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Smart Indoor Vertical Farming System

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Abstract

Smart indoor vertical farming (SIVF) systems represent a rapidly developing approach to agriculture, addressing challenges of land scarcity, resource efficiency, and food security. This paper investigates the design and implementation of a SIVF system, focusing on automation capabilities. The core functionalities includes a Sensor Network which will Continuously monitor environmental parameters like temperature, humidity, light intensity, and nutrient levels within the vertical farm. Then Utilizing sensor data to regulate LED lighting spectrums, irrigation systems, and nutrient delivery for optimized plant growth.The paper explores the hardware components, software architecture, and control algorithms employed in the SIVF system. We present a case study demonstrating the effectiveness of the system in maintaining optimal growing conditions and discuss the potential benefits of SIVF technology for sustainable and productive urban agriculture.

Keywords: *Agriculture, Farming, IoT, Data acquisition system, Urban*

1 Introduction

Vertical farming is a revolutionary method of crop production that utilizes vertically stacked layers instead of sprawling horizontal fields. This innovative technique optimizes space utilization and aims to address the growing challenges of traditional agriculture.

Core Principles:

- Vertical Stacking: Crops are grown in vertically stacked beds, shelves, or containers within a controlled environment. This allows for significantly higher yields per square foot compared to conventional farming.
- Controlled Environment Agriculture (CEA): Vertical farms leverage CEA technologies to meticulously manage factors like temperature, humidity, light spectrum, and nutrient delivery. This creates optimal growing conditions for specific crops, irrespective of external weather fluctuations.
- Soilless Cultivation: Vertical farms often employ soilless farming techniques like hydroponics, aquaponics, and aeroponics. These methods eliminate the need for traditional soil, utilize less water, and enable precise nutrient delivery to plant roots or foliage.

Benefits of Vertical Farming:

- **Increased Productivity**: The stacked layer design allows for significantly higher crop yields on a smaller footprint. This is particularly advantageous in urban areas or regions with limited arable land.

- Reduced Environmental Impact: Vertical farms use significantly less water compared to traditional agriculture. Additionally, controlled environments minimize pesticide use and fertilizer runoff, promoting eco-friendly practices.
- Year-Round Production: CEA technology allows for consistent growing conditions, enabling year-round production of crops irrespective of seasonal variations. This can enhance food security and supply chain stability.
- Reduced Food Miles: Vertical farms can be located closer to urban centers, reducing the transportation distance for fresh produce. This lowers the carbon footprint and allows consumers to access fresher, locally grown food.

Applications of Vertical Farming:

- Leafy Greens: Lettuce, kale, spinach, and other leafy greens are popular choices for vertical farms due to their rapid growth cycles and high demand.
- Herbs: Fresh herbs are another suitable crop for vertical farming as they thrive in controlled environments and offer high profit margins.
- Microgreens: These nutrient-dense young vegetable and herb seedlings are a perfect fit for vertical farms due to their compact size and short growing time.

Table 1: Crops produced using Vertical Farming

Fruit	Tomatoes, watermelon, cantaloupe, strawberries, berries, grapes, lemons, oranges, bananas
Vegetables	Leafy greens, celery, cucumbers, potatoes, peppers, onions, carrots, peas, watercress, broccoli, corn, beets
Herbs	Chives, oregano, mint, basil, sage, rosemary
Grains	Rice, barley

Challenges and Considerations

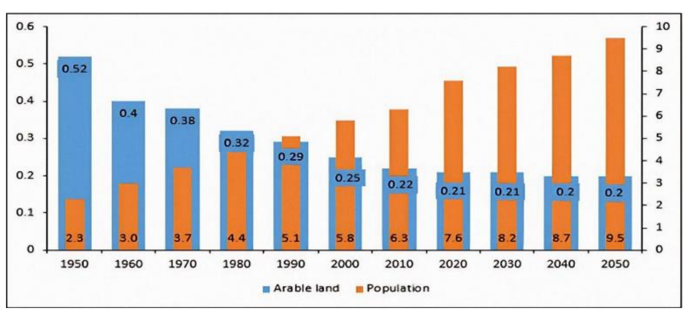
- High Start-Up Costs: Establishing a vertical farm requires significant investment in infrastructure, technology, and environmental control systems.
- Energy Consumption: The use of artificial lighting and climate control systems can lead to high energy demands. Research is ongoing to develop sustainable and energy-efficient solutions for vertical farming.
- **Labor Skills**: While vertical farming can be automated to some extent, skilled personnel are needed to manage the complex CEA systems and ensure optimal crop growth.

Vertical farming represents a promising approach to revolutionizing agriculture. By optimizing space, minimizing environmental impact, and enabling year-round production, this technology has the potential to address food security challenges and contribute to a more sustainable future.

Growing Techniques: These methods focus on how nutrients are delivered to the plants' root systems.

- Hydroponics: This is the most common method in vertical farming. Plants are suspended in a nutrient-rich water solution, eliminating the need for soil altogether. Precise control over nutrient delivery optimizes plant growth.
- Aeroponics: Similar to hydroponics, aeroponics suspends plants in a controlled environment. However, instead of a water solution, the roots are misted with a nutrient-rich fog several times per hour. This method requires precise control over humidity and air circulation.
- Aquaponics: This unique system combines aquaculture (fish farming) with hydroponics. Fish waste provides natural nutrients for the plants growing in a soilless medium, while the plants filter the water for the fish. This creates a closed-loop system, minimizing waste and water usage.

2 Background



According to UN calculations, by 2050 there will be 9.7 billion people in the world, in other words around 2 billion more mouths to feed than in 2020.[1] This increasee according to FAO (the UN food and agriculture agency), needs to be met through a 70 % rise in agricultural production. In fact, over the past 40 years, we've lost a third of our arable land, which is land capable of being plowed and used to grow crops. This urgent need for sustainable solutions is paving the way for revolutionary farming practices—among them, vertical farming stands out as a promising frontier. And here, we will look into how this innovative approach is transforming our approach to agriculture. The situation poses a serious challenge to the member states of the UN with regard to the 2030 Agenda, and specifically SDG 2, which aims to end world hunger by ensuring access for all, especially the poor and vulnerable, including babies, to healthy, nutritious and sufficient food throughout the whole year. And all this without forgetting that in addition, the food industry is currently responsible for 30 % of the world's energy consumption and 22 % of greenhouse gas emissions. The challenge, therefore, is not just producing more food, but doing it sustainably. Due to the escalating global population, innovative approaches are required to address the rapidly increasing demand for food. One noteworthy agricultural practice that has gained traction in recent years is vertical farming. This method enables the cultivation of a greater quantity of food per unit of land, alleviating the need to continually seek additional arable land to sustain the growing population. Nevertheless, vertical farming presents its own set of challenges. Read on to delve into the intricacies of vertical farming and discover how cutting-edge technologies such as the Internet of Things (IoT), wireless sensors, and artificial intelligence are contributing to a transformative revolution in food production.[2] In addition to the increasing purchasing power of people and the change in their consuming preferences like shifting towards more organic and pollution free food due to the rising health awareness.

As the world's population keeps growing and cities sprawl outward, there's less and less space left for traditional farms. This land squeeze is just one reason why vertical farming is gaining ground. On top of that, climate change is making weather patterns more unpredictable, which can wreak havoc on crops. Traditional farming, which relies on rain and sunshine at the right times, can struggle in these conditions. Vertical farms offer a solution: they're built indoors in stacked layers, so they don't need as much space as traditional farms. Plus, they use special systems to control the light, temperature, and water that plants need to grow, so they're less affected by what's happening outside. Another benefit is that vertical farms can be built close to cities, which cuts down on how far food needs to travel before it reaches people's plates. This reduces food waste and keeps things fresh. Overall, vertical farming is a promising way to grow more food in less space, with less risk from the elements, and with a smaller environmental footprint.[3]

Figure 1: World population versus arable land 1950-2050

Smart indoor vertical farming systems rely on a combination of technologies to create a controlled and optimized environment for plant growth. Here are some key components:

1. Sensor Networks:

These are the eyes and ears of the system, constantly monitoring various environmental parameters like:

- Temperature
- Humidity
- Light intensity and spectrum
- Nutrient levels in the water supply (hydroponics)
- Carbon dioxide (CO_2) levels

2. Automated Control Systems:

Based on sensor data, these systems can automatically adjust various aspects of the environment:

- LED lighting systems: Can be dynamically controlled to provide the optimal light spectrum and intensity for each plant stage.
- Irrigation systems: Deliver precise amounts of water and nutrients directly to the plant roots using methods like drip irrigation or aeroponics.
- Heating and cooling systems: Maintain consistent temperature ranges crucial for plant growth.
- Ventilation systems: Regulate air circulation and CO_2 levels to optimize photosynthesis.

3. Data Analysis and Machine Learning (ML):

The heart of the smart system, this involves:

- Collecting and storing sensor data over time to identify trends and patterns.
- Using ML algorithms to analyze data, predict potential issues like nutrient deficiencies or pest outbreaks.

- Recommending adjustments to optimize growth parameters and resource usage (water, nutrients, energy).

4. Additional Technologies:

- Robotics and Automation: Can be employed for tasks like:
  - Seeding and planting
  - Plant monitoring and health checks
  - Automated harvesting
- Environmental Monitoring Systems: These can include:
  - Cameras for visual inspection of plant health
  - Spectral imaging to assess plant stress levels

5. Internet of Things (IoT):

- Underpins communication between all these technologies, allowing for real-time data collection, monitoring, and control from a central hub or even remotely.

By integrating these technologies, smart indoor vertical farming systems can create highly efficient and productive growing environments, maximizing yield while minimizing resource consumption and environmental impact.

3 Related Work

An article written in The Journal of Horticultural Science and Biotechnology said that:

Global food security has been significantly threatened by the Covid-19 Pandemic along with the prolonged drivers of food insecurity including climate change, shortage of agricultural resources, an energy crisis, an increase in population, and urbanization. Land/soil degradation is a particularly serious issue for global food security highly affecting the scarcity of arable land for crop production. Reduction in the global land area will require a 50 to 100% increase in food production per unit hectare on existing land by 2050. Many countries depending on imports for their food supplies are struggling to afford food and there are less choices for healthy food due to their higher prices and insecurity of accessibility. Therefore, we urgently need to rethink the way we farm.

Vertical farming is a modern agricultural practice of growing crops, stacked vertically in a protected indoor environment, which mainly utilizes a hydroponic or aeroponic cultivation system. Vertical farming offers numerous potential benefits, including more efficient uses of space, reduced water usage, shorter growing times, reduced need for pesticides/herbicides, and shelter from extreme weather. In addition, since vertical farms can be set up practically anywhere, even underground, they could enable hyper-localised production, thus shortening food supply chains and providing fresh and nutritious local foods all year around.[4]

Vertical farms are a novel type of farming in a controlled-environment with a total replacement of solar radiation with artificial lighting that provides the necessary nanometers of the spectrum for the growth and development of plants. In vertical farms, plants grow in soilless cultivation systems such as hydroponic (roots are immersed in multiple substrates, i.e., perlite, rockwool enriched water with nutrient solution), aeroponic (soilless air/mist solution) or even aquaponic (co-cultivation of fish and hydroponic plants) systems that allow stacking multiple layers or columns of plants horizontally or vertically. Vertical farms are located in completely isolated spaces from outdoor environment with thermally insulated installations (especially when at the top floor of the building) and airtight structures that give the opportunity to the farmers to control the environment in terms of temperature, humidity and CO_2 (Avgoustaki and Xydis, 2019). Since vertical farms can theoretically be placed anywhere in the urban network, they allow local, nutritious and fresh consumption for consumers. In specific, a study conducted by Jill (2008), mentioned that food sourced from conventional farming uses 4 to 17 times more fuel compared to locally grown food and emits 5 to 17 times more CO2.[5]

Many companies and entities have tried and applied the concept of Vertical Farming with different implementations. For example, the iFarm Company have established a number of their vertical farms in many countries with extreme weather conditions like Russia and Saudi Arabia, where they have succeeded in cultivating crops that haven't been planted there before with that ease and success.

Table 2: Successful Vertical Farms around the world

Name	Location	Website
The Plant Vertical Farm	Chicago	www.plantchicago.com
Sky Greens Farm	Singapore	www.skygreens.appsfly.com
VertiCrop	Canada	www.verticrop.com
Plantlab VF	Holland	www.plantlab.in
Vertical Harvest	USA	www.verticalharvestjackson.com

4 Project Details

As a result of what we discussed before, some points were proposed to achieve our vision and to help emphasize the power of vertical agriculture.

1. Make an eco-friendly, ergonomic, easy to use device to help spread the idea to the normal user.
2. Make a super design that can fit in many places (homes, schools, smart buildings, ..etc.)
3. Build a community for the VF (vertical farming) this will enormously help spread the idea especially among those who takes agriculture as a hoppy.
4. Make a scalable design that can be easily modified or just assembled to build a bigger farm with minimum area requirements.
5. Use the power of IoT to make a data acquisition system that allows data collecting and analysis.
6. Make an ergonomic, super friendly design that fits all the ages.

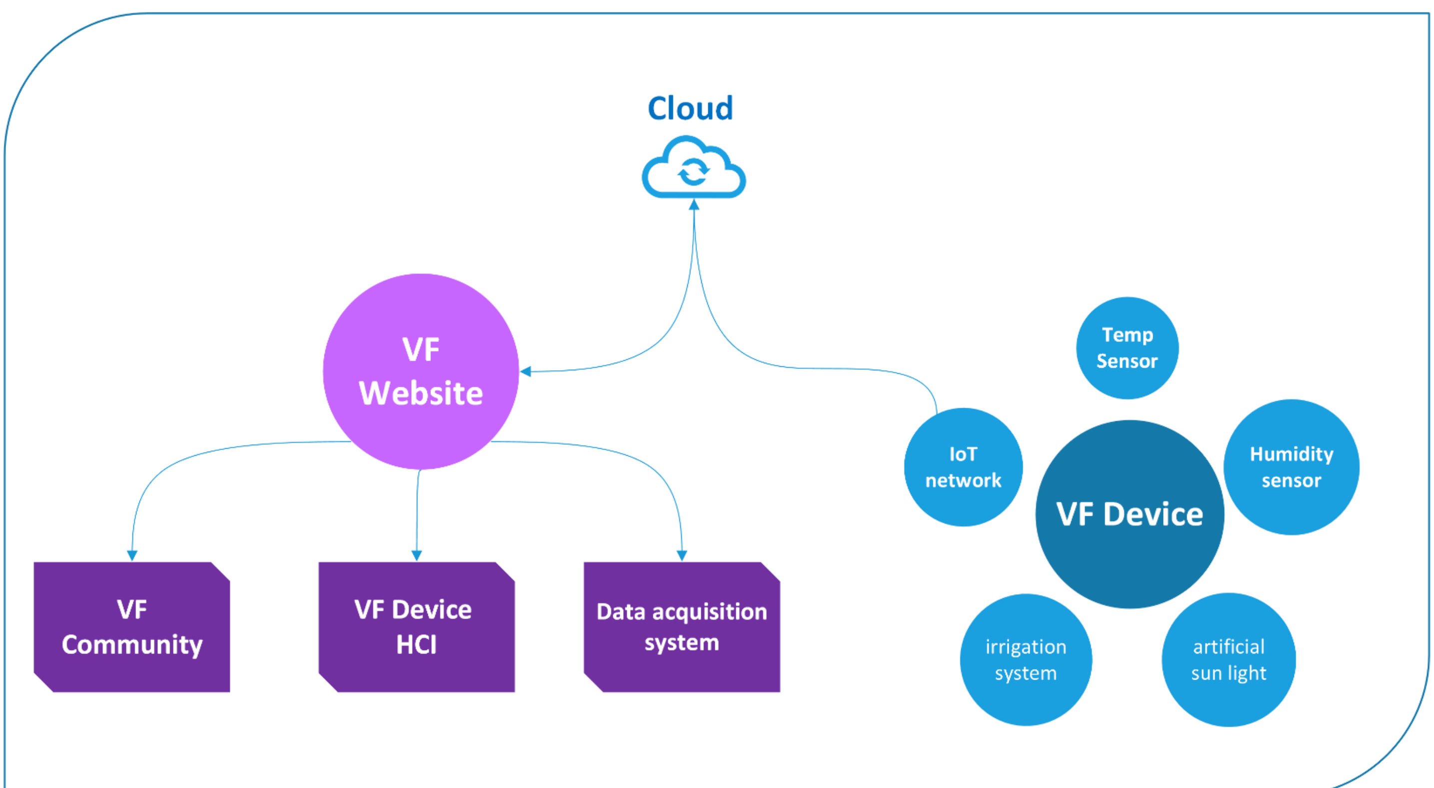


Figure 2: System Main Components

4.1 System Design

Having the above-listed goals in mind, we came to very good system that can achieve each goal and satisfy our needs and also of course customer's needs.

As shown in figure 3 The system will consist of two main components:

- **Our VF device:** This device will allow users to perform automatic vertical agriculture farming and help them monitor their planet until it healthy grow up. We are going to discuss them in more details in this chapter.

  The VF device will be equipped with modern sensors to help achieve the automatic farming operations and also establish the data acquisition system.

- **The VF website:** This website will establish a community for vertical farmers and will act as a HCI (Human control interface) for the user to interact or control the VF device.

4.2 The VF device.

The VF device is basically a structure that holds container in which we can start to plant corps. The VF device achieves the goals we mentioned before and makes it users to fall in love with the idea of VF.

At this section will illustrate our design concept, control system and sensor attached to the VF device which made it possible to achieve our mission and objectives.

4.2.1 VF Design Concept

In our VF design we introduced a new idea of converting the VF from being used in the big agricultural and crops production industry to more simple things that can be used by normal life people or small children.

Our concept focusses on build a structure that is ergonomic and reduce the hassle of VF but, in the same time we needed this device to be scalable that can also be used in a crops mass production industry.

After doing some heavy research and many drafts we came up with a design that satisfies our goals and applies our design concept.

4.2.1.1 VF device main design features

Our proposed design consists of the following components:

- **The Soil Container:** it's simply a box that will contain the soil needed to plant the crops. Those boxes design was chosen to be very friendly to normal life people as they can see something familiar every day.
- **The L Shape Stand:** This stand will hold a set of cantilevers which will hold the soil used to plant the crops. The L shape gives a huge advantage making it possible for users to just hand the device on any wall or put it above any ground or table. It also makes it possible to scale it to a bigger shape that can take more soil containers. The L shape stand will have a slot to enable user to adjust the distance between the soil containers and customize the number of containers per stand.
- **The Cantilever:** this part is used to connect soil containers with the L shape stand. It has some metal connectors that clutches with the slots in the L stand. Each container will require a two Cantilever connector to fasten it. The Cantilever shape was selected to apply the concept of plug and play for the containers and also, it's easier to analysis the stresses around it.
- **The sensors clippers:** those parts are used to attach the sensors to the soil containers. This makes it easier to do repairs and fixes. Also, this will allow users to use any preferred containers, all they just need is to attach the sensors clippers.

Using those main components, we managed to build a VF device that can be used in both personal hobby and mass production farming**.**

Figure 4 shows the final design:

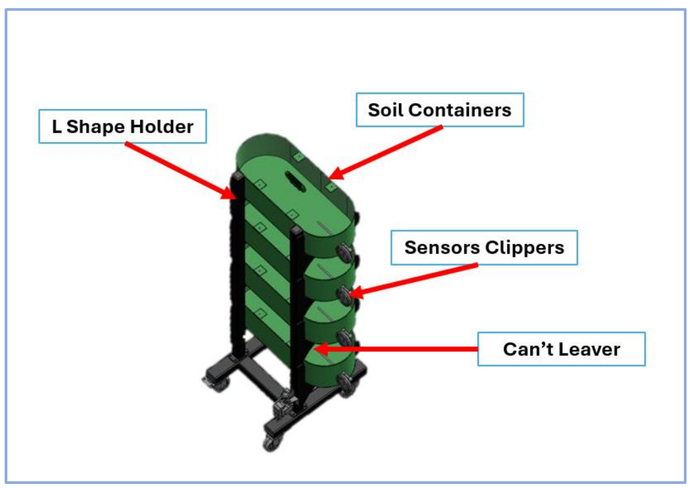


Figure 3: VF Device Final Design

4.2.1.2 Material Selections

Our goal was to build an ergonomic device and eco-friendly. We also needed our device to be cheap so that it can be affordable for normal users and to achieve this we needed to select a cutting-edge material.

- **For (stand – cantilevers):** we made a quick comparison between 3 main materials (stainless Steel – Aluminum – PVC) those three material will make the VF device reach its own goals.

Table 3: Comparison between Aluminum, Stainless Steel and PVC

Feature	Aluminum	Stainless Steel	PVC
Material	Metal	Alloy	Plastic
Weight	Lightweight	Heavy	Lightweight
Strength	Strong	Very Strong	Weakest
Cost	Inexpensive	More expensive	Most expensive

Aluminum was chosen for its high strength – light weight – corrosion resistance and cost.

- **For Soil Container and Sensors Clippers**: Plastic was chosen but a certain type of plastic called PET (Polyethylene Terephthalate) - PET is commonly used in beverage bottles, food packaging, and synthetic fibers. It is highly recyclable and is commonly collected by recycling programs.

4.2.2 VF Device Control

The VF Device System Design utilize the power of IoT to do the following:

- Capture different sensors data and upload it to the cloud.
- Allow vast areas communication between the VF device and its users.
- Helps to make the planting – irrigation operations automatic to reduce the hassle on the users.
- Contribute with the website to make the VF device more user-friendly and more enjoyable for young edge children.
- Gives the system the ability to super scale to a mass production VF eco-system.

The VF device control system consists of two main layers as shown in figure 5.

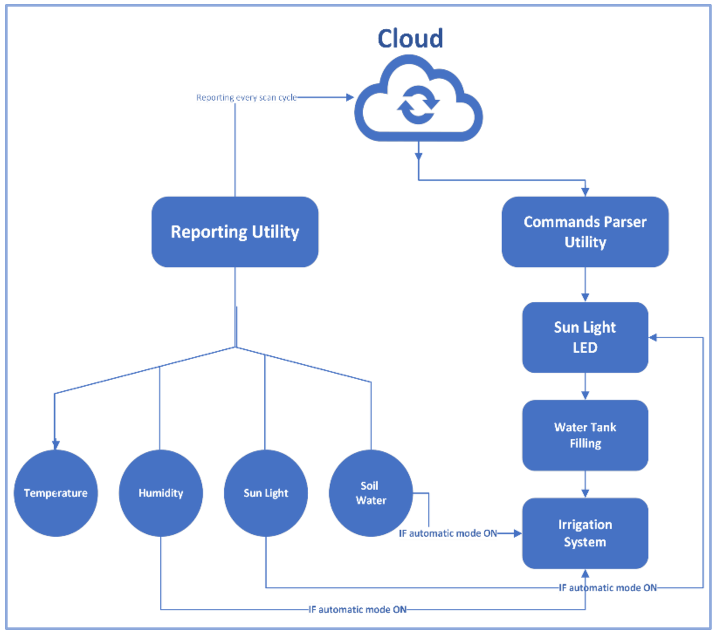


Figure 4 - VF device Control System Block Diagram

4.2.2.1 Reporting Utility

This layer is responsible for interfacing with the sensors to read the data and then upload it to the cloud.

The reporting utility has something called <u>Reporting Scan Cycle (RSC)</u>. The RCS is a periodic time that the IoT chip will report the data, this means data won't be real time incase the RSC was a big number. The RSC can be configurable by the user. We introduced the RSC concept to help reduce the Current consumption of the VF device.

The reporting utility is connected to the following:

- **Temperature Sensors**: ambient Temperature sensing to measure the air temperature for each Soil Container. In case the mass production the Temperature sensor will be per room or greenhouse.
- **Humidity Senor**: measure the H_2O percentage in the ambient air. This sensor reports is data to the cloud and can directly control the irrigation system as listed in the block diagram in figure 5.
- **Soil Water:** measure the current Soil state if it is dry or super dry or flooded. This sensor can directly control the irrigation system as well as the humidity.
- **Sun Light Sensor:** This sensor measures the strength of the sun light beam to determine the state of the weather if is (cloudy – Sunny – Raining (needs Soil Container to

be in open space). In Automatic Mode this Sensor controls an artificial sunlight LED with variable brightness.

4.2.2.2 Command Parser Utility

This layer is responsible for parsing different commands that will come from the cloud (issued by the HCI in the website).

This utility is real-time means that once the user gives an order, the command operation will be executed at once.

The command parse can interface and control different parts:

- **Irrigation System:** this is a small system that can deliver the water to each Soil Container independently. This gives a huge advantage to our system that it can plant different crops that shares the weather conditions but doesn't share the water amount. The irrigation system is also connected to the (humidity – Soil Water) sensors to help control the soil water level automatically.
- **Water Tank Filling:** this system keeps the water level inside the irrigation tank at a required level. The level is configurable by the user and the user have an option to fully fill the tank in case the user will leave the device for a long time.
- **Sun light LED:** it is an artificial LED that can substitute the sun light for some while. Most of these LEDs are commercially known as "full spectrum" or "daylight" LEDs. Each Soil Container Has its own LEDs to allow different crops farming.

5 Results

We have proposed a different implementation for the concept of vertical farming in the form of a domestic device to be used by anyone in an easy way, the device has been tested and used so we moved on to the next phase and went on to upgrade it by integrating more features and concepts like IoT and Machine Learning technologies for the device to be integrated in the lives of people in a seamless way.

Figure 5: Our device

6 Conclusion

This research investigated the design and implementation of a smart indoor vertical farming (SIVF) system, highlighting its potential to address challenges in traditional agriculture. The core functionalities of the system – sensor networks, automated controls, and data analysis – enable the creation of a controlled environment optimized for plant growth. By continuously monitoring environmental parameters and utilizing real-time data to adjust factors like lighting, irrigation, and nutrient delivery, SIVF systems can significantly improve resource efficiency and crop yield.

The case study presented in this paper demonstrates the effectiveness of the SIVF system in maintaining optimal growing conditions and highlights its potential benefits. As the global population continues to grow and arable land becomes increasingly scarce, SIVF technology offers a promising solution for sustainable and productive urban agriculture.

However, further research is necessary to fully unlock the potential of SIVF systems. Future advancements in areas like resource optimization, AI integration, and crop diversity will be crucial for improving efficiency, scalability, and economic viability. Additionally, exploring social and economic considerations is essential for successful integration of SIVF systems into existing food systems.[6]

In conclusion, SIVF technology represents a significant step forward in sustainable food production. By fostering continued research and development, we can leverage this technology to create a more secure and resilient food system for generations to come.

7 Future Work

The field of smart indoor vertical farming is dynamic and brimming with potential for further exploration. Here, we explore some key areas that warrant future research endeavors:

Optimizing Resource Efficiency: A critical focus will be on maximizing crop yield while minimizing water and energy consumption. This could involve advancements in LED lighting technology for improved efficiency, development of closed-loop water systems with minimal waste, and integration of renewable energy sources to power the vertical farms.

Advanced Environmental Control: Future research can delve into more precise control of environmental factors like temperature, humidity, and CO2 levels. This might involve the development of intelligent systems that dynamically adjust these parameters based on real-time data on plant needs and growth stages.

Integration of Artificial Intelligence (AI): AI holds immense potential to revolutionize vertical farming by enabling sophisticated decision-making. Future research can explore using AI to optimize nutrient delivery systems, predict and prevent pest outbreaks before they occur, and personalize growing conditions for specific plant varieties.

Expanding Crop Diversity: Current research primarily focuses on leafy greens and herbs. Future work can explore the feasibility of cultivating a wider range of crops in vertical farms, including fruits, vegetables, and even certain grains. This would require advancements in lighting technology, nutrient delivery systems, and potentially even automation for more complex crops.

Economic and Social Considerations: As vertical farming technology matures, research on its economic viability and social impact becomes crucial. This could involve studies on cost reduction strategies, potential job creation in urban areas, and integration with local food systems to improve access to fresh produce in underserved communities.

Integration with Other Sustainable Technologies: Future research can explore the potential for integrating vertical farms with other sustainable technologies like aquaponics (combining fish farming with plant cultivation) and waste heat recovery systems from buildings.

By addressing these areas of future work, researchers can further improve the efficiency, sustainability, and scalability of smart indoor vertical farming systems. This will pave the way for a more secure and resilient food production system for the future.[7]

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