Robotic Implementation to Automate a Vertical Farm System

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ABSTRACT

Continued global population growth, increasing loss of cultivated land to urban sprawl, land degradation, and climate change provide a serious threat to our society, particularly how we feed our society, agriculture. Our agricultural production will be expected to produce an ever increasing amount of food with much less arable land. These problems will require us to innovate and continue to advance agricultural technology. One of the recent trends gaining traction is the use of vertical hydroponic indoor farms. Unlike traditional outdoor farms that span hundreds acres, these farms are stacked vertically to maximize limited space and are protected from some of the more dangerous elements of outdoor environments, such as pest, unfavorable weather or seasons. These systems are designed to maximize crop yield and reduce turnover by providing crops the most ideal lighting and environment constantly. This paper proposes implementing a robotic and vision system to plant and harvest crops in a preexisting vertical farm system. We will also propose two algorithms to control the automated procedures. A robotic system would allow a vertical farm to maximize efficiencies to tackle the problems agriculture will face. We will conclude with a discussion on the promising potential of uniting robotics with vertical farms.

Keywords

Vertical Farm, Automation, Soil-less Farming, Hydroponics

1. INTRODUCTION

As of 2015, our current global population is estimated at 7.3 billion people. Population is expected to peak at 10 billion before the end of the 21st century with growth rates above 1% per year [1]. As a result, during the next 50 years, demand for food is projected to grow by at least 70%. Over the decades we have experienced significant human migration from rural areas to cities, more than half of the world's population now lives in highly dense urban areas [1]. This great migration to urban areas is expected to accelerate the loss of cultivable land to urban sprawl [2]. These factors in combination with land degradation via soil erosion and salinization, loss of arable land to urban expansion, and climate change creating unfavorable conditions for crops are some of causes threatening agricultural land as a resource [3][4]. As our population continues to grow, we need to innovate agricultural technology in an effort to maximize our crop efficiencies, in crop yield and turnover. We must also find ways to efficiently use land for production, as space becomes a scarce commodity in urban environments.

One of the proposed solutions is vertical farming. The underlying idea for vertical farming is to increase productivity by extending cultivated area vertically instead of horizontally, in doing so we increase the land efficiency to produce crops [5]. Vertical farming can be implemented both in the large and small scales. Large scale vertical farming involves vertically stacking building sized facilities such as glass houses or controlled environments into high rises. On the smaller scale, there are vertical farming systems, which use the same idea on smaller room size scale, maximizing crop yield by vertically stacking the floor area. Common examples of vertical farming systems include vertical columns [6], conveyer driven stacked growth systems [7], A-frame designs using conveyer driven systems [8], and plant factory approaches seen below [9].

Figure 1. A plant factoring and its use of artificial lighting

Plant factory refers to a plant production facility with a thermally insulated and nearly airtight warehouse-like structure [10]. These warehouses are stacked with multiple culture shelves lit with energy efficient LEDs. Plant factory also use other equipment to optimize the indoor environment, such as air conditioning, air circulation fans, carbon dioxide and nutrient solution supply, and an environmental control unit. Stacking more culture plates will increase crop production efficiency. These plant factory systems were designed to bring agriculture to areas generally not suited for it, such as an urban environment [10]. The enclosed and controlled environment of these factories offers unique advantages to crops, such as consistent humidity, lighting, and the avoidance of pest.

The aim of this paper is to propose an affordable implementation of a robotic and vision system to work within a vertical farm. The proposal would be applied to an existing small scale vertical farm system with the intention to potentially extending the proposal to larger scale plant factories. A robotic harvesting/planting system would allow for greater efficiency in crop turnover and production. The camera system proposed should also be able to identify when a crop is ready to be harvested or removed based on different factors such as size and color. Finally, the robotic system should allow plant factory to remain enclosed most of the time, keeping crops in the ideal created environment, but still allow for human interaction with crops when necessary.

1.1 Related Work

The promise of vertical farming crop efficiency has inspired many variations. However, automated or semi-automated vertical farms remains an underdeveloped field. Current approaches automate certain parts of the vertical farming system. More common approaches involve automating growth plate movement for easy human manipulation and uniform sunlight, while others focus on automating environmental control and crop maintenance. Below we describe two vertical farm systems that served as inspirations for the proposed robotic system.

One of the first examples of semi-automated vertical farm comes out of the Singapore. SkyGreen has created a system using "A-Go-Gro" technology. This technology uses hydraulic water-driven vertical farming system. The rotation system is gravity aided water pulley system, the same water used to power the rotation is recycled and filtered before returning to the plants. The vertical farm uses the A-frame design, roughly 6 meters tall. Each A-frame tower consists of 22 to 26 tiers of growth troughs, rotated around the frame to ensure uniform distribution of sunlight and good airflow. The towers are housed in a protected environment of PVC roofing and netted walls [11].

Figure 2. SkyGreen "A-Go-Gro" vertical farm

The SkyGreen vertical farm has several advantages. One advantage is the vertical farm does not rely on electricity but rather a source of water that also serves the plants. Another advantage is its enclosed structure allows for sunlight but keeps pest out. A couple of disadvantages however do exist within this vertical farm system. The A-frame vertical farm system is large and tall; this would require a large space to contain a modest scale farm. Another drawback is the system is dependent on the weather, using any available sunlight and rain to power its rotation. Its size and dependence on environmental factors limit its potential as a replacement for more traditional methods of farming.

Figure 3. CityCrop automated indoor farming

The CityCrop Automated Indoor Farming system is a mini vertical farm system out of Greece. This system is intended to bring vertical farming to your home or small business. CityCrop aims is to make an intelligent farming system that will only require the users to plant and harvest their crops, and let their system take care of the rest. The CityCrop Automated farm is equipped with a climate control system used to control temperature, humidity, lighting, etc. In addition it uses hydroponics to give plants nutrients, LED growth lights, adjustable trays, and even has its own app to control its indoor environment as well as monitor and manage crops. It has two trays with 12 pods for planting each, so a user can plant a maximum of 24 plants. This automated farming specializes on growing leafy green crops such as lettuce. [12].

The City Crop automated indoor farming system offers a couple of advantages to traditional farming methods. One primary advantage is its small dimensions, allowing households and businesses to potentially grown their own fresh crops indoors. Another advantage is the system is not dependent on the user of optimal crop growth, with its automate controlled environment it reduces some of the learning curve required for farming various crops. Despite these advantages, we still do not have a completely automated system. CityCrops system still requires the user to know when to harvest a crop as well as planting new ones. This procedure requires constant opening and closing of this carefully controlled environment, this disturbance reduces the potential for maximum crop production.

2. DESIGN

The proposed robotic implementation is designed for use in the CityCrop Automated Indoor Farm and hence should fit those dimensions. The robotic system will have a camera to identify crops that are ready to be harvested or removed. The camera vision system will be mounted between the robotic manipulator such that it can harvest and remove the identified crops. The robotic manipulator can serve a dual role as a planter as well. In addition, we will propose an algorithm to control the behavior of the camera and robotic manipulator.

2.1 Camera Vision System

The camera device proposed for the vision system is an inexpensive commercially available USB camera. The Minoru 3D USB webcam uses two VGA CMOS color sensors with a maximum resolution of 800 x 600 pixels and a maximum frame rate of 30 fps. The cameras are on the same plane at a distance of 6 cm apart. This device has the option to take two individual image from both cameras or one combined stereo image. In either case the left and right camera shutters do not synchronize with a maximum deviation of 16.5ms. The device has a manual focus from 10 cm to infinity and for our purposes it would remain fixed once set [14]. This camera was selected because its features allow us adapt to a variety of crops that may require more visual information before harvest.

Figure 4. Minoru 3D webcam

Figure 5. Minoru 3D Webcam stripped front to remove excess material

2.1.1 Estimating distance with vision system

The camera vision system should serve multiple purposes in terms of identification. In order to harvest or plant crops the system will need to identify a variety of factors such as color, size and location of the targeted crop. One of the main factors the robotic manipulator will need to know is distance from the camera to the crop. In order to successfully harvest a crop, we need to account for the distance perceived by the camera to the crop, then make any adjustments related distance between camera and the robotic manipulator to avoid damaging the crops.

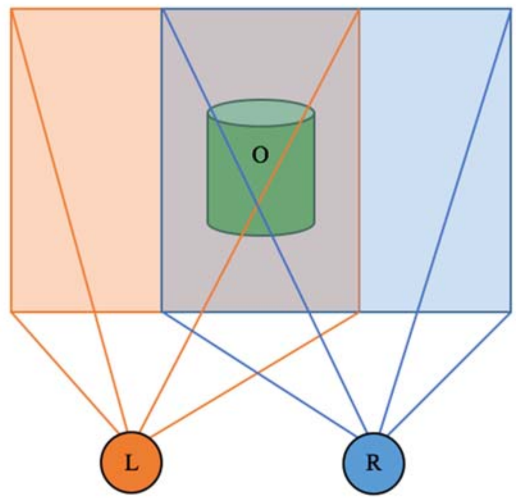

Figure 6. Overlapping image from left camera (L) and right camera (R) on object (O) creating stereovision image

As stated before, the two cameras on the Minoru 3D webcam takes one photo from each camera. These cameras are a certain distance apart, which produces different images of the same object, this is known as a stereovision image. These two images of the same object are at a known but at different point of views, with this information we can analytically estimate the target relative position and distance, and the objects absolute diameter.

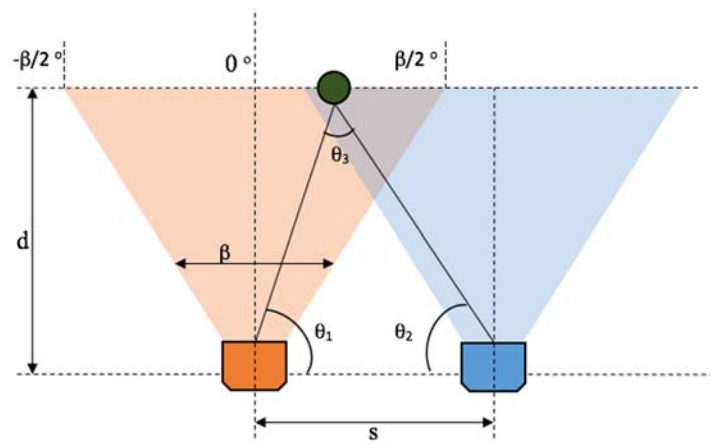

Figure 7. Schematic representation of camera and object with parameters involved in the calculation of the distance estimation

Figure 7 above shows us a diagram representation of the parameters involved in calculation relative distance and position. Where s is the known distance between the two cameras, d being the distance between the cameras and object, and β is the horizontal angle of the view of the cameras. Analytically computing θ_1, θ_2, and θ_3, we can calculate the distance with the equation below.

$$d = \left|\frac{s \cdot sin\theta_1 \ \cdot sin\theta_2}{sin\theta_3}\right|$$

We should note this equation only allows us an estimation of the distance between cameras and the object. The distance estimation could be greatly improved with more specific camera calibrations beyond what the manufacturer requires.

2.2 Robotic Frame

The robotic system frame that we propose be implemented in the automated farm is based on 3D-printer frames. These farm offer great movement through a planar environment. In figure 8 we can see a CAD rendering of the proposed design. Designed to fit in the confined space of the CityCrop Automated farm (~17in x 17in x 34in) [13]. This design will allow our manipulator to vertically up and down with the four rails, useful for avoiding sweeping through crops. The mechanism also allows for movement left, right, forward and backwards to ensure our ability to reach any pod for harvest or planting material. This frame could successfully be powered by a couple motors and a belt driven system, much like found in some modern 3D printers.

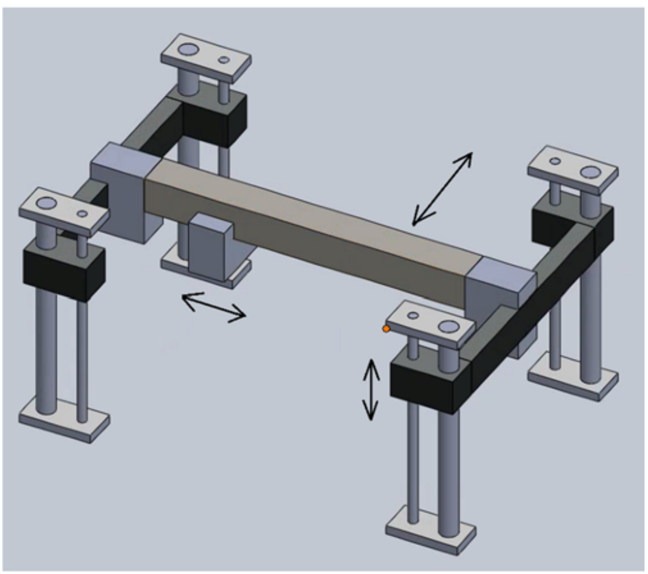

Figure 8. The robotic frame used to move the manipulator around a vertical farm stack

2.3 Robotic Manipulator

For the robotic manipulator we propose using a premade gripper and adapting it with our vision system. ROBOTIQ produces 2-finger grippers that could be ideal for our purposes, our manipulator needs to be able to pick up and drop off crops. The 2-finger 85 offer 20 to 235 N of grip force and only adds about 2lbs of weight to our system [14]. The gripper proposed can be seen in figure 9, the left most gripper in the image.

Adaptations to the gripper may be necessary to avoid damaging fragile crops. These could include adding a rubberized gloves or reducing the closing speed to ensure we don't crush leafy crops. These manipulators claim to be easy to install, and if adapted correctly would be able to work with our proposed frame as well with a traditional robotic arm if designs must change. This manipulator with the proposed vision system attached to it, along with the proposed frame should allow the automated vertical farm to successfully harvest and plant its crops. Adaptations to the gripper to reduce risk of damaging fragile crops.

Figure 9. ROBOTIQ 2-finger grippers

3. PLANTING/HARVESTING ALGORITHM

In order to ensure the proposed automated vertical farm plants and harvest procedures work as intended, we will implement a planting and harvesting algorithm. The planting algorithm should allow the robotic implementation to decide to plant a new crop based on factors such as an opening for a crop, stock of planting material, and success of previous harvests. The harvesting algorithm should take into account several factors of the crop, such as size and color, before deciding to harvest. In addition, the harvesting algorithm should work in conjunction with the planting algorithm to decide whether harvesting is the most efficient step considering planting supply. The features included with the CityCrop automated vertical farm, specifically the app, would allow for a fluid communication between the user and algorithm to maximize production.

3.1 Harvesting Algorithm

The harvesting algorithm is designed to check all the pods and determine whether to give it a planting flag and whether to harvest or not. The harvesting cycle is originally designed to run every 12 hours, but there would be an option to change how often the cycle is to happen. The robotic system will start from the rest position and check the first pod in the sequence. The vision system will check whether the pod is empty, if the pod is empty the robotic system will virtually tag that pod for planting and move onto the next "unchecked pod". If at this point all pods have been checked it will stop the process and begin the planting algorithm, otherwise it will check the next pod in the sequence.

If the pod is not empty, the system checks the date planted log to see when this pod was planted. Here we have one of our first critical checks, this check involves time, the algorithm checks when current crop was planted. If the crop has not reached a certain amount of time in the farm, determined by previous or standard crop averages, the system will ignore the pod and move onto the next one. If the crop has been in the farm long enough, it will go through the second check, a color check. If the color of crop is not within an acceptable range from the standard crop, such as a crop that has died, it is removed and the pod is given a virtual warning tag and the system moves onto the next pod. If the crop passes the color check, it moves onto the final check, a size check. If the size of the crop is within harvestable size, from averages or standards, it is harvested and virtually tags the pod to be planted, otherwise it moves onto the next pod.

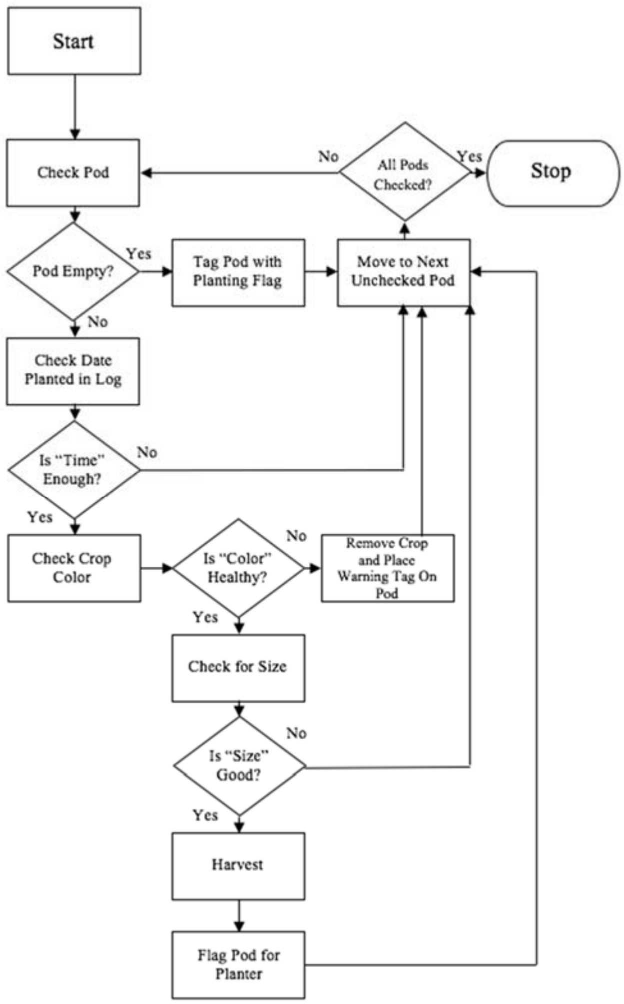

Figure 10. The harvesting algorithm which checks all pods, tagging which pods need to be planted and which could be harvested

3.2 Planting Algorithm

The planting algorithm is activated once the harvesting algorithm completes its actions. The planting algorithm works to plant new crops in empty pods and also works to notify the user if there is a pod producing poorly. The algorithm starts by checking if there is any supply to plant new crops. If there is no supply the system is to alert the user via the app and stop the planting process until the supply is refilled. If there is planting supply the algorithm checks for pods that contain the virtual planting flag. If there are no pods with planting flags the algorithm stops and waits for next harvesting cycle. If there is a pod with an identified planting flag, the system will first grab planting material and move to the flagged pod. Once the robotic system reaches the pod it will search the pod history for any warning flags, if there are consecutive warning flags the system will alert the user of the under producing pod to make sure the pods hydroponic system is in working order. Otherwise the system proceeds to plant the new crop. Once new crop is planted it removes the virtual planting flag and logs the date and time it was planted. Once planted the system will again check for planting flags to close the loop.

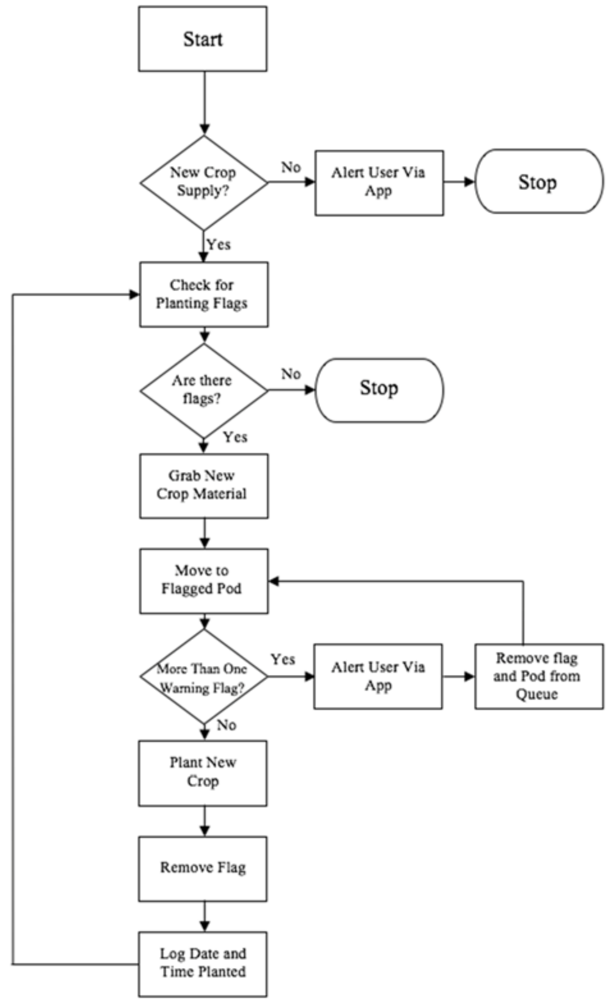

Figure 11. The planting algorithm plants new crops and identifies which pods are not producing properly

4. FUTURE WORK

By examining the current landscape and anticipating future trends in both technology and population/environmental needs we proposed further automation of vertical farming systems with the help of robotics. The idea proposed in this paper are just the first steps to what I believe will be a highly invested field. However promising the idea, there still remains work to be done. Future work would include building and testing a small scale of the proposed system. With a built system we could continuously improve upon our own design. In addition, we must improve current vertical farm design to work in conjunction with emerging technologies. Improving vertical farm designs to allow for easy implementation of technology should improve maximum crop production. Improvement on our own design could come in the form of a better camera or a different form for the vision system, we could also change our robotic manipulator to a more traditional robotic arm form. We want to make this system implementable in the current CityCrop systems as it is an ideal enclosed system, and eventually scale up to larger scale plant factories.

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