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Design and Implementation of a Compact Automated Spirulina Cultivation System for Households

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Abstract. Spirulina is considered to be the most nutritious whole food source in nature. It is promoted as a dietary supplement and an active ingredient in functional foods. Factors such as conflicts, supply chain disruptions, and economic fallout are driving food prices to unprecedented levels. Low- and middle-income populations are affected by these rising costs. The design and implementation of a compact Spirulina cultivation system to be used in the household is presented in this paper. The system contains light, temperature, pH, and turbidity sensors. All sensors are connected to microcontrollers which activate a heater, air pump, mixing pump, pool fall pump, and two LEDs according to the readings received to ensure proper and continuous growth of Spirulina. The proposed system is user-friendly, economical, and can be easily stored and operated at homes to stimulate and monitor the growth of Spirulina. The primary objective of the proposed compact cultivation system is to furnish the necessary tools for generating a nutritionally valuable food source on a smaller scale, specifically within households, at a relatively affordable cost.

Keywords: cultivation, pH level, salinity concentration, sensors, spirulina

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1. Introduction

Recently, there has been particular interest in microalgae's biomass production, particularly phytoplankton, as it has the potential to serve as an alternative source of protein in food. Microalgae with high levels of pro-vitamin A carotenoids, such as Spirulina, Dunaliella, and Chlorella, are typically produced and sold commercially [1]-[2]. These microalgae are widely available because of their high provitamin A content and their nutritional value, which includes proteins, minerals, and vitamins. Spirulina, in particular, has been utilized as supplements, functional foods, drug additives, and other foods [3]. Although some studies have focused on other microalgae, Spirulina blue-green algae is considered the most promising due to its high protein content, high levels of amino acids, as well as the significant quantity of vitamins and minerals present [4]-[6].

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Spirulina has been employed in the transformation of various conventional food items, including the incorporation of Spirulina into cookies, pasta, and ice cream, and its blending with juices, such as its combination with pomegranate juice [7]-[9]. The analysis of industrial and market trends indicates that the Spirulina-based dietary supplement market is at the forefront, and it is projected that by the year 2031, the market is poised to reach a value of $254 billion, experiencing a Compound Annual Growth Rate (CAGR) of 9.4% [10].

Due to its wide range and high concentration of nutrients, Spirulina has gained recognition as a superfood. It is considered to be the most nutritious whole food source in nature. Spirulina is promoted globally as a dietary supplement, as well as an active ingredient in functional foods and beverages. It is widely accepted in Europe, North America, and parts of Asia and Oceania, due to the various health benefits it offers. Spirulina's dense nutritional composition makes it an excellent dietary supplement for individuals of all ages and lifestyles [11]-[18].

Numerous studies have documented the immune-boosting benefits of Spirulina, including its ability to enhance resistance to viral infections. Users have reported a reduction in the incidence of colds and flu after consuming Spirulina for decades, and pre-clinical animal studies have demonstrated its effectiveness as an immunostimulant in a variety of species [19]-[20]. In humans, as well as mammals, chickens, and fish, Spirulina promotes immune stimulation by improving resistance to infections, influencing hemopoiesis, and stimulating the production of antibodies and cytokines. Additionally, Spirulina has been shown to activate T and B cells, as well as macrophages. Sulfolipids derived from Spirulina have also proven effective against HIV, while Spirulina biomass extracts have been found to combat herpes virus, cytomegalovirus, influenza virus, and other pathogens. Furthermore, Spirulina extracts have been shown to inhibit carcinogenesis [21].

In a report issued on July 15th, 2022, the World Bank stated that skyrocketing food prices have triggered a global crisis that is poised to force millions of people into severe poverty and worsen hunger and malnutrition. Factors such as the Ukraine conflict, supply chain disruptions, and the ongoing economic fallout from the COVID-19 pandemic are eroding years of progress and driving food prices to unprecedented levels. Low- and middle-income populations are disproportionately affected by these rising costs [22].

Spirulina can be grown using various techniques such as open systems like ponds and lakes, which are susceptible to contamination by animals and other toxic algae species, or closed systems like photovoltaic reactors, which are not. To avoid contamination by toxins from other toxic algae species that become mixed up during harvest, it is necessary to study spirulina production processes at home. Spirulina production is influenced by several environmental parameters such as lighting, temperature, pH, water quality, and overall micronutrient richness [23].

The design and implementation of a compact Spirulina cultivation system are presented in this paper. The proposed system is user-friendly, economical, and can be easily operated by users at home to stimulate and monitor the growth of Spirulina. The main goal of the proposed design is to provide users with a compact economical alternative that can be used in the household to produce a food source that is rich with nutritional value.

In Hawaii and California, the United States of America houses some of the world's largest intensive farms. For example, Earthrise operates on a vast 43-hectare plot in the Sonoran Desert of Southeastern California, utilizing mineral-rich water from the Colorado River. In 2002, this site produced approximately 450 tonnes of product. Additionally, Cyanotech uses a specially-bred strain of Spirulina platensis, known as Spirulina pacifica, to cultivate 350 tonnes per year on 32 hectares of shallow, open ponds. These ponds are located adjacent to the Pacific Ocean and are filled with a combination of fresh water and deep ocean water supplements, with sodium bicarbonate and carbon dioxide, as well as inorganic fertilizers serving as the primary inputs [12].

Since 1987, the State Science and Technology Commission in China has provided funding for spirulina cultivation. Production occurs in four primary geographic regions: (i) Chenhai Lake, a plateau alkaline salt lake farm located in Yunnan; (ii) the southern coastal outdoor farms in Guandong, Hainan, Fujian, and Jiangshu; (iii) inland semi-closed systems in Hubei and Shandong; and (iv) high latitude saline-alkaline water farms located in the Yellow River Valley and Hubei [12].

At the Thai National Inland Fisheries Institute, researchers conducted studies and isolated Spirulina strains, primarily from the northeastern region of Thailand. The strains that demonstrated the ability to grow in brackish water were then blended with either cassava or fish meal, resulting in a protein source that could be locally produced and used for fish feed [24].

The Solarium Biotechnology Group for Desert Development has established a spirulina production system in the heart of Chile's Atacama Desert. This system involves culturing spirulina in polyvinyl chloride-lined raceway ponds, with agitation provided by a paddle wheel. A thin layer of translucent polyethylene film that is resistant to UV radiation covers the ponds, thereby maintaining ideal temperatures in the culture medium for most of the year and facilitating optimal growth of spirulina [25].

According to the authors' understanding and their analysis of relevant literature, the majority of existing research has a strong focus on large-scale Spirulina production. This inclination could be attributed to the potentially greater profitability associated with large-scale production compared to smaller-scale alternatives. Additionally, a lack of widespread awareness regarding Spirulina and its advantages may contribute to this emphasis on large-scale production.

In contrast, the main goal of this paper is to propose a compact cultivation system to provide the essential resources required for producing a nutritionally valuable food source on a smaller scale, particularly within household settings, and at a cost that is comparatively more affordable.

2. Materials and Methods

The system architecture of the proposed cultivation system is shown in Figure 1. There are two microcontrollers used in the system. The LattePanda is connected to the light (LUX) sensor, temperature sensor, pH sensor, turbidity sensor, a screen, and 6 relays. The relays are connected to the heater, air pump, mixing pump, pool fall pump, and two LEDs. The second microcontroller is the ESP8266 D1 R2 and it is connected to the conductivity sensor. Both microcontrollers send data wirelessly using WIFI to the Blynk cloud server. The user can easily interact and control the system through a mobile application which is used to monitor the Spirulina cultivation process.

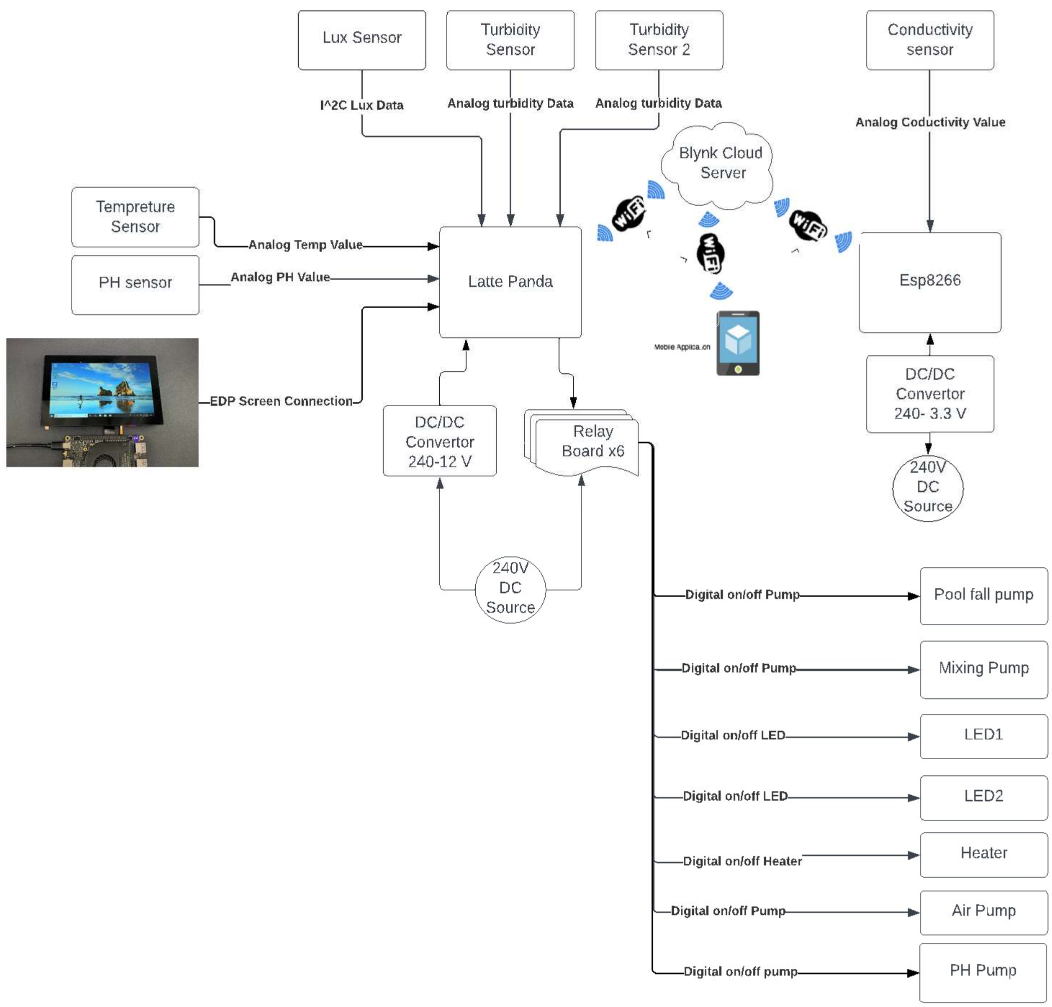

Figure 1. System Architecture

The sensors are used to monitor different important parameters in the system to ensure correct functionality. The light sensor is used to measure light intensity and the temperature sensor is used to monitor the temperature while the system is operating. Furthermore, the turbidity sensor is used to measure the relative clarity of the water and hence the growth rate of the Spirulina algae. It uses a light source and a photoelectric cell that measures the intensity of light dispersed at a 90° angle by the particles in the water. A pH sensor is used to keep track of the pH level in the water. The peristaltic pump's precise flow enables the user to maintain perfect pH levels in the tank. All of these sensors are connected to the LattePanda microcontroller.

Table 1 lists all the components used in the implementation of the proposed Spirulina cultivation system. The total cost includes the cost of the tank and all of the hardware components.

Table 1. Components Used in the Cultivation System and Their Cost

Component	Quantity	Cost ($)
LattePanda 3 Delta 864 + Case	1	279.0
ESP8266 Microcontroller	1	10.0
Analog pH Sensor	1	56.9
Analog Ambient Ligth Sensor	1	8.9
Digital Peristaltic Pump	1	35.5
Analog Temperature Sensor	1	89.0
Analog Turbidity Sensor	3	30.0
5V1 Channel Relay Module	6	19.6
Analog Conductivity Sensor	1	79.0
7 inches Touch Display (Edp)	1	76.7
LED	2	19.6
Small Pump	1	4.9
Big Pump	1	8.2
Air Pump	1	13.0
Heater	1	8.2
Tank	1	114.0
Blynk IoT Platform License	1	7.0
Spirulina Farming Kit	1	176.7
(Salt + Nutrients) for freshwater	1	9.0
Total		**1,045.2**

3. Results and Discussion

In the hardware implementation phase, the primary objective is to transform the proposed hardware circuit design into a functional prototype that operates as intended. This involves installing hardware components into the cultivation prototype and integrating them with the software, all while considering all requirements and specifications of the Spirulina cultivation system. As mentioned previously, the proposed system aims to automate the process of Spirulina cultivation. To achieve this goal, the system is equipped with sensors that detect and measure various parameters such as light, pH levels, salt concentration, and Spirulina concentration.

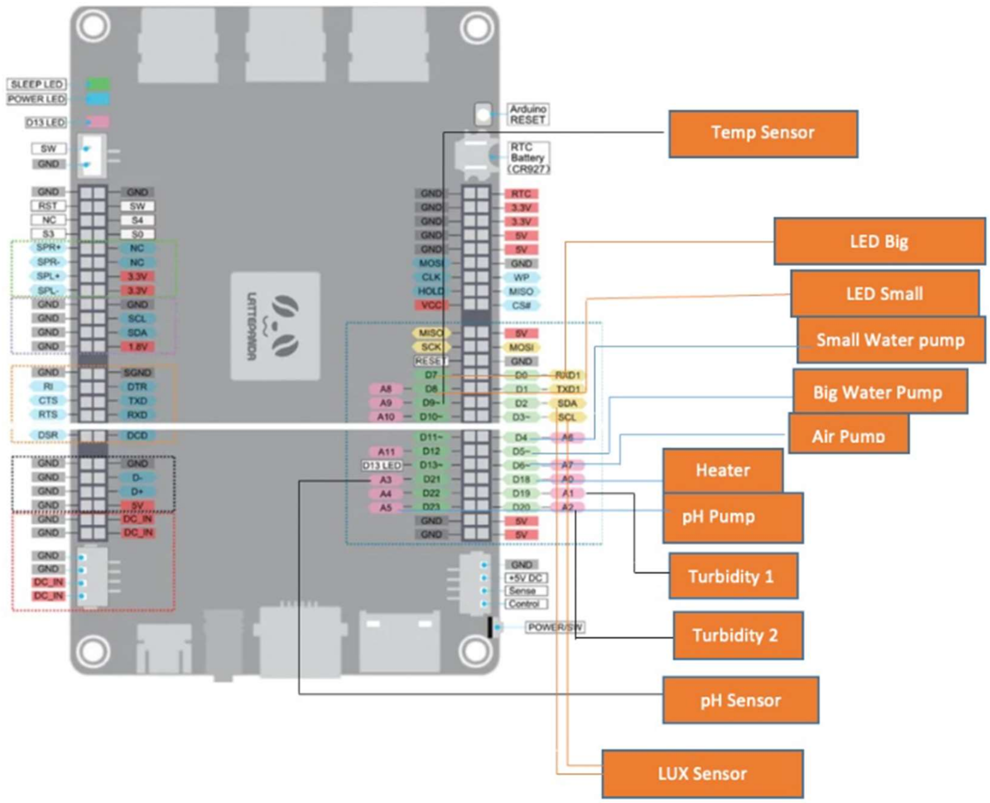

Figure 2. Connections between components and LattePanda microcontroller

The system then uses the data received to control and regulate the cultivation process automatically. The system design comprises a heater and air pump for the water tank, both of which are connected to a relay sensor. The water circulation process is facilitated by a water pump that pulls in and out the water, along with a mixing pump, pH pump, pool fall pump, air pump, heater, and two LEDs, each of which is connected to a relay. In total, the system contains six relay modules that are mainly responsible for turning the components on and off. Detailed connections between different components and pins in the LattePanda microcontroller are shown in Figure 2. Relays are used to control LEDs, all pumps, and the heater. Seven relays in total were used in the system. The actual connections to the LattePanda and placement of the relays are shown in Figures 3 and 4, respectively. The conductivity sensor is connected to the second microcontroller used which is ESP8266 as illustrated in Figure 4.

(a) (b)

Figure 3. LattePanda and Placement of the Relays: (a) Connections Between Components and LattePanda Microcontroller; (b) Relay Connections

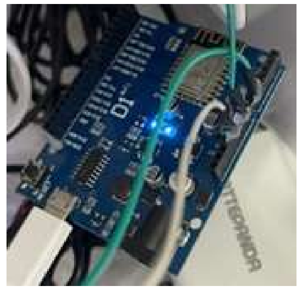

Figure 4. ESP2866 Microcontroller Connected to Conductivity Sensors

Once all the requirements for proper Spirulina cultivation are obtained, it was concluded that the following parameters must be met to ensure optimal growth conditions [26-28]. These parameters include a pH level between 9-11 pH, a salt concentration between 25.2 to 60.9 mS/cm, and an illuminance reading between 650 to 3000 LUX. The temperature should ideally be maintained at 35°C, but it can range between 25° and 40° C. The air pump should operate continuously for 24 hours, while the LEDs should be turned on and off for a period of 12 hours. All sensors must operate continuously for 24 hours to constantly monitor the environment inside the water tank.

When the user turns on the cultivation system and connects the mobile application via WIFI, all components and sensors start working simultaneously. Depending on the pH level prespecified by the user and the actual reading of the pH sensor inside the tank, the pH pump will be turned on if the actual reading is below the specified value and vice versa. The same applies to the conductivity sensor where the water pump is activated to maintain the percentage of salt inside the tank at a particular level. The heater is turned off and on according to the readings provided by the temperature sensor to maintain the temperature inside the tank at the desired value which is between 24° to 36°. The readings of all sensors of the cultivation system are displayed on the application and the user can manually control the components if and when needed.

The software section of the proposed Spirulina cultivation system was developed using the micro-C programming language and the Blynk framework for system application development, both of which were implemented under the Arduino IDE platform. The Arduino IDE was used to write and develop the necessary code instructions to implement the required functionalities of the sensors and other components connected to the LattePanda microcontroller. The software for the system includes a dashboard for the mobile application that was developed to present data in a graphical and user-friendly visual format, as illustrated in Figure 5. The dashboard provides key indicators and metrics relevant to the cultivation process. The dashboard primarily displays five main indicators: temperature, conductivity, pH readings, lux, and turbidity. These data are measured and retrieved from the connected sensors and then transferred to the system's dashboard the Blynk framework. The dashboard also provides the user with the ability to manually control different components of the system.

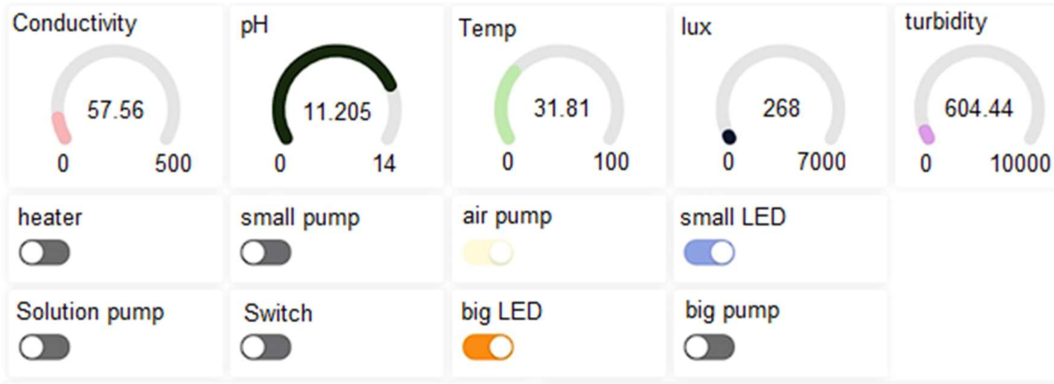

Figure 5. Data Displayed in the Dashboard of the Application

Figure 6. Spirulina Cultivation System

Figure 7. Recorded Sensors' Readings

Figure 6 presents the proposed automated Spirulina cultivation system. As shown in the figure, the tank is of small size and can easily be used in the household. The screen is attached to the outer side of the tank to provide the user with real-time readings of each sensor. Furthermore, the application records and keeps track of the sensors' readings, thus allowing the user to check the functionality of the system and monitor the growth of the Spirulina algae as shown in Figure 7.

As far as the authors are aware and based on their observations, the majority of existing studies predominantly emphasize the large-scale production of Spirulina. Unfortunately, there appears to be a scarcity of available research that investigates a small-scale household cultivation system suitable for comparison with our proposed system. Nonetheless, our testing of the system demonstrates the feasibility of proposed compact cultivation system. The clarity of the water and, consequently, the growth rate of Spirulina were utilized to ascertain the optimal harvesting time. The authors have successfully harvested and filtered Spirulina, subsequently incorporating it as an ingredient in various meals.

4. Conclusion and Recommendation

This paper introduces a household-oriented, compact, and automated system for cultivating Spirulina. The proposed system places a strong emphasis on user-friendliness. Within this cultivation system, an array of sensors is employed to continuously monitor pH, salinity, and temperature levels. These sensors' data are utilized to oversee various parameters in the cultivation environment and subsequently activate or deactivate specific components based on the received readings. This dynamic control mechanism ensures the creation of optimal conditions for enhancing Spirulina algae growth.

Future developments will involve the incorporation of additional sensors capable of tracking Spirulina growth percentages. This enhancement will facilitate the determination of the ideal Spirulina density for harvesting. Furthermore, a dedicated harvesting system will be developed to automatically collect Spirulina when sensor readings reach the desired values. An integrated calculator will also be implemented within the system's application to measure and display the necessary quantity of each element on the screen, customized according to user preferences.

The authors suggest enhancing public awareness regarding the advantages of Spirulina as a cost-effective and nutritionally rich food source. One potential approach is to consider establishing a specialized website that demonstrates the merits of Spirulina and offers diverse recipes showcasing its potential as an ingredient in various homemade dishes. Furthermore, the ongoing technological progress in 3D printing and the integration of AI into coding are expected to contribute to the reduction in the cost of the compact cultivation system proposed in this study.

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