Nile Journals

Nile Journal of Communication &Computer Science

Volume 2, Number 1, February 2022

Journal Webpage: https://njccs.journals.ekb.eg

Print ISSN: 2805-2366
Online ISSN: 2805-2374

Proposed Model for Sustainable and Scalable Vertical Farm

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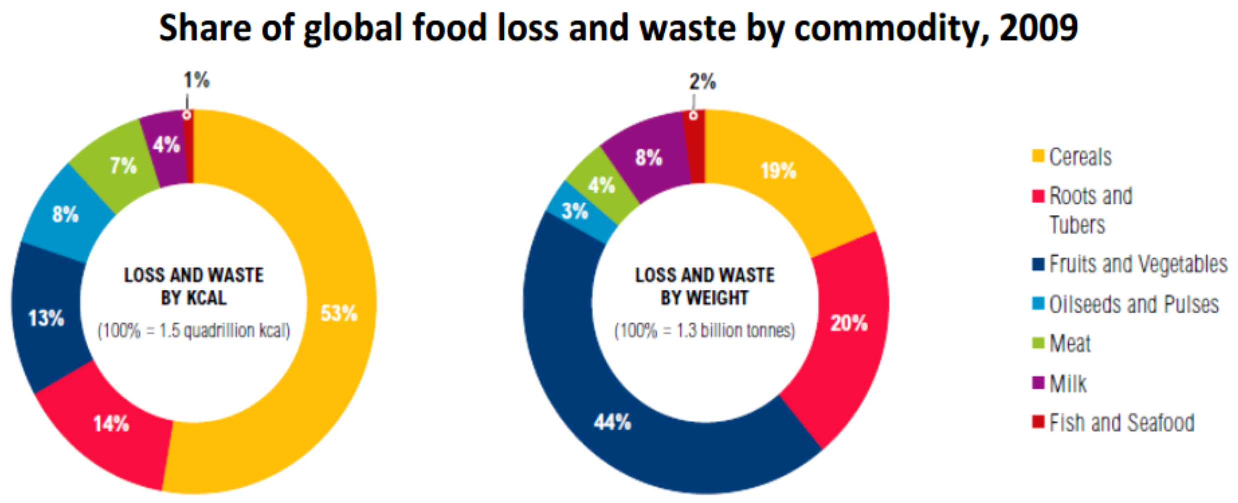
Abstract

This project summarizes the implementation of vertical farming that uses a Wi-Fi network to communicate with sensors and actuators from multiple nodes. It addresses the issue of ordinary vertical farms, which require the user to monitor it occasionally to provide fertilizer and water. The system can be easily configured to automatically control the supply of nutrients, water, and light requirements for various plant types through a mobile application enabled Interface. The mobile application dashboard can further provide a complex analysis of the whole system by collecting values from different sensors. The designed vertical farm system is power efficient, self-sustained, and can be set up easily by the user as each vertical rack acts as a single node or module. The user only needs to plant the seeds and fill up the tanks. Due to the modular approach, the system is also scalable without the requirement of more complicated materials or wiring.

Keywords: *Wi-Fi, Raspberry Pi, Scalable, Sustainable, Vertical Farming.*

1. Introduction

Vertical farming can be viewed as a way to combat the world's ever-increasing metropolitan areas, which are reducing the availability of agricultural land [1-3]. Figure 1 presents the share of global food loss and waste. Vertical farming opens the door to individuals being able to produce herbs and vegetables indoors with the assurance that the yield is 100% organic and hence considerably healthier. In addition, vertical farms are better for the environment than traditional farming because they have less carbon imprint (UN, 2019) [4]. Table 1 briefs the pros and cons of vertical farming.


Share of global food loss and waste by commodity, 2009

Data source: Reducing food loss and waste, World Resources Institute, 2013.

Fig.1. Share of Global Food Loss and Waste.

Ordinary vertical farms, on the other hand, will require users to take time out of their busy schedules to give water and fertilizer, as well as a source of light, which can be natural or artificial. If sunlight is preferred, the user may need to locate a location with the best availability. Artificial lights, on the other hand, must be efficient in two ways: they must supply the correct color for the specific plant species [5-6], and they must be energy efficient to avoid high electricity bills.

Table 1. Pros and Cons of Vertical Farming [7-10].

Pros	Cons
• It offers a plan to handle future food demands.	• It could be very costly to build and economic feasibility studies haven't yet been completed.
• It allows crops to grow year-round.	• Pollination would be very difficult and costly.
• It uses significantly less water.	• It would involve higher labor costs.
• Weather doesn't affect the crops.	• It relies too much on technology and one day of power loss would be devastating.
• More organic crops can be grown.	
• There is less exposure to chemicals and diseases.	

This research proposes a solution in the form of an IoT-enabled vertical farm to address these issues. IoT is a network of items with a variety of sensors, software/applications, network connectivity, and computing capabilities that can connect, alter, and share data via the internet to enable smart solutions. IoT is already providing new potential for solving a variety of environmental challenges such as clean water, landfill waste, deforestation, and air pollution, and will eventually aid in reducing the environmental effects of human activities. According to a report, the market for IoT will grow significantly around the world because all major corporations believe in the importance of IoT for both human life and the environment [11-12].

In this study, we offer a one-of-a-kind, totally self-contained, and energy-efficient vertical farm that can be placed anywhere indoors at the user's convenience. The user only needs to put up the shelf, rack the soil containers, place the seeds inside, and fill the water and fertilizer tanks. The user can then access the one-of-a-kind web-enabled dashboard that is offered. We call our unique ecosystem software the “Digital Farmer”, which as the name suggests, takes management of the farm on behalf of the user generating promising harvests. The user can also configure the farm as well as get important real-time data.

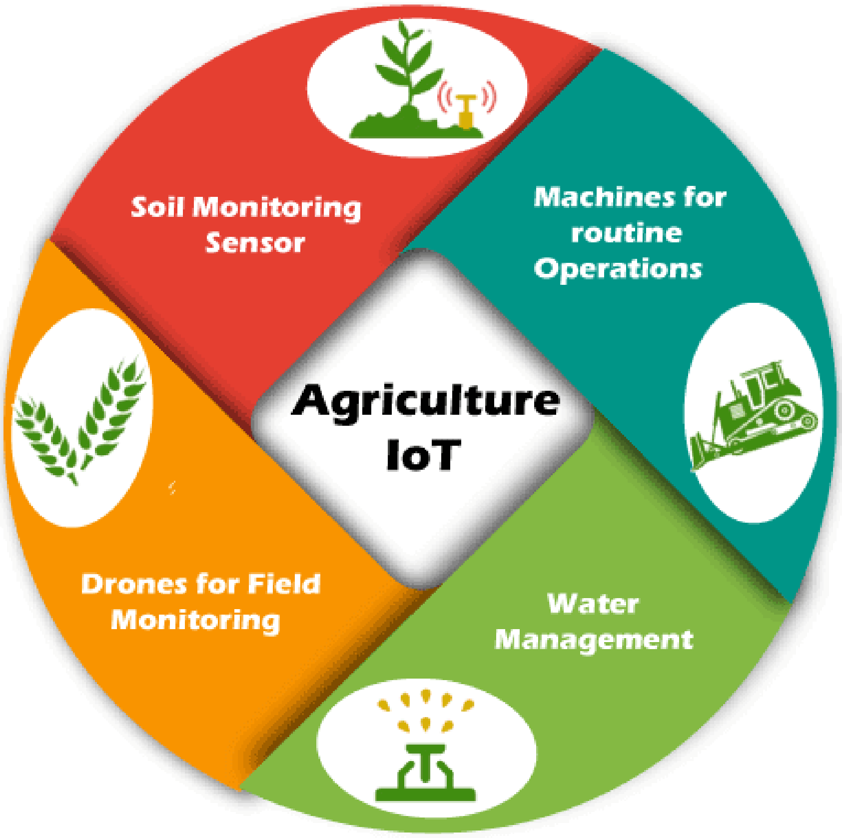


Fig.2. Agriculture using IoT, [Source: Javapoint].

The Digital Farmer kit includes extensive software features that allow for various configurations for cultivating a variety of herbs and vegetables, as well as a watering and fertilizing system that is automated. On-board Wi-Fi modules were used to build a communication link between the shelves and the microcontroller-based server. Through this, the REST API is used to seamlessly convey control signals to the server. The farm's data and status information, on the other hand, is sent via HTTP. In the Proposed Solution section, there is further information on the system.

The necessity for a new agricultural system is unavoidable, given the predicted growth in the global population and the current climate change epidemic [1], [13]. Vertical farming appears to be the ideal option. The farm is just several layers of a typical farm piled on top of one other, each with its light, temperature control, water, and fertilizers. Despite extensive research, there has yet to be a solution capable of providing a fully self-sustaining, scalable, cost-effective, power-efficient, and water-efficient farm available to the user as a plug-and-play product.

2. Related Work

Many researchers around the world have developed different vertical farming systems. Tsai and Liang [14] suggested a vertical farm monitoring system. The system, on the other hand, is merely a proof of concept until it is put to the test on a farm. The Arduino Yun is the sole microcontroller used, and only a single temperature sensor is tested. Sensory data is collected and written to a file, from which it is uploaded to a database and shown on the dashboard.

While drip irrigation is one of the most efficient watering systems, hydroponics is a method of growing plants or vegetables without the use of soil [13]. The application of hydroponics in small vertical farms is investigated by Ruengittinun et al. [15]. The authors' system is similar to the one described in this paper, except it is geared toward hydroponics. Sensor data is collected and stored in a database via a lightweight messaging protocol called MQTT broker once again in the system design. The system dashboard is represented by a mobile application with manual and automatic modes. An Arduino microcontroller is used, similar to Tsai and Liang, however this time the model is the cheaper Uno. It's connected to an Arduino WiFi shield, which is in charge of data transfer.

The decision-making mechanism in Ruengittinun et al. control system does not incorporate any type of hysteresis, which could result in many motor on-off cycles. Furthermore, the proposed dashboard does not automatically monitor the growing process by taking into consideration the plant kind. For example, the user must enter a setup that they may not be familiar with, necessitating some agricultural expertise. Key attributes to the farm's success, such as power consumption, whether the autonomous mode can grow plants or veggies, and whether it is scalable, are all lacking from the results.

Ismail et al. [16] used a traditional vertical farming approach. An Arduino Mega with an Ethernet shield, a DC motor-driven water supply, LEDs, and soil moisture and water level sensors were all part of their IoT-enabled vertical farm. The system works by requiring the user to open a web browser, navigate to the dashboard's webpage, and view the farm's current status.

From there, the user must provide a lot of information because it does not take any activities on its own and instead relies on the user to turn things on and off manually. The idea is that when there is less water, the user will be warned and must take action based on their judgment. This is inconvenient for the user because it takes time.

Kalantari et al. [17] conducted a comprehensive survey of vertical farming's prospects and problems. The research looks at a variety of vertical farms, the majority of which are large-scale. The characteristics of each farm are also described. LED lighting, sensors, efficient watering, and automation are all common features of farms. The report discusses the different environmental, economic, and social effects of vertical farming, the majority of which indicate that this area has a bright future. In line with our previously proposed design, the goal of our proposed solution is to be able to deliver high-end features in a practical and economical packaging by Liwal et al. [18].

Belista et al. [19] have presented a scalable vertical farm that uses aeroponics and promises a household-oriented product. A water level sensor, a pH level sensor, and temperature and humidity sensors all monitor the farm. The data from the sensors is saved on network-attached storage (NAS) device. The Raspberry Pi Zero W is the microcontroller that handles the storage and monitoring. There is no analog-to-digital converter included with this device, and no alternative is provided in the article.

Furthermore, while the framework supplied appears to be excellent for scalability, there are no explanations on how this might be accomplished. LEDs have been adjusted for individual plants, delivering the proper light spectrum for growth; however, there is no information on how this will be implemented. Because no implementation appears to have taken place, no information on power efficiency or cost-effectiveness is available. Overall, the design appears to have all advanced features, but it is still incomplete, raising the question of its viability.

3. Proposed Model

This Project is a smart solution over IoT using vertical hydroponics (a growing system based on water, not soil), growers can farm a variety of crops indoors and with minimal square footage. The vertical farm is completely climate controlled, uses LED lights to promote rapid growth, and connects to the app with Wi-Fi, making it easy for farmers to manage their crops remotely. Vertical hydroponics lends itself very well to leafy green vegetables [20]. We are growing successfully lettuces (romaine, boston bib, spring mix), cabbages (red and green), herbs (basil, cilantro, mint, dill, chives), spinach, kale (dwarf curly variety), broccoli, and petunias.

3.1. Project Aims

This project aims to: (i) spot the light on vertical farming and eco-friendly agriculture; (ii) introduce a new eco-friendly system for solving the problem of resources limitation. (iii) increase the production of crops for achieving worldwide food demand; (iv) preserve the soil where the use of chemical fertilizer; (v) decrease resources consumption by recycling the water, required for growing the plants; (vi) bioremediation and reduce pollutions.

3.2. Methodology

An IoT-based system is employed for the suggested solution, with a focus on scalability and sustainability. An overall outline of the proposed vertical farm is shown in Figure 3.

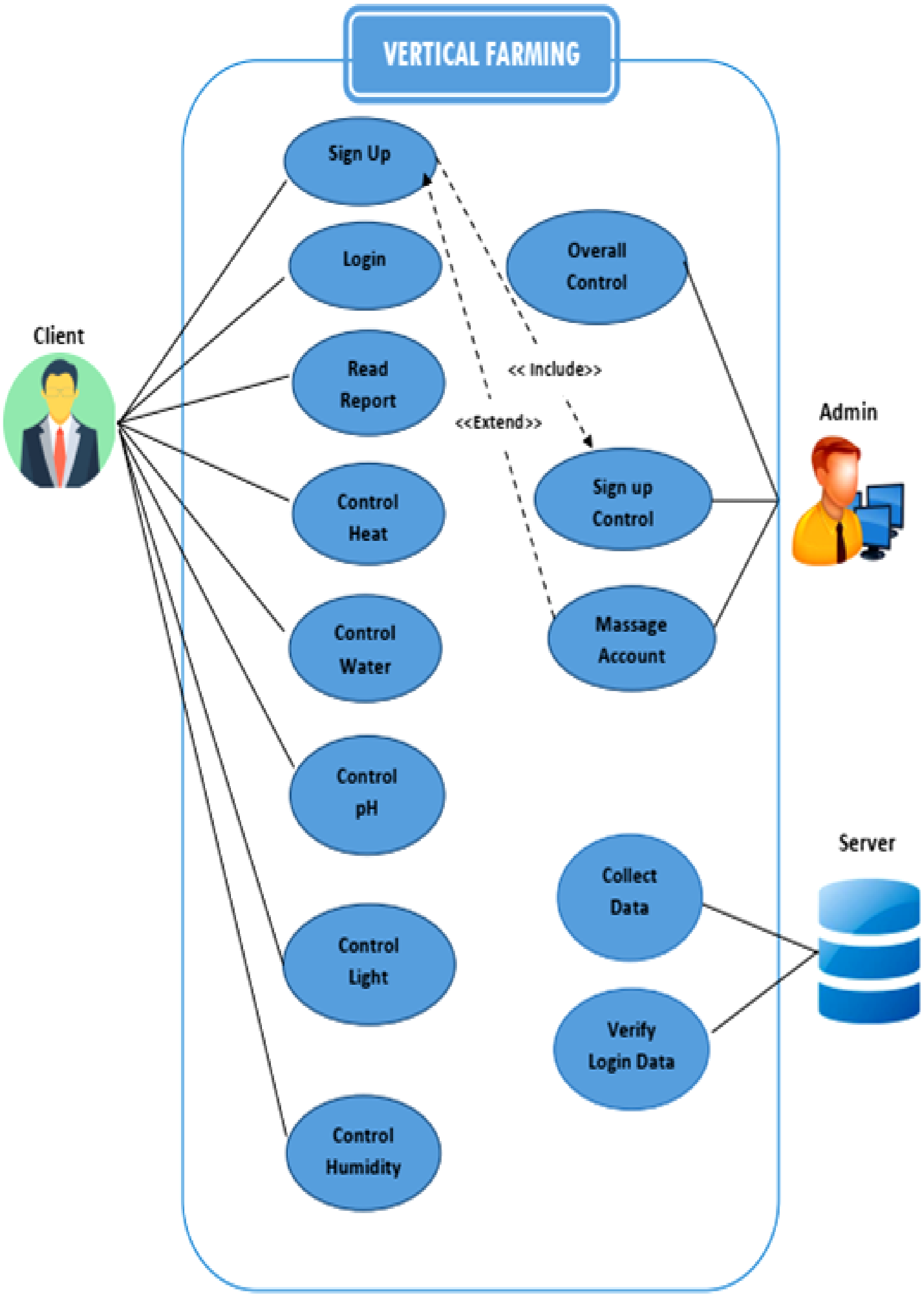


Fig.3. System Use Case Diagram.

The IoT server acts as the master node for the entire operation, controlling N racks or slave nodes at a single location. Each slave node has its sensor, light, water supply, and fertilizer supply motors, all of which are interconnected to better care for the plant in that rack. A rack will now be referred to as the slave node, while the IoT server will be referred to as the master node. The water supply is loaded with the appropriate nutrients to assist the plants in obtaining the nutrition they require to support their growth. The nutrient levels are carefully analyzed and managed to help the plants grow to their maximum potential. Water is re-circulated, allowing for high efficiency, typically exceeding 90% on water consumption. Our vertical design allows us to pack more plants into a smaller space. We're producing too many plants in a space that's smaller than 5 x 5.

The IoT server performs a variety of functions and is the primary point of access to the entire system. It provides a local web-based interface for controlling each node individually. It also needs an internet connection for security upgrades and, if necessary, remote access. The master node also provides a Wi-Fi hotspot, allowing any slave node to connect to the master node and immediately get an IP address through the Dynamic Host Configuration Protocol (DHCP) [21] for easy integration of additional nodes. By delivering the required commands via HyperText Transfer Protocol, the master node arranges fixed water and fertilizer supply for each node (HTTP) [22].

Second, the nodes themselves are made up of hardware that connects to a variety of sensors, such as temperature, humidity, and an analog soil moisture sensor. The modules utilized in a single slave node are shown in Table 2. Raspberry pi is a low-cost, low-power Wi-Fi microchip with full TCP/IP stack and microcontroller capabilities [23].

Table 2. Project Components and Cost.

Index	Components	Price in L.E.	URL
1	Raspberry Pi 4B 4GB	2000	https://ram-e-shop.com/product/raspberry-pi-4-4gb-made-in-uk/
2	Enclosure For Raspberry Pi 4B	175	https://ram-e-shop.com/product/enclosure-for-raspberry-pi-4b-9-layers-acrylic-cooling-fan/
3	Raspberry Pi 4B official 15.3W USB-C Power Supply	350	https://ram-e-shop.com/product/raspberry-pi-4-official-15-3w-usb-c-power-supply-5v-3a/
4	Heat Sink Set for Raspberry Pi 4B Board	35	https://ram-e-shop.com/product/heat-sink-set-for-raspberry-pi-4-board-gold-aluminum-copper/
5	MicroSD Card - 128GB	400	https://www.amazon.eg/-/en/PNY-PRO-Elite-MicroSD-Card/dp/B091JDB3FV/ref=sr_1_305?crid=1QG5A94A4JRW0&dchild=1&keywords=memory+128gb&qid=1635106621&sprefix=memory+128gb%2Caps%2C403&sr=8-305
6	7" LCD Capacitive Touch Screen HDMI For Raspberry Pi	1350	https://ram-e-shop.com/product/lcd-hdmi-7-hi-1024/
7	7 Inch LCD Acrylic Screen	200	https://ram-e-shop.com/product/7-inch-lcd-acrylic-

	Case Holder Bracket For Raspberry Pi 4		screen-case-holder-bracket-for-raspberry-pi-3/
8	Raspberry Pi Camera Module	850	https://ram-e-shop.com/product/raspberry-pi-camera-module-v2-official-8-megapixel-hd/
9	50CM Raspberry Pi Camera Cable	35	https://ram-e-shop.com/product/50cm-raspberry-pi-camera-cable-ribbon-ffc-15pin-0-5mm-pitch/
10	Analog pH Sensor	850	https://ram-e-shop.com/product/kit-ph-meter/
11	Water Level Sensor	175	https://ram-e-shop.com/product/xkc-y25-npn-intelligent-non-contact-liquid-level-sensor-water-level-sensor/
12	Water Flow Sensor FS300A G 3/4"	175	https://ram-e-shop.com/product/sen-fs300a-water-flow/
13	2* Liquid Pump – 2000GPH (12vdc)	1100	https://ram-e-shop.com/product/liquid-pump-2000gph-12vdc/
14	6* Fan	360	https://ram-e-shop.com/product/220vac-fan-size-12x12x3-8-cm2/
15	Hair dryer max 709 - 5000 watt	216	https://www.amazon.eg/-/en/Hair-dryer-max-709-black/dp/B09988T9PR/ref=pd_sbs_1/260-5789939-5372936?pd_rd_w=7KnSs&pf_rd_p=35010005-9e6c-41f1-bac1-9982e8d385be&pf_rd_r=MQGV81TKNFT4G322QZN9&pd_rd_r=582d328c-6dc3-4879-9470-a83aad5c6433&pd_rd_wg=KIw5x&pd_rd_i=B09988T9PR&psc=1
16	WS2812B 5050 RGB LED Strip	900	https://www.amazon.eg/-/en/WS2812B-Strip-Individual-Addressable-waterproof/dp/B09FFHDT7Z/ref=sr_1_68?dchild=1&keywords=led+strip&qid=1635106332&sr=8-68
17	Color Sensor	195	https://ram-e-shop.com/product/color-sensor-tcs3200-with-focusable-lens/
18	SMPS	250	https://ram-e-shop.com/product/kit-smps-12v-8-5a/
19	Body	4500	N.A.
20	ML & PVC Tubes	950	N.A.
21	Reflective Thermal Felt	261	https://greenhouse-egypt.com/product/thermo/
22	Hydro Power	55	https://greenhouse-egypt.com/product/a-%d9%87%d9%8a%d8%af%d8%b1%d9%88-%d8%a8%d8%a7%d9%88%d8%b1-1-%d9%84%d9%8a%d8%aa%d8%b1/
23	5cm Hydroponic Cups	95	https://greenhouse-egypt.com/product/net5100/
	Total Cost	15477	

A Raspberry Pi is used to keep the system running. It also controls the watering cycles, pH levels, fertilizer levels, lighting cycles, and ventilation fans. All system parameters must be continuously monitored and updated. The Raspberry Pi is also used to keep track of all of the system's operational data and make it accessible through a series of web services. Figure 4 summarizes the proposed model scenario.

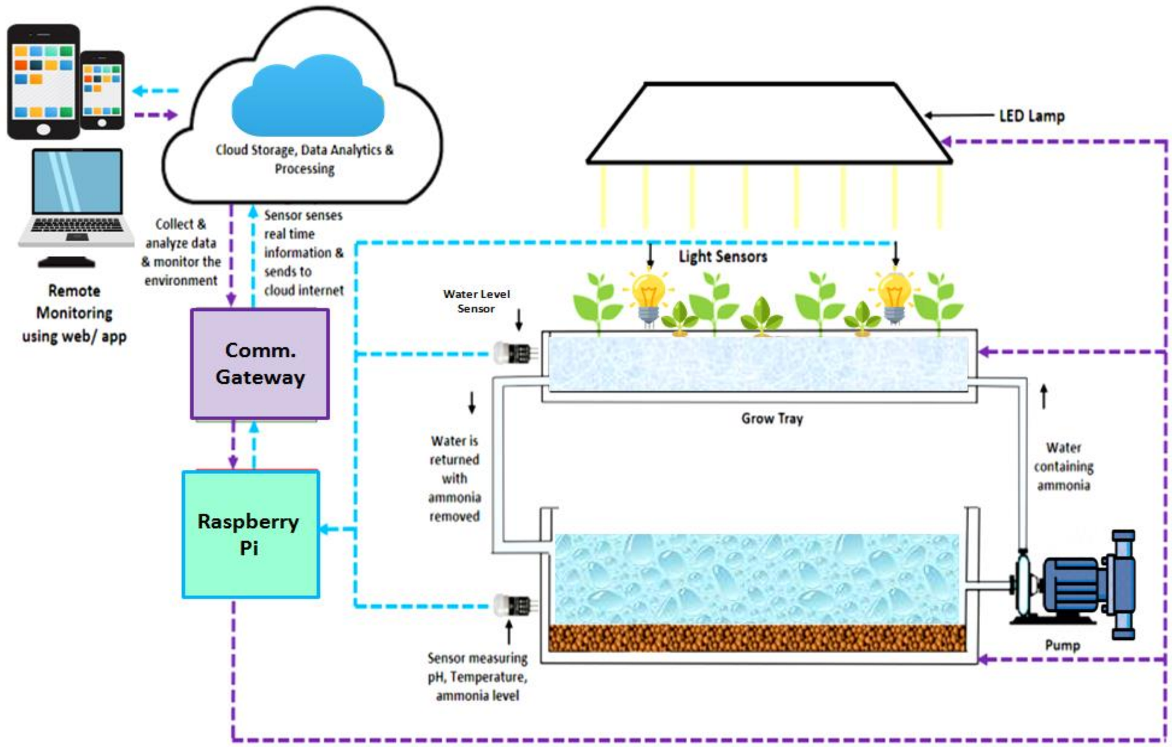


Fig.4. Proposed Model Scenario.

A companion Smartphone or tablet application connects to the Raspberry Pi and allows you to configure and monitor your entire system from anywhere. A web service connects the Raspberry Pi and the app. This application has three main layouts as follows: (i) Control Layout; (ii) Reports Layout; (iii) Help Layout. These layouts are presented in Fig 6.

Description	Crop	I
....	Tomato	1
....	Pepper	2
....	Carrot	3
....	Cucumber	4
....	Watercress	5
....	Herbs	6
....	Celery	7
....	Strawberry	8
....	potato	9
....	Onion	10
....	Garlic	11
....	Rosemary	12
....	Leaf Lettuce	13

Fig.6. Mobile Application Layouts.

4. Challenges and Future Research Directions

Vertical farming still has many limitations [24-27] as follows: (i) No Established Economics: The financial feasibility of this new farming method remains uncertain. The financial situation is changing, however, as the industry matures and technologies improve. (ii) Difficulties with Pollination: Vertical farming takes place in a controlled environment without the presence of insects. As such, the pollination process needs to be done manually, which will be labor-intensive and costly. (iii) Labor Costs: As high as energy costs are in vertical farming, labor costs can be even higher due to their concentration in urban centers where wages are higher, as well as the need for more skilled labor. Automation in vertical farms, however, may lead to the need for fewer workers. Manual pollination may become one of the more labor-intensive functions in vertical farms. (iv) Too Much Dependency on Technology: The development of better technologies can always increase efficiency and lessen costs. But the entire vertical farming is extremely dependent on various technologies for lighting, maintaining temperature, and humidity. Losing power for just a single day can prove very costly for a vertical farm. Many believe the technologies in use today are not ready for mass adoption.

Otherwise, many open issues need researchers efforts, these challenges could be summarized as [28-30]: (i) Lack of experienced farmers familiar with this technology; (ii) Economic viability of providing enough water and energy to a large scale farm; (iii) “Food from Chemicals”; (iv) Requires a collective effort of indoor agronomists, businessmen, engineers, architects, politicians, etc.

5. Conclusions

Vertical farming is still a relatively new technology. Companies have yet to succeed in mass-producing crops cost-effectively to fulfill rising food demand. How crucial a role vertical farming will play in the future to meet the challenge of rising food demand will be determined by the performance of farms like AeroFarms. However, technology created for vertical farms is being adopted by other areas of the indoor farming sector, such as greenhouses, which can utilize natural sunlight but require much more space and longer routes to market. The suggested farm regulates the environmental conditions needed to produce plants in indoor vertical farms autonomously. It excels in scalability and convenience, since extra racks or slave nodes may be quickly added without requiring the end-user to perform any complicated wiring or setups. The dashboard that comes with it may easily be expanded to undertake a complicated analysis of the many variables received by the sensors.

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