PeaPod - Design Report

Primary Written Deliverable for the Deep Space Food Challenge Phase 1

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Contents

1 Design Abstract

Our solution is a modular aeroponic plant growth environment based upon controlled-environment agriculture principles. The ability to precisely control environmental parameters allows our system to grow any plant imaginable.

2 Design Report

2.1 Description

Part A

An automated and isolated aeroponic crop growth system, able to generate any environment from a combination of independent environment parameters, with both environment and crop growth data collection. The system takes the form of an enclosed cube, with most crew interaction limited to water and nutrient refill. Hardware components can be broken down into 4 primary categories: Feedback Systems, Resource Supply, Support Structures, and Electronic Control. Together, these 4 components create the "Black Box" seen in Figure 1.

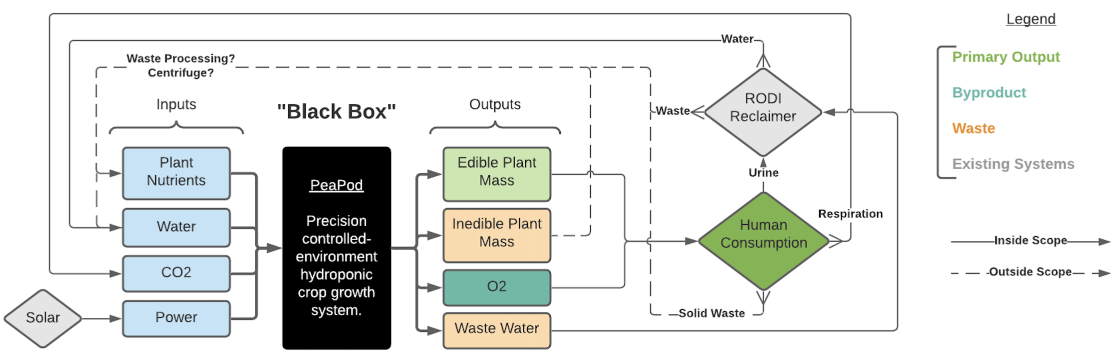

Figure 1: "Black box" function diagram for our solution.

Part B:

2.2 Innovation

2.3 Adherence to Constraints

2.3.1 Outer Dimensions, Volume

PeaPod is a modular system of "unit cells," each consisting of a .5 x .5 x .5 meter cube frame with insertable insulation walls. This cell is expandable to physically link with neighbouring cells, creating a single frame. An "expanded system" may share a single control module and have no separating wall (thus producing the same environment), or may have multiple control modules operating in either a master-slave topology (again, producing a homogenous system with no separation) or may be linked only physically (having no sharing of environment or control). The adaptibility of PeaPod ensures it meets the constraints of its environment while yielding as much produce as possible.

2.3.2 Power Consumption

Electrical power is consumed by most subsystems. Most are negligible (<100W, i.e. the computer), so only the greatest consuming systems are listed.

Lighting - Highly efficient drivers (up to 96%) were selected to minimize energy waste. 5 LED series x 3 LEDs per series x 9 LED boards = 135 LEDs[1]. The maximum consumption per LED is 3V @1.2A = 3.6W. Max Consumption: **486W**[1]

Air & Water Thermoregulation - Although less energy efficient than compressor- or resistance-based heating/cooling mechanisms, this is offset by both their reduced footprint and complexity, as well as the ability to be directly controlled electrically. This allows us to further tune the efficiency via PID control. The maximum consumption per thermoelectric tile is 8.5A @15.4V = 131W[2]. Max Consumption (2+2 Tiles[1]): **524W**

Overall Max Consumption: 1000-1200W[3]

[1] Per unit (see 2.3.1)

[2] Per-unit, although neighbouring units may be configured to run in a "follow" configuration, where they mimic the environment of the "host" unit, and may omit this system.

[3] *NOTE*: This is running ALL LEDs and both air and water thermoregulation at max power. The system's power output is over-engineered, and will likely never be used this way in most use cases.

2.3.3 Water Consumption

Water is consumed by two systems:

Humidification: By using a mesh nebulizer to produce smaller and more consistent droplets (vapour), a less non-vapour mist was produced, thus resulting in a greater overall water consumption efficiency.

Aeroponics: Aeroponics by design uses far less water than traditional farming (up to 98%). In addition, higher quality nozzles with adjustable directionality allow for more of the water to be sprayed directly at the root zone and with better and more consistent droplet sizes for better uptake (5-50 micron mean droplet diameter). Finally, by enclosing the root zone in a waterproof bag, no water escapes, and excess/runoff water collected at the bottom of the bag can be removed via an outlet and recycled (RO reclaimer).

2.3.4 Mass

Through the optimization of volume, the mass of PeaPod was indirectly minimized. By using smaller parts, power consumption and complexity was reduced along with volume and mass. PeaPod's mass was also optimized through minimizing density across components. Aluminum was chosen for the framing due to it's high strength to density ratio. For insulation, a less dense foam coated in mylar was used to maintain PeaPod's insulating capabilities while reducing mass.

2.3.5 Data Connection

Automation: All of PeaPod's operation is automated, save for a select few maintenance tasks. This is controlled by a central computer, which uses a "program" to enact the desired environment at each point in time throughout the plant life cycle.

This program comprises of a set of **time-series instructions** concerning the various environment parameters (i.e. set leaf zone air temperature to 23 degrees C at 16:30 each day). These parameters include:

- Leaf zone air temperature;
- Leaf zone humidity;

- Aeroponics nozzle activation (on/off);
- Root zone/aeroponics spray temperature;
- Light activation (% per LED series);
- etc.

Remote Control: The program may be changed at any time instantaneously, remotely or on-board. These changes are reflected as an **appended instruction set** to the program, and take effect immediately.

Alongside and fuelling this automation is an array of environment parameter (aka feedback) and plant metric sensors. These include:

- Leaf zone air temperature;
- Leaf zone air humidity;
- Water temperature (pre-aerosolization);
- Root zone air temperature;
- Leaf zone CO_2 ppm;
- Leaf zone top-down and side camera capture/live feed, with computer vision analysis for:
  - Leaf health indicators (i.e. leaf tip burn, leaf curl, chlorosis);
  - Leaf count, size distribution;
  - Leaf density;
  - Canopy dimensions/surface area;
  - Plant height;
  - Fruit/harvest body size, ripeness;
  - etc.

Feedback: The feedback sensors provide the computer with information that will influence the control it exerts. For example, if the program indicates the leaf zone temperature should be set to

22 degrees C, the computer would apply greater power to the heater if the current temperature was 18 degrees C as opposed to 21 degrees C. This forms a control loop for each parameter, relying on one of many control functions (bang-bang, PID, etc.).

Data Presentation: This data collection, accompanied by a number of "known" quanities (i.e. aeroponics flow rate, per-LED spectral data) allows for a full quantitative description of each plant's growth environment to be displayed on-board and remotely, instantaneously, with live updates (i.e. real-time data, live video feed).

2.3.6 Crew Time Requirement - Setup & Maintenance

Since PeaPod automates data collection and nutrient transfer, the only operational costs for the crew are to harvest plants and fill resources. Harvesting is simple, since the plant just needs to be removed from its cup. And, since nutrient mixing is an automated, inline process, crews need only fill nutrient solution resevoirs as they empty. This lack of manual solution mixing results in mere minutes of work per week.

2.3.7 Palatability of Crop Output

Hydroponic crops have seen commercial success, suggesting that their output is of sufficient hedonic quality to be desired. Additionally, PeaPod is designed to optimize for edible plant mass, nutrient denisty, and other health indicators—pushing hedonic quality up over time.

2.3.8 Operational Constraints

Gravity informed the use of an aeroponic system, as this allows plants to be placed in a hanging cup secured only on one side. Ambient pressure is critical for component selection regarding the tank, bladder, and nozzle, all of which are designed to produce the outputs we desire at this air pressure. Ambient temperature and humidity allow the use of mylar as an insulator, as it is of sufficient quality to work in these conditions.

2.3.9 Processing Time for Outputs

By creating a solution to "grow plants," PeaPod has been designed from the ground up to produce food that requires no additional processing time. Harvesting is an instantaneous process, and raw produce is immediately consumable, as the user can decide precisely what they wish to grow.

2.4 Performance Criteria

2.4.1 Acceptability

Acceptability of Process

Acceptability of Food Products

2.4.2 Safety

Safety of Process

Safety of Food Products

2.4.3 Resource Inputs and Outputs

Resource Inputs

System Outputs

Optimization

Maximizing output is perhaps the greatest strength of PeaPod. Since it is fully automated, growth cycles have a high degree of certainty that let researches hone in on the perfect conditions—and then repeat them ad infinitum. By collecting data in an isolated environment like this, optimization can be done on any number of parameters, including quantity of inputs. As trials are conducted and PeaPod gathers data, it measures the quantity of inputs taken and a plethora of plant data related to usable quantity, bringing PeaPod to the most efficient conditions over time. In addition, the array of sensors used to collect data double as input for PID control, letting PeaPod react to unpredictable events such as poor seed health and salvage otherwise poor outputs.

Food Output Quality

2.4.4 Reliability and/or Stability

Process Reliability

By nature of its design, PeaPod will last three years at near 100% functionality on minimal maintenance. This is achieved by self-monitoring component health, using servicable materials, and providing smart notifications to the user when maintenance is needed. For one, PeaPod is designed to be assembled by a single user with readily available tools. This means it can be disassembled, cleaned, and put back together by one person in a non-restrictive amount of time. For another, the sensors used to monitor plant health and growing conditions allow PeaPod to notify the user when a part needs to be fixed or replaced. For example, if humidity readings fall below historical levels for current water output, PeaPod will notify the user to replace the insulating material in the nozzle area. If light intensity begins to drop in a certain sector, PeaPod will tell the user to replace a certain bulb.

This said, every component in PeaPod has an expected lifespan over three years. From the LEDs (rated for 5 years) to the nozzle (only needs periodic cleaning) to the bonding agents (tested for materials used), replacement monitoring is only needed as a backup.

Scheduled maintenance breaks down to three primary tasks: refilling nutrients, cleaning spray nozzle, and harvesting/replacing plants. Since PeaPod mixes the nutrient solution automatically, the only required maintenance is replenshing stores of water and individual nutrients. By tracking consumption rates and using past trends, PeaPod can schedule the most efficient refill time in advance and notify the user. The spray nozzle, by way of its fine mesh, will build fine amounts of sediment over time. This can be easily cleaned by the user at either pre-determined times or, as mentioned above, when the unit detects an issue. Finally, plant harvesting is a quick task that simply constitues opening the unit and removing the plant. Replacing it only requires the user to open the unit, place the seed in the grow cup, and digitally set the grow conditions for PeaPod to follow.

Input and Output Stability

2.5 Terrestrial Potential

Customer-facing Food Service

At present, a restaurant requires either a local supplier or a substantial amount of outdoor space (and labour) to serve fresh produce. Both of these are cost-prohibitive, and the latter is entirely impossible in many situations. Local suppliers' high costs are the result of a few things:

- Limited seasonal availability
- Frequent transport need
- High costs with little demand

PeaPod has the potential to reduce these barriers in a cyclic way. Partnerships between local suppliers and restaurants will provide these restuarants with space- and time-efficient PeaPod units with the purpose of generating both produce and data. The increase in produce will reduce the frequency at which suppliers need to make deliveries, while the data produced will let suppliers maximize output. Over time, this can increase efficiency to the point where local suppliers can provide produce at a lower price.

Crowdsourced Research

Due to PeaPod's automated nature, off-site research is a feasibile method of collecting data. As a result, universities and other institutions can save costs related to space and energy usage by subsidizing PeaPods to consumers, schools, or even restaurants. Users would receive sets of paramters within which to grow crops, and the data would be sent back to the institution. The user can use the produce, at the cost of space and energy, while the institution continues to provide parameters with which to grow. The end result is a massive set of data, conducted in identical conditions in different places, verified by comparison with the myriad devices conducting the same tests.

De-centralized Production

Many crops are only feasible in certain climates, making global transport a necessity to sell them worldwide. This reduces freshness, necessitates various preservatives, and increases carbon consumption. By upscaling PeaPod technology to a farm scale, it becomes possible to produce climate-bound crops in any location. This creates region-based farms that can produce a tremendous variety of crops, vastly reducing transport needs and making it easier to have a local food diet.

Blockchain By collecting data provided by a large variety of users and institutions, we are able to create an n-dimensional set of data for any given plant that, with enough data points, can find correlations between any of n parameters. In the same way current cryptocurrencies rewards nodes for validating all information on the network, PeaPod would reward nodes for validating data produced by other nodes. When hundreds of units produce statistically similar results in independent trials, all units are rewarded for their contribution to the network. This allows consumers the option to operate a PeaPod as a passive source of income, with the unit paying for itself by producing food and cryptocurrency before starting to make a profit.

This also incentivizes the network to find critical points in the n-dimensional set of data that would otherwise not be checked. For example, few users would purpposely grow plants in drought conditions at this will produce subpar produce. But, by incentivising users to fill otherwise sparse sections of data, we can generate information critical to developing crops for territories ravaged by climate change.