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Moisture Control Using A Low-Cost Experimental Approach For A Vertical Agricultural Indoor Module

Control de humedad mediante un enfoque experimental de bajo costo para un módulo agrícola vertical de interior

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Resumen: Este artículo describe un enfoque de cultivo vertical de interior de bajo coste realizado bajo consideraciones de aprendizaje experimental. Se construyó una estructura de aproximadamente un metro de altura, 0,27 metros de anchura y 0,38 metros de profundidad para examinar el crecimiento de semillas de rúcula. La estructura de cultivo vertical fue equipada con emisores de luz artificial para facilitar la fotosíntesis de las plantas de rúcula que estaban plantadas en bandejas en un edificio sin suficiente luz natural. Además, se controló la humedad del suelo en las bandejas, de modo que se activaron bombas

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de agua electromecánicas cuando se detectó un alto nivel de sequedad en el suelo. Como unidad de control se utilizó un microcontroladorESP32 el cual se programó para leerlos sensores y aplicar las señales de control necesarias. Adicionalmente el ESP32 se configuró para enviar los datos de los sensores a una página web orientada al Internet de las Cosas (IoT), lo que permitió supervisar el sistema a distancia. BIPES (Block-based Integrated Platform for Embedded Systems) es una herramienta de programación intuitiva que está disponible para el público en general a través de Internet, que se utilizó para programar el ESP32. Como aspecto final, investigadores de la Universidad Distrital Francisco José de Caldas, la Corporación Universitaria Minuto de Dios, en Colombia, y la Universidad de Federal de Sao Carlos, en Brasil, se interesaron en la agricultura vertical como un tema en el que involucrarse, lo que llevó al desarrollo de un primer acercamiento que se presenta en este trabajo. Gracias a nuestra investigación, se demostró que los módulos de cultivo vertical de bajo coste con sistemas electrónicos integrados son viables, y que estos módulos pueden ofrecerse a los ciudadanos como método alternativo para producir comidas en casa.

Palabras clave: Agricultura vertical intramural, micropython, programación basada en bloques, ESP32, luz artificial.

Abstract: This paper describes an indoor vertical farming low-cost approach undertaken under experimental learning considerations. A structure measuring approximately one meter in height, 0.27 meters in width, and 0.38 meters in depth was constructed to examine the growth of arugula seeds. We equipped our vertical farming structure with emitters of artificial light in order to facilitate the photosynthesis of arugula plants that were planted in trays in a building without sufficient natural light. Further, soil moisture in the trays was monitored so that electromechanical water pumps were activated whenever a high level of soil dryness was detected. As a control unit, an ESP32 microcontroller was used. It was programmed to read sensors and to apply control signals as required. Additionally, ESP32 was configured to send data from sensors to an Internet of Things (IoT) web page, enabling us to monitor the system remotely. BIPES (Block-based Integrated Platform for Embedded Systems) is an intuitive programming tool that is available to the general public through the internet, which was used for programming the ESP32. As a final aspect, researchers at the Universidad Distrital Francisco José de Caldas, the Corporación Universitaria Minuto de Dios, in Colombia, and the Universidade Federal of Sao Carlos, in Brazil, became interested in vertical farming as a topic to be involved in, leading to the development of a first approach which is presented in this paper. Through our research, we have demonstrated that low-cost vertical farming modules with embedded electronic systems are feasible, and these modules may be offered to citizens as an alternative method of producing meals at home.

Keywords: Indoor verfical farming, micropython, block based programming, ESP32, artificial light

1. INTRODUCTION

Food production is increasingly addressing a variety of global challenges related to population growth, water scarcity, and food safety. In terms of sustainability, urban vertical farming has emerged as a viable alternative to traditional food production methods. According to [1] VF has been extensively researched over the last decade with promising results. At [1] vertical farming (VF) is defined as the practice of growing food indoors, in addition, a [2] it is argued that VF has become a viable agricultural practice as a result of advances in technology, energy-saving artificial light (LED), and automated controls. Because it eliminates soil, reduces space and energy, and increases crop yield, VF is a promising agricultural practice.

In terms of the reported contributions, the design ofa multi-layervertical farming rackthat can serve as a component of fully automated ginger cultivation is presented in [3]. The two rows of 19 meters will contain 96 plants of which 64 will be treated with LEDs, and the remaining 32 plants will be left untreated for experimental purposes. A sowing of fenugreek in pots and VF modules equipped with smart technology aiming the progress monitoring of the plants every 10 days is described in [4]. A study in which several artificial light sources, including daylight compact fluorescent lamps, blue and red LEDs with wavelengths of 475 and 650 nm, were assessed for their effects on the height, chlorophyll content, carbon dioxide release, and water content of leaves of Typhonium Flagelliforme plants [5].

In this paper, we describe an experimental interdisciplinary approach to indoor vertical farming that integrates computer programming, embedded electronic systems, and agricultural practices.

We describe the platform that we have configured in section I, while we describe the embedded system in section 2. Lastly, we discuss our results and share our conclusions, future works, acknowledgments, and references.

2. VERTICAL FARMING PLATFORM GENERAL DESCRIPTION

In this paper, we share information about the first phase of progress that was conducted in Bogota, Colombia. The reason we selected arugula is that it can be planted directly in suitable soil. In this way, we are able to germinate plants from the trays of the structure. The arugula plant belongs to the Brassicaceae family and is commonly called rucola (or garden rocket); it originated in the Mediterranean region and has been cultivated since the Roman and ancient Egyptian eras. In traditional medicine, arugula is used to treat digestive disorders and has a number of other medicinal indications as well as aphrodisiac properties [6].

In order to grow arugula plants, a structure was constructed using metallic materials in order to support two trays containing soil. It is 90 cm in height, 38.5 cm in depth, and 27.5 cm in width. Figure 1 illustrates the dimensions of the structure.

Figure 1. A view about VF structure its dimensions and elements

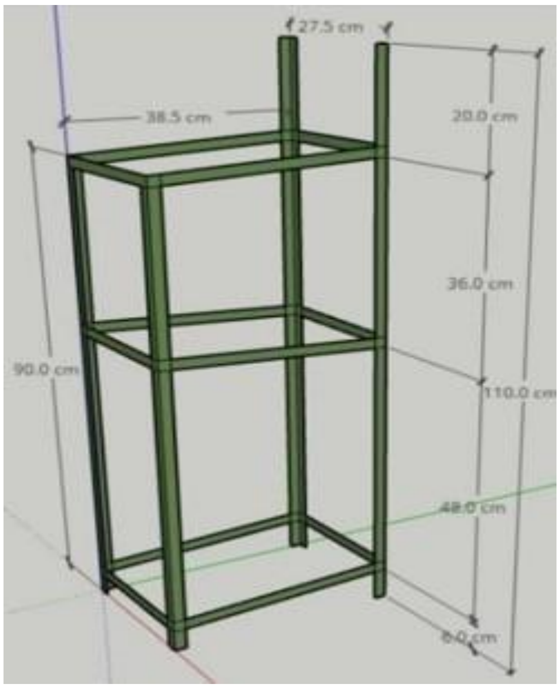
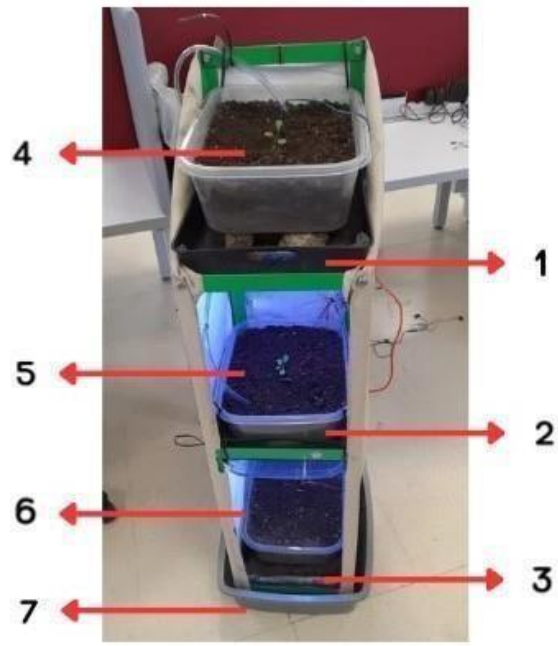


Figure 2 illustrates the installed soil trays on the structure in which the labels 1, 2, and 3 indicate trays, while 4, 5, and 6 indicate soil in each one. Correspondingly, water is contained in a button tray indicated by label 7.

Figure 2. VF structure



Labels 8 and 9 in Figure 3 indicate the position of the LED light emitters used to illuminate the arugula plants, accordingly LED light emitters were installed below the middle and upper trays. Labels 10, 11 and 12 refer to mini-boards that connect soil moisture sensors with an ESP32 microcontroller. In label 13, it is depicted a mainboard in which the ESP32 is located.

Figure 3. VF structure

The moisture sensors we use are described in [8]. Through the use of two conducting probes that measure the resistance between each probe, they can determine the moisture content of the soil as a function of changes in its moisture content. Therefore, each tray is equipped with a moisture sensor, whose analog output has been connected to the analog reader port of the ESP32, enabling monitoring of moisture sensor measurements.

Regarding the LED light emitters, we made two attempts, for the first we used a NeoPixel RBR LED Ring which is a small electronic component that consists of addressable RGB LEDs arranged in a closely spaced circle and each LED can be controlled by outputting a tuple of three 8 bit values ranging from 0 to 255 to control color and brightness. We used a Neopixel with 12 LEDs which is arranged in a ring containing 12 uniquely addressable LEDs. These LEDs are placed in a circular shape that can be programmed using a microcontroller. The used LED ring is shown in Figure 4.

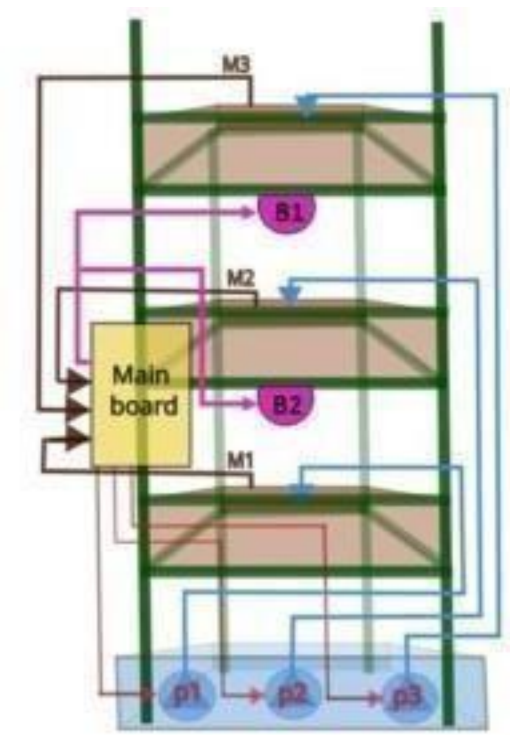
For a second attempt, another LED light emitter was used, in this case it corresponds to a bulb manufactured by Feit Electric company for which technical details can be verified datasheet which is downloadable in Feit (2023b). The used bulb is shown in Figure 5. Reasons leading to the use of this bulb are shared in the results and discussion section.

Figure 4. Neopixel LED Ring 12 bit, Adafruit (2023a)

Figure 5. Grow light bulb, Feit (2023b)

In regard to the electronic embedded system which is an important aspect in our approach, Figure 6 is intended to share an explanation of our approach, in accordance, the main board block represents by itself a board on which we have installed an ESP32 microcontroller and suitable power stages to drive water pumps (p1, p2, and p3) as well LED light emitters B1 and B1. From ESP32 on the main board control signals are applied to power stages whereas M1 and M2, labels correspond to signals that are read from soil moisture sensors.

Figure 6. Rear view vertical farming approach



BIPES is open-source software and a service that is freely available through the website http://www.bipes.net.br. It was conceived after several years of experience developing embedded systems and Internet of Things (IoT) applications. Anyone can use this tool to quickly and reliably design, program, build, deploy, and monitor embedded systems, IoT devices, and applications using blocks or Python-based programming. Since it is fully based on a web environment, no software installation is required on the client developer's computer. Thus, a tablet, a netbook, a Chromebook, or any other device can be used to program and test various types of devices. In general, it utilizes MicroPython or CircuitPython, WebREPL, WebSockets, Web Serial API, HTML, JavaScript, and Google Blockly to translate no-code programming (blocks) into Python code for deployment. Additionally, it does not require server-side processing, so it can be deployed as a Progressive Web Application (PWA), making it possible to use it even when the computer is offline. With only a web browser, it is compatible with a variety of low-cost boards such as mBed, BBC micro:bit, ESP8266, ESP32, and Raspberry Pi [7].

Regarding embedded programming, we selected the BIPES (Block-based Integrated Platform for Embedded Systems) tool because the described approach was developed collaboratively by undergraduate students and professors who are committed to contributing to the achievement of learning outcomes in programming-related subjects. Therefore, we determined that BIPES is by itself an excellent tool for introducing embedded systems in a friendly manner, which facilitates establishing a starting point and provides a means for reviewing progress in micropython learning through the examination of the code generated by BIPES.

Figure 7 depicts all programmed BIPES code. Taking into account that it is difficult to distinguish at all, regarding following figures will include just sections of code. For a while let's share key details about BIPES code: A while loop nests a try-except block, after the try-except block it is a delay block for 1 second. Nested in the try-except block we have code which we will describe following.

In order to detail the information flow corresponding to code represented in Figure 7, it was sectioned from Figure 8 until Figure 12 aiming a detailed description about its working. In accordance, all code nested in a while loop which nests a try-except block which in turn nests a sort of code. Correspondingly, Figure 8 shows the first section of code nested in the try except-block, which includes a block for connecting our ESP32 to a Wi-Fi network and consequently to the internet. Once the internet connection has been established, the next step is to initiate a communication session using the MQTT protocol [9]. Next, we introduced a block to get the current date and time according to the time zone for Bogotá, in Colombia, then we introduced a while loop in which we used blocks to set a list to get from the current time the hour and the minute.

Figure 8 is followed by the code section in figure 9 in which, using the established MQTT session, an MQTT publisher block for which it is defined a topic as "1" such that the published value for topic 1, corresponds to the analog reading of a moisture sensor connected to the pin D35 at our ESP32. According to the show another MQTT publisher block is used which is defined as a topic as "2" such that the published value for topic 2, corresponds to the analog reading of another moisture sensor in this case connected to the pin D34 at our ESP32. Next Figures will continue describing the code.

Figure 7. While loop and Try-except block hosting all code

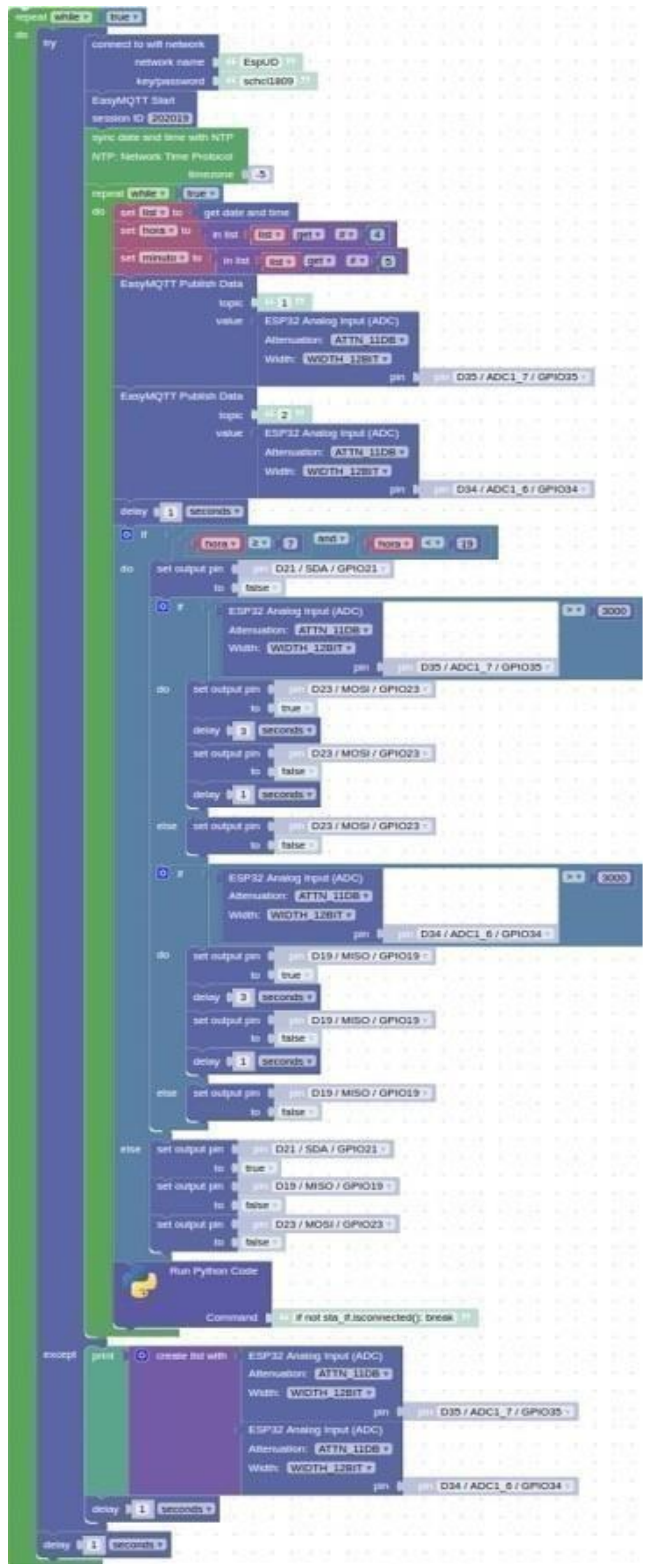


Figure 8. First section of code in Figure 7.

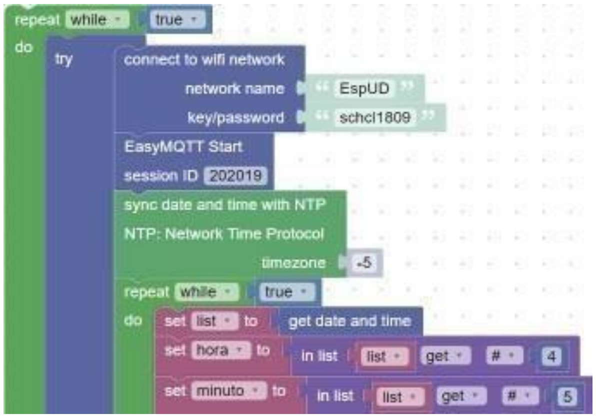
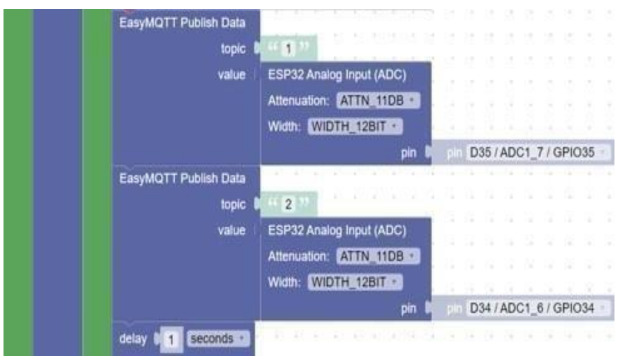


Figure 9. Second section of code in Figure 7 and following section in Figure 8



The previous code section finished with the publication of topics. Following we have the code section in Figure 10 in which a 1-second delay was introduced, after that, we verify the current time such that if it is between 7 and 19 hours, then we set the D21 ESP32 pin in order to activate the led light emitters. Following we nested a conditional block to verify if soil moisture connected to the D35 ESP32 port is over an experimentally determined value so that if true, we set the D23 ESP32 port which in turn is suitably wired to activate a water pump. D23 is just set for 3 seconds and after that, a 1-second delay is used.

The code following is shown in Figure 11 in which a conditional block is used to verify if soil moisture connected to the D34 ESP32 port is over an experimentally determined value so that, if true, we set the D19 ESP32 port which in turn is suitably wired to activate another water pump. D19 is just set for 3 seconds and after that, a 1-second delay is used. Depicted conditional blocks in this paragraph turn off corresponding ESP32 ports if the conditional block condition is condition false. The following code section will be explained next.

Figure 10. Third code section of code in Figure 7 and following section in Figure 9

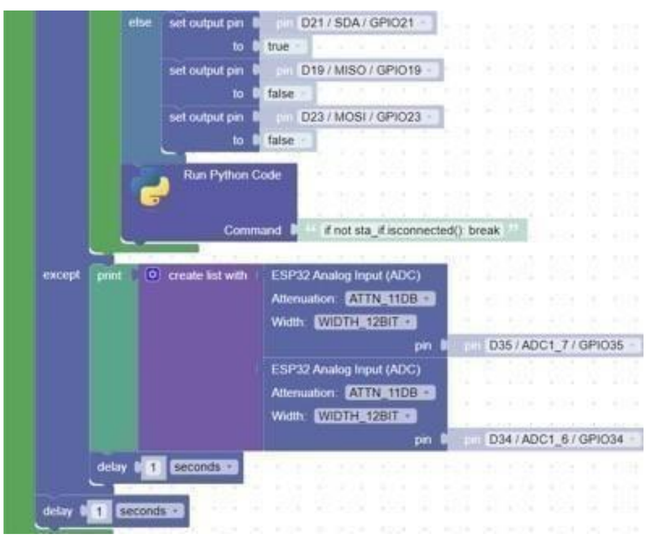
Figure 11. Fourth code section of code in Figure 7 and following section in Figure 10

Following the previous section of code we have Figure 12 showing the code section in which if conditional starting in Figure 10) is false, we set true ESP32 D21 pin, whereas D19 and D23 pins are set to false. Note that the internal while loop keeps working. According to the try-except block moisture sensors readings are printed on the shell, delaying 1 second. Following the try-except block we include a 1-second delay in order to try again.

3. RESULTS AND DISCUSSION

At the first attempt we used LED rings as light emitters [10]. We planted each tray an arugula seed on 12th July 2023 observing both seeds germinated and a so low-growing was reached, deciding to measure the plant's highness on 12th September 2023 noting that from the bottom of trays the arugula plants reached 13.5cm. The state of plants on 12th September 2023 is shown in Figure 13.

Figure 12. Fifth code section of code in Figure 7 and following section in Figure 11

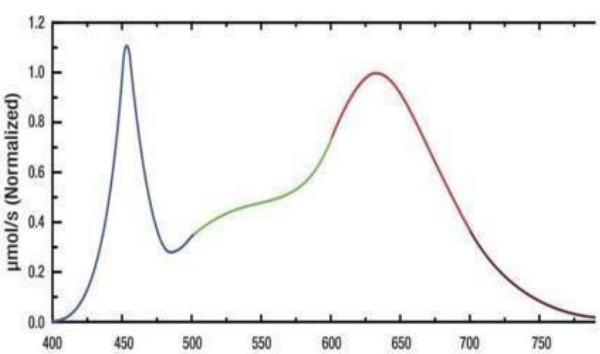


After two months of insufficient growth, we examined possible causes, followed by reviewing technical information about the LED diode used in Neopixel LED rings [11], realizing that this artificial light source emits red, green, and blue light in a wavelength spectrum of 620nm-630nm for red, 515nm-530nm for green and 465nm-475nm for blue, and according to literature review about light requirements for plant growing led to evidence that Neopixel LED rings did not offer the required wavelength spectrum.

Figure 13. State of plants after two months from planting using Neopixel Led Rings

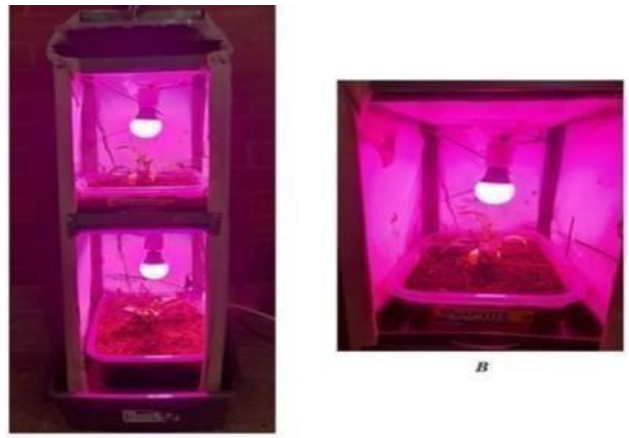
Our review about technical specifications revealed that a bulb may likely Works, in this case we selected the bulb described in [12, 13]. That LED light bulb emits precisely the wavelengths and colors that are necessary for a photosynthetic reaction, as well as experimenting with a low heat emission that prevents leaf burn and crop damage, and a low energy consumption since it uses only 9 watts. Looking for details about the offered spectrum of the light bulb, we discovered that the manufacturer company shares information about where to buy [12]. This led us to review information shared by the seller, which states that this bulb has been rated for high humidity use, emitting light in the 448nm blue spectrum and 630nm red spectrum, which accelerates all phases of indoor plant growth. Figure 14 provides graphical information about the spectrum offered by the seller, noting that this spectrum offers the light that plants require to grow.

Figure 14. Normalized photon flux of LED light bulb



The LED bulbs were installed in the early hours of 12 September 2023. Figure /ref [Fig: 15 A] illustrates our entire VF module, whereas Figure 15 B illustrates a close view of a tray. Both pictures were taken on 22 October 2023.

Figure 15. VF module at work



A *B*

Initially, we observed that plants grew notoriously after Neopixel LED rings were replaced with LED bulbs, but after 40 days (October 22, 2023), some measurements were taken. In accordance with Figure 16A, our plants are approximately 13.5 cm to approximately 20 cm high, measured from the bottom of the tray. Further, we observed that the lateral measurements were approximately 14 cm and 18.5 cm, as shown in Figures 16B and 16C. Thus, the plant's growth was slow when the Neopixels LED rings were used, whereas it grew quickly when the LED bulbs were used.

Figure 16. State of plants after 40 days using grown light bulbs

A *B* *C*

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For soil moisture, it is precedent to point out that we used the experience of agronomists in this project to determine the suitable soil moisture using the feeling by hand method Keese (1969). As a result, we compared soil moisture by hand feeling with readings from moisture sensors and set a threshold of 3000 for the ESP32 to interpret as a high level of dryness. According to the embedded program, the water pump must be activated when moisture readings reach 3000.

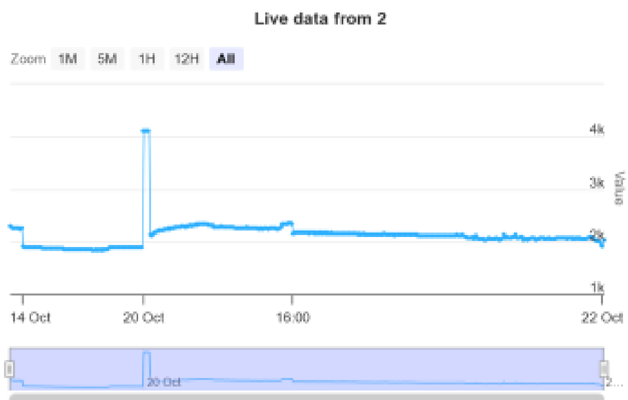
The moisture data for the two trays are shown in Figure 17 and Figure 18. The plots were taken directly and remotely via the internet from the BIPES tool, and they illustrate how soil moisture changes over time.

Figure 17. Plot of a moisture sensor readigs

Moisture sensors indicate a value of 4096 in conditions of maximal dryness. In Figure 17 we present the results of a trial conducted from October 13, 2023, until October 22, 2023. According to the data shown, the corresponding sensor was under acceptable moisture conditions during this period. A few days prior to this experiment, we applied water to the corresponding tray.

As shown in Figure 18, another soil tray exhibited moisture behavior over the same period of time. Nevertheless, on October 20, the sensor was removed for a short period of time, observing that the moisture value increased to 4096 over the period of time. However, once it was placed back in the soil, its lectures returned within our threshold (3000).

Figure 18. Plot of a moisture sensor readings



4. CONCLUSIONS AND FUTURE WORKS

As soon as moisture levels are detected below a predetermined level, water is supplied to each soil tray. As water is applied to each tray, it drains through the soil as it falls over the lowest level of that tray. Due to this, drained water from the upper tray falls over the lower tray. It would be preferable to change it, directing all drained water directly to the bottom deposit by modifying the structure.

In the future, we plan to install a pH-sensor in the bottom water tank in order to monitor the pH of the water and determine when it should be changed.

Our research team's agronomists believe that the yellow leaves visible in Figure 16 are the result of an excessive amount of water in the soil. Considering this, we plan to use sensors to measure the quantity of water applied in the future, since we are just using time to supply it at the moment.

By providing a friendly interface for programming embedded systems, BIPES facilitates the teaching of embedded systems programming through the coupling between blocks and their corresponding code in micropython, contributing to the reinforcement of programming skills on the part of students and even professors.

In this first approach, we observed that the arugula plants germinated and grew. Moving on to future stages, we intend to conduct experiments to evaluate the performance of the plants in our module in comparison with conventional gardening.

During this first approach, we became aware of the importance of knowledge of photonics in order to address indoor vertical farming in a methodologically appropriate manner. Towards the next stage of our research in this field, we plan to develop experiments to identify the spectrum offered by potential light sources.

This approach is characterized by the decision to take on the project from a learning-by-doing perspective, which resulted in a very interesting dynamic that attracted the attention of highly valuable individuals who worked as a team towards achieving the project's goals. While implementing the project, we experienced happiness as a result of the expectations generated over the use of computers and electronics in agriculture even in urban settings.

In our opinion, vertical farming indoors represents an opportunity for society to produce food in urban areas and even within the home.

5. ACKNOWLEDGMENTS

In recognition of Prof. Gerardo Muñoz generosity in offering us a space to host our experimental modules, his helpful advice on embedded systems, and his continued interest in our project, we would like to express our sincere gratitude. We would also like to thank the professors of the LASER research group of Universidad Distrital for allowing us to use the LASER lab when necessary.

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