

MICROGRAVITY PLANT HABITAT –PHYSICAL AND ELECTRICAL PROTOTYPING

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ABSTRACT

The article explores the intricacies of the "Microgravity Plant Habitat" through an in-depth investigation of its design, functionality, and implications for space exploration and colonization. Focusing on ongoing experiments like Veggie Plant Growth System, Advanced Plant Habitat (APH), and Space Greenhouse Experiments, the paper emphasizes the vital role of plant cultivation in supporting life, nutrition, and psychological well-being during deep space missions. The article proposes a novel solution to the challenge of water distribution in microgravity by introducing a modified aeroponics technique within a two-chambered module. This innovative approach ensures even water distribution, overcoming the complexities of gravity-free water droplet behavior. The Concept Article further details the parameters, experimental setup, and expected outcomes of the proposed system, highlighting its potential for reducing mission costs, conserving resources, and enhancing space habitability. The study contributes to advancements in space agriculture, aiming to create a sustainable and efficient system for plant growth in the unique environment of microgravity. The implications extend to the development of water management strategies critical for the success of future space exploration and habitation initiatives. The article concludes by proposing corrective measures and referencing relevant research to support ongoing efforts in space-based agriculture.

Keywords: Microgravity Plant Habitat, Extraterrestrial plant cultivation, Space agriculture, Space agriculture, Microgravity simulation

INTRODUCTION

In recent years, the exploration of space has expanded beyond the confines of our home planet, Earth, and has ignited fervor for understanding the potential of sustaining life in extraterrestrial environments. One critical aspect of this endeavor is the cultivation of plants in microgravity—a unique environment that challenges traditional notions of plant growth and development. The Microgravity Plant Habitat, a cutting-edge apparatus designed to facilitate plant growth in space, stands at the forefront of scientific innovation in the quest for sustainable life beyond Earth.

This research paper aims to explore into the complexities of the Microgravity Plant Habitat, exploring its design, functionality, and the profound implications it holds for future space exploration and colonization efforts. As humanity sets its sights on venturing further into the cosmos, the ability to cultivate plants in microgravity becomes paramount, not only for nutrition but also for the profound role plants play in maintaining life support systems and contributing to the psychological well-being of space travelers. Development of such plant habitat module will result in a bioregenerative life support system that will help in future deep space exploration and colonization of extraterrestrial planets. These modules can also cut the cost of space missions.

The challenge of establishing outposts on the Moon or Mars requires thoughtful consideration of nourishment strategies. Space-based agriculture faces significant hurdles due to harsh conditions and limited resources. Researchers explore innovative solutions like hydroponics and aeroponics to meet nutritional needs and enhance well-being in extraterrestrial settlements. Beyond technological prowess, creating space bases demands a holistic approach, addressing biological and psychological aspects. Navigating deep space exploration emphasizes that food isn't just a logistical challenge but a symbol of our resilience and determination to thrive beyond Earth's confines.

1. Veggie Plant Growth System (Ongoing): The Veggie Plant Growth System has been in operation on the International Space Station (ISS) since its installation in 2014. Ongoing experiments within Veggie continue to contribute to our understanding of microgravity plant growth, with periodic updates and new insights emerging regularly. The Veg-01, in which romaine lettuce were grown. The plants grew to be about 6 inches tall and produced edible leaves. However, some of the plants in Veg-01 were stunted and did not produce leaves.

Another experiment was Veg-03A, which grew dwarf basil plants. The basil plants grew to be about 4 inches tall and produced edible leaves. However, some of the basil plants in Veg-03A were also stunted.

2. Advanced Plant Habitat (APH) on the ISS (Ongoing): The Advanced Plant Habitat has been active on the ISS since its deployment in 2017. Continuous experiments within APH

provide a long-term dataset on plant responses to microgravity. Research efforts in this facility contribute to evolving technologies and methodologies for supporting plant growth in space.

Plant Habitat-02 (radishes): This experiment evaluated the nutritional value and growth parameters of radishes grown in APH. Results showed successful radish growth with comparable nutrient levels to Earth-grown radishes, though some variations in flavor and enzyme activity were observed.

Plant Habitat-03 (*Arabidopsis thaliana*): The study aimed to understand the genetic and epigenetic effects of spaceflight on plants. *Arabidopsis*, is a small flowering plant, was chosen for its rapid growth and well-studied genome. Initial results indicate that spaceflight can induce changes in gene expression and DNA methylation patterns, but further analysis is ongoing.

Plant Habitat-04 (Hatch chile peppers): This ongoing experiment is the first to cultivate peppers in space. The long growth cycle of peppers will test APH's ability to support sustained plant development and provide valuable insights into pepper cultivation for future space missions.

Plant Habitat-06 (tomatoes): This study investigates the impact of spaceflight on plant defense responses. Tomatoes grown in APH are exposed to immune system activators, and their responses are compared to ground controls. Understanding how plants defend themselves in space is crucial for ensuring healthy crop growth during long-duration missions.

3. Space Greenhouse Experiments (Ongoing): Ground-based space greenhouse experiments have been conducted over the past decade, with ongoing efforts to refine techniques and systems for plant cultivation in simulated microgravity conditions. These experiments are part of an iterative process to improve the efficiency and reliability of space agriculture technologies.

4. Biomass Production in Microgravity (Ongoing): Research focused on biomass production in microgravity has been ongoing for several years, with experiments conducted in parabolic flight campaigns and ground-based facilities. These experiments contribute to a growing body of knowledge, and advancements are expected to continue in the coming years.

PARAMETERS

The parameters related to the Microgravity Plant Habitat encompass a range of factors that are crucial for the successful cultivation of plants in the unique environment of microgravity. These parameters include:

- 1. Temperature Control: Optimal Growth Temperature:** Maintaining a stable and optimal temperature range is essential for plant growth. The Microgravity Plant Habitat

regulates temperature to create a conducive environment for germination, growth, and reproduction.

2. **Humidity Levels: Relative Humidity:** Controlling humidity levels is vital to prevent excessive moisture loss or accumulation. The Microgravity Plant Habitat carefully manages relative humidity to create a balanced atmosphere for plant development.
3. **Nutrient Delivery: Hydroponic Systems:** The Microgravity Plant Habitat often employs hydroponic systems for nutrient delivery. These systems ensure that plants receive the necessary minerals and nutrients required for their growth, as soil-based systems are impractical in microgravity.
4. **Lighting Conditions: LED Growth Lights:** In the absence of natural sunlight, the Microgravity Plant Habitat relies on specialized LED growth lights to provide the optimal spectrum of light for photosynthesis. These lights are programmable to simulate day and night cycles.
5. **Gas Composition: Oxygen and Carbon Dioxide Levels:** Maintaining the right balance of oxygen and carbon dioxide is critical for photosynthesis. The Microgravity Plant Habitat carefully monitors and adjusts gas composition to support plant respiration and growth.
6. **Watering Systems: Automated Watering:** In microgravity, traditional watering methods are impractical. Automated watering systems within the Microgravity Plant Habitat ensure controlled and precise delivery of water to the plant roots.
7. **Microgravity Simulation: Centrifuge Systems:** To simulate microgravity conditions on Earth, the Microgravity Plant Habitat may utilize centrifuge systems. These systems create a microgravity-like environment, allowing scientists to study plant growth under conditions similar to those in space.
8. **Monitoring and Data Collection: Sensors:** Various sensors are integrated into the Microgravity Plant Habitat to monitor environmental parameters, plant growth, and overall system performance. Real-time data collection enables scientists to make informed adjustments to optimize plant growth.
9. **Plant Species and Varieties: Selection Criteria:** The choice of plant species and varieties is crucial. Scientists carefully select plants that can thrive in microgravity conditions and contribute to a sustainable life support system.

PROBLEM STATEMENT

In microgravity, providing water to plant roots is complex. Unlike on Earth, where gravity aids water distribution, microgravity disrupts droplet behavior. Without a dominant gravitational force, droplets float unpredictably, challenging controlled water delivery to plant roots. The

floating nature of water droplets in microgravity can lead to several issues in ensuring adequate hydration for plants:

1. **Uneven Water Distribution:** The lack of gravity makes it difficult to direct water to specific areas, resulting in uneven distribution.
2. **Formation of Floating Water Clusters:** Water droplets may cluster together in microgravity, forming floating water clusters.
3. **Limited Soil Absorption:** In microgravity, the absence of this gravitational pull may limit the natural process of soil absorption, further complicating the delivery of water to plant roots.

EXPERIMENTAL SETUP

Microgravity Water Distribution Study: To investigate and understand the behavior of water droplets in microgravity and its impact on the controlled distribution of water to plant roots.

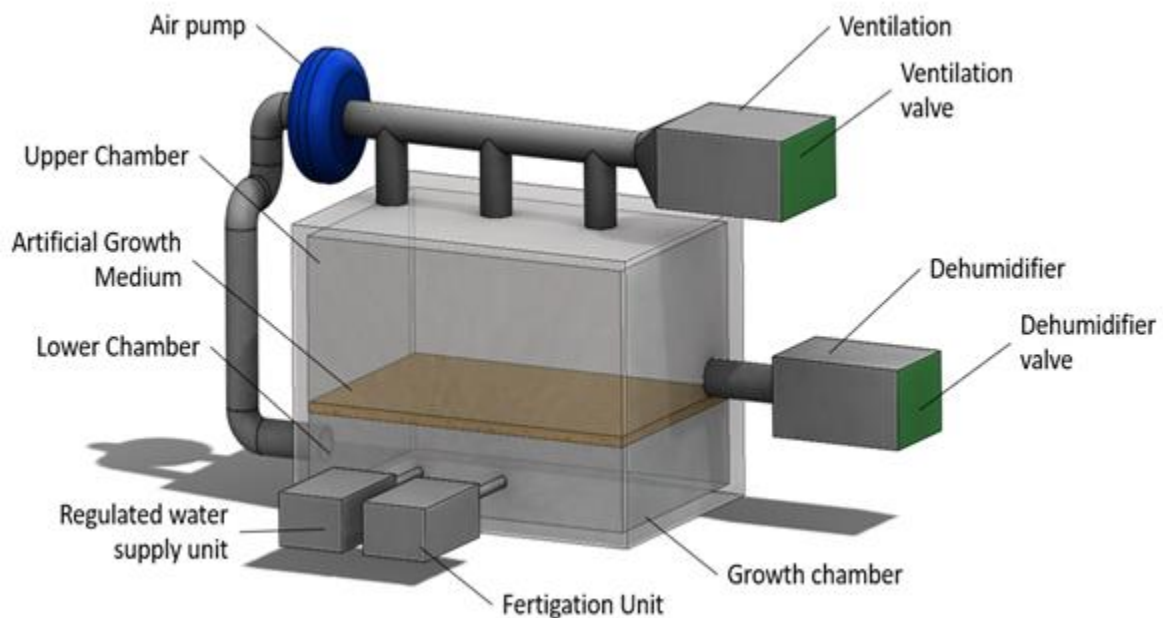


Figure 1: Experimental plant module

Even distribution of water

In our pursuit of achieving even distribution of water for the proper and regulated watering of plants within the growth module, we are implementing a modified aeroponics technique. This innovative approach involves the utilization of a two-chambered module, where water is supplied from a regulated water supply unit into the lower chamber, creating an efficient and

controlled watering system. Here is a detailed breakdown of the key components and mechanisms involved in our modified aeroponics system:

1. **Two-Chambered Module:** The growth module is designed with two chambers, separated by a layer of artificial medium positioned on a mesh. This physical division ensures a distinct upper and lower section within the module.
2. **Regulated Water Supply Unit:** A specialized water supply unit is employed to deliver water into the lower chamber of the module. This unit is equipped with precision controls to regulate the amount and frequency of water supply.
3. **Piezo Electric Plate:** Within the lower chamber, a piezo electric plate is installed. This plate vibrates at a fixed frequency, causing the supplied water to break into fine droplets or mist. This transformation of water into mist is a crucial step in facilitating efficient absorption by plant roots.
4. **Circulation System:** A circulation system is integrated into the module to create a controlled airflow. This system pulls air from the upper portion of the chamber and channels it down into the lower chamber where the mist is generated. This circulation of air ensures the upward movement of fine water droplets.
5. **Artificial Medium Layer:** The artificial medium layer, positioned on the mesh separating the two chambers, plays a pivotal role in water absorption. As the fine water droplets move upward with the circulating air, they reach the artificial medium layer. Here, the droplets are efficiently absorbed into the medium, creating a reservoir for plant use.
6. **Efficient Water Utilization:** The trapped water within the artificial medium serves as a readily available and evenly distributed water source for plant roots. This innovative system optimizes water utilization, ensuring that each plant within the module receives a consistent and regulated supply.
7. **Uniform Water Distribution:** The combined action of the piezo electric plate, circulation system, and artificial medium layer results in the uniform distribution of water throughout the module. This approach addresses the challenge of uneven water distribution in microgravity, providing an effective solution for sustaining plant growth.

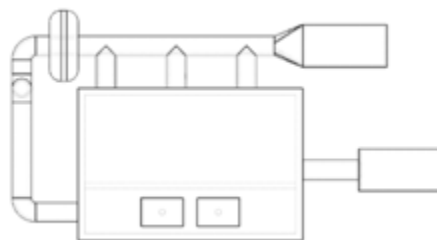


Figure 2: Side view of module

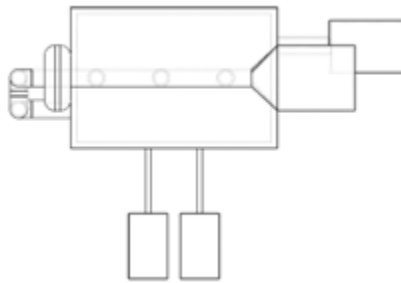


Figure 3: Top view of module

Artificial Planting Medium

In the challenging microgravity environment, traditional soil-based mediums prove impractical for cultivating plants due to their weight and inability to function effectively without gravity. To address this, we propose the use of an artificial planting medium that not only circumvents the weight limitations but also enhances water distribution and use efficiency within the plant module. Components of the Artificial Planting Medium:

1. **Foam Layers:** The artificial medium comprises two layers of foam, serving as the top and bottom boundaries of a specialized planting structure. Foam is chosen for its lightweight nature and versatility. The minute pores in the foam play a critical role in facilitating the movement of water droplets through the layers.
2. **Sphagnum Moss Layer:** Positioned in the middle of the foam layers, a layer of sphagnum moss acts as the central element of the planting medium. This moss layer serves multiple functions, including water retention and absorption. Sphagnum moss is known for its high-water absorption capacity, making it an ideal component for a microgravity planting medium.

The use of an artificial planting mix, made up of foam and sphagnum moss, is a novel solution to the challenges posed by microgravity in space-based agriculture. The clever design of this mix enables a smooth water distribution system, with droplets moving through foam layers and tiny pores to efficiently reach plant roots for consistent and controlled hydration. Furthermore, the water absorption and retention abilities of the foam and sphagnum moss contribute to prolonged water availability, improving overall water use efficiency. This distinctive sandwich-like structure not only optimizes water distribution but also ensures efficient water use, reducing the need for frequent water supply and promoting sustainable resource management. Moreover, the weight reduction achieved by using this lightweight artificial mix is crucial for optimizing resource utilization in space environments. Supported by a mesh partition allowing maximum movement of water and air between chambers, this innovative planting mix becomes a

significant contributor to the sustainability and functionality of plant modules in the challenging conditions of microgravity.

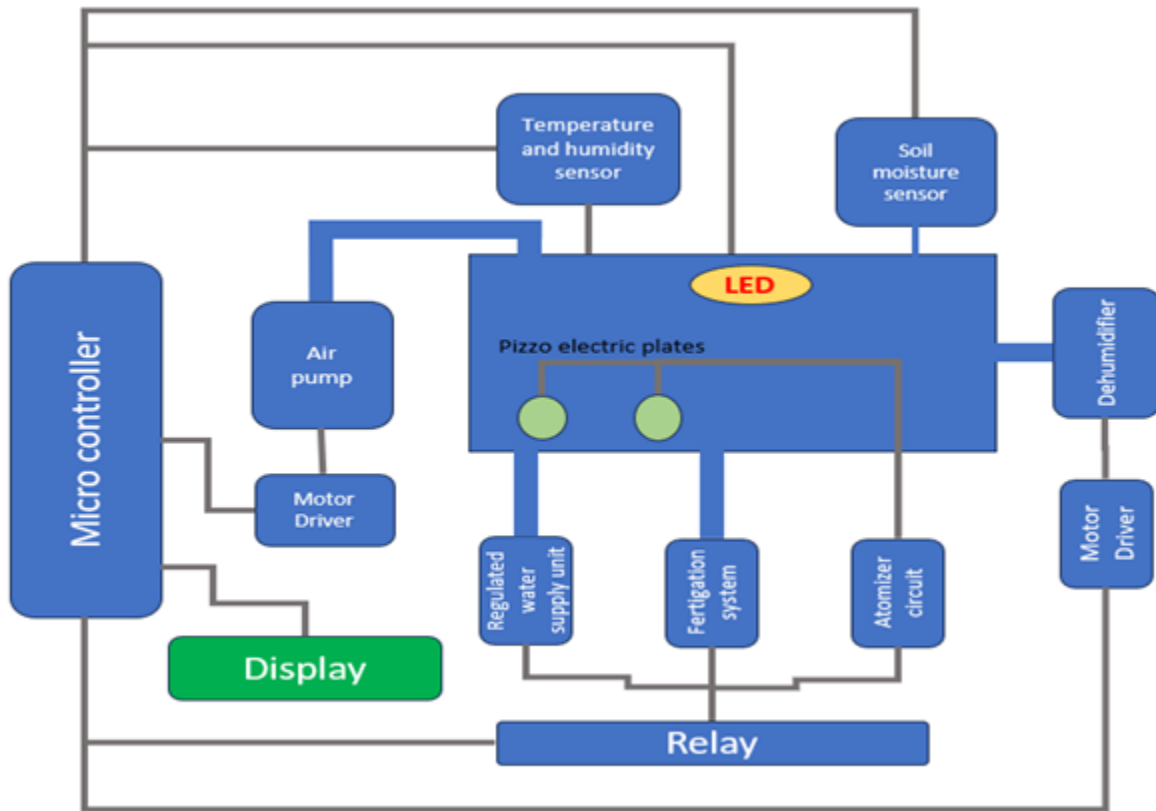


Figure 4: Electrical schematic of module

Regulated Water Supply Unit

The Regulated Water Supply Unit is the cornerstone of our precision watering system for the growth module, ensuring optimal hydration levels for plants. Controlled by the main CPU, this automated unit features motorized components, including syringes for precise water delivery. The syringes, driven by motors, guarantee a fixed water output, crucial for consistent plant hydration. Automation allows for precise control over timing and duration, adapting to plant needs at different growth stages. Designed to be adaptable and scalable, the system accommodates various plant requirements. Equipped with fault detection and correction, it ensures reliability, while energy-efficient components contribute to sustainability in space-based agriculture.

Air circulation and ventilation

Air circulation and ventilation system are essential for optimal plant growth within the module, addressing key functions such as air refreshment, humidity control, and water distribution. The core is the Air Circulation Unit, featuring a pump for dynamic airflow regulation. Inlet and outlet configuration, controlled by the Central Processing Unit (C.P.U.), ensures efficient air circulation between upper and lower chambers. The upper chamber opening, managed by the C.P.U., serves dual purposes of fresh air intake and controlled ventilation. The system also contributes to humidity control by moistening the growth medium. Variable airflow speed, adjustable by the C.P.U., caters to diverse plant growth requirements. Automated and synchronized by the C.P.U., this system enhances the overall environmental conditions for space-based agriculture, prioritizing plant health and growth.

Humidity control

For optimal plant growth in microgravity, there is integration of a Dehumidifier Unit into the upper chamber of the plant module. This unit efficiently regulates humidity and extracts water from the air, featuring key components like the Peltier Module for thermoelectric cooling. The air flow configuration directs upper chamber air to the cooling side of the Peltier module, inducing condensation. This condensed water is collected or absorbed by the unit, serving a dual purpose of humidity control and water extraction. Integrated with ventilation mechanisms, the unit maintains desired humidity levels and contributes to water-saving initiatives. Automated by the central processing unit (C.P.U.), the dehumidifier unit ensures continuous monitoring and adjustment of humidity levels, aligning with our goal of creating a self-sustaining ecosystem for space-based agriculture.

Expected Outcomes

The outcomes are summarized in bullet points:

1. **Microgravity Veggie Cultivation:** The module enables successful cultivation of vegetables in microgravity conditions, particularly in space stations. Provides a controlled environment for plant growth, addressing the challenges posed by the absence of gravity.
2. **Cost Reduction for Space Missions:** Contributes to cost reduction for space missions by establishing a sustainable source of fresh food within the space station. Reduces the dependency on Earth-based supply missions for certain food items, lowering overall mission costs.
3. **Resource Conservation:** Significantly saves important resources by creating an in-situ food production system. Limits the need to transport large quantities of perishable food items from Earth, conserving valuable resources such as fuel and cargo space.

4. **Long-term Sustainability:** Enhances the long-term sustainability of space missions by providing a continuous source of fresh and nutritious food for astronauts. Reduces the logistical challenges associated with resupplying food from Earth over extended mission durations.
5. **Scientific Advancements:** Contributes to scientific advancements in space agriculture and microgravity plant growth research. Provides valuable data and insights for future space missions, including those aimed at establishing human habitats on the Moon, Mars, or beyond.
6. **Space Habitability Improvement:** Improves the habitability of space stations by introducing a bioregenerative system that supports both plant growth and human life. Creates a more holistic and self-sustaining environment for astronauts during their missions.
7. **Bioregenerative life support system:** This will allow us advance in the technology of life support system. This type of life support system will help in the establishment of colonies at extraterrestrial habitat.

IMPLICATIONS

The results of this experiment will contribute to the development of innovative water management strategies for space agriculture, aiding in the design of systems that can reliably deliver water to plant roots in microgravity conditions. This understanding is crucial for advancing the sustainability of ecosystems beyond Earth and ensuring the success of future space exploration and habitation initiatives.

To address the challenge of proper water supply in microgravity, researchers and engineers working on space agriculture initiatives are actively pursuing innovative solutions and technologies. Several corrective measures have been identified to overcome the hurdles posed by the unique conditions of space. These measures include:

1. **Advanced Irrigation:** Develop microgravity-specific irrigation systems for targeted water delivery to plant roots.
2. **Hydroponics Optimization:** Implement and optimize soil-less hydroponic systems for efficient space-based agriculture.
3. **Capillary Action:** Explore capillary action mechanisms to guide water movement in the absence of gravity, ensuring even distribution.
4. **Water Recycling:** Integrate water recycling systems for sustainable resource management in space habitats.
5. **Smart Sensors:** Deploy real-time smart sensors to monitor soil moisture and plant hydration, optimizing water delivery.

6. **Aeroponics Investigation:** Research aeroponics techniques for controlled water and nutrient delivery in microgravity.
7. **Gravity Simulation:** Use gravity simulation devices to create localized gravitational conditions for specific plant growth areas.
8. **Adaptive Plant Varieties:** Cultivate plant varieties adaptable to microgravity, ensuring success in altered water supply environments.
9. **Collaborative Research:** Foster collaboration among space agencies, research institutions, and private companies for accelerated water management solutions.
10. **Continuous Testing:** Continuously iterate and test water supply systems to address challenges and optimize performance in space missions.

These corrective measures collectively contribute to the ongoing refinement and advancement of space agriculture, ensuring that plants receive adequate water supply for growth and sustenance in the microgravity conditions of space habitats.

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