D printer's native voxel resolution [22]. This approach is designed to handle data sources and to generate material distributions during slice generation (on-slice-time) and, therefore,it permits the incorporation of external data as the primary design element in the creative process for multi-material 3D printed objects(Figure 2.7). The multi-material voxel-printing method that enables the physical visualization of data sets commonly associated with scientific imaging, and as it helps prevent alternation of data and loss of information in the produced physicalization, so it bridges the gap between digital information representation and physical material composition [23]. Based on this method, different types of scientific data has been processed into the physical entities, such as point cloud data(Figure 2.8), volumetric data(Figure 2.9), and curve and graph data(Figure 2.10).

The different 3D printing methodology that appeared in the research has pointed toward new design opportunities for overcoming the barriers between the digital and physical domains with ease, and enabling the physical visualization of almost any types of data sets.

2.2.3 Digital Data and Haptic Display

The interpretation and understanding of complex scientific data can be enhanced by haptic display, through adding kinesthetic feedback that provides the sense of touch. There has been one project that allows people to gain insight into scientific data without the use of vision through two different methods. One of the methods is to convert visual information into tactile information, which has indicated that simplification of an image can greatly enhance its recognition potential. Another method is to use the Phantom Haptic Interface, a three degree of freedom (DOF) force feedback mechanism, to generate forces to the user's fingertip or to the tip of a penstylus, which allows the user to feel the grid without interfering with the data itself [24]. The data plots that represented through haptic shows great potential for opening a new door to explore information without using vision.

Besides, the haptic engagement can also help people engage with the objects in real life in a much more informed and sophisticated ways. For example, the haptic remembrance book has applied haptic vibration to the book to build empathy for one another when sharing strong positive memories [25]. The haptic display in the project has helped strengthened the memory sharing process, and has improved the intergenerational users to interact with each other and gain meaning from the content.

2.3. Summary

The research in this chapter is mainly about plants' natural functions and different physical data expression methods.

Plants have been almost universally regarded as senseless automatons, yet an emerging body of research has showed that plants are electrically active system, which can carry highly advanced systems to sense and respond to the environment changes like light, gravity, temperature and etc, and plants' integrated natural functions also have widely explored and interfaced to machines and proposed into the interactive design.

To present plants' growth changes, different physical expression methods also have been explored from previous research. Graphic representation has been widely used to simplify the data understanding, however, it is also inadequate in many cases such as the engagement improvement and the interpretation of the data impact. With the development in the 3D modeling, the generative design methodology has been widely used in 3D design process, which has created more dynamic design with interconnected relationship between organism and environment. Some research projects also have 3D modeling into data processing based on the generative design principle. Besides, at the same time, haptic display has also enhanced the interpretation and understanding of complex data. With the kinesthetic feedback, users can get more engaged into the information understanding without using vision.

Chapter 3
Concept Design

3.1. General Goal

Raising plants can bring back a lot of pleasure and satifactory, yet as we cannot communicate directly with plants, there also exist a lot of boundaries for plant owners to have a good understanding of their plants' growth and develop a closer relationship. So in this project, the goal is to explore a design methodology to increase plant owners' deeper understanding of plant's growth an develop closer relationship with the raised plant.

The key to helping plant owners increase the deeper understanding of plant's growth is to show the plant's growth changes in a method that is easy to be identified. Based on the findings in the related research, various previous research has proved that plant organisms carry unique sensing and expression abilities [11], and there are many external factors in the living environment affect plants' growth, such as moisture, light, temperature and many other factors.

3.2. Fieldwork in Meri's house

To have a deeper understanding of plant owner's planting life, we did a fieldwork in a plant owner's house. Meri, who loves planting a lot, has raised a lot of different types of plants in her house.

3.2.1 Interview with Meri

During the interview, she told us that planting had brought great pleasure to her life. However, although she had already had rich planting experience, she still felt many boundaries existed with her plants. For example like watering plants, she

(Source: Photo shot in Meri's House)

Figure 3.1 Meri and the Plant She Raised for Thirty Years

didn't know whether the moisture amount just met the plants' needs. And she didn't know whether the place she put her plants was good for their growth.

Besides her confusion with raising plants, she also told us that taking care of these plants had gradually cultivated her deep feelings with them. They were just like children in her life. There was a plant(Figure 3.1) that she had raised for thirty years. She said that she had a lot of memories with this plant, and if it died some day, she would feel very sad.

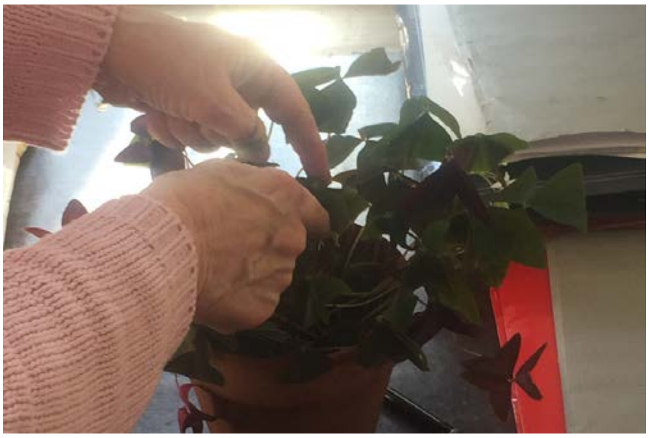
Through this fieldwork, we had following discoveries.

- Even for plant owners with rich planting experience, they still have many difficulties to understand the plants' growth.
- The planting experience will help cultivate plant owner's feelings with their plants, and their planting memories are quite precious and unique, which are hard to be replaced.

3.2.2 Meri's Treatment with Plants

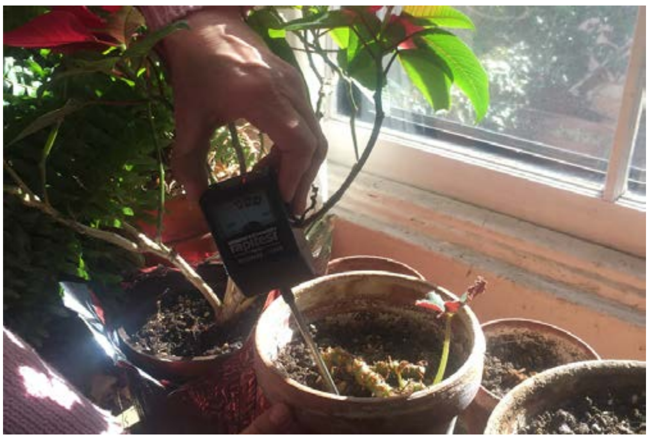
We also observed how Meri interacted with her plants. Here are the factors we found which are quite important in her treatment of the plants.

- Touching



(Source: Photo shot in Meri's House)

Figure 3.2 Meri was Touching the Plants' Leaves during the Fieldwork



(Source: Photo shot in Meri's House)

Figure 3.3 Meri was Measuring the Plants' Moisture Level

(Source: Photo shot in Meri's House)

Figure 3.4 The Plants Got Different Amount of Sunlight

In the fieldwork, we found that Meri usually touched her plants(Figure 3.2). Sometimes she gently touched her plants' leaves, sometimes she got rid of the grass in the pot.

- Moisture

  Another quite important thing is watering her plants(Figure 3.3). As she told us, she regularly watered them, but still got confused whether the moisture level just met the plants' growth.

- Light Condition

  We noticed that her plants were placed in different places(Figure 3.4), which got different amount of sunlight.

3.3. Concept

When considering the intuitive expression method, one of the best ways is to physically express the plant's growth changes based on the affect from those factors. In this research project, we would like to pick the representative factors which can reflect plant owners' treatment in their planting life. Based on the observation from the fieldwork, our research will go depth into these three factors, which are plant owners' touching, moisture and light condition, and figure out different characteristics of the collected data.

To create an intuitive method for expressing the data changes, there are previous research that showing many different physical expression methods, such as artwork explanation, 3D modeling design and haptic vibration. Among all these methods, 3D modeling design is the method that is able to generate dynamic and transformative design. As showed in previous research, 3D printing technology has been widely used to enable the physical visualization of data sets. While the imported data into the 3D software can be converted into a boundary representation, the advanced products can be generated through sophisticated design processes with complex geometries [22] containing data-informed patterns. The generative methodology that widely used in 3D design offers an unconventional way of conceptualising and working [20], which can be utilized as a valuable tool for the customizable generation of geometrically complex 3D printable artifacts for use in creative workflow and the generation of unique 3D printable objects. [22] Apart from that, other design methods such as haptics is also combined with the setting to assist with the information interpretation and to increase the understanding level showed in some research. So converting digital data into their physical embodiment such as generative design in 3D modeling software can have an intuitive expression to the plant owners of the plant's growth changes, and through haptic engagement - materially informed and sophisticated ways to engage with the physical embodiment that can help further enhance the understanding.

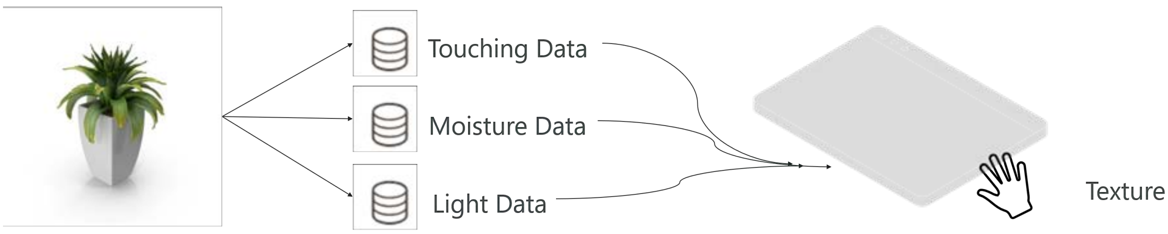


Figure 3.5 Concept in the Project

In this project, we are going to focus on the physical embodiment design which is the creation of a piece of texture as the media for physical expression(Figure 3.5). There are two design points in this concept. First is to decide the data type that can best represent plant owners' treatment on plants in their planting life, and do the analysis of the data characteristic. Another design point is the design of this piece of texture which is for the physical expression of the collected data.

3.4. Plants and Data Collection

In this project, we are going to go depth into three representative data type that can affect plant's growth in plant owners' planting life, which are plant owners' touching, moisture, and light. So in the first step of design process, we are going to collect these data first, and then analyze their different characteristics.

3.4.1 Data Collection Setup

The data we got from plants is based on real-time data collection. We first used arduino connected with different sensors to extract three types of data from plants, and then to store the data into Excel files through PLX-DAQ. (Figure 3.6)

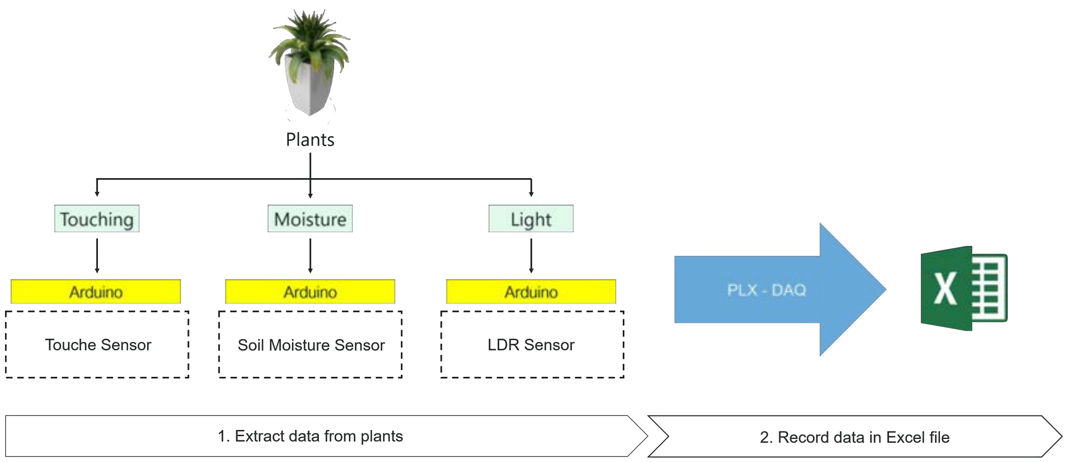


Figure 3.6 Technology System of Real-time Data Collection from Plants

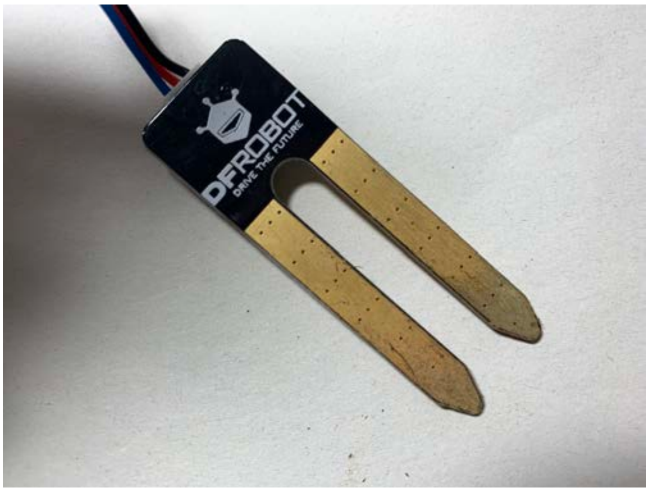


Figure 3.7 Soil Moisture Sensor

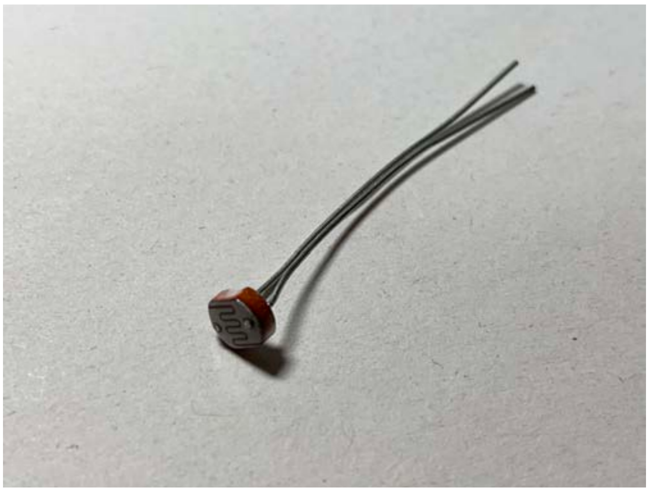


Figure 3.8 LDR Sensor

In the arduino circuit, we have used three different types of sensor to get the data. Touche circuit [26] is used to detect plant owners' touch events on plants. It is a novel capacitive touch sensing technology that can determine touch events by identifying changes in this signal caused by the electrical properties of the human hand. In our research, we can define plant owners' different levels of touch event on plants through touche sensor. To get the moisture value, we plug in the soil moisture sensor(Figure 3.7). To identify the surrounding light condition, we get the value through LDR sensor(Figure 3.8).

Then we use Excel files to record the real-time data collection. In this process, the serial port of arduino is connected with PLX-DAQ(Figure 3.9), which is a Parallax micro-controller data acquisition add-on tool for Microsoft Excel, to send data directly into Excel files and store the data.

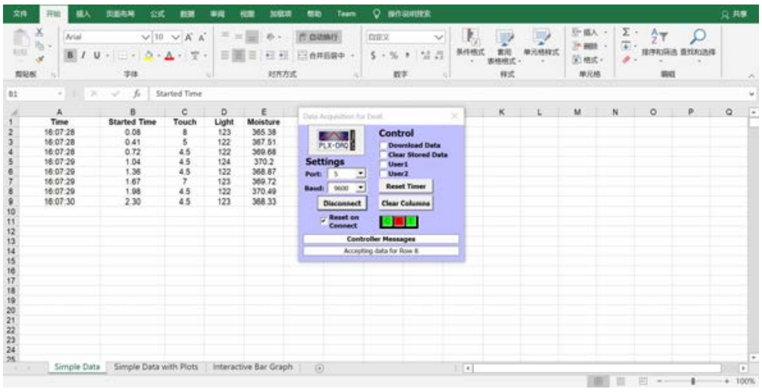


Figure 3.9 PLX-DAQ

3.4.2 Data Analysis

Based on the real-time collected data, we analyzed the characteristics of these three types of data separately.

Touching Data

As showed in the graph(Figure 3.10), the touch events changing on plants can be identified in the data changes. As the touch is stronger, the data value also get increased. From the collected data, the touching value above 22 has been identified as heavy touch in this project.

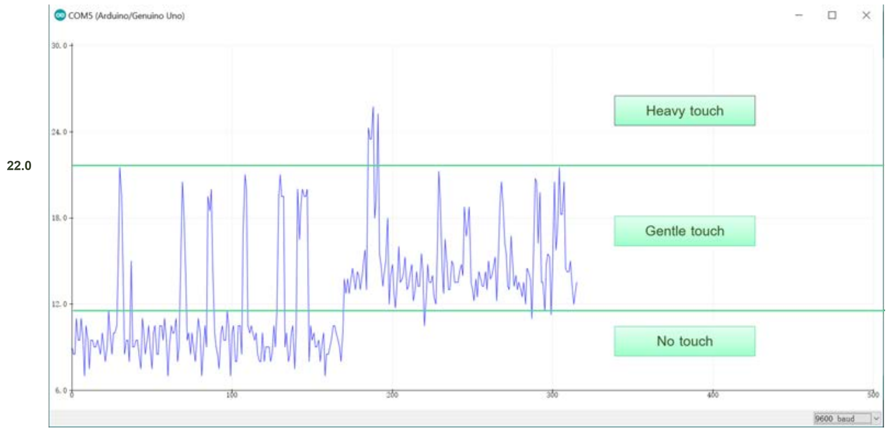


Figure 3.10 Graph of Touching Data

Moisture Data

For the characteristics of moisture data, we analyzed the data in two different cases. In the first case, we analyzed the plant's moisture value changes within one day, as showed in the left graph(Figure 3.11). In the second case, we took the average moisture value, and analyzed the plant's moisture value changes within one week, as showed in the right graph(Figure 3.11). We discovered that the moisture value of a plant doesn't have significant changes within one day. But there are obvious changes on a one-week data base.

Light Data

The location where plant owners place their plants affect the light condition of the plants' growth. As the light condition in the day and night is quite different, so in this project in order to measure the light influence on plants, we will collect the light data(Figure 3.12) of a plant during the same time period in the day time to make sure the light data we get can reflect the changes of plants' light condition every day.

(Left: Plant's moisture value changes within one day;

Right: Plant's average moisture value changes within one week)

Figure 3.11 Graph of Moisture Data

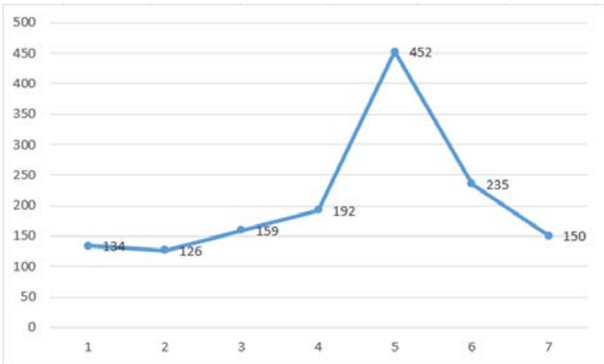


Figure 3.12 Plant's Average Light Data within One Week

3.5. Texture Design Elements

To have a better interpretation of the growing data in plant owner's planting life, many design elements have been considered for the physical expression. The texture design elements are listed as followed:

- Timeline

  As changes are happening continuously in plants' growing, considering timeline into the texture design can help plant owners better understand the growing changes responding to their treatments that happening in the process.

- Treatments Evaluation

  Satisfying plants' needs is a quite essential point to raise a plant. For example, specific amount of moisture should be paid attention to when watering plants. Neither too much nor too little moisture is good for plants' growth. So the plant owners' treatment evaluation will all be taken into account, in order to help them identify the good treatment and bad treatment, and to adjust their treatment methods later.

- Customized Generation and Data Expression

  Different types of data collection present different characteristics. So the design methodology that can be customized should be explored to make it easy for people to understand the data differences and changes.

3.5.1 Timeline

Considering timeline into the texture design can be quite helpful to reflect plants' growing changes responding to plant owners' treatment, and help them have an easy understanding of the changing process.

Based on the previous data analysis, we discovered that some data value changes, such as moisture and light condition, are not obvious within one day, but every other day can see obvious changes. Considering these reasons, the design of each piece of texture will be based on one-week data(Figure 3.13), and the texture piece will be divided into seven parts for each day in a week.

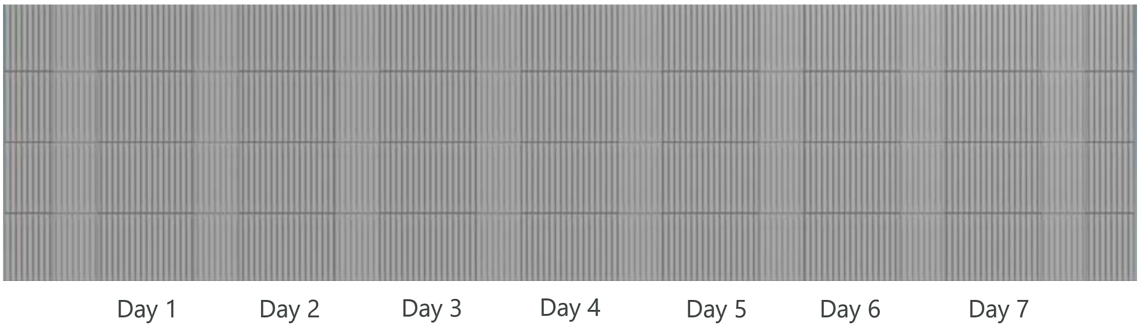


Figure 3.13 One-week Based Texture Design

3.5.2 Treatments Evaluation

In most cases, plant owners' thoughts about plants' needs don't truly satisfy plants' needs in the planting life. At the same time, some plant owners may spend less time caring about their plants during the period they get too busy. To bridge this understanding gap and to help adjust plant owners' later treatment methods, we are going to reflect the treatments evaluation from the texture design, for the easy identification of the good treatment and bad treatment.

First, we associate the treatment evaluation design with haptic sensation. The degree of good or bad treatments is reflected by the roughness of the touching(Figure 3.14). So if the plants are treated well during this week, the texture will touch smoothly. In contrast, if plants are treated badly during the week, the texture will touch roughly.

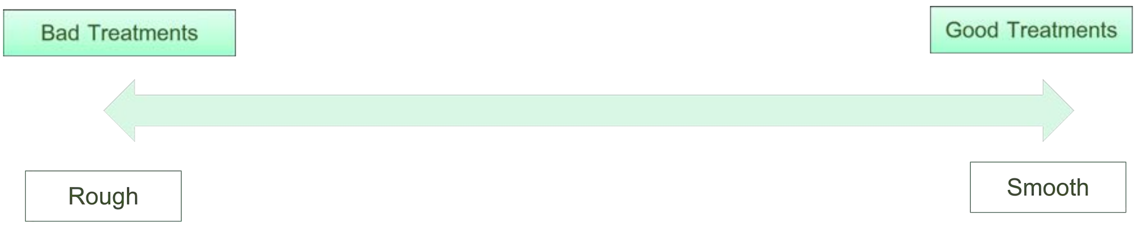


Figure 3.14 Identification of Treatment Evaluation

Next, we classified the treatment evaluation based on the different characteristics of these three data types(Table 3.1). First is the classification of touch events. When raising plants, plant owners sometimes touch the plants consciously and unconsciously. For example, like getting rid of some grasses from the pot, or fiddling with plants' leaves. At the same time, the plant may also be touched by something else instead of plant owner during their growth. The gentle touching on plants still can be fine, but if the touch on plants is too heavy, plants will get hurt. So the heavy touch of plants will be regarded as bad treatments in the evaluation. Next is the classification of watering plants. If plants get moderate amount of moisture value, then it is good planting treatment. But if the plants get too much or too little moisture, then it is bad treatment which is not good for plants' growth. Last is the classification of the light condition. Light is the driving force for photosynthesis, a plant process that changes sunlight into chemical energy. So if the plants can be raised in the place with more sunlight, then it is good treatment for growing plants. But if the plants are placed in the dark environment, then it is bad treatment for the plants to grow.

Table 3.1 Classification of Treatment Evaluation

	Good Treatment	Bad Treatment
Touch		Heavy Touch
Moisture	Moderate Amount	Too Much/Too Little
Light	More Sunlight	Dark Environment

3.5.3 Customized Generation and Data Expression

In our project, one of our design goals is to translate the abstract data we collected from plants into physical expression, in order to help plant owners have a better understanding of their plants' growth. As different data types present different characteristics, it is quite important to explore the design methodology that can be customized to display the differences and the data changing. Inspired by the related research, 3D printing technology and haptics are considered into our prototype design.

Touching

In the treatment evaluation, we have classified heavy touch as bad treatments. So there are two key points in the physical expression design of the touching data. The first key point is to let the plant owner easily understand the degree that the plant got harmed by heavy touch during this one week, including the conscious touching and unconscious touching. As explained in the data analysis part, the touching events changing on plants can be identified in the data changes, and we can identify the heavy touch from the touching events based on the data value. To show the degree that the plant got harmed by heavy touch during a week, the heavy touching frequency within one week will be the collected data for the design.

The second key point is to drive plant owners to adjust their treatments on plants in the following weeks by feeling the roughness of the texture. To do this, we are going to express the data changes through the surface roughness(Figure 3.15). Considering the customization generation from the data, we first get the data value of the heavy touching frequency, and then change into the correspondent surface roughness in the Houdini software(Figure 3.16). The surface increases the roughness level if the frequency value get increased.

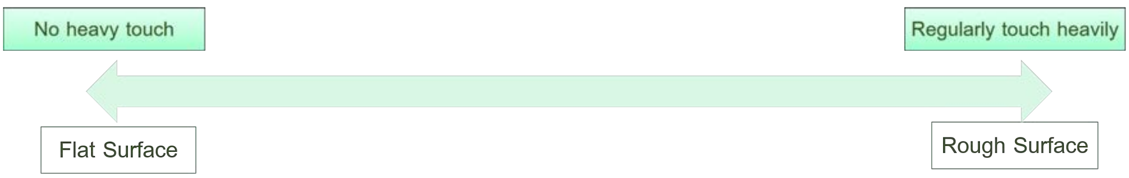


Figure 3.15 Surface Design

Moisture

According to the analysis of plants' moisture data, we discovered that the obvious changes can be seen if we compared the average moisture value of each day. So to express the change of plants' moisture level in the growing process, the average moisture value of each day is the data we are going to collect for the design.

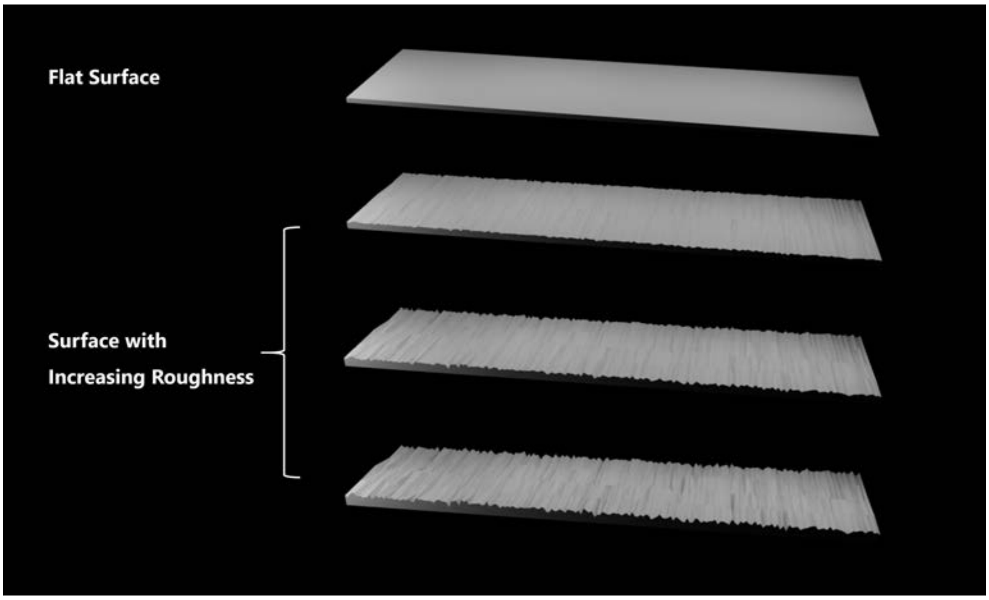


Figure 3.16 Surface with Different Roughness Level

As the moisture value needs to be classified into different categories to express the level, so the geometries variation has been considered into design to create dynamic forms for the physical expression. We consider two factors during the geometry design. (Figure 3.17)One of the factors is the expression of moisture volume. In our design, we use the geometry scale to present the volume changes. The scale will get increased, if the moisture volume get higher. Another factor is to correspond the geometry characteristics to the treatment evaluation. If the moisture value belongs to the moderate range, then the geometries will also touch smoothly. But if the moisture value is less or more than the moderate range, the geometries will also increase the roughness. We adjust the geometries' roughness level through the change of angle numbers in Houdini Software (Figure 3.18) The smoothest level is the sphere-like touching, and with the increasing of roughness, the geometries' angle will also be reduced correspondingly.

Light Condition

Light is the driving force for photosynthesis, if plants can get more sunlight, then the sunlight can be changed into more chemical energy during the process. But

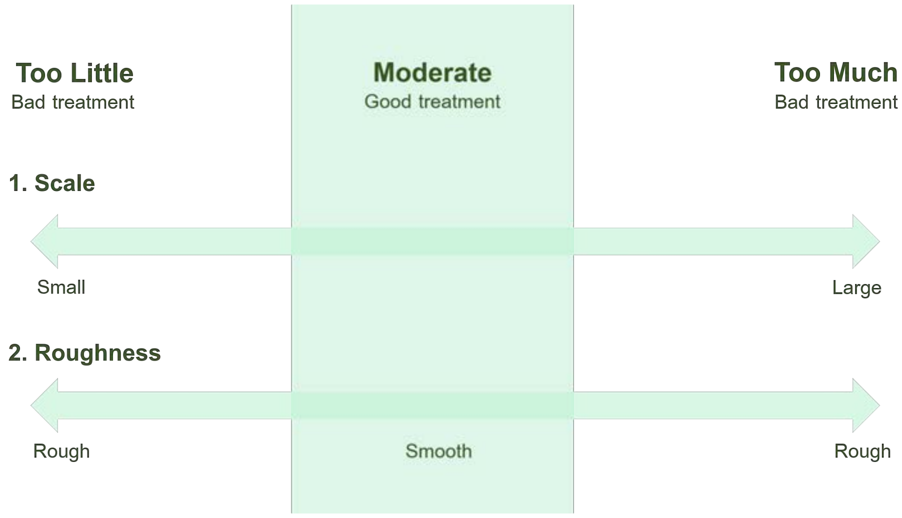


Figure 3.17 Geometry Design

Figure 3.18 Geometry Roughness Design

at the same time, the light condition changes also rely on different factors, such as the location where plant owners put their plants, or the weather condition changes. So for the physical expression design of the light condition, we aim to enable plant owners to identify the light changes happened every day easily, and help them figure out whether the location they place their plants can provide good light condition. Based on our previous data analysis, we will collect the daily average light data to reflect the light changes happened every day.

During the design process, haptic vibration has been considered as the expression method for the information interpretation. We create different types of vibration patterns by changing the vibration frequency(Figure 3.19). If the pattern is with low-frequency vibration, then it gives much gentler haptic feedback. But if the pattern is with high-frequency vibration, then it provides quite strong and tense haptic feedback. As for our design, we want to encourage plant owners to pay more attention to the plants' light condition, and remind them to give them more sunlight. So the high value of light data will be correspondent to low-frequency vibration with gentle haptic feeling, and the low value of light data will be correspondent to high-frequency vibration which provides the strong and tense feedback.

Figure 3.19 Vibration Design

3.6. Texture Design Overview

3.6.1 Software System

During the texture design process, Houdini is used for doing the surface design and geometry design, and Techtile Toolkit is used for generating the vibration.

- Houdini

Houdini software is used for the customized generation of the surface roughness and the geometry variations. After processing the data, the model will be designed with the correspondent characteristics based on the range which the collected data belongs to. For the surface roughness, the texture will be adjusted to the surface with correspondent noise display. For the geometry generation, there will appear geometries with correspondent size and shape.

- Techtile Toolkit

  Techtile toolkit is used for generating vibration patterns. The sound files with different frequency beeps are imported into techtile toolkit, and then transformed into the vibration with different frequency.

3.6.2 3D Printing

After the design in Houdini Software, the file is then sent to the 3D printer. The printing material used in this project is white resin, which can help clearly see the geometry shape on the texture(Figure 3.20).

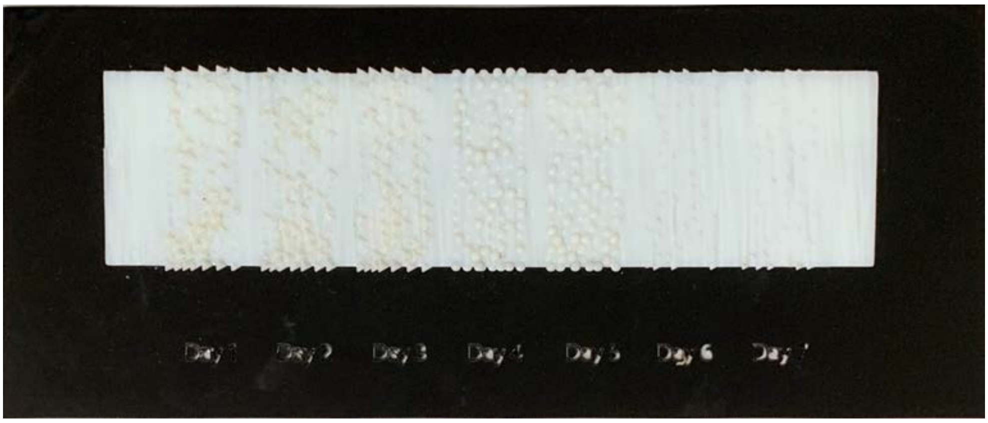


Figure 3.20 3D Printed Texture

3.6.3 Sensors

FSR sensors(Figure 3.21) are sensors to detect physical pressure, squeezing and weight. In our project, FSR sensors are sticked to the the area in the texture that represent each day. These sensors are correspondent to different vibration patterns of each day through arduino. If pressed by people, the vibration patterns will then be changed correspondent to each day in the week.

Figure 3.21 FSR Sensor

3.6.4 Texture Design Flowchart

The texture design flowchart is showed as followed(Figure 3.22). The collected data of touching and moisture are processed to generate the correspondent 3D models in Houdini, and then sent to the 3D printer for printer. The collected data of light is processed to generate the correspondent vibration pattern with the connection of Arduino circuit.

3.7. Algorithm Design Setting

During the texture design, different levels of roughness and vibration frequency have been set to tell the difference in the data changing. However, the identification ability of the visualization and touching senses varies from person to person. The algorithm setting in each category should be easy for people to figure out their differences. In order to identify the algorithm design needed for each category, several levels of roughness and vibration frequency have been created.

In this chapter, I will first describe the user test experience for algorithm design. The test results and users' feedback have provided the basis for the algorithm

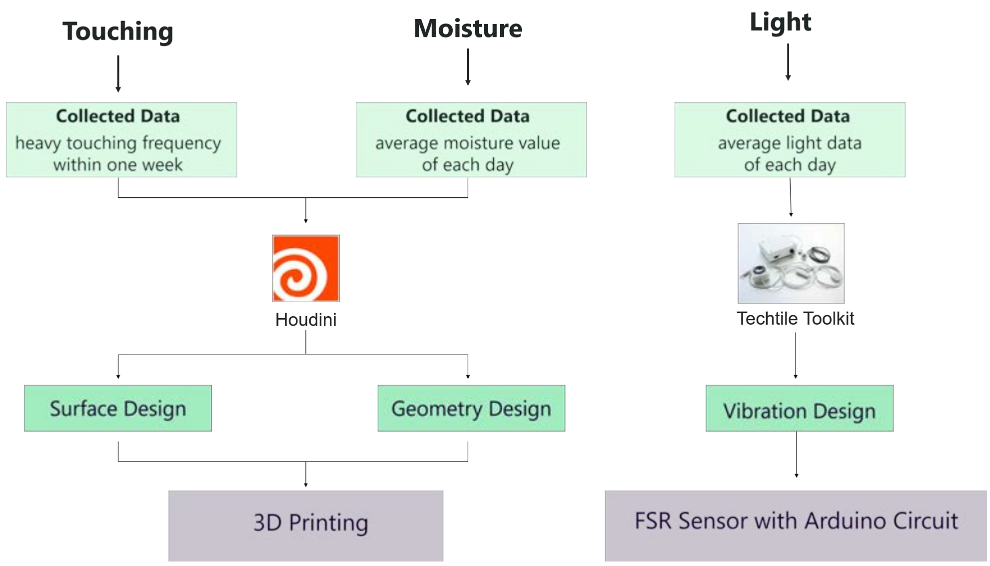


Figure 3.22 Technology Flowchart

setting. Then I will make the data classification based on the setting, and present the application to the texture design.

3.7.1 User Test on Algorithm Design

Setting and Participants

This user test is to test different people's identification ability of the visualization and touching senses, in order to provide the basis for the algorithm design in the texture that people can easily figure out the differences. Users in this test haven't been restricted, that range from different age groups and different occupations. 20 participants have joined in this user test.

Several levels of roughness and vibration frequency have been created in each category. For the surface design(Figure 3.23), four levels have been created, which are flat surface and other three surfaces that with different levels of roughness. For the geometry design(Figure 3.24), seven levels have been created, which are sphere, and geometries with three different angle levels that have the big and small sizes on each side respectively. For the vibration design, four types of vibration patterns that with different frequency have been created.

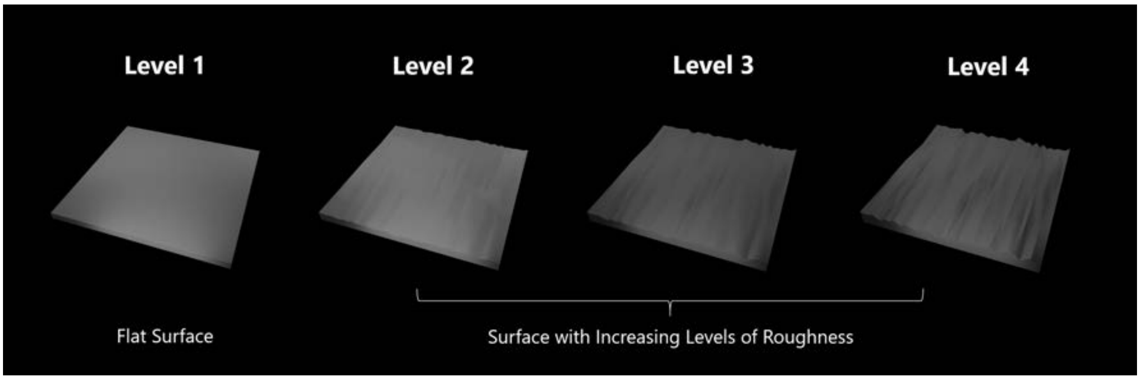


Figure 3.23 Surfaces with Different Levels of Roughness

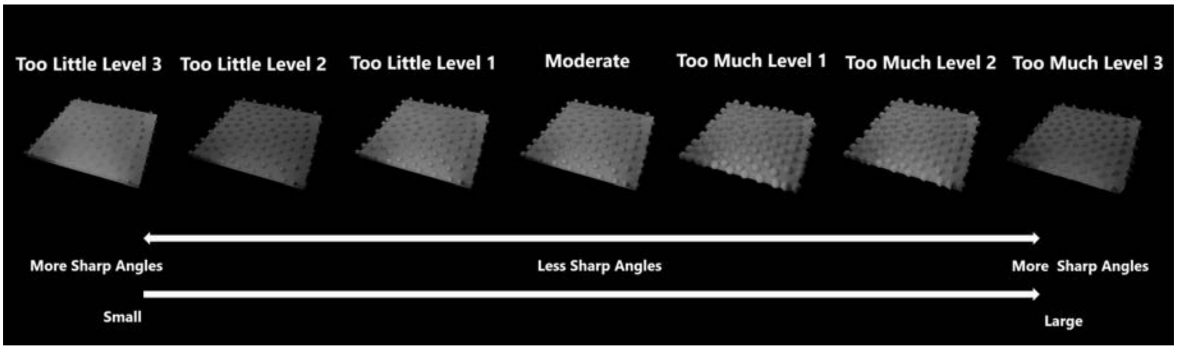


Figure 3.24 Geometries with Different Levels of Sizes and Roughness

Experience

For each category of the test, which are surface roughness, geometry design and vibration patterns, the texture that mixed with different levels have been prepared. Taking the category of surface roughness as an example, the texture that prepared for the test has randomly mixed with the roughness of different levels. Users are asked to touch the sample on the side to feel the differences of roughness levels first(Figure 3.26), and then need to write the correspondent level when touching the parts on the tested texture one by one.

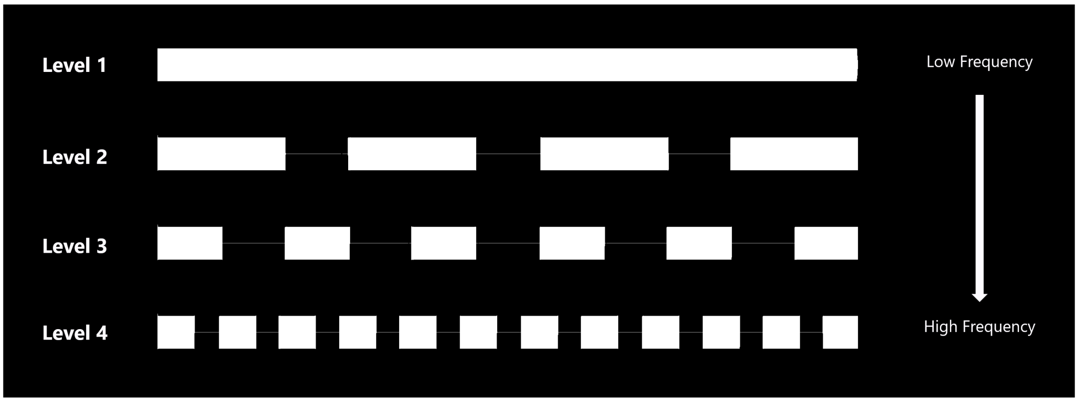


Figure 3.25 Vibration Patterns with Different Levels of Frequency

Figure 3.26 User Test for Algorithm Design

As the identification ability is varied person to person, three difficulty levels that are simple level, medium level and difficult level have been set for each category respectively during the test(Figure 3.27). For example, like surface roughness, in the simple level, there are only two roughness levels, which are the flat level level 0 and the roughest level level 4, randomly mixed. However, in the difficult level, all four roughness levels get mixed randomly. As the roughness levels get further subdivision, the complication of identifying differences also has been increased.

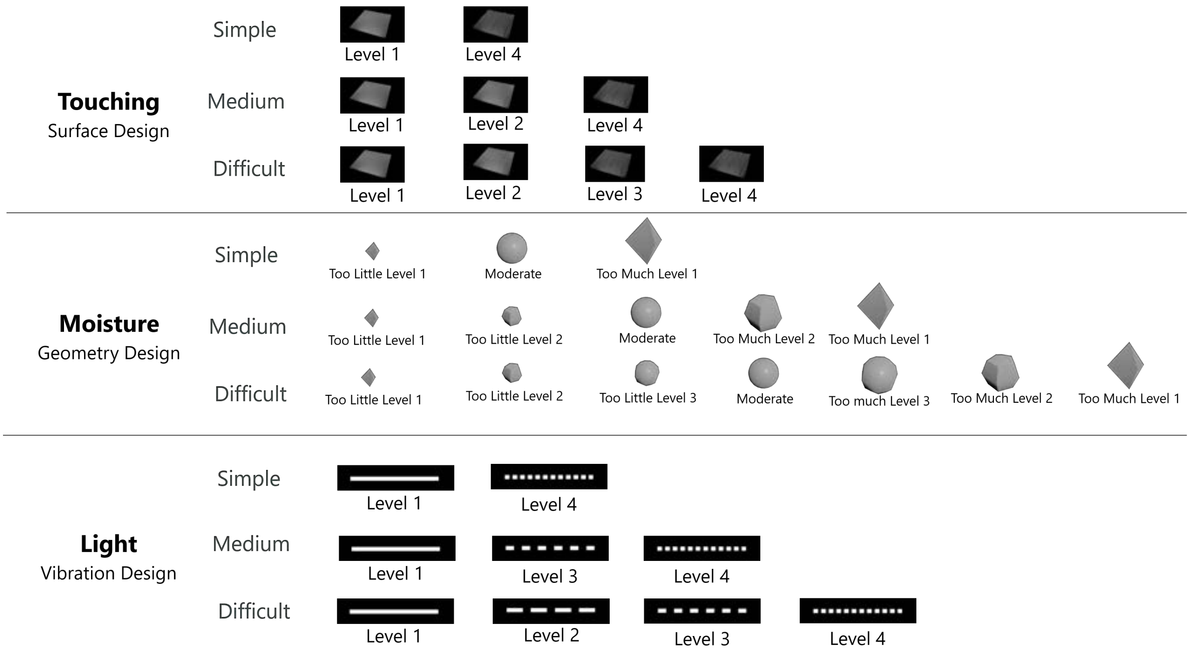


Figure 3.27 Difficulty Levels that Set in Each Category

Results and Feedback

The accuracy rate of each category level has been calculated and analyzed after the test(Figure 3.28).

- Touching

  In the touching category, the average value of both simple level and medium level have exceeded 90%, which have quite high accuracy. However, only in

		Average Value	Accuracy Rate above 90%	Standard Deviation
Touching (Surface Design)	Simple	97%	87.50%	9.06%
	Medium	98%	93.75%	4.31%
	Difficult	88%	37.50%	8.31%
Moisture (Geometry Design)	Simple	94%	81.25%	13.60%
	Medium	83%	43.75%	15.68%
	Difficult	65%	12.50%	19.30%
Light (Vibration Design)	Simple	99%	93.75%	3.63%
	Medium	98%	87.50%	6.84%
	Difficult	85%	50.00%	16.59%

Figure 3.28 Data Analysis of the User Test

the medium level that there are more than 90% of users have the accuracy rate above 90%. But in the simple level, the percentage of users that has the accuracy rate above 90% is also close to 90%. Besides, the standard deviation value of these three levels are all below 10%, which have low variations among users' accurate rate.

According to the feedback, many people reflected that as the levels of complication increasing, it also got much more difficult to identify the difference. And someone said that although he knew the difference, it was a little bit hard to correspond the feeling to the roughness level.

- Moisture

  In the moisture category, only the average value of simple level has exceeded 90%, and the average values of medium and difficult level are below 85%. The accuracy rate in all these three levels are not high, and the difference gap between each level is quite large. Besides, the value of standard deviation in these three levels are all above 10%.

  Most users reflected that it was too hard to identify the differences in both medium and difficult level. Someone said like this, 'In the simple level, besides sphere which is the moderate level, the too little level 1 and too much level 1 are not difficult to identify. But when getting into the harder levels, the variation between some geometries are too similar to differentiate, for example like too little level 3 and the sphere, or like too much level 3 and too much level 2, are quite hard to identify.' Besides, many of the users told to me that they identified the differences not only through touching and feeling them, but also through finding the difference in visualization and guess the shape.

- Light

  In the light category, the average rate of both simple level and medium level are above 95% and nearly 100%, which have quite high accuracy. In the simple level, the accuracy rate that above 90% is above 90%, and in the medium level, the accuracy rate that above 90% is also almost nearly 90%. Besides, the standard deviation level of both the simple level and medium level are below 10%, which don't have a lot of variation among the users in these two levels.

  Some users said that vibration difference was not very hard to differentiate, just in the difficult level, the level 2 vibration pattern and the level 3 vibration pattern got a little bit similar, and sometimes felt it a little bit hard to differentiate.

In general, the users have achieved better testing results in surface design for touching category, and the vibration design for light category. Although the results of difficult level in both these two categories shows the variation among users, many users still can get high accuracy in the both simple and medium levels. Some users also reflected that the vibration difference is the easiest one to identify among all these three different design. However, compared with these two categories, the testing result of geometry design for moisture category is less satisfying, and the variations among users' identification ability is quite large. Many users said that if there were too many different geometries put together, especially the geometries with similar size and shape, it was quite confusing, and mostly they gave the answer by guessing it. But if in the simple level and only with these three different types of geometries, it was still not difficult to identify them.

3.7.2 Algorithm Setting

Algorithm Levels

Based on the results and feedback from the user test, we set the algorithm levels for each category as followed. For the subdivision of surface roughness, we set three levels of roughness. Flat level level 0 refers to the status that plants almost haven't got any harm by heavy touching during the period. Roughness level 2 refers to the status that plants have got a little bit hurt from the heavy touch, and roughness level 4 refers to the status that plants are often touched heavily and got a lot of hurt during the period. For the subdivision of geometry design, we set three levels of geometries. Too little level 3 refers to the status that plants don't have enough moisture. Moderate level refers to the status that plants have got suitable amount of moisture, and too much level 3 that refers to the status that plants have got too much moisture above the needs. Finally, for the subdivision of vibration design, we set three levels of vibration patterns. The lowest frequency vibration pattern level 1 refers to the bright environment. Level 2 refers to the normal environment that is with average light condition, and the highest frequency vibration pattern level 4 refers to the dark environment.

Data Classification

Next step is to make a data classification based on the algorithm setting. As the characteristics and the need of moisture and light are different from plants to plants, so in this project, we take Nichinichi Grass(Figure 3.29) as the plant type for testing. To get the data for classification, three plants have been raised to get the related data. During the studying process, the growing status of each plant has been recorded(Table 3.2).

Table 3.2 Three Plants' Growing Status during One Week

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Plant 1	Good	Good	Good	Good	Good	Good	Good
Plant 2	Good	Good	Good	Good	Get Worse	Get Worse	Get Worse
Plant 3	Good	Good	Good	Get Worse	Get Worse	Get Worse	Get Worse

Figure 3.29 Nichinichi Grass

Figure 3.30 Touching Data Changes

- Touching

  In the previous data analysis part, we have identified the touching value that above 22 will be regarded as heavy touch in this project. To get the data of the heavy touching frequency within one week, we divide the total number of the collected data by the data value that is above 22.

  To identify the classification of the heavy touching frequency, the data collected from three plants have been studied. The data of three plants are stated as followed. Plant 1 is 15.95%, plant 2 is 12.56%, and plant 3 is 34.60%. Bases on these data values, we classify the levels into three ranges(Figure 3.30). The range that is below 10% refers to the good status. The range that is between 10% and 20% refers to the status of a little harmful, and the range that is above 20% refers to the status of harmful.

- Moisture

  To identify the moisture amount that plants need for growth, we also collected these three plants' average moisture value change within one week, and recorded their status every day.(Figure 3.31) We classified the levels as followed(Figure 3.33). The range that is below 500 is a little bit dry for plants' growth, so it refers to too little moisture. The range that is between 500 and 600 is suitable for plants' growth, so it refers to moderate moisture. The range that is over 600 is a little bit wet for the growth, so it refers to too much moisture.

- Light

  To classify the light data changes, we changed the light environment, and then collected the data(Figure 3.32). The light data range is divided into three levels as followed(Figure 3.33). The data range that is below 150 refers to bright environment. The range that is between 150 and 300 refers to the normal environment that is with the average light condition, and the range that is above 300 refers to the dark environment.

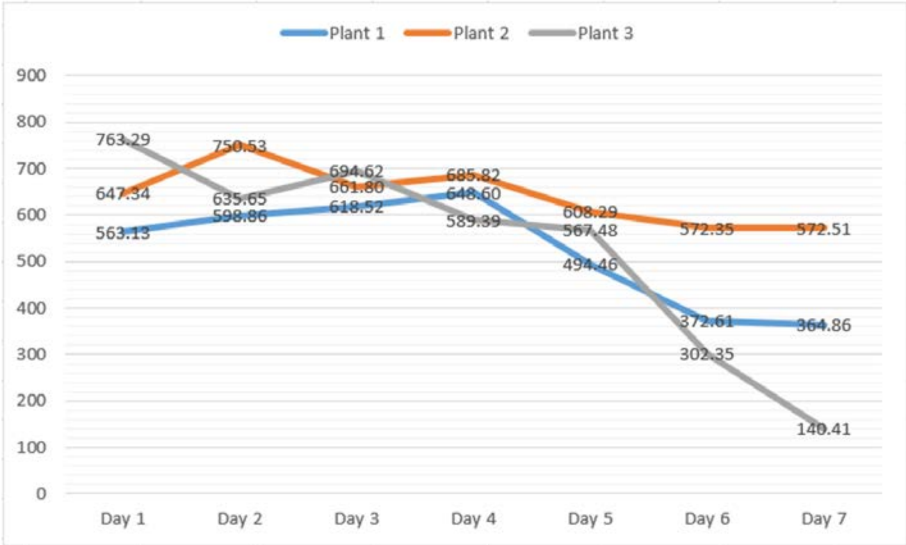


Figure 3.31 Three Plants' Average Moisture Value Changes within One Week

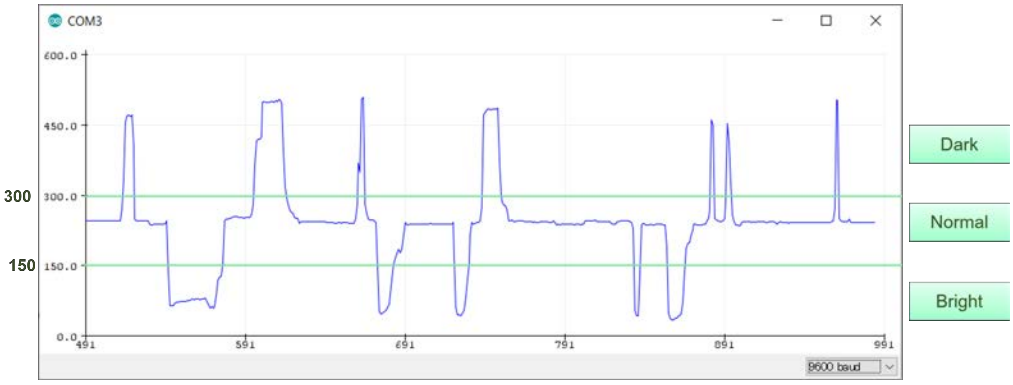


Figure 3.32 Light Data Changes

3.7.3 Application of Algorithm Design

Based on the previous classification, we set the algorithm design as below(Figure 3.33). The surface design for touching has been divided into three levels, which are good status, status of a little harmful and status of harmful. The flat surface level 1 is correspondent to good status, level 2 is correspondent to the status of a little harmful, and then level 4 is correspondent to the status of harmful. The geometry design for moisture has been divided into three levels, which are too little moisture, moderate moisture and too much moisture. The geometry that marked too little level 3 is correspondent to the too little moisture level, the sphere is correspondent to the moderate level, and the geometry that marked too much level 3 is correspondent to the too much moisture level. Finally, the vibration design for light has been divided into three levels, which are bright, normal and dark. The lowest frequency level 1 is correspondent to bright environment, level 2 is correspondent to the normal environment that is with average light condition, and the highest frequency level 4 is correspondent to the dark environment.

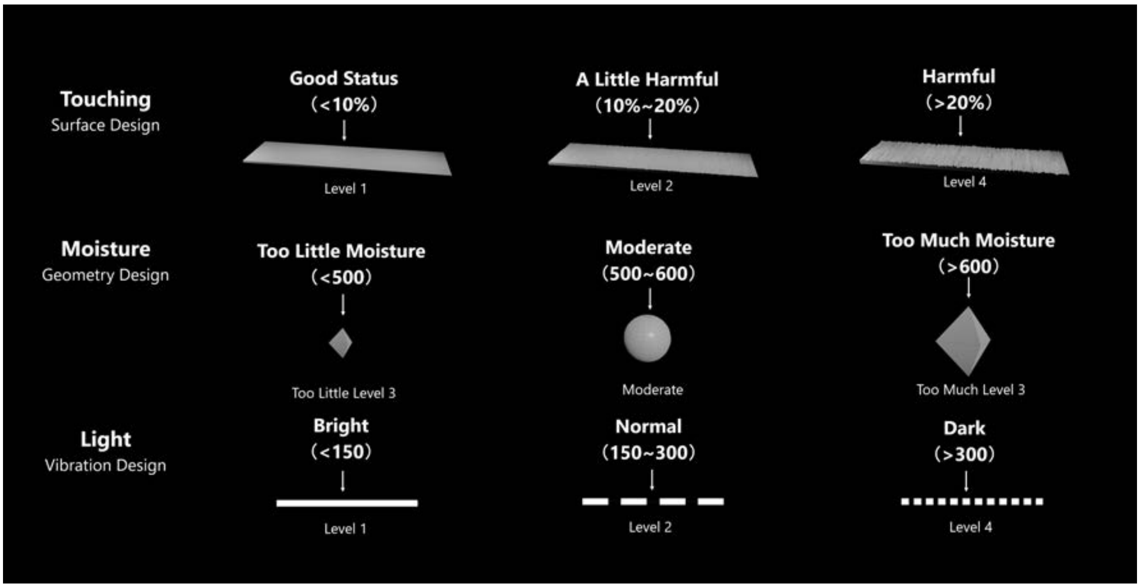


Figure 3.33 Algorithm Setting and Data Classification

3.8. Product Design

In order to build a closeness relationship between plant owners and their plants, several components have to be included. During the fieldwork, one of the discoveries was that the planting experience will help cultivating plant owners' feelings, and their planting experience is precious and unique which is quite hard to be replaced. The development of the closeness relationship needs a long-term process, and the components of designing this product are considered to continually improve users' understanding about their plants' needs and to increase the users' engagement in planting activities. These components are as followed.

- Exploration and Understanding about Plant's Needs

  When first starting to raise a new plant, there still exist a lot of difficulties and uncertainty for many plant owners to know about plant's real needs. To understand more about plant's growth and to find a better way to raise plants is the first step in the planting process.

- Reference for Plants' Growth

  With a reference of plant's growing changes, the owners will have a better understand of what are the plant's real needs, and to adjust their treatment to their plants later. Through the process of continuous adjustment and exploration, the owners will get much more familiar with the plant's growth, which helps build a closer relationship between the owner and the plant.

- Comparison of Changes in the Planting Process

  The texture that designed based on plant's data changes can help owners understand the plant's growing status in the previous week. But in order to get a deep understanding and to get user much more engaged in the planting life, longer process is required. As the plant's growing status and plant owner's treatment methods keep changing week by week, doing the comparison of the weekly changes, can help know plant's growing process further, and the changes in their planting method during the time, which can build a deeper relationship with their raised plants.

Considering these components, we designed the products that help plant owners build a closeness relationship with plants gradually in the long term. It is a series of product design(Figure 3.34) that including a plant platform and a memory album(Figure 3.35). Every week, the data is collected from the plant, and generate the texture with correspondent characteristics. Then in the following week, the texture is put on the plant's platform, which shows the owner the plant's growing changes in the previous week, and providing a reference to them when they take care of the plant in the current week. After that, the texture can be put into the memory album, which has collected all the texture made before. So for plant owners, they can compare the difference among all the previous texture, and feel their past planting experience through the memory album.

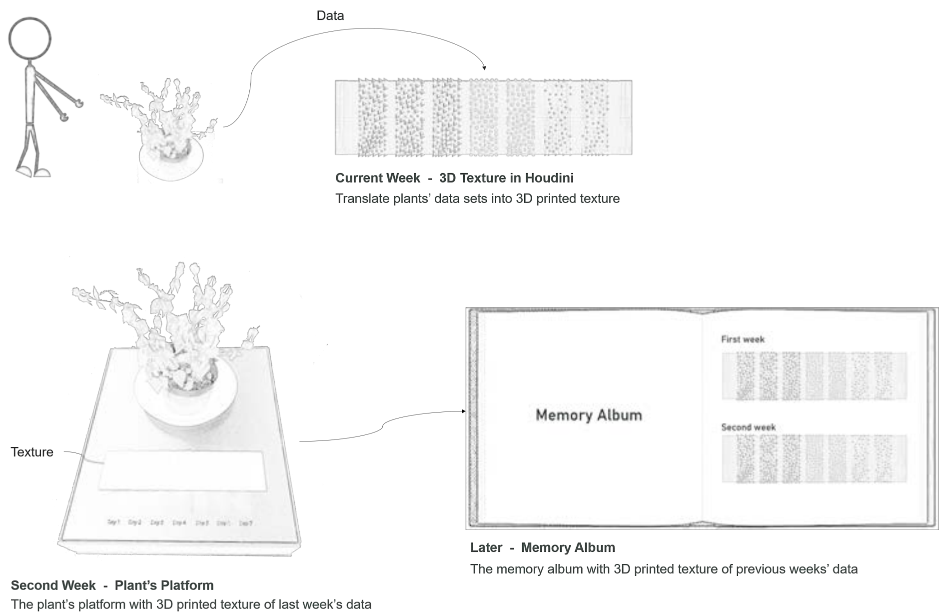


Figure 3.34 Comparison of Participant One's Records and Data Classification of Light

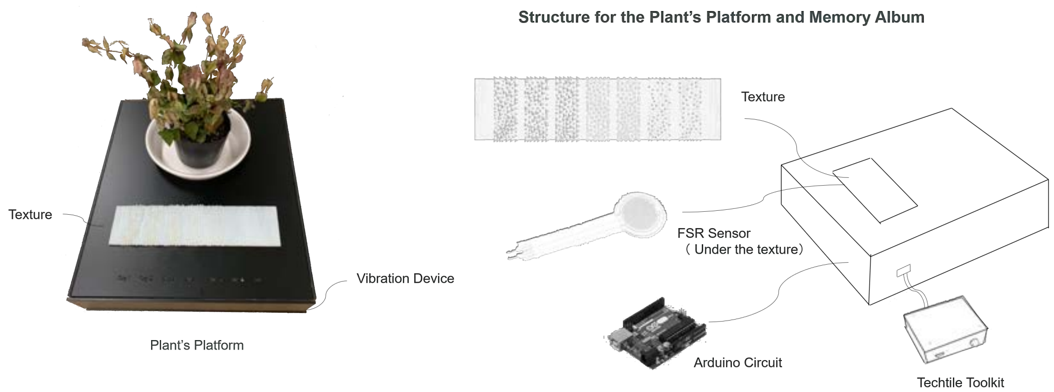


Figure 3.35 Comparison of Participant One's Records and Data Classification of Light

Chapter 4
Validation

4.1. Long-term User Experience

4.1.1 The Vision

The design goal of this project is to increase plant owners' deeper understanding of plants' growth and to develop closer relationship with raised plants. In this project, in order to evaluate plant owners' understanding changes of plant's growth and intimacy changes with plants, several users have been asked to raise plants for a period of time for doing long-term user studies. In this chapter, I will describe the observation from each user test and their feedback, and then talk about the findings from all the tests.

4.1.2 Setting and Participants

There are three participants have joined in the long-term user test. The participants of this test are with different levels of knowledge about raising plants. The time length of this user test is three weeks. In the user test, the participants were given the plant *Nichinichi Grass*, and were asked to raise it during the period. The data of their raised plants were collected every day, and then the data was processed every week and made into the correspondent texture. Once a week, the users were asked to do the test. All the three participants chose to raise the plant at home. The details of the evaluation method is described as followed.

Participants' Planting Profile

In order to know about each participant's experience levels of raising plants, the participants were first asked to take a questionnaire before the test. The questions are about their planting experience and planting attitudes.

Measurement of Understanding Changes during the Long-term Process

In the experiment, participants' understanding level about the plant in different weeks have been compared, in order to measure their understanding changes during the long-term process.

To know about participants' understanding level about plant's growth each week, the participants were asked to record their plant's growing status every day from three aspects based on their own understanding, which are touching, moisture and light. Then once a week, the participants were asked to feel the texture that is made based on the collected data from the previous week(Figure 4.1). Participant's recording data, which is based on their own understanding about their plant's growth every day, and the data classification have been compared, in order to know about their understanding level every week.

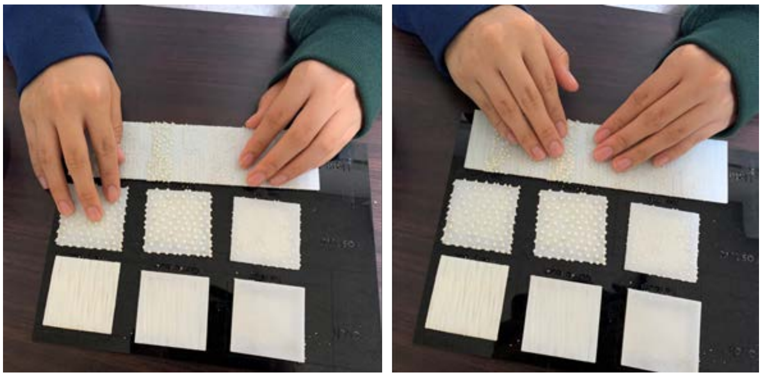


Figure 4.1 Participants are Feeling the Texture during the User Test

Measurement of Intimacy Changes during the Long-term Process

To measure participants' intimacy changes during the long-term process, two things have been considered. First is their feedback during the test. Every time after they felt the texture, the feedback was collected from the participants.

The second thing is the result of the inclusion of other in the self(IOS) scale test. The IOS test is a questionnaire that is a single-item, pictorial measure of closeness. [27] The figures were designed so that the total area of each figure is constant(thus as the overlap of the circles increases, so does the diameter), and the degree of overlap progresses linearly, creating a seven step, interval-level scale. It was used to measure plant owner's own subjective perception of their degree of closeness to the plant. Respondents need to select the picture that best describes their relationship from a set of Venn-like diagrams each representing different degrees of overlap of two circles(Figure 4.2). The IOS test was conducted four times during the period. The first time was before they raise the plant, and another three times were conducted after each week. The test results every time are compared, and the changing during the long-term process is regarded as one of the reference to measure the participants' intimacy changes with the plant during the process.

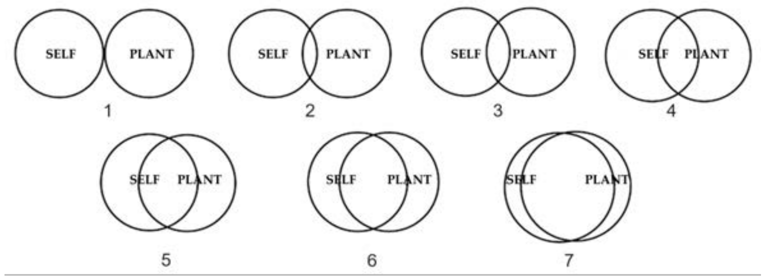


Figure 4.2 The Inclusion of Other in the Self(IOS) Scale

4.2. Analysis of Each Participant

4.2.1 Participant 1

Planting Profile

The first participant in the test is a working person. He doesn't have much planting experience, and he is not good at raising plants. When he was given the plant for the test, he said it was his first time to raise this plant, and not very familiar with it. In this experiment, he chose to raise the plant in his balcony(Figure 4.3).

(Left: the Plant's Status before the Experiment; Right:the Plant's Status after Three Weeks)

Figure 4.3 Participant 1 has raised the Plant in the Balcony

Understanding Changes during the Long-term Test

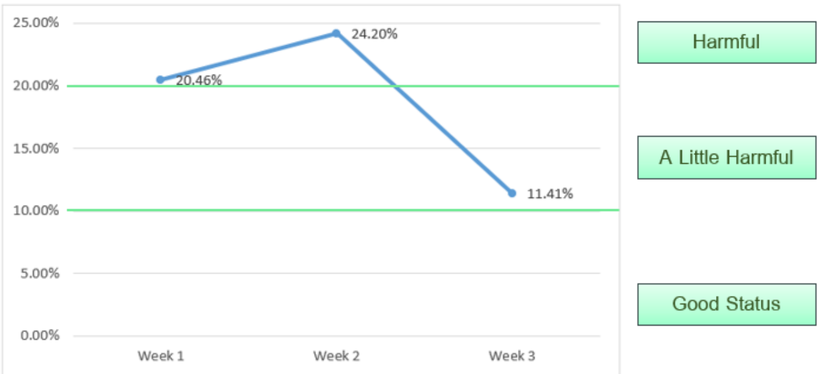
- Understanding Comparison

  The comparison of participant one's own recording and the data classification has been showed below. In the first week, the participant thought that the plant was in good status(Figure 4.4), got enough moisture to grow(Figure 4.5), and the light condition was also quite good(Figure 4.6). Compared with the data classification, the light changes during the week was similar to what he had expected. However, there still exist many understanding deviation in the classification of other two aspects. The plant had been touched heavily for several times, which was classified as harmful to the growth, the moisture level of the plant hadn't been controlled well, that sometimes it was watered too much, and sometimes it was watered too little.

  In the second week, compared with the data classification, the result of most of the days has matched the participant's understanding. The times he touched the plant was more than he expected(Figure 4.4). But in the moisture aspect, there have been more matching(Figure 4.5). In the light aspect(Figure 4.6), participant thought that most of the days in the week, the environment was dark, which is similar to the classification.

  In the third week, the touching classification matches the participant's expectation(Figure 4.4). In the moisture aspect(Figure 4.5), the participant thought that the plant was watered a lot in the first few days, and didn't

Data Classification:



Participant's Understanding:

Week 1	The plant is in the good status, it hasn't been hurt.
Week 2	The plant hasn't been hurt, but maybe was touched unexpectedly when I moved it.
Week 3	This week more attention has been paid to the plant. The plant hasn't been touched a lot.

Figure 4.4 Comparison of Participant One's Records and Data Classification of Touching

Data Classification :

Day 1	Too Much
Day 2	Moderate
Day 3	Moderate
Day 4	Too Little
Day 5	Too Little
Day 6	Too Much
Day 7	Too Much

Participant's Understanding :

Day 1	Moderate
Day 2	Moderate
Day 3	Moderate
Day 4	Moderate
Day 5	Moderate
Day 6	Moderate
Day 7	Moderate

Data Classification :

Day 1	Too Much
Day 2	Moderate
Day 3	Too Little
Day 4	Too Little
Day 5	Too Little
Day 6	Moderate
Day 7	Too Little

Participant's Understanding :

Day 1	Moderate
Day 2	Moderate
Day 3	Too Little
Day 4	Too Little
Day 5	Moderate
Day 6	Moderate
Day 7	Too Little

Data Classification :

Day 1	Moderate
Day 2	Too Little
Day 3	Too Much
Day 4	Too Little
Day 5	Too Little
Day 6	Too Little
Day 7	Too Little

Participant's Understanding :

Day 1	Too Much
Day 2	Too Much
Day 3	Moderate
Day 4	Too Little
Day 5	Too Little
Day 6	Too Little
Day 7	Too Little

Figure 4.5 Comparison of Participant One's Records and Data Classification of Moisture

Data Classification :	
Day 1	Bright
Day 2	Bright
Day 3	Bright
Day 4	Bright
Day 5	Normal
Day 6	Bright
Day 7	Bright

Participant's Understanding :	
Day 1	Bright
Day 2	Bright
Day 3	Bright
Day 4	Bright
Day 5	Bright
Day 6	Bright
Day 7	Bright

Data Classification :	
Day 1	Bright
Day 2	Dark
Day 3	Dark
Day 4	Dark
Day 5	Dark
Day 6	Normal
Day 7	Dark

Participant's Understanding :	
Day 1	Bright
Day 2	Normal
Day 3	Dark
Day 4	Normal
Day 5	Normal
Day 6	Dark
Day 7	Normal

Data Classification :	
Day 1	Normal
Day 2	Normal
Day 3	Bright
Day 4	Bright
Day 5	Bright
Day 6	Bright
Day 7	Bright

Participant's Understanding :	
Day 1	Dark
Day 2	Normal
Day 3	Normal
Day 4	Bright
Day 5	Normal
Day 6	Bright
Day 7	Bright

Figure 4.6 Comparison of Participant One's Records and Data Classification of Light

get enough moisture the last few days. Compared to the collected data, the data in the first three days were almost around the edge of the data range, so there were also some deviation in the participant's understanding. And the data classification in the following days has matched the participant's thought. In the light aspect(Figure 4.6), the participant also has noticed the light condition changes. During the week, he thought that most of the days the environment got dark or normal, but most of the days in the week, the light condition was quite good. Compared to the data, for most of the days, the classification has matched most of the participant's understanding, except there were some days the collected data was around the edge of the data range.

- Experience Feedback

  During the interview, the participant was asked to touch the printed texture(Figure 4.7), the feedback after each week is showed as below.

  Feedback after the first week:

  I thought I haven't touched the plant this week. But maybe I unexpectedly touched it, or by some other things when trying to move them. And about the watering, I watered them every day, but maybe I still haven't controlled well the moisture I think.

  Feedback after the second week:

  This week, I haven't touched it heavily I think, but maybe just unexpectedly touched by something else. For the moisture this week, I first observed the plant's status and then decided the watering amount.And it is almost rainy days this week, so the growing environment is quite wet and dark.

  Feedback after the third week:

  This week I got quite busy and didn't have much time watering the plants, so the moisture change was quite similar to what I expected.

- Analysis of Participant's Understanding Changes

  Comparing participant's understanding level during these three weeks, in the first week, the participant still hasn't clear ideas about the planting

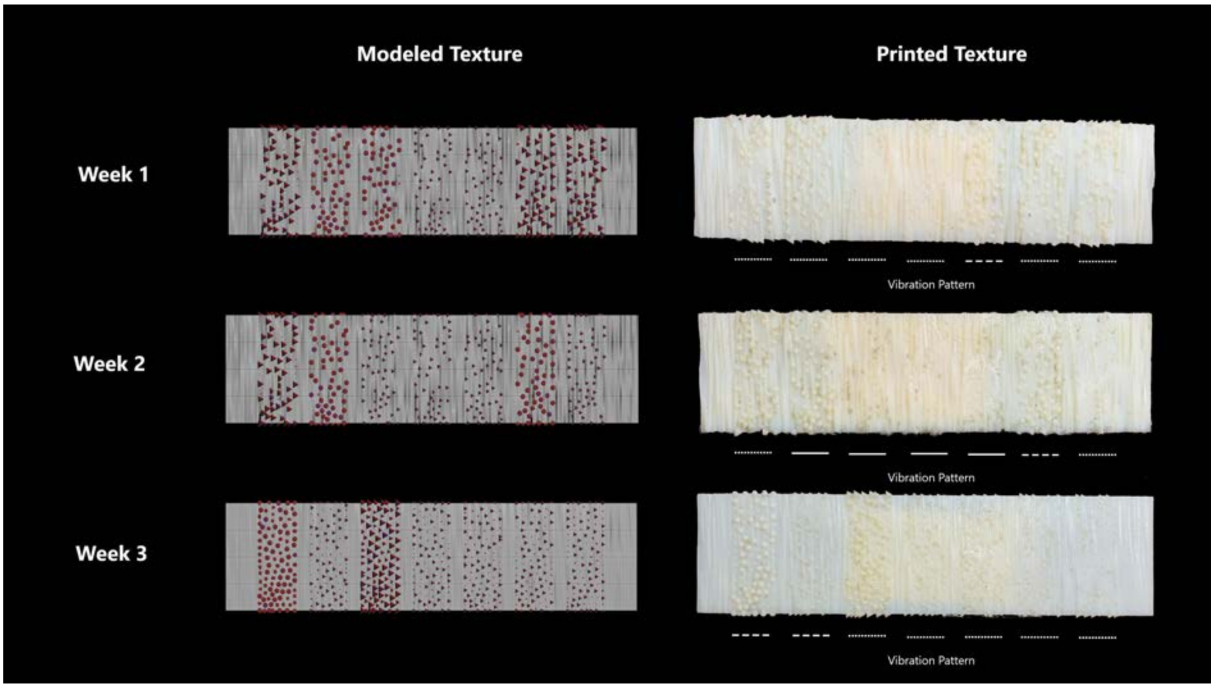


Figure 4.7 Participant One's Modeled Texture and Printed Texture

method. There existed many differences in his own understanding and the data classification. In the next two weeks, the participant has improved his understanding about the plant's growth, and his understanding has matched more with the data classification. He started to take the weather and the environmental changes into account. He also has noticed the variations in the growing process, and tried to make adjustments in his treatment methods.

Intimacy Changes during the Long-term Test

- IOS Scale

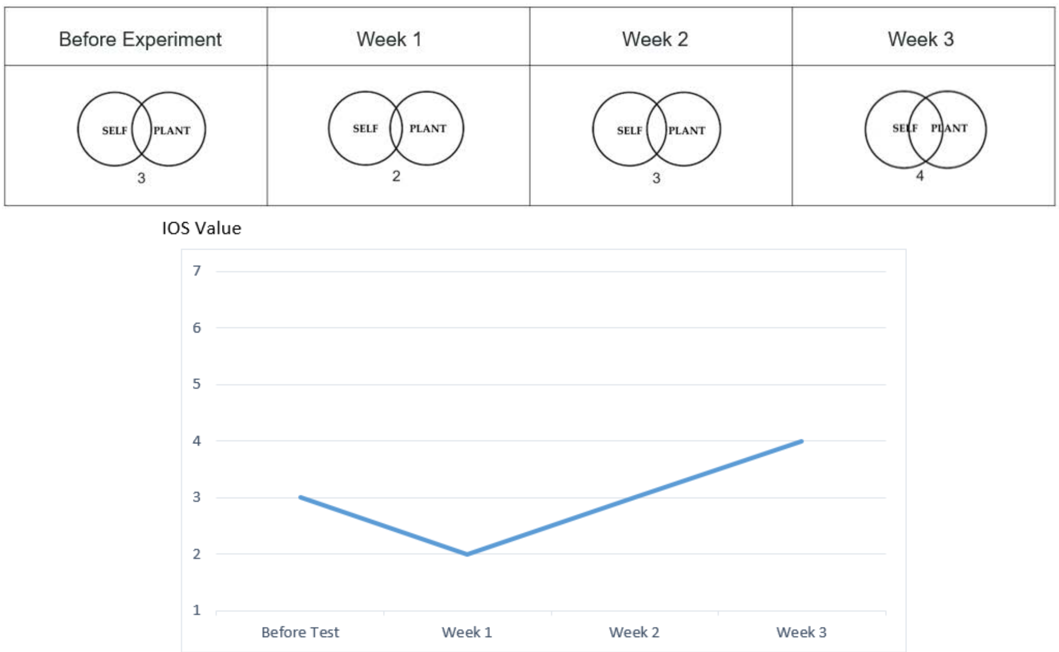


Figure 4.8 Participant One's IOS Scale Value Changes During the Test

During the long-term test, the participants were asked to circle the picture in the IOS scale that best describes their current relationship with the plant every time when doing the test, which are relatively before starting the test, after the first week, after the second week and after the third week.

The figure below(Figure 4.8) has showed his relationship changes with the raised plant during the long-term test.Before the test, he chose the third level. After week one, the relationship level got decreased into the second level. After week two, the relationship level returned to the third level, and after the third week, the relationship level increased into the fourth level. So, based on the IOS scale, the value once dropped after the first week, and then continuously got increased in the following two weeks.

- Experience Feedback

  Participant One:

  Before the test, I was unfamiliar with this type of plant, but as I still had the basic knowledge of how to raise a plant, so I chose the third level. After the first week, the result of the plant's growth was a little different from what I expected, and then felt a little bit alienated with the plant. In the following two weeks, I started to have a better exploration in the planting method, and gradually understood the plant's needs. But at the same time, I felt these three data cannot fully reflect the plant's status, because the flowers have withered after three weeks, but it was hard to identify the plant's status just from these data information(Figure 4.3).

- Analysis of Participant's Intimacy Changes

  Based on the IOS result and the feedback, the understanding improvement in plant's growth has helped build a closer relationship with the plant to some extent, but at the same time the limited factors also cannot fully reflect the plant's status, so there still exist barriers between the user and the plant.

4.2.2 Participant 2

Planting Profile

The second participant in the test is also a working person. She has raised plants before, but not quite often. She loves flowers, but she is not good at planting. When she was given the plant for the test, she said that she just generally knew that plants need moisture and light, but was not familiar with raising this plant. In the experiment, she has raised the plant indoor(Figure 4.9).

(Left: the Plant's Status before the Experiment; Right:the Plant's Status after Three Weeks)

Figure 4.9 Participant 2 has raised the Plant Indoor

Understanding Changes during the Long-term Test

- Understanding Comparison

  The comparison of participant two's own recording and the data classification has been showed below. In the first week, the participant thought that the plant hasn't been hurt, so it was in the good status(Figure 4.10). While the data classification has showed that it was a little bit hurt by the touch. In the moisture aspect(Figure 4.11), in the participant's own understanding, she thought that the plant had got moderate moisture level every day during the week. Reflected by the processed data, the moisture level was a little bit higher than the plant actually needs. In the light aspect(Figure 4.12), she thought that the living environment for the plant had been bright enough for its growth. According to the data, the data classification was similar to what she expected.

  In the second week, in the participant's own opinion, she thought that the plant hadn't been hurt a lot, but reflected by the data, the heavy touching frequency was around 18.55%, which was classified as a little harmful(Figure 4.10). In the moisture aspect(Figure 4.11), according to the participant's own understanding, she thought that most of the days in the week the plant had got moderate moisture level, but there were some days that the moisture level was below the plant's needs. Reflected by the processed data, during this week, the moisture level of most of the days was above

Data Classification:

Participant's Understanding:

Week 1	The plant was in good status, hasn't been touched.
Week 2	The plant hasn't been hurt a lot.
Week 3	The plant has taken good care and hasn't been hurt.

Figure 4.10 Comparison of Participant Two's Records and Data Classification of Touching

Figure 4.11 Comparison of Participant Two's Records and Data Classification of Moisture

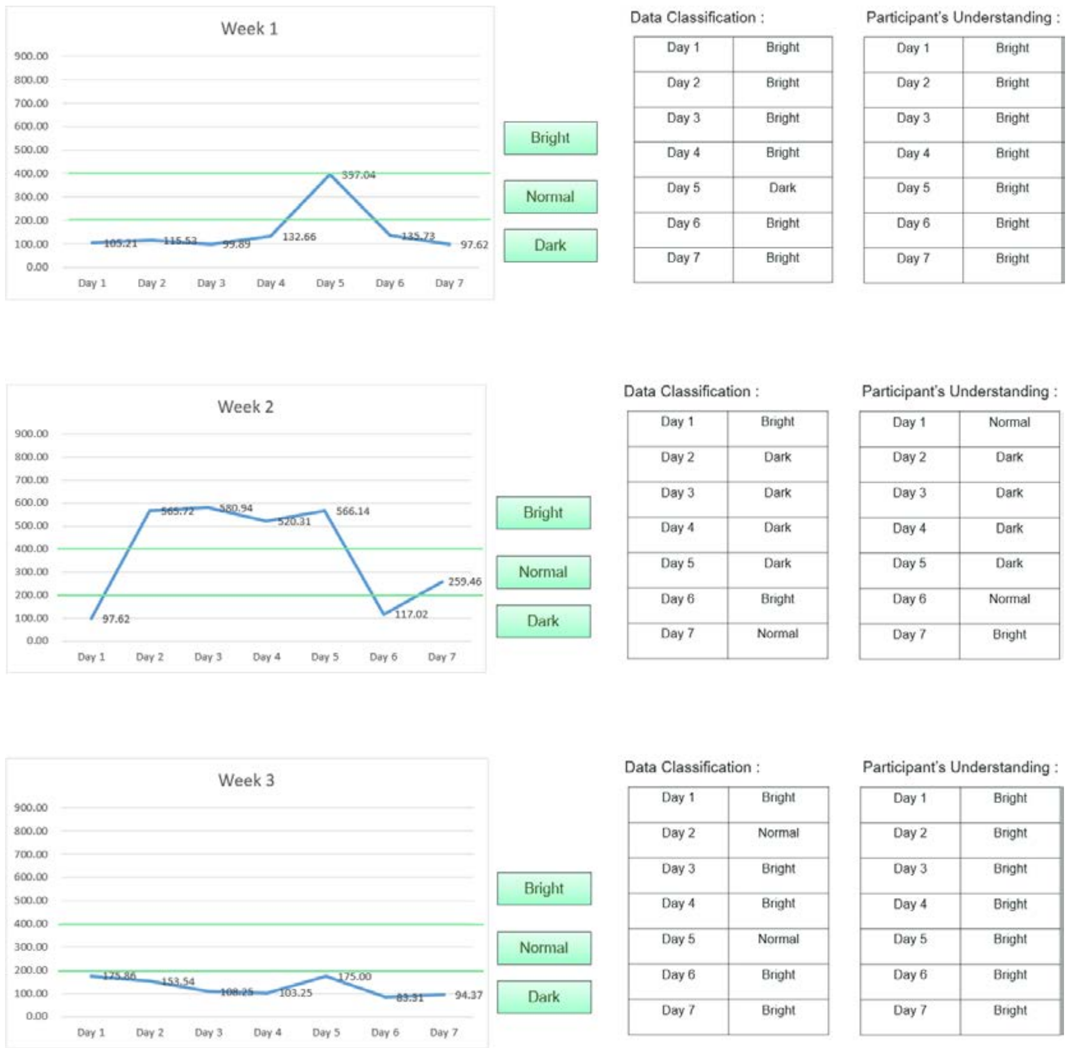


Figure 4.12 Comparison of Participant Two's Records and Data Classification of Light

the plant's needs, and the other days were moderate level. In the light aspect(Figure 4.12), she thought that most of the days in the week the light condition was not quite good and the room looked quite dark, but there were some days a little bit brighter. Compared to the data, the classification this week was quite close to the participant's thought.

In the third week, in the touching aspect(Figure 4.10), the participant thought that the plant had been taken good care during the week, and hadn't been hurt. As showed in the data, the heavy touching frequency was only 11.61%, which was classified as a little harmful, yet close to the value range of the good status. In the moisture aspect(Figure 4.11), the participant noticed the variations in the moisture level change during the week. First two days, she thought that the moisture level got a little bit higher, and then it kept as moderate level in the most of the following days. As showed in the data classification, most of the days during the week, the plant had got moderate level, but for some days the moisture level was a little bit lower than the plant's needs. In the light aspect(Figure 4.12), according to the participant's understanding, she thought that the light condition during the week was quite bright, and compared to the data classification, it also had showed the light condition was almost bright every day during the week.

- Experience Feedback

  During the interview, the participant was asked to touch the printed texture(Figure 4.13), the feedback after each week is showed as below.

  Feedback after the first week:

  I thought that the light condition this week was good, because the plant has been raised near the window. And I thought the watering amount was moderate, but maybe it was too much. I still felt not very understand the plant's needs right now I think.

  Feedback after the second week:

  I reduced the watering amount a little bit this week, because I watered too much in the first week. Besides, as the light condition this week was not good, so I think that the light condition this week was dark. The

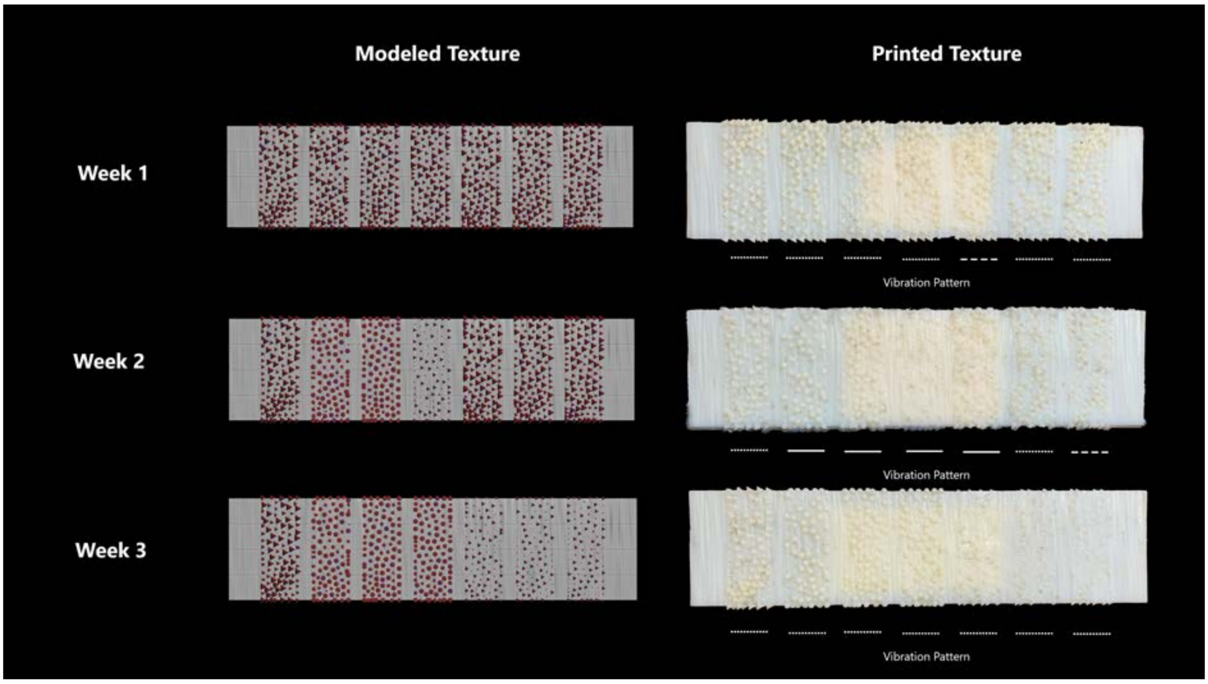


Figure 4.13 Participant Two's Modeled Texture and Printed Texture

classification this week got more similar to what I expected.

Feedback after the third week:

This week, I mostly grow the plants based on the weather changes. For example, if it was a rainy day, then I would correspondingly reduce the watering amount, and the light condition would also be darker than other days. I think the data this week is quite similar to what I expected.

- Analysis of Participant's Understanding Changes

  Comparing participant's understanding level during these three weeks, the participant's own thought got much more similar to the data classification, which turned out that she had a better understanding about the plant's growth. At the same time, she started to realized the weather changes also can be one of the factors to affect the data result, so she began to decide the watering amount every day depending on the weather.

Intimacy Changes during the Long-term Test

- IOS Scale

  The figure below(Figure 4.14) has showed participant two's relationship changes with the raised plant during the long-term test. Before the test, she chose the third level to represent her relationship level with the plant. After the first week, the relationship level got decreased into the second level. After the second week, the relationship level suddenly increased into the fifth level, and after the third week, the relationship level continually increased into the sixth level. So, based on the IOS scale, the relationship between the participant two and the plant was once got alienated after the first week, and then the closeness got largely increased in the following two weeks.

- Experiment Feedback

  Participant Two:

  I love flowers, but it is my first time to raise this plant, so still not very familiar with its growth. After knowing the result of the plant's growth

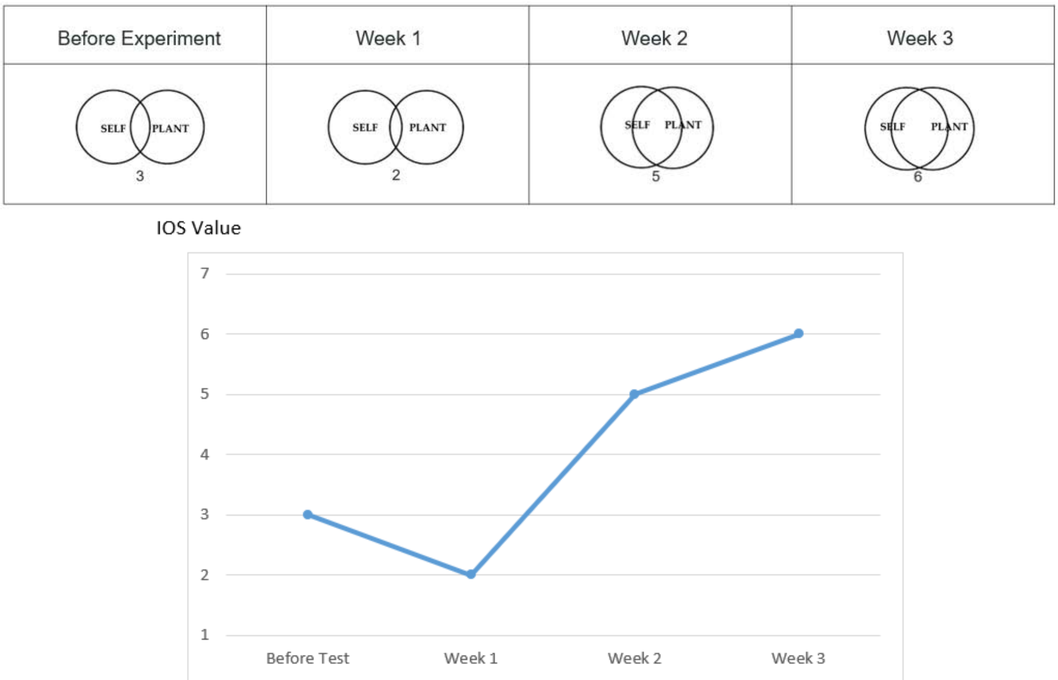


Figure 4.14 Participant Two's IOS Scale Value Changes During the Test

during the first week, I felt many things were quite different from what I thought before, so the relationship has got a little bit alienated. Later, I started to pay more attention to the plant's status every day, and gradually understood their needs. Besides, I also felt I have cultivated the deep feelings with this raised plant with the time increases.

- Analysis of Participant's Intimacy Changes

  The increasing understanding about the plant's growth has help help the participant build a closer relationship with the plants. Besides, as she loves flowers, so the deep feelings with this raised plant has been cultivated with the time increases.

4.2.3 Participant 3

(Left: the Plant's Status before the Experiment; Right:the Plant's Status after Three Weeks)

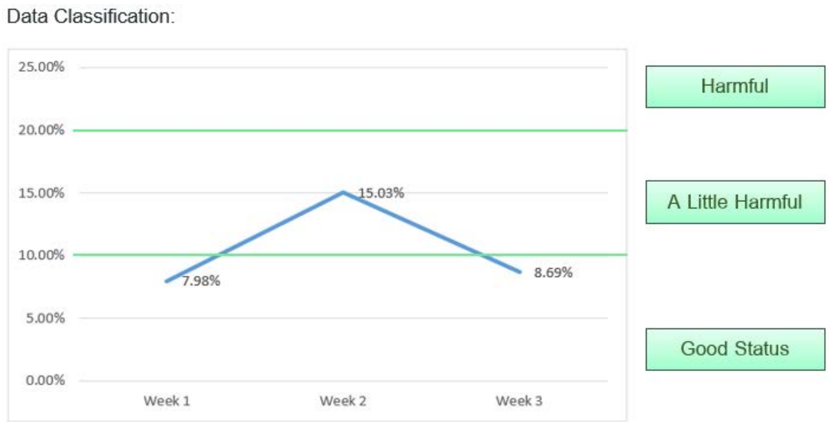
Figure 4.15 Participant 3 has raised the Plant in the Balcony

Planting Profile

The third participant doesn't have work outside. She loves plants, and also have quite rich experience of planting. When she was given the plant for the test, she said that although she wasn't too much familiar with this type of plant, she was quite glad to have a try. In the experiment, she has raised the plant in the balcony(Figure 4.15).

Understanding Changes during the Long-term Test

- Understanding Comparison

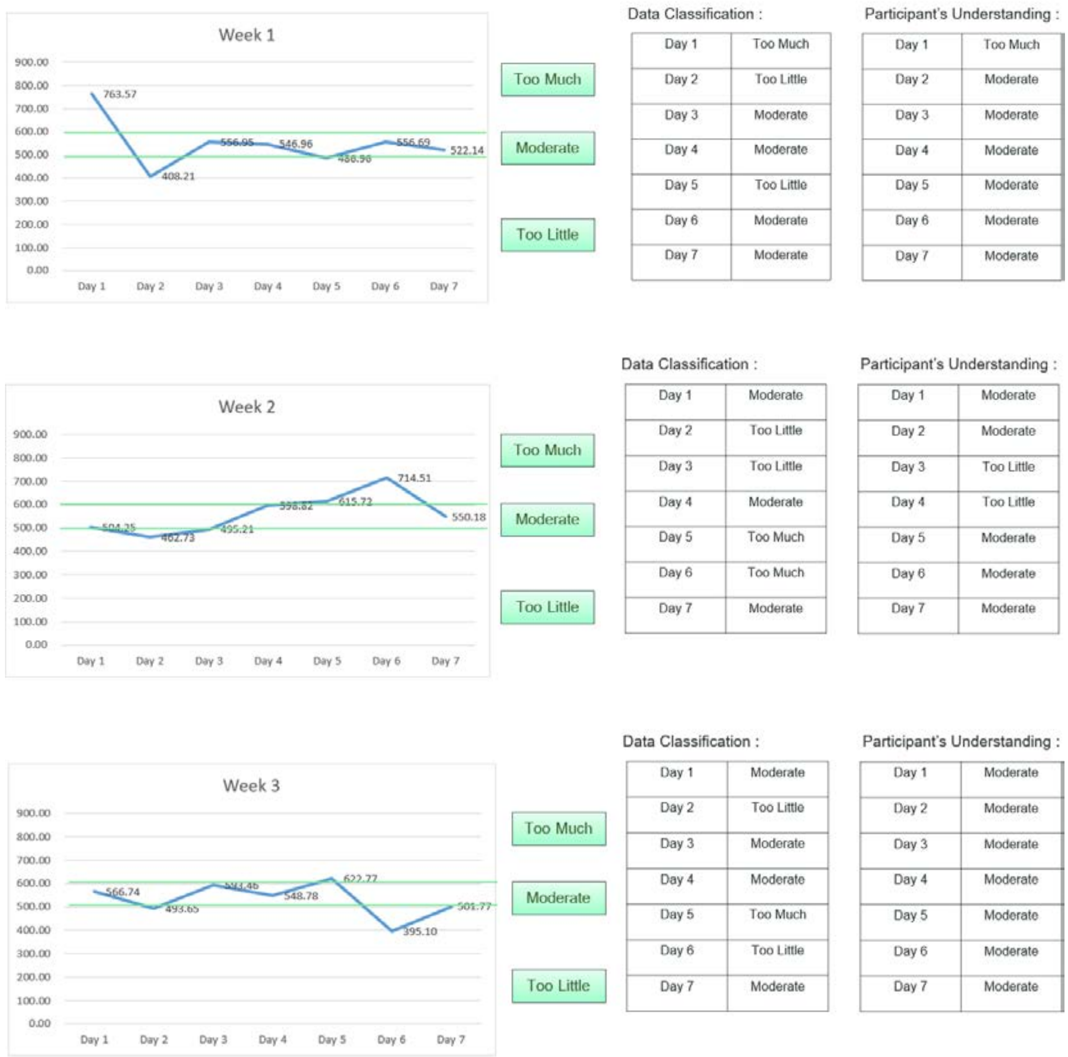


Participant's Understanding:

Week 1	The plant was in good status.
Week 2	The plant was in good status.
Week 3	The plant was in good status.

Figure 4.16 Comparison of Participant Three's Records and Data Classification of Touching

The comparison of participant three's own recording and the data classification has been showed below. In the first week, the participant thought that the plant hadn't been hurt, and the result was just as she expected(Figure 4.16), which was classified as good status. In the moisture aspect(Figure 4.17), the participant thought that most of the days the plant got moderate moisture, just on the first day, the moisture was a little bit too much for the plant. According to the data, most of the days the plant's moisture was controlled quite well, just a few days the moisture was a little bit too much or too little for the plant. In the light aspect(Figure 4.18), the participant thought that on most of the days in the week, the light condition was good, and some days were normal. But according to the data, the light condition was worse than the participant had expected. There were also a few days that the light condition was a little bit dark. So through the comparison, the participant



Week 1 — Data Classification:

Day 1	Too Much
Day 2	Too Little
Day 3	Moderate
Day 4	Moderate
Day 5	Too Little
Day 6	Moderate
Day 7	Moderate

Week 1 — Participant's Understanding:

Day 1	Too Much
Day 2	Moderate
Day 3	Moderate
Day 4	Moderate
Day 5	Moderate
Day 6	Moderate
Day 7	Moderate

Week 2 — Data Classification:

Day 1	Moderate
Day 2	Too Little
Day 3	Too Little
Day 4	Moderate
Day 5	Too Much
Day 6	Too Much
Day 7	Moderate

Week 2 — Participant's Understanding:

Day 1	Moderate
Day 2	Moderate
Day 3	Too Little
Day 4	Too Little
Day 5	Moderate
Day 6	Moderate
Day 7	Moderate

Week 3 — Data Classification:

Day 1	Moderate
Day 2	Too Little
Day 3	Moderate
Day 4	Moderate
Day 5	Too Much
Day 6	Too Little
Day 7	Moderate

Week 3 — Participant's Understanding:

Day 1	Moderate
Day 2	Moderate
Day 3	Moderate
Day 4	Moderate
Day 5	Moderate
Day 6	Moderate
Day 7	Moderate

Figure 4.17 Comparison of Participant Three's Records and Data Classification of Moisture

Data Classification :

Day 1	Normal
Day 2	Normal
Day 3	Bright
Day 4	Bright
Day 5	Dark
Day 6	Bright
Day 7	Dark

Participant's Understanding :

Day 1	Bright
Day 2	Bright
Day 3	Normal
Day 4	Bright
Day 5	Normal
Day 6	Bright
Day 7	Bright

Data Classification :

Day 1	Bright
Day 2	Normal
Day 3	Normal
Day 4	Normal
Day 5	Dark
Day 6	Bright
Day 7	Dark

Participant's Understanding :

Day 1	Bright
Day 2	Bright
Day 3	Normal
Day 4	Normal
Day 5	Bright
Day 6	Bright
Day 7	Dark

Data Classification :

Day 1	Dark
Day 2	Normal
Day 3	Normal
Day 4	Dark
Day 5	Dark
Day 6	Dark
Day 7	Bright

Participant's Understanding :

Day 1	Dark
Day 2	Dark
Day 3	Dark
Day 4	Dark
Day 5	Dark
Day 6	Dark
Day 7	Bright

Figure 4.18 Comparison of Participant Three's Records and Data Classification of Light

had a better understanding in plant's moisture level, but had some deviated judgement in the light condition.

In the second week, the participant thought that the plant was still in the good status(Figure 4.16), but as showed in the data, it was classified as getting a little bit hurt by the touch. In the moisture aspect(Figure 4.17), in the participant's opinion, she thought that plant's moisture was moderate in most of the days, but there were two days may a little bit less than the plant's needs. Based on the data, there were a little bit fluctuation in the plant's moisture level, as some days were just enough, some days were a little bit too much, and some days were a little bit lower than the moisture level. In the light aspect(Figure 4.18), the participant recorded that most days were bright and normal, and there was one day in the week was dark. According to the data, the light condition this week was quite similar to the participant's expectation. In the second week, the participant had a better understanding of plant's light condition, but as there happened the weather changes during the week, there existed some differences in her understanding of the plant's moisture level.

In the third week, in the touching aspect(Figure 4.16), the participant thought that the plant was still in the good status, and the result was just as her expect, belonging to the good status. In the moisture aspect(Figure 4.17), the participant thought that the plant got moderate moisture level every day, and as showed in the data, most of the days in the week was moderate, and there were some days lower than the moderate level, and some days were higher than the moderate level. In the light aspect(Figure 4.18), the participant thought that the light condition during this week was dark on most of the days, and only the last day was bright. According to the data, most of the days, the light condition was dark or normal, and the last day was bright.

- Experience Feedback

  During the interview, the participant was asked to touch the printed texture(Figure 4.19), the feedback after each week is showed as below.

  Feedback after the first week:

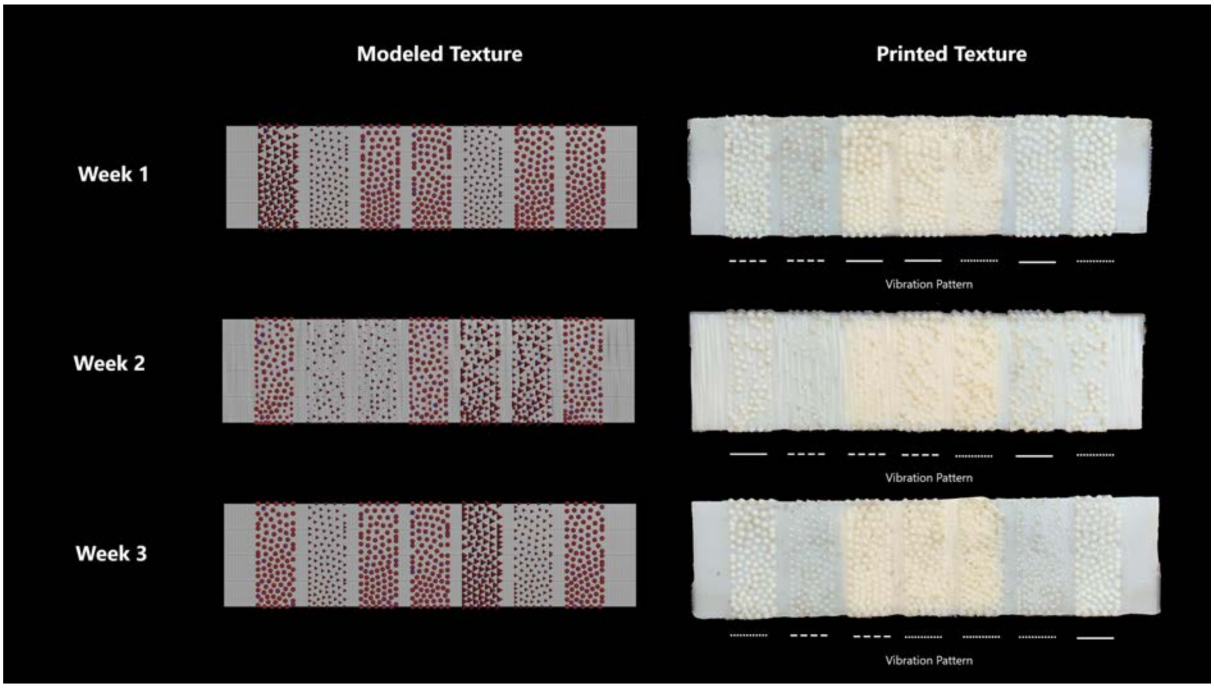


Figure 4.19 Participant Three's Modeled Texture and Printed Texture

I watered the plant mainly based on their status every day, and after the comparison, I felt it is quite similar to what I expected. But the light condition is a little bit different from what I expected I think.

Feedback after the second week:

Because there were some days raining this week, so I adjusted the watering amount to the plant every day. After the comparison, I feel that on those rainy days, maybe still watered a little bit too much, so that the moisture level went beyond the plant's actual needs.

Feedback after the third week:

Most of the days during the week were raining, so the light condition wasn't quite good. And mostly on the rainy days, I reduced the watering amount. After the comparison, I felt that the light condition was quite similar to what I expected, and for the moisture level, maybe on some rainy days, it was also better to water a little bit based on the humidity in the atmosphere.

- Analysis of Participant's Understanding Changes

  Comparing the participant's understanding level during these three weeks, the participant's recording was quite similar to the data in all. As she has quite a lot of planting experience before, she has a good understanding in the plant's moisture level and light condition, and knows to control the watering amount depending on the weather changes, although there also existed some differences in the understanding sometimes.

Intimacy Changes during the Long-term Test

- IOS Scale

  The figure below(Figure 4.20) has showed participant three's relationship changes with the raised plant during the long-term test. Before the test, she chose the fifth level to represent her relationship level with the plant. After the first week, the relationship level got increased into the sixth level. After the second week, the relationship level got a little bit decreased into the fifth level, and after the third week, the relationship level got increased into the sixth level again. So, based on the IOS scale, the relationship between the

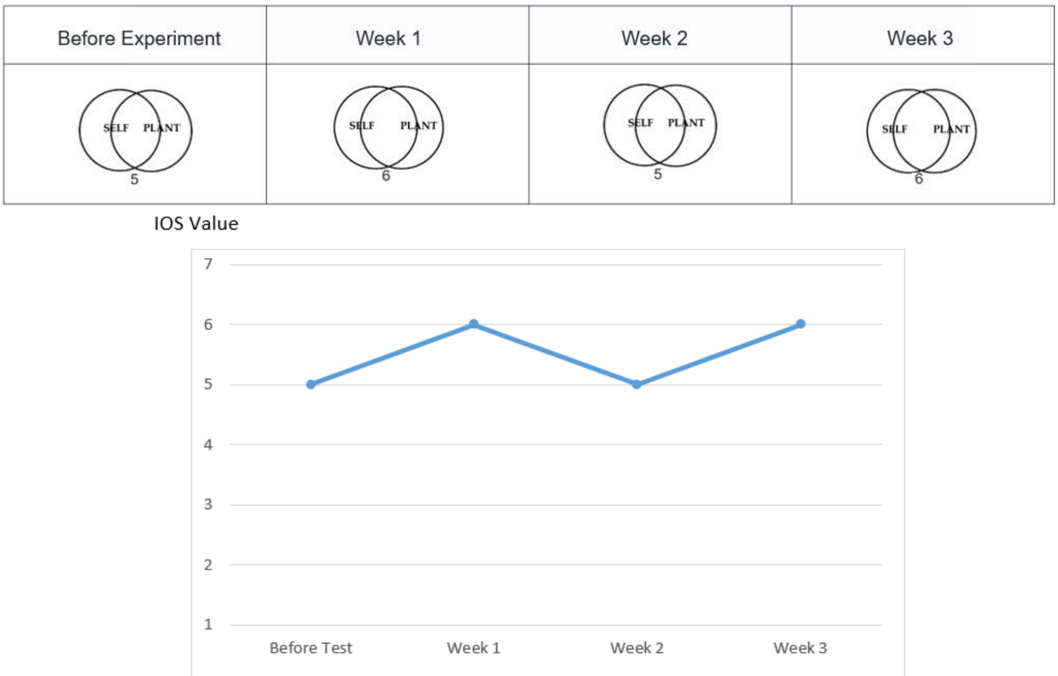


Figure 4.20 Participant Three's IOS Scale Value Changes During the Test

participant three and the plant has almost maintained in a quite high level these three weeks.

- Experiment Feedback

  Participant Three:

  I quite love plants, and also have much planting experience before. The result of the plant's growth is quite similar to what I expected. During the test period, I felt deep feelings with this raised plant.

- Analysis of Participant's Intimacy Changes

  As the participant has rich planting experience, and loves plants a lot, so she had better understanding of plant's needs compared to the other two participants. She had a quite deep attachment with the plant during the test.

4.3. Behavioral Changes during the Process

4.3.1 Individual Differences

During the test, the behavioral changes in three participants during the process have been observed.

For participant one, the relationship with the raised plant gets closer than before, but not too much. For participant two, she has developed a closer relationship with raised plants, and start to have more passion about planting and pay more attention to the plant's growing environment. For participant three, as she has rich planting experience, so she maintain the great passion about the planting life.

4.3.2 Common Changes

For the common changes in these three participants, I discovered that compared to before, they have a better understanding of plants' growth and plants' needs. Comparatively, their relationship with the raised plant get closer than before.

4.4. Sharing Experience

4.4.1 The Vision and The Setting

The Vision

The experience of sharing has been done after the long-term user test. Three participants' texture have been shared to other people in order to explore whether their planting experience can be shared based on the texture.

The Setting

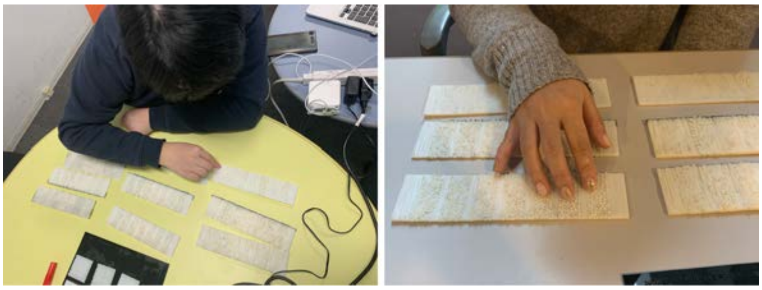


Figure 4.21 Sharing Experience

The texture of these three participants were placed on the table, and other people were asked to feel the three-week texture of each participant and to talk about their feedback(Figure 4.21).

4.4.2 Feedback and Observation

Here are the collected feedback from the sharing experience:

- It seems that participant three's texture looks better than the others. And I feel that the participant one has an adjustment in the watering control during these three weeks.
- I feel it's still quite hard to imagine their planting process only based on the texture. And as most of the texture touch quite rough, which makes me feel that it's quite hard to take good care of plants.

- The three-week texture feels like the increasing of the age. For example, like this user's texture, the first-week one touches like 20 years old, the second-week one touches like 40 years old, and the third-week one touches like 80 years old.

4.4.3 Conclusion

Through the sharing experience, we get to know that the plants' status, good or bad, can be roughly figured out based on the roughness of the texture, but there are still many limitations of the texture in the sharing process. For example, the texture design is still too abstract for other people to imagine the planting life without the reference of plants' changes, the details such as the adjustment in the process are easily ignored by other people, and the three participants' relationship changes with the plants are quite hard felt by the other users.

In the future, the texture design for providing a better sharing experience to other people will be explored as a future direction.

4.5. General Analysis

Through these three participants' long-term user test results, we have discovered that the physical expression of the texture has helped them to get a better understanding of the plant's growing status to some extent. Based on their different planting experience level, in the first week participant three who had more experience had a better understanding of the plant's needs than the other two participants reflected by the data. However, after a period of time in the experiment, the result showed their improvement of understanding, and such kind of understanding improvement also has affected their treatment of plants. For example, they started to care more about the weather affects on plant's growth, and began to adjust the watering amount depending on the weather conditions. Besides, they also started to pay more attention not to touch the plant heavily.

Apart from that is their relationship changes with the plant during the test. According to their IOS scale results and their feedback, in the beginning participant one and participant two still had felt the distance with the plant, but at the end of the experiment, their intimacy level with the plant had been improved.

Participant three, however, due to her rich planting experience and the love for flowers, so her intimacy level with the plant had stayed in a relatively high level overall.

However, there still exist some insufficient points in this prototype design.

- Limited Expression of the External Affects

  For the prototype design, there are three external factors having been considered, which are touching, moisture and light condition. But during the long-term experiment, more external factors proved to be important to show the plant's growing status, such as the temperature, flowers' blooming term. From the feedback in the interview, they also have reflected that although the data showed that the plants got a better control of the moisture level, and they also started to pay more attention not to hurt the plant, but the flowers started to wither, and there are more other external reasons lead to that.

- Limited Algorithm Setting

  The limited algorithm setting right now has offered a wide range of classification for each category. Therefore, for the present data classification, it is quite hard to identify the value difference classified into one range and the gap with the moderate status.

- One-week Delay of the Expression

  The texture design is showed to the participant every time after one week. There still exist a time delay of the expression that it cannot showed the growth changes in the real time.

Besides, the sharing experience of these three participants' texture also have been explored. For other people, they can roughly make the judgement of the plant's status through the texture, but there still exist a lot of barriers for them to have a clear understanding of the participants' planting life and their changes during the process. The texture design for sharing experience will be considered as the future direction in the project.

Chapter 5
Conclusion

This project has explored the design method that can help plant owners have a better understanding of the plant's growth, and then develop their closer relationship with the raised plants. In chapter 1, the background of this project has been described for why this project design is important. It showed that the understanding barriers between plant owners and plants, and also described the importance of understanding plant's growth, and plant owners' emotional attachment changes during the planting life.

Next in chapter 2, the related research has been done for the deeper exploration of this project. It was discovered that plants are electrically active system, which can sense and respond to the environmental changes such as light, temperature and etc. Besides, different expression methods also have been explored in this part, and have found that the 3D modeling method can create dynamic design used for data procession based on generative design principle, and the haptic display can also help enhance the interpretation and understanding of complex data.

Chapter 3 has described the design process of the texture. Based on the findings in the fieldwork, three important factors have been chosen to reflect the plant growing status, which are plant owners' touching, moisture and light condition. These three different types of data have been collected from the plants for the further analysis. The characteristics of these three factors have been explored in depth based on the data analysis, and then correspondent to each design methods of the texture, which are surface design, geometry design and vibration design. The algorithm experiment also has been done for the algorithm setting in the texture design. The final product of this project is a plant's platform that is used to present the texture to the plant owner that was made based on every previous-week data.

Chapter 4 has described the details in the validation process of this prototype design. A long-term user test that lasting for three weeks have been conducted in order to measure users' understanding changes and their relationship changes with the plant during the process. For the measurement of their understanding changes in the long term process, three participants were asked to record their plant's status based on the classification, and their recording were compared with the exact data classification. Besides, their feedback has also been collected. For the measurement of their relationship changes with the plant, the IOS scale test has been conducted, and their feedback also have been collected. Each participant's changing process have been analyzed, and their behavioral changes also have been observed individually during the process. Apart from that, the sharing experience of the planting process to other people also has been tested in this project as the future direction to explore. It has showed that there still have been a lot of improvement for the texture design used for sharing experience, and the limitations in the design also has been concluded in the chapter.

In conclusion, this project has explored the physical expression design of the three important factors that affect plant's growing which are touching, moisture and light condition, in order to enhance plant owners' understanding of their plant growth, and then further to develop a closer relationship with their raised plants. The idea of designing the texture based on data changing has been proposed, and the plant's platform has been designed for placing every texture based on previous week's data. To some extent, the texture design has helped users improve the understanding, but at the same time, there still exist some insufficient points such as limited expression of the external affects, limited algorithm setting and the one-week delay of the expression. For the sharing experience, the current design of the texture still has a lot of limitations, such as too abstract for other people to imagine the planting process without the reference of the plants' growing status, or hard to feel their relationship changes with the raised plants. There are still a lot of improvements to explore in this project. I am confident that the future research can make up for these problems, and offer a better expression method of plant's growing status.

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Appendices

A. Three Participants' Texture

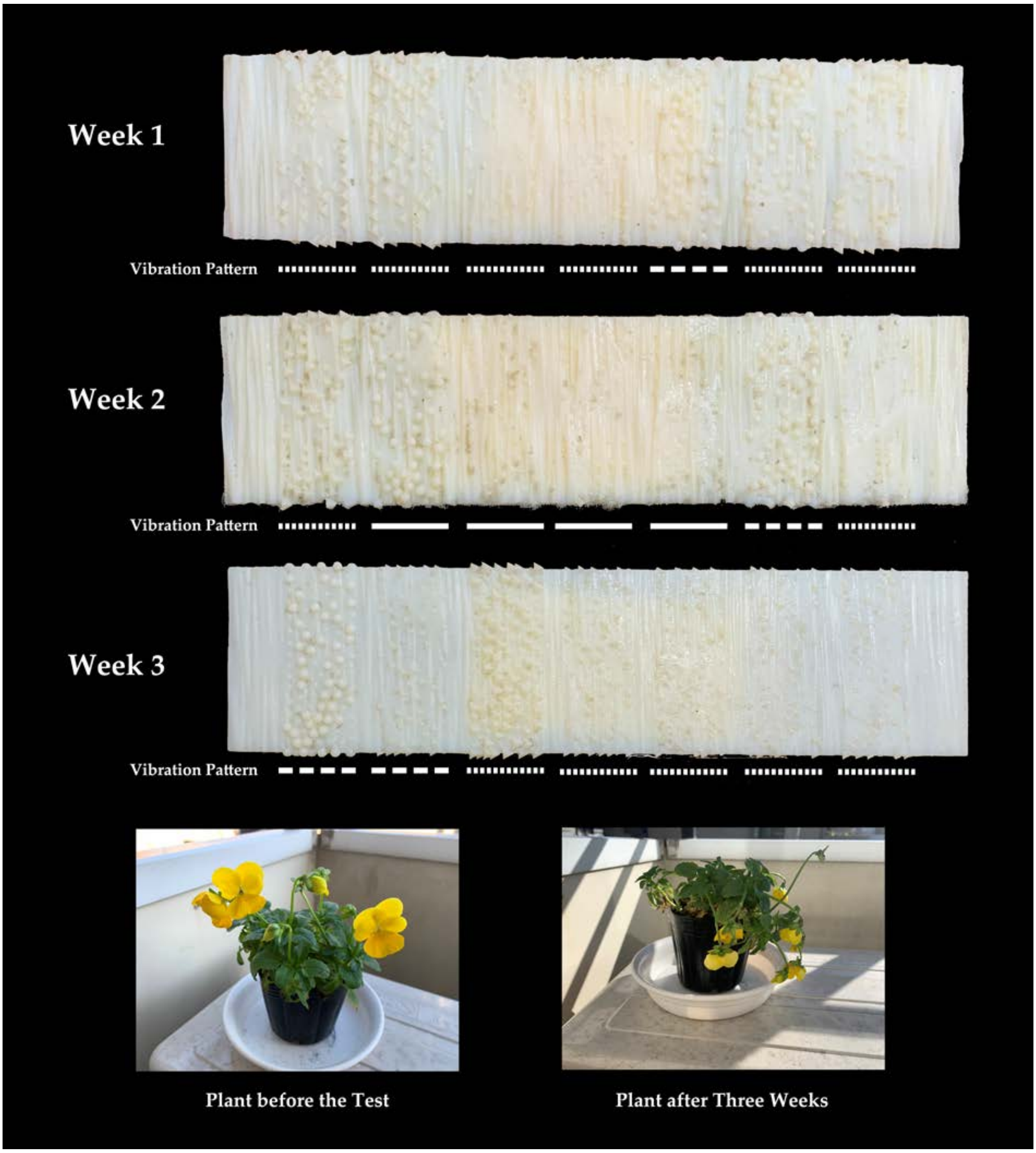

Figure A.1 Participant 1's Texture

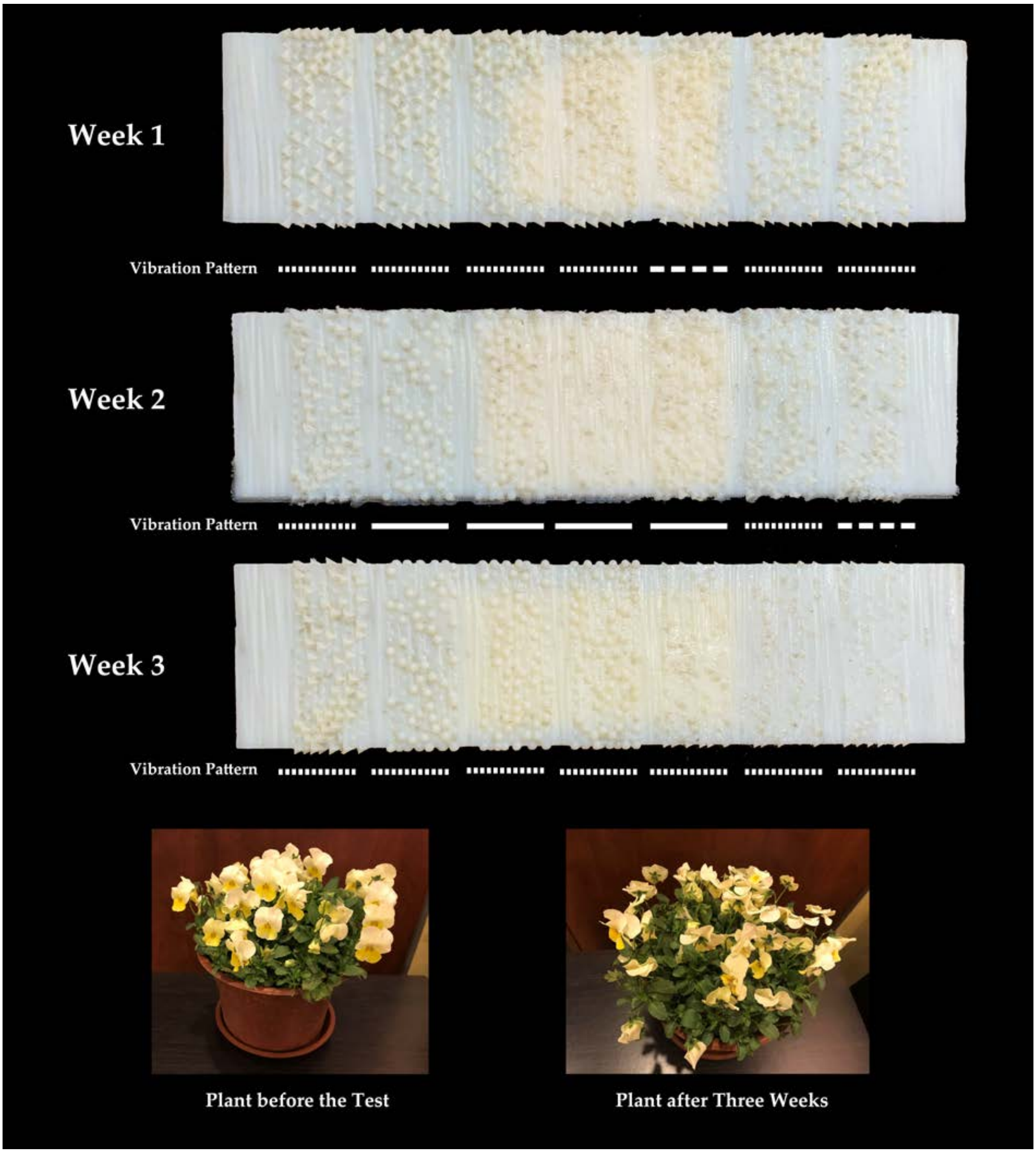

Figure A.2 Participant 2's Texture

Figure A.3 Participant 3's Texture