IoT-Based Precision Irrigation System for Eggplant and Tomato

Maria Gemel B. Palconit[*1,2,a], Edgar B. Macachor[*2,b], Markneil P. Notarte[*2,c], Wenel L. Molejon[*2,d], Arwin Z. Visitacion[2,e], Marife A. Rosales[1,f], Elmer P. Dadios[1,g]

[1]De La Salle University, Manila, Philippines; [2]Cebu Technological University, Cebu City, Philippines
[a]maria_gemel_palconit@dlsu.edu.ph, [b]edgar.macachor@gmail.com, [c]markneil404@gmail.com, [d]wenelzkie@gmail.com,
[e]arwin.visitacion@ctu.edu.ph, [f]marife_rosales@dlsu.edu.ph, [g]elmer.dadios@dlsu.edu.ph

Abstract. Water management, specifically for areas with scarce water, is essential. Hence, the sensors and smartphone camera were deployed to gather data the needed parameters and to access these data through an application remotely. The data gathered from the soil moisture sensor was used to set up an automatic irrigation system that would irrigate the precise water needed for the tomato and eggplant. In 4 weeks, the irrigation system watered the tomato with a total volume of 4009.875 mL and 4543.08 mL for the eggplant while in traditional watering, the tomato consumed a 6650 mL and 8550 mL for the eggplant. Overall, this resulted in a total of 44% water consumption savings, while the plants were visually healthier than the traditional watering method.

Keywords: Precise Irrigation, IoT, Remote Monitoring and Control, Smart Agriculture

1. INTRODUCTION

Agriculture has been one of the foundations in sustaining the economy of a country. Farming is a type of agricultural activity that involves planting crops, and if the crops are fully grown, they harvest it. Farming applies irrigation in which it is a system that consists of watering the plants. Monitoring the plants and automating the irrigation system is one factor in achieving efficient farming. Necessarily, the irrigation provides all water needed for a crop to fulfill its growth. Over 40 years, the solution for an efficient irrigation system has been continually expanding [1].

Precision irrigation has been recently seen as a growing field in agriculture to properly utilize the water resources according to the specific need of plants in which its success is dependent on the monitoring and control schemes [2]. In this regard, the Internet of Things (IoT) and Wireless Sensor Network (WSN) is deemed efficient enabling technologies to provide low-cost materials, do it yourself (DIY) approach, and real-time monitoring of the plants, soil, and the related environment conditions [2],[3]. Other technologies include satellites and Unmanned Aerial Vehicles (UAV). While approaches to control the irrigation varies from a closed-loop system from linear regression to intelligent controls and an open-loop system according to time and volume [2].

Based on the study, most of the related works of precision irrigation system has used soil moisture as the most measured soil parameters, among others. However, 68% of the cited papers did not disclose the sensors' details, 10% with incomplete information, while 22% has disclosed the utilized sensors. For the weather condition, the air temperature and humidity are mostly monitored [3]. The soil parameters and weather conditions opted to use low-cost sensors rather than commercial ones to gather the needed data. For low-cost sensors, calibration is a critical factor in ensuring the sensors' measurement accuracy according to the true value [4]. However, most of the paper cited in [3] did not mention how the sensors were calibrated; this paper includes its discussion on the sensors' calibration.

In a tropical country like the Philippines, tomato [5] and eggplant [6] are common. In this regard, this study intends to investigate the deployment scenario and technical discussions of an IoT based system on tomato and eggplant to precisely control and monitor the irrigation concerning measured soil moisture and environmental parameters. There are several works on precision irrigation technology advances related to chosen plants using IoT, and WSN [7] [8] [9], while some studies utilized vision-based UAVs to gather the measurements aside from the sensors [10]. Concerning irrigation control, several works utilized artificial intelligence [11], such as a fuzzy-based system [12], [13], and neural network, while others used multiple linear regression[14]. Specifically, this paper uses a closed-loop irrigation control according to the specific soil moisture of tomato and eggplant. At the same time, the weather conditions such as air temperature, humidity, and time were used to correlate and find the most important influence in the context of the irrigation frequency and water volume using exhaustive search algorithm in MATLAB.

This paper covers the specific sensors used and its calibration, IoT modules and platform, design of the system, comparison of the water savings, and the plants' growth using the traditional watering approach and IoT-based irrigation system.

2. METHODOLOGY

The study introduces three subsystems, namely the monitoring system, the irrigation system, and the control system. *Figure 1* shows the overview wherein in this system, details of the sensors, namely: temperature sensor, humidity sensor, and soil moisture sensor, were distributed

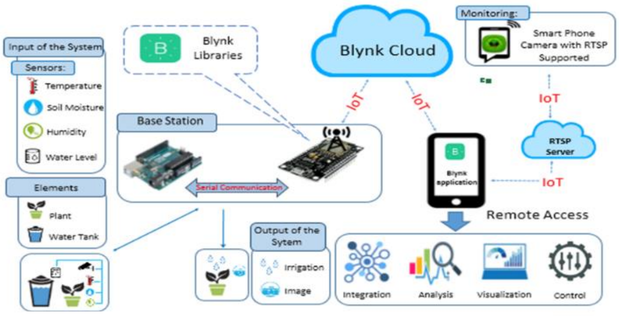


Figure 1: System Overview

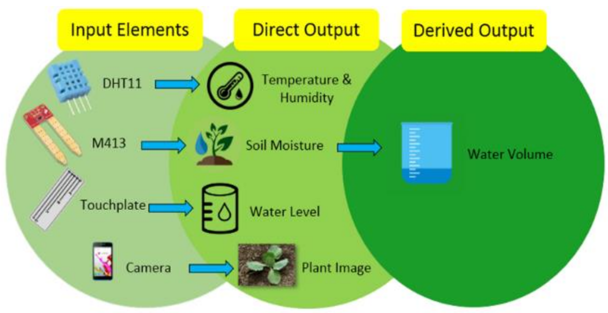


Figure 2: Data Collection Overview

throughout the crop field to gather the data of the conditions of the crop and soil. A water level sensor was also designated in the water tank to monitor the amount of water continually while a separate surveillance camera was installed to capture a visual image of the crop field.

The collected data from the different sensors were used to trigger the relay to irrigate water into the crop field. Correspondingly, the collected data and the image taken would be sent to the Blynk server using IoT. The received data was visualized in a GUI using Blynk application to provide clear information on the crop field. The link used to connect the server and the device was the Blynk application. Blynk handles the communication and authentication between the smartphone, and the ESP8266, and keeps an eye on the board to gather data time by time. The Arduino UNO was responsible for collecting data from the sensor. The ESP8266 received data from the Arduino Uno and was responsible for sending the collected data to the Blynk server. Blynk server would communicate to the ESP8266 using authentications and libraries and receive data messages that were sent and displayed to the GUI in the smartphone using IoT. Generally, the data can be accessed through any smartphone's provided with an internet connection and an account to the Blynk.

The air temperature, humidity, soil moisture, water level of the tank, and the crop field area were the parameters monitored. Respectively, the temperature sensor, humidity sensor, soil moisture sensor, and water level sensor were used to monitor the conditions every five seconds (see *Figure 2*). Furthermore, a positioned surveillance camera was used to capture the whole crop field area.

The use of the smartphone camera in the study was to capture the image of the crop field. However, since the camera cannot capture the whole crop field's view, a servo motor was used to act as a camera position manipulator to capture the crop and crop field correctly. The servo rotates whenever a command was sent from the GUI. Drip irrigation was used in which the water pump would release water from a water container guided by a hose directed to the stem of the plant to propagate water directly to the surface than to the roots of the plant.

To achieve precision irrigation, the volumetric water needed per day for the tomato and eggplant, were used to determine the desired threshold moisture content of the soil for each plant by conducting experiments. The soil moisture sensor (M413) was placed in a cubic feet container filled with a specific type of soil suited for each plant then the water required for the plant was poured into the container to measure the moisture of the soil. This experiment was conducted at least five times to ensure the reliability and accuracy of the system. The number of samples gathered from the experiment was evaluated and served as the reference threshold soil moisture for the study's irrigation system. This volume of water was based on the study [15] and [16] wherein they stated that the pot capacity (PC) or the volume of water present in the soil to produce good growth and optimum water requirement for the tomato was 75 % which is equivalent to 0.3 to 0.4 liters and the eggplant was around 0.75 to 1.35 liters.

Table 1 shows the volumetric water present in the soil, the water pump rate, and threshold soil moisture for both tomato and eggplant. The specified water volume in the soil was used as the reference for the experiment in getting the threshold soil moisture for both plants. The experiment utilized five pots for each type of plant-filled with soil recommended for the plants. For tomato, 0.3L of water has been poured to each of the pots and measure its soil moisture by using the calibrated soil moisture sensor of the system designated only for tomato. Based on the collected data readings of the sensor, the threshold soil moisture for tomato was 25%. The same experiment was conducted for the eggplant using a 27% threshold.

The volume of water V_w is calculated using (1), wherein the pump rate, P_r=0.867 mL/sec, the time t pumps at 5 seconds while f_{tr} is the watering frequency or occurrence of soil moisture less than the threshold, as shown in *Table 1* and *Figure 3*. For the precision irrigation system, the plants will be irrigated using (1) every time the soil moisture is less than the set threshold, while for the traditional watering method, the plants were watered every morning with a 25% increment of water volume range specified in *Table 1*. Note that during rainy days, the plants using the two approaches were not watered.

$$V_w = P_r \times t \times f_{tr} \quad (1)$$

2.1. Prototype and GUI Design

The GUI of the system served as the graphical representation of the data acquired using the sensors and surveillance camera as shown in *Figure 4* while the camera view can be controlled by sweeping the scrolling icon in the

Table 1: Volumetric and Soil Moisture Data

Crop	Volumetric Water in the Soil (L)	Rate of Water Pump (mL/sec)	Threshold Soil Moisture (%)
Tomato	0.3 to 0.4	0.867	25
Eggplant	0.75 to 1.35	0.867	27

Table 2: Validation of RMSE for the Sensors Before and After Calibration

Parameter	Before Adjustment	After Adjustment
Temperature	1.05	-
Humidity	4.81	0.63
Soil Moisture for Tomato	28.91	0.51
Soil Moisture for Eggplant	28.45	0.11

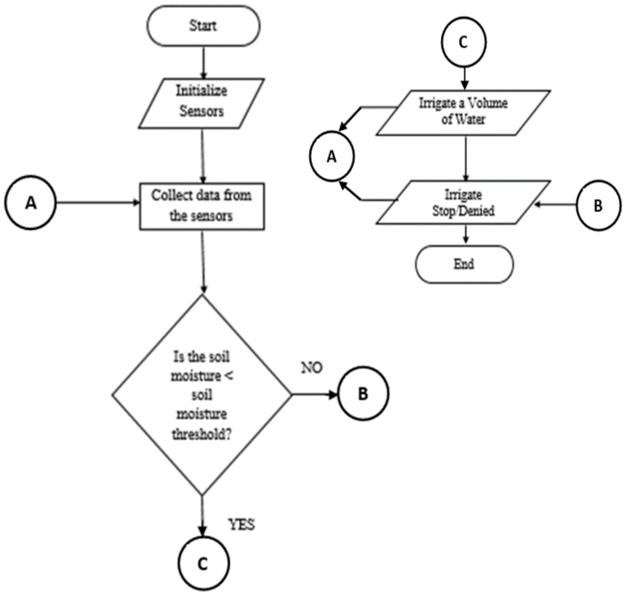


Figure 3: Precision Irrigation System Flowchart

GUI, which displays a real-time video of the crop and the area. Figure 5 shows the prototype design in this study. It also shows the layout, the setting, and the system components being deployed in the field area.

2.1. *Calibration of the Sensors*

Each sensor was calibrated using reference instruments with a sampling size of *n=10* to validate the sensors' reading' accuracy. Adjustments were made for the sensor readings that were deemed far from true or reference value. For the calibration of DTH11, the thermometer and digital hygrometer were used while the M413 soil moisture sensor used the Sartorius Moisture Balances. Adjustments were made according to the root mean square error (RMSE) depicted in (2) in which the sensors' observations $\hat{y}_i$ and the reference measurement from the instrument y_i are calculated.

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(\hat{y}_i - y_i)^2}{n}} \quad (2)$$

The results of before and after calibration are shown in *Figure 6* and *Table 2* wherein the temperature was not adjusted because its RMSE was deemed tolerable, the humidity sensor was adjusted by 4.81 with respect to digital hygrometer. In contrast, the soil moisture sensors obtained the highest error before calibration. Since the threshold value for the soil moisture is 25 to 27 needed for the plants, the uncalibrated sensor would result in an error rate greater than 100%. Thus, its reading was adjusted by 28.91 and 28.45 for tomato and eggplant, respectively.

3. DEPLOYMENT OF THE SYSTEM

Two pairs of each eggplant and tomato were used for implementation, as shown in *Figure 7*. Eggplant A and Tomato A were watered using the installed irrigation system, while the other two plants that were not applied with the system were labeled as Eggplant X and Tomato X. It was discussed that the plant Eggplant X and Tomato X was enforced with a traditional irrigation system and was used

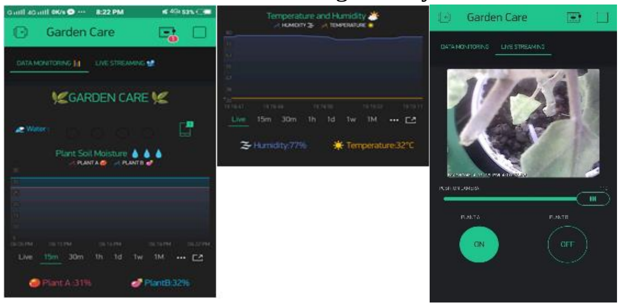


Figure 4: GUI Sensor Data and Surveillance Camera Footage

Figure 5: Prototype Layout of the Mini-Garden Irrigation System

as a basis for the comparison from the former plants.

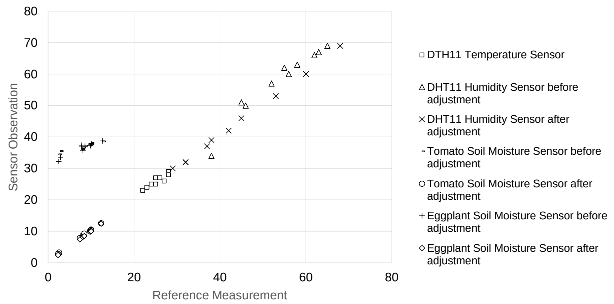


Figure 6: Calibration of Sensors using Reference Measuring Instruments

Figure 7: Deployment of the Irrigation, Monitoring and Control System

The Eggplant A and Tomato A had each soil moisture sensor to monitor their soil moisture content and a hose connected to the water pump for irrigation while the water tank had a water level sensor for monitoring the refill of the water. The soil moisture sensor was positioned and buried at the plant's side to quickly gather the data while the hose was placed closed at the ground. This type of irrigation is called drip irrigation, where the watering hose was positioned close to the soil to avoid stressing the plant and damaging it when being watered. Inside box was the base station, such as the Arduino Uno and ESP8266, relay module for the water pump, water pump, wirings. The and the DHT11 was attached outside of the enclosure. This enclosure was used to protect the devices away from water and other objects that may damage their connection. In *Figure 8*, the servo motor was used to rotate the smartphone 180° and was attached to a wooden plank. The smartphone surveys the plant and the area to assess the presence of objects or developments in the plants that may affect its growth. For the irrigation to activate, a specific plant's soil moisture was used to trigger the relay and water pump.

4. RESULTS AND DISCUSSIONS

The precise irrigation system and traditional watering method were deployed to four-week-old tomato plants and 10-week old eggplants. Its growth progress is recorded weekly, such as plant height, number of leaves, and its visual appearance for a one-month duration. The correlation of the watering frequency, water volume, and weather parameters were also recorded.

4.1. Plant Height

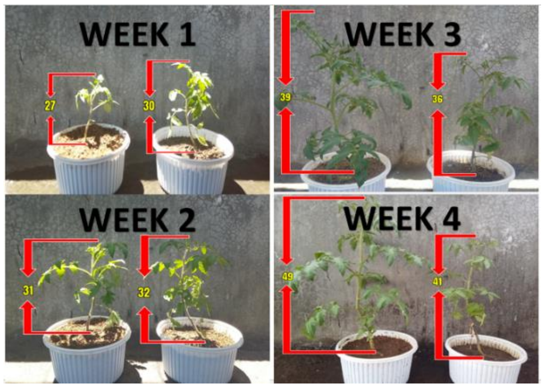
Table 3 and *Figure 9* shows the measured weekly height of each plant using a tape measure. It can be observed that the tomato significantly obtained a higher growth rate using the precise irrigation system compared to the traditional watering method from the first week to the fourth week. In contrast, the eggplant shows a slow growth rate for both watering methods.

Table 3: Plant Heights of Tomato and Eggplant

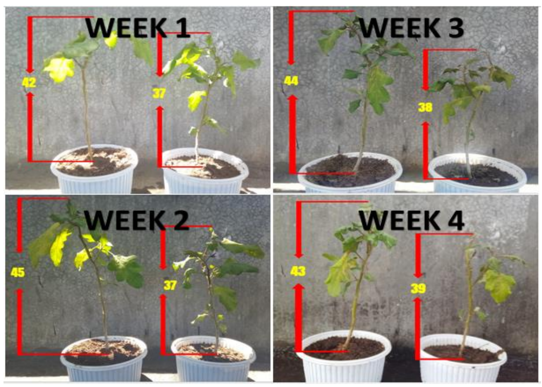
Week	Tomato *(cm)*		Eggplant *(cm)*	
	Plant A	***Plant X***	***Plant A***	***Plant X***
1	27	30	42	37
2	31	32	45	37
3	39	36	44	38
4	49	41	43	39
Growth Rate	81%	37%	2%	5%

Figure 8: Servo Motor and Smartphone Surveillance Camera

4.2. Number of Leaves



(a)



(b)

Figure 9: Actual Photo: (a) Tomato Height Comparison (b) Eggplant Height Comparison

As the week progresses, each plant's leaves may sprout and wither due to climate, overwatering, drought, or disease. These plants were vulnerable to diseases and pesticides that may hinder the leaves from growing and causes to wither. In *Table 4*, the number of leaves was counted, and it can be observed that the plants with implemented precise irrigation systems obtained superior increase count of leaves compared from the traditional watering approach for both plants. On the other hand, it is noticeable that at the end of the fourth week, the number of leaves for eggplant X (using traditional watering) decreases.

Table 4: Number of Leaves of Tomato and Eggplant

Week	Tomato		Eggplant	
	Plant A	***Plant X***	***Plant A***	***Plant X***
1	27	57	18	27
2	78	96	26	34
3	145	129	32	28
4	158	122	23	17
Increase Rate	485%	114%	28%	-37%

Table 5: Overall Appearance of Tomato and Eggplant

Week	Tomato		Eggplant	
	Plant A	***Plant X***	***Plant A***	***Plant X***
1	better	better	better	better
2	better	better	better	better
3	better	good	better	good
4	better	good	good	bad

Table 6: Water Consumption of Tomato and Eggplant

Week	Tomato *(mL)*		Eggplant *(mL)*	
	Plant A	***Plant X***	***Plant A***	***Plant X***
1	689.27	800.00	810.65	1,000.00
2	1,382.87	1,800.00	1,517.25	2,400.00
3	1,473.90	2,450.00	1,668.98	3,150.00
4	463.85	1,600.00	546.21	2,000.00
Total	4,009.88	6,650.00	4,543.08	8,550.00

4.3. Overall Appearance

The overall appearance of each week for both plants was determined from the factor of whether the plant was in a better state like sprouting leaves, a good color appearance, spanning bigger in width or height, plant activities such as budding, flowering, the ripening of fruits; or in a good state like average color, height, width, and plant activity of the plant; or a bad state like leaves withering and wilting, stagnant height and width, no plant activities, and diseases or pests' presence. For each week, the plant was observed and was categorized for its appearance. In *Table 5* and *Figure 9*, the state of the plant is shown. Consistent with the previous evaluations, the plants with installed precision irrigation systems obtained better results compared to the traditional plant-watering method.

4.4. Water Consumption

From the data in *Table 6*, the traditional plant watering method consumes more water than the plants with irrigation systems. Specifically, the plants with an installed irrigation system consumed less water by 40% and 47% for tomato and eggplant, respectively.

4.5. Watering Frequency Considering Time and Weather Conditions

Figure 10 shows the gathered data from the 1st and 2nd day of the deployment. The watering frequency indicates the occurrence count of soil moisture less than the specified threshold, while the water volume was computed using (1). As can be seen, the same trends were observed for both eggplant and tomato for two days. During the nighttime, there is no need for watering while the peak watering hours are between 9:00 AM to 12:00 NN.

Time	Temp (°C)	Humidity (%)	Tomato		Eggplant	
			Watering Count < 25% soil moisture	*Total Volume (mL)*	*Watering Count < 27% soil moisture*	*Total Volume (mL)*
12:00:00 AM	25	0.77	0	0	0	0
3:00:00 AM	25	0.79	0	0	0	0
6:00:00 AM	25	0.78	4	17.34	11	47.685
9:00:00 AM	27	0.71	32	138.72	21	91.035
12:00:00 PM	29	0.61	20	86.7	19	82.365
3:00:00 PM	30	0.57	12	52.02	12	52.02
6:00:00 PM	30	0.63	2	8.67	1	4.335
9:00:00 PM	27	0.72	0	0	0	0
Total			***70***	***303.45***	***64***	***277.44***

(a)

Time	Temp (°C)	Humidity (%)	Tomato		Eggplant	
			Watering Count < 25% soil moisture	*Total Volume (mL)*	*Watering Count < 27% soil moisture*	*Total Volume (mL)*
12:00:00 AM	25.00	0.77	0	0.00	0.00	0.00
3:00:00 AM	25.00	0.78	0	0.00	0.00	0.00
6:00:00 AM	25.00	0.77	7	30.35	11.00	47.69
9:00:00 AM	27.00	0.68	26	112.71	25.00	108.38
12:00:00 PM	29.00	0.61	16	69.36	17.00	73.70
3:00:00 PM	30.00	0.63	12	52.02	12.00	52.02
6:00:00 PM	29.00	0.70	1	4.34	1.00	4.34
9:00:00 PM	27.00	0.78	0	0.00	0.00	0.00
Total			***62***	***268.77***	***66***	***286.11***

(b)

Figure 10: Chart for the watering frequency and water volume of the precise irrigation system according to time, temperature and humidity considering the soil moisture for tomato and eggplant:
(a) Day 1; (b) Day 2

Input	Tomato		Eggplant	
	Training	*Checking*	*Training*	*Checking*
Time-Temp	0.0118	2.7597	0.0493	1.9676
Time-Humidity	0.1272	11.1905	0.1042	7.4799
Temp-Humidity	1.4200	59.9199	3.3152	38.4173

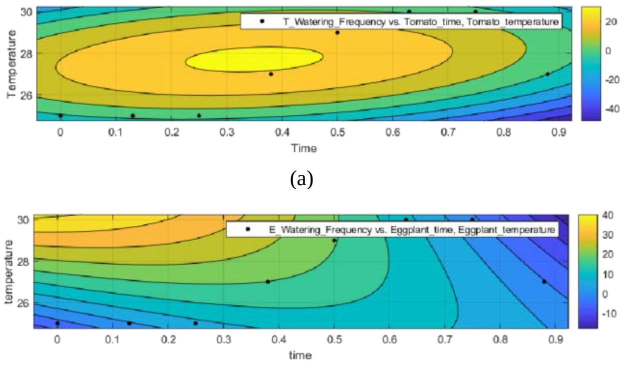
Figure 11: RMSEs of Exhaustive Search Result for Tomato and Eggplant Using Two-Input Parameters out of Three Candidates

The gathered data were used to find to most influential parameters of the watering frequency with the input parameters, namely, the time, humidity, and temperature. This was done using an exhaustive search algorithm (exhsrch) in MATLAB. Generally, this algorithm was designed for input selection in an adaptive neuro-fuzzy inference system (ANFIS) but can also be applied to any data set which needs to map the most influential factors attributed to the predicted measures. The data gathered on the first and second days were used for training and checking sets, respectively. Since the number of relevant input parameters is still unknown, the selection was varied between one and two out of three candidates. Results have shown superior RMSEs for two-input parameters compared to the one-input parameter. As shown in *Figure 11*, the time and temperature obtained the lowest RMSEs for both checking and training, which means that they are the most influential parameters considering the watering frequency. Using regression, this resulted in equations (3) and (4) with 0.9498 and 0.9419 R-squared for tomato and eggplant, respectively. The obtained R-squared means that the fitness of equations is good while their training RMSEs are 4.948 and 4.019, and checking RMSEs are 5.6 and 3.0 for (3) and (4), respectively. The plot of the generated equations can be seen in *Figure 12*.

$$f(x,y) = -2969 - 170.5x + 218.7y - 93.01x^2 + 8.503xy - 4.001y^2 \quad (3)$$

$$f(x,y) = -460.5 + 383.6x + 26.8 - 54.94x^2 - 13.1xy - 0.3385y^2 \quad (4)$$

where: x represents the time, y represents the temperature and $f(x,y)$ represents the predicted watering frequency



(a)

(b)

Figure 12: Surface plot of the equations (3) and (4) considering the time and temperature with predicted watering frequency

5. CONCLUSION AND RECOMMENDATIONS

By using the soil moisture sensor, water level sensor, and the DHT11 for gathering the temperature and humidity, a monitoring system was successfully developed to inspect remotely, control, and automate the condition of the plant and its environment. The data collected by the sensors helped the user to monitor if the plants are suffering from extreme heat, drought, and limited water. With the use of a soil moisture sensor, the irrigation system precisely actuates the right amount of water to maintain the needed soil moisture such that overwatering or under watering the plants can be avoided, thus, optimizing its growth. The irrigation system's effectiveness was verified by its less water consumption, visually healthy plants based on its height, the number of leaves, and overall appearance compared to the traditional watering of plants. Among the input parameters, it is also worth noting that the time and temperature are considered the most influential parameters for the watering frequency, with peak watering hours between 9:00 AM and 12:00 NN for both plants.

The work presented in this paper can be further improved with the use of computer vision and artificial intelligence. Gathering of additional weather parameters such as cloud percentage, wind direction, gust, and rain could improve the watering frequency estimation.

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