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Proposal for an automated greenhouse to optimize the growth of hydroponic vegetables with high nutritional content in the context of smart cities.

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Abstract. Hydroponics is a cultivation method that has been gaining ground for a long time worldwide, due to its high nutritional content, low water consumption, scalability and zero use of pesticides, in addition to the versatility that this technique has to be implemented in almost any space. This is why the Antonio José de Sucre University Corporation, taking advantage of the characteristics of this cultivation technique, proposed the construction of an automated hydroponic greenhouse that serves as a model in the sustainable generation of food from the cities, following the example of smart cities ; Within the construction of this proposal, it was necessary to study the requirements for planting the vegetables under hydroponic conditions in order to establish the technology that should have been used in their automation, for which the basic chemical and climatological needs in production were identified. of plant organisms, selecting those critical factors that intervene in productivity, in order to establish the appropriate types of sensors and an action protocol that maintain the values of these variables in optimum, tending to obtain healthy fruits and vegetables and superior in taste and nutrition. As a result, the design of a metallic hydroponic farm was obtained, for the location of the vegetables, recyclable materials such as PVC pipes were used and for the automation of the farm a raspberry pi electronic card was used complemented with PH, conductivity, temperature and humidity sensors. and lighting with the aim of obtaining quality products.

1. Introduction

Globally, there is widespread concern about a future food and water crisis due to the demographic explosion that is taking place in urban areas, and the effects of climate change; Thus, the cities of tomorrow will be increasingly populated and will require a greater quantity of food and efficient water management [1]. That is why it has been innovating in the improvement of crops, towards more productive ones and less prone to climatic and terrain variables, leading to the emergence of the hydroponic cultivation method, since the traditional planting presents various limitations such as the availability of fertile land and the use of water; limiting factors present in many nations when trying to ensure the food basket, so you have defined strategies for agricultural strengthening based on modernization and technological innovation, leading to food production through various techniques and methodologies, proving to be one of the hydroponic sowing is more effective, since from this a higher yield of crops is obtained, increasing their productivity above the traditional



ones, since the availability of water, nutrients, radiation levels, environmental temperature, and the density of sowing or disposition of plants are not limiting, so they can be easily controlled. In addition, that the action of pathogens or pests is easily reduced, thanks to the control of the development conditions of the crop, allowing to optimize the crop performance, and achieve a clean and organic production [2].

Greenhouses and hydroponics are not a novelty in the agricultural technological environment, but they pose great opportunities to improve its advancement, an example of this are the plant factories, a method used in the industrial production of food of plant origin in greenhouses hydroponics; This production method was invented in the 80's, and it has been evolving in conjunction with the development of electronics and computing, so that today this industry has more efficient processes thanks to the automation and control of production parameters [3].

Thus, in order to avoid the nutritional vulnerability to which people with limited economic resources of the municipality of Sincelejo are exposed, it is necessary to explore alternatives that contribute in a sustainable way to the increase of the food stock of the region in the production of balanced sources of food so that the economy of the most vulnerable actors is not harmed.

All of the above is described within public policy at the international, national, regional and local levels, from the United Nations Sustainable Development Goals (SDG), which in turn is immersed in the new science, technology and innovation guidelines. for sustainable development set out in the Green Book 2030 and presented by the national government, in the guidelines for Responsible Production and Consumption, Zero Hunger, Well-being and Health, and Sustainable Cities and Communities, given the continuous expansion of the urban environment and with This increases the resources for the support of the population; likewise, the government of Sucre, who prioritizes food and nutritional security in the region, through the sustainable development of agricultural production, guaranteeing the consumption and sustainable production of the resources that the population requires, such as food; The Mayor of Sincelejo also assumes its commitment to these specific sustainable development objectives through some of the subprograms of its Comprehensive Health for All program [4][5]. Thus, ensuring a rich and balanced nutrition for the well-being and health of the communities, framed in a sustainable production scheme, is a priority for both the national and local government.

1.1 General aspects of hydroponics

The term hydroponics is based on the Greek hydro (water) and pónos (labor), and refers to the cultivation of plants in aqueous solutions or in a support medium, which can be gravel, sand, coco peat, pellets of expanded clay, a mixture of these elements, among others; It is for this reason that this method of agriculture is also known as “soilless agriculture”, since plants do not require this medium for their development [6].

The development of this production method did not occur by chance, since it is due to the evolution and experimentation of agricultural practices due to the serious problems that it presents with the use of soil and water by some countries, such as they are the loss of fertility, the availability of water resources, extreme climatic conditions, in addition to the problems associated with soil diseases and pests that end up affecting crop yield. Sowing in hydroponics allows cultivating without the problems associated with land production, but despite the benefits that this technology has in productivity, pathogen control and resource management, it presents challenges, such as the initial cost of these projects, which is high. , greater care of the plants to avoid infections caused by the recirculation of water, and the need for higher standards in the handling and management of these, but despite all this, the instrumentation in this production technique has contributed to reducing the effect of these limiting factors, thus achieving excellent results compared to other sowing methods;

It is so much so that in the nations of northwestern Europe in recent decades the application of hydroponics has been increasing as a result of unfavorable soil conditions and monoculture in fertile areas, in addition to the legislation in countries such as the Netherlands and Germany it prohibited greenhouse production by direct administration of soil substrate due to the risk of groundwater contamination, being hydroponic sowing or sowing without soil the most viable option in the development of agricultural activity in greenhouse [7].

Thanks to the different technological advances, ways have been developed that facilitate the use of this cultivation method, among which the optimization of the same through automation is presented, as is the case of Fernandez, Costa, and Lemos [8], who built a small prototype of a transparent hydroponic greenhouse, where the internal environmental conditions of temperature, nutrients, and luminosity were monitored, controlling the first two in order to achieve optimal plant growth; The device also carried out the monitoring of plant growth through a camera and image processing software, which not only showed the progress of plant growth, but also the environmental conditions under which it was developed, it also allows the user can access information and images in real time of what happens in the greenhouse from anywhere on the internet of things, which facilitates the care of the conditions in the prototype and therefore of the crop.

Thus, from the boom that this technique has had together with the advances made in it, that today there are industrial facilities known as green factories, where in highly controlled environments due to the set of sensors and actuators arranged in variable such as lighting, temperature, nutrients, water quality and CO₂ levels, such as those available in green factories located in Tokyo Bay in Japan, which produces up to 1,000 heads of lettuce organized per day, but all this does not possible without the heating, ventilation and air conditioning ducts and fans that keep the room in optimal climatic conditions and a concentration of 1,000 ppb (parts per million) of carbon dioxide, along with LED tubes that go on from 16 to 17 hours a day, and constant measurements of the quality of the water circulating through the greenhouse [9].

It should be noted that due to the versatility that this cultivation method has been implemented in areas with extreme climatic conditions that range from quasi-desert areas to very low temperatures; It is noteworthy that the international space station has its own hydroponic module in the development of experiments on the effect of zero gravity on the development of plants.

1.2 Requirements and care of plants in hydroponics

Production in a hydroponic medium is not exempt from the effect of variables that limit the growth and development of plants, and when it refers to variables, reference is not only made to the chemical part of the process, since the state of the plant both in the medium Hydroponic as in land is linked to the conditions of the environment to which the plant is exposed, that is why it is in this method where extra precautions must be taken so that the productivity of the crop is not affected; therefore it is necessary to talk about what these variables are and what precautions should be taken with them.

1.2.1 Support medium. The medium in which the plant is to be cultivated in the hydroponic state directly intervenes in the periodicity with which they must be irrigated, since the porosity and permeability of these media is directly linked to the transport and water retention capacity, and with it to the passage of oxygen and essential minerals to the roots. The water retention capacity of the medium is a factor that influences the type of crop that can be planted in it, since some plants have roots that are susceptible to high levels of humidity; In conclusion, when selecting the sowing medium, it is good to keep in mind the type of culture with which to work, water retention, oxygenation, structural integrity and sterility.

The last two conditions are related to the fact that the medium is maintained despite the growth of the plant and to avoid the incidence of pests and diseases in the roots as a result of a poorly sterile medium.

1.2.2 Water. Water is one of the essential factors in agriculture, since it is the source of all life and this does not exclude plants, which are composed of between 80% - 95% of this liquid and the rest of dry material. It is important to understand the importance of water when talking about photosynthesis, a process in which the energy from sunlight, nutrients and carbon dioxide from the air are transformed into oxygen and a building block for the plant in the form of sugars; In this, the water is responsible for transporting the nutrients from the soil to the root, and from the root into and out of each of the cells of the plant, to end its cycle in the evapotranspiration process, where through transpiration of water the vegetable cools. It should be noted that, the greater the perspiration, the greater the amount of water that the plant will need to adsorb from its roots in order not to lose its rigidity or turgor, otherwise when the body does not have enough water, it must slow down the transpiration process by closing their stomata in order to avoid the loss of water, which leads to its loss of turgor and begins to wilt, while essential minerals are lost. This type of stress causes growth to slow down and crop yields are reduced, because the stomata are responsible for capturing carbon dioxide (CO₂), so if they are not completely open, photosynthetic activity is reduced. and it can even be stopped [7].

1.2.3 Illumination. Light is one of the requirements of photosynthetic activity in plants, but not all light is involved in it, since chlorophyll only uses the visible light spectrum in metabolic activity. It is known that chlorophyll is what gives the green color to plants and that in these there are organelles called chloroplasts, which contain chlorophyll-a, chlorophyll-b and carotenoids. Plants have evolved millions of years to better convert the energy in sunlight into carbohydrates and sugars, so they mainly absorb energy from the violet-blue and red light band of the visible spectrum, since these wavelengths coincide. With the range that goes from 400nm to 700nm, where photosynthesis is stimulated, in addition to this factor it is necessary that the quality and light intensity received are optimal, see figure 1.

The effective wavelengths in photosynthesis are within the range described above, since they are responsible for stimulating the metabolic processes of the plant, such as phototropic activity, stem and leaf growth, flowering, fruit production. , the generation of antioxidants, the formation of chlorophyll, and the photosynthetic activity; These processes are characteristic of specific wavelengths, Ultraviolet light (10nm-400nm) that at wavelengths of 350nm promotes the accumulation of phenolic compounds, improves the antioxidant activity of plant extracts, but has no significant effect on the increase; Blue light (430nm-450nm) is responsible for promoting vegetative growth, essential for the germination of seedlings and young plants during the vegetative stage of growth, limits the growth of mature plants, stimulates the production of secondary pigments that improve colors and encourages the production of aromatic compounds; Red light (640nm-680nm) has a very strong reaction to the photosynthetic action, which stimulates the generation of carbohydrates and sugars in the crop, allowing them to have a better flavor and a greater amount of nutrients within their composition and fruits, it also has a strong impact on the germination and flowering processes [8].

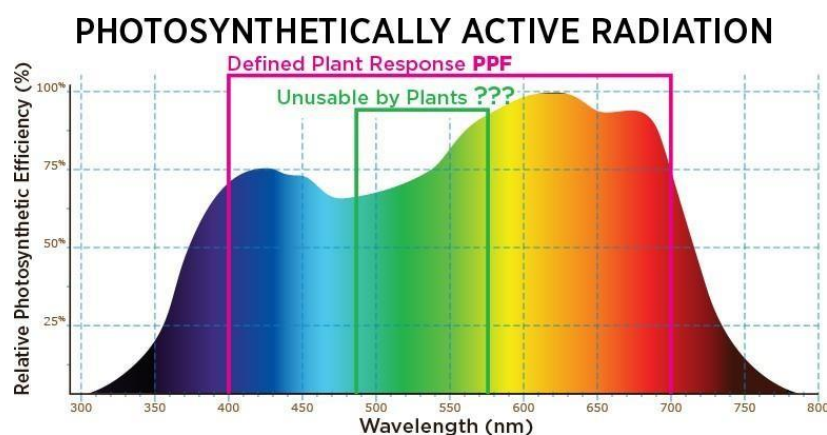


Figure 1. Active photosynthetic range (Source: Light spectrum and plant growth, p.2).

In addition to the wavelengths perceived by the leaves, another important factor with regard to lighting is the light intensity to which the crop is exposed, which is represented as the amount of energy the plant receives per day, and is given By the time the plant is exposed to the active photosynthetic range, figure 2 shows the effective saturation range for most plants, since those that are from very cold climates or from very hot climates are located on the outside of the same, since they are used to a lesser or greater solar irradiation. In conclusion, the effect of lighting is directly linked to photosynthetic activity, which is intrinsically related to plant growth, nutritional content, flowering and production cycles.

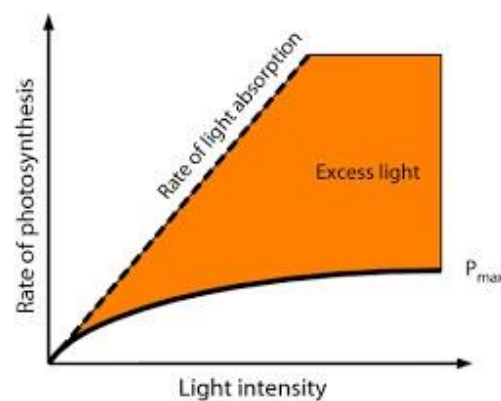


Figure 2. Photosynthetic activity vs light energy (intensity). (Source: Hydroponics for the home grower, p. 26).

Temperature and relative humidity of the air. The relationship between plant organisms and temperature is given based on their transpiration, since the higher the temperature, the greater the amount of water they will need to evaporate to keep their leaves fresh, however, as in other living beings if the relative humidity of the air is high, this interferes with the perspiration cycle reducing the cooling effect and therefore this slows or completely stops photosynthesis as seen in figure 3. It should be added that at high radiation loads UV plant leaves tend to burn, so in greenhouses UV filter coatings are used in order to remedy the consequence of this rays.

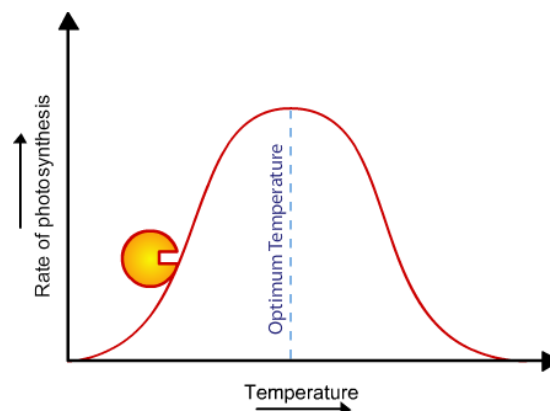


Figure 3. Effect of temperature on photosynthesis. (Source: Hydroponics for the home grower, p. 27).

Carbon dioxide (CO₂) levels. Gaseous CO₂ is the main source of carbon used by plants in the process of generating carbohydrates and sugars, essential blocks in obtaining energy for their growth and development, as can be seen in figure 4; That is why when growing in the greenhouse, the concentration of this gas within it must be known, since the environmental levels (400ppm) of the same are not sufficient to reach the optimal concentration (800ppm - 1200ppm), the which is 2- 3 times higher than the environmental one, as shown in figure 5 [9].

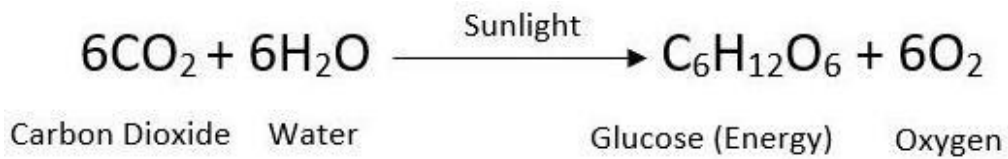


Figure 4. Photosynthesis equation. (Own source)

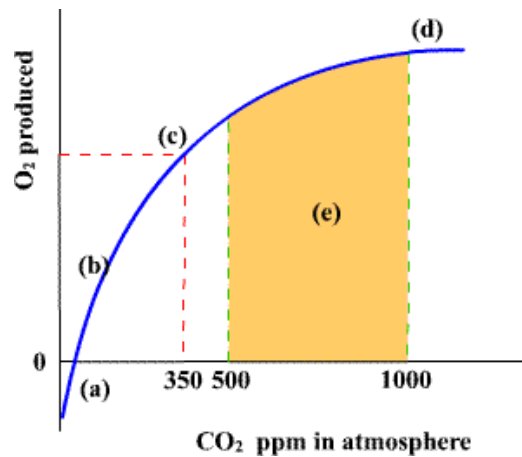


Figure 5. Photosynthetic activity vs carbon dioxide concentration. (Source: Hydroponics for the home grower, p. 28)

1.2.4 Oxygen concentration in the roots. The oxygen in the roots of the plants is a critical factor in the active transport of the nutrients dissolved in the water towards the plant.

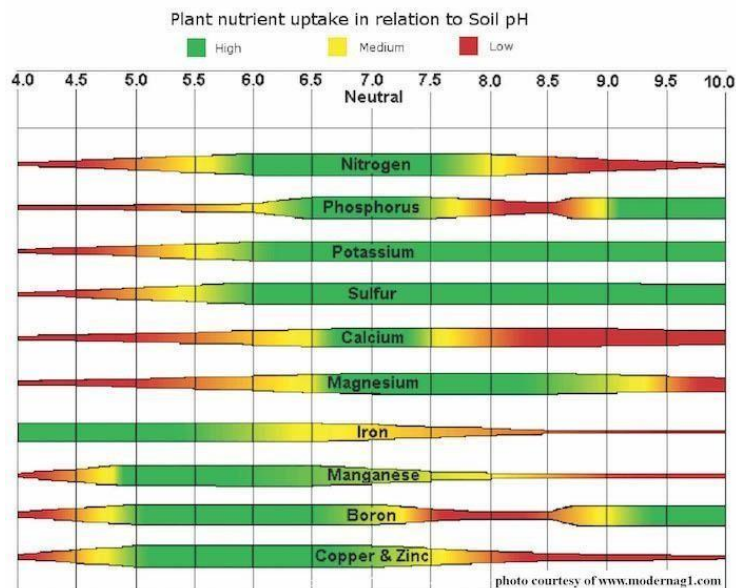


Figure 6. Effect of pH on the availability of nutrients for the plant. (Source: Hydroponics for the home grower, p. 36).

1.2.5 Essential nutrients. The minerals necessary for plants to grow and develop are known as essential, some of these are obtained through water and air, such as carbon (C), hydrogen (H) and oxygen (O), while others They are present in the soil and are transported to the organism by the water that the roots capture; These essential nutrients taken from the soil are divided into two categories, those that are required in a higher proportion and others in a smaller or much smaller proportion. Macronutrients include Nitrogen (N), Phosphorus (P), Potassium (K), Sulfur (S), Calcium (Ca) and Magnesium (Mg); and 8 micronutrients, Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Boron (B), Molybdenum (Mo), Chlorine (Cl) and Nickel (Ni). The deficiency or excess of these minerals can be seen directly in the disorders of the color and shape of the plant and others not so visible in the taste and nutritional content of the same.

1.2.6 pH. In nature, minerals are found in an insoluble and soluble form, those corresponding to the macronutrients and micronutrients necessary for plants are soluble and available; However, if the medium has a very acidic or basic pH, this will affect the solubility of the minerals and with it their availability, generating a deficit in the plant, said behavior is presented in Figure 6 [10].

2. Methodology

This document corresponds to a proposal developed in order to identify the requirements and instruments necessary in the automation process for a hydroponic greenhouse that was built at the Antonio José de Sucre University Corporation. In the process of identifying these requirements, a study was carried out of the factors that intervene in the growth and development of plants in the aforementioned environment, to later identify in which of these variables measurement and control action could be carried out, establishing the itself the type of possible sensors to use according to the weather conditions of the area where the project was developed, this being the city of Sincelejo, and the control actions to be developed in the management of said factors. The following research was developed in 3 stages, as evidenced below:

2.1 Stage 1: Research development.

In this first stage of the project, a study of an investigative nature was carried out with the purpose of stipulating the physical-chemical requirements that plants require in a hydroponic production method in order to guarantee their efficient production. Where the following activities were carried out.

- Bibliographic review of the methodologies and technologies applied in hydroponic planting in order to determine their advantages and disadvantages based on the criteria of production, space and necessary resources.
- Selection of the ideal hydroponic seeding technique for its application in the urban environment of the city of Sincelejo based on the spatial and climatological conditions of the area.
- Analysis of the electronic components for measurement and control of physicochemical variables that the hydroponic greenhouse requires for its automation.
- Inquiry about the types of plants to be used in hydroponic production for their selection according to their growth characteristics and nutritional contribution.
- Study of the effect of physical and chemical variables on the development and production of the selected plants.
- Establishment of the existing relationships between the physical-chemical parameters studied with the level of growth, production and food quality of the study plants in hydroponics.

2.2 Stage 2: Technological development.

This stage corresponds to the construction of the hydroponic greenhouse prototype for the Antonio José de Sucre University Corporation based on the automation operational criteria stipulated in the previous stage. Where the following activities were carried out.

- Design of the schematic circuit of the automated hydroponic greenhouse based on the measurement sensors and controllers defined in the previous stage.
- Coding of the hydroponic greenhouse monitoring and control system based on the correlational factors determined in the previous stage.
- Construction of the automated hydroponic greenhouse based on the technological and spatial criteria analyzed in its development.
- Analysis of the technical functionality of the prototype based on the testing of the monitoring and control systems of its physical-chemical variables.
- Evaluation of the productive capacity of the prototype.

2.3 Stage 3: Implementation of the system.

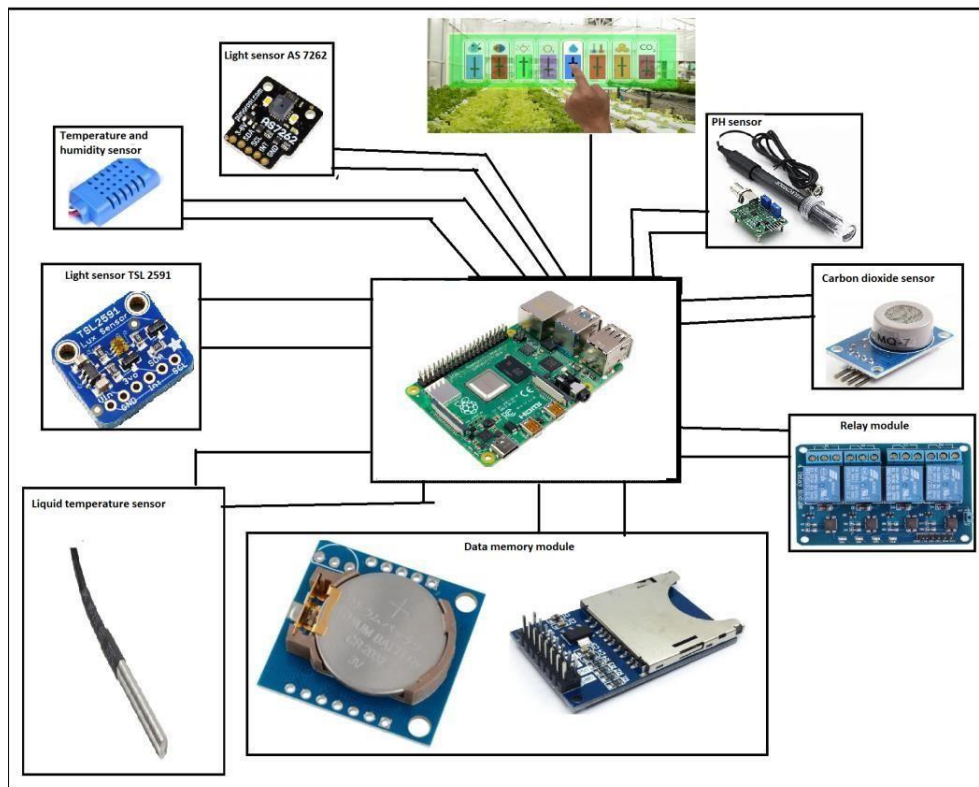


Figure 7. Block diagram of the proposed system.

3. Results

In the results phase, the main factors studied in the automation process in hydroponics were initially analyzed, which corresponds to the optimization of the cultivation space, the control of nutrients with precision, the elimination of pests and diseases transmitted by the soil, the quality of the light to which the plants should be exposed, since this factor has a direct inference with the development of the vegetables, mainly influencing the profitability of the crops, their nutrient content and flavor profile. Other factors that were taken into account were the pH of the irrigation water, a variable that can only be adjusted by adding acidic or alkaline substances as the case may be, the oxygenation of the water, the level of carbon dioxide, the conductivity of the water and the time of the macronutrients and micronutrients in the system.

To measure the level of carbon dioxide inside the greenhouse, a CO₂ monitor was used in order to know its concentrations and, if necessary, look for auxiliary methods that help to increase the concentration of the gas inside the greenhouse, for this reason, a CO₂ sensor MG811 was used to control this variable within the greenhouse.

In the proposed greenhouse, a light intensity sensor and a visible light sensor were used to calculate the lighting, the ones chosen being the TSL2591 and the AS7262 respectively, since both devices have good sensitivity to the physical variables detected and operate within the temperature range of the system.

The temperature and relative humidity of the air are factors involved in the transpiration process of the plant, directly intervening in photosynthesis, which is why a sensor is required that has the ability to measure these two variables, and more so in weather conditions from the city of Sincelejo, whose temperatures range between 20 °C and 36 °C, these being the most extreme conditions. The sensor chosen for this task was the AMT1001 Humidity and Temperature Sensor, which presents a very accurate reading of these environmental variables.

The conductivity in the aqueous solution that contains the nutritional substrate and is linked to the level of mineral salts present in it, this indicator does not allow to individually detect the levels of each of the mineral compounds dissolved in the storage tank, however, gives an idea of when the levels of these are decreasing, serving as an indicator of when substrate must be supplied to the system again. As a monitoring device for this variable, an analog electrical conductivity sensor compatible with the Raspberry pi platform is used, used to measure the levels of electrolytes in water, and mainly applied in agriculture in order to establish the levels of fertilizers within of the aqueous solutions that are supplied to the greenhouse.

The pH of the aqueous solution is a factor that can limit the assimilation capacity of mineral salts by the plant, so this variable must be known at all times in order to avoid a deficiency of nutrients in it. The sensor used for this task is an analog pH sensor, whose temperature specifications and measurement precision determine the state of the water quality at all times.

During the transpiration process of the plants, fluid will be lost by evaporation, so in order to maintain operational water levels, a water level sensor in the tank will be added to the system, since the lack of said liquid can affect drastically the development of these.

The use of photovoltaic solar energy to power these systems is advisable, since it helps to reduce the energy resources used, relying on the free energy that the sun presents and even more so in the Colombian Caribbean, where it has a great photovoltaic potential.

Finally, in figure 8, the final design of the hydroponic greenhouse prototype is evidenced, conformed with dimensions of 4 meters wide by 7 meters long with a height of 2.6 meters high, fully metallic, lined with transparent paper caliber number 3, with 6 tubes of 4 inches, which contain 50 holes each, with their respective baskets where the seeds will be deposited for the growth of vegetables, on the other hand, the greenhouse has a 250-liter tank, which houses a PH, conductivity and water level sensor, a 10 W aeration pump, a 15w ejection pump and a 1 HP electric pump. As can be detailed in figure 8 and 9.



Figure 8. Final external structure of the hydroponic greenhouse prototype.



Figure 9. Final internal structure of the hydroponic greenhouse prototype.

In figure 10, we can see the distribution of the sensors.



Figure 10. Organization and location of the hydroponic farm sensors.

4. Conclusions

The automation in the production of hydroponic crops entails multiple benefits in the generation of healthy organic food, rich in nutritional content and with a high yield, the initial investment in these processes may be expensive, but it is rewarded in a higher productive capacity Since you are working all year round and without the restrictions imposed by the weather. These climatic restrictions are overcome thanks to the set of control measures, which are more efficient by having a set of sensors and actuators that automatically contribute to keeping production in optimal conditions and at the same time keeping the farmer informed, supporting the taking of decisions of the same.

By automating this process, it also optimizes the use of resources and energy, since it helps to reduce the man-hours invested in the care of the plants, only the necessary amount of inputs that the system requires would be used, the total energy used in the development of agricultural activity is reduced thanks to the use of a less amount of fossil fuels and there would be a greater homogeneity in production by having the whole system under the same conditions.

5. References

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