PeaPod - Solution Overview

Outlining a Proposal to the PeaPod Requirements

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1 Introduction

1.1 Purpose & Design Process

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

It accomplishes this via the following process:

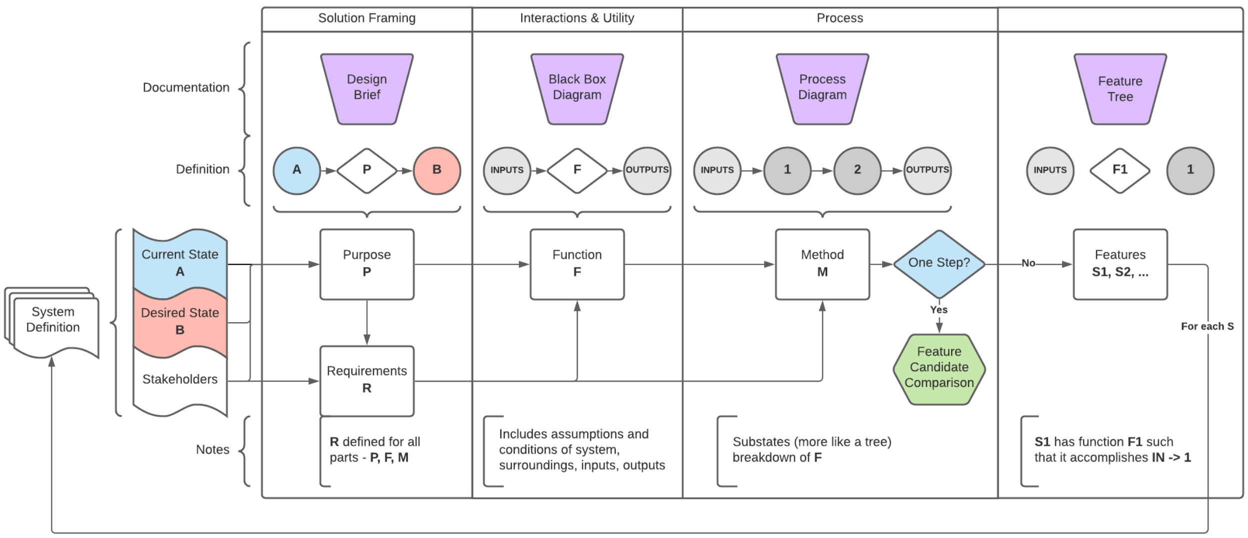

Figure 1: Engineering design process.

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].

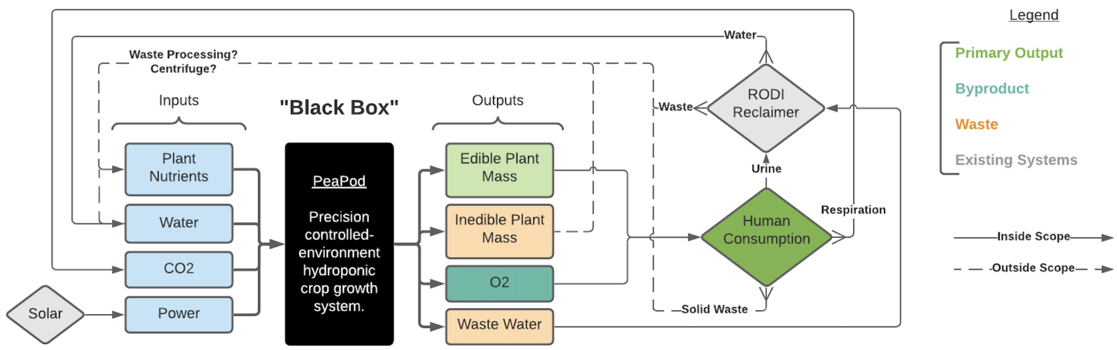

Figure 2: "Black box" function diagram of PeaPod.

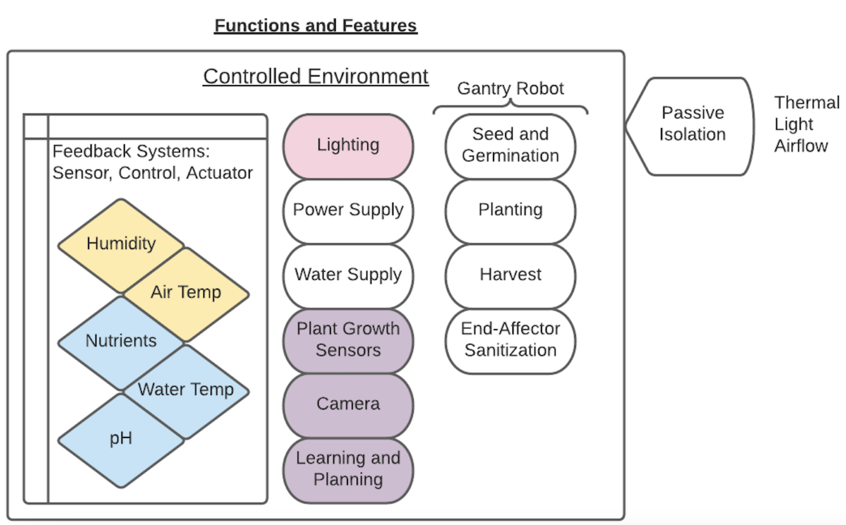

Figure 3: Features and feature types of PeaPod.

2.1 Automation

Purpose: 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.

Function:

- **Inputs**: Power, network connection, environment sensor reading signals, program
- **Outputs**: Actuator control signals, crew messaging

Method:

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** (2.1.1) with internal clock and network connection;
- Environment sensors (*Sense*) for each **environmental control** (2.4);
- **Program** (2.1.2) of time-series and/or control target instructions (*Plan*);
- Actuators (*Act*) for each **environmental control** (2.4);

Justification:

- **Purpose**: Increased accuracy/precision over human interference, minimize human hours spent. Enables control over all parameters simultaneously.
- **Method**: 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.

2.1.1 Computer System

Purpose: Primary operating infrastructure. Automation, data transmission, remote control.

Function:

- **Inputs**:
- **Outputs**:

Method:

Features:

Justification:

- **Purpose**:
- **Method**:

2.1.2 Program

Purpose: Set of environment parameter instructions for the automation system.

Function:

- **Inputs**:
- **Outputs**:

Method:

Features:

Justification:

- **Purpose**:
- **Method**:

2.2 Housing

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

Method:

- 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; all connections are *quick-disconnect* (i.e. quick-connect tubing for grow tray, push connectors for lighting):
  - Grow trays - Support plants (via grow cups), aeroponic nozzles (See 2.3, and misting container.
  - Lighting trays - Support LED boards, driver board (See 2.4.7).

Justification:

- **Function**: Insulation increases thermal and light efficiency. Isolation increases safety against cross-contamination, pathogens, harmful substances.
- **Method**: 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

Purpose: Delivers *nutrients* and *pH*-balanced, *temperature*-controlled *water* to the plants via a *fine mist* (50 micron mean droplet diameter).

Function:

- **Inputs**: Filtered/RO water under positive pressure, pH up & down solutions, concentrated nutrient solutions, pump control (on/off relay to pump power), nozzle control (on/off relay to solenoid)
- **Outputs**: 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.

Method:

- Water is sourced from an external RO system with positive pressure;
- Water is pressurized to constant 80psi;
- Water is heated or cooled to a given temp (2.1.2);
- Nutrient and pH-adjustment solutions are mixed in-line at an adjustable ratio (2.1.2); [1]
- Flow to nozzle is controlled (on/off) (2.1);
- Nozzle turns pressurized water into mist;

Features (in order of plumbing; source ⟶ nozzle):

- *Water Source*: Input for filtered, reverse-osmosis water.
- *Diaphragm Pump*: Self-priming, auto-shutoff at 80psi. Power is controlled by external relay signal (2.1).
- *Inline Water Heater/Cooler*: Thermoelectric heater/cooler
- *Accumulator Tank*: Uses an air bladder to create and stabilize pressure.
- *Pressure Sensor* reports to computer (2.1). Allows for shutoff of pump in case of emergency.
- *Adjustable-rate Siphon Injection Manifold*: A set of venturi-based siphon injectors for flow-ratio siphoning of solutions (onen siphon per). See 2.3.1.
- *Solenoid Valve* - Enables on-demand (2.1) misting.

[1] I.e. add X mL of nutrient solution Y per mL water to achieve Z ppm, or add A mL of pH down solution per mL water to achieve a pH of B.

- *Grow Tray Quick-Disconnect*: Connectors between aeroponics supply and nozzles that allow for quick disconnection with auto-shutoff so the trays may be removed.
- *Nozzle*: Mounted to grow tray, pointed at plant roots. 80psi water through a 0.4⟶0.6mm orifice produces 5⟶50 micron water droplets.

Justification:

- **Purpose**: A high pressure aeroponics system eliminates water parameter feedback, and is 98% more water efficient than traditional farming.
- **Function**: RO water has no dissolved nutrients and a neutral pH of 7.0. This enables easier and more reliable calculations. In addition, it has no particulate or minerals, minimizing the chances of nozzle clog.
- **Method**: System is medium-free, eliminating risk of pathogens developing within root zone. Using a nozzle ensures the nutrient solution is evenly distributed. 5-50 micron mean droplet size is optimal for plant growth.

2.3.1 Solution Injection Manifold

Purpose:

Function:

- **Inputs**:
- **Outputs**:

Method:

1.

Features:

-

Justification:

- **Purpose**:
- **Method**:

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.

Function: *Regulates temperature* of the air in growth environment at a desired temperature through automation.

Method:

- Air Management (*circulate air and measure temperature*):
  - Fans - Located in growth environment to circulate air evenly.
  - Temperature Sensor - Located in growth environment to measure air temperature.

- Thermal Exchange (*mixing solution into water stream*):
  - Heat Sinks - Connected to peltier devices. Exchanges heat between air and peltier devices.
  - Peltier Devices - Moves heat from one side to another. Subsequently moves heat into or out off growth envrionment.

Features:

- Both heating and cooling can be accomplished by the same peltier devices through switching the polarity of the peltier devices.
- Peltier devices require no refridgerant and compressor to operate as a cooler.
- Peltier devices have no moving parts (increases reliability) and are compact, only requiring low voltage dc electrical connection.
- Heat sinks and peltier devices are cheap and readily available.

Justification:

- **Function**: Air management ensures an even temperature throughout the entire growth environment. Thermal exchange effectively pumps heat into or out of the growth envrionment.
- **Method**: Peltier devices have better space and energy efficiency, less complexity (no liquids, pressurized fluids, etc.), and can provide precise temperature control at low voltages through automation via methods such as PID.
- **Features**: Peltier devices are commonly used as cooling components in mini refridgerators.

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

Function: *Removes moisture* from the growth environment on demand. Used in conjunction with humidity sensor and humidification system to maintain a desired humidity.

Method:

- Circulation (*moving air through system*):
  - Chamber - Where air is dehumidified. Only one in, and one out.
  - Fan - Blows air into the growth environment from chamber, subsequently draws air through humidification system.
  - Filter - HEPA filter is located at inlet of chamber. Eliminates risk of any airborn pathogens being transferred onto silica beads.
  - Shutters - Isolates dehumidification chamber when not in use. One located at chamber inlet, and one located at chamber outlet.
- Dehumidification (*remove moisture from air*):
  - Cartridge - Holds silica beads. Allows beads to be removed quickly and easily.
  - Silica Beads - Absorbs moisture from air passed around it.
- Rejuvenation (*remove moisture from silica*):
  - Evaporator - Warms cartridge to evaporate moisture collected by silica beads.

Features:

- Silica gel beads provide very efficient dehumidification.
- Silica beads are non-toxic.
- Silica beads are completely passive and require no active electricity (aside from shutters and fans).
- Silica beads change color to indicate saturation.
- Silica beads can be easily reused by drying them out. Moisture can be captured during the drying process and be recycled.

Justification:

- **Function**: Silica beads are completely passive and provide very efficient dehumidification.
- **Method**: Cartridges make replacing the silica beads very quick and easy.
- **Features**: Silica gel is non-toxic and non-organic. Silica beads can be sourced easily and are not too expensive. Silica beads change color to indicate saturation, making it easy to tell when they need to be rejuvenated.

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

Function: Formulates the correct concentration of nutrient solution by *precisely injecting* the correct amounts of nutrient solution into the water stream.

Method:

- Water Supply (*water into system*):
  - RO System - External filtration system.
  - Unidirectional Valve - Located between RO system and venturi syphons to prevent backflow into RO system.
  - Pump - Same pump as 2.3. Draws water from RO system.
- Injection (*mixing solution into water stream*):
  - Venturi Syphon - Located between unidirectional valve and pump. Creates a vacuum that draws nutrient solution into main water stream.
  - Proportional Control Solenoid - Located at side inlet of venturi syphon. Enables controlling flow of nutrient solution into water stream.
  - Unidirectional Valve - Located between proportional control solenoid and nutrient solution container. Prevents dilution of nutrient solution container.
  - Nutrient Solution Container - Holds nutrient solutions.
- Control (*maintaining solution ratio*):
  - Flow Sensor - Located at intlet of venturi syphon. Measures flow into venturi syphon.
  - Solution Sensor - Located at outlet of venturi syphon. Measures solution concentration. Data is combined with flow sensor to control the porportional solenoid valve through automation.
- ∴ All appropriate fittings and tubing.

Features:

- Venturi syphon is passive and relies on the main pump to draw solution into main stream.

- Proportional control solenoid is very precise and allows for precision control over solution ratio.
- System has minimal moving parts which increases reliability.
- Both venturi syphon and proportional control solenoid can be bought as off the shelf components.

Justification:

- **Function**: Water supply moves water into system. Injection formulates correct solution ratio. Control enables injection management through automation.
- **Method**: This system enables precise inline solution injection which eliminates need for a resevoir. Proportional control solenoid allows for very precise control of solution ratio. Venturi syphon is completely passive, completely eliminating the need for a solution pump.
- **Features**: All parts are common and can be bought off the shelf. Venturi syphon is a proven reliable way to mix solution into a main stream. Is used in many applications from paint sprayers to fertilizer injectors.

2.4.6 Solution pH

Function: Formulates the correct pH of the solution by *precisely injecting* the correct amounts of pH up/down solutions into the water stream.

Method:

- Water Supply (*water into system*):
  - RO System - External filtration system.
  - Unidirectional Valve - Located between RO system and venturi syphons to prevent backflow into RO system.
  - Pump - Same pump as 2.3. Draws water from RO system.
- Injection (*mixing solution into water stream*):
  - Venturi Syphon - Located between unidirectional valve and pump. Creates a vacuum that draws nutrient solution into main water stream.
  - Proportional Control Solenoids - Located at side inlet of venturi syphon. Enables controlling flow of pH up/down solutions into water stream. One for each solution.
  - Unidirectional Valve - Located between proportional control solenoid and nutrient solution container. Prevents dilution of pH up/down solution containers.
  - pH Solution Containers - Holds pH up/down solutions. One for each solution.
- Control (*maintaining solution ratio*):
  - Flow Sensor - Located at intlet of venturi syphon. Measures flow into venturi syphon.
  - Solution Sensor - Located at outlet of venturi syphon. Measures solution pH. Data is combined with flow sensor to control the porportional solenoid valves through automation.
- ∴ All appropriate fittings and tubing.

Features:

- Venturi syphon is passive and relies on the main pump to draw solution into main stream.
- Proportional control solenoid is very precise and allows for precision control over solution ratio.
- System has minimal moving parts which increases reliability.
- Both venturi syphon and proportional control solenoid can be bought as off the shelf components.

Justification:

- **Function**: Water supply moves water into system. Injection formulates correct solution pH. Control enables injection management through automation.
- **Method**: This system enables precise inline solution injection which eliminates need for a resevoir. Proportional control solenoid allows for very precise control of solution ratio. Venturi syphon is completely passive, completely eliminating the need for a solution pump.
- **Features**: All parts are common and can be bought off the shelf. Venturi syphon is a proven reliable way to mix solution into a main stream. Is used in many applications from paint sprayers to fertilizer injectors.

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.

Method:

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