MEng Project in Mechanical Design
The Design of a Safe System for Plant Dissection
(Engineering Report)

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Abstract

This report is on the design, prototype and the end result of a Plant Dissection System. The automated laser system needs to be built for dissecting plants. The system is safe for users as the laser can only be turned on when the system is completely closed off from the outside. The laser is currently focused down to a spot size of 0.4mm. The system features temperature control and UV serialization capabilities. In the current system, the user is able to put plant tissue in a petri dish onto a stage and then perform a controlled cut. Future work still needs to be done to automate the system.

Nomenclature

Spot size or diameter: the diameter of a focused beam of laser.

2020 aluminum extrusions: An aluminum rod that has a cross-section of 20x20mm.

T and L brackets: accessories used to connect two separate parts in a perpendicular way.

M3 screws: a type of screw

Drop-in T nut: a type of nut used to connect with the screws

ICS-9: An interlock controller for laser safety

PC-1G: laser controller

CW: Continuous wave mode for PC-1G

RMC: Remote machine control mode for the PC-1G

CNC xPro V5: a motion controller that moves the laser beam along the desired cut

Jumper: used to connect electric pins

Air assist: an air pump that blows air at the point where the laser is cutting to increase cutting efficiency

GUI: graphic user interface

1. Introduction

Plant transformation can be done by gene-editing bacteria. To do so, a cut or wound needs to be made to introduce the bacteria. Afterward, the transformed plant cells have to be separated from the ones that are not. However, the cutting of the plants is a labor-intensive process. We are designing a system to automate the dissecting process. The exposed plant tissues are fragile and need to be in a sterile and temperature-controlled environment so that they aren't infected by undesired bacteria or damaged by undesirable lab temperatures. The final system would have all the features controlled by one computer, and it would identify the placement of the needed cuts and then execute the cuts.

2. Material and Methods

Design Requirement

An automated laser system needs to be built for dissecting plants. The system must be safe for users so that the laser can only be turned on when the system is completely shut off. And the laser will shut off when the system is opened by the user. The laser should be focused down to a spot size on the micron scale and the stage control should have that amount of precision. In the final product, a user should be able to put the plant tissue in a petri dish onto a stage. The cutting chamber needs to be sterile and temperature controlled. The final system should be completely automated, where all the user needs to do is place the plant on the cutting platform, and the system would identify the placement of the needed cuts and then dissect the plant.

Laserproof Cutting Chamber

The laser we have is the Coherent Diamond Series CO_2 20W Laser which is a class four laser. It has a wavelength of 10600.00nm and a beam diameter of 1.8±0.2 mm. A CO_2 laser was chosen because it is absorbed well by water and is best suited for soft tissue. The goal is to incorporate it into a class one laser system by completely containing the laser so that no protective gear is required for operating this system. The frame uses 2020 aluminum extrusions, and the walls use acrylic and aluminum panels. The acrylic that was chosen can absorb the frequency of light admitted by the IR laser. CAD was used to place and design the 2020 aluminum extrusions and acrylic panels to ensure the laser is contained in the box. Fans were then added to ensure the laser had enough cooling. Once everything was designed and checked for fit and tolerance in CAD, the aluminum extrusions were cut with a bandsaw and the laser cut the acrylic panels and assembled everything together. The acrylic panel slides into the slots of the extrusions. These extrusions were held together by aluminum T and L brackets and M3 screws with drop-in T nuts. Holes were cut in the outer aluminum casing for fans and wiring. A Thorlabs optical table was placed inside. Mounts were designed and 3-D printed to secure the laser to the optical table.

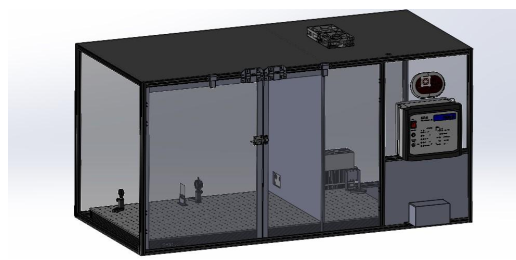

Fig.1 CAD Model of System

Laser Interlock system

Next, the interlocks and an emergency stop button for the laser were set up. The following picture shows the magnetic proximity sensors which sense if the door is open.

Fig.2 Magnetic proximity sensor

The sensors are connected to the ICS-9, which deals with the interlocking logic and sends signals to the LED warning light and laser. The warning light is green when the system is not armed and red if it is. If the system is armed, the ICS-9 sends the corresponding signal (ground) to the PC-1G. The PC-1G is the controller for the laser. It switches the laser on and off and also controls its power. The PC-1G interlock signal has to be grounded for the laser to be turned on. The emergency stop button is connected to the laser's power supply, so if it is pressed, it immediately cuts the power to the laser.

Fig.3 Picture of Interlock components

The following picture shows the wirings of the ICS-9

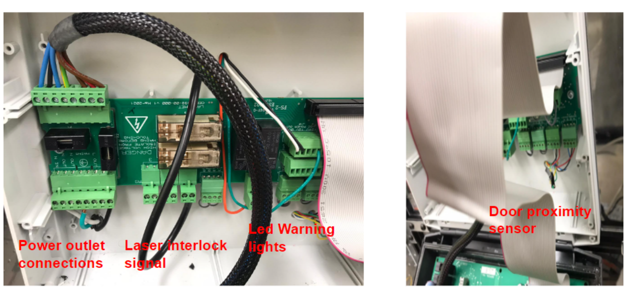

Fig.4 IC9 wiring

Laser Alignment and Redirection

Once a safe and usable laser was implemented, the next goal was to align the laser and the optical components. The problem lies in the fact that the IR laser can only be turned on if the system is closed off. The following solution was conceived: two cards are placed down the path of the laser. The laser will burn a hole in each card. Then a red alignment laser can be used to represent the path of the IR laser if it also goes through both holes. The further apart the two cards, the better the alignment.

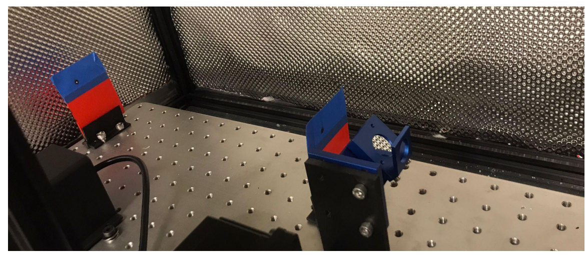

Fig.5 The two cards with a hole

With a visible laser alignment of other optical components is possible.

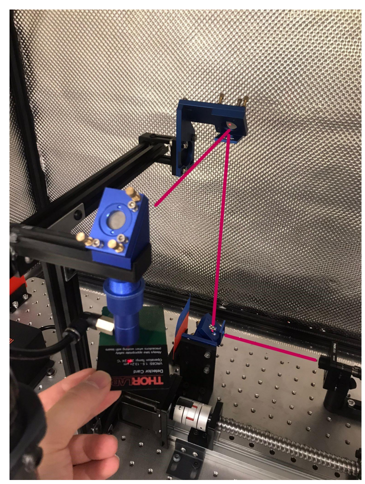

Fig.6 Alignment of mirrors and lenses with red alignment laser (bottom right).

The Ultrarayc K Series CO2 Laser Head Set was incorporated to hold the 20 mm Mirrors and Lens. To fix them in place, stands were designed and 3-D printed. The main structure was also made of the 20*20 extrusion. Screws can be adjusted for alignment.

With a beam width of 1.8mm and a lens with a focal length of 50.8mm, we should theoretically achieve a spot diameter of 0.38mm. If a small diameter needs to be achieved one solution is to expand the beam of the laser prior to the lens. With an expansion factor of 3, the spot goes down to 0.127mm. For the prototype, the current size is acceptable.

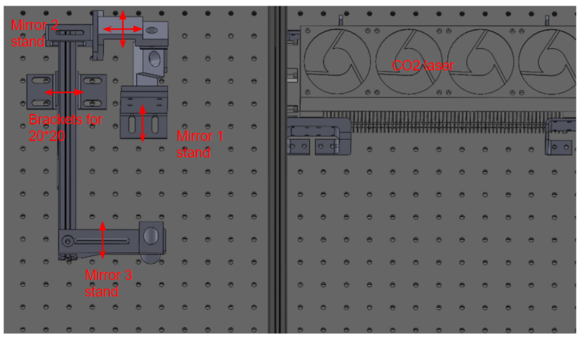

Fig.7 Layout of optical components and their mounts

We needed the final cutting direction of the laser to be going down so it can cut the plats on the petri dish. To do so we also needed enough clearance to not only fit the dish but also the stage that is going to move the stage. So we need to first bounce the laser up before redirecting it down. It was decided that the cutting action should take place toward the center of the chamber for easy access. The initial beam of the laser is located towards the back for maximum clearance, as nothing can interrupt the path of the laser. These decisions resulted in the setup in Fig.7, where Mirror 1 would bounce the light up, Mirror 2 would bounce the light towards the center and Mirror 3 would finally bounce it down. For the mirrors to redirect the laser they have to be in the path of the beam and stand. The stands are specifically designed to allow for movement so that the mirrors can be adjusted to cross the beam path, as shown in Fig.7.

Temperature Control and UV Sterilization

To prevent the temperature from damaging the plants, the system needed a way to control its temperature. Small AC units were installed on each side of the chamber and insulation was also added to the walls. The insulation had an aluminum surface, which was selected to ensure it could not be burnt by the laser. The AC units and two thermometers were connected to a controller in order to maintain a certain temperature.

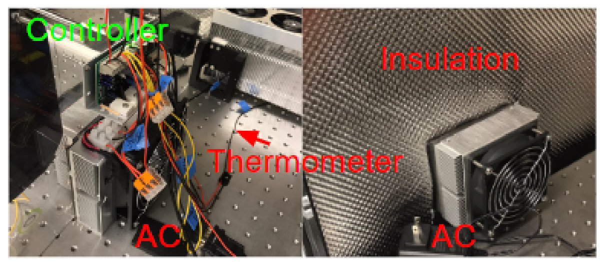

Fig.8 The Components of the Temperature control system.

For sterilization, we mounted two UV lamps onto the ceiling. This way, they can shine evenly on all surfaces. They were mounted by cutting two round holes in the ceiling. The stand of the lamp would sit upside down on the outer side of the top, and the bulb would go through the hole and screw into the stand.

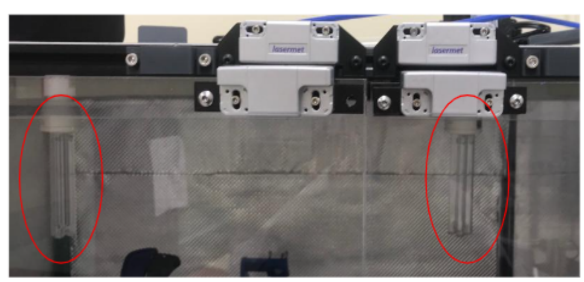

Fig.9 UV lights

Fine Laser and Stage Control

Setting the PC-1G to its local mode controls the power of the laser by using a turning knob. However, this method was not precise enough, and it was hard to get repeatable results. Thus, it was required to use the remote mode with the extension pin. A 0-10V control pin was used and, to do so, the jumper on the J3 inside the PC-1G needed to be in the top configuration.

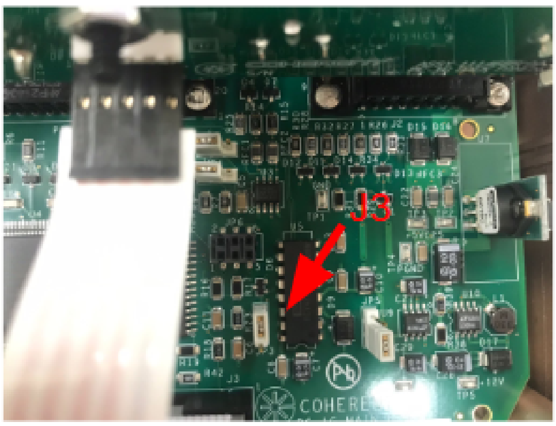

Fig.10 J3 Jumper in the PC-1G

A Teensty 4.1 was used to test this. The output pin can provide an analog output of 0-3.3 V from a digital range of 0 to 255. A script was written for testing in which the user types 0-255 as an input to the serial monitor, resulting in the control pin outputting the corresponding output and pulling the gate pin high. The gate pin has to be high in order for the laser to be on.

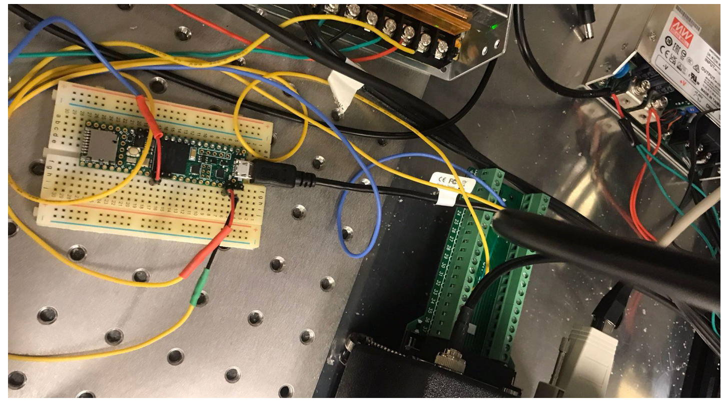

Fig.11 Teensy 4.1 connected to PC-1G connection Pins

Initial test cuts showed that the smoke interfered with the cut so an air assist was added which would blow the smoke away. It also cools the edges of the cut allowing for a cleaner cut. Results show that air assist is needed for a clean cut.

A microscope was added to observe the plant. The 3- stage moves the plant for the cut. The CNC xPro V5 was used to control the stage.

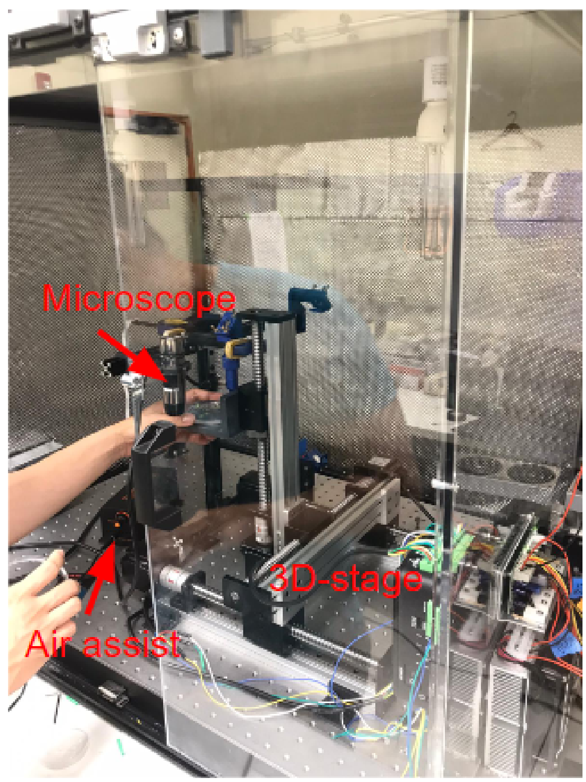

Fig.12 Cutting components

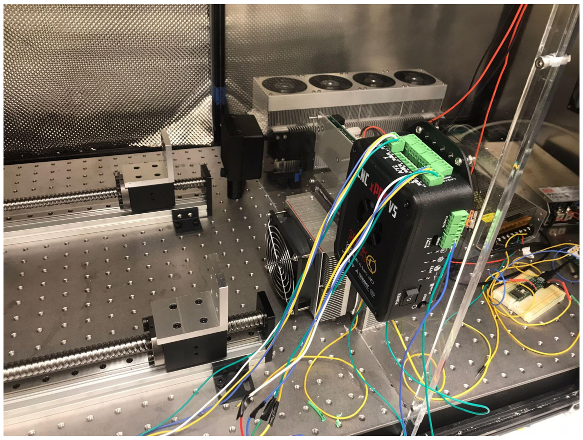

Fig. 13 CNC xPro V5

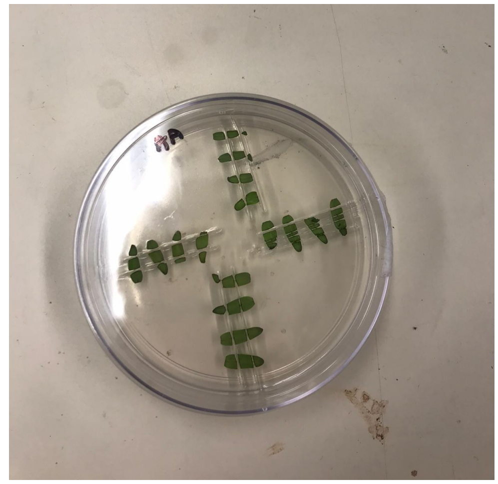

Fig. 13 Some successfully cut plants

3. Results and Discussion

Currently, we have a safe and functional system. To use it the user has to first plug in all the power cords and turn everything on. Place the petri dish on the stage plate and turn on the air assist. After locking the doors switch the IC9 on, and arm it by twisting the key and pressing the arming button. To use the laser, the setting on the PC-1G should be: power on, CW, and RMC. Run the script in the appendix to control the power of the laser. The Range of power is from 0-225. We found 180 is the best power cut through the plant cleanly. The stage can be moved by using a web GUI for the spark_Pro for the cuts. The picture below shows the results of some cuts.

The system is able to successfully cut plant tissue, and the tissues were able to regenerate.

Though the current laser system is functional it can be improved. The system has a lot of parts that work separately, so one of the next logical steps is to bring everything together in one unified system, under one control interface.

Wire management needs to be improved.

Smoke ventilation is one of the problems we have. The Cutting process produces smoke that gets trapped in the chamber which may lead to problems. A safe and sanitary venting system needs to be devised.

Functional imaging software has not yet been implemented. The microscope camera can’t see the full range of the petri dish, so the script needs to stitch the pictures together and figure out the coordinates with respect to the stage. Using this we can figure out where to move the plant to cut the parts we want.

4. Conclusions

After a year's worth of work, the school now owns a class one laser system capable of precisely cutting multiple pieces of plant tissue at once, through manual control of the laser. The system is safe, sanitary, and temperature controlled. The current laser system is still not automatic, and control elements of the system need to be merged into one program. A ventilation system also needs to be added. Future work has to be made to solve these issues.

Acknowledgments

Work was done with the help and supervision of Khoi Ly, who also made final design decisions and ordered the parts needed. Work was also done along with Grace Shirota, who worked on the temperature and stage control.

References

Add cited references.

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2. "Welcome to the CNC xPro V5 (32 Bit) GRBL Motion Controller Documentation!" *GitHub*, github.com/Spark-Concepts/xPro-V5/wiki. Accessed 14 May 2023.
3. "ICS-6 Instruction Manual" Lasermet, May. 2014. No 01000-53-000
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Appendix

Script for laser power control:

```
// Define the pin for
outputting the voltage
int controlPin = 13;
int gatePin = 15;
void setup() {
  // Initialize the serial
communication
  Serial.begin(9600);
  // Set the pin mode for the
output pin to OUTPUT
  pinMode(controlPin, OUTPUT);
  pinMode(gatePin, OUTPUT);
}
void loop() {
  // Check if there's incoming
serial data
  if (Serial.available() > 0) {
    Serial.println("Input int
between 0 and 255 ");
    // Read the incoming
voltage value as a string
    String inputString =
Serial.readStringUntil('\n');
    // Convert the string to a
float
    float inputVoltage =
inputString.toFloat();
    // Check if the input
voltage is within the valid
range of 0-5V
    if (inputVoltage >= 0 &&
inputVoltage <= 255) {
```

```
      // Map the input voltage
value (0-255V) to a PWM duty
cycle (0-255)
      int outputDutyCycle =
map(inputVoltage, 0, 255, 0,
255);
      // Output the voltage on
the control pin and gate pin
      analogWrite(gatePin,
300);
      analogWrite(controlPin,
outputDutyCycle);

Serial.println(outputDutyCycle)
;
    } else {
      // Print an error message
if the input voltage is out of
range
      analogWrite(controlPin,
0);
      analogWrite(gatePin, 0);
      Serial.println("Input
must be between 0 and 225.");
    }
  }
}
```