Robotic Arm Prototype - IN5590 Project

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***Abstract*—For my upcoming Master's thesis I will create a program for optimizing plant growth by varying the position of a light source. To move the light source we need a robotic arm to hold the light source. The aim of this project was to create a prototype of such a robotic arm and to learn how to control them. We managed to successfully create a functioning prototype, which can be further developed into a finished product to be used in the Master's project.**

I. Introduction

The general topic of my Master's project is to optimize the growth of a plant. To do this, we will vary the position of an LED array using a robotic arm. The goal is to use a search network to find the position of the LED array that will provide the most light to the plants leaves, thereby optimizing growth.

To do this, we will need to control the variables of the system. We will place the plant inside an airtight glass box, where the air flow can be controlled. The box will also have a watering system that will allow the water consumption to be kept static. A robotic arm will hold an LED array that will light up the plant from various angles. As the position of the light source changes, the amount of light that hits the leaves will also change. Through the process of photosynthesis, the more light that hits the leaves, the more CO2 is consumed by the plant. We should be able to see a difference in the level of CO2 in the air by varying the position of the light source. The level of CO2 in the air will act as the loss function for a search network that will attempt to find the optimal position for the light source to produce the greatest growth.

Research into the process of growing plants with artificial light is important for several reasons. Using artificial light will allow humans to start using the space underneath the ground to grow crops. As humans look to expand to other planets, like our neighbor Mars, it is also important that we are able to grow food and plants both on the interplanetary journey, but also at the destination. Finally, research into how to position the light source for efficient growth can help in reducing the energy consumption while growing.

The purpose of this project is to create a prototype of the robotic arm that will be used in my Master's thesis. The problem we will attempt to solve is how can we create a light weight, but steady, arm that can lift an LED array with precision.

II. Relevant methods and technologies

A. Photosynthesis

While plant physiology is not part of the scope of this project it is important to understand the process of photosynthesis because my project relies of photosynthesis to optimize the position of the light source.

Photosynthesis is the process by which green plants, algae and various bacteria use light energy to produce glucose and oxygen from carbon dioxide and water. Essentially, it is a chemical reaction that allows the plant to produce "food" to survive. For the plant to perform photosynthesis it needs water, carbon dioxide and light.

$$6CO_2 + 6H_2O + Light \rightarrow C_6H_12O_6 + 6O_2$$

When growing crops, the plants will usually use the light coming from the sun, but in recent years researchers have began using artificial light to "feed" the plants. There are several benefits to this, by using artificial light we have more control, it also allows us to grow crops under the ground away from the sun as well as having a light source 24 hours a day.

By keeping the flow of water static, as well as controlling the air flow of the system, we should be able to only have one dynamic variable; the light source. As we vary the position of the light source using the robotic arm, the amount of light that hits the leaves will change. More light means the plant will consume more carbon dioxide from the air.

B. LED arrays

There are many reasons why using Light-emitting diodes (LEDs) for growing plants is a good idea. They are small in size, very durable, have long operating lifetime, wavelength specificity, and have relatively cool emitting surfaces which make them superior to many other light sources when it comes to plant-based uses [1]. Most of the work that has been done with LEDs thus far has been performed with food crops, the observed benefits should also apply to most other crops as well.

We also use LED arrays because they direct far less infrared radiation at the plant than High intensity discharge (HID) lighting. HID lighting will cause infrared radiation, which will cause molecules to vibrate and heat up when it hits them. This will heat up the plant, and too high temperatures will cause a decrease in plant growth or simply kill it.

LEDs are also more efficient than many other forms of lighting, so they require less watts to produce the same amount of light. The whole idea of this project is to reduce the amount of lighting needed to grow the plant, so it makes sense to go with the lighting option that also requires the least amount of power.

Another advantage to using LED arrays is the much improved operating life. Current LED technologies can maintain 70% of the original luminous output after 50,000 hours of operation, and this is most likely a conservative estimate [2]. In practical use, Kim et al (2007) has reported consistent operation of an LED array over a test period of over 10,000 hours [3]. The very long operating life is hugely beneficial because the labour cost of replacing arrays is low.

While it is possible to get LEDs that simulate natural sunlight, plants do not need the whole light spectrum to grow. To perform photosynthesis, light interacts with specific chemicals in the leaves, most importantly Chlorophyll A and B. A mainly absorbs the higher red wavelengths, while B absorbs the lower blue. While the green and yellow wavelengths in between are absorbed by the plants as well, the red and blue light are the most important.

According to NASA [4], the most staple waveband of light for plant growth is red, with broad-band red (600-700 nm) providing the highest efficiency for photosynthesis, although some blue is needed as well. We can therefore predict that using an LED with mainly red light and some blue will be the most optimal for this project.

C. Robotic actuators

The servos we will use for this project are the Dynamixel MX-64AT servos (see Fig 1). They have a high degree of precision and great durability. For my thesis I will need servos that can withstand heavy usage and accurate readings, which make the MX-64AT excellent. The MX-64AT also has a much lower temperature during operation than its predecessor the MX-64, which is beneficial to my thesis since heat can impact the growth of the plant. The MX-64AT is however not exactly lightweight, weighing 135g, which is not great for this project where we will only create a smaller prototype of the final version for my thesis, however in my thesis the weight will be less of an issue since we will need to create more durable joints anyways.

D. Software

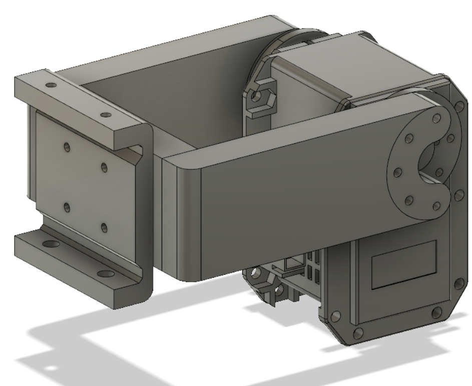
The software we will use to manage the servos is RoboPlus 2.0 (R+), a collection of ROBOTIS software that contains programs for firmware management, motion, programming, and more. R+ is an excellent tool that makes controlling Dynamixel actuators easy. However, this tool is fairly limiting in what it can do, so we will also attempt to control the servos directly using a Python script and a Python library called pydynamixel.

Fig. 1. Dynamixel MX-64AT Robot Actuator

III. Details

We started out with designing a model of the servos in Fusion 360 so that it would be easy to see how all the parts work together and we could make sure the parts fit. Once this was done the parts that would connect the servos together were designed. Having this connection be two parts was beneficial so that more length could easily be added in between the servos if wanted, as well as being able to easily change the direction of the joint. These parts should have been made out of aluminum or steel, but since the queue for CNC milling was long, the parts were simply printed using PLA. Since PLA is a much weaker substance, the thickness of the parts had to be tripled.

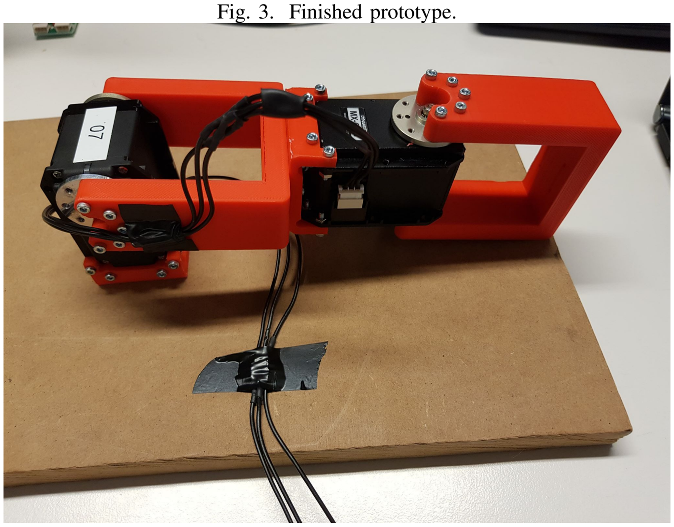
Fig. 2. Design of printed parts.



For the base an attempt was made to create a clamp so that the arm could be attached to a table. This would provide a very stable base that would not take up too much space. Since time was running short, it was instead decided to use a large piece of heavy wood and attach the first servo to this wooden base. While this solution is an eyesore and very spacial, it did provide a solid base for the arm, and will work fine for this prototype.

To control the arm we wanted to connect directly to the servos using a Python script and a library called pydynamixel. This was not easy to get to work properly, all that was managed to do was turn on and off the LED light on the actuators, not actually control the servo horn. Therefore, RoboPlus 2.0 was used to move the arm, which worked fine.

Fig. 3. Finished prototype.



IV. Conclusion

As discussed, research into making horticulture more effective using robots and artificial light is important if humans want to look to expanding to other plants or start utilizing the space underneath the ground. The purpose of this project was to research how to create a robotic arm using actuators, and to create a simple prototype of the arm needed for my upcoming Master's thesis. This was achieved as we managed to create the prototype as well as gaining valuable information on what (not) to do when the prototype will be developed further into the finished product to be used for the later porject.

References

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