NILE

Polar Robotics System Concept

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1.0 Introduction

Conventional agricultural methods overcompensate plant and soil needs through wasteful watering practices and excessive application of pesticides and fertilizers, leading to substantial environmental damage. This damage takes on various forms, including pollution via runoff, soil depletion, and the extinction of local pollinators.

1.1 Requirements

NILE has chosen to combat this issue with a system designed to nurture crops between the planting harvesting phases. This system will make optimal use of available resources via the precise application of water and nutrients to crops. To achieve this NILE has defined the following requirements.

a. The system shall be capable of measuring the water saturation for the soil at any point within the growing zone.
b. The system shall be capable of measuring the pH-level of the soil at any point in the growing zone.
c. The system shall be capable of measuring the temperature of the growing zone.
d. The system shall be capable of irrigating crops within the growing zone with a field application efficiency greater than 90%.
e. The system shall be capable of supplying the nutrients needed to maintain plant health within the growing zone.
f. The system shall be capable of exterminating parasites from any point in the growing zone.
g. The system shall be capable of determining the location of plant foliage, plant stems, and parasites within the growing zone.
h. The system shall be capable of being certified to an ingress protection level of IP55.
i. The system shall be capable of communicating plant health, soil health, and the detection of parasites to the end user.

The requirements stated above refer to several terms that have been explicitly defined for the context of this project. Refer to the Appendix A for definitions.

1.2 Existing Solutions

There have been numerous attempts by individuals and organizations to revolutionize farming in recent years. One of the most significant developments in modern history is the center-pivot irrigation system. This 1950s technology made the industrialized agriculture model seen across the western united states possible but vastly decreasing labor costs and increasing water efficiency [1]. However, with the devastating effects of global warming and increased environmental protections the center-pivot is increasingly obsolete.

Many organizations have stepped up to the plate, but it remains to be seen what the game changing technology for this century will be. During our research phase we found a variety of approaches from factory style greenhouses and mobile platforms for large farms to backyard solutions and machine learning tailored care.

One such approach is the democratization of agriculture through systems such as the FarmBot [10]. These small, backyard systems aim to increase access to produce by automating food production on a small scale with robotics. This novel approach has many advantages but, in its current state, is not suitable for meeting the needs of large populations.

Another approach can be found at AgBotic Inc. and their robotic gantry which allows for significantly increased control over individual plants when compared to traditional systems [3][6]. Unfortunately, it requires significant infrastructure investment in greenhouses and supporting equipment which prohibits widescale adoption.

One intriguing, fully mobile approach is Rowbot. Designed for the autonomous navigation of row-based fields, this system can address the seeding and fertilizing needs of farmers [4]. However, it is not entirely applicable to our problem statement due to its somewhat limited scope.

Furthermore, in our research we have found numerous academic examples of the integration of sensors and irrigation systems to assess plant health, but few truly autonomous systems. For example, machine learning has been paired with computer vision to scan images of plant leaves, and identify individual plants, as well as distinguish between healthy and diseased crops based solely on physical appearance [5][8].

2.0 Concept Development

Given the vast scale of the problem we have chosen to tackle we needed to break things down into more manageable components. The first step of that process was the writing of requirements in which the basic capabilities of the system were defined. Then we defined the general functions of system need implement the requirements. These base functions are as follows.

a. **Mode of Locomotion**: how the system maneuvers end effector(s) in the growing zone.
b. **Power System**: the method used to provide power to the electronic components.
c. **Fluid Handling**: how water and fertilizer is transported within the system.
d. **End Effector Operation**: how sensors, nozzles, etc. are mounted to the end effector.
e. **Watering End Effector**: the tool by which water is delivered to the growing zone.
f. **Parasite Removal End Effector**: the tool used to eliminate parasites.
g. **Detection Hardware**: the physical devices used to determine the location of plants.
h. **Detection Software**: how the system would determine plant health data.
i. **Communication**: how the system would communicate its status to the end user.
j. **Growing Zone**: the environment in which the system will operate.

Given these numerous functions we brainstormed numerous concepts that could potentially implement them. To evaluate the numerous possibilities, we compiled them in the following morphological chart.

2.1 Morphological Chart

A morphological chart was used to compile all the design ideas and condensed them into categories.

Functions	Concepts						
	1	2	3	4	5	6	7
Mode of Locomotion	*A-Frame*	*Polar*	*Cartesian*	*Train*	*Bug*	*Strand-beast*	*Mobile-Arm*
Power System	*Bat. /Inductive*	*Bat. /Solar*	*Bat. /Grid*	*Bat. /Swap*	*Rail*	*Grid Power*	
Fluid Handling	*Combined Fluid Line*	*Dual Fluid Line*	*Fertilizer Mixing*				
End Effector Operation	*Hot-Swap*	*Rotary*	*Multiple*	*Omnibus*	*Hand*		
Watering End Effector	*Nozzle*	*Needle*	*Water Capsule*				
Parasite Removal End Effector	*Drill*	*Prong*	*Laser*	*Fire*	*Wedge*	*Taser*	
Detection Hardware	*Camera*	*False NDVI*	*Stereoscopic*	*Infrared*	*LIDAR*		
Detection Software	*CV Segmentation*	*CV and ML*	*Spidering*	*User Input*			
Communication	*Terminal*	*Web app*	*Screen*				
Growing Zone	*Raised Bed*	*Pots*	*Field*				

Figure 1. Design Concept Morphological Chart

2.1.1 Mode of Locomotion

a1. A-Frame: cartesian gantry system mounted on a set of wheels for lateral translation
a2. Polar: polar gantry system mounted in place, rotating about a central axis
a3. Cartesian: 3-axis cartesian frame mounted in place, translating along 3 mutually perpendicular axes
a4. Train: train-like mobile chassis with actuated linkages
a5. Bug: collection of 4 miniature, single-purpose mobile systems
a6. Strand-beast: multi-legged mobile system with sensors embedded in footpads
a7. Mobile-Arm: 6 degree-of-freedom dexterous manipulator mounted on rail for lateral translation

2.1.2 Power System

b1. Inductive battery: battery-operated system with inductive recharging
b2. Solar battery: battery-operated system with solar recharging
b3. Grid battery: battery-operated system with power grid recharging
b4. Swappable battery: interchangeable battery powered system
b5. Rail: contact rail conductive power
b6. Grid Power: standard wall outlet powered system

2.1.3 Fluid Handling

c1. Combined Fluid Line: single conduit for delivering hydration and fertilizer
c2. Dual Fluid Line: separate conduits for hydration and fertilizer
c3. Fertilizer Mixing: hydration flow directed through fertilizer compound

2.1.4 End Effector Operation

d1. Hot-Swap: interchangeable, single purpose end-effectors
d2. Rotary: single end-effector rotating to present different tools and sensors
d3. Multiple: numerous, single purpose end-effectors with independent actuation
d4. Omnibus: single end-effector with all probes and sensors contained
d5. Hand: end-effector for grasping individual tools and sensors

2.1.5 Watering End Effector

e1. Nozzle: above-soil spray of water at targeted locations
e2. Needle: pressurized below-soil water application probe
e3. Water Capsule: dissolvable water packets to be dispensed at targeted locations

2.1.6 Parasite Removal End Effector

f1. Drill: high-speed drill bit for shredding parasite structure
f2. Prong: gripped prong for plucking up parasite structure
f3. Laser: focused light beam for incinerating targets
f4. Fire: focused combustible substance for incinerating targets
f5. Wedge: sharp edge for pressing into and destroying parasites
f6. Taser: electric arc application for destroying parasite tissue structure

2.1.7 Detection Hardware

g1. Camera: single lens optical sensor
g2. False NDVI: economical heat-based imaging and analysis
g3. Stereoscopic: dual lens optical sensor with depth perception
g4. Infrared: full scale heat-based imaging and analysis
g5. LIDAR: environment perception with laser range finding

2.1.8 Detection Software

h1. CV Segmentation: computer vision image segmentation for plant detection
h2. CV and ML: computer vision and machine learning for plant detection and identification
h3. Spidering: optical shape analysis for plant location and shape detection
h4. User Input: user-provided coordinates for plant and parasite locations

2.1.9 Communication

i1. Terminal: non-graphical data output through serial terminal
i2. Web application: internet-supported graphical user interface
i3. Screen: onboard graphical user interface

2.1.10 Growing Zone

j1. Raised Bed: above-ground soil container
j2. Pots: individual soil containers for each plant
j3. Field: plot of landscape with tillable soil

2.2 Decision Matrices

Decision matrices were used to make our design choices less subjective. Weights were implemented to quantify the value of certain design criteria, ensuring appropriately prioritized results. The weights are on a one-to-five scale listed under the 'Priority' column. Five was used to indicate highest importance and one represented the lowest importance. Scores within each design concept category were also ranked with a one-to-five scale, where five indicated a suitable fit, and one represented a poor fit.

The percentages are calculated by multiplying the priority weight by the category score and then dividing by the best total score possible for all combined criteria. Yielding a mathematical expression for how well a particular design concept aligned with key metrics. The criteria used to evaluate each aspect of conceptual design differed between each category, below is a list of all criteria and definitions applied during the full evaluation process.

a. **Ease of Implementation:** simplicity in fabrication, assembly, and installation
b. **Ease of Control:** feasibility in electrical and kinematic operation
c. **Ease of Maintenance:** simplicity of structural and mechanical maintenance
d. **Robustness:** a measure of resistance to deterioration in performance over time
e. **Scalability:** how well the system can be adapted to large-scale operations
f. **Precision/Dexterity:** exactness in positioning, orientating, or generating valid outputs

g. **Water Efficiency:** water application efficiency, see Appendix A for definition
h. **Plant Location Metrics:** accuracy in determining location of plants and parasites
i. **Plant Health Metrics:** accuracy in determining status and well-being of plants
j. **Communication Effectiveness:** readability and accessibility of system data to end user
k. **Cost:** financial expenses, or demands in processing power requirements

2.2.1 Locomotion

Criteria	Priority	Design Concepts						
		A-frame	**Polar**	Cartesian	Train	Bug	Strandbeast	Mobile Arm
Ease of Implementation	3	4	4	5	3	2	1	3
Ease of Control	5	4	5	5	2	2	1	4
Ease of Maintenance	4	5	5	5	4	4	1	1
Robustness	2	3	4	3	3	2	1	1
Scalability	3	5	3	2	5	5	1	2
Cost	3	3	4	3	2	2	1	0
Totals		**82%**	**86%**	**81%**	**62%**	**57%**	**20%**	**41%**

Figure 2. Locomotion Decision Matrix

The polar configuration scored the highest on our decision matrix which was to be expected. Since the polar gantry form of locomotion is the most mechanically simple, the easiest to control, and the most feasible considering a 6-month project length our team made the conclusion that this solution was the most appropriate. With simpler mechanical components, there would be more focus on developing successful software analysis of the plants. The cartesian and A-frame both scored high but required more parts, driving the overall cost up, and were less robust.

2.2.2 Power

Criteria	Priority	Design Concepts					
		Tram	**Grid**	Battery Inductive	Battery Solar	Battery Grid	Battery Swap
Ease of Implementation	4	4	5	2	4	3	4
Ease of Maintenance	3	4	5	3	3	4	3
Robustness	5	2	3	3	5	4	3
Scalability	4	5	5	3	5	4	1
Cost	3	5	5	3	3	3	1
Totals		**77%**	**89%**	**56%**	**83%**	**73%**	**49%**

Figure 3. Power Supply Decision Matrix

Grid, solar, and tram scored the highest on the decision matrix. Overall, using power from the grid was both the most feasible and how the system would be powered if used in industry. If the project timeline/budget allows for it, there is the possibility to utilize solar powered batteries for the robot.

2.2.3 Fluid Handling

Criteria	Priority	Design Concepts		
		Combined Line	Multiple Lines	Fertilizer Mixing
Ease of Implementation	4	4	3	3
Ease of Control	4	5	5	4
Ease of Maintenance	3	4	3	3
Robustness	5	4	5	3
Cost	3	4	3	2
Totals		**84%**	**79%**	**61%**

Figure 4. Fluid Application Decision Matrix

The combined line provided the opportunity for cleaning which was an extra benefit that the multiple lines and fertilizing mixing did not allow for. The combined line was an easy decision since it scored the highest in every category. The multiple lines scored high but required more mechanical parts, driving the overall cost up, and would be more difficult implement.

2.2.4 End-Effector

Criteria	Priority	Design Concepts				
		Hotswapping	Rotary	Multiple	**Omnibus**	Grabber
Ease of Implementation	4	2	4	5	5	2
Ease of Control	5	3	4	4	5	2
Ease of Maintenance	3	5	4	3	4	4
Robustness	5	3	2	4	3	2
Precision/Dexterity	4	3	4	3	3	2
Cost	2	2	3	1	4	1
Totals		**60%**	**70%**	**72%**	**80%**	**43%**

Figure 5. End-Effector Decision Matrix

Omnibus, rotary, and multiple scored the highest on the decision matrix. Overall, using the omnibus was both the most feasible and the easiest to control which will optimize the robot's water efficiency stated by the system requirements. The multiple scored high but required more mechanical parts, driving the overall cost up, and would be more to control.

2.2.5 Watering

Criteria	Priority	Design Concepts		
		Nozzle	Syringe	Water Capsules
Ease of Implementation	4	5	5	2
Ease of Control	5	5	5	3
Ease of Maintenance	3	5	4	1
Robustness	5	4	3	5
Water Efficiency	4	4	5	3
Cost	2	5	4	0
Totals		**92%**	**87%**	**55%**

Figure 6. Water Delivery Decision Matrix

The main debate of this decision matrix was the decision between using the syringe and the nozzle. The syringe would have a higher water transport efficiency but risks being clogged by the soil. Because of this, risking the integrity of the system was not worth the slight increase in water transport efficiency that it would provide.

2.2.6 Parasite Removal

Criteria	Priority	Design Concepts					
		Drill	Prong	Laser	Fire	Wedge	Taser
Ease of Implementation	3	4	5	3	0	5	4
Ease of Control	5	4	2	5	1	4	4
Ease of Maintenance	4	3	4	2	1	5	4
Robustness	4	4	4	2	3	5	4
Precision/Effectiveness	5	5	4	5	1	2	4
Cost	3	4	5	0	1	5	3
Totals		**81%**	**77%**	**63%**	**24%**	**83%**	**78%**

Figure 7. Parasite Removal Decision Matrix

For parasite removal, the main concern was ease of control and precision in operation, as the system needed to be able to target specific parasites without damaging neighboring plants. The drill concept scored the highest, and taser the second highest. However, after further discussion we decided to implement the taser due to it requiring fewer moving parts.

2.2.7 Detection Hardware

Criteria	Priority	Design Concepts				
		Camera	False NDVI	Stereoscopic	Infrared	LIDAR
Physical Implementation	4	5	5	5	5	3
Digital Implementation	2	4	4	4	4	3
Plant Health Metrics	5	3	4	3	5	1
Plant Location Metrics	4	3	4	5	3	5
Cost	4	5	4	5	5	4
Totals		**79%**	**84%**	**87%**	**89%**	**62%**

Figure 8. Detection Hardware Decision Matrix

For the system requirement of locating and distinguishing plants and parasites within the growing zone, we considered all viable options for inspecting the contents of the plant bed. Placing high priority on properly identifying plant health, the decision matrix depicted above in Figure 8 highlights the fact that infrared imaging scored the highest, however our team had immediate access to hardware needed for the stereoscopic solution. Thus, in the interest of budget, we chose to implement the stereoscopic option.

2.2.8 Detection Software

Criteria	Priority	Design Concepts			
		Computer Vision	Machine Learning	Spidering	User Input
Ease of Implementation	5	4	3	3	5
Robustness	3	3	4	2	3
Plant Health Metrics	4	4	5	1	3
Plant Location Metrics	5	3	4	4	5
Computation Cost	3	5	4	5	1
Totals		**75%**	**79%**	**60%**	**74%**

Figure 9. Detection Software Decision Matrix

Focusing more specifically on our system algorithm for processing data and assessing plant detection and health metrics, we weighed both simple and sophisticated approaches. Considering accuracy in results, our decision matrix shown above in Figure 9 conveyed machine learning as the most sufficient option. This approach will utilize a combination of computer vision and machine learning, as described in the Software Concept section.

2.2.9 Growing Zone

Criteria	Priority	Design Concepts		
		Raised Bed	Pots	Field
Ease of Implementation	4	4	5	3
Plant Compatability	3	5	3	5
Scalability	5	4	3	5
Cost	4	3	4	2
Totals		**79%**	**75%**	**75%**

Figure 10. Growing Zone Decision Matrix

Although our chassis design could be adaptable to any flat growing surface, we selected type of growing zone enclosure for completeness. With a narrow margin, implementing a raised bed soil container was shown to be the best solution for accommodating different plant varieties, while allowing for rapid scalability and reasonable price ranges.

2.2.10 Communication

Criteria	Priority	Design Concepts		
		Terminal	**Web Application**	Onboard Screen
Ease of Implementation	3	5	4	3
Ease of Use	4	2	5	4
Comunication Effectivness	5	1	5	4
Cost	3	5	4	2
Totals		**57%**	**92%**	**68%**

Figure 11. Communication Decision Matrix

Figure 11 lists our three concepts for communicating updates, reminders, and status information to the end user. With a heavy emphasis on communication effectiveness and readability of output data, development of a web-based application satisfied the criteria most adequately, even outscoring the competing concepts in ease of implementation and lower financial cost.

3.0 Conceptual Design

After going through the morphological and decision matrix process, we know the general outline of our design. The NILE system will consist of a polar robot that will operate in a raised bed growing zone and receive power from the grid along with water/fertilize from storage tanks. All the required tasks will be performed by an omnibus end effector consisting of a nozzle for watering, a taser type system for parasite elimination, and a stereoscopic imaging system. Furthermore, image processing will be done by a machine learning algorithm and the system will communicate its status to the end user via a web app.

The following sections will cover how this general outline could be implemented in the real world while taking cost, time, and the requirements in mind.

3.1 Mechanical Concept

Given the decision to create a polar robot, we took inspiration from the ubiquitous center-pivot irrigation system in our design. Our proposal consists of a rotational joint about the center, a horizontal translational joint along the gantry, and a vertical translational joint at the end effector. With these three joints the robot could reach any point within the circular growing zone.

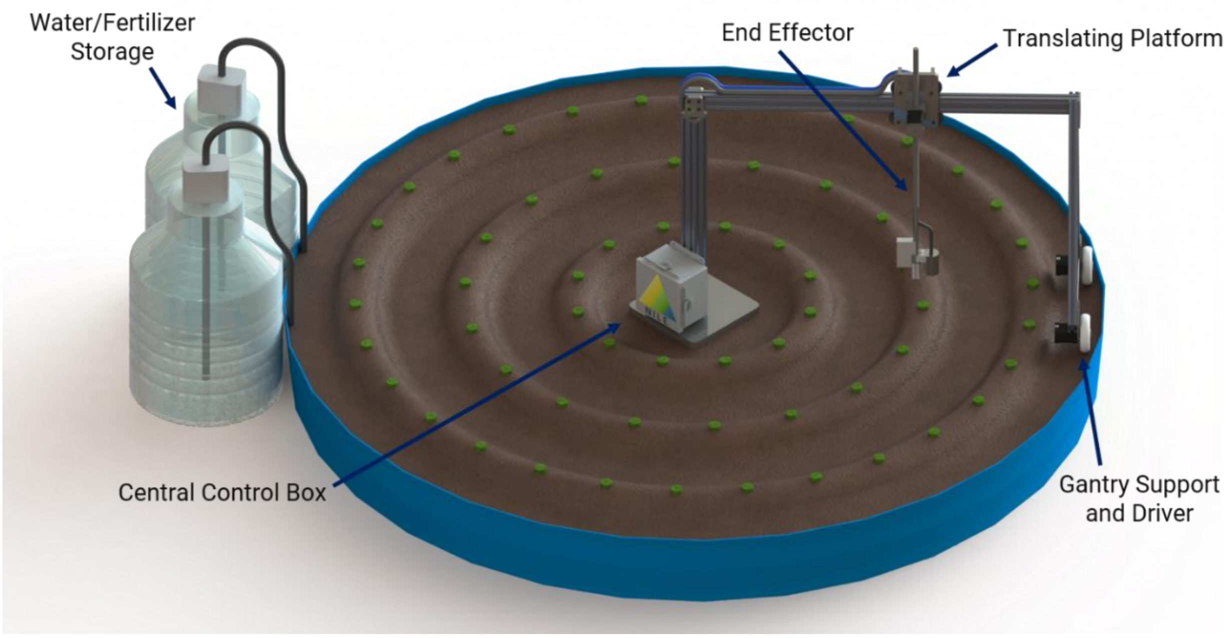

Figure 12. NILE Conceptual Design

As can be seen above in Figure 12, the static central base supports the onboard microcontrollers and power distribution to be discussed in section 3.2. Rotation is achieved via motorized wheels at the end of the rotating gantry to maximize torque. The angle of rotation will be determined by an encoder located at the central tower.

In addition to the robotic system, water and liquid fertilizer will be stored nearby to be pumped to the end effector when need. The growing zone will be constructed from a round plastic basin, otherwise known as a kid’s swimming pool, and will have a 2-meter diameter.

3.1.1 Translation Platform

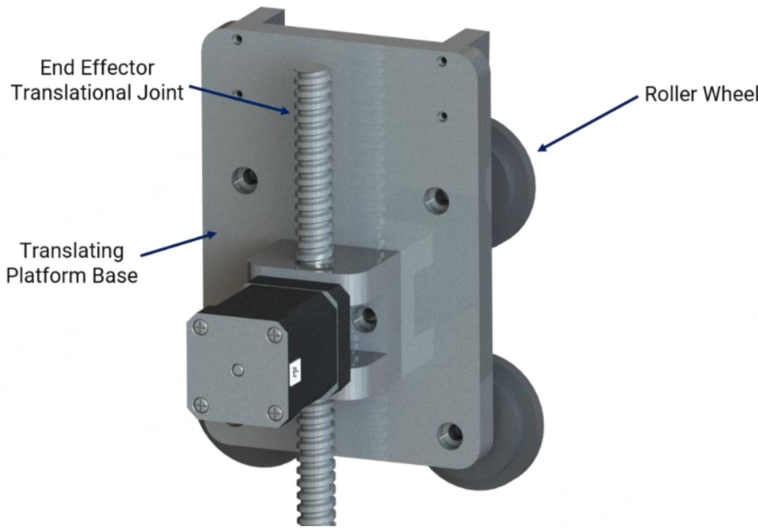

Figure 13. NILE Translational Platform

The translational gantry platform, as seen in Figure 13, translates horizontally using the roller wheels on the horizontal rail. Vertical translation is achieved by a translation joint connected to the translating platform base. Motor encoders are used for determining the horizontal and vertical positions.

3.1.2 End Effector

The end effector omnibus maintains an efficient movement to data ratio. The subsoil sensors can all be pressed into the soil at the same time, working with the robot to gather all the necessary data in one movement. The Taser's position allows for parasite removal with the same movement commands as data gathering, making for simple control schemes. The location of the water nozzle allows for precise application close to the soil and the plants roots.

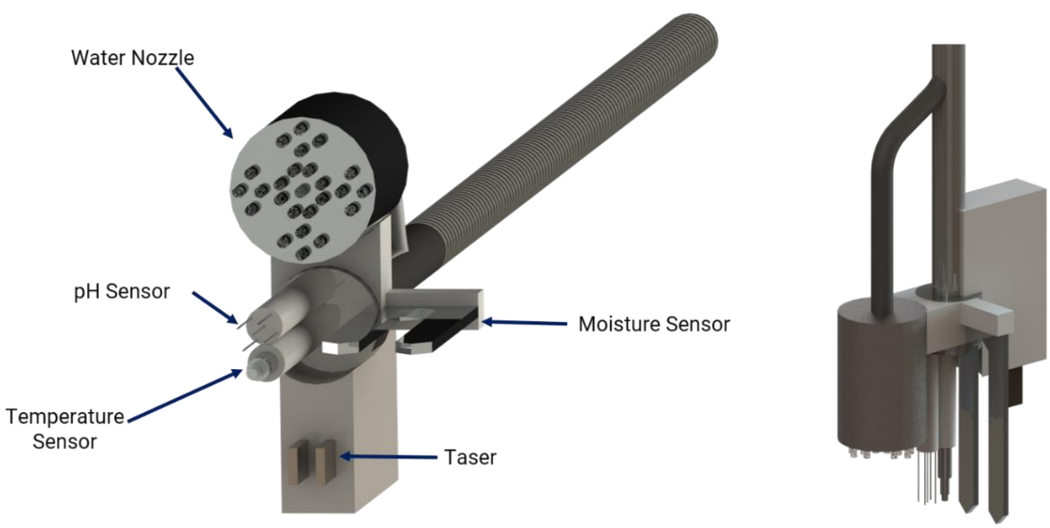

Figure 14. NILE End Effector

3.2 Electrical Concept

Power distribution on the robot will be relatively simple. 120 Vac mains power will be fed into a power supply which will be capable of outputting 12V for motors, pumps, and the taser and 5V for the microcontrollers and sensors. It would need to be capable of providing around 5 A-10 A of current in to ensure the motors are properly driven and to feed the high-power taser.

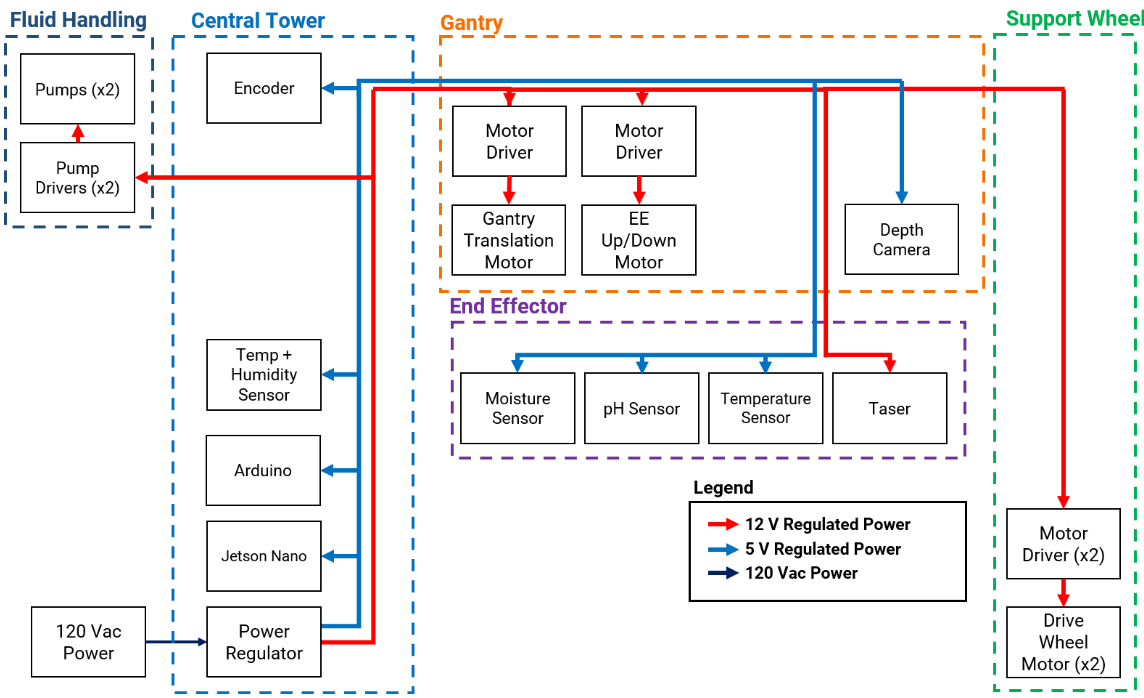

Figure 15. Power Block Diagram

3.2.1 Taser Circuit

To facilitate the removal of parasites, the robot will be equipped with a high-voltage parasite elimination system that disrupts xylem tissue, causing immediate death. This will be done via a taser / stun-gun circuit, which uses a transformer to boost the 12V power up into the 10kV - 25kV range to produce an electrical arc. The frequency of this arc can then be controlled via the Arduino, so it is only on when desired. A general design of this circuit is displayed below. [9]

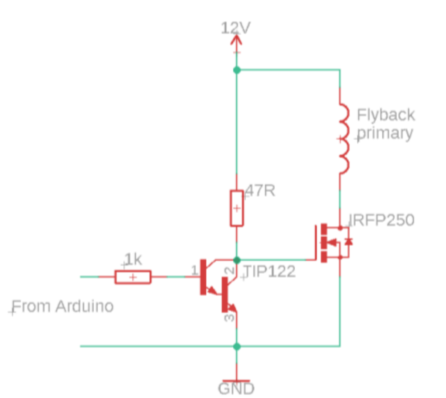

Figure 16. Taser Circuit [9]

3.3 Software Concept

The system will include two control units; an NVIDIA Jetson Nano and an Arduino. This system architecture allows for image and data processing to occur in parallel with low level motor control and data acquisition. The two microcontrollers will communicate via a USB serial connection.

Acting as the brain of the system, the Jetson will request data from the Arduino, process it, and then issue commands back to the Arduino to drive the motors. The Jetson also uploads the processed data to an external server so it can easily be displayed to the end user via a web application. This server connection in bidirectional so users can specify certain actions (e.g., watering amounts, times, fertilizer thresholds, etc.) for the system to accomplish.

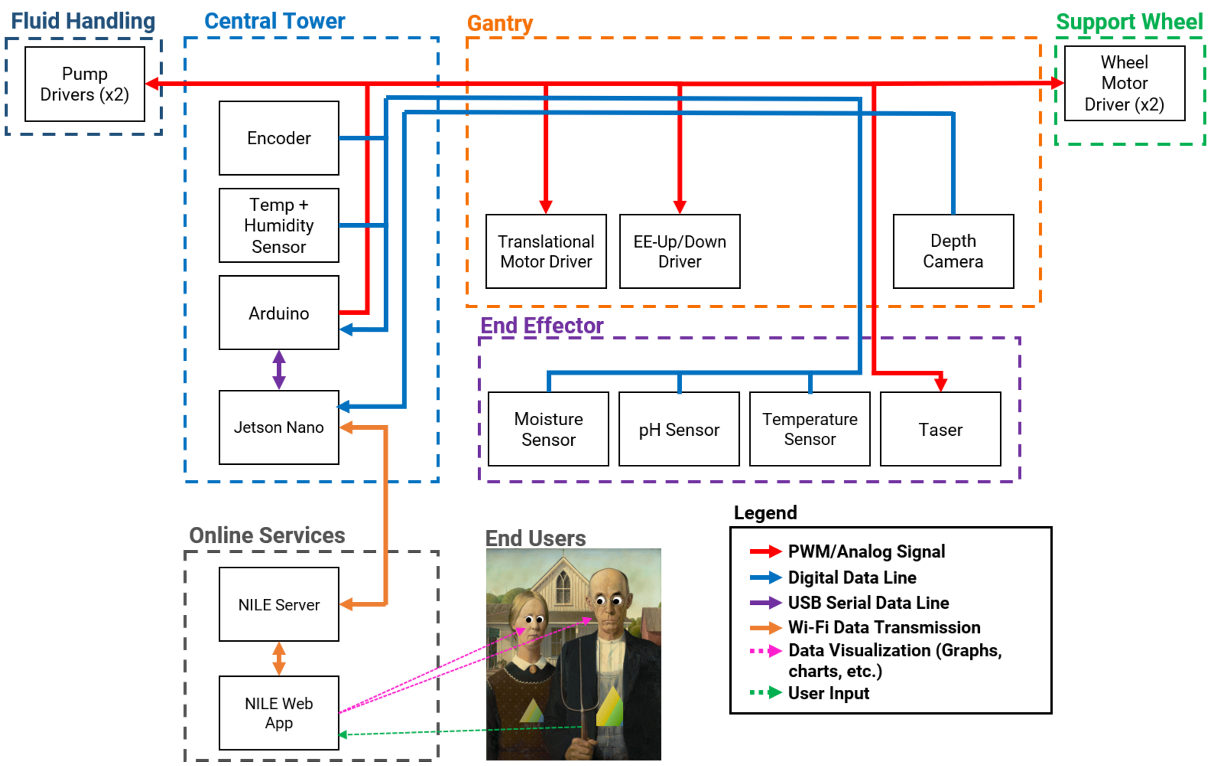

Figure 17. Data Block Diagram

3.3.1 Plant Maintenance Algorithm

To tend to plants within the growing zone, the system will implement a waypoint inspection algorithm. When not active, the processor will remain in a state of computational sleep. At regular intervals determined by an internal clock, the central processing unit (CPU) will spring to life and position the end effector at predetermined waypoints for analysis. Upon reaching a waypoint, the CPU will capture an image from the stereoscopic camera and perform a combination of image processing and machine learning synthesis. This process is described in greater detail in the next section.

Once complete, the algorithm will use the processed results to determine whether a plant exists at the specified waypoint. If no growth is found, soil temperature and pH measurements will be taken at that location. When a growth is detected, the algorithm will address it in one of two ways. For parasites, the end effector will be positioned over the plant such that the High Voltage Parasite elimination tool is able to contact the top of the growth, killing the parasite upon contact. For desired plants, the system will use the plant metrics inferred through the computer vision and machine learning deduction to apply water and fertilizer as needed.

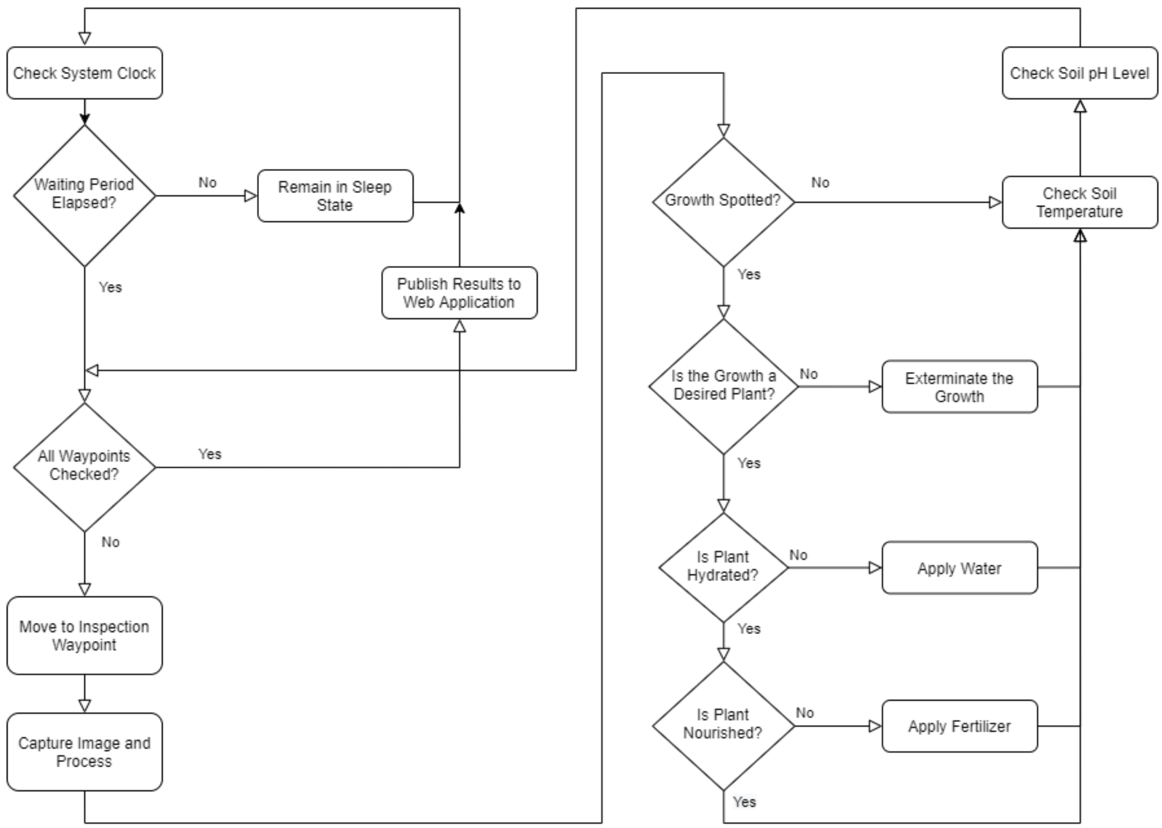

Figure 18. Plant Care Flowchart

3.3.2 Plant Position and Health

The determination of plant location and health metrics within the growing zone will be accomplished via a combination of computer vision image processing and machine learning based reasoning.

The waypoints discussed above will be spaced such that a collage of images taken at each location will produce a complete picture of the growing zone. Then, using the capabilities of stereoscopic imaging, separation of foreground and background can be performed. Additionally, a point cloud of image depths can be applied to further to distinguish individual leaves and plant structures that overlap and occlude one another.

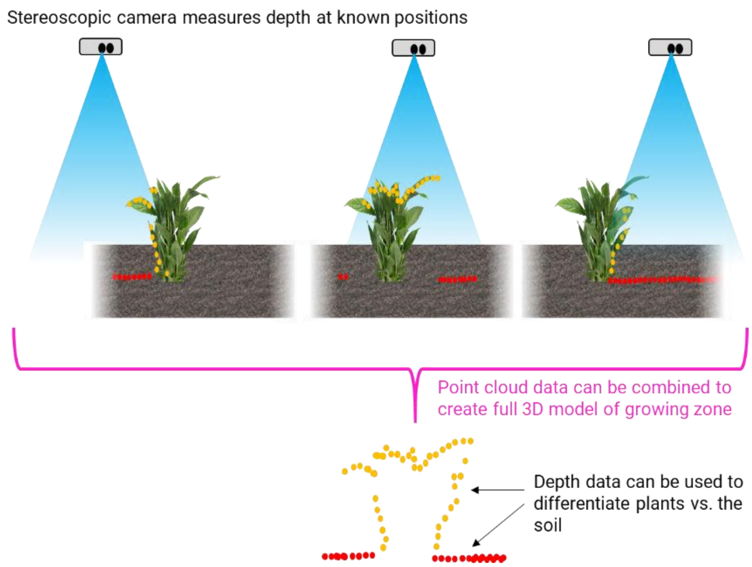

Figure 19. Point Cloud Data Combination Concept

From here, the still image will be converted from the RGB (Red-Green-Blue) to the HSV (Hue-Saturation-Value) color space [7]. This will produce more accurate pixel color data in the presence of shadows and varied light conditions. Using this altered color data, a histogram of pixel content will be generated and stored for later use. Moving on to identifying individual leaf structures, the image will be converted to black-and-white, otherwise referred to as grayscale. Using an image processing function called Hu moment detection, numerical descriptors will be generated for the outlines perceived [5]. Lastly, a secondary image processing function called Haralick texture analysis will be applied within the identified outlines to analyze texture patterns. This is useful for differentiating leaves from soil, as well as extracting features of healthy versus unhealthy leaves. For the last step of analysis, the post-processed images, as well as the color histogram, shape, and texture data will be fed into a Random Forest Classifier [5].

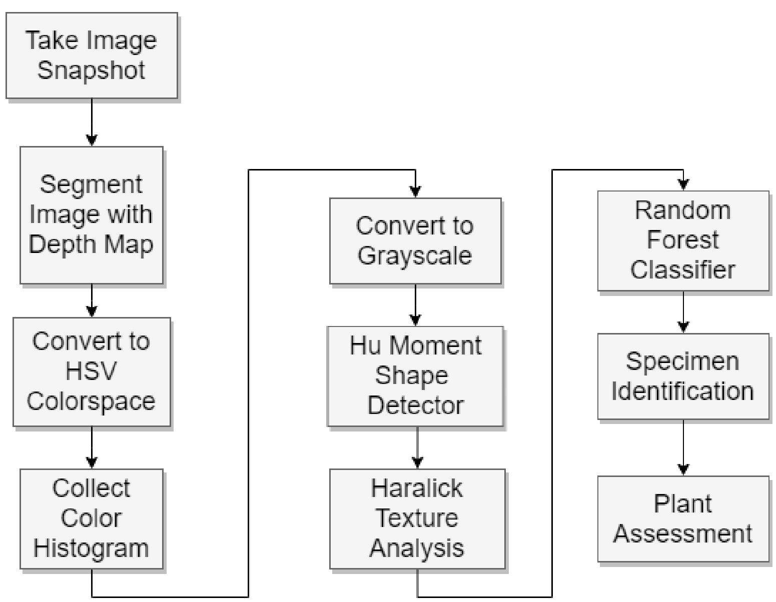

Figure 20. Plant Health Identification Flowchart

This algorithm, a form of supervised computer learning, will generate conclusions about the image contents in real time. Because the classifier is supervised, it will be pre-trained with a set of test images. This dataset will be a mixture of plants and weeds, healthy and unhealthy. When implemented, this classifier will be able to distinguish crops from weeds, as well as generating verdicts for healthy versus diseased leaf structures.

4.0 Conclusion

Overall, this conceptual design successfully meets all system requirements. Designed with budget and scalability in mind, it represents a mechanical simple solution for tending to a variety of plants and growing zone configurations.

Combining a semi-mobile gantry with advanced image processing techniques, our system will be able to inspect and tend to plants during different growing stages, applying nutrients and hydration to specific areas as needed. With this emphasis on precision of analysis and application, the design is on track to exceed our requirement of water application efficiency greater than 90%.

5.0 Appendix A: Definitions

Soil health: a myriad of measurable parameters relating to the soil's ability to provide water and nutrients to the plants. For the scope of this project these parameters include:

- Soil Moisture: indicator of soil water saturation, the ratio of air to water within the soil.
- Soil pH: indicator of mineral and nutrient content in the soil.
- Soil Temperature

Plant health: a variety of conditions that either inhibit or assist in the growing and continued life of the plant. For the scope of this project these parameters include the following:

- Water consumption: average water requirement for a given plant at a specific stage of development.
- Nutrient needs: various minerals and organic compounds consumed by a plant throughout its growth stages.
- Physical health: integrity of fruit, foliage, stems, and root systems.

Growing zone: the three-dimensional soiled volume from the surface to a depth of 5 centimeters.

Parasite: any unwanted plant that directly, or indirectly derives some or all of its nutritional requirements from the growing zone.

Application Efficiency: a measure of how well an irrigation system performs when directed to deliver a specific amount of water.

Ingress protection level IP55: an enclosure that provides protection against ingress of dust such as not to interfere with the satisfactory operation of the equipment. In addition, the enclosure must ensure water projected by a 6.3-millimeter nozzle from any direction shall have no harmful effects. [2]

6.0 Citations

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