Urban Gardening: Yin-Yang Farming

Improve gardening experience through the use of Internet of Things

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Abstract **— Singaporeans are increasingly interested in growing plants as a recreational hobby. In response, The National Parks Board has come up with Urban Farming initiatives such as converting vacant pockets of land into spaces and gardens. Many of these new hobbyists, being amateur gardeners, lack sufficient knowledge in maintaining thriving plant growth conditions. This paper presents our proposed IoT solution to enable urban farmers to take better care of their plants. We also discuss various system management features and technical challenges. This research paper aims to improve plant growth conditions and facilitate alerts for the watering process using IoT.**

Keywords- Urban Farming; Internet of Things (IoT); Smart Gardening

I. INTRODUCTION

Since 2005, at least 700 gardens with plants, fruits, herbs and vegetables have been built nationwide [5]. As more Singaporeans are interested in growing their own plants for hobby or consumption, Urban Farming is initiated by the National Parks Boards' [6] to convert vacant pockets of land into spaces for such activities [4]. Some of the reasons include increasing preference for fresh produce from homeowner's own kitchen, growing as a hobby, and even as part of promoting community bonding. Urban farming also helps Singaporeans realize that some level of self-sufficiency is important, especially after the worldwide food security crisis in 2007, which disrupted the supply of rice and many staple foods [5].

As more Singaporeans adopt urban farming, one of the biggest challenges that they face is disregard the conditions that plants require to establish a thriving root system, which may cause by the fast-paced lifestyle that Singaporeans tend to forget or are too busy to water the plants. Hence, taking care of plants has become quite a tedious task which requires attention, as well as a deeper knowledge of the plants to successfully keep them alive. Research have shown that the top 3 reasons that cause plants to die are mainly water, sunlight and temperature issues [3].

Firstly, different plant species have different watering requirements and some understanding must be present to understand how often we should water each plant species. The weather also plays an important role in determining the amount of water the plant needs. In the event of a change in weather, the plant will also require a different amount of water. For example, during rainy days, we might not need to provide the regular amount of water to the plants if it is being placed outdoors. When the wrong amount of water is given to the plants, it will also cause them to die as overwatering can lead to air suffocation in plant's roots and lead to root rot [1]. Secondly, research shows that plants will need a minimum of 3 to 6 hours of sunlight exposure daily [2]. Without sufficient sunlight, it will adversely affect the growth of the plant. Lastly, plants will also not be able to grow properly under unsuitable temperature and humidity levels. Some plants will not live long if they are being grown in the wrong season or in wrong locations.

The development of IoT solution would help amateur gardeners or busy Singaporeans solve underwatering, overwatering and insufficient sunlight problems that caused the plant to die. In Singapore, the temperature and humidity levels are constant and therefore our IoT solution will not be focusing on that condition. We assume that plants grown in Singapore are already able to grow within the temperature and humidity ranges. The components of our IoT solution uses Raspberry Pi, GrovePi+, Grove light and soil moisture sensors to monitor the condition of the plants. To test the feasibility of our IoT solution, two experiments are conducted in two phases at different environment, indoor and outdoor.

In the first phase, we monitor the growth of green beans by simulating two gardeners. One gardener waters the green beans with the aid of IoT, the other gardener waters based on intuition.

The second phase was conducted at Singapore Management University, SMU Grow's garden. The outdoor environment at SMU Grow condition is like any urban garden in Singapore, which gave us a great environment to kickstart our prototype. The aim of this experiment is to test the accuracy of the sensors under harsh weather conditions such as warm weather or heavy rain.

In this paper, we present the benefits of using IoT to grow plants against regular farming as well as highlighting the reading accuracy and sensitivity of the sensors. The soil moisture sensors are more consistent in the changes detected but are less consistent in achieving the same readings and the light sensors are less consistent in the changes detected but are more accurate in achieving the same readings.

The rest of this paper is organized as follows: Section II discussed the IoT solution and overview of the system architecture. Section III detailed the components required for environment extraction. We analyze the data collected on an indoor and outdoor experiment in section IV. Finally, we conclude the paper with limitation, challenges faced and future work in section V.

II. IoT Solution & System Architecture

A. *Solution*

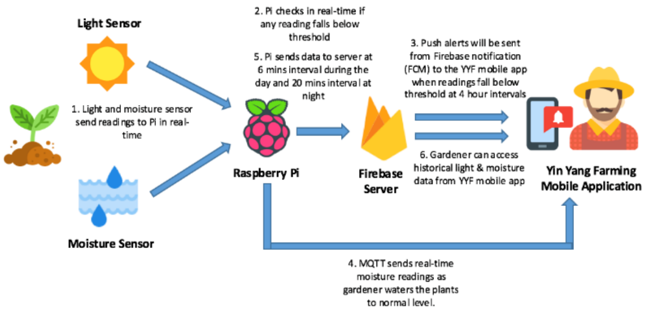

Figure 1. Solution

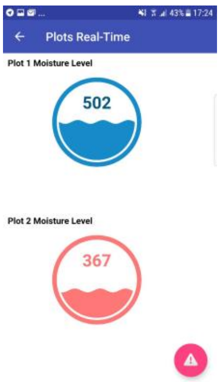

Figure 2. Yin-Yang Farming Android Application real-time watering

The sensor data from light and moisture sensors are sent to the Raspberry Pi for processing and aggregation in real-time. The Yin-Yang Farming android mobile application will retrieve the real time data to display to the user, for example the real time moisture level of the soil and as user waters the plant the sensor will be able to detect, send over a new data point and the mobile application will reflect the real time data of the new moisture level of the soil. Thus, real-time data enable the user to know quickly the moisture level of plant by referring the Figure 2 when water is within healthy threshold it will be blue where user can stop watering the plant, otherwise if is in pink then user will have to water the plant. Furthermore, the Raspberry Pi would also then check in real-time if any of the data falls below the threshold values and send alerts to user. With real-time data analysis, user will have the information of their plants in their fingertips as compared to non-real-time data analysis.

If it falls below the threshold, a warning message will be sent to the Firebase server with relevant information. The backend server will then record the information in the database and sends Firebase Cloud Messaging (FCM) notification to the gardener through Yin-Yang Farming mobile application if readings fall below the threshold at every 4-hour intervals. Using the relevant information, the gardener will be able to know how much the moisture or light level is below the threshold. The Raspberry Pi MQTT would also send real time moisture readings (2 seconds interval) to the app, so that the gardener would be able to water the plant up to the appropriate moisture level on the spot.

At every interval of 6 minutes during the day (6am-8pm) and 20 minutes at night (8pm-6am), the data collected from the sensors will be aggregated and sent over to the Firebase server via Wi-Fi. The data in the server will then be used to provide insights for the stakeholders through statistical tables and charts. For example, with the soil moisture chart data, we can better understand and analyses the limits of the threshold that the plants are able to survive.

B. *System Architecture Overview*

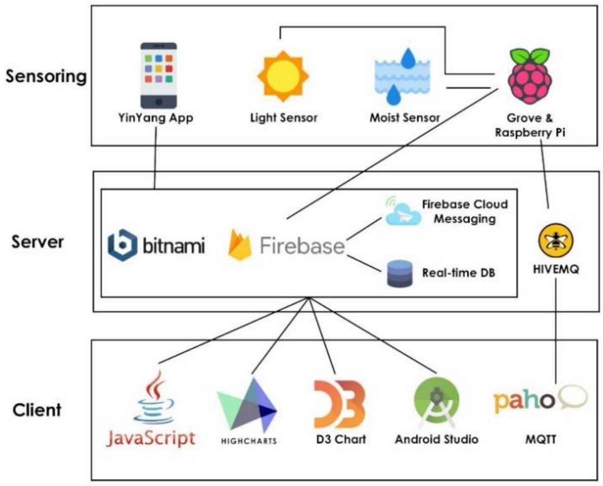

Figure 3. System Architecture

In the above system architecture diagram, there are three components, as follows:

1. Sensoring
2. Backend Server
3. Mobile Dashboard Application

In this system, the android application is hosted on a bitnami server. It is developed using android studio and data is transformed and displayed using highchart and d3 javascript libraries. The light and moisture sensor are wired connected with the GrovePi+ Board and Raspberry Pi. Data will be transmitted to the Firebase Server which will be stored in the real time database. HiveMQ is an MQTT broker that will allow the Raspberry Pi to publish and the client paho-MQTT will subscribe to receive data.

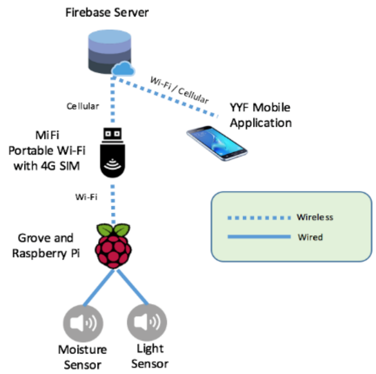

Figure 4. Hierarchical Architecture

In this hierarchical architecture, devices are on tree topology, the light and moisture sensor are interfaced with GrovePi+ board which is attached to the Raspberry Pi. The Raspberry Pi is connected to the internet via the Wi-Fi or the MiFi Portable Wi-Fi with 4G SIM. Sensor data collected will be transmitted to the Firebase server to store for future analysis. The android application is connected to the internet via Wi-Fi and Cellular, it will retrieve data from the Firebase server to be transformed and display in different form of charts.

III. Components Required

To optimize two of the most important conditions for plant health, namely light and water, we have decided to use a light and moisture sensor to measure the readings. The light sensor is used to track the amount of sunlight the plants would receive above ground level, at the deployment area. The moisture sensor is used to track the water level of the soil, under ground level, at the deployment area.

A. Light Sensor

Figure 5. Grove - Light Sensor

The light sensor integrates a light dependent resistor to detect the intensity of light. The resistance of light dependent resistor decreases when the intensity of light increases. A dual OpAmp chip LM358 on board produces voltage corresponding to intensity of light. The output signal is converted from analog to digital value using GrovePi+, the brighter the light is, the larger the value.

B. Moisture Sensor

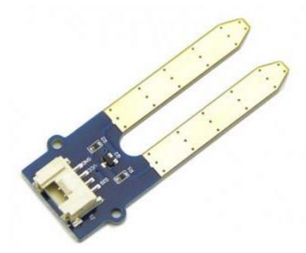

Figure 6. Grove - Moisture Sensor

This Moisture Senor is used for detecting the moisture of soil if there is water around the sensor, it is placed in the soil to get the moisture level of the soil. This sensor is very easy to use, simply insert in into the soil and read the data from GrovePi+. The output signal is converted from analog to digital value using GrovePi+, the more moisture in the soil present, the larger the value.

C. GrovePi+

Figure 7. GrovePi+ Board

The GrovePi+ board is a prototyping board to easily interface with Grove sensors. It is designed to attach on Raspberry Pi which communicate via I2C interface

D. Raspberry Pi 3

Figure 8. Raspberry Pi 3

The Raspberry Pi 3 is a credit-card size computer that preinstalls Linux, despite the small size, it can handle most of the same tasks as your desktop.

E. MQTT Protocol

This project, HiveMQ is used as the MQTT broker. Besides the stellar performance, HiveMQ is the leading innovator among MQTT brokers and is improving businesses that rely on MQTT day-to-day. MQTT is a lightweight messaging protocol based on publish/subscribe paradigm for constrained devices and unreliable networks.

IV. Analysis and Results

A. Indoor Analysis

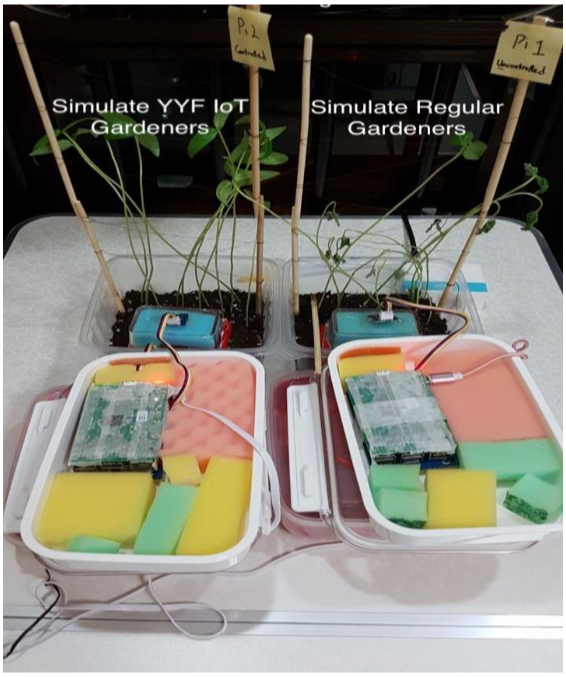

Figure 9. First Phase, Indoor Experiment

In the first phase, we tested indoors on a pair of green beans. The aim of this experiment was to find out the optimal threshold of the soil moisture level and lighting conditions for plants to grow. This was conducted by having 2 setups as seen in Figure 9, where the plant on the right, named plot 1, was watered based on a gardener's intuition and the plot on the left, named plot 2, was watered only when the gardener receives a notification from the android application. The experiment lasted for 2 weeks and we analyzed the data collected from the sensors. The analysis for the indoor experiment is conducted from March 17 to March 24.

1) Indoor Soil Analysis

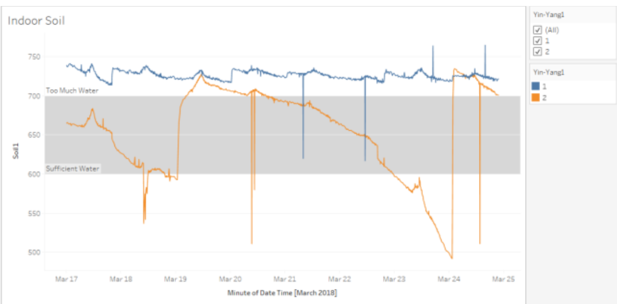

Figure 10. Indoor Soil Analysis Comparing 2 Plots of Plant

The blue-colored line graph indicates the soil moisture of plot 1 and the orange colored line graph indicates the soil moisture of plot 2. The grey area indicates the acceptable level of soil moisture for the plant. Any readings which fall below the grey area threshold indicates that there is insufficient water and any reading points fall above the grey area threshold indicates that there is too much water. From Figure 10, by comparing both plots, plot 1, the plot without the use of IoT, show a trend of too much water intake compared to plot 2 that have a relatively consistent trend of water intake within the right amount.

At the end of two weeks, plot 1 had an observable number of stems which were wilting due to overwatering while plot 2 on the other hand was still growing healthily as seen in Figure 9.

2) Indoor Soil Analysis with IoT Solution

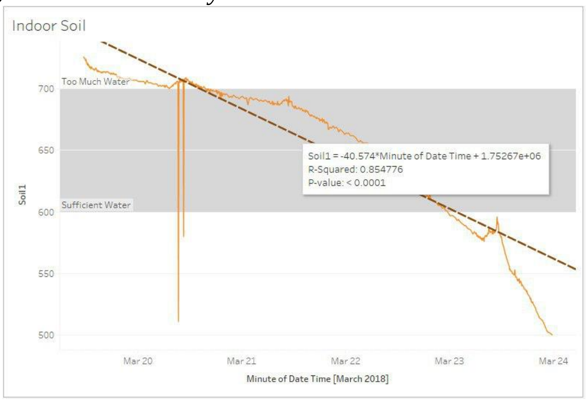

Figure 11. Indoor Soil Analysis with IoT Solution

To understand the water "drinking" pattern of the plant, an analysis can be made on the line graph of the soil moisture using IoT. Only the downward slopping line, indicating that water is being consumed by the plant, is analyzed and a regression line is plotted with a gradient of -40. Based on the minimum and maximum threshold level set by the gardener, in this case 600 and 700 respectively with a difference of 100, it is estimated that it will take about 2.5 days for the soil moisture level to fall below the minimum threshold when the gardener will be notified to water the plant again.

3) Indoor Light Analysis

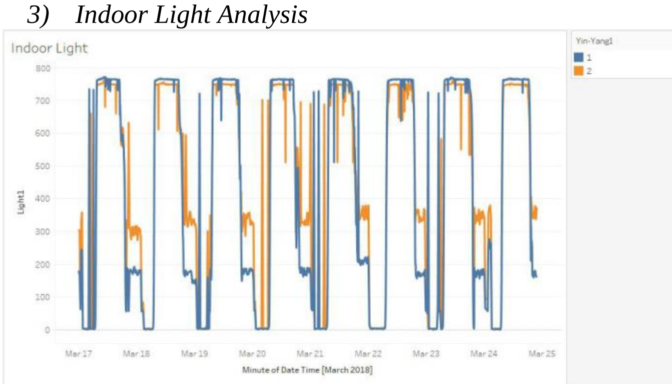

Figure 12. Indoor Light Analysis Comparing 2 Plots of Plant

The line graph for the light readings shows a U-shaped graph, indicating the areas when light is present and not present. From Figure 12, readings above 740 is identified to have the presence of light required for the plant to absorb while readings below 740 is assumed to be not absorbed by the plant. This will be used in our analysis for the percentage of light absorbed by the plant below.

4) Indoor Light Intake Analysis

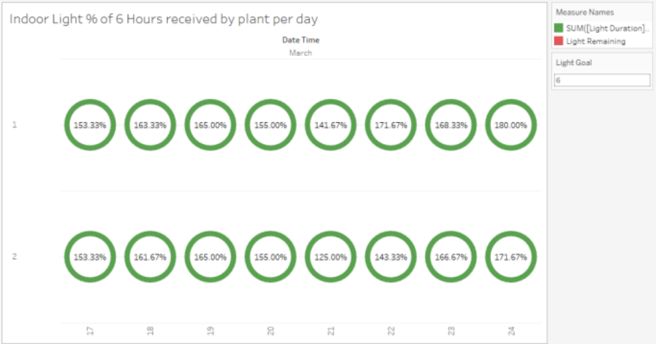

Figure 13. Indoor Light Intake % Against 6 Hours Per Day

As plants require 3 to 6 hours of light per day, a donut chart of light absorbed per day can analyze if the location of the setup feasible. The top row shows the percentage of light intake against 6 hours for Plot 1 while the bottom row shows the percentage for Plot 2 across the days. The result shows that both plants are receiving sufficient amount of light as the percentage daily is above 100%, indicating that they are receiving more than 6 hours of light.

Based on the indoor experiment, IoT can assist gardeners not only understand when to water, but also the right amount of water to provide for their plant. It also able to let gardeners know if their plants are receiving sufficient light. This is in contrast with a non-IoT gardener where they may supply too little or too much water for an extended number of days and not understanding why their plant is wilting. In addition, they will have no information about the amount of sunlight their plants are receiving.

B. Outdoor Analysis

Figure 14. Second Phase, Outdoor Experiment

In the second phase, we tested outdoors at our pilot test plot in SMU GROW's garden. Two sets of Yin-Yang Farming IoT solution were deployed on opposite sides of the crop plot as it was relatively big. The Raspberry Pi on the right is Pi 1 and the Raspberry Pi on the left is Pi 2. We wanted to find out if placing it on opposite ends would give us different readings. The aim of this test was to test the accuracy of our moisture and light sensors in an outdoor environment and see if the threshold values from the indoor phase would be able to apply in that context. The analysis for the outdoor experiment is conducted from April 3 to April 9.

1) Outdoor Soil Analysis

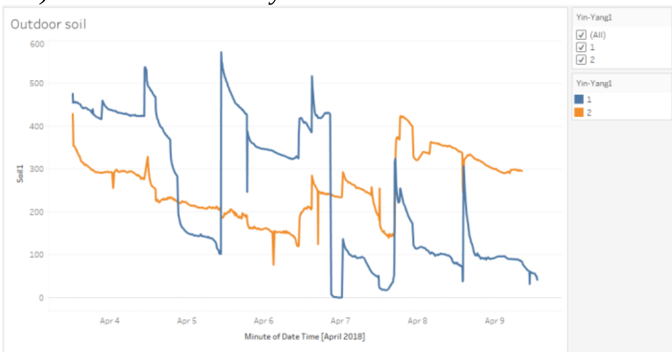

Figure 15. Outdoor Soil Analysis Comparing 2 Plots of Plant

The blue-colored line graph indicates Pi 1 and the orange-colored line graph indicates Pi 2. From April 3 to April 6, the readings recorded from Pi 1 is generally higher than Pi 2. On April 6, 9PM, the moisture sensor for Pi 1 was displaced due to a falling stem. As a result, there was difficulty in placing the sensor fully into the soil again due to the hardness of the soil. This resulted in a lower reading from April 7 onwards. Therefore, the placement of the moisture sensor affects the accuracy of the readings.

Despite being placed on the same plant, both sensors gave a totally different reading. One possible reason is due to the way the sensors were inserted into the soil.

2) Outdoor Soil Sensitivity Analysis

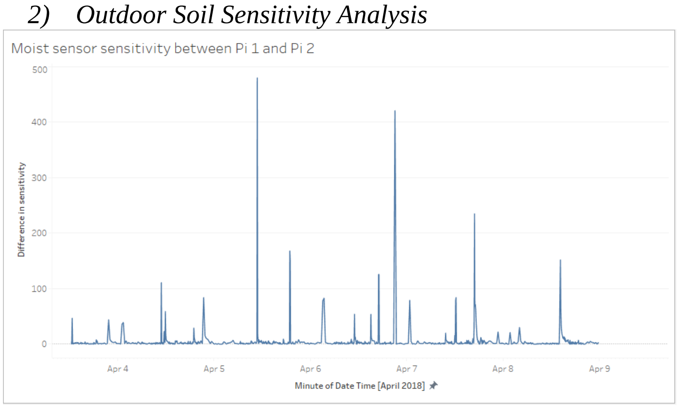

Figure 16. Difference in Soil Sensitivity for Pi 1 and Pi 2

Despite a difference in readings for both sensors, the pattern in which they increase/decrease should be similar considering that they are being tested on the same plant. A sensitivity analysis can be conducted to understand the difference in increase/decrease of the sensors. The closer the graph is to zero, this will mean that both sensors recorded a similar increase or decrease in their readings. From Figure 16, most of the time (94.33%) the amount of change in readings between the 2 sensors are consistent.

3) *Outdoor Light Analysis*

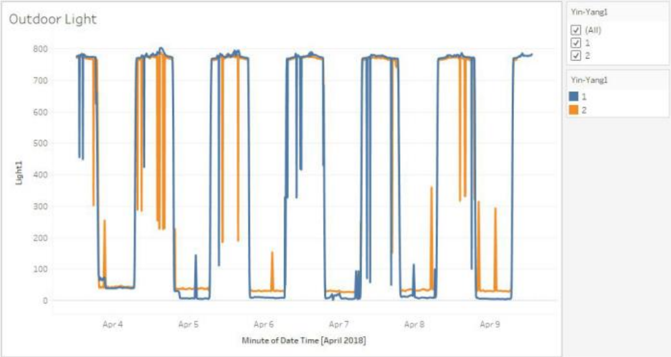

Figure 17. Outdoor Light Analysis Comparing 2 Plots of Plant

The line graph for the light readings shows a U-shaped graph, indicating the areas when light is present and not present. In an outdoor setting where the amount light can be affected due to many reasons such as the obstruction of buildings, the readings recorded from both light sensors are still almost binary with a large amount of fluctuation. When it was raining in the afternoon on 7th and 8th April, the readings recorded on both days are still on the same level as the rest of the days. One possible reason is because the light sensors are not as sensitive to changes in light.

4) *Outdoor Light Sensitivity*

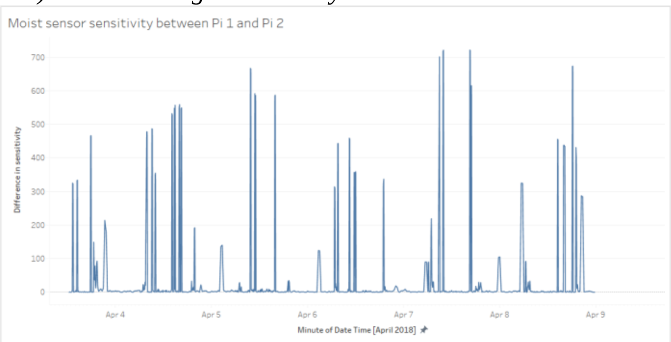

Figure 18. Difference in Light Sensitivity for Pi 1 and Pi 2

By conducting a sensitivity analysis on the light sensors, most of the time (85.67%) the amount of change in readings between the 2 sensors are consistent.

Based on the outdoor experiment, the moist sensors are generally consistent in the changes in readings and the absolute reading is relative to each other. The light sensors are generally consistent in their absolute readings but are less consistent in the changes in readings detected.

V. CONCLUSION

IoT has gained awareness and popularity in current technological world today. Many things surround us are anticipated to be attached with sensors, so that they can communicate with each other without human involvement. For sensors to communicate with each other, data has to be collected and go through a transformation process in order to transform data into wisdom.

In this project, a prototype was successfully designed and tested. There are limitations and challenges faced in this project and was mainly environmental issues. For the outdoor experiment, Wi-Fi was an issue as the range was not widely enough to cover the plot, so a portable Wi-Fi was used to extend the connection. In addition, as sensor were placed outdoor, power source was a critical issue. Portable battery was used in this prototype. However, overheating occurred and drained the energy that it could last only for 3 to 4 hours. Thermal insulators are used to cover the battery to reduce the heat, so the battery would last longer. Another issue was that the moisture sensor is too short for an outdoor environment, as the roots of the plant will grow deeply in the soil, our moisture sensors will not be able to capture the true moisture of the plant.

For future extension of this project, we recommend that replace portable battery to solar panel to power the sensors, moisture sensors should be replaced with an appropriate moisture sensor designed for outdoor environment, also changing Wi-Fi connection to an 3G dongle might be a better option.

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