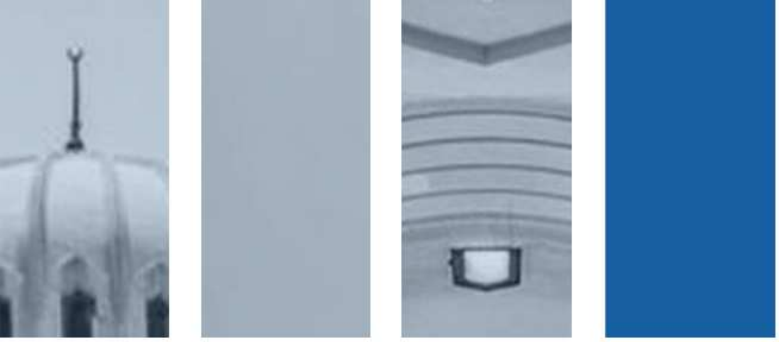


Cartesian Writing Robot

Program:

Course Code: MCT333s

Course Name: Mechatronic system design

Ain Shams University
Faculty of Engineering
Spring Semester – 2022

Submitted for:

Dr. Mohamed Ibrahim
Dr. Omar Mohamed
ENG. Hossam Mohamed

Student Names:

Ashraf Mohamed AbdelSabor	1802427
Eslam Sayed Rady	1902236
Mohamed Hassan Mohamed	1807742
Mohamed Hussein Adel	1802683
Mohamed Ibrahim AbdelMoniem	1808031
Walaa Hassan Mohamed	1805008

1. Submission Contents

01: Introduction

02: Cad detailed design

03: MATLAB model and simulation

04: Actuator sizing

05: Electrical schematic and simulation

06: component selection

07: software design and framework

Table of Contents

Table of Figures

2. Abstract

The term “CNC” is a generic term which can be used to describe many types of devices, this would include plotters, vinyl cutters, 3D printers, milling machines and others. CNC stands for Computer Numerically Controlled and basically means that the physical movements of the machine are controlled by instructions, such as co-ordinate positions that are generated using a computer

3. Intro to cartesian Robot:

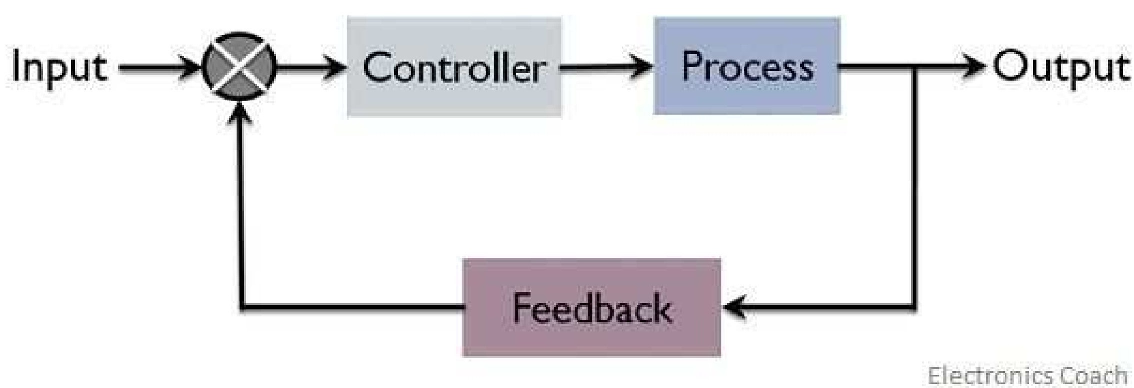
Cartesian coordinate geometry is an excellent method for mapping three-dimensional space in a simple, easy-to-understand numerical system. In the Cartesian system for three-dimensional space, there are three coordinate axes that are perpendicular to each other (orthogonal axes) and meet at the origin.

The three axes are generally referred to as the x-axis, y-axis, and z-axis. Any point in three-dimensional space is represented by three numbers as (x, y, z). X represents the distance of the point from the origin along the x-axis, y is the distance from the origin along the y-axis, and z is the distance from the origin along the z-axis.

Cartesian robots have an overhead structure that controls the motion in the horizontal plane and a robotic arm that actuates motion vertically. They can be designed to move in x-y axes or x-y-z axes. The robotic arm is placed on the scaffolding and can be moved in the horizontal plane. The robotic arm has an effector or machine tool attached to the end of the arm which is a pen

closed loop control system

A closed loop control system is a mechanical or electronic device that automatically regulates a system to maintain a desired state or set point without human interaction.



4. *Cad detailed Design*:

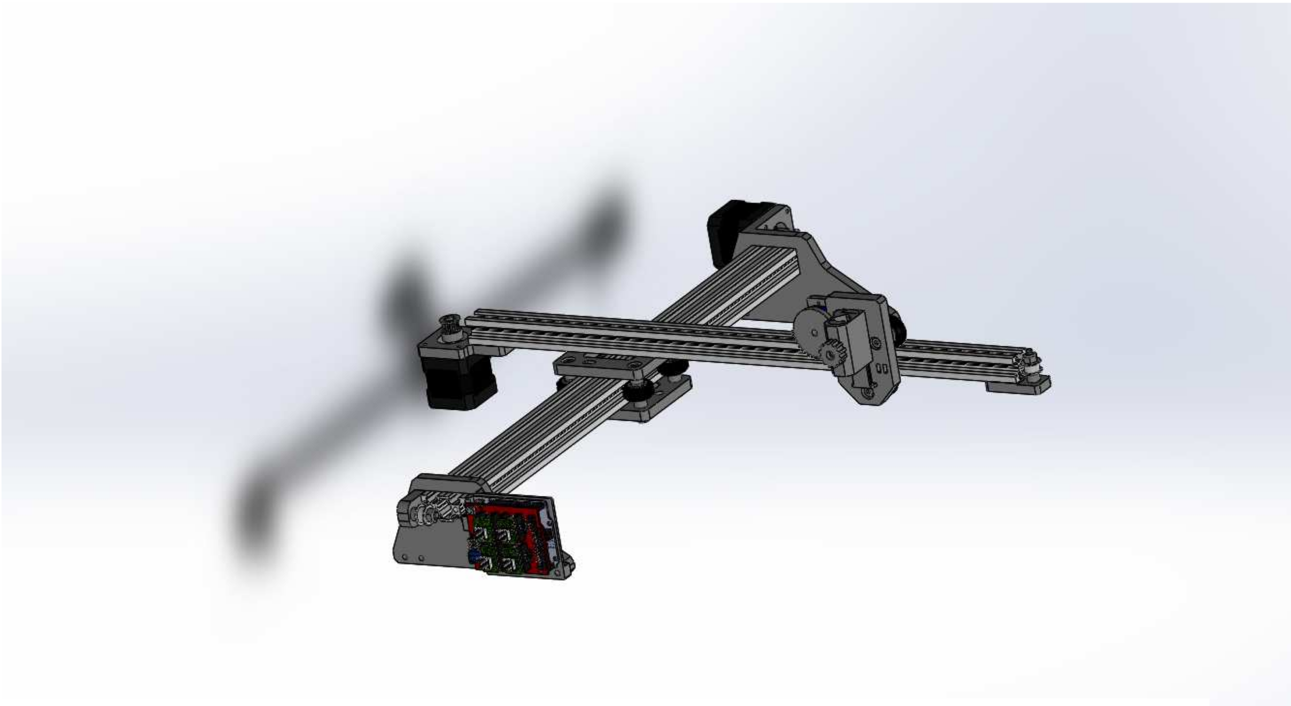


Figure 1Assembly

Figure 2Assembly

5. MATLAB model and simulation:

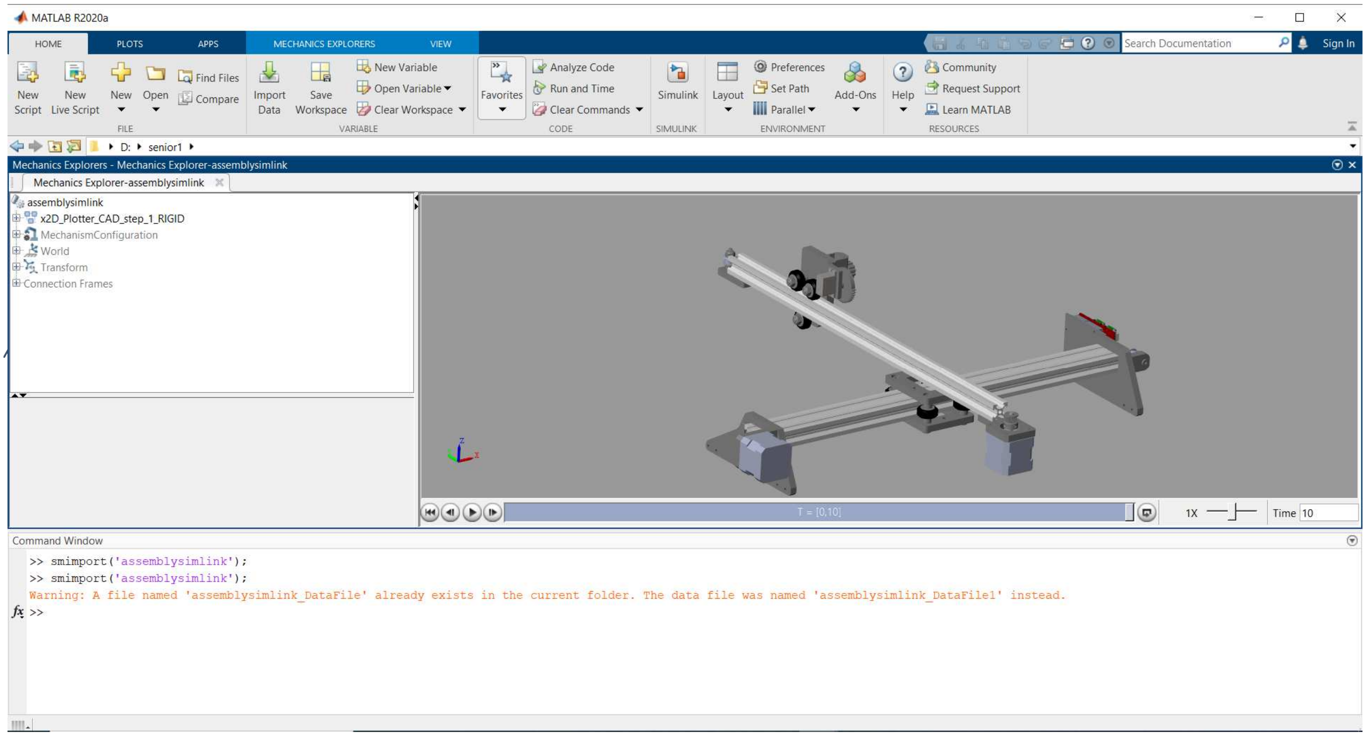


Figure 3Simulink simulation

6. Actuator sizing by Simulink

Figure 4x-axis

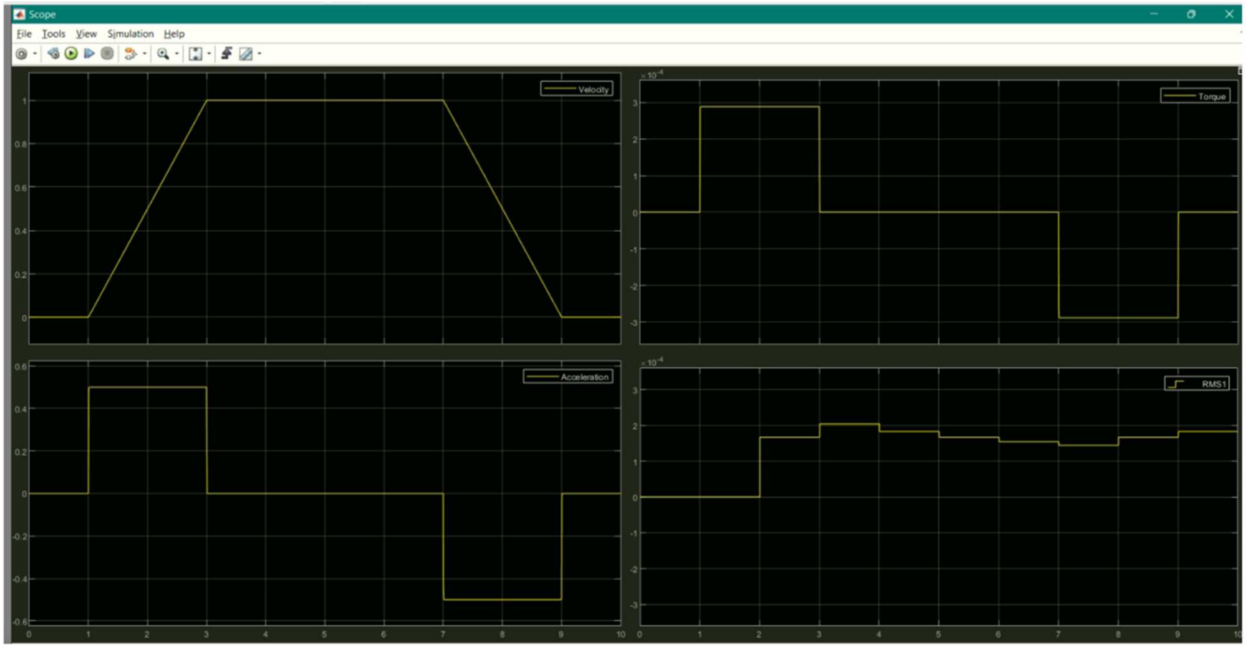


Figure 5y-axis

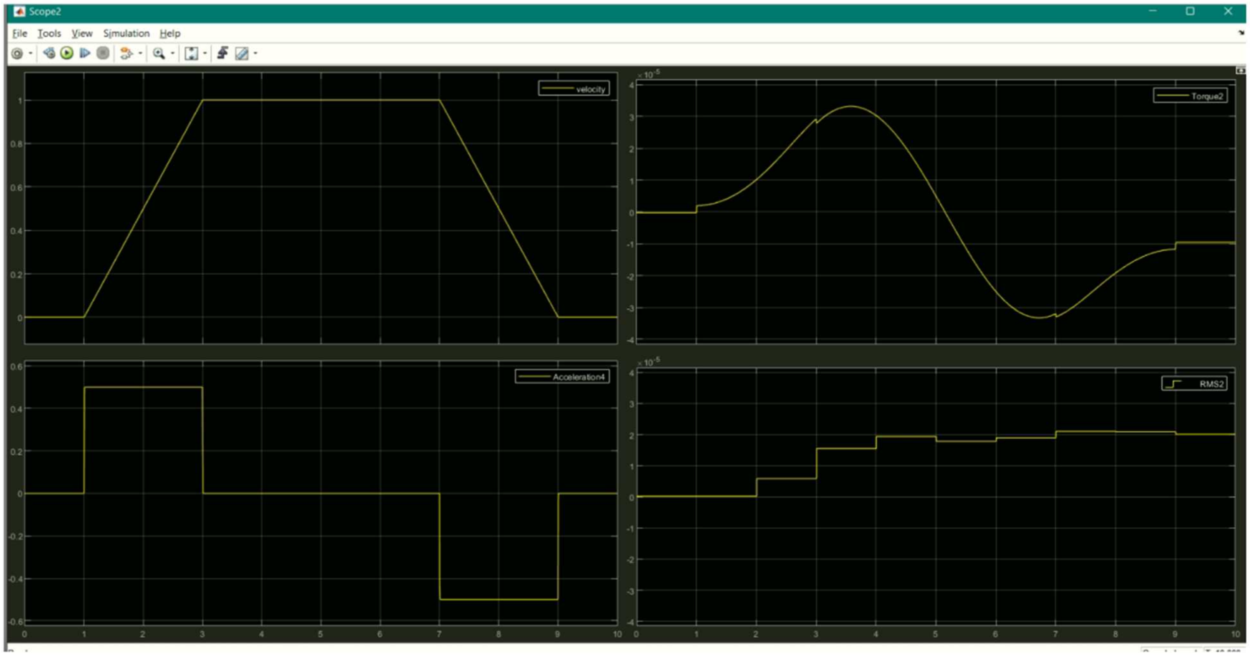


Figure 6z-axis

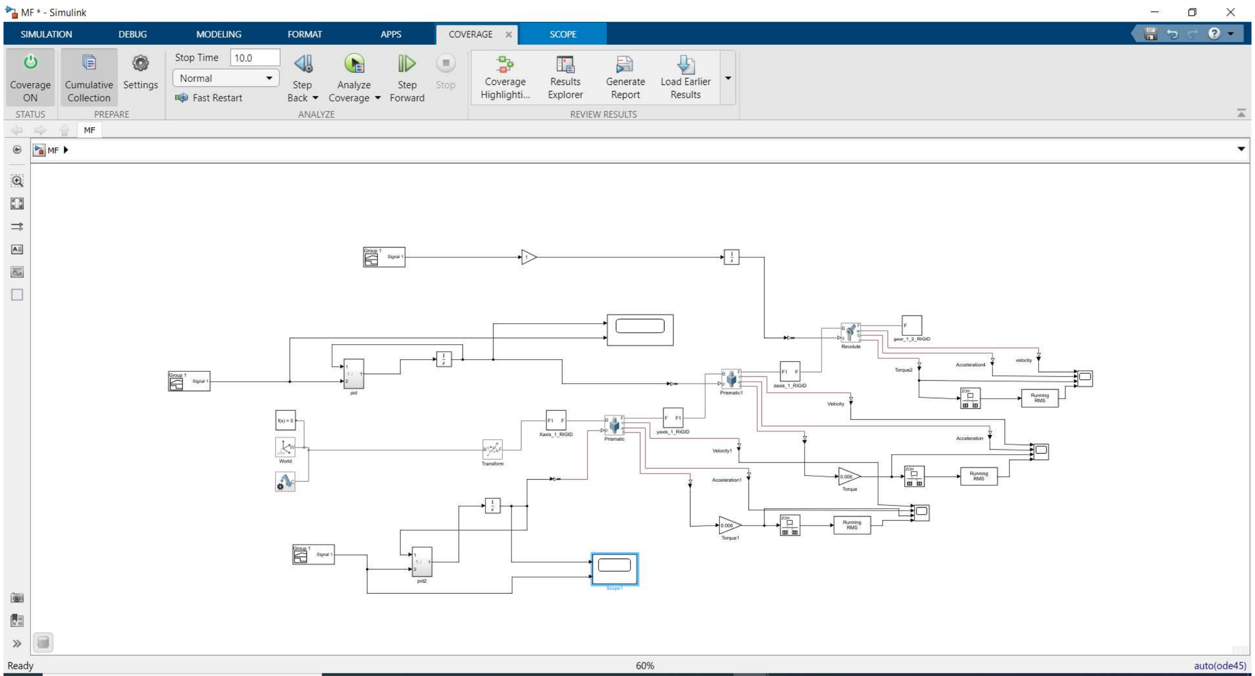


Figure 7block diagram of Simulink

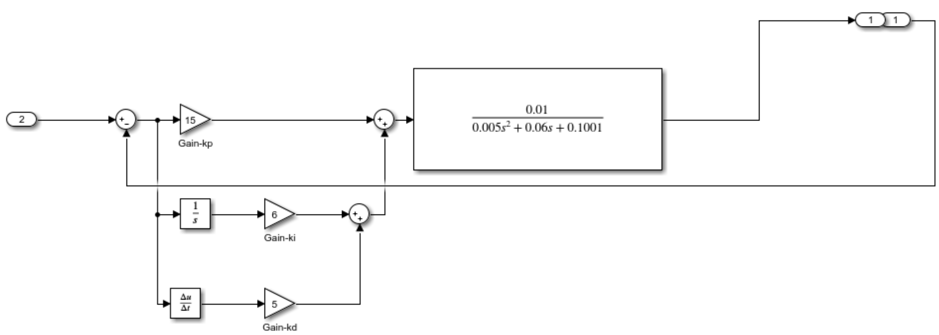


Figure 8 blocks for PID-control

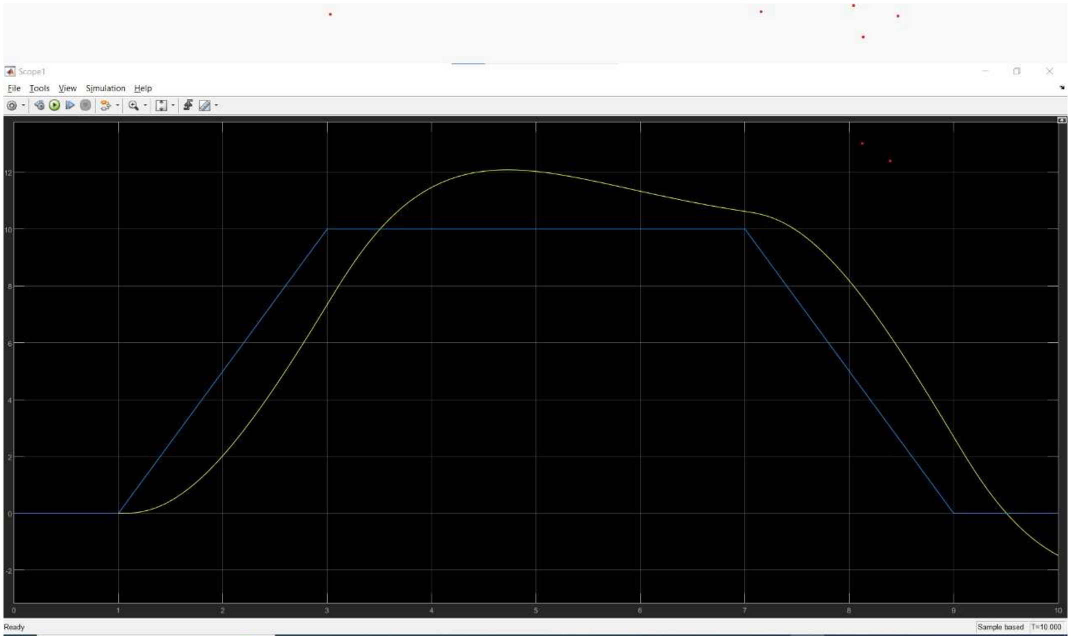


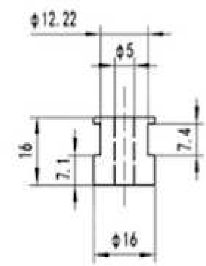
Figure 9 PID graph

8.Actuator sizing:

Belt drive X

For pully inertia:

$d_m = \frac{16+12.22}{2} = 14.11 \text{ mm} = D$



$r_{inner} = \frac{5}{2} = 2.5\text{mm}$

made of aluminum $\rightarrow \therefore \rho = 2700 \frac{kg}{m^3}$

$\text{Volume} = V = \frac{\pi}{4} h (D^2 - d^2)$

$\therefore V = \frac{\pi}{4} * (16 * 10^{-3}) * [(14.11 * 10^{-3})^2 - (5 * 10^{-3})^2]$

$V = 2.188 * 10^{-6} m^3$

$\rightarrow m = \rho V = 2700 * 2.188 * 10^{-6} = 5.9 * 10^{-3} \text{ kg}$.

Assume we neglect the mass of belt

$\therefore i = \frac{1}{2} m r^2 = \frac{1}{2} * 5.9 * 10^{-3} * \left[\left(\frac{d_m}{2} \right)^2 + r_{inner}{}^2 \right]$

$= 0.5 * 5.9 * 10^{-3} * \left[\left(\frac{14.11 * 10^{-3}}{2} \right)^2 + (2.5 * 10^{-3})^2 \right] = 1.65 * 10^{-7} kg.m^2$

2 motors → $\boldsymbol{2\ pulleys\ , and\ speed\ ratio = 1}$

$$\boldsymbol{\therefore i_{eff.} = 2 * i = 3.305 * 10^{-7}\ kg.m^2}$$

as $\boldsymbol{i_{motor} = \frac{1}{1} i_{eff.} = 3.305 * 10^{-7}\ kg.m^2}$

- For motor: Inertia is equal to $5.4 * 10^{-6} kg.m^2$

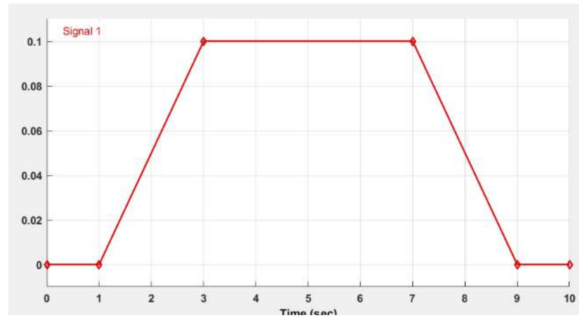
$i_{total} = 5.4 * 10^{-6} + 3.305 * 10^{-7} = 5.73 * 10^{-6} kg.m^2$

$$i_{total}\ddot{\theta} = \sum T \qquad \rightarrow 1$$

*Assuming that writing Speed (end effector speed)

Let V_{max} = 250 mm/s ,

$\therefore \dot{\theta}_{max} = \frac{V}{r} = \frac{250}{6.11} = 40.916\, rad/s$



Assume that the height of a letter is 2 cm

and max Velocity is 200 mm/s

$\therefore$ the time could be taken = $\frac{2 * 10^{-2}}{0.25}$ = 0.08 s

Assume $\rightarrow$ $t_a = t_r = t_d = 0.08\, s$

$\therefore \ddot{\theta} = \frac{\dot{\theta}_{max}}{t} = 511.45\, rad/s^2$

$T_{friction} = F_{friction} * r = \mu mg * r$ =0.00578 Nm

From (1) $\rightarrow T_m - T_{friction} = (\, i_{total.}) * \ddot{\theta}$ =0.00293

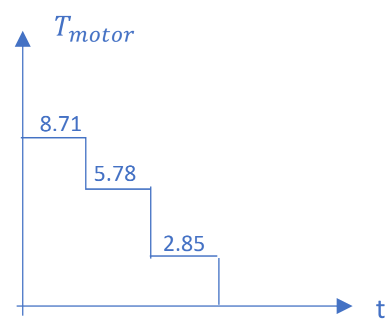
$\therefore T_m = 8.71 * 10^{-3}$ N.m

$T_{rms} = \sqrt{\frac{\int_0^{T_{cycle}} {T_m}^2(t)\, dt}{T_{cycle}}}$ =$1.77 * 10^{-3}$ N.m

$T_a = 0.00871$N.m

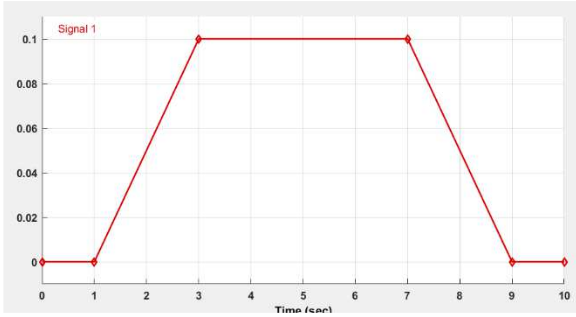
$T_r = 0.00578\, N.m$

T_d =0.00285 N.m



Belt drive Y

For pully inertia:



In (Y)

$$d_m = \frac{16+12.22}{2} = 14.11 \text{ mm} = D$$

$$r_{inner} = \frac{5}{2} = 2.5\text{mm}$$

made of aluminum $\rightarrow \therefore \rho = 2700 \frac{kg}{m^3}$

$$\text{Volume} = V = \frac{\pi}{4} h\,(D^2 - d^2)$$

$$\therefore V = \frac{\pi}{4} * (16 * 10^{-3}) * [(14.11 * 10^{-3})^2 - (5 * 10^{-3})^2]$$

$V = 2.188 * 10^{-6} m^3$

$\rightarrow m = \rho V = 2700 * 2.188 * 10^{-6} = 5.9 * 10^{-3}$ kg .

Assume we neglect the mass of belt

$$\therefore i = \frac{1}{2} m r^2 = \frac{1}{2} * 5.9 * 10^{-3} * \left[\left(\frac{d_m}{2}\right)^2 + r_{inner}{}^2\right]$$

$$= 0.5 * 5.9 * 10^{-3} * \left[\left(\frac{14.11 * 10^{-3}}{2}\right)^2 + (2.5 * 10^{-3})^2\right]$$

$$= 1.65 * 10^{-7} kg.m^2$$

2 motors $\rightarrow$ $2\ pulleys\ \ , and\ speed\ ratio = 1$

$$\therefore i_{eff.} = 2 * i = 3.305 * 10^{-7}\ kg.m^2$$

$$\frac{1}{2} m v^2 = \frac{1}{2} i_{eff} \omega^2 \quad \rightarrow \therefore\ i_{eff} = m r^2 = 9.557 * 10^{-6} kg.m^2$$

as $i_{motor} = \frac{1}{1}(3.305 * 10^{-7} + 9.557 * 10^{-6}) = 9.887 * 10^{-6}\ kg.m^2$

- For motor: Inertia is equal to $5.4 * 10^{-6} kg.m^2$

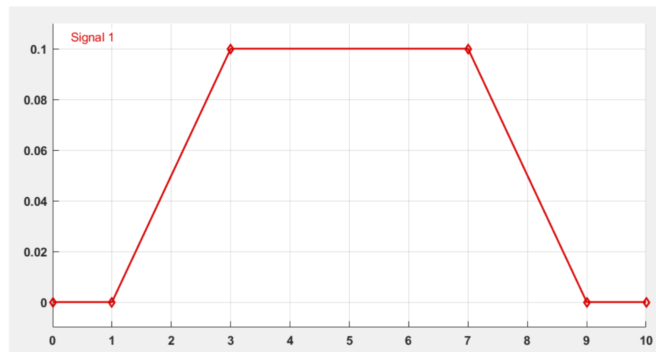
$i_{total} = 5.4 * \ 10^{-6} + \ 9.887 * \ 10^{-6} = 1.5 * 10^{-5} kg.m^2$

$$i_{total}\ddot{\theta} = \sum T \qquad \rightarrow 1$$

*Assuming that writing Speed (end effector speed)

Let V_{max} = 250 mm/s ,

$\therefore \dot{\theta}_{max} = \frac{V}{r} = \frac{250}{6.11} = 40.916\ rad/s$



Assume that the height of a letter is 2 cm

and max Velocity is 200 mm/s

$\therefore$ the time could be taken = $\frac{2 * 10^{-2}}{0.25}$ = 0.08 s

Assume $\rightarrow\ t_a = t_r = t_d = 0.08\ s$

$\therefore \ddot{\theta} = \frac{\dot{\theta}_{max}}{t} = 511.45\ rad/s^2$

$T_{friction} = F_{friction} * r = \mu mg * r$ =0.00578 Nm

$T_w = F_w * r = 0.00936\ N.m$

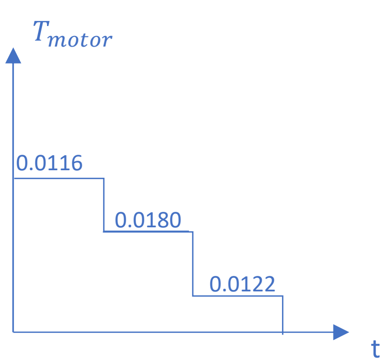
From (1) $\rightarrow T_m - T_{friction} - T_w = (\ i_{total.}) * \ \ddot{\theta}$ =0.00293

$\therefore T_m$ = 0.0116 N.m

$T_a =$ 0.0116N.m

$T_r = 0.01807\ N.m$

T_d =0.0122 N.m



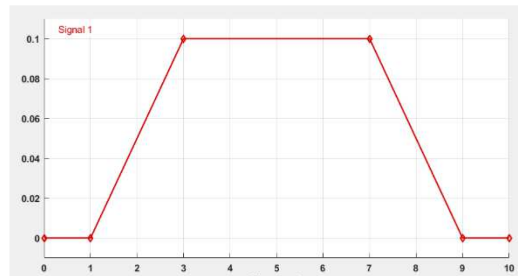
Rack and Pinion:

$$\frac{1}{2} J_{eff}{\omega_m}^2 = \frac{1}{2} J_{p}.{\omega_m}^2 + \frac{1}{2} m{v_r}^2$$

$$J_{eff} = \frac{J_{p.}}{N^2} + \frac{mR^2}{N^2}$$

$$rack\ and\ pinion\ has\ same\ profile \rightarrow \therefore N = \frac{N_1}{N_2} = 1$$

$$J_p = \frac{1}{2}mr^2 = 0.5 * 0.008 * (2.4 * 10^{-3})^2 = 2.3 * 10^{-8} kg.m^2$$



$$\therefore \frac{mR^2}{N^2} = \frac{0.053*(2.4*10^{-3})^2}{1} = 3.053 * 10^{-7}$$

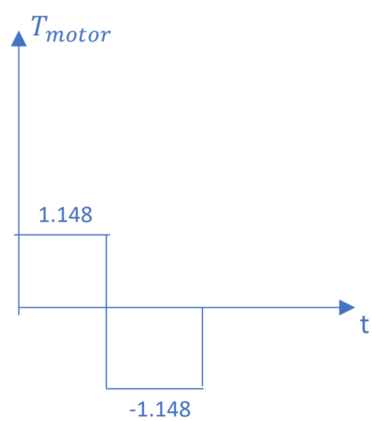
$$\therefore J_{eff} = 3.28 * 10^{-7} kg.m^2$$

$$assume\ \frac{J_m}{J_{eff}} = 1 \quad \therefore J_{total} = 6.566 * 10^{-7}\ kg.m^2$$

Finding max. speed

assume $t_a = t_r = t_d = 30\ ms$

Assume $\theta_{total} = \pi$



$$\theta_{total} = \dot{\theta}_{max} \left(\frac{t_a + 2t_r + t_d}{2}\right)$$

$$\therefore \dot{\theta}_{max} = 52.35\, rad/\sec$$

$$\ddot{\theta}_a = \frac{\dot{\theta}_{max}}{t_a} = \frac{52.35}{30*10^{-3}} = 1745 \quad rad/sec^2$$

$$\ddot{\theta}_r = 0 \qquad , \qquad \ddot{\theta}_d = \frac{-\dot{\theta}_{max}}{t_d} = -1745\, rad/sec^2$$

$$\therefore T_{ma} = J_{total} * \ddot{\theta} = 6.566 * 10^{-7} * 1745 = 1.148 * 10^{-3}$$

$$\therefore T_{md} = J_{total} * \ddot{\theta} = 6.566 * 10^{-7} * 1745 = -1.148 * 10^{-3}$$

$$\therefore T_m = 0.0146 * 1.25 = 0.0186\, N.m$$

$$T_{rms} = \sqrt{\frac{(0.0148)^2 * 30 * 10^{-3} + (-0.0148)^2 * 30 * 10^{-3}}{150 * 10^{-3}}} \qquad assume\ t_{dw} = 60\ ms$$

$$T_{rms} = 0.0094\ Nm\ * 1.25 = 0.0118$$

9.Electrical schematic and simulation:

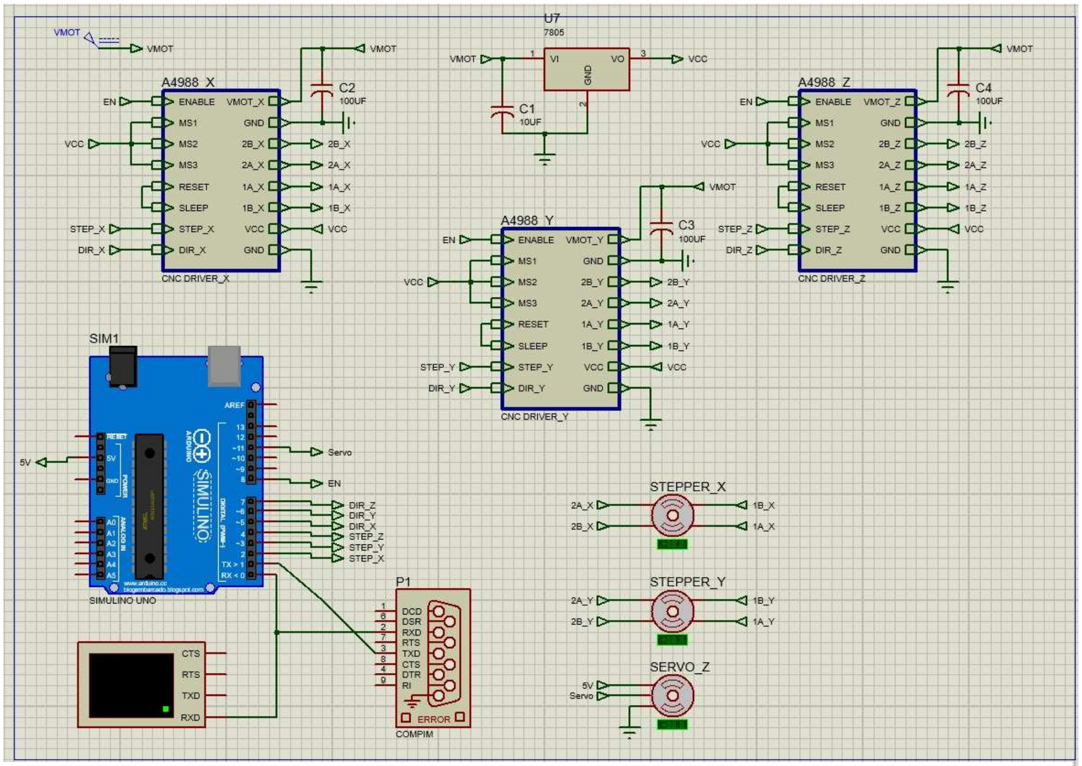


Figure 10Parent Sheet

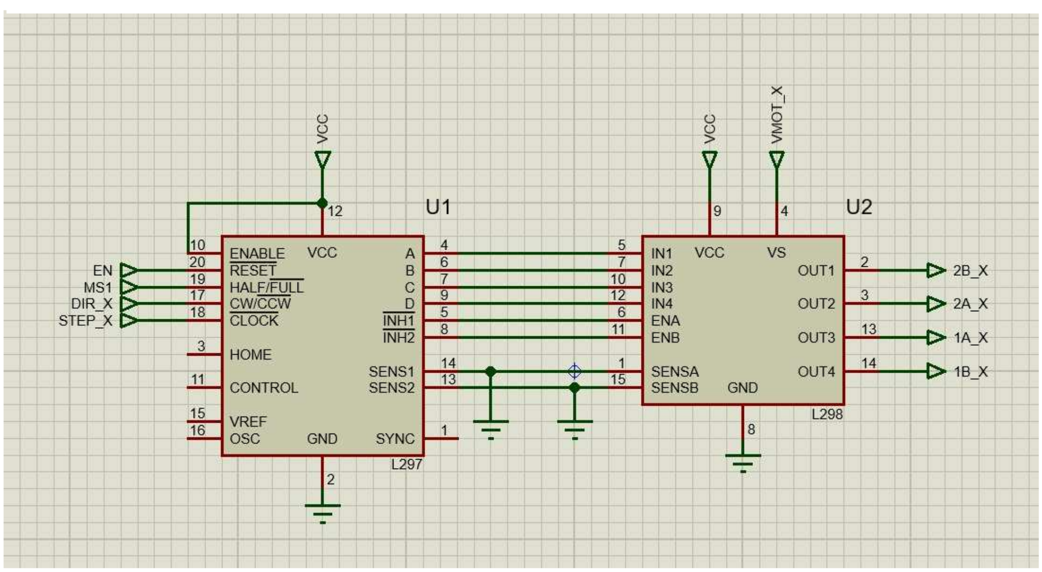


Figure 11CNC Driver-X child sheet

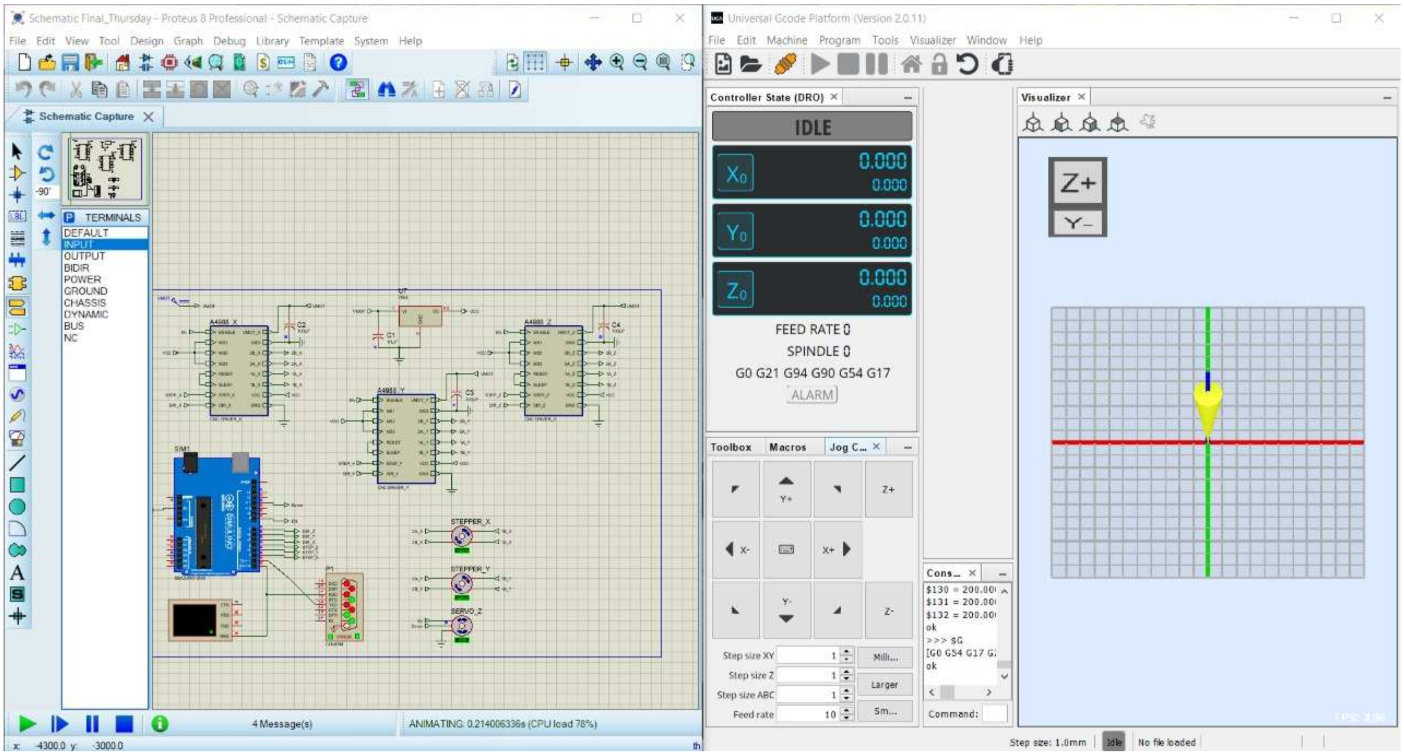


Figure 12Simulation

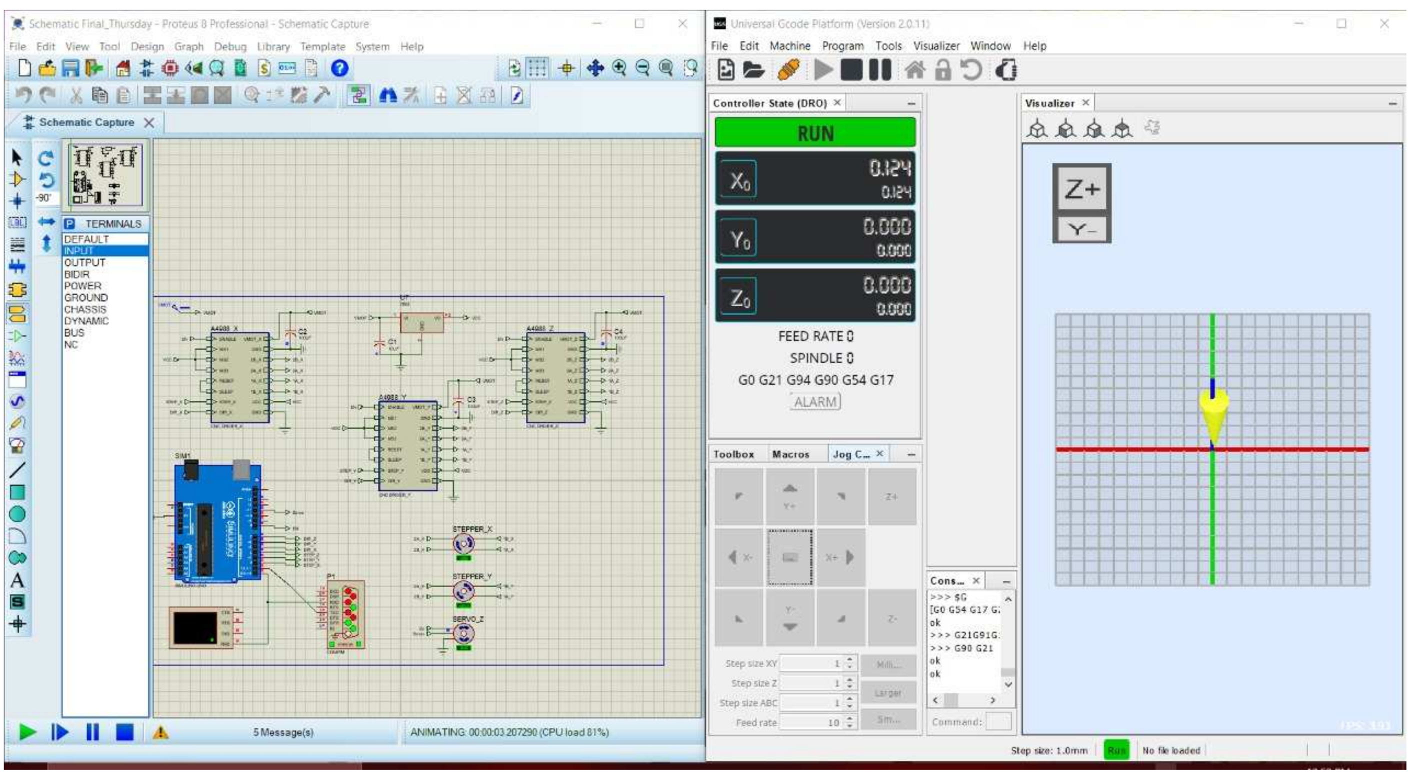
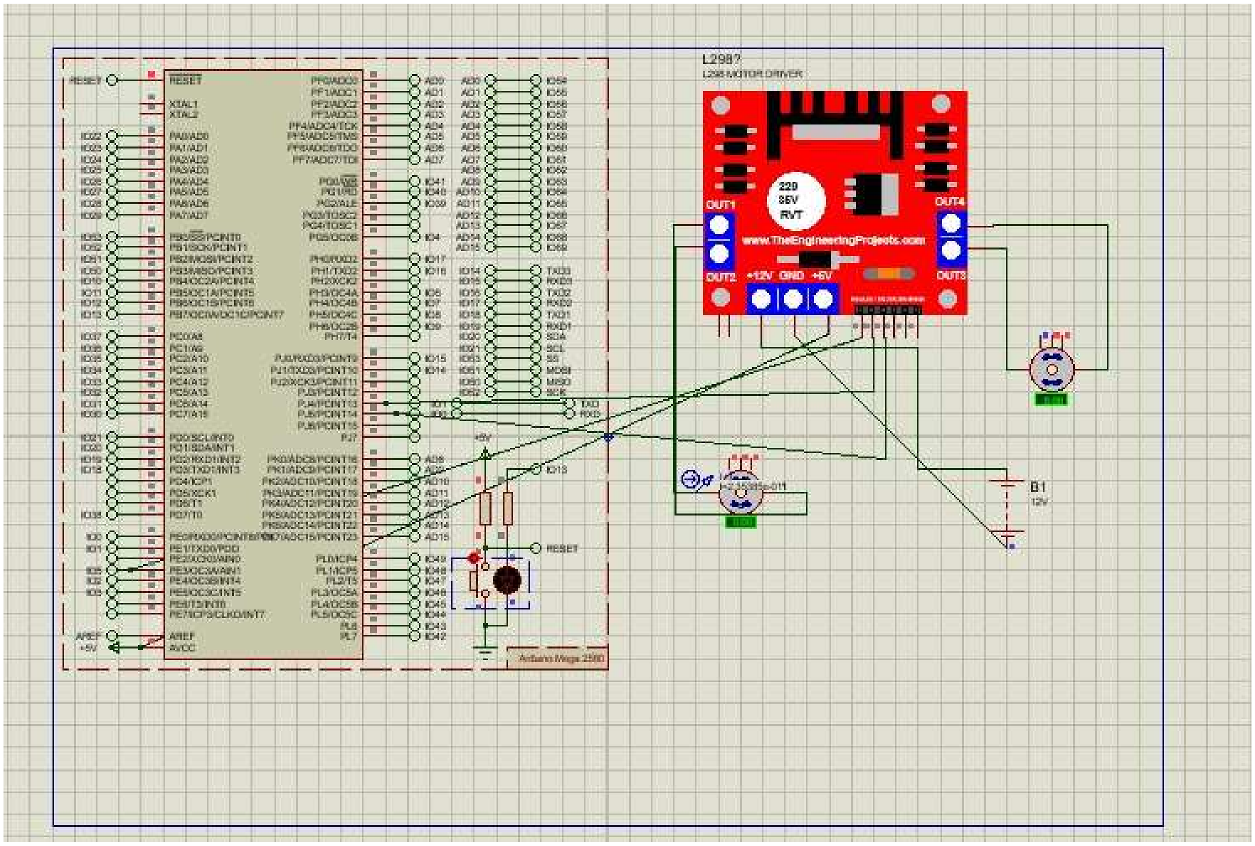


Figure 13Simulation2



10.Component selection

	components	Reason for selection	Specification

	**GT2 Bore 5mm 20 Teeth Timing Aluminum Pulley Fit GT2-6mm Open Timing Belt**	Changing the direction of forces and easy to moving slider by using belt	• Color: silver • Tooth number: 20 • Tooth pitch: 2mm • Bore diameter: 5mm • Flange: double • Tooth width: 7mm (Very Suitable and good for 6mm synchronous belt)
	**Meters GT2-6mm Open Timing Belt**	Translate rotational motion of stepper to linear motion by cart	• Color: black • Pitch: 2mm • Width: 6mm • Material: fiber reinforced rubber
	**DC Geared Motor 50r/min , 0.62 N.m 2.9 Watt**	geared DC Motor has a gear assembly attached to the motor. The speed of motor is counted in terms of rotations of the shaft per minute and is termed as RPM . The gear assembly helps in increasing the torque and reducing the speed	Rated Voltage: 12Vdc No Load Current: 140mA No Load Speed: 50 r/min Load Torque Current (With Load): 800mA Load Torque Speed (With Load): 36 r/min Torque: 6.3 Kgf.cm (0.62 N.m) Output Power: 2.3 W Stall Current: 3000mA Motor Weight: 350~400 gm
	**C-Beam Linear** **Rail**	C-Beam linear rail is the ultimate solution combining both linear motion and a modular, structural framing system. It's lightweight yet rigid and provides an smooth track for precise motion. It is compatible with all out standard V-slot parts and accessories.	Material: 6063 T-5 Aluminum.

	3d printing parts	Provide housing for the robot	Material: PLA Density 1.2g/cm2 Fillin: 50%
	**Servo motor**	Hold pin and give direction in z axis	

	**Metal V-Groove Bearing Kit**	These are specialized metal bearings that are used in linear motion systems. The v-groove bearings generally ride on our rail	(2) Ball Bearings - 625 2RS (1) OpenBuilds Dual V Wheel - Metal (5mm Bore) (1) 5mm Precision Shim (1) 1/4" Aluminum Spacer (1) M5 * 25mm Low Profile Screw (1) Lock Nut with Nylon Insert
	**DC motor shield**	the L293D is a dual-channel H-Bridge motor driver capable of driving a pair of DC motors or single stepper motor. As the shield comes with two L293D motor driver chipsets, that means it can individually drive up to four DC motors making it ideal for building four-wheel robot platforms	HiLetgo L293D DC Motor Drive Shield Stepper Motor Drive Shield Expansion Board for Arduino Duemilanove Raspberry Pi
	**Arduino**	The Arduino Mega is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.	Arduino mega

	**Encoder**	an encoder is a sensing device that provides feedback. Encoders convert motion to an electrical signal that can be read by some type of control device in a motion control system. The encoder sends a feedback signal that can be used to determine position, count, speed, or direction. A control device can use this information to send a command for a particular function.	Rotary Encoder E6B2-CWZ3E (1000 P/R)
	**Arduino**	**Arduino** is an open source hardware and software c ompany, project, and user community that designs and manufactures single board microcontrollers and mi crocontroller kits for building digital devices.	UNO
	**Power supply**	power supply is an electronic circuit that converts the voltage of an alternating current (AC) into a direct current (DC) voltage. It is basically consisting of the following elements: **transformer, rectifier, filter and regulator circuits**.	12 V , 5 A

11.Software design and frame work

First: Open loop

In this project we will use 3 main open sources software programs:

1) **Inkscape**: it's our HMI. used to convert the image needed to be drawn into path and then creates GCODE file to be sent to Arduino.

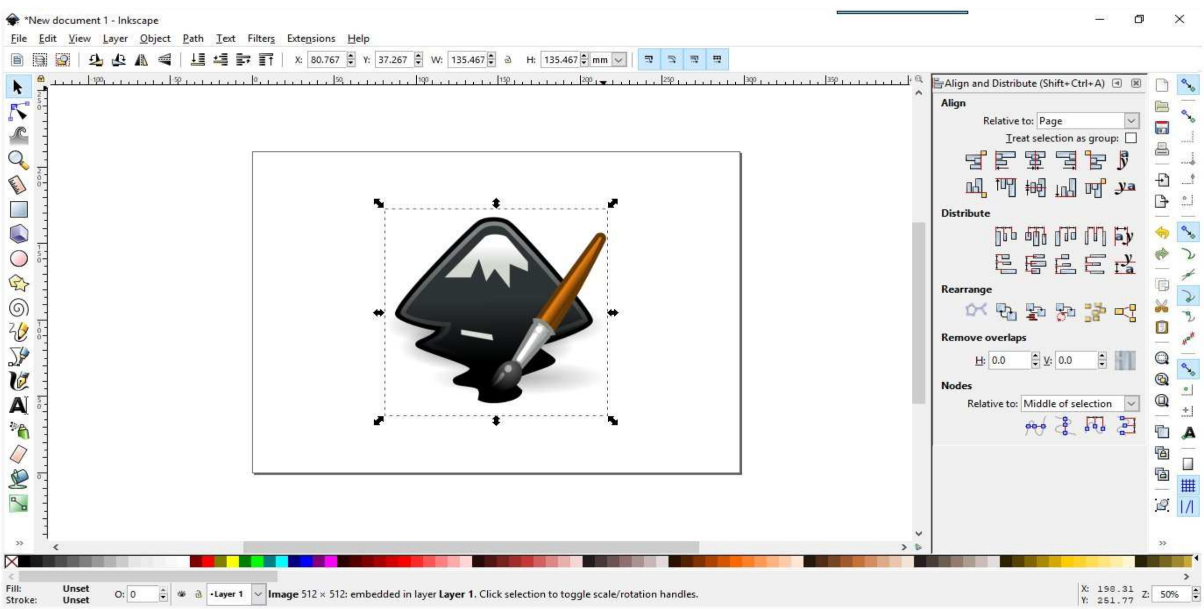


Figure 14Inkscape

***Universal G-code sender (UGS)**: it's the communication between our machine and computer, it has advantages of like more oversight of the machine and a real time view of the toolpath.*

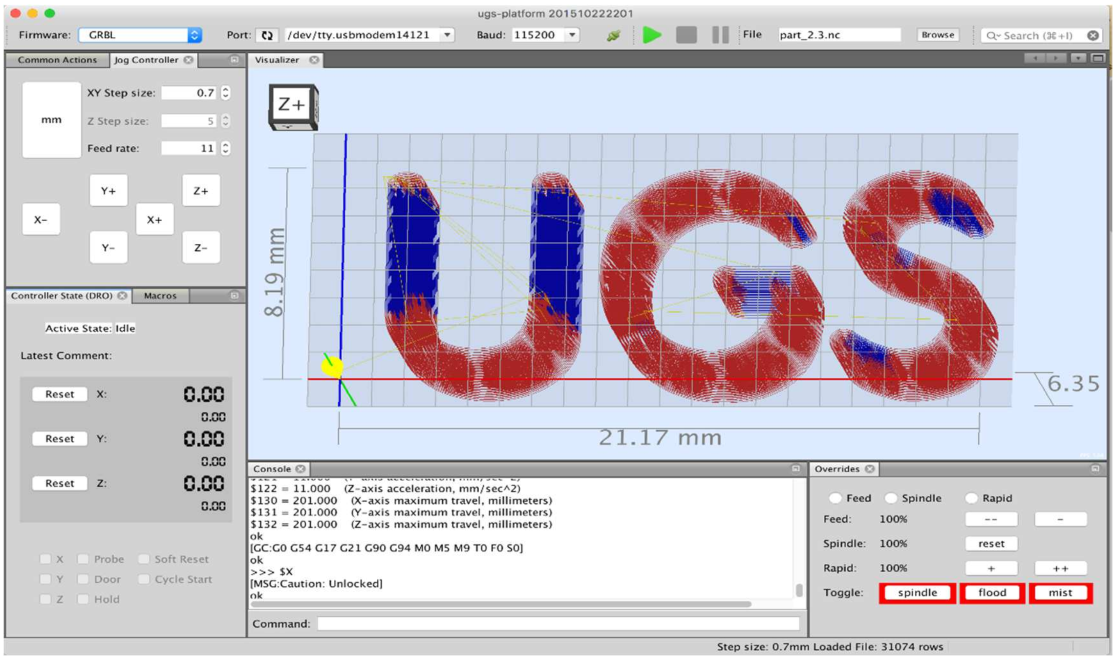


Figure 15UGS

2) **GRBL**: it's the main software running on Arduino that converts G-code into electrical signals to motor drivers (CNC shield).

Run GRBL on Arduino:

download the GRBL library and extract it in the Arduino's library folder. now open Arduino ide and open GRBLMAIN in example sketches, and upload "GRBL to Arduino Sketch" to your Arduino UNO board. and that's it. you have uploaded GRBL to your Arduino board

3)**GRBL-Plotter**

GRBL-Plotter is a graphic converter and gcode sender for all purposes.
The main focus is on the post-processing of vector graphics, the specialty is the preparation of the generated Gcode, which is based on properties of the imported graphics, such as Layer, pen color or pen thickness

Flowchart for open loop

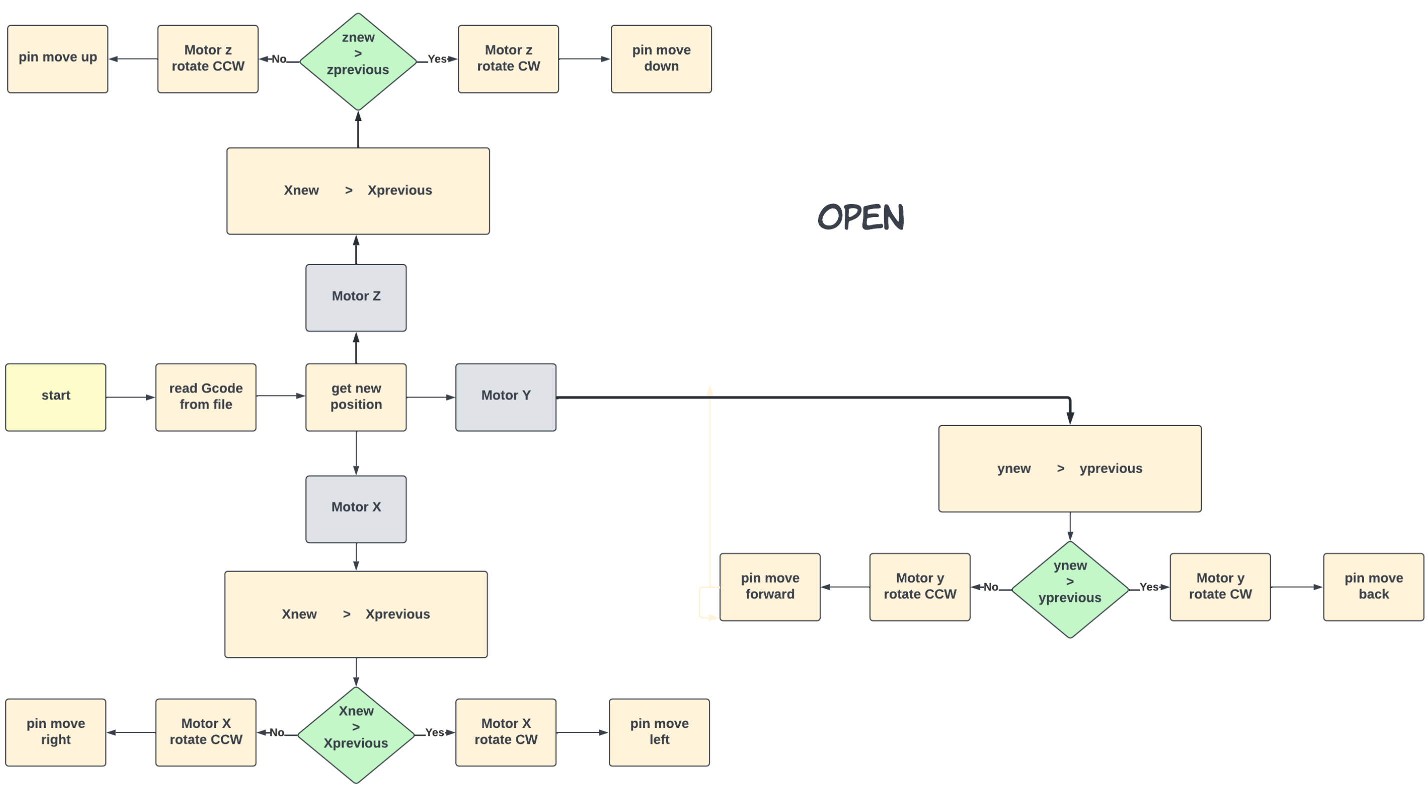


Figure 16Open loop

Second: closed loop

in closed loop we will control dc motors using PID and encoders, so we will use only Inkscape to get GCODE from, and universal G-code sender to send to Arduino. then we code Arduino file and make it reads the new position of each axis from this G-code file, then calculate the number of Rotation needed to be rotated by each axis from this equation $(x_{new} - x_{pre}) \times (number\ of\ rotation\ / mm)$

Flowchart for closed loop

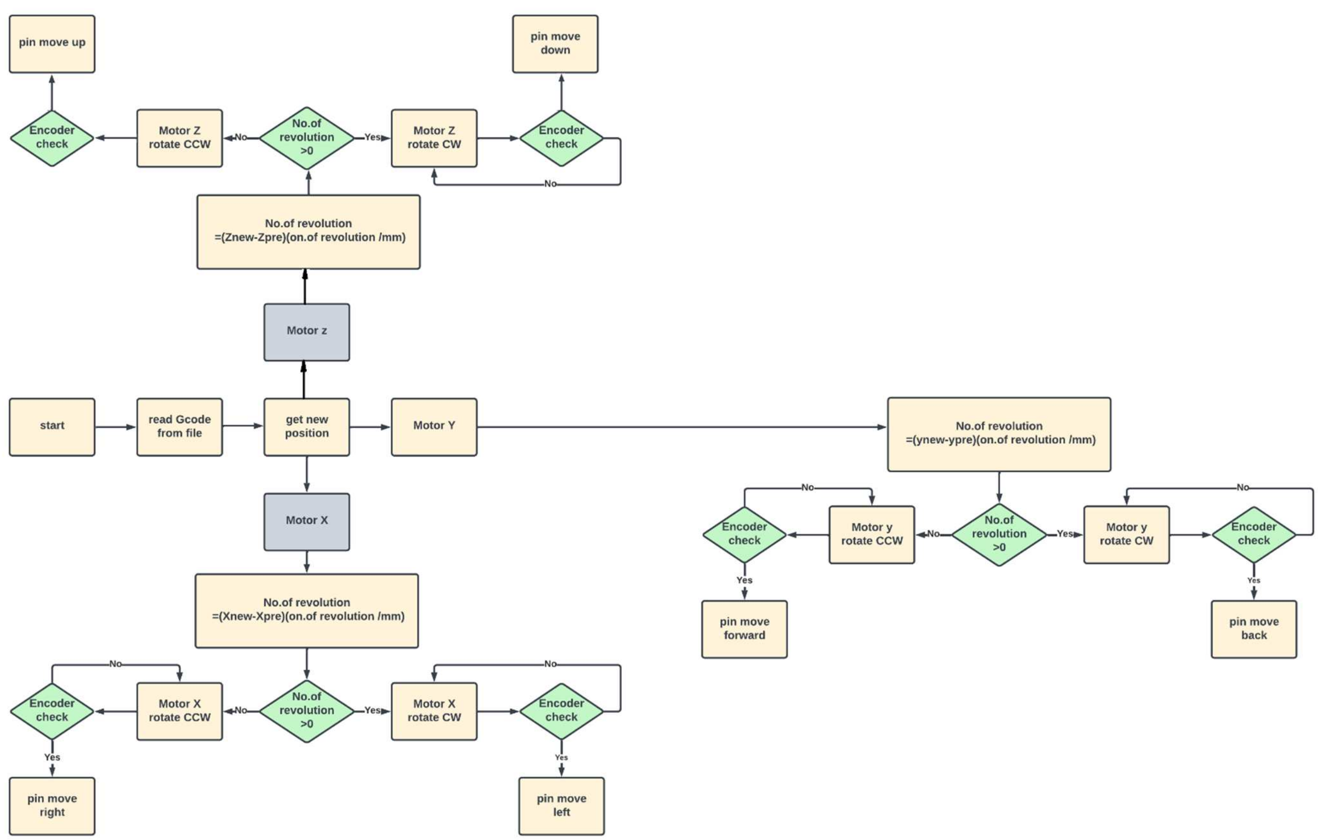


Figure 17Closed Loop

12.Trials

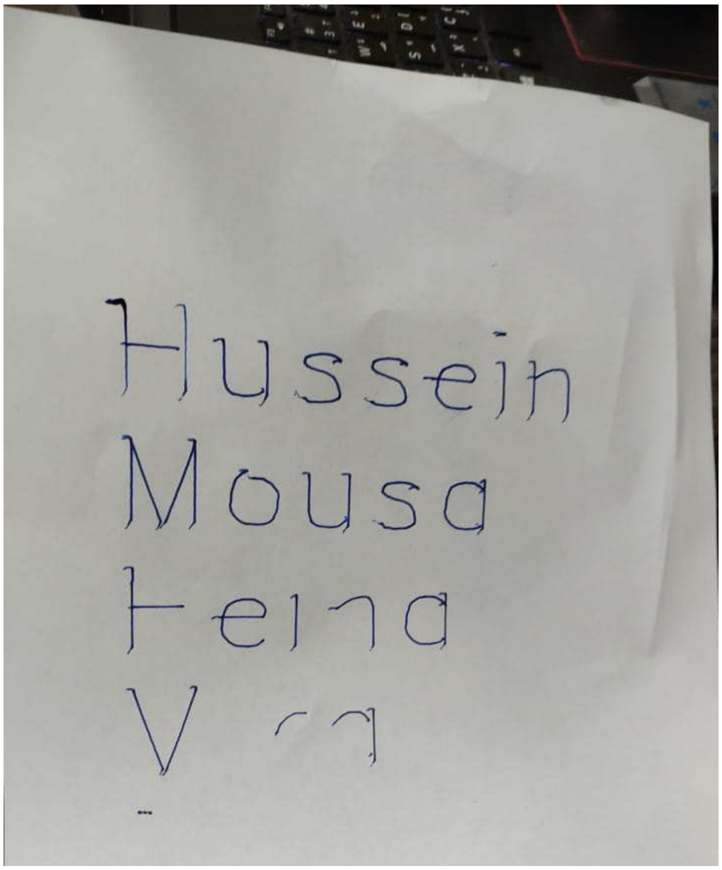


Figure 18First Trial

Servo doesn't work

Reason: because Pinion broken

Solution: we printed Pinion

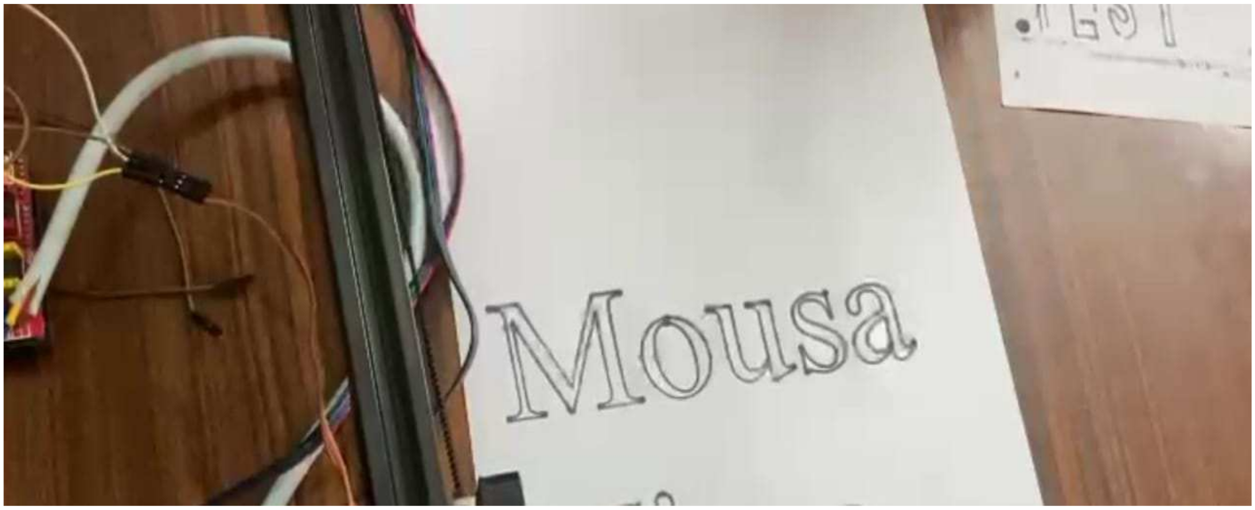


Figure17Second Trial

Closed loop trail