Automated aeroponics vegetable growing system. Case study Lettuce

Lenyn Lucero
Facultad de Ingeneniería en Ciencias Aplicadas. Universidad Técnica del Norte.
Ibarra, Ecuador
ltluceroa@utn.edu.ec

Dora Lucero
Facultad de Ciencias Agropecuarias. Universidad Técnica de Ambato.
Ambato, Ecuador
deluceroa@utn.edu.ec

Eliana Ormeno-Mejia
Facultad de Ingeneniería en Ciencias Aplicadas. Universidad Técnica del Norte.
Ibarra, Ecuador
ecormeno@utn.edu.ec

Gerardo Collaguazo
Facultad de Ingeneniería en Ciencias Aplicadas. Universidad Técnica del Norte.
Ibarra, Ecuador
gicollaguazo@utn.edu.ec

***Abstract*—Traditional Agriculture is considered the first form and the most expansive method of cultivation employed until now. It requires many resources, such as soil, water, time, human labor, machinery, etc., that directly influence production cost, ecosystems deterioration, etc. The accelerated increment in the world population faces significant challenges, including ensuring an adequate supply of food and agricultural products. In order to improve productivity and reduce damage to the environment caused by conventional agriculture, the present work describes the implementation of an automated aeroponic cultivation system for a green leaf lettuce culture, controlling parameters of temperature, humidity, and irrigation time, by misting nutrients to the plant roots. It is a low-cost Arduino-based system with an Internet of Things (IoT) tool for remote monitoring variables by connecting to a web server. The proposed method offers an appropriate control action for the aeroponic environment proving to be more efficient than traditional farming. The green leaf lettuce crop compared to a conventional culture show a growth of over 40% in leaves production and diameter; furthermore, in the roots length and the cultivable area density, a performance approximately 400% higher is achieved.**

***Keywords*—aeroponic, monitoring system, automated system, Arduino, IoT, lettuce.**

I. Introduction

Agriculture is one of the most important productive sectors and sources of food, especially for developing countries; however, the increment of the population density generates that agricultural lands are limited. In Ecuador, the population growth rate is 1.8%, reaching in the last decade, approximately 17.48 million inhabitants [1]. Therefore, greater areas of land intended for agriculture to satisfy food needs are required; nevertheless, the land-use dedicated to permanent crops in the country shows a decrease of 0.60% between 2016 - 2017 [2]. Furthermore, climate change, the indiscriminate use of soil, water, and the advancement of deforestation increasingly lead to the degradation of ecosystems. In this sense, alternatives for an environmentally friendly farming system are sought, such as aeroponics, hydroponics, aquaponics, etc.

Objective 6 of *"Plan Nacional de Desarrollo de Ecuador"* emphasizes the value of promoting alternative production models that consider agro-ecological purposes to encourage food autonomy [3]. In this context, agriculture using automated aeroponics systems gains importance, as it is a cultivation procedure intended to increase production, reducing the resource uses, and having an alternative approach.

Aeroponics is an advanced soil-less culture system that is innovative and responsible for the environment and is considered the most useful plant growing method for sustainable development and food security, compared with different cultivation systems [4]. The basic aeroponic principle consists of exposing plant roots to a closed or semi-closed environment, saturated with a fine mist of nutrient-rich solution delivered by sprayers, misters, or other devices; therefore, no soil or grow media is required along the entire life cycle [5], [6]. This technique can be developed in growth-controlled environments, such as greenhouses, and has been applied successfully for the production of different horticultural species, including lettuce, tomato, potato, cucumber, and ornamental plants [7]. Moreover, culture aeroponic provides fast and efficient food production, requires lower consumption of space, water, and nutrients, and is easy to manage; however, a fault in the pumping system or in sprinkle time can damage the crop [8]. Therefore, adequate monitoring and control system is needed.

In Ecuador, the agricultural sector has been typically managed by small producers and peasants, who in most cases, have low economic resources. Furthermore, the monitoring and controlling activity are commonly carried out in manual, requiring an investment of resources, human labor, time, and money, with results that do not necessarily guarantee its effectiveness [9], consequently, most of them have been expecting to benefit from the use of technological tools.

In order to take advantage of resources and optimize agricultural production, it is necessary to implement innovative methods for integrating monitoring and control systems, to obtain accessible, immediate, and available information on the state of the culture, focused on preventing economic and crop losses. [10], [11]. This concept involves the use of technologies, such as automated systems and communication interfaces. An automated system in agricultural processes, not only allows proper monitoring of the crops, but also with the inclusion of other tools, as the Internet of Things (IoT), the variable data can be collected and used in subsequent studies

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to improve crop growth and optimize important factors in productive development [12], [13].

In this context, the purpose of this work is to present the results for an automated aeroponic cultivation system for green leaf lettuce crop, by controlling parameters of temperature, humidity, and irrigation time, into the misting of nutrients at the root level. The system is low-cost and is presented as an environmentally friendly alternative for the lettuce production, being this vegetable one of most consumed in daily family feeding. This system is based on Arduino and uses an IoT tool for remote monitoring through a web server.

II. Development Methodology

This section describes the study area and proposes an intelligent and manageable architecture for a lettuce aeroponic culture, using an Arduino microcontroller and electronic devices to integrate the monitoring and control systems.

A. Description of the study area

The present study was carried out for a vegetable crop located in Ibarra, Imbabura, Ecuador, latitude 0º17'47.83" and longitude -78º08'46.21", at a distance around of 6.1 km from the city center, as shown in Fig. 1. This farm has two greenhouses with 1680 m^2 and 800 m^2, respectively.

Fig. 1. Study area location

Irrigation systems for the area's greenhouses are generally operated entirely in manual using drip techniques. Furthermore, a small space outside is dedicated to traditional cultivation. Remoteness and complicated access to the place make it indispensable to control the water resource to avoid unnecessary loss; therefore, one or more workers must perform the irrigation process, continuously and manually. Consequently, the need to implement a modern culture system that operates autonomously as an alternative to other conventional farming methods is observed.

B. System description

The electronic system carries out the programmed actions for the crop automated operation. It has been designed with different components that allow monitoring and manipulating the system variables to improve production performance, either on-site or remotely. Fig. 2 shows the block diagram of the aeroponic culture monitoring and control system.

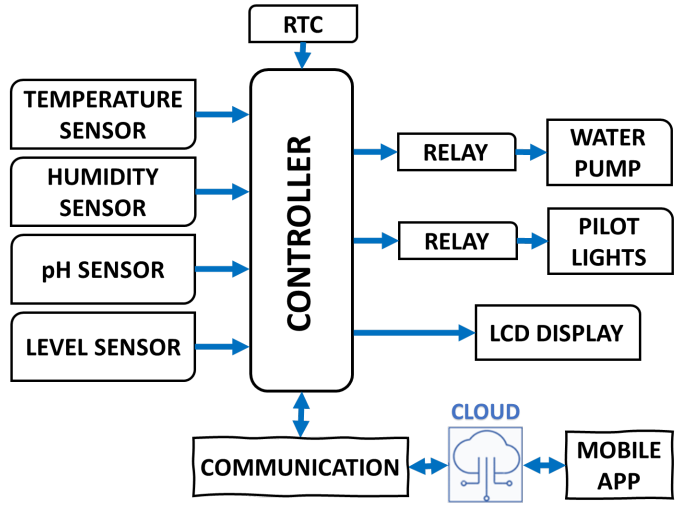

Fig. 2. Monitoring and control system block diagram.

The system manages many activities at the same time: acquires data (sensors: temperature, humidity, level, pH), shows values to users (LCD), sends information remotely (communication) and operates power processes (relay), in a synchronized and timed mode (RTC). All the electronic devices must resist high demands such as adaptation to environmental conditions (temperature variations), continuous operation without interruptions (with auto reset), and good precision.

The main function is to acquire temperature and humidity from the environment and the pH of the nutritional solution to keep the crop within the required conditions. The level measurement of the reservoir tank prevents the culture from running out of irrigation. Arduino performs the data processing and, according to the variables reference conditions, makes decisions to achieve an adequate production process. The data are sent to the cloud through GPRS communication.

C. Hardware components

Some electronic elements used in this project are sensors, force elements, and active parameter display; all this controlled by a programmable device capable of processing information. The system is designed to scale along with the hardware. Tab. I describes most important devices functions.

D. Design consideration for the aeroponic culture monitoring and control system

The proposed system is implemented using the circuit diagram shown in Fig. 3, and the flowchart in Fig. 4 describes the behavior for the aeroponic culture monitoring and control system with an IoT application. Two operation states are considered: manual and automatic.

The manual mode allows the pumping system and nebulizers to supply the nutrient solution to the crop, employing start and stop buttons, when the automatic mode is not available for maintenance, diagnostics, or fault.

TABLE I
THE FUNCTION OF HARDWARE COMPONENTS

Device	Function
Arduino Mega 2560	Device microcontroller-based. Processing and execution functions are programmed according to the conditions required by the crop.
Real Time Clock (RTC) DS1307	RTC allows adequate control of processes in real-time.
Temperature and humidity sensor AM2301	Temperature and relative humidity are environmental variables that influence plants' growth; hence, they must be monitored to take compensatory actions against possible deviations outside the ranges allowed.Recommended temperature range of 4°C to 30°C. Recommended relative humidity between 60% - 80% [4].
pH sensor module 4502C with electrode E201-BNC	The unique method of feeding the plant is by the nutritional solution; therefore, the culture requires adequate pH ranges to avoid possible toxicity damage. The pH sensor has the function of measuring this parameter in the nutrient solution to determine if it is suitable for the crop. Recommended pH range of 5.8 to 7.2 [14].
Ultrasonic Level Sensor JSN-SR04T	The sensor gets the level percentage in the reservoir tank of the nutrient solution.
LCD screen 2x16 + I2C module	System variables status are displayed in the LCD screen, which communicates with Arduino using I2C.
Relays 5VDC-120VAC	The relays receive control signals from the microcontroller to perform actions on the water pump power circuit.
Shield GSM GRPS SIM900	The greenhouse geographical conditions do not allow access to internet services; remote communication is required to know the crop status. The Shield SIM900 is a device for connecting to the Internet, making or receiving calls, and text messages by GSM GRPS wireless connection.
Water pump 0.5 HP and nebulizers.	The pump is used in the plant roots irrigation process, taking the nutrient solution from the reservoir tank until the nebulizers. The pump on/off times are programmed in Arduino according to the crop water needs.

In automatic mode, all programmed functions are carried out autonomously, according to the following:

- The microcontroller through the RTC module determines the period (day or night). According to the programmed irrigation configuration, the on/off states of the pumping system and nebulizers are controlled.
- The data from the temperature, humidity, pH, and level sensors are requested and processed.
- If the temperature magnitude is greater than 35°C, the irrigation time is modified due to the plant roots lose humidity faster, as is described in the next section. Furthermore, if the pH and level variables are out of range, the user is alerted to take the corresponding actions.
- Finally, the measured variables are sent to the webserver and displayed on the LCD screen; then, the process runs repeatedly.

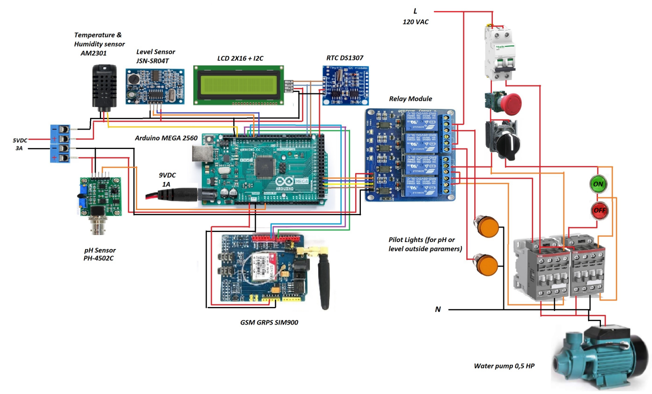

Fig. 3. Control and power circuits

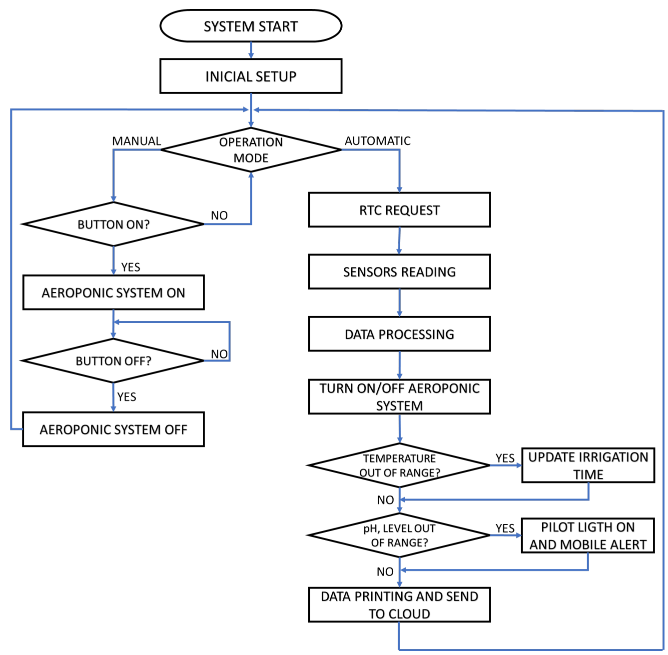

Fig. 4. System flow diagram

III. IMPLEMENTATION CONSIDERATIONS.

A. General diagram of automated aeroponic culture

Fig. 5 presents the general distribution of the system. It shows the aeroponic culture, the control panel, sensors, irrigation and recirculation pipes, pumping system, reservoir tank, among others. The control panel, with all electronic devices for system operation and communication module, has been installed the closest to aeroponic culture, likewise the humidity and temperature sensor, in order to measure the variable data more accurately. The pH is measured from a sample of the nutrient solution collected from the reservoir tank, using a mini-pump, to avoid incorrect values due to pumping and recirculation inside the tank. The ultrasonic level sensor has been installed in the tank lid to measure the reserve percentage of the nutrient solution.

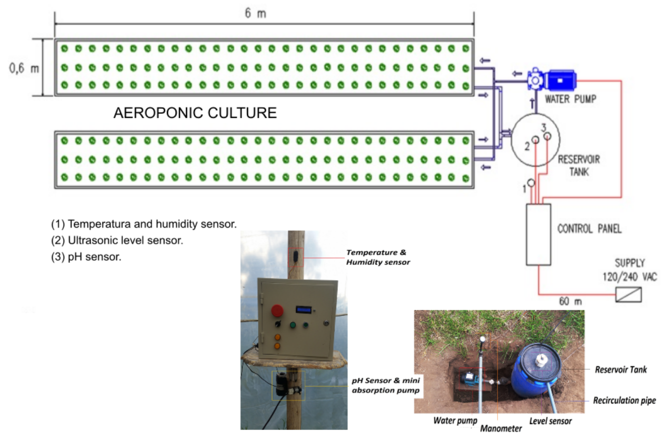

Fig. 5. Schematic of the proposed design.

B. Irrigation times for the aeroponic crop.

In an aeroponic culture, irrigation is essential because it is the only means to feed the plant. According to the experimentation, an average irrigation period has been obtained, considering estimated times for the plant roots could retain the nutritive solution, in order to perform a more efficient production process and avoid roots deterioration.

The irrigation time depends on the plant development stage. During sowing, the root has a dimension between 4 to 5 cm; therefore, it needs constant watering, due to its low liquid retention capacity. Subsequently, the intervals between watering are extended because of the root increases in size and liquid retention capacity. Likewise, the time of day influences the plant-feeding process. For example, at night, the environment humidity increases, which allows the roots to remain for more times without the need for watering. Otherwise, during the day, the relative humidity decreases due to the increment in temperature, so shorter times must be had between irrigation periods.

The irrigation periods configuration to obtain an improved production process, for the proposed aeroponic system that benefits to accelerated growth, both of the roots and leaves, in a green leaf lettuce culture, are shown in Fig. 6.

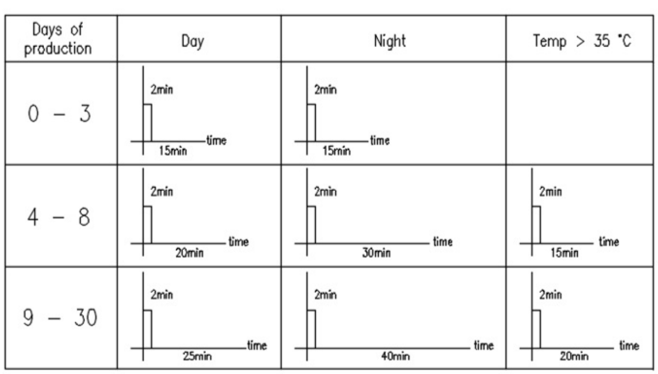

Fig. 6. Irrigation times of aeroponic culture.

IV. Analysis of Results

Compensation due to changes in environmental variables in an aeroponic culture is more complicated in manual operation. It is a procedure that requires accuracy to avoid damage or rapid death of plants during the growing period, and it mostly depends on the farmers' expertise. Therefore, monitoring and controlling the process by adopting an automated system like the proposed in the present work enhances the culture's performance.

Data acquisition of parameters in real-time that influence the cultivation and programming of the system with the inclusion of monitoring tools based on IoT, for the correct feeding of the plant depending on the growth stage and the environmental deviations through irrigation configuration times has been observed for a period. That has evidenced a successful application of the methodology. Also, a comparison with traditional soil agriculture is presented because it is still a widely used method in agricultural production. These analyzes are described in the following sections.

A. Remote monitoring and data interpretation.

IoT refers to the digital interconnection of commonly used objects by the internet. The adoption of IoT in industrial processes and agriculture is increasing due to the multiple tools it offers, including remote data monitoring as one of its most utilized applications. Likewise, the information and control solutions that this type of technology provides allows for obtaining significant advantages.

In the present work, motorization, analysis, and visualization of system variables are made using a free web server designed for IoT-based applications, called ThingSpeak. The SIM900 Shield connects to Arduino and establishes a GPRS connection for information transfer with ThingSpeak, through the use of AT commands.

Variables analysis during the experimentation are detailed below and Fig. 7 shows the trend graphs from the mobile application:

Fig. 7. Remote monitoring of variables using the ThingSpeak mobile app

a) Temperature and humidity: Temperature and relative humidity are parameters in conventional greenhouses, such as exist in our region, hard to control automatically due to the investment in infrastructure. The measured temperature inside the greenhouse was between 8°C and 44°C, and the relative humidity was between 10% and 94%. The lettuce crop presents better productive performance in climatic conditions with low temperatures and high humidity; hence, the system takes compensatory actions of irrigation control when an excess temperature occurs to attenuate the low moisture in the roots.

b) Reservoir tank level: The values measured by the sensor show that the tank irrigation level is related to the ambient temperature. Despite the recirculation, the water evaporates quickly at a higher temperature, and the level decreases faster. From the experimentation, it was determined that 50-liters tank capacity supply irrigation for around five days; after this time, it is necessary to add an extra nutritional solution.

c) Hydrogen potential (pH): It is used to determine the nutrient solution's status and depends on the dose of the supplied nutrient. According to the data at the process beginning, the pH is approximately 6.9, and the lowest value is 5.9 before change water and nutrient. Therefore, it has been inside the allowed parameters. If the pH of the nutrient solution becomes outside the required range, a dashboard pilot light will come on, and an alert would be triggered on the Thingspeak mobile app to take corrective action.

B. Comparative between traditional and aeroponic culture.

Two cultivation methods were examined during the same production time for green leaf lettuce plants: aeroponic and traditional. Fig. 8 shows the growth process for both cases. It can be seen immediately that leaf growth has been more accelerated in aeroponic culture, getting 57% more in the number of leaves, while the medium diameter of the leaves is 42% greater than in a traditional one.

In average root growth, a greater difference between both crops is observed. In aeroponics, a development about 400% higher than traditional culture is achieved, as shown in Fig. 9.

Fig. 8. Development process for traditional and aeroponic cultivation in lettuce plants

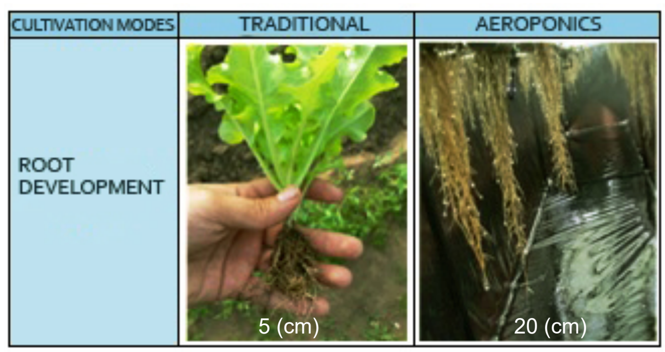

Fig. 9. Comparison of plant root growth

Another significant difference is the employed cultivation area. For the experimentation, two productive modules of 3.6 m^2 were used for the aeroponic crop, in which 180 plants were sown. For traditional cultivation, a land area of 3.6 m^2 was occupied, for 21 lettuce plants. To have equivalent regions, it is compared only with a productive module; therefore, plant density that aeroponic cultivation has reached respect for traditional crops is approximately 430% greater. Besides, the adequate management of water resources in an aeroponic crop should be noted, in which 50-liters reservoir tank capacity supplies for approximately five days of irrigation, while in a traditional crop, it only provides for one day.

V. Conclusions.

Aeroponics is a modern cultivation method that can be used as an alternative to conventional farming. This culture procedure improves production, eliminates pesticide use, and take advantage of the cultivable physical area. However, it demands a well-controlled surrounding climate, including adequate compensation for environmental conditions changes, precision in irrigation intervals, fault detection in the aeroponic system that shut down the nutrient supply, or other situations that can contribute to permanent plant damage. Therefore, in the present work, a supervision and control system that operates autonomously has been proposed to improve the efficiency of agricultural activities in an aeroponic crop for green leaf lettuce.

Additionally, an IoT applications for remote data monitoring has been included that allows to know the variable's status for the proper system operation. The results show that the 50-liters reservoir tank capacity supplies for approximately five days of irrigation; moreover, it depends on the environmental temperature, because evaporation and consumption by the plant are more necessary when this parameter is higher. The pH value remained in suitable ranges, with an approximate reduction of 6.9 to 5.9. The temperature and relative humidity were highly variable due to the greenhouse climatic conditions, obtaining measurements around 8°C to 44°C and 10% to 94%, respectively.

The automated aeroponic system proposed, reduces errors in operation due to human intentions, and can provide the nutrients solution in the amount necessary for adequate plant growth, considering its development stages, and environmental conditions, which improves production by accelerating development due to better root oxygenation. Also, more appropriate use of water resources has been achieved. Finally, it is possible to offer continuous and hygienic vegetables throughout the year, regardless of weather conditions.

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