3D Traversing Plasma Wound Treatment

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Senior Design Project I, ME195A - 06

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Abstract

The 3D Traversing Plasma Wound Treater is one of Professor Syed Zaidis Senior Projects for San Jose State University Fall 2023- Spring 2024. The objective of this project is to combine ground breaking sterilization technology with mechatronics. The project will consist of three main components; Cold Atmospheric Plasma, a camera, and a 3 Dimensional Gantry Robot. The Cold Atmospheric Plasma will be responsible for sterilizing wounds and promoting wound recovery. Cold Atmospheric Plasma is a mixture of Hydrogen, Helium, Argon, and Oxygen that prompts stimulation to skin cells resulting in faster recovery times. The 3 Dimensional Gantry robot will guide the plasma to ensure the patient receives proper coverage to the wound. The Gantry Robot will be operated using an Arduino board and three stepper motors. Each stepper motor will be responsible for its own axis. The final component to our robot is a camera that will utilize image processing to detect a wound. The camera will also be responsible for feeding the stepper motors the proper coordinates of the wound location.

Exclusive Summary

This project aims to meet the growing demand for groundbreaking new medical treatment through the use of mechatronic solutions to increase volume and low cost availability. By using our knowledge of mechatronics and mechanical engineering principles, we built upon an existing version of a 2D gantry robot designed to administer cold atmospheric plasma treatment to cauterize wounds and adapted it to be fully autonomous in the x and y direction through the use of image processing to read the image and generate a tool pathway for the robot to follow and user controlled in the z direction to control the intensity of the plasma being applied to the wound surface. This executive summary provides a concise overview of the project's objective, methodology, and key findings.

The primary objective of this project is to build upon an existing design for a 2D robot that will administer cold atmospheric plasma treatment to a wound to be functional in all 3 dimensions and use image processing to automatically detect the wound and perform the treatment with minimal user intervention. Realizing that automation is the future for cheap and accessible health care, our project aims to break new ground and pave the way for more widespread usage of mechatronic solutions in healthcare.

Our methodology towards completing our project objective is to automate the x and y dimensions that the robot will operate on through a combination of image processing using MATLAB and Arduino to control the stepper motors that will be responsible for traversing the wound surface to minimize user input. Our design will take the form of a Traversing Gantry robot as this is the most effective solution in terms of cost and performance. The Gantry Robot will be operated using an Arduino board and three stepper motors in tandem with a camera that takes a photo of the wound and a MATLAB script that reads the data and creates a tool pathway

for the robot to follow. The robot will have control in the z axis to adjust the intensity of the plasma. This is all done in an effort to reduce the costs of this groundbreaking new treatment and make it more accessible as a result. Our methodology also consists of extensive testing, prototyping, and getting all of the systems of our robot to function in unison.

We have yet to construct our fully functioning prototype as we faced unexpected delays with complications related to acquiring parts. This has delayed our testing process as we are unable to test an unfinished mechanism. However, we are making significant progress in getting some of the robot's systems to function independently. The MATLAB code for the image processing and generating a tool pathway is under development and is nearly ready for implementation. We also verified the functionality of the existing 2D gantry robot and have code for moving the stepper motors. Our next steps include getting the MATLAB script and the Arduino to communicate and allow for full control of the stepper motors based on information processed with the MATLAB script.

In conclusion, the completion of this project will be another step forward in the widespread implementation of mechatronic solutions in the healthcare field. Our 3D gantry robot will serve as a model for future developments in the healthcare industry to automate treatment procedures and thus reduce the amount of personnel necessary to perform CAP treatment. This will bring the price down and increase the availability of the treatment for a wider range of patients.

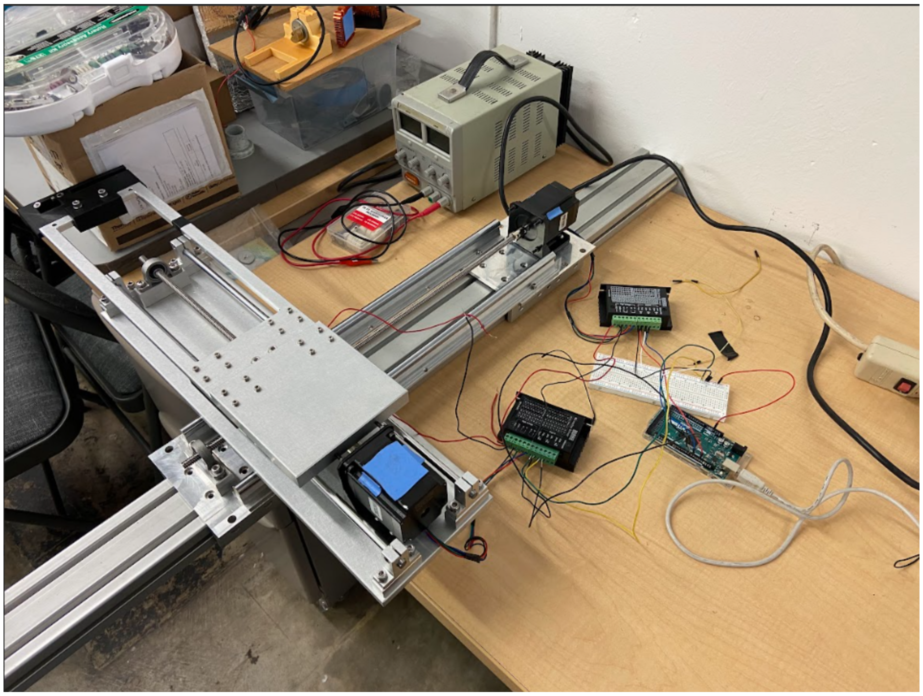

Figure 1: The preexisting 2D robot that will be adapted to function in 3 dimensions

Introduction

Background:

Sterilization is one of the most important procedures to ensure proper recovery of a wound. The most common method of sterilization is using harmful chemicals which are known to damage tissue resulting in a delay to recover. We can reduce the amount of damaged tissue by having properly trained staff members but will cost time and money. Cold Atmospheric Plasma will be the replacement to these chemicals to ensure recovery rates increase. This technology is relatively new meaning there are not many resources and machinery available and the ones on the current market are extremely expensive. This Project will dramatically reduce the cost of proper wound sterilization while drastically reducing the price.

Objectives:

The primary goal of this project is to fix all of the minute and unforeseen issues that were inherited from last year's team. The biggest physical issue that we have encountered is over torqued screws that caused leadscrew bowing and aluminum to parts to flex. The previous code that was used does not work so we decided we will create all of the code from scratch. The secondary goal of this project is to incorporate the z-axis to the project. The z-axis will be responsible for holding the plasma torch and will be controlled using a potentiometer. Controlling the z-axis is an important safety feature in case the skin temperature begins to rise. The next objective is to create an image processing code using Matlab to detect a wound from an image. The following objective is to create a code to move the X, Y, & Z axis stepper motor. Lastly, we aim to gather coordinates from the image processing to feed the stepper motors. These coordinates will allow the Cold Atmospheric Plasma to be applied to the wound autonomously.

Literature Review:

When it comes to wound sterilization, multiple methods can be performed. One of the most common methods to sterilize a wound is by using antiseptics. Antiseptics is one of the most common methods because it does not require a medical professional to sterilize. The most common antiseptics include iodine solution, rubbing alcohol, and hydroperoxide. Even Though this method of wound care is relatively cheap and has been proven to kill microorganisms, it is becoming obsolete. Antiseptics are known only to kill microorganisms and can be very painful to the patient. The application of the products can be highly inconsistent because it is based on how much an individual decides to apply on a wound. According to the National Library of Medicine, an excess amount of antiseptic will kill off microorganisms bacteria and damage surrounding cells, causing a delay in wound healing(). Cold Atmospheric Plasma (CAP) is a new up-and-coming technology proposed for wound sterilization. CAP is a mixture of gasses such as helium, argon, nitrogen, and oxygen mixed to create the plasma. Cold Atmospheric Plasma can kill and reduce microorganisms around a wound while promoting tissue repair. According to the National Library of Medicine, the Plasma touch creates a hierarchy group of reactive oxygen and nitrogen species named RONS when in contact with the skin(). This reactive oxygen and nitrogen group increases skin tissue microcirculation and monocyte stimulation. One of the most significant downsides to using Cold Atmospheric Plasma is the meticulous requirements to have ideal performance. The Gas mixture to the plasma plays a key role in the performance and must be perfectly mixed and can vary by application.. While reading through the articles we noticed there is a lot of information on Cold Atmospheric Plasma and how it works but we did not find much information regarding how it operated or machines to apply the plasma.

Since the Cold Atmospheric Plasma is a relatively new technology there isn't much information in regards to the machine. Most operating machines on the market are extremely expensive and hand held. While a handheld device allows us to clean and disinfect a wound, there is a lot of room for operator error causing improper disinfection. In order to guarantee patients get disinfected properly our group's goal is to create a budget friendly device that will automate the sterilization process. Since the market is very limited and new there is not a lot of competition we had to determine how and what we will use to automate the sterilization process. After some research we found that our best option for now was creating a Cartesian Robot. A cartesian otherwise known as Gantry robot is a mechanical divide that uses linear axes movements in the 2D or 3D space. Generally the linear motion is caused by servo, stepper, dc motors connected to belts,cables, screw, pneumatic, rack and pinion systems. Gantry robots are known for their high level of accuracy and precision and can have tolerances ranging as low as micrometers. Gantry robots also have a relatively low cost to build and have a huge online support system that makes them easy to program. Some popular examples of these types of robots are CNC milling machines, 3D printers, Soda Machine systems etc. Typically Gantry robots are “blind” and have a pre-set code that commands what the system will do. One huge advantage of these robots is the ability to add any kind of vision device such as cameras and sensors in order to help automate the robot. We decided to combine both cold atmospheric plasma and gantry robot technologies.

In order to understand how image processing works, we need to understand what an image is. In the simplest terms, an image is a function of two variables X & Y. Each coordinate point has its own value of color and brightness at that location. The set color and brightness at this location is called a pixel. In order to differentiate the colors we use a RGB color model to represent the pixel color value. When processing an image, we take advantage of the RGB values for specific colors and program our code to look for these values in an image.

Progress:

As of December 2023, the progress to the project has unfortunately been slower than ideal but consistent. The logistics of receiving parts for our project was the biggest challenge and delay to date. Fortunately for us, we received all of the necessary to complete the project at the end of the semester. Even Though we had an unforeseen delay, We managed to get a good amount of work completed. The first objective that has been completed is straightening out the metal that was deformed. Fixing this issue allowed us to reduce the necessary voltage to spin the stepper motors of 23 Volts down to 9 Volts. The final z-axis assembly and circuit have been completed as of late November 2023. Lastly, the image processing code can successfully detect wounds from a project and provide three different methods of detection depending on the operator's choice. The options for the boundary conditions are scattered wounds, entire wounds, allowing the operator to make a manual boundary box.

Methodology:

The Plasma Wound Treatment Mechanism should process digital images of 2-dimensional wounds via Matlab. Our mechanism will utilize a camera to photograph the wound when initialized. Once the picture has been taken, the picture file will be set up as an MxN matrix of pixels for the length and height of the image. After the matrix is created, the program will detect the boundaries of the wound using RGB values in the pixels that make up the picture matrix. To start parametrizing the edge of a wound, we would initialize a range of specific pixel values that equate to having a dominant “RED " RGB value, which will mean that a flesh wound is present, and our script will save the RGB value in each pixel where it will outline the flesh wound from the rest of the skin.

Alongside the digital image processing, our mechanism will plot a path that the stepper motors will interpret as distances that our stage must traverse to cauterize the wound. The mechanism will have a mounted z-axis assembly with a potentiometer-driven stepper motor that will carry the glass plasma torch and camera. The z-axis assembly’s full range of motion will be within a range of 100mm. This range of motion will dictate how much plasma is applied on the wound surface and in turn affect how quickly the wound can begin healing without adding more damage to the surface.

Team Member Roles:

Name	**Role**
Nicholas Sandberg	Technical Lead: MATLAB/Programming, Communications Director
Jorge Quintero	Technical Lead: Manufacturing, Assembly
Eric Montoya	Technical Lead: Hardware, Assembly
Unurbayar Bayarsaikhan	Group Manager, Technical Lead: Image processing
Manuel Espindola	Technical Lead: Writing, CAD Modelling

Figure 2. GANTT Chart

Timeline:

Our initial goal was to be completely finished with our project by December 11th. Unfortunately due to logistics this completion date has been pushed back to the end of February.

Functional Requirements:

- Stepper Motor must not surpass 50% of loading torque
    - Motor must support loading torque of 0.781 $\frac{N}{m}$
- Stepper motor must move at a speed of $\frac{1\,inch}{2\,Second}$
- 10 Cm of z-axis movement
- 1 mm of plasma overlap
- Image processing must detect RGB values of 0 to 255

Theory Background

Our Plasma Wound Treatment Mechanism combines Cold Atmospheric Plasma (CAP) technology with a Cartesian Gantry Robot system to automate wound sterilization. Using MATLAB, digital imaging of 2-Dimensional wounds are processed. We achieve this using a camera module which captures wound images, converted into MxN matrices of pixels via MATLAB. The program detects wound boundaries by analyzing RGB values, identifying dominant "RED" values to delineate the wound from healthy skin. Simultaneously, the mechanism plans a path for stepper motors based on the processed image. The system includes a z-axis assembly driven by a stepper motor, controlling a glass plasma torch and camera. The z-axis's 100mm motion range determines plasma application on the wound, balancing sterilization effectiveness and minimizing surface damage to expedite healing. By integrating image processing and precise motor movements, this mechanism aims to automate wound sterilization with CAP, ensuring consistent application while minimizing human error.

Design

Z-Axis Assembly:

The Befenbay stepper motor with linear rail guide and lead screw mechanism was selected because the performance specifications and price met our requirements. With a maximum horizontal load capacity of 2.5kg and 1kg vertically, it more than exceeded what was needed to carry the plasma and camera assembly. A range of speeds between 0 to 120 mm/min means that the plasma torch is able to move vertically in the z-axis quickly enough to maneuver around three-dimensional objects as it follows the path generated by our image processing. The z-axis stage is intended to move in tandem with the traversing x and y-axis stages, thus its 100 mm effective travel length will be more than enough for the initial tests. The motor requires a 24V DC source as well as 0.5 A of current. Testing the mechanism alongside the two Nema 23 stepper motors will reveal the electrical output requirements to ensure steady and smooth operation as all three motors operate. Its step angle of 1.8 degrees means additional conversions will not be required to determine the necessary speeds at which the z-axis stage will need to move to match the traversing stages. Befenbay claims a repeated positional accuracy of ± 0.05mm which means the precision of the generated path that requires movement ranges of 1 to 0.5mm will be preserved. One limitation we have encountered is that the weight of the assembly after installation of the plasma torch and camera mount may exceed 0.272kg. This factor may significantly affect the electrical output requirements for the entire system. A manufacturer specified holding torque of 6 N*cm is enough to maneuver the 40 gram plasma torch and camera mount effectively, however, testing will reveal if the rotor inertia of 8 g*cm will affect its ability to follow the generated paths without jitter. Fortunately, we can disassemble the entire product giving us the option of making any necessary modifications. As a preliminary choice, the Befenbay assembly has enough versatility to remain in the final product.

In order to mount the z-axis mechanism to the traversing stage, we took measurements of each platform and replicated the entire system on SolidWorks. At the end of the y-axis stage, an array of four mounting holes of 5.5mm diameter, spaced 32.5mm apart were used to align the mount. The c-shaped clamp portion of the mount is 10mm thick on each side to provide enough rigidity to support the mounting plate that hugs the outer perimeter of the Befenbay mechanism. Four 3mm holes are aligned with the threaded holes on the mechanism and for the meantime will utilize M3-0.5x45mm hex cap screws to fasten the mount. The z-axis stage also has four mounting points with the same threaded hole dimensions spaced out in a square pattern at 20mm. The mount that carries the plasma torch uses a clamping design that requires a single screw to generate force to retain the torch at the desired orientation and position. An extension with a 6mm hole aligns with the preliminary position of our Arducam Mega camera. An M6 thread pitch on the back of the camera will require a large screw for assembly. Its position relative to the torch was selected for its 68.75° viewing angle to ensure a complete field of view for the wound detection. Once the CAD models were complete, we used Ultimaker Cura to convert the files to 3-d printer code. The prototypes are made of PLA at 100% infill giving the mounting parts an average value of 55 MPa tensile strength. Once testing is complete and no defects or signs of fatigue are detected, we will proceed with manufacturing the parts from 6061 aluminum**.** The figure demonstrating the CAD model of the assembly can be found in the appendices figure 3. Figure 4 shows the rendering of the complete system.

Testing, Results and Analysis

The whole device is built in mind to work by itself with minimal user interference. The substantial portion of the user interference needed for the device is to adjust the distance of the plasma torch from the wound, which is the z-axis. The other user interference would be confirming the bounding box created by the Matlab is acceptable. Rest of the process would be done automatically by the device. To test the machine, we utilized images of wounds we found online to feed into the Matlab code we created. Different types of images were processed to check the accuracy of the wound detection. Two images (Figure 2 and Figure 5) were selected to be tested primarily as their red pixel displacements had different orientations. For Figure 2, the red pixels were scattered after the red filter using RGB as shown in Figure 3. As for Figure 5, the red pixels were bundled around for the most part as shown in Figure 6. Our first version of the code was written to put the bounding box around the most concentrated area of red pixels. As a result of the way the code was written, the bounding box of Figure 2 only covered part of the wound due to the red pixels being scattered. For Figure 5, little more than half were covered by the bounding box. For the second version of the code, we wrote it to draw the bounding box around all red pixels. As shown in Figure 4 and Figure 7, the bounding box covered all around the pixels. Only drawing back from the second version of the code is the bounding box can be too big as shown in Figure 7. This is due to the code detecting a red pixel away from the wound. As a result, an additional code was created in which a user can readjust the bounding box after the user runs either version 1 or version 2.

Figure 3: Test image of wound 1

Figure 4.1: Test Image of wound 2

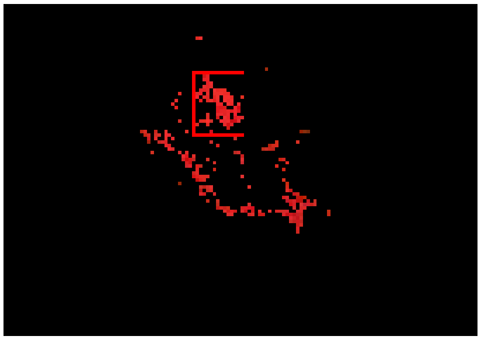

Figure 3.1: Bounding Box around concentration of red pixel

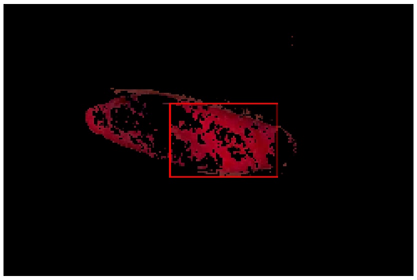

Figure 4.2: BoundingBox around concentration of red pixels

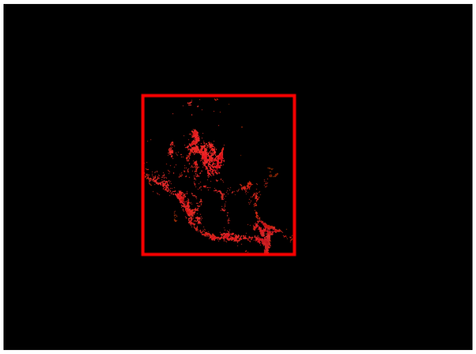

Figure 3.2: Bounding box around all red pixels

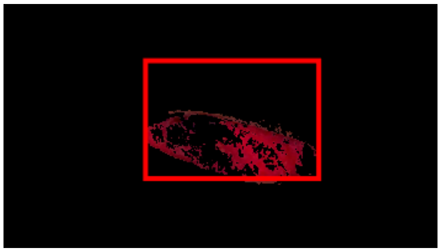

Figure 4.3: BoundingBox around all red pixels

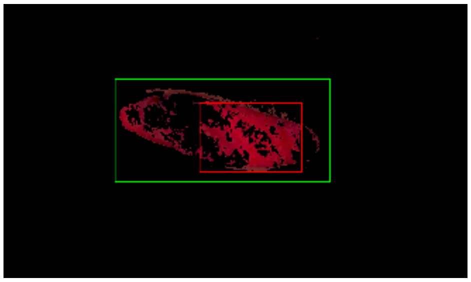

Figure 5: BoundingBox controller by user

Conclusion & Future Work

In conclusion, the primary objective of this project is to build upon an existing design for a 2D robot that will administer cold atmospheric plasma treatment to a wound to be functional in all 3 dimensions and use image processing to automatically detect the wound and perform the treatment with minimal user intervention. CAP treatment is a revolutionary and groundbreaking treatment that can be used to cauterize wounds efficiently without damaging the tissue of the patient. Our group elected to construct our solution as a 3D gantry robot as this option provided the optimum performance on a relatively cheap budget without being overly complicated to design and implement. This gantry robot uses image processing and reads the data collected from the camera to control stepper motors in the x and y direction while an operator controls the z axis motion of the plasma torch to adjust the intensity of the plasma being applied to the patient.

We have yet to complete our testing phase as we experienced unforeseen delays with parts acquisition, but we have made significant strides towards a fully functioning system with the parts that we currently have available to us. We are currently working to get each individual system to function on its own prior to combining all the systems to work together. We were able to get the image processing and tool pathway scripts in MATLAB to work as well as the Arduino code for the stepper motors. We have yet to implement the z axis control as well as getting the entire system to work together.

When fully completed, the gantry robot will be fully autonomous in the x and y directions and manually controlled in the z axis. It will be able to accurately determine the location and size of a wound to automatically generate a tool pathway for the traversing table component to follow and administer the plasma in a zig-zag pattern. It will be able to perform treatment quickly and effectively and the mechanism will be cost effective to manufacture and implement on a larger scale.

In the future, we would like to complete our project and have it be fully functional as intended. We are aiming to start testing our mechanism in early 2024 and have it be fully functional by March. Beyond the scope of this project, we would like to improve upon the design to improve performance and increase the level of automation while making the design cheaper as well. Our mechanism can even be adapted for other purposes and administer other forms of treatment with some modification to the design. Overall, we aim for our device to break new ground and contribute to the spread of mechatronic solutions in healthcare.

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Appendices

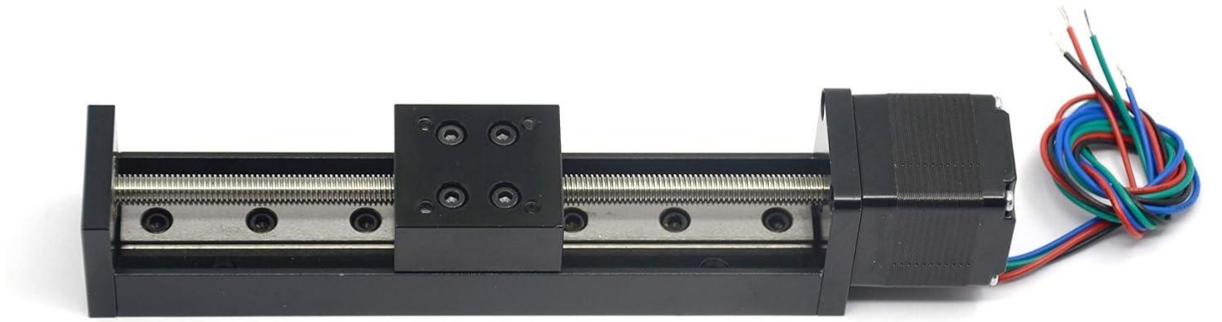

Figure 1. 100mm Linear Rail Guide assembly w/ Lead screw for Z-axis

Motor Requirements:

1. **Steps to move 25.4mm**
   a. $25.4\,mm \cdot \frac{1\,Rev}{2\,mm} \cdot \frac{1600\,Pulses}{1\,Rev} = 20,320\,Pulses$.
2. **Position Accuracy**
   a. $\frac{2\,mm}{Rev} \cdot \frac{1\,Rev}{1600\,Pulses} = \frac{0.00125\,mm}{Pulse}$.
3. **Motor Speed**
   a. $\frac{25.4\,mm}{2\,Sec} \cdot \frac{1\,Rev}{2\,mm} = \frac{12.7\,Rev}{2\,Sec} \cdot \frac{60\,Sec}{1\,Min} = 381\,RPM$.
4. **Weight to move = 4.053 Kg**
   a. Top Mount = 1.22 Kg
   b. Bottom Mount = 1.79 Kg
   c. Z-Axis = 1.043 Kg
5. **Torque Required**
   a. 0.780 $\frac{N}{m}$

Figure 2. Stepper Motor Specifications

CAD Models:

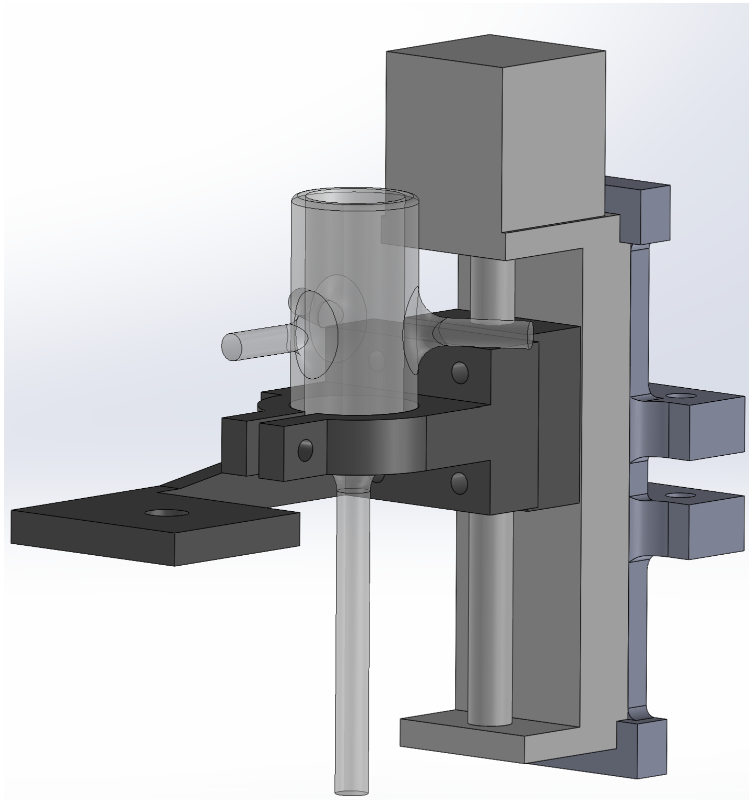

Figure 3. Z-axis assembly with mounting bracket and plasma torch/camera mount.

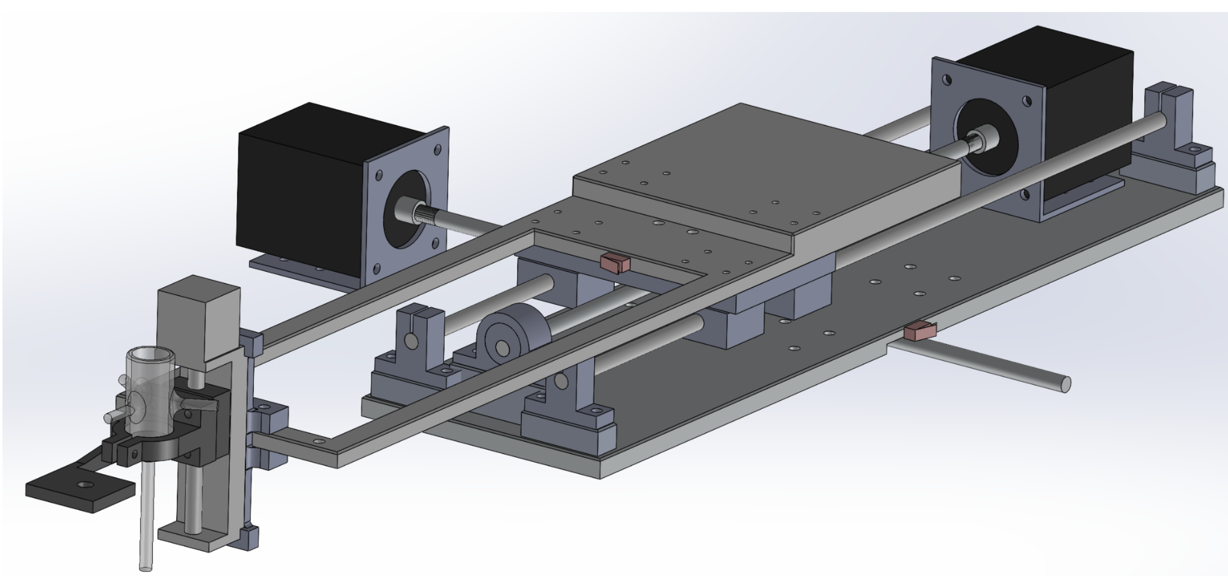

Figure 4. CAD model of the entire assembly.