The Write-inator

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Description: A three axis arduino-controlled writing machine that prints out a desired output.

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Class: Engineering Sciences 50
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ABSTRACT

The goal of our project was to build and program an automated writing machine that makes use of a pen moving through three axes: x, y and z to print out the input it gets. The pen is attached to a servo motor that moves it up and down and two stepper motors that play the role of moving the pen horizontally or vertically which then allows for motion in three axes. This project combines all our interests as a group being: Computer Science, Mechanical Engineering, and of course Electrical Engineering. The main goal of the project was to create a writing machine that incorporated all of those aspects with emphasis on the use of electrical components. We overall wanted to create something that was both fun and challenging and representative of our semester as ES50 students. The motivation of the project stemmed from the fact that the world is becoming more and more automated by the day, so who knows maybe writing will become obsolete one day too. Unfortunately, we were unable to produce an output of our desired machine due to errors that we were unable to debug. Our x-axis motor wouldn't work when connected with the rest of the machine, and after many trials and tests we concluded that there must have been an issue or fault with the CNC shield that connects the motors. We were unable to replace the shield in time, but we're confident this is where our problem lay.

INTRODUCTION

By utilizing Arduino to make a writing machine, the goal was to use software that symbolized any desired writing output. This system is a cleverly embedded system that is based on the Computer Numerical Control (CNC) machine. It uses an Arduino development CNC board that connects outer peripherals like motors, that provide the necessary pen movement, to the arduino. The machine makes use of one servo motor and two stepper motors to achieve the pen movement and x-y axis gantry movement respectively based on the input image that is fed into the system. The pen which is fitted in the system is part of the z axis movement. The servo motor helps in the vertical movement of the nib of the pen so that the pen nib will touch the paper only when something needs to be written and is raised above when not needed. This motion of the pen in the z axis coupled with the x and y axis movement achieved through the stepper motors results in a two dimensional sketching on the paper.

We were interested in this project for several reasons but one of the driving motivations was how useful it could be in the real world. The proposed automated writing system is overall meant to make someone's clerical or leisurely work simpler by programming this machine to do it for them. This system is a valuable setup and can be utilized in everyday life. There are many areas in life that require written work that could easily be replaced by a machine like ours. For example, the writing machine could prove most useful in administration, judicial and possible police work where manually writing out is required. The project is feasible in both the present and future where automation is becoming second nature and almost all manual work is reliant on a machine.

DESIGN

Because there are ample examples of this machine online, we wanted to implement a design that was unique to the ones we saw in that it would be both more cost effective and more sustainable. Fig.1 and 2 show examples of online machines that we used as inspiration. From these figures you can observe the use of metal and plastic that we overall tried our best to avoid unless it was recycled. After many conversations with both mechanical engineering TFs and students we decided to use wood and cardboard for the structure of the machine, as they both symbolized how one could recycle these materials to create something cool. Our initial plan was to create many 3D-printed components and jigsaw puzzle our way to making the structure of the machine, but because we wanted to inspire sustainability we decided against using new plastic.

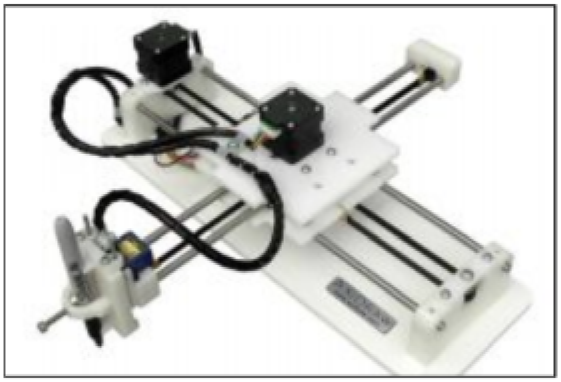


Fig 1. AxiDraw Machine (https://www.axidraw.com)

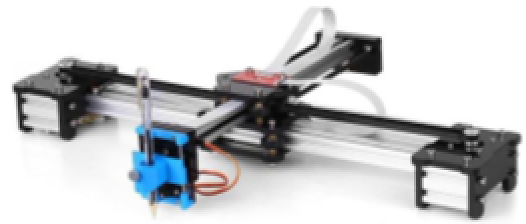


Fig 2. Setup Writing Machine (https://www.walmart.com/ip/Meterk-Desktop-DIY-Assembled-XY-Plotter-Pen-Drawing-Robot-Drawing-Machine-Painting-Handwriting-Robot-Kit/853006447)

The next step in our design process was ensuring our structure could support the weight of our two stepper motors. After googling the weight of the stepper motors and discovering that they were 0.5lbs, we decided that cardboard would suffice in holding the x-axis motor up. We took extra precaution of this, as this was one of the most important aspects of the machine, and we decided we would add a cardboard platform beneath the cardboard panel that would hold up the stepper motor. We also concluded that because the NEMA 17 Stepper motors that we were using for the machine were 1.7 inches x 1.7 inches, we would cut the wood that would hold them up to a height of 1.8 inches. This decision was based on the fact that we wanted the machine to have a cleaner finish.

With our wood, cardboard and motors plan sorted, we then started on the planning for the rods that would actually move the pen platform in the x and y directions. Our initial thought was to buy steel rods of a certain height and move forward as plans, however when we discovered that they were going to be around $30 we asked the MechE lab for advice. They pointed us to rods from their lab that we would have to cut to achieve the best result. The machine is altogether reliant on the gliding motion across the rods so we ensured that the rods would work for this with basic testing on the friction of the rods. The other obstacle we stumbled upon was how to connect one of the rods, per axis, to the stepper motor. This was a mix of trial and error and creativity, but in the end we self-engineered a design using cut up pen barrels. Using a simple black bic pen, we cut the barrel of the pen into 3cm cylinders that would connect the rods to the motors. We realized that the two had different circumferences and attempted to first put the base of the pen around the stepper motor and then attach the cylinder. This worked out great for holding the motors and rods in place. This was a really important aspect because if the motors were not connected to the rods directly they would not be able to spin them thus the machine would be ineffective. Fig 3. shows the rods, wood and pen barrel schematic and how it connects the stepper motor to the rod on the y-axis.

Fig 3. Rods, wood and motor connection for y-axis

The last step of the structural design process was a way in which we could fix the pen to the machine so that it would be 90 degrees to the paper. With the obvious choice of superglue in mind we still had a major problem to tackle. We needed to figure out how to attach the pen to the servo motor so that the motor would move the pen nib up and down onto the paper when instructed to do so. As seen in Fig 4., we decided to use string as well as a spring to ensure the pen would function well. We were confident that these plans were solid for the structure of the machine which in the end was one of the aspects we were most proud of. Once we agreed upon a design for the platform for the project, we moved on to figuring out the electronics and software.

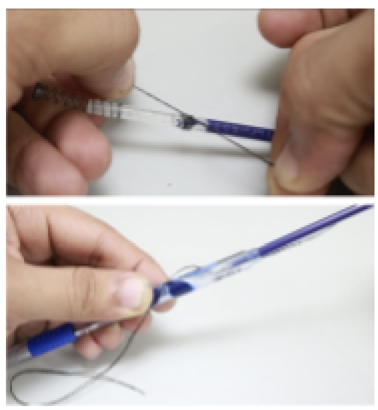
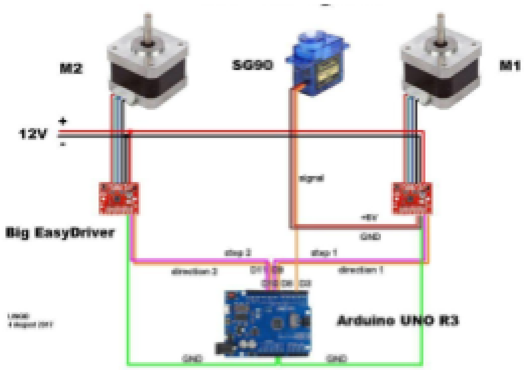


Fig 4. String, spring and pen to attach to servo motor.

Fig 5. shows a block diagram for our writing machine with Fig. 6 demonstrating the wiring of the hardware components to the arduino. We intended to stick to this setup and in order to power and connect the driver motors we made use of a CNC shield. We decided upon the CNC shield because it was a commonly used platform for the drivers in many designs we saw. We were also interested in learning the mechanisms of CNC controlled machines as they truly are fascinating. We googled the voltage and current each motor needed and calculated that a 12-36V power supply would suffice because the NEMA-17 Stepper motors run at voltages of 3.4V and the servo motor required 4.8V thus we were confident with the power supply in that regard. We didn't quite understand the ampere rating per cycle phenomena and we miscalculated the amount of current each motor would draw when the machine was up and running.

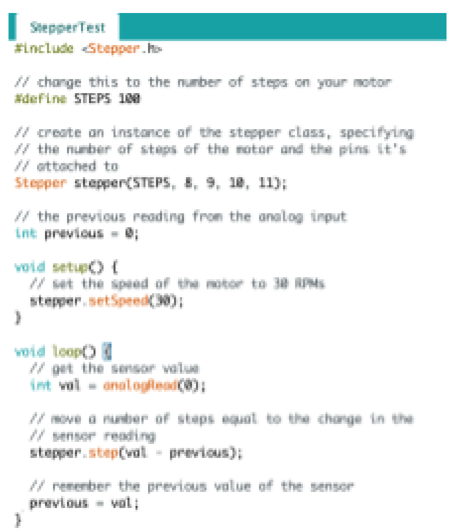


r Fig. 6 Wiring of hardware components.

The NEMA 17 draws 1.5-1.8A per phase and it is a four phase motor which means altogether it requires around 6A. Our power supply only provided 5A. Initially when our machine wasn't working with the X-axis stepper motor refusing to move, we thought it may have been a current issue. However, we connected the motor and the machine to a power supply in the lab that provided 10A and we still yielded the same malfunctioning motor when it was connected through the CNC shield. We concluded that this was not the issue with the motor because when we tested the current draw for each motor we got values that were < 2A each.

Knowing that electrical components can be faulty we tested out our motors beforehand to ensure they worked accordingly. We first checked the wiring of the motors to ensure everything was balanced as it should be. We used red LEDs to test them, but unfortunately didn't think to take video footage of this. We got the idea from youtube and in Fig. 7 the youtuber is testing the motors as we did in the lab. The purpose of this was solely to test that the wiring of the motors was intact and working well. We also wrote basic Arduino code to test our motors that is shown in Fig 8. and also attached in the zip folder with the other code.

Fig. 7 Stepper Motor LED testing

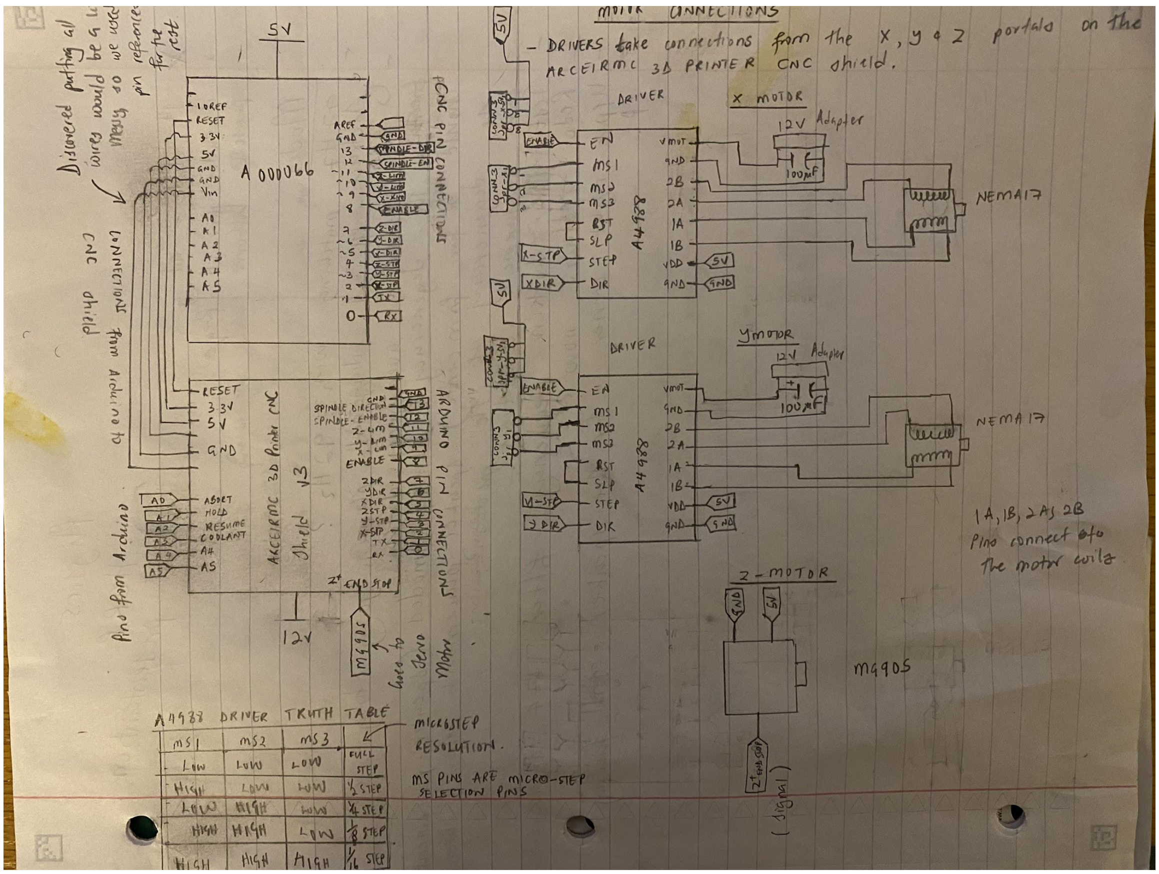


```
StepperTest
#include <Stepper.h>

// change this to the number of steps on your motor
#define STEPS 100

// create an instance of the stepper class, specifying
// the number of steps of the motor and the pins it's
// attached to
Stepper stepper(STEPS, 8, 9, 10, 11);

// the previous reading from the analog input
int previous = 0;

void setup() {
  // set the speed of the motor to 30 RPMs
  stepper.setSpeed(30);
}

void loop() {
  // get the sensor value
  int val = analogRead(0);

  // move a number of steps equal to the change in the
  // sensor reading
  stepper.step(val - previous);

  // remember the previous value of the sensor
  previous = val;
}
```

Fig. 8 Arduino code for testing stepper motor

After concluding that the motors were working fine we decided that we had a solid enough plan to get going on actually making the machine. What we failed to test and should have tested during our testing stage was whether the motors were working when connected to the CNC shield. Instead we only tested them directly connected to the arduino through a breadboard. If we had tested the functionality of the motors through the CNC shield we would have caught the mistake early and created our envisioned machine. Despite not doing this, it ended up being a great learning experience for us as first time electrical engineering students. We have definitely absorbed our acquired knowledge for any future electrical engineering projects. The figure below shows a complete version of our circuit schematic for our writing machine.

CIRCUIT SCHEMATIC



The software design was the most challenging aspect and with the advice from our TFs we used code from the internet to implement our writing machine. In order to implement the machine many software applications were required. The software applications we decided on were: Arduino, Inkscape (for creating gcode files from images) and Processing (for processing gcode files). Gcode files are necessary for arduino controlled machines because it allows the device to read an image as if it were lines of instructions it can send to a machine like this one. It took a lot of research to find out the best way to incorporate this and we had challenges incorporating it on a macbook laptop. The code for the arduino is attached in the zip file saved as “Arduino_code”; processing code as

“Processing code”, gcode files as “Gcode” and the testing we did on the motors as “Stepper tests”.

PARTS LIST

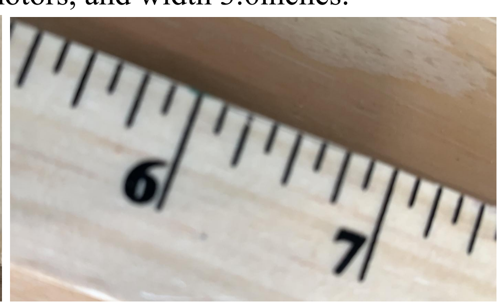
Parts	Full name with part numbers	Quantities used	Link(s)	Price
Arduino Uno	Arduino Uno REV3 [A000066]	x1	https://www.amazon.com/dp/B008GRTSV6/?coliid=I3EI685R8XXFZM&colid=3WBU8Q33PK5U&psc=1&ref_=_sed_dp	$22.77
CNC Shield	CNC Shield V3 Engraver Expansion Board	x1	https://www.amazon.com/dp/B07TT3C3HB/?coliid=I6US016SMSSNA&colid=3WBU8Q33PK5U&psc=1&ref_=gv_ov_lig_pi_dp	$10.99
Motor drivers and heat sinks	A4988 Driver Module x Radiator	x4	https://www.amazon.com/dp/B07TT3C3HB/?coliid=I6US016SMSSNA&colid=3WBU8Q33PK5U&psc=1&ref_=gv_ov_lig_pi_dp	(included in above price)
Stepper Motor	17HS13-1334D Nema 17 Stepper Motor with 1m Cable and Dupont Connector	x2	https://www.amazon.com/dp/B08HWGYY9D/?coliid=I3JA5F5R7CH3GE&colid=3WBU8Q33PK5U&ref_=_sed_dp&th=1	$23.99
Servo Motor	MG90S 9g Metal Gear Micro Tower Pro Servo Upgraded SG90 Digital Micro Servos	x1	https://www.amazon.com/dp/B07NV476P7/?coliid=I3C7X6HT5TI9S3&colid=3WBU8Q33PK5U&psc=1&ref_=gv_ov_lig_pi_dp	$10.99
Power Supply	ALITOVE DC 12V 5A Power Supply Adapter Converter Transformer AC 100-240V input with	x1	https://www.amazon.com/dp/B01GEA8PQA/?coliid=I2XJGCJ4LS60P5&colid=3WBU8Q33PK5U&psc=1&ref_=gv_ov_lig_pi_dp	$12.89

	5.5x2.5mm DC Output Jack			
Wood panel	90cmx90cm wood board	x1	Found in Maker’s Lab	-
Cardboard panel	30cmx30cm cardboard panel	x1	Found in Maker’s Lab	-
Steel and metal rods	-	x5	Found in Maker’s Lab	-
Pen	BIC Round Stic Xtra Life Ballpoint Pen	x2	Used from personal stock	-
String	Black sewing string	N/A	Found in Maker’s Lab	-
			Grand Total	$81.63

PROJECT IMPLEMENTATION

<u>Step 1: Cutting wood and cardboard</u>

We need two wood pieces for each axis of our design that supports the rods and stepper motors. So our initial step is to cut four identical rectangles of wood of height 1.8 inches, as this is the height of our stepper motors, and width 3.6inches.



<u>Step 2: Drilling holes in wood rectangles</u>

Next we need to drill holes in our wood rectangles in appropriate places by measuring where stepper motors and rods would fit through. We used a ruler to measure where the center of the stepper motors would be. We drill two holes on two of the rectangles for the y-axis and three holes on two rectangles for the x-axis. We added another rod here for balance reasons.

<u>Step 3: Cut rods for axes</u>

We cut the rods using a hacksaw that we used to cut the wood. This was challenging especially since it was our first time doing it but we used a table clamp to make the cutting easier. We decided to cut the rods 8.5 inches. Got a bit of a finger cut doing this but overall a fun experience!

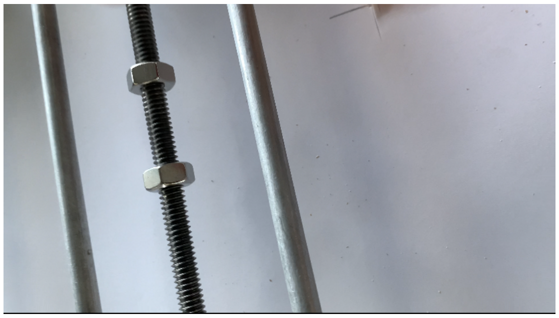
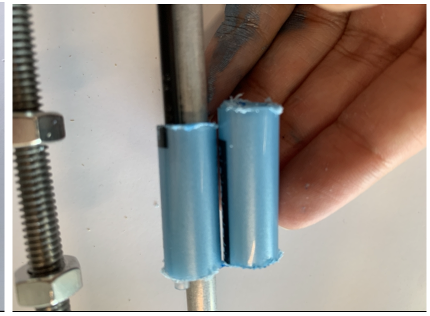
 

<u>Step 4: Create two rod-to-motor connections</u>

We used the ballpoint pen shafts to create small cylinders that are to be used to connect bolt rods to motors. In order to secure the connection we used superglue and tested out the connection between the stepper motors and bolt rods by manually turning the motors and seeing if the rods move with it. This is an aspect we could have improved but we enjoyed the creative thinking behind it.

<u>Step 5: Add sliders to rods</u>

Cut a larger pen/marker to produce a larger cylinder that slides along the rod next to the motor rod. Then since the rod connected to the motor is like a bolt rod, add two nuts that will help the bolt rod move appropriately. This was an easy step that also required creative thinking, but overall easy to implement.

Step 6: Put y-axis together

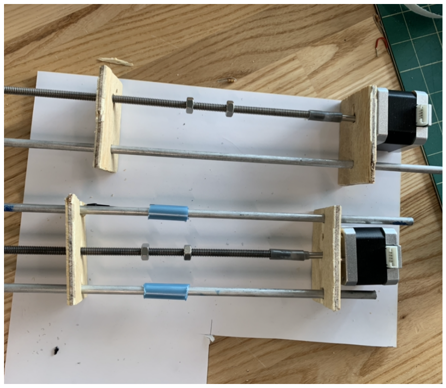
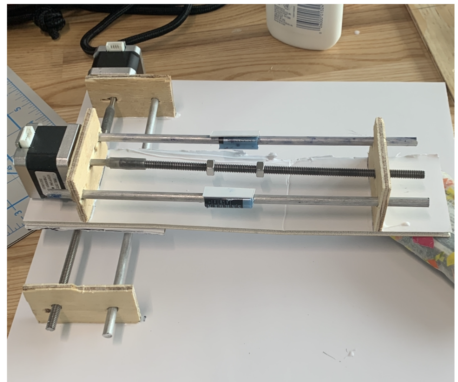
Now let's put everything we have constructed for the y-axis together. First attach the motors and rods through the two drilled holes in the wooden rectangles. Then glue the motor to the wooden rectangles and glue the wooden rectangles onto a cardboard platform.

Step 7: Put x-axis together

Now let's put everything we have constructed for the x-axis together. First attach the motors and rods through the three drilled holes in the wooden rectangles. We are going to glue this to two thinner cardboard platforms that will sit at a 90 degree angle to the y-axis where another cardboard platform will be secured on the sliders.

Step 8: Attach axes to cardboard platforms

Next we attach the x and y axes to cardboard platforms that we have constructed and glue them at 90 degrees to each other. We used quick drying superglue to achieve this. After this step we are almost done with the structural components of the device!

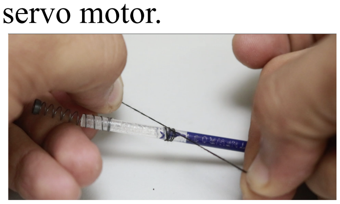
 

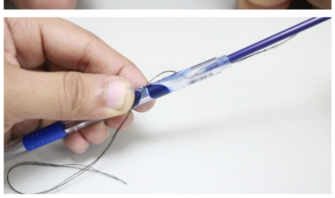
<u>Step 9: Attach servo motor to x-axis</u>

Glue the servo motor to a cardboard platform that will attach to the sliders on the x-axis. Ensure the servo motor stays upright. First we tried to tape it but it kept moving so we decided to superglue it.

<u>Step 10: Attach pen nib to servo motor</u>

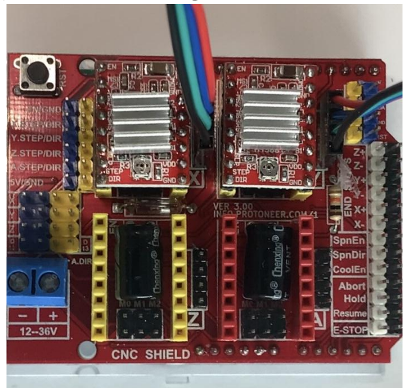
Our last step of our structural design is to glue a pen at 90 degrees vertically to the base of the platform and attach a spring and string that will move the pen when attached to the servo motor.



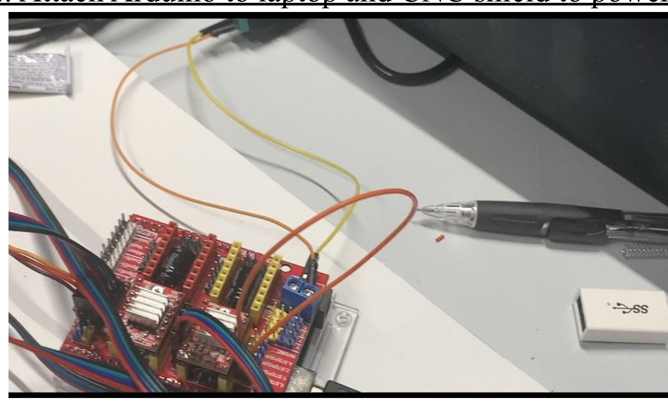


<u>Step 11: Wiring CNC components together</u>

Attach CNC shield to Arduino Uno R3. This is easy because the pins align with each other. First we assemble our CNC shield. Attach the motor drivers to the correct ports and ensure their heat sinks are secure then ensure the 12V-36V power supply is connected by wires from the CNC shield to the power supply. Attach the stepper motor wires to the desired ports next to their motor drivers. Proceed to attach the servo motor as well following circuit schematic. (See circuit diagram to understand these connections)



<u>Step 12: Attach Arduino to laptop and CNC shield to power supply</u>



<u>Step 13: Download and install necessary software and run necessary code</u>

The software needed to implement this writing machine on a Macbook is:

- Arduino: See code in appendix entitled “main_code” that was used to program machine altogether
- Inkscape (for making g code from images): Insert any image or shape or word onto the inkscape application to produce gcode files.
- Processing (used as GRBL encoder): Makes working the machine more user friendly. Reads a gcode file and sends information to the arduino. (see processing code in appendix)

<u>Step 14: Upload arduino code</u>

Run the code and watch the code work!

Unfortunately at this step, after checking and understanding all the coding, one of our stepper motors wasn’t functioning. We concluded that it didn’t work due to an error in the CNC shield. To see this problem described in more detail and steps we took to try debugging it, see outlook and possible improvements section.

TEAM MANAGEMENT

We used zoom and a group chat to discuss our timeline and allocation of tasks. Unfortunately Ghedion Beyen got a concussion so couldn't help with the implementation of the project, however he did help with the initial design proceedings.

Maggie Mano: Carried out the structural design of the x and y axes, as well as the implementation of the software of the project.

Rodrick Shumba: Testing and wiring of electrical components and creating the Z-axis for the pen to move in an up and down motion.

OUTLOOK AND POSSIBLE IMPROVEMENTS

One of our motors did not function well because the CNC shield board did not function for one of the axes. As a result, one of the axes did not work, which made our machine not write in one of the axes.

With more Time and resources, the first step towards the improvement of this project will be getting a different board, one that has all the axes working, attaching it and making the machine work with that. With more time, the mechanical structure could also be improved by adding an additional support system, such that the weight of the top axis is supported mechanically, not by the pen itself. Using wood instead of cardboard would also make the machine more mechanically apt, which would make the machine function better.

The design itself could be updated to use only the familiar arduino and motor drivers, such that we would not run into issues with boards that we do not fully understand. Through updating the code, we think using the arduino without the CNC Shield would be something worth looking into.

We look forward to trying these possible improvements over the summer so that we can learn more about arduino and have fun!

ACKNOWLEDGEMENTS:

We received help from Marko Loncar in debugging the Nema-17 stepper motor. We also received help from multiple Maker's lab TFs and staff in the making and design of our project. Benjamin Brown helped us order our parts and helped us pick out a power supply for our project.

DISCLAIMER

Everything on this report may be shared with future students.

REFERENCES.

For block diagram:
https://www.ijrte.org/wp-content/uploads/papers/v8i2S2/B10620782S219.pdf

Stepper Motor testing:
https://youtu.be/1U9pf7S_ov4

Block diagram:
https://www.ijrte.org/wp-content/uploads/papers/v8i2S2/B10620782S219.pdf

Inspiration and block/wiring diagram:
https://create.arduino.cc/projecthub/vishnunandp/writing-and-drawing-machine-b40566

Inspiration and Arduino code:
https://create.arduino.cc/projecthub/diyprojectslab/make-diy-homework-writing-machine-at-home-44c515

Code:
http://www.mediafire.com/file/n1iwt7lq4vuk5lu/CNC_complete_data_archive.zip/file

More inspiration:
https://www.instructables.com/Homework-Writing-Machine/
https://www.creativitybuzz.org/how-to-make-homework-writing-machine/
https://www.youtube.com/watch?v=PYxZg5_J4rA&list=WL&index=30&t=474s
https://www.youtube.com/watch?v=Li_atZt4qUI&list=WL&index=34&ab_channel=Inventor101