SoilBright - Using IoT to Teach Users about the Important Properties of Soil

Dan Brickner
dbrickner3@gatech.edu

Abstract—Some of the most important properties for plants to grow successfully rely on its soil. Hobby gardeners and professionals often have a lot of frustration and produce a lot of plant waste due to a lack of knowledge of their soil. This paper presents SoilBright, which gives the users the power to detect properties of their soil directly through IoT, and has the user learn about the importance of their soil and its properties.

1. INTRODUCTION

Gardening has been found to be linked to greater mental health (Shiue, 2016), and can help people create a friendlier home. For elderly people, gardens help create a sense of home and provide them with a sense of control of their bodies. (Bhatti, 2006) Gardening also shares an important relationship with farming. We are currently in dire need of a new generation of farmers. (Volenec et. al, 2012)

Unfortunately, efforts of gardening are often wasted due to poor soil conditions. Poor soil conditions are one of the biggest problems that gardeners face continually. (Calamaio, 2018) These bad soil conditions do not just affect the domain of hobby gardeners, but also extend to professional farmers. Each year, over 5 billion tons of waste are produced from agriculture each year. (Cherubin et al, 2018) This contributes to over 13% of the worlds carbon footprint. This makes agriculture the world's second largest contributor to climate change. (Russel, 2020) With soil quality as one of the leading causes of plant waste, this problem needs to be solved.

While sustainable farming and permaculture have been used traditionally to solve plant waste problems, the adoption rate is low and often criticized for producing low yield. (Adegbeye, 2020) Additionally, soil quality and plant waste are still a problem with these systems. (Weber, 2019)

Technology has been used to help reduce waste and increase crop yield. IoT and automated farms can produce an acre's worth of crop yield in only 100 sq. ft. compared to the non-IoT enabled farms. (Ayaz et al., 2019) Unfortunately, many of these systems are extremely expensive and complicated. Expense and technological literacy are cited as some of the most prominent reasons farmers are not adopting technology in their practices. (Medvedev & Molodyakov, 2019) These systems also do not consider home gardeners, who will likely not have the time or money for expensive IoT systems.

There needs to be a technological system that is accessible to professionals and hobby gardeners alike that can make users more aware of their soil conditions. These improved soil conditions can reduce plant waste and increase awareness.

This paper presents SoilBright, an IoT soil-based sensor and learning application. SoilBright measures a few key properties of the user's soil, reports on them, and then teaches the user about soil.

2. RELATED WORK

There has been work with technology applied this area to help with the problem of plant waste, ultimately targeting soil as one of the central problems.

Some of the works presented here include LeafSnap, SoilWeb, SOC, and already existing soil sensors.

2.1. LeafSnap

One of the most popular and accurate mobile applications is called LeafSnap. LeafSnap allows the user to take a snapshot of the plant they are interested in, and it will identify the plant for them. Additionally, it can give them back a list of basic needs for the plant. (Thang, 2019)

LeafSnap is currently owned by the mobile applications company Appixi, and was originally created by scientists at Colombia University, the University of Maryland, and the Smithsonian Institute. (An Electronic Field Guide, 2011)

LeafSnap has been studied academically, and found to be successful at plant identification and can actually monitor the spread of climate change by tracking the spread of exotic plants. (Kress et. all, 2018) LeafSnap has given users the ability to identify plants with a simple phone application and without any prior knowledge. This is a major contribution to the field of horticulture and agriculture since it puts more information power into the hands of common users.

While both LeafSnap and SoilBright both aim for users to have successful plants, LeafSnap is focused on the needs of the plant and requires the users to already understand their soil conditions. SoilBright focuses more on the soil conditions themselves, which is in service of purchasing more compatible plants.

2.2. SoilWeb

SoilWeb is a web application that contains a navigable map that allows the user to determine what type of soil exists in their region. The map contains details such as the rockiness, density, and other properties. (Sanden, 2012)

This application was developed by UC Davis in an effort to give users access to USDA-NCSS soil surveys.

SoilWeb is another effort to democratize access to important data that is related to agriculture and horticulture. It provides users with up to date information on soil survey information that has been collected for over 100 years. (Mathew et. al, 2019) It not only contributes information to the field of agriculture and horticulture, but to other industries like construction and real estate.

While SoilWeb is powerful and allows the user to understand the soil in their general area, it doesn't consider different micro-zones. For example, in one garden bed the soil way be wet and dense, and in another it may be dry and sandy. It also relies the most up to date soil survey information, which will not account for changing soil conditions on a home owner's property. There is also the consideration of containers, which themselves have different conditions. (Hershey, 1990) In this sense, SoilBright and SoilWeb differ because of the size of the area to which they apply.

2.3. SOC

Another body of work is a web application called Soil Organic Carbon, or SOC for short. Soil Organic Carbon is often used to judge the health of a soil, and is important to the plant's ability to photosynthesize. SOC provides an easy app to allow users to calculate the Soil Organic Carbon in their soil. (Bautista et. al, 2016)

SOC was developed by Francisco Bautista, Eduardo Garcia, and Angeles Gallegos from the Universidad Nacional Autónoma de México.

The SOC application provides the ability for professionals to easily diagnose and calculate the Soil Organic Carbon in their soil. It affects the fields of agriculture and horticulture because it reduces the likelihood of an error in the calculation of SOC, which can be complicated. (Bautista et. al, 2016)

While this application provides an important metric for determining soil quality, it is targeted at professionals. Most gardeners would not understand this term, let alone look for a tool to measure this attribute, Additionally, it requires the user to manually measure the soil and report back to the app to get their calculations.

2.4. Existing Soil Sensors

Finally, there are other soil sensors in existence. There are a myriad of components available that can be added to an Arduino or Raspberry Pi. Additionally, there are out-of-the-box ready sensors that simply readout the soil properties.

These sensors have been developed from various electronic components manufacturers around the world.

These sensors and components are able to offer electronic manufacturers and electronic hobbyists a way to measure the important soil characteristics. Indeed, SoilBright was developed using these sensors. The standalone devices go one step further and allow novice users to measure important soil properties. Given the low expense and availability of these devices, they have the capacity to lead to more gardeners measuring their soil conditions.

However, the electronic components are of limited to use to both hobbyists and professionals since they require knowledge of electronic components and firmware development. The standalone sensors, while providing soil characteristics, do not lead to the user understanding the soil. This is where SoilBright differs from these devices: SoilBright is focused on teaching the user and improving their understanding of soil. It does this in a simple way that only requires the user have the ability to operate a smartphone.

3. SOLUTION

3.1. Overview

To address the problems of understanding one's soil and why it's important, I present SoilBright. SoilBright allows the user to measure their own soil using a sensor, discover the soil's characteristics, and then learn more about soil. The target user base is for both hobby gardeners and professionals. For hobby gardeners, it provides a convenient way to measure their soil and learn more about it. For professionals, it provides another measuring tool and information on sustainable practices.

As such, SoilBright consists of three key components that make up the entire product: a soil sensor, the application, and the learning contents.

What follows is a general architecture of how the SoilBright product works and then a review of each component.

3.2. The SoilBright Architecture

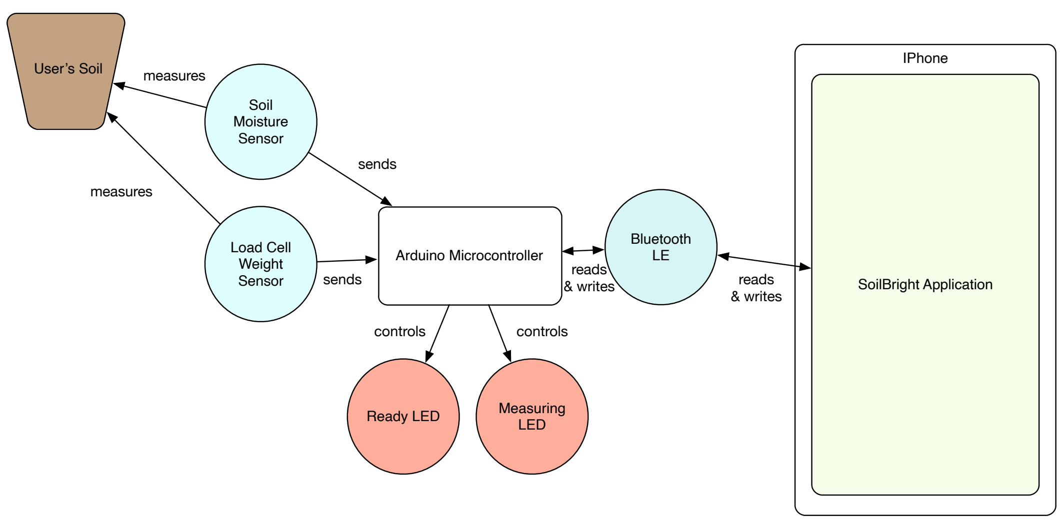

Figure 1—The SoilBright Architecture

SoilBright uses an Arduino for the central processing in the sensor. The Arduino microcontroller receives sensor data, and establishes different modes. These modes determine what sensor is being used, and what communication it will send and receive to the iPhone. These modes will also signal the user via

LED whether the sensor is ready or measuring. Communications between the application and sensor are handled via a Bluetooth LE module. Most of the process control is done through the application, which dictates when the sensor should be moved to a new measuring mode.

3.3. The SoilBright Sensor

The SoilBright sensor is the IoT component to SoilBright. While the user does need to interact with it, the workflow of measuring and learning are controlled by the application.

All of the code for the sensor was developed using C++. The sensor contains modes or states that determine the kinds of inputs and output expected.

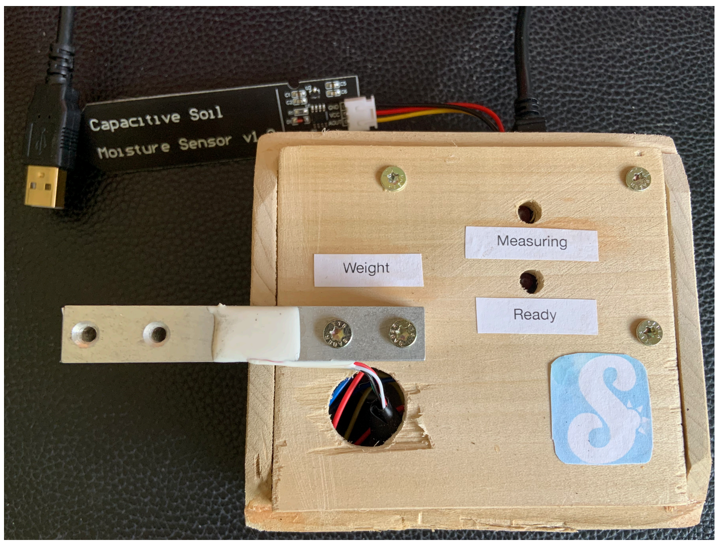

Figure 2—The SoilBright sensor. At the top, the usb cable and moisture sensor are shown. The silver bar on the left is the mounted weight sensor. The measuring and ready light holes are shown on the case. The Arduino and bluetooth units are housed within the case.

This tool consists of several components:

- A soil moisture sensor: this measures how wet the soil is.
- A weight sensor: this is used to gauge the soil density, which can tell the user if their soil is clay, sand, loam, or a mix.

- An Arduino controller: the Arduino reads the sensors and outputs to the LEDs. It also communicates with the Bluetooth module.
- A Bluetooth LE module: this is needed for communications between the sensor and the application.
- A USB cable to provide power
- A Ready LED and Measuring LED to inform the user the state of the sensor
- A case for safe handling

The choice of the Arduino platform is because of its ideal balance between cost, support for sensors, and its microcontroller design.

The reasons for measuring soil moisture and soil weight is because these sensors are inexpensive, and easy to operate for the user. They are also among the most important soil properties.

3.4. The SoilBright Application

The SoilBright application contains the workflow for measuring soil and also the leaning content. The application was written for iPhones and done in the SWIFT programming language.

The application is split into three different sections, a measurements section, the results section, and the learning section (covered in the next header).

3.4.1. *The Measurements Section*

When the application first starts, it asks the user to plug in their phone to begin their measurements. Once they continue, the phone makes a bluetooth connection to the sensor.

The user is then directed to make a series of measurements using the soil sensor and directed by the phone. At the end, the user is directed to the results screen.

3.4.2. *The Results Section*

Once the user reaches the results screen, the application has already determined the properties of the user's soil. The moisture is presented in terms of three distinct saturation categories: Dry, Medium, and Wet.

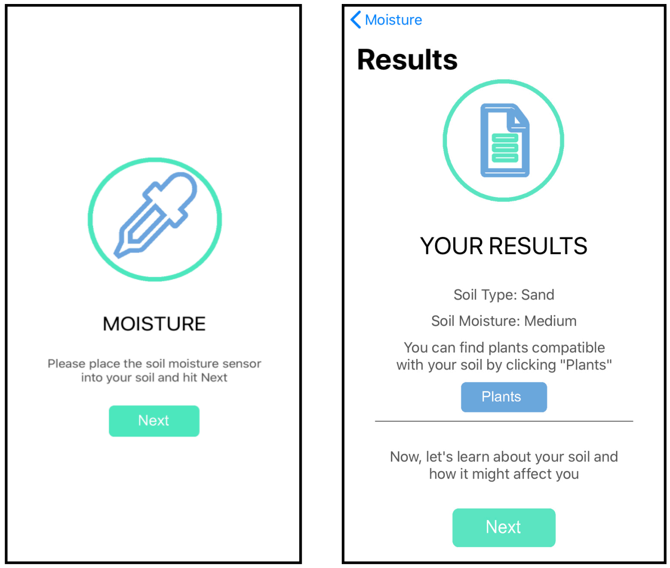

***Figure 4**—(left) The moisture measurements screen. The measurement screens are designed to be very simple and easy to follow. (right)* The results screen. The results present the soil properties, a plant finder search, and direct the user to the learning content. They can also conduct another series of measurements by going back.

The soil type is also presented, which is a function of the soil's dry density. In effect, the dry density is a function of how much air pore space is available. The most dense and grainy soils are labeled as sand. Medium density soils are considered silt/loam, while the lowest density soils are clay.

The user is able to then optionally click the "Plants" button, which directs the user to the Gardenia Plant Finder website. This allows the user to use advanced search for plants that would be compatible with their soil.

Lastly, the directions have the user continue onto the learning section. Information on this can be found in section 3.5.

3.5. The SoilBright Content

The learning content is designed to teach the user about soil from the ground up. The content itself follows the methodology behind connectivism. Connectivism is a theory of learning that suits the information age. It posits that all knowledge is contained within nodes, and learning happens when we make connections between those nodes. There are a volume of resources on the internet that allow users to make these connections and strengthen their learning. (Tschofen & Mackness, 2012)

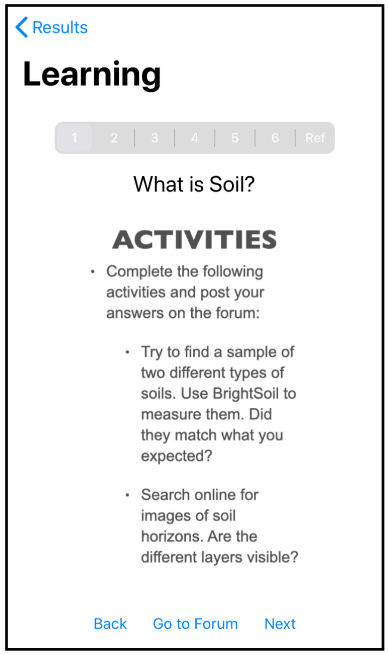

Figure 5—The learning screen. This screen directs the user to complete two activities and then post on the forum.

The content is arranged into 6 majors sections, each containing a presentation, activities, and external links. The activities direct the user to participate in an online forum discussion, while the external links provide a reinforcement to the user's learning process.

The learning sections contain the following content presentations:

- What is soil?
- Why is soil important to our plants?
- How does it affect what plants I should buy?
- Can I do anything to amend my soil?
- What are the important characteristics of soil?
- How does soil affect sustainability and climate change?

4. METHODOLOGY

SoilBright's evaluation has not been fully evaluated by a large study. Thus far, the evaluation has relied on the feedback of my peers, my mentor, and my family.

Some of the important areas where feedback was solicited was in terms of the structure and presentation of both the app and learning content. These were, however, not the exclusive areas of feedback I received.

The first milestone presented was simply the functionality of the soil sensor, where the second milestone included both a sample of the learning content and the application user experience.

I was able to test the usability of my application by having some friends sample SoilBright using their own soil. I was also able to test various different types of soil from my own yard to test accuracy.

5. RESULTS

The SoilBright sensors was tested in two areas: the accuracy of the sensor and the resulting properties, and the application's effectiveness in teaching users about soil.

5.1. Soil Sensor Accuracy

The soil sensor was studied objectively by sampling three very different types of soil. One soil was a dry sandy soil, another was dry clay soil, and the last was waterlogged clay soil. The soil sensor was able to successfully determine the density of the soil, identify the soil type, and identify the correct category of moisture.

5.2. Learning Effectiveness

I was able to include a small user study which included my wife and my mother. Both users are gardeners and indicated to me that they learned something new about soil from my application. They also indicated to me that the activities helped to put the theory into practice, making the learning more effective. Finally, my peers regarded the learning section as "very informative".

6. LIMITATIONS

6.1. User Study

The scope of the user study on learning effectiveness was a very limited. A larger scale user study that targets a wider variety of audience members would provide better feedback on the usability of the application.

6.2. Soil Measurements

SoilBright currently only supports two methods of measuring soil. It only measures the soil moisture and the soil weight. There are many other properties of soil that are important including pH, soil organic carbon, soil organic matter, nutrients, compaction, and more.

6.3. Smartphone Platforms

As it stands today, SoilBright only supports Apple IOS. In order for this application to have a better community outreach, Android should be supported as well. It is also worth noting that this application has only been released on the TestFlight application, Apple's beta-testing platform.

6.4. Manufacturing Constraints

The SoilBright sensor was entirely designed, wired, and soldered by me. This is most evident in the design of the case, which is made from hand-cut poplar wood. If this sensor is to be truly scalable and user ready, the creation of this sensor should include a manufacturing process.

6.5. Plant Finder

The plant finder linked by SoilBright is an external one provided by Gardenia. This search still requires the user manually input their information into the search engine. This could be enhanced by doing this automatically for the user, or by providing the plants for the user automatically in SoilBright.

7. CONCLUSION

Gardening is an important and healthy pastime for many people, but it can be frustrating and wasteful. At scale, poor soil conditions are leading to plant waste and contributing to some of today's worst problems. There have been attempts to resolve this matter by various means, but few these efforts are geared towards helping the gardener understand the underlying reasons why soil is important. There are also limited applications of IoT to soil.

SoilBright creates a unique opportunity to allow users to use IoT technology to understand their soil, and learn about the important properties and characteristics of it. It does this by integrating a soil sensor into a smartphone application that can report on the properties of their soil, and offers connectivism style content to the user.

While the audience was small, SoilBright does identify characteristics properly and improves the user's understanding of soil.

Limitations include the soil characteristics that it measures, the platforms it targets, the need for automated manufacturing of the sensor, and the need for a more integrated plant finder mechanism.

8. FUTURE WORK

The limitations presented previously provide ample opportunity for improvement to this application.

Another improvement that will be worked on will include user login and a database. Presumably, the user may use this application to store information about various soil areas in their garden. As it stands, there is no data retention or user logins that would make this application suitable to that usage. The plan to include a user login page and database will allow this use-case to occur.

Finally, a large-scale and robust user study is needed for this application. A large-scale user study would provide valuable data to determine how effective SoilBright is at both measuring and providing a place of learning. This will allow the application and sensor to evolve into better technology.

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