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# Autonomous Robot for Small-Scale NFT Systems

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**Abstract.** *Hydroponics is currently a very successful technique for growing crops like lettuce and results in cleaner, healthier and cheaper yield. Requirement of periodic labor and a systematic arrangement of plants make it a good candidate for automation. Large-scale systems that automate the growing of lettuce already exist, but these require large capital investments and large footprints that limit the use to only large-scale growers. Our goal is to develop inexpensive robotic systems that a small-medium scale grower can afford to implement and that are compatible with the existing infrastructure. The robot is designed to pick and place plants and seedlings from one spot to other on an Nutrient Film Technique (NFT) system autonomously. We describe the design and construction of the gantry-based robot with an arm that moves on rails. By using this approach a single robot can serve a large number of plants in a greenhouse. We also describe algorithms for perception, robot path planning, and manipulation of densely planted leafy crops using a camera and Microsoft Kinect 3D imaging system. Results are demonstrated experimentally using a small AmHydro NFT system we have constructed in our lab.*

**Keywords.** Automation, Hydroponics, Manipulation, Microsoft Kinect, NFT, Visual Servoing.

## Introduction

Agriculture is considered as the backbone of a country's economy and the importance of agriculture has increased as the human population increases. This increase in food demand calls for more efficient agricultural practices. Automation in agriculture, thus, is an important consideration for increasing farm efficiency and reducing production costs via the deployment of self-guided, low-cost agricultural machines to automate farm operations and reduce worker load. This is needed to ensure the availability of inexpensive and quality products to meet the increasing food demand. The technology for food production in greenhouses has advanced a great deal in the last 20 years. One of these advancements is hydroponics and in particular Nutrient Film Technique (NFT) (Graves, 1983). The advantage of NFT systems is the closed loop water circuit, which results in easier quality control of nutrients, resulting in decreased environmental impact, less waste products and improved crop quality (Jensen, 1999).

Robotics has been an area of active research for increasing industrial production for around 50 years. In recent years, several advances have been made in the field of robotics, the operating speed of robots has surpassed that of humans and robots are catching up with other skills. Robots can work continuously and consistently with minimal maintenance (Koren, 1985). In the last decade, agriculture has also caught attention of the robotics researchers world-wide, resulting in development of numerous techniques such as autonomous prime movers (Hamner et al., 2010; Bergerman et al., 2012), autonomous thinning of peach trees (Aasted et al., 2011) and intelligent irrigation using wireless sensor networks (Kohanbash et al., 2011). By combining hydroponics and robotics significant improvements can be made in the efficiency of producing food. Besides being used for labor tasks, robotic systems can also be used for monitoring tasks. By combining the robot with a monitoring system a grower can remotely monitor parameters of the crop and the environment and act accordingly (Kohanbash et al., 2011). Hydroponics is a good platform for robotic automation, because it requires periodic labor, a systematic approach, repetitive motion and a structured environment. One of the most attractive features of urban agricultural techniques is their space efficient nature and reduced reliance on land and natural resources. This space efficiency can be further optimized in an unmanned greenhouse where robots control all the regular operations, the robots can be semi-autonomous and slow but should be space efficient and accurate. Also, the availability of short-term labor is sparse, which makes an automated greenhouse self-sufficient. Large-scale systems that automate hydroponic farms already exist, but require a large capital investment (Michael, 2001). Current automation systems fail to reach the stage of commercialization, because of their low operating speeds, low success rates and high costs (Grift et al., 2008). The goal of this project is to provide an economically viable robotic system that is compatible with the existing hydroponic farms without structural alterations. In this paper, we describe the design and fabrication of a robot that has the ability to work in a hydroponic greenhouse, with minimal human intervention.

## NFT system

The NFT system used for testing our robot is an AmHydro 612 NFT Production Unit (Figure 1). It is a production unit that can store 144 plants and 144 seedlings and uses a closed loop water system. The plants are put into small holes in long gullies so that the roots of the plants are submerged in a small stream of flowing nutrient rich water. The NFT system consists of the following parts: table, gullies, water reservoir, tubing and a water pump. Above the NFT system are artificial lights to improve indoor growing conditions. In this case the NFT system was used to grow lettuce. The gullies lay on an inclined table so that water flows passively to the end of the gullies. At the end of the gullies water is collected and directed to the water reservoir. A pump is positioned in the water reservoir to pump water to the top of the gullies. The plants are first put into small netted pots before inserting them into the holes, so as to avoid any damage caused by the handling of plants with the robotic gripper.

Figure 1: AmHydro 612 NFT System

## System Design

As discussed above, an optimal robot that automates such a hydroponic setup could be slow in the rate of operation but should be accurate in its positioning and operation, for e.g., moving seedlings from the nursery to main plantation. We have focused our attention on precision rather than speed for the same reason. Also the robot should be mobile so as to serve a complete greenhouse or a portion of a greenhouse depending upon the size. With these requirements in mind we describe the design of the robot in 3 steps, each dealing a separate aspect of the complete system:

1. Gantry and driving systems
2. Electronic and control systems
3. Software

## Gantry and driving systems

The mechanical structure of the robot is best described as a 3-axis gantry with a manipulator mounted on the vertical axis. To manipulate the plants on the NFT system without human intervention a robot was developed as shown in Figure 2. The robot was designed as a gantry with four v-grooved wheels running on two inverted angle iron v-grooved tracks (x-axis). On top of the gantry is a carriage that can move back and forth over the gantry (y-axis), this is perpendicular to the x-axis. On the carriage is a mechanism to move an arm up and down (z-axis), down being the negative direction. At the end of the arm is a two degree of freedom (DOF) gripper that can open, close and rotate around the y-axis.

The structure is made primarily from Bosch Rexroth aluminum framing that allows the robot to be adjusted to accommodate different sized NFT systems. To drive the three independent axes, various driving mechanisms were designed. The x-axis is driven by two stepper motors and chains. Each side, left and right, with two wheels each is driven by a single stepper motor that are coupled to the two wheels using a chain. The carriage on the gantry is connected to a stepper motor by a timing belt. The arm on the carriage is balanced by a counterweight and is driven by a stepper motor and a chain. The gripper at the end of the arm is actuated by three linear actuators, two miniature linear actuators are used to open and close the gripper and a larger linear actuator is used to rotate the gripper around the y-axis.

The robot requires minimal spacing between adjacent NFT systems when placed in a greenhouse. The robot drive is designed to manage slight misalignment in the rails and the motors used are limited in torque, so that the system can't derail itself and as a safety measure in case a person gets in the path of the robot.

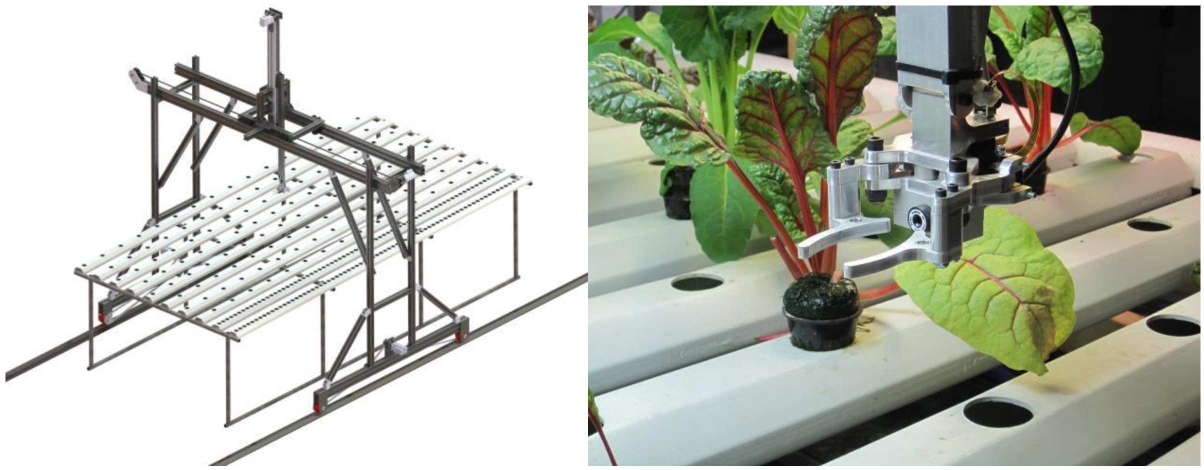

Figure 2: (a) Robotic gantry with NFT system (CAD Model). (b) Robotic gripper with a camera.

## Electronics and control systems

The layout of the electronic components is depicted in the Figure 3. The system is equipped with tactile sensors in the form of limit-switches that limit the motion of various components. Two cameras are mounted on the system to provide vision feedback and the integrated encoders on the linear actuators provide electronic feedback. All three linear actuators are driven by a relay board that communicates with a Phidgets interface board. The interface board is in turn connected to the main computer, which runs a Linux Server. The Microsoft Kinect camera and the interface board communicate with the computer over Universal Serial Bus (USB). The stepper motors communicate with the computer using an RS485 serial protocol. The limit switches are connected to the stepper motors directly as hard stops. A miniature camera is attached on top of the gripper to get a close view of the plants while picking them up and is connected to the main computer directly via USB. The system has two emergency stop switches on either side that can power to all the actuators in order to avoid any possible accident.

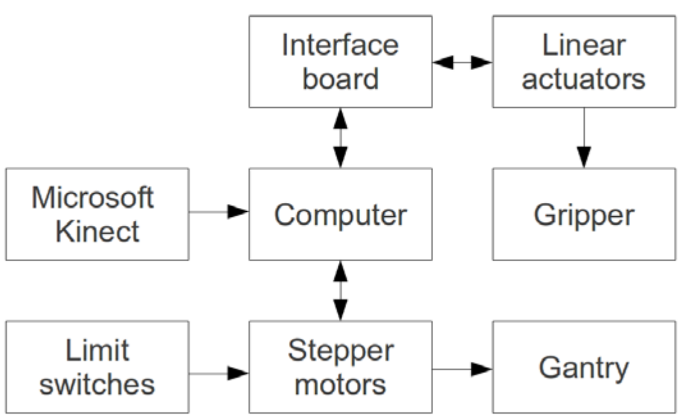


Figure 3: Block diagram of the electronic components and communication paths.

## Software

The framework used to implement the control and vision software is Robotic Operating System (ROS). ROS is a software framework for robotic software development, providing an operating system functionality on a heterogeneous computer cluster, available under BSD license (Quigley et al., 2009). The overview of the software architecture is shown in Figure 4. Every sensor and actuator communicates with its own ROS node. A ROS node is a program running in the ROS environment that can communicate with other ROS nodes. Nodes can publish messages to a topic as well as subscribe to a topic to receive messages. The main nodes are: stepper motor node, gripper node, interface board node, position node and Kinect node. The position node keeps track of the x, y and z-position of the robot and a GUI was designed to provide low level control of the system.

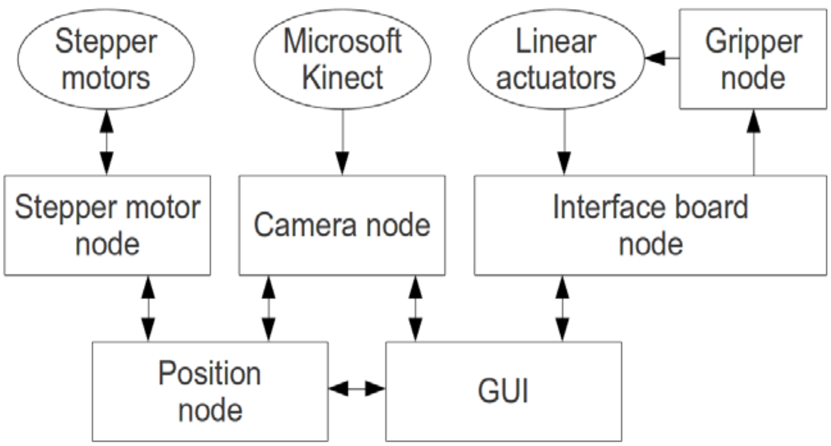


Figure 4: Software architecture for the control and actuation system

## Visual Feedback system

Because all stepper motors are controlled by an open-loop step control system, accurate positioning requires the use of extra information. A vision system is thus added to the robot to provide 3D visual information so a Position Based Visual Feedback algorithm can be used to control the robot. This algorithm uses a Microsoft Kinect which was initially designed for home-entertainment purposes by Prime Sense. The Kinect is a low cost and readily available RGB-Depth (RGB-D) camera that is an affordable alternative to stereo cameras and laser scanners (Ramey et al., 2011) to do 3D sensing. This camera combines a standard RGB camera with a time-of-flight camera, making it an RGB-D camera. It captures RGB images and per-pixel depth information (Figure 5(a) and 5(b)). By combining classical 2D image analysis techniques and IR based depth measurement the 3D position of the plants are extracted. The Kinect is located on the carriage and is facing downwards (negative z-axis).

The vision system detects the plants and guides the robot accurately to the base of the plant, residing in small netted pots (Tanke et al., 2012). The algorithm first detects the gullies, because the plants are only located on the gullies. All gullies are oriented long the x-axis and are straight. The straight lines are detected using a Probabilistic Hough transform for line detection (Guo, 2012). By filtering the detected lines by using prior knowledge about the NFT system, the edges of the gullies was identified (Figure 5(c)). After the identification of the edges, the lines were grouped, resulting in a segmentation of the gullies. The plants are grown in round cups and were detected using a Hough Transform for circles detection (Yuen et al., 1990) (Figure 5(d)). After filtering, the coordinates of the plants in the image frame are known. The OpenNI

(Villaroman et al., 2011) driver transforms the IR sensor values into distances in meters by using a fitting function. This serves as an open loop control input for the stepper motor.

By adding an extra camera on the gripper additional information can be gained that might be useful to improve the accuracy of the gripper (Tanke et al., 2012), so a miniature camera is added on the gripper that gives a closer view of the plants and regions that are not visible to the Kinect.

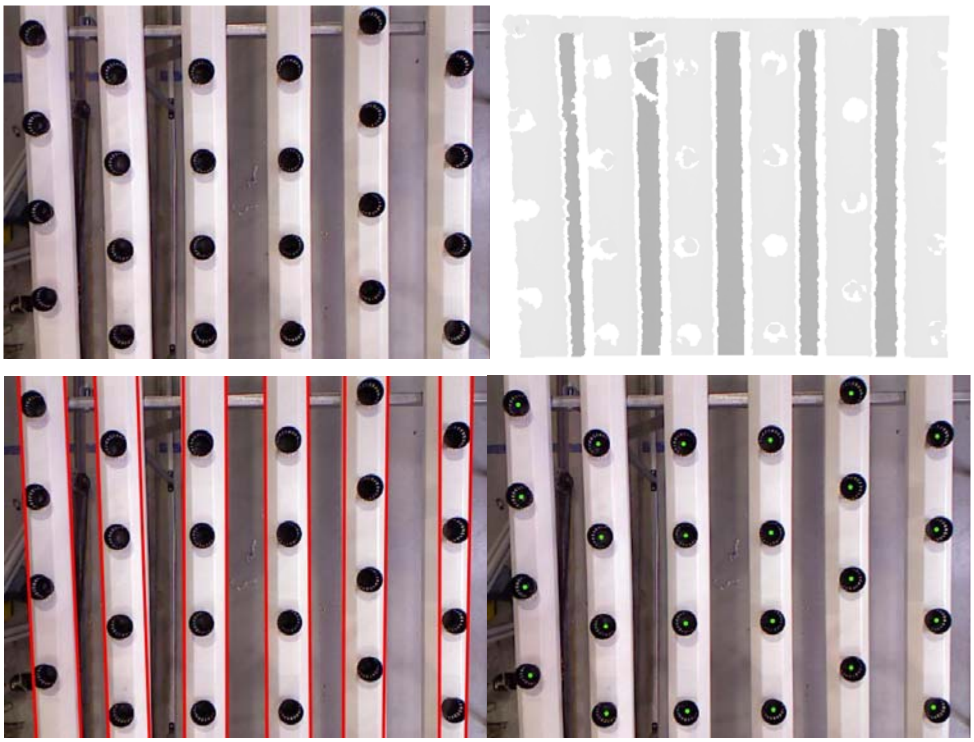

Figure 5: (a) Kinect RGB image. (b) Kinect depth image. (c) Segmented gullies. (d) Detected plants spots

## Results

The robot discussed above has the ability to do the basic operations required to run an NFT plantation such as moving seedling and plants in and out of the gullies. It is a potential and an economically viable substitute for the existing automated systems, especially for medium farm-size growers. Integrating this with other existing intelligent control systems could be vital step forward towards affordable completely automated hydroponics plantations.

## Conclusion

The advantage of our system lies in its affordable hardware, flexibility and software. It’s a 3-axis gantry that has a vision system capable of detecting plants and a manipulator to manipulate the plants. By using inexpensive hardware and smart vision software this system has the potential to be deployed in existing greenhouses without major changes to it and without major capital investments.

## Future work

There is plenty of scope of research for achieving the vision of an economically viable unmanned greenhouse operation. Computer visions algorithms that could estimate plant health, age and other attributes could be useful if greenhouses were to be monitored completely by such a system. More tests need to be conducted with different plants to ensure the plant safety issue of the system. We also need to do a thorough user interface study on how to make it user friendly and understandable for growers having little acquaintance with computers.


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## Appendix

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| **CAD** | Computer Aided Design |
| **DOF** | Degrees of Freedom |
| **GUI** | Graphical User Interface |
| **NFT** | Nutrient Film Technique |
| **RGB-D** | Red Blue Green-Depth |
| **ROS** | Robot Operating System |
| **USB** | Universal Serial Bus |