PeaPod - Solution Overview

Outlining a Proposal to the PeaPod Requirements

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1 Introduction

1.1 Purpose

The purpose of this document is to outline the fuction and features of a design proposed to meet the PeaPod Requirements.

It accomplishes this by addressing the following prompts on a recursive tree basis:

1. **What** is the design's purpose and function?
2. **How** does it accomplish this? What is the method/process?
3. Justification on how the selected features meet the method better than alternatives.

2 Design

The purpose of the design is derived from the opportunity statement:

PeaPod is "an automated and isolated aeroponic crop growth system, able to generate any growth environment from a combination of independent environment parameters, with both environment and crop growth data collection for optimization".

The primary function of the overall design are derived from both the overall purpose as well as the system inputs and outputs as defined by the DSFC Applicant Guide [1].

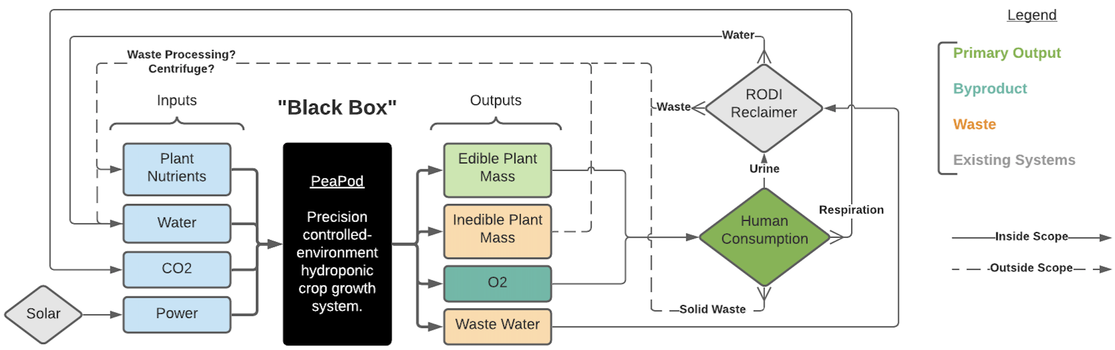

Figure 1: "Black box" function diagram of PeaPod.

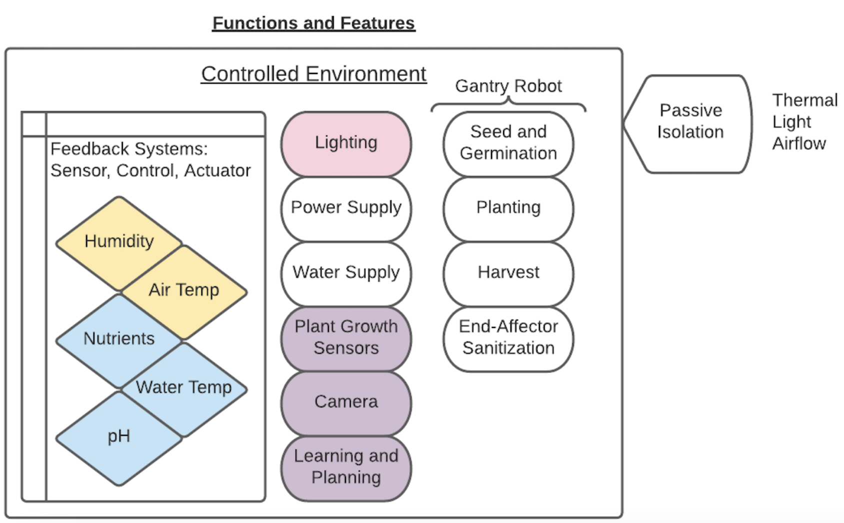

Figure 2: Features and feature types of PeaPod.

2.1 Automation

Function: Performing growth-, maintenance-, and data-related tasks autonomously on the basis of both schedule and necessity to reduce crew maintenance time. Maintains the homogeneity of the internal environment.

Process:

1. User inputs program:
    - Action-at-timestamp, e.g. lights on at 08:00;
    - Control target with start/end, e.g. hold air temperature at 22°C from 11:00 to 18:00;
2. Notification on maintenance requirement (i.e. non-automated input/output management);
3. "Sense, Plan, Act" robotics/control model:
    (a) *Senses* current conditions;
    (b) *Plans* a path to desired condition;
    (c) *Acts* to change current condition to desired condition;

Features:

- Central computer system with internal clock and cloud connection;
- Environment sensors (*Sense*);
- "Program" of time-series and/or control target instructions (*Plan*);
- Actuators (*Act*);

Justification:

- **Function**: Increased accuracy/precision over human interference, minimize human hours spent. Enables control over all parameters simultaneously.
- **Process**: Data structure matches $\vec{E}$ from the optimization routine (see Section 2.5). Control loop-style topology is common is well suited for controlled-environment agriculture.
- **Features**: Automation implies computers. Sensors and actuators directly parallel process components.

2.2 Housing

Function: *Isolates* and *Insulates* growth environment from exterior environment (heat, light, humidity). Provides structural integrity and mounting points for other subsystems (*Frame*).

Process:

- Insulation (*keep in*):
  - Heat - Insulative/reflective internal shell
  - Light - Reflective internal shell
  - Moisture - "Sealed" shell
- Isolation (*keep out*):
  - Heat - Insulative shell
  - Light - Opaque shell
  - Moisture - "Sealed" shell
- ∴ Frame skeleton w/ solid, internally-reflective, "sealed" panels;
- Standard subframes for mounting entire subsystems modularly;

Features:

- Aluminum extrusion skeleton w/ standard mounting channels;
- Foam insulation panels w/ mylar internal coating slide into exoskeleton channels;
- Trays - base subframe unit, adaptable; mounted to vertical internal channels for vertical repositioning:
  - Grow trays - Hold up plants, aeroponic nozzles (See 2.3, and misting container.
  - Lighting trays - Many LED boards, one driver board (See 2.4.7).

Justification:

- **Function**: Insulation increases thermal and light efficiency. Isolation increases safety against cross-contamination, pathogens, harmful substances.
- **Process**: Solid frame-and-panel construction is efficient for packing away, and is honestly just simple. Adaptable tray subframes make future feature development easier, and allows to modularly swap subsystems.
- **Features**: Aluminum extrusion is commonly used for frames. Allows strong, repositionable mounting via channels. Foam insulation is highly insulative and opaque, and mylar ensures

internal light reflection. Sliding directly into extrusion channels boosts "seal".

2.3 Aeroponics

Function: *Delivers nutrients* to the plants via a fine mist. Utilizing a diaphram pump and pressure accumulator tank, filtered water with correct ph and nutrient concentration is pressurized to 80 psi before being atomized by the nozzle and subsequently abosorbed by the roots.

Process:

- Solution Formulation (*PH and Nutrients*):
  - Filter - Water is sourced from an external RO system.
  - PH - PH solution is added to the water either through a resevoir or manifold. This process is controlled through automation.
  - Nutrients - Nutrient solution is added to the water either through a resevoir or manifold. This process is controlled through automation.
- Pressurization (*Maintaining 80-100 psi*):
  - Pump - Pump pressurizes water to 80 psi.
  - Accumulator Tank - Uses an air bladder to stabilize and maintain 80 psi.
  - Pressure Sensor - Located between tank and solenoid to monitor the pressure of the system. Data is used in automation.
- Delivery (*Atomizing*):
  - Solenoid Valve - Located between tank and nozzle. Enables on demand misting for automation.
  - Quick Connector - Connects nozzle to main supply line (from solenoid). Allows grow trays to be removed quickly and efficiently.
  - Nozzle - 0.4mm - 0.6mm orifice produces 5 - 50 micron water droplets. Mist is sprayed onto plant roots.
- $\therefore$ Correct fittings and tubing for all components.
- All components rated for 125 psi.

Features:

- Pump is self-priming.
- Pump has auto pressure regulation, will automatically turn off at 80 psi of back pressure.
- Tank has safety valve that prevents over pressure.

- Quick connects allow grow tray to be removed and installed very quickly without the need for tools.

Justification:

- **Function**: A high pressure aeroponics system eliminates water parameter feedback. Nozzles are located in root zone on grow platforms, grow platforms are completely passive and only require the quick connect to the main supply line. grow 5 - 50 micron droplet size is the optimal range for root abosorbtion.
- **Process**: System is medium-free, eliminating risk of pathogens developing within root zone. System is 98% more water efficient. Using a nozzle ensures the nutrient solution is evenly distributed. Using RO filtered water eliminates the common problem of the nozzles clogging with calcium.
- **Features**: Components are non-specialized and can be sourced easily at attainable prices. Diamphram pumps are reliable due to less moving parts and self-priming so the pump can draw its own water without the need for back pressure.

2.4 Environment Control

The environment control feature can be broken up into **control systems** (2.4.1-2.4.3; sometimes in two parts) and **set systems** (2.4.4-2.4.7).

2.4.1 Air Temperature

What: Maintaining desired air temperature within the enclosure.

How: Thermoelectric heating/cooling system (peltier tiles w/ polarity switch, 'dimming' current control, PID) on a heat sink w/ fan, feedback from distributed temp sensors.

Why: TECs have better space and energy efficiency, less complexity (no liquids, pressurized fluids, etc.), better control vs other methods. PID provides best control.

2.4.2 Air Humidification

What: Adding water vapour to air.

How: Ultrasonic nebulizer (piezo disc w/ custom driver circuit), RO water.

Why: Piezo for droplet size, commonly used; RO for purity of water vapour.

2.4.3 Air Dehumidification

What: Absorbs water vapour from the air.

How: Silica gel bead cartridges with fans/valves to control airflow across.

Why: Non-toxic, safe, cheap, effective. Color-changing indication at saturation, easily reset by baking and recapturing water.

2.4.4 Solution Temperature

What: Maintaining desired water temperature within the water store.

How: Same as 2.4.1; on a water block.

Why: Same as 2.4.1.

2.4.5 Solution Nutrients

What: Precisely dosing the correct amount of various nutrients (K^+, NO_3^-, etc.) to the water system at setup/water addition.

How: Syringe-like dosage via servo motor to set ppm based on fill volume.

Why: Syringe dosage is precise, easy to refill.

2.4.6 Solution pH

What: Precisely adds pH up/down solutions to set the solution pH at setup/water addition.

How: Same as 2.4.5.

Why: Same as 2.4.5.

2.4.7 Lighting

What: Wide spectrum precision LED lighting targeting PAR.

How: N LED series/colors, N controlled-current PWM drivers, M LEDs per series = NxM LEDs. Custom LED boards wired in series, one power board per tray, w/ diffusion.

Why: LED > every other type in every way, PWM easy protocol, CC because they're LEDs.

2.5 Optimization

Function: Continuously improve yield/etc. of crops as more environment parameter and crop metric data is gathered.

Process:

Assume a plant's growth rate (or state change) is related to its current internal state $\vec{P} \in \mathbb{R}^n$ (for n plant metrics) and the environment conditions $\vec{E} \in \mathbb{R}^m$ (for m environment parameters). Let these both be functions $\vec{P}(t), \vec{E}(t)$ defined at each t, where $t = 0$ indicates the time of planting. Assume that this relationship is constant for all members of a given species.

Define plant state change $\vec{P}'$:

$$\vec{P}'(t) = \frac{d}{dt}\vec{P}(t)$$

Define the plant-environment behaviour function Q:

$$Q(\vec{P}(t), \vec{E}(t), t) = \vec{P}'(t)$$

Aka given the current internal and external states, determine the plant's state change.

By setting $\vec{E}_{set}(t)\ \forall\ t$, recording $\vec{P}(t)\ \forall\ t$ and $\vec{E}(t) \approx \vec{E}_{set}(t)\ \forall\ t$ (See 2.4), and calculating $\vec{P}'(t)\ \forall\ t$, we can fit $\vec{Q}$ to our data.

By fitting $\vec{Q}$, we can predict $\vec{P}$ at any $\vec{E}$ and t. For example:

$$\vec{P}(t + \Delta t) = P(t) + \Delta t \cdot Q(\vec{P}(t), \vec{E}(t))$$

Features:

- Machine learning model to represent Q
- Environment sensors to collect $\vec{E}$

- Plant metrics to collect $\vec{P}$

References

[1] "DSFC Applicant Guide," Impact Canada, launched by NASA/CSA. [Online]. Available: https://impact.canada.ca/en/challenges/deep-space-food-challenge/application-guide