Plant Box: A Controlled Environment Agriculture Technology Platform

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Abstract - *Plant Box is a physical simulation that cross links phenotypic response in plants (taste, nutrition, etc) to environmental variables, biologic variables, and resources required in cultivation (inputs). The Plant box makes use of a collection of sensors that constantly monitors the internal climate within a special growing chamber and adjusts it to the needs of the environmental conditions so that it may remain consistent and optimum. The climate within a growing chamber can be tightly controlled and also be used as a tool to enhance both quality and production of food. It is a platform which utilizes soilless agriculture technologies involving a hydroponic system and artificial lighting system to grow crops and vegetables indoors. Plant box can be plugged into the water and electricity at any building, and it does not need any other resources. Indian farmers are not very much aware about the latest technologies that are related to vertical farming or controlled environment agriculture(CEA). So, this technique is possibly good for farmers to get self-educated as well as for students. Plant knowledge can be shared and stored, which can definitely prove to be paid for the next generation of farmers to let them get familiar with nature, learn about science, and get good and nutritious food through the Plant box.*

Key Words:Plant Box, Deep Water Culture, Growing Chamber, Raspberry pi 3, Adafruit IO, etc

1.INTRODUCTION

By the year 2050 the population across the world is expected to grow to more than 9 billion people [1]. According to the United Nations, this population growth will require the world food supply to almost double within the next 30 years alone [2]. One challenge is that the conventional way of growing crops is not really that efficient . Across the world each year 70% of freshwater supply is dedicated just to growing crops [3]. Further the amount of land required to grow the food we consume each year is also insanely large. The issue here is that we are sort of running out of space [4]. Increasing the food supply through expanding the available farmland is simply not going to be an option in future. The earth could be in a pretty dangerous place, if it cannot provide the nutrient rich foods we humans need to survive in the very near future. In order to cultivate more food with less space new approaches to farming will have to be used.

A new framework whereby plants and crops are controlled and monitored by computer-based algorithms [5] and provides the possibility not only to replicate experiments easily, but also to collect, analyze, and learn from the data obtained to discover new traits and patterns. And have the potential to assist plant optimization methods achieving more autonomous, efficient, and intelligent plant growth models. Using Controlled Environment Agriculture, the artificial control of temperature, light, humidity, and gases makes producing foods and medicine indoor possible. Artificial lights help us to provide different wavelengths based on the requirement that helps the plant to nourish their growth smoothly.

The project plant box fulfills the above framework in which light is provided continuously without any interruption and promotes growth at a faster rate. The growth rate on a hydroponic plant is 30-50 percent faster than a soil grown plant, under the same conditions and uses 95% less water.

2. PLANT BOX

The Plant Box is a tabletop-sized, controlled environment agriculture technology platform that uses robotic systems to control and monitor climate, energy, and plant growth inside of a specialized growing chamber. Climate variables such as air temperature, humidity, potential hydrogen,electrical conductivity, and root-zone temperature are among the many conditions that can be controlled and monitored within the growing chamber to yield various phenotypic expressions in the plants. Plant Box, stores all the data collected inside the growing chamber into a database and can be operated remotely [6]. LED lighting technology is used as an artificial light source in order to simulate the growth of plants by emitting the necessary electromagnetic spectrum required for photosynthesis to occur. Instead of soil as a growing medium, hydroponic growing techniques are used to grow the plant inside the growing chamber.

Fig-1 is the block diagram showing connections of sensors and actuators to raspberry pi which is the brain of the system. The electronic structure of the Plant Box is built around the open-hardware platform Raspberry Pi 3 . The Raspberry Pi has a strong community of users. This SBC provides enough flexibility because it embeds both multi-purpose ports such as Universal Serial Bus (USB) as well as General Purpose Input/Output (GPIO) ports, which allow the integration of more complex circuits. The Raspberry Pi 3 CPU runs at A 1.2GHz 64-bit quad-core with an ARMv8 architecture. This architecture is supported by most of the Linux distributions, allowing access to relevant tools such as different programming languages and compilers, robotics-related software, etc.

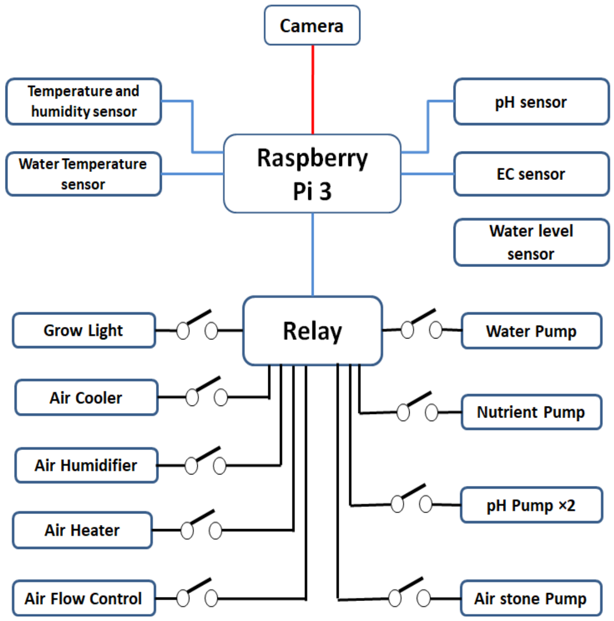

Fig -1: Block Diagram

The Raspberry Pi 3 collects data from sensors placed in both the growing chamber and the hydroponic system, then it process the data collected, using the logic provided to the raspberry pi through python program, and performs the required actions using the actuators placed in both the growing chamber and the hydroponic system. In order to connect sensory input with actuation power which requires high power switching, JQC-3FF 5V relays are used.

For powering the plant box, 230V supply is used. Grow lights can be directly connected to the 230V supply and it is stepped down to 12V for the cooling and heating modules , and to 5V supply for Raspberry pi and relays.

The construction of the Box and climate variable for this project has been considered based on the assumption of growing lettuce in the box.

2.1 Box

For the construction of the box the material chosen is wood, which is cost-efficient. Certain factors that are considered for the construction of the box are the average size of the plant (lettuce) ranging from 6 to 12 inches or 15 to 30cm , size of the hydroponic system , distance of the lighting system from the plant 45cm and space for the brain of the plant box . After considering all these factors the box is made and has a structural frame of 50×45×60cm . At the front-side (Fig-2) of the box a grow light on top, a glass window of size 40×35 cm in wooden frame with hinge to open the box. Inside the box it has two net pots 15cm apart where the plants are kept. And at the bottom side a slide in a reservoir of 40×35×15cm in size has a volume capacity of 15 litres which is slightly slanted outward to clearly see the door mechanism of the window, the 2 net pots and the slide in mechanism of the reservoir. On the backside of the box where the box resides. The server also has a glass window of size 40×35 cm and can be opened. The server is partitioned into top and bottom. On top side the brain of the box which consists of raspberry pi, relays and circuit connections. And at the bottom side consists of nutrient solution, ph up and ph down solutions.

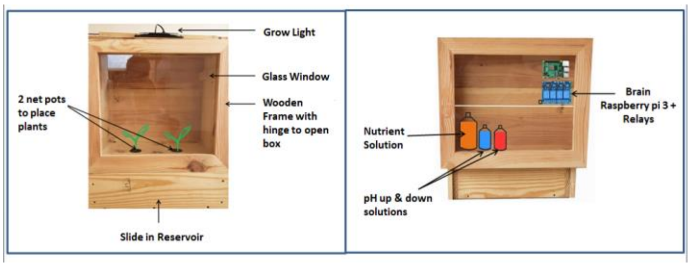

Fig -2: Front and Back side of Plant Box

2.2 User-Interface

The project requires a cloud computing platform for storing and accessing data over the internet instead of using them locally. This allows the sharing of resources across devices through a centralized storage. Adafruit IO is one such cloud provider focusing more on IoT deployments on the cloud. Adafruit IO supports different hardware like Raspberry PI, ESP2866, and Arduino.

IoT developers prefer Adafruit IO over other IoT cloud providers for the following reasons:

a)Powerful API - Provides us libraries for various programming languages, which also provides the built-in user interface support.

b)Dashboard - Understanding data via charts and graphs enables us to make better decisions.

c)Privacy - Data is secured in the cloud platform with better encryption algorithms.

d)Documentation & Community - Many blogs with amazing community support allow continuous developments of the products.

User-Interface (Fig-3) contains 10 feeds to control the plant box and a dashboard to see and analyse the data. 6 feeds to get the data from the raspberry pi and 4 feeds to send the data to the raspberry pi. Unique key from the

Adafruit io is used in the code to ensure security of the data.

Various feeds used are:

1. Temperature control
2. Temperature monitoring
3. pH control
4. pH monitoring
5. EC Control
6. EC monitoring
7. Water temperature monitoring
8. Humidity control
9. Humidity monitoring
10. Camera feed

Feed data is stored in Adafruit database.Which can be exported to CSV or JSON format. This data can be analysed and helps to understand the condition of the plant.From the feed menu we can see the graph and are able to download the data individually.

Dashboard consists of sliders and gauges to view and adjust the feed values. Controlling feeds are connected with sliders and monitoring feeds to gauges. Camera feed is connected to the image viewer in the dashboard. Real time data is updated in the dashboard.

Triggers are used for automating various aspects which work in a timely manner like changing water in the reservoir it is set for a week. Another feed is connected with triggers to send data to raspberry pi. Since it is expandable we can add multiple features and facilities onto the system.

Fig -3: User-Interface

2.3 Lighting System

The process of conversion of light energy into chemical energy occurs in plants with a maximum photosynthetic efficiency of approximately 6%.since the project accounts for growing plants in a closed environment,the artificial lighting is provided for the plants growth and photosynthesis process. Both red and blue light are required for photosynthesis. Lettuce requires mostly the high end of the blue spectrum of light at an intensity of 17 moles/m2/day of PAR.Red light focus on the function of plant reproduction and is essential for stimulation of flowering and fruiting and the Blue light stimulates chlorophyll production on a larger fraction than any other light wavelengths[7].Plants also require both dark and light periods,so as the lighting time should be adjusted by switching them on and off at set intervals..

Besides all the lights available LEDS provide more efficient wavelength required by the plants to grow and are being selected based on having good ppfd values..The average light period for lettuce was between 12-18hrs and the remaining should be dark hours,of this 12 to 16 hrs is timed commonly.Lights should be place at a certain height so that it doesn't harm the plants like an average of 4 to 6 inches from leaf and 8-12 inches of ideal height above the plant which varies with different varieties and methods and type of light used.The amount of lumens required for plants like lettuce based on the box measurements ranges from 2000 to a maximum of 5000 lumens.Lumens slightly more than 5000 does not destroy the plant but its not necessary which may result in energy wastage or slight taste changes of the plant.

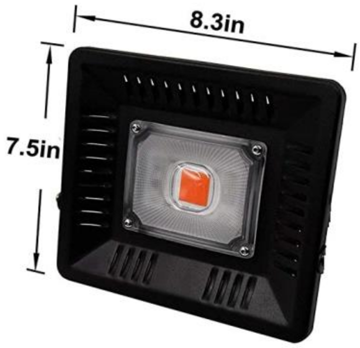

Fig -4: 50w fluorotronics IP65 COBled grow light

Here the light used is a 50w fluorotronics IP65 COBled grow light having combined red(630-660nm) and blue light spectrum(440-460nm).They contains a thermal control IC to regulate light power to maintain body temperature under acceptable limits.Provides high photosynthetic radiation per unit power,having good plant light fill effect and efficient lumen to power ratio.Their length width heights are 22*19*2 respectively .The light which have chosen had a slight drawback of having more than 5000 lumens but it doesn't affect the plant growth.The growth was specific as direct spectrum is received by plants without any deviation.The plant was being placed away from the light of about 16 inches and was being operated for a period of 12hrs daily...

2.4 Climate Control

To provide optimum climate conditions for the plant to grow inside the Growing chamber, the temperature and humidity should be controlled.

2.4.1 Temperature Control

The temperature required inside the chamber, which will vary for different plants, can be given using a slider widget in the UI of the planter box.Raspberry pi will be collecting the actual temperature inside the chamber using DHT22 sensor and will keep on comparing the actual value to that has been set using the UI . If the actual value inside the chamber is greater than the value fixed using UI, the Air cooler module inside the chamber will be turned on, until the temperature is reduced to the fixed value or if the actual value inside the chamber is lower than the value fixed using UI, the Air heater module inside the chamber will be turned on, until the temperature is raised to the fixed value.
Air heater:- Nichrome wire heater (12V 250W)
Air cooler :- TEC1-12706 peltier module (12V 6A) with heatsink and fan.

2.4.2 Humidity Control

The humidity required inside the chamber, which will vary for different plants, can also be given using a slider widget in the UI of the planter box.Raspberry pi will be collecting the actual humidity inside the chamber using DHT22 sensor and will keep on comparing the actual value to that has been set using the UI . If the actual value inside the chamber is greater than the value fixed using UI, the Air flow module inside the chamber will be turned on, until the humidity is reduced to the fixed value or if the actual value inside the chamber is lower than the value fixed using UI, the humidifier module inside the chamber will be turned on, until the humidity is raised to the fixed value.

The Air flow in the chamber is controlled using two fans placed into two circular holes on opposite faces of the cuboidal chamber. One of the fans will be placed 10 cm lower from the top, this fan will act as an exhaust fan(directing air outwards) and the other will be 10cm higher from the bottom of the chamber, this fan will suck air into the chamber.

Humidifier module:- Portable Humidifier,25 x 25 x 216 mm ,230V

2.5 Hydroponic System

In this method plants are grown without soil, and nutrients required for plant growth are supplied through nutrient solution. Plant roots are supported by rock wool. There are different ways to grow plants using hydroponics [6 hydroponics]. This project will use a method called Deep Water Culture (DWC). The platform that holds the plants is made of Styrofoam and floats directly on the nutrient solution. An air pump supplies air to the airstone that bubbles the nutrient solution and supplies oxygen to the roots of the plants. In DWC the roots of the plants are constantly submerged in water. The nutrients that are required for a plant is divided into two categories, macronutrients and micronutrients. Macronutrients include nitrogen, phosphorus, potassium, carbon etc. Micronutrients include iron, zinc, copper, nickel etc. The nutrient solution used are LEAFY 200A (macro elements) and LEAFY 200B (micro elements). The suitable water and ambient temperature for growing lettuce is between 18-30°C. pH is a parameter that determines the acidity or alkalinity of a solution. pH value affects photosynthesis process in plants. pH range between 5.5 - 6.5 is suitable for lettuce. Electrical conductivity (EC) measures the concentration of nutrients in nutrient solution. It is measured in PPM (Parts per Million) or in milliSiemen (mS).The optimal EC range for lettuce is between 1.5 - 2.2

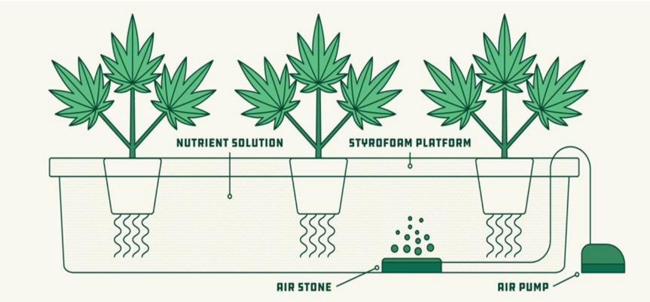

Fig -5: Hydroponics system

2.5.1 EC Control

The EC required for the reservoir can be adjusted using a slider widget in the UI of the planter box.Raspberry pi will be collecting the actual EC of the solution inside the reservoir, using EC sensor having EC range : 0-2000us/cm and resolution: ±5%(STP), and will keep on comparing the actual value to that has been set using the UI . If the actual EC of the solution is lower than the value fixed using UI, the nutrient solution will be pumped into the solution through a 12V DC Peristaltic Dosing Pump(5~40 ml/min), until the EC is raised to the fixed value.

2.5.2 pH Control

The pH required for the reservoir can also be adjusted using a slider widget in the UI of the planter box.Raspberry pi will be collecting the actual pH of the solution inside the reservoir, using pH sensor(9V RC-A-353 pH module) having measuring range:- 0-14 pH and accuracy :- 0.01 pH, and will keep on comparing the actual value to that has been set using the UI . If the actual pH of the solution is greater than the value fixed using UI, the pH down solution will be pumped into the solution through a 12V DC Peristaltic Dosing Pump(5~40 ml/min), until the pH is reduced to the fixed value or if the actual pH of the solution is lower than the value fixed using UI, the pH up solution will be pumped into the solution through a peristaltic pump, until the pH is raised to the fixed value.

3. CONCLUSIONS

In this paper, an integrated technical solution of the 'controlled-environment agriculture technology platform' was introduced.This system provides a platform to grow plants in their optimal climatic conditions. Any user logged in the adafruit io dashboard specified for the plant box can control the climatic conditions. This system can be used as a research platform and also as an educational tool.The open-source nature of the Plant Box improves the quality of the support for the end users by providing full access to knowledge at every level.This paper provides the main hardware, software and design components behind the Plant Box

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