Aquaponic Deep Water Culture Systems

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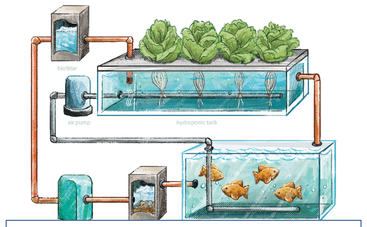
Abstract

In collaboration with Pure Reason AI, a start-up company, we constructed neural networks to identify nutrient deficiencies in lettuce plants. We designed and trained convolutional neural networks, such as U-Nets, to categorize images of lettuce plants as either fully nutritious or deficient in potassium (K), phosphorus (P), or nitrogen (N) using the Python libraries Tensorflow and Keras. In this poster, we explain the design of a Deep Water Culture system that promotes plant and fish growth in a shared water environment. Additionally, we validate the basic economic feasibility of hydroponic systems by examining a case study of Freight Farms, a company that manufactures controlled 'container farms.'

Introduction

- Hydroponic systems are agricultural systems that do not require the use of soil. A Deep Water Culture (DWC) system is a hydroponic system where plant roots are submerged in an oxygenated, nutrient-rich water solution. To maximize the quantity of healthy plants generated per cycle, the nutrient solution concentration can be changed based on observations from sensors, such as the machine-learning assisted identification of nutrient shortages in the produce by cameras.
- Our collaborators are developing a type of DWC system referred to as an aquaponic system that is attached to a fish tank.
- In this system, the fish tank becomes contaminated with ammonia-rich waste from the fish. Then, this water feeds into a biofilter, containing beneficial bacteria that converts toxic ammonia into nitrate and removes solid waste. This water is then pumped into tanks of the DWC system equipped with air pumps and floating sheets to support plant stems above water. The plants absorb the nitrate, serving as a natural, nutritious fertilizer, from the solution. Lastly, the purified water re-circulates into the fish tank.
- When compared to conventional agricultural systems, DWC aquaponic systems provide the following benefits:
  - They are water-efficient.
  - The fish provide nutritious nitrates to the plant.
  - They eliminate soil-borne diseases.



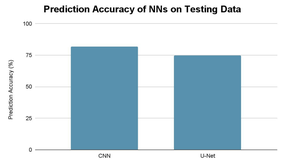
A diagram of an Aquaponic DWC system.

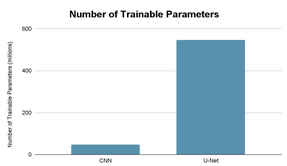
Results from Machine Learning

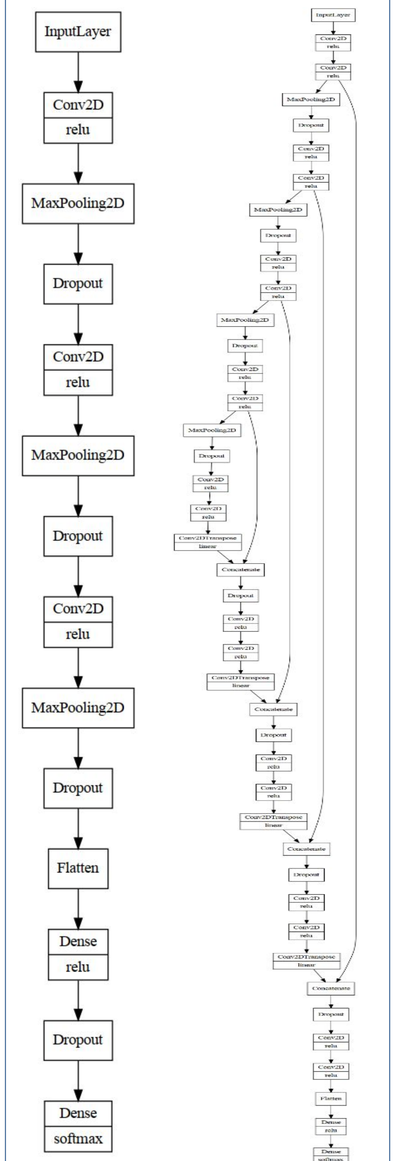
- A neural network (NN) is a type of mathematical function mapping one vector space into another. If a dataset of corresponding input and output vectors is provided, then the set of parameters defining the neural network is obtained as a local minimum of a function related to the accuracy of the NN's predictions.
- Our goal is to classify images of lettuce (the input vector) into one of four categories (the output vector):
  - Fully nutritious (FN)
  - Potassium deficient (-K)
  - Nitrogen deficient (-N)
  - Phosphorus deficient (-P)
- We trained two types of NNs:
  - A convolutional NN (CNN)
  - A more complicated type of CNN called a U-Net

Category	# of Images
FN	12
-K	72
-N	58
-P	66

The numbers of images used in our dataset for training and testing







Layer diagrams for our CNN (left) and U-Net (right).

Economic Analysis

- Our collaborators intend to develop their existing aquaponic DWC system into a vertical system integrated into a climate-controlled shipping container.
- Freight Farms, a company based in Boston, Massachusetts and founded in 2011, manufactures similar hydroponic systems.
- The container systems provided by Freight Farms have an upfront cost of roughly $165,000, but they have the following advantages over traditional, soil-based agriculture:
  - Yields are typically close to 100%, whereas soil-based farms typically lose around 25% of their crops due to uncontrollable circumstances.
  - The climate-controlled farms can operate year-round, whereas traditional agricultural in fields is naturally seasonal.
- Freight farms has comparable yields to that of a traditional 5 acre farm. The upfront cost of a 5 acre farm in Louisiana is roughly $155,000.
- The main difference in price between Freight Farms and a traditional 5 acre farm is the total yearly costs
  - Freight Farms Yearly Cost is roughly $26,245
  - Yearly cost of a traditional 5 acre farm is roughly $81,297

Conclusions

This semester, we were able to train two types of neural networks to classify images of lettuce plants into four categories: fully nutritious, potassium deficient, nitrogen deficient, and phosphorus deficient. We researched and explored the method of hydroponic farming using Deep Water Cultures and gained more information on a company that is producing shipping containers that grow plants hydroponically.

Some future plans for this project are to research more methods to detect nutrient deficiencies. Specifically, our collaborators at Pure Reason AI are interested in image classification with light, and the possibility of applying Spectral Theory to this problem of detecting nutrient deficiencies. Some more work needs to be done with the trained neural networks to develop a user friendly system that can be used by everyone.

We are also interested in further developing the neural networks to be able to handle image classification problems such as noise, lights, and shadows that may appear on the images. Solving this problem would enable users to easily classify the nutrient deficiencies and enable this system to be used by anyone growing plants hydroponically.

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