INSTITUTO SALESIANO

DESIGN AND APPLIED TECHNOLOGY
FINAL YEAR PROJECT

Laser Engraver

2022-2023
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Content

1. Abstract:

Laser engravers are machines that use laser beams to engrave materials such as wood, plastic, and metal. Controlled by a computer, the laser beam is directed onto the material to create intricate designs with high precision and accuracy. Laser engraving involves selectively removing microscopic layers of material to create visible marks on the treated surface. The laser-material interactions depend on the materials, with ablation being the primary mechanism of action on harder surfaces. There are three main genres of engraving machines: X-Y table, cylindrical, and stationary with galvo mirrors. Laser engravers are commonly used for creating personalized items, such as 2D Data Matrix Codes, Bar Codes, QR Codes, and Logos.

In a project utilizing laser engraving technology, OpenCV is used to detect and cut out the face in the photo with great accuracy. Afterward, halftone technology is employed to convert the photo into several dots for engraving. The halftone method used in this project is the Floyd-Steinberg dithering, which creates high-quality halftone images with great precision and accuracy. Finally, GRBL is used to control the engraving machine and adjust the engraving speed and depth. By utilizing these techniques, high-quality and accurate engravings on different materials can be achieved with ease.

2. Background:

Laser engraving can be used on a wide range of materials, including wood, plastic, metal, glass, and more. It is a popular method for creating personalized items such as trophies, plaques, and jewelry, as well as for industrial applications such as engraving product identification numbers or logos onto machinery or equipment.

Laser engraving is the process of selectively removing microscopic layers of material, thus creating visible marks on the treated surface. Depending on the materials, the laser-material interactions can be different. On harder surfaces, the mechanism of action is primarily the ablation where the focused beam of laser dislodges microscopic particles from the substrate. Engraving can achieve depth of 100 um and beyond, whereas laser marking is typically shallower.

There are three main genres of engraving machines. The most common is the X–Y table where, usually, the workpiece (surface) is stationary and the laser optics move around in two dimensions, directing the laser beam to draw vectors. Sometimes the laser is stationary, and the workpiece moves. Sometimes the workpiece moves in one axis and the laser in the other. A second genre is for cylindrical workpieces (or flat workpieces mounted around a cylinder) where the laser effectively traverses a fine helix while on–off laser pulsing produces the desired raster image. In the third genre, both the laser and workpiece are stationary and galvo mirrors move the laser beam over the workpiece surface. Laser engravers using this technology can work in either raster or vector mode.

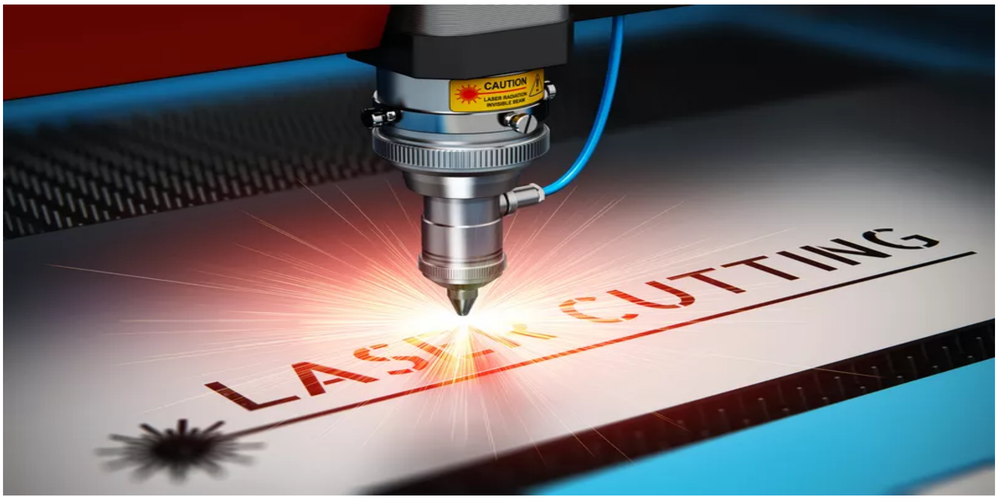
There are several types of laser engraving, including:

1. CO2 laser engraving: This type of laser engraving uses a carbon dioxide laser and is often used on organic materials such as wood, leather, and paper.
2. Fiber laser engraving: This type of laser engraving uses a fiber laser and is often used on metals and plastics.
3. Diode laser engraving: This type of laser engraving uses a semiconductor diode to produce a coherent beam of light and is often used on metals and plastics.

Laser engraving offers several advantages over traditional engraving methods, including:

1. High precision and accuracy: Laser engraving can create intricate and detailed designs with high precision and accuracy.
2. Versatility: Laser engraving can be used on a wide range of materials, making it a versatile method for creating designs and patterns.
3. Speed and efficiency: Laser engraving can be completed quickly and efficiently, making it a cost-effective option for large-scale engraving projects.

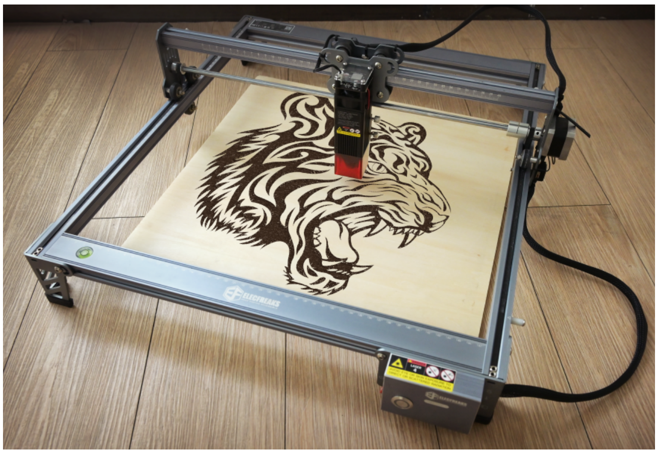
Overall, laser engraving is a popular and versatile method for creating designs and patterns on a wide range of materials.



3. Design:

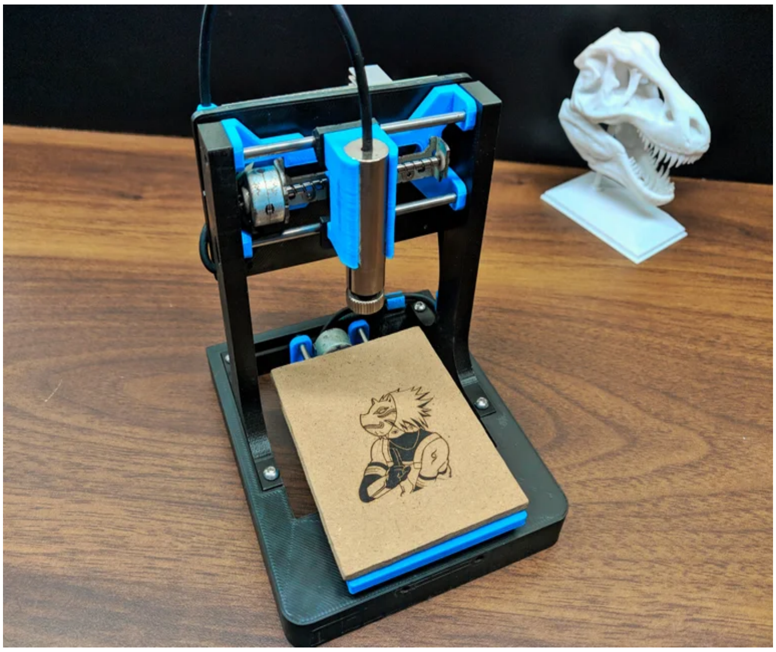
3.1 EXAMPLES

We refer to other laser engraver machines (fig.1) and figure out that it has high accuracy. When we offer the picture, the g-code will be sent from the computer to the Arduino nano, and the Arduino nano can control the stepper motor 0.0125mm per step in theory. Thus, it has a high accuracy.



(fig.1)

In fig 2, two DVD driver mechanism are required, one for the X-Axis and the second for the Y-axis.
The stepper motors are 4-pin Bipolar Stepper Motor. The small size and low cost of a DVD motor mean that you can't expect high resolution from the motor. That is provided by the lead screw. Also, not all such motors do 20 steps/rev. 24 is also a common spec. You'll just have to test your motor to see what it does.



(fig.2)

3.2 MOTOR

Servo motor, DC series motor, brushless DC electric stepper motor are in all our choice, but servo motor only can turn 180 degrees, and DC series motor is required to be embedded the open-loop-system, also at a high cost. That's why we choose stepper motor because it is brushless which offers a longer life and great repeatability at a reasonable price.

We use stepper motors, brushless DC electric motors in our laser engraver machine, and it offers a great speed control and high reliability, but it has several disadvantages such as it's not easy to operate at an extremely high speed. Most of the laser engraver machines use stepper motors that provide the most powerful kinetic energy and drive the laser head to move at tremendous speed.

Transimission :

1. DC motor + belt drive spindle
    - Rotate speed: 2400 RPM
    - Life span: 300 hrs
    - Torque: large
    - Low accuracy
2. Inverter brushless motor
    - Rotate speed: >3000 RPM
    - No need to change charcoal brush

3.3 DESIGN TARGETS

Our laser engraver machine is expected to be a highly efficient and precise tool that can create beautiful engravings of human faces on an A4 size picture. To achieve this, we require that the machine be controlled by an Arduino Nano microcontroller, which will provide the necessary programming and control functions. We also expect the machine to be lightweight, with a weight of around 1000 g, making it easy to move and maneuver as needed.

To ensure that the machine can handle the engraving process with speed and accuracy, we require a stepper motor with a 440 RPM rating, and an aluminum surface that provides the necessary durability and strength. With these specifications, we can be confident that the machine will be able to produce beautiful and lasting engravings that meet our high standards.

In addition, we expect our laser engraver machine to be capable of scanning human faces and engraving them onto the surface of the picture. This will require advanced computer vision techniques and image processing algorithms to detect and analyze the features of the human face, and then translate that information into the precise movements of the laser module.

Overall, we are committed to creating a laser engraver machine that is reliable, efficient, and capable of producing high-quality engravings.

4. Technical specifications:

4.1 HALFTONE

Images can be represented in 2D arrays of pixels, with each pixel representing a small unit of the image. Each pixel can be assigned a value that corresponds to its brightness or color, and this value can be used to simulate shades of gray or to create full-color images.

One way to simulate shades of gray is to vary the size of the dots used to represent the pixels. When a dot is small, it appears darker because it covers less area and allows more of the background to show through. When a dot is large, it appears lighter because it covers more area and obscures more of the background.

Our eyes are able to spatially integrate and blend fine details in an image, which allows us to perceive the overall intensity or brightness of the image from a sufficient distance. This is why images that are made up of large dots or pixels can still be perceived as having shades of gray or even full-color when viewed from a distance.

The size of the dots used to represent pixels in an image can affect the resolution and quality of the image. If the dots are too large, the image may appear blocky or pixelated, with visible edges between adjacent pixels. If the dots are too small, the image may appear blurry or indistinct, with fine details lost in the noise.

Overall, representing images with varying dot sizes to simulate shades of gray is a useful technique for creating high-quality visual representations of complex data, and it takes advantage of our eyes' ability to integrate and interpret visual information.

4.2 CLASSICAL HALFTONING

Resolution:

Screen printing: 45-65lpi

Laser printer (300 dpi): 65lpi

Laser printer (600 dpi): 85lpi

4.3 DIGITAL HALFTONING

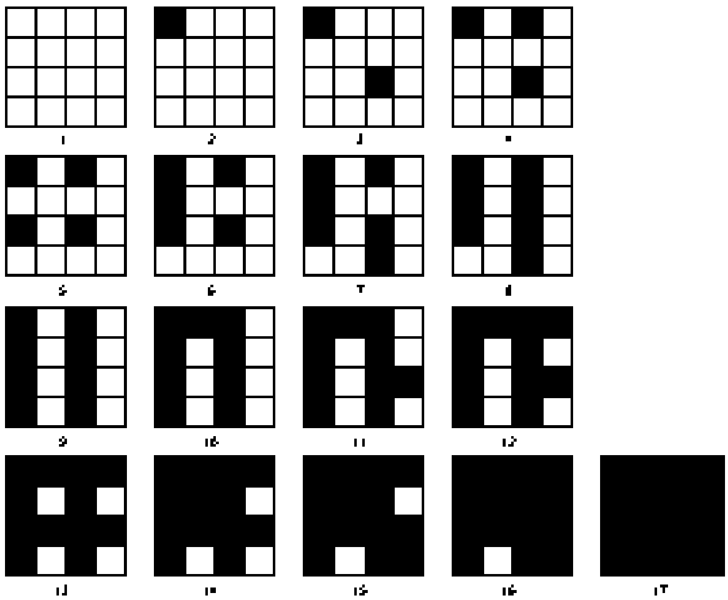
The image is decomposed into a grid of halftone cells. Elements of an image are simulated by filling the appropriate halftone cells. The greater number of black dots in a halftone cell, the darker the cell appears.

4.4 THREE COMMON METHODS OF HALFTONING

1. Patterning

It generates an image that is of higher spatial resolution than the source image. The number of halftone cells of the output image is the same as the number of pixels of the source image

However, each halftone cell is subdivided into a 4x4 grid. Each input pixel value is represented by a different number of filled squares in the halftone cell. Since a 4x4 grid can only represents 17 different intensity levels, the source image must be quantized.



2. Dithering

Unlike patterning, dithering creates an output image with the same number of dots as the number of pixels in the source image.

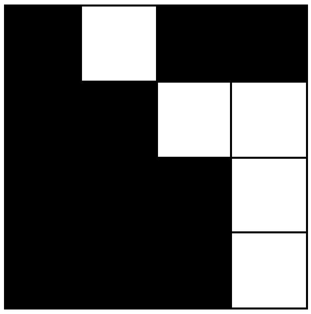
Dithering can be thought of as thresholding the source image with a dither matrix. The matrix is laid repeatedly over the source image. Wherever the pixel value of the image is greater than the value in the matrix, a dot on the output image is filled. A well-known problem of dithering is that it produces artifacts of patterns introduced by fixed thresholding matrices.

12	51	34	121
78	254	10	97
45	113	110	16
90	200	206	34

input image

0	60	0	60
45	110	45	110
0	60	0	60
45	110	45	110

repeated dither matrix



output image

3. Error Diffusion

Error diffusion is another technique used for generating digital halftoned images. It is often called spatial dithering. Error diffusion sequentially traverses each pixel of the source image. Each pixel is compared to a threshold. If the pixel value is higher than the threshold, a 255 is outputted; otherwise, a 0 is outputted. The error - the difference between the input pixel value and the output value - is dispersed to nearby neighbors.

Error diffusion is a neighborhood operation since it operates not only on the input pixel, but also its neighbors. Generally, neighborhood operations produce higher quality results than point operations. Error diffusion, when compared to dithering, does not generate those artifacts introduced by fix thresholding matrices. However, since error diffusion requires neighborhood operations, it is very computationally intensive.

4.5 FLOYD-STEINBERG DITHERING

The Floyd-Steinberg dithering algorithm is utilized in this project. It was first introduced by Robert W. Floyd and Louis Steinberg in 1976 and is widely used in image manipulation software. The algorithm is particularly useful when converting an image to a restricted color palette, such as the 256-color limit of GIF format.

The algorithm uses error diffusion to achieve dithering, which involves adding the residual quantization error of a pixel onto its neighboring pixels. The algorithm scans the image from left to right and top to bottom, quantizing pixel values one by one. Each time, the quantization error is transferred to the neighboring pixels while not affecting the pixels that have already been quantized. The diffusion coefficients have a property where if the original pixel values are halfway between the nearest available colors, the dithered result is a checkerboard pattern.

To achieve optimal dithering, the counting of quantization errors should be accurate enough to prevent rounding errors from affecting the result. Some implementations use serpentine scanning or boustrophedon transform dithering, where the horizontal direction of scan alternates between lines.

The pseudocode for the algorithm works for any approximately linear encoding of pixel values, such as 8-bit integers, 16-bit integers, or real numbers in the range [0, 1].

4.6 OPENCV

OpenCV (Open Source Computer Vision) is an open-source computer vision and machine learning software library that allows developers to build real-time computer vision applications. It provides a wide range of functions and algorithms that are designed to help developers build applications that can analyze and understand visual data.

One of the most popular features of OpenCV is its ability to detect and cut out faces from photos with great accuracy. This feature is particularly useful for applications that require facial recognition or analysis. The library has a range of pre-trained models that can detect and recognize faces, making it easy for developers to implement this functionality in their projects.

OpenCV's application areas include:

- 2D and 3D feature toolkits
- Ego motion estimation
- Facial recognition system
- Gesture recognition
- Human–computer interaction (HCI)
- Mobile robotics
- Motion understanding
- Object detection
- Segmentation and recognition
- Stereopsis stereo vision: depth perception from 2 cameras
- Structure from motion (SFM)
- Motion video tracking
- Augmented reality

4.7 GRBL

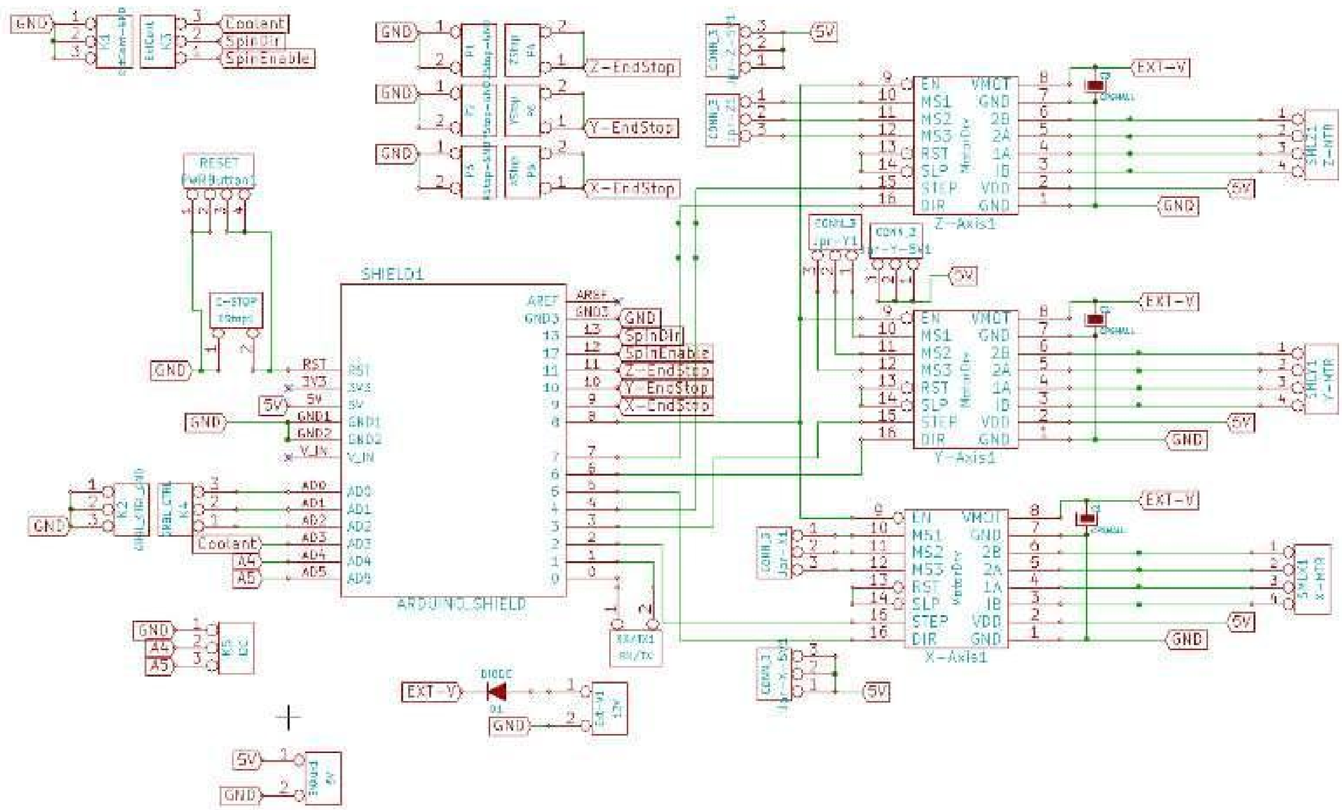
GRBL is a popular open-source software that is widely used in the CNC community. It was specifically developed as a motion control program for microcontroller boards, making it possible to use an Arduino to operate CNC machines. This has made it a popular choice for hobbyists and makers who want to build their own CNC machines.

One of the key advantages of GRBL is that it is free and open source, which means that developers can modify and customize the software to suit their specific needs. This has led to a large and active community of developers who are constantly working to improve the software and add new features.

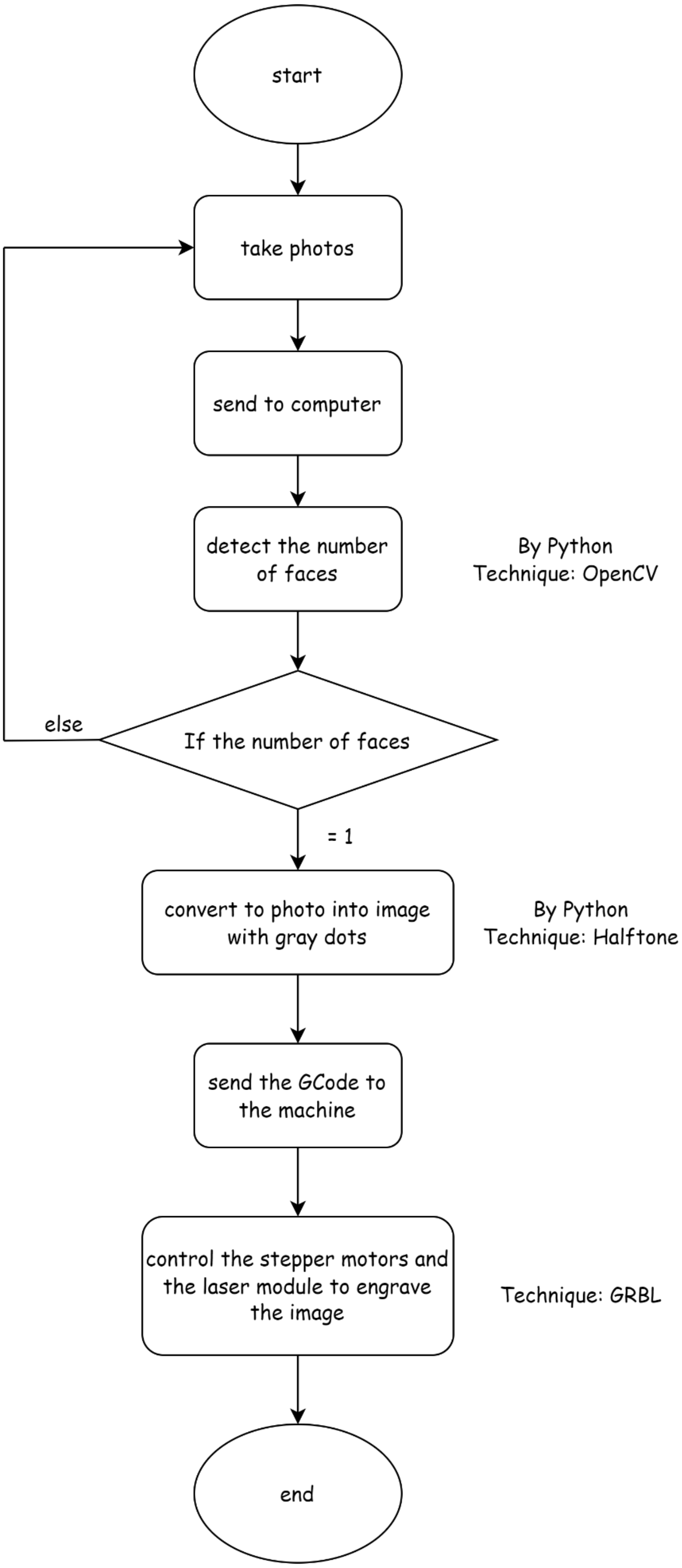
GRBL is typically used in combination with the Arduino Uno, which is a popular microcontroller board that is widely available and easy to use. The software is designed to be lightweight and efficient, which means that it can run on a wide range of microcontroller boards with limited processing power.

Overall, GRBL is a powerful and flexible software that has made it possible for hobbyists and makers to build their own CNC machines using affordable and widely available hardware. Its open-source nature and active community of developers have helped to make it one of the most popular motion control programs in the CNC community.

4.8 WIRING DIAGRAM



4.9 FLOWCHART



4.10 PROGRAM

Extracting Face and Halftoning

```
import cv2

import numpy as np

from PIL import Image, ImageDraw


def floyd_steinberg_dithering(image, dot_size, levels):

   width, height = image.size

   new_width = 100

   new_height = int((height/width) * new_width)

   process = image.resize((new_width,new_height))

   pixels = process.load()


   # Create a new blank image with the same size as the input image

   dot_image = Image.new('L', (new_width * dot_size, new_height * dot_size), 255)

   # Create a new ImageDraw object for drawing circles

   draw = ImageDraw.Draw(dot_image)

   # Define the circle radius as half the dot size

   radius = dot_size // 2


   for y in range(new_height - 1):

       for x in range(1, new_width - 1):

           old_pixel = pixels[x, y]

           new_pixel = int(round(old_pixel / 255 * (levels - 1)) * (255 / (levels - 1)))

           # Set the dot color based on the quantized pixel value

           dot_color = int(new_pixel) + 50

           # Draw a circle at the current pixel position

           x_pos = x * dot_size + dot_size // 2

           y_pos = y * dot_size + dot_size // 2

           draw.ellipse((x_pos - radius, y_pos - radius, x_pos + radius, y_pos + radius), fill=dot_color)


           quant_error = old_pixel - new_pixel
```

```
            # Distribute the error to neighboring pixels
            if x + 1 < new_width:
                pixels[x + 1, y] += int(quant_error * 7 / 16)
            if x - 1 >= 0 and y + 1 < new_height:
                pixels[x - 1, y + 1] += int(quant_error * 3 / 16)
            if y + 1 < new_height:
                pixels[x, y + 1] += int(quant_error * 5 / 16)
            if x + 1 < new_width and y + 1 < new_height:
                pixels[x + 1, y + 1] += int(quant_error * 1 / 16)
    return dot_image

# Import the image
img = cv2. imread('123123.jpg')
# Edit the image
gray = cv2.cvtColor(img, cv2.COLOR_BGR2GRAY)
# Create a face detection classifier
faceCascade = cv2.CascadeClassifier('face_detect.xml')
# Detect the number of faces
faceRect = faceCascade.detectMultiScale(gray, 1.1, 8)
# Print the number of faces
print(len(faceRect))

if len(faceRect) == 1:
    # Loop through the list of faces and extract each one
    for i, (x, y, w, h) in enumerate(faceRect):
        # Extract the face from the original image
        face = img[y:y + h, x:x + w]
    # Convert the face to a PIL Image object
    pil_face = Image.fromarray(face)

    # Convert the PIL Image to grayscale and apply halftone
    input_image = pil_face.convert("L")
    # Apply halftone with the desired parameters
    output_image = floyd_steinberg_dithering(input_image, dot_size=50, levels=10)
    # Display the output image
    output_image.show()
    # Save the halftone image as a JPEG file
```

```python
    halftone_array = np.array(output_image)  # Convert the PIL Image to a NumPy array

    cv2.imwrite("face_halftone.jpg", halftone_array)  # Save the NumPy array as a JPEG file


elif len(faceRect) == 0:

    print("No faces detected")

else:

    print("More than one face")
```

This code is a Python script that applies the Floyd-Steinberg dithering algorithm to a detected face in an input image. The input image is first converted to grayscale using OpenCV's cvtColor() function. Then, OpenCV's CascadeClassifier() is used to detect faces in the grayscale image. If one face is detected, it is extracted from the original image and converted to a PIL Image object. The floyd_steinberg_dithering() function is called on the PIL Image object to apply the dithering algorithm with the desired parameters. The resulting halftone image is displayed and saved as a JPEG file using OpenCV's imwrite() function.

The floyd_steinberg_dithering() function takes in three parameters: the input image to apply dithering on, dot_size which controls the size of the dots in the output image, and levels which controls the number of quantization levels used in the dithering process. The function first resizes the input image to a new width of 100 pixels while maintaining the aspect ratio. It then creates a blank output image with the desired dot size and draws circles on it using the ImageDraw module to represent the dithered dots. The function applies the Floyd-Steinberg dithering algorithm to the input image by iterating over each pixel and distributing the quantization error to neighboring pixels. The function returns the output image as a PIL Image object.

4.11 RELATIONSHIP BETWEEN THE SIZE OF GEARS AND THE BELT

Circular motion is a type of motion that occurs when an object moves along a circular path. In circular motion, there are two important formulae that relate the linear and angular displacement, as well as the linear and angular velocity of an object moving in a circular path. These formulae help us understand the relationship between the size of the gear and the linear displacement and velocity of the object that is moving along the circular path.

The first formula, $s = r\theta$, relates the linear displacement (s) of an object moving in a circular path to the radius (r) of the circle and the angular displacement (θ) of the object. This formula tells us that the linear displacement of an object is directly proportional to the radius of the circle and the angular displacement of the object. The second formula, $v = r\omega$, relates the linear velocity (v) of an object moving in a circular path to the radius (r) of the circle and the angular velocity (ω) of the object. This formula tells us that the linear velocity of an object is directly proportional to the radius of the circle and the angular velocity of the object.

When the size of the gear is larger, the radius of the circular path is also larger, which means that the linear displacement of the object is greater with the same angle of rotation from the stepper motor. This is because the larger gear has a larger circumference, which means that it covers a greater distance with each rotation.

However, when the size of the gear is larger, although the velocity of the belt is greater as the radius is directly proportional to the linear velocity, the linear displacement is also greater, leading to a high velocity and a low resolution. This means that the object moves faster along the circular path but covers a greater distance with each step, which results in a lower resolution of the motion. Conversely, when the size of the gear is smaller, the velocity of the object is lower, but the linear displacement is smaller, resulting in a higher resolution of the motion.

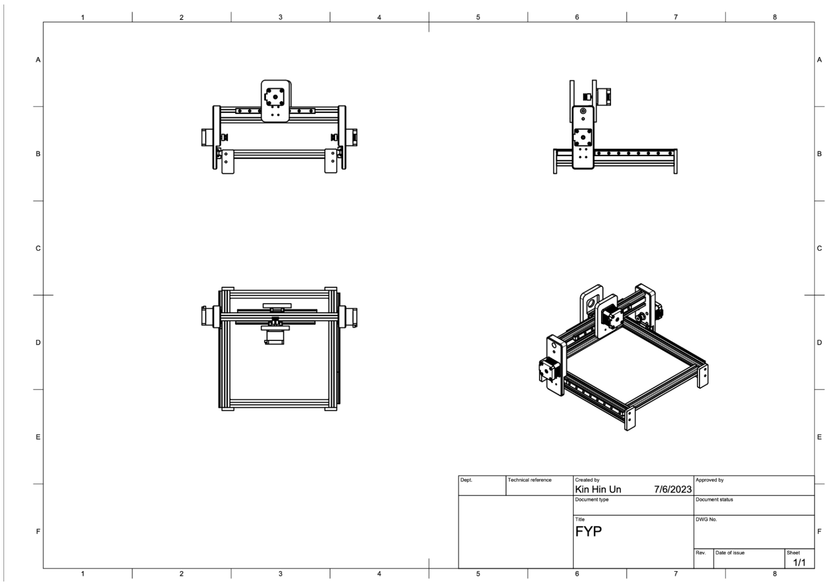
In summary, the size of the gear used in circular motion affects both the linear displacement and velocity of the object moving along the circular path, and it is important to consider the tradeoff between velocity and resolution when choosing the size of the gear.

5. Design specifications:

5.1 BODY DESIGN

- Micro controller: Arduino ESP32
- Input voltage: 12V
- Length: 391mm Width: 312 mm Height: 245 mm
- Weight: approximately 2kg
- Material: Aluminium, Acrylic, PLA, Aluminium Alloy

5.2 CAD



We began by setting the size of the frame to A4 and then proceeded to gradually incorporate the various components. This allowed us to ensure that each component was properly integrated, and that the final product was both functional and aesthetically pleasing. As we added each new component, we carefully considered its placement and how it would affect the overall design of the frame. By taking a methodical approach and paying close attention to detail, we were able to create a finished product that met all of our requirements and exceeded our expectations.

5.3 VERSIONS

At the beginning, we reckoned that we would use belts only for the transmission, whereas it was not fit and there were large gaps, so we added four linear motion guides.

We decided to install the linear motion guide on the inner part of the frame, but it doesn’t have enough space for it to move because our requirement is to engrave an A4 size picture, so it is moved to the outer part of the frame. Additionally, we change the material of the connector because 3D can reduce weight effectively.

Also, we replaced the control board and laser module for improving the performance of a laser engraving system. In some cases, the original components may not be able to provide the level of control over the laser's intensity that is required for specific applications. Upgrading to more advanced components can provide greater precision and flexibility in controlling the laser, which can lead to higher quality output and improved efficiency.

Once the new components have been installed, it's important to test and calibrate the system to ensure that it is operating correctly. This may involve adjusting settings and parameters to optimize the laser's output and ensure that it is consistent and accurate. Ongoing maintenance and monitoring may also be required to ensure that the system continues to operate effectively over time.

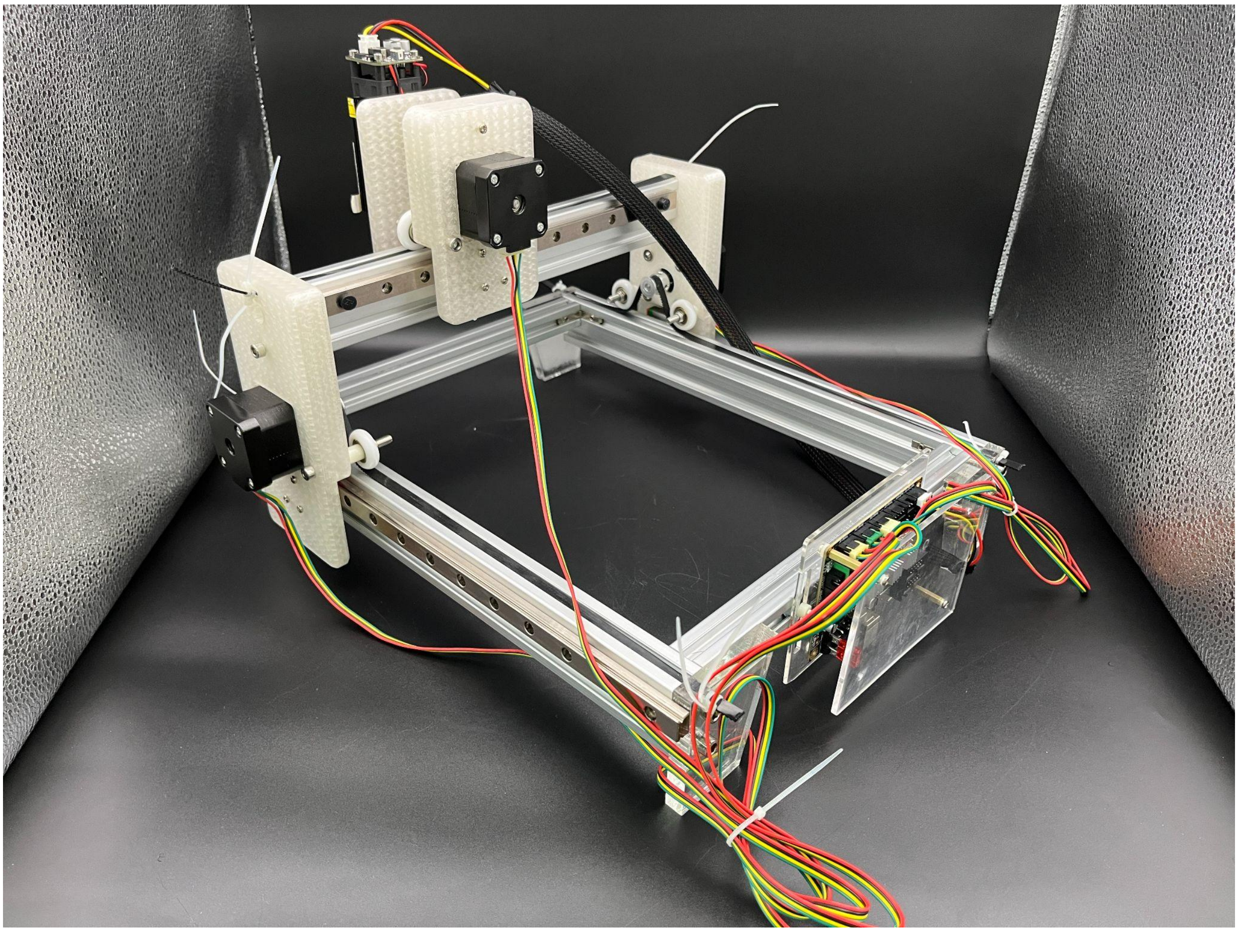
5.4 MATERIAL

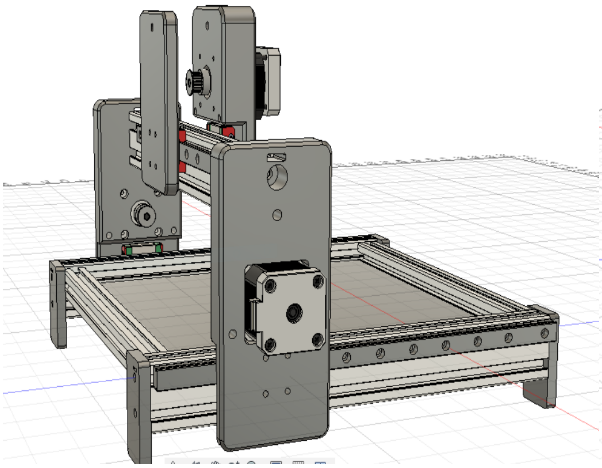
We refer to other materials such as wood, plastic, glass, carbon fiber, but some materials do not accord with our standard for instance wood and plastic have lower service life, carbon fiber costs high, so we use aluminium as our optimal choice because it has an approximate specific weight of 2.71 g/cm3 which can reduce the weight of our machine and has a greater corrosion resistance to prolong the service life in the lower prices. In addition, we change the material of the support to aluminium alloy so that the machine can be more firm.

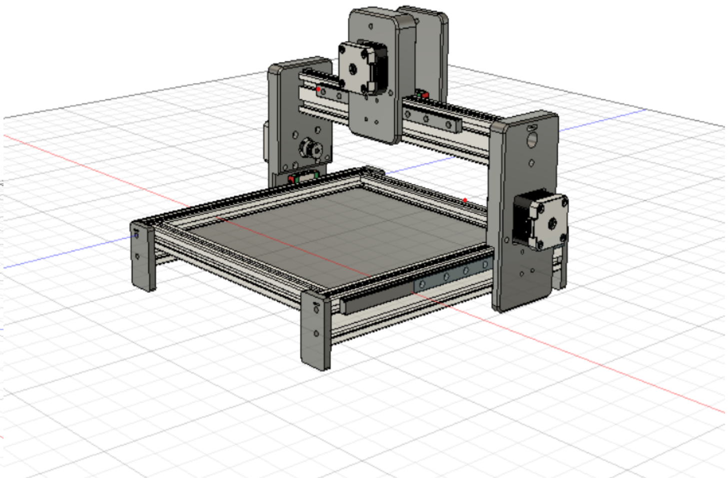
6. Result:

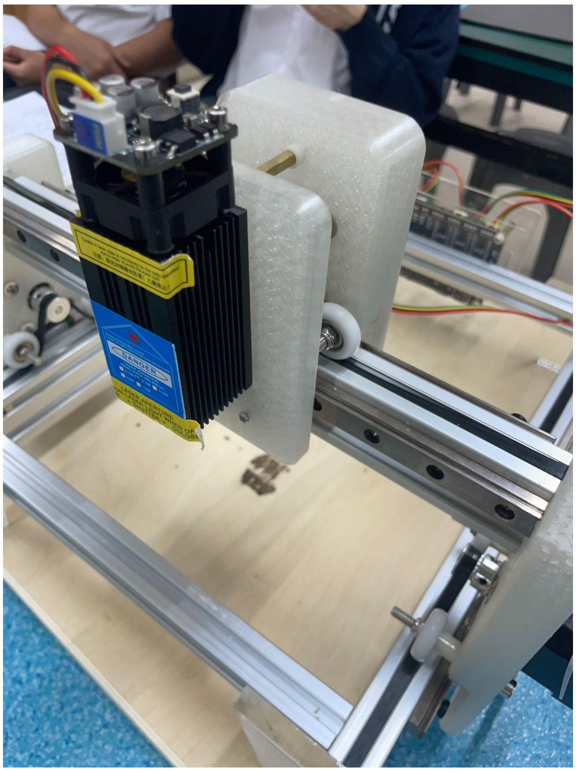
6.1 PROTOTYPE

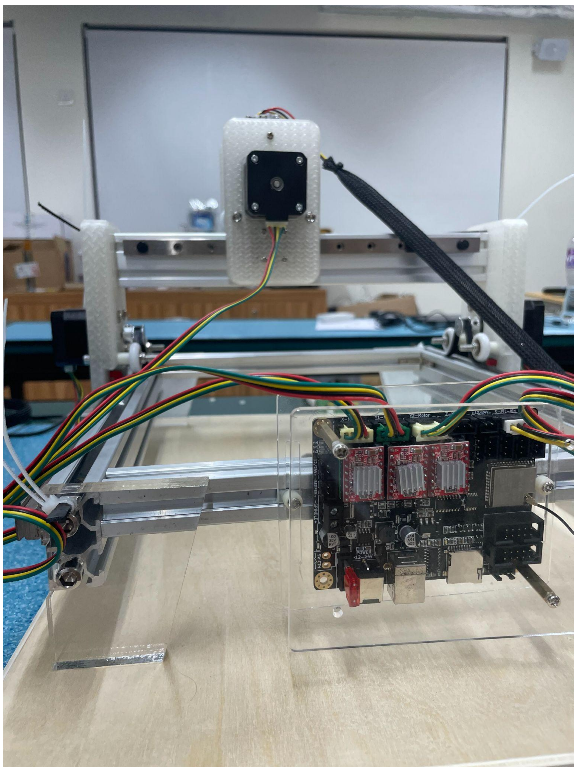
Laser Engraver

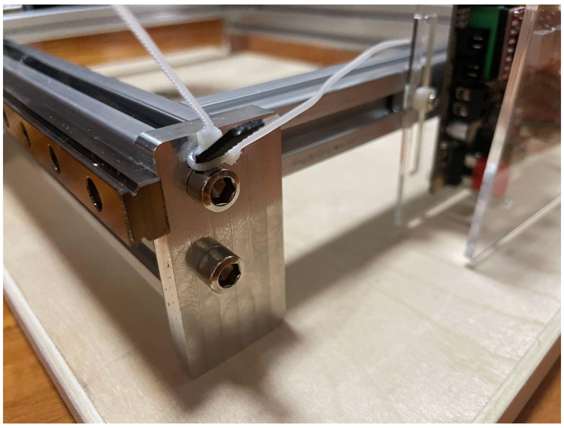


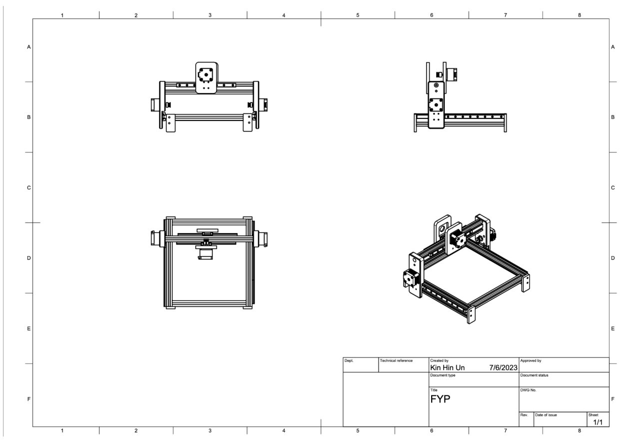








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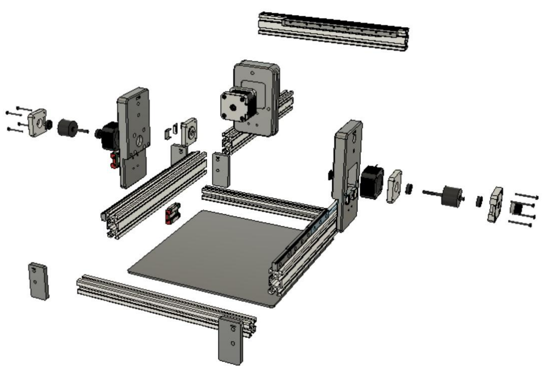
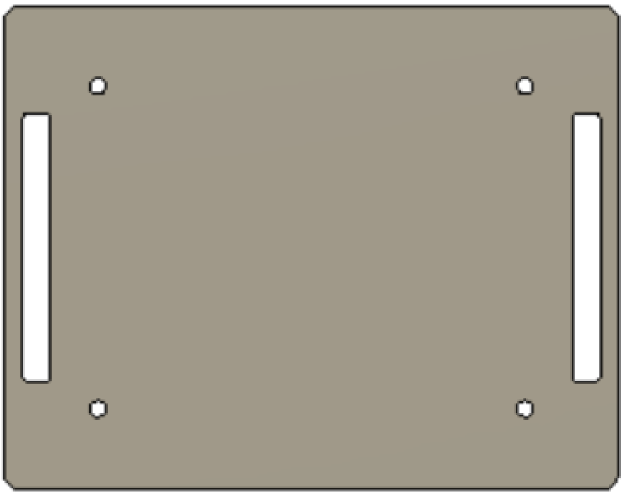
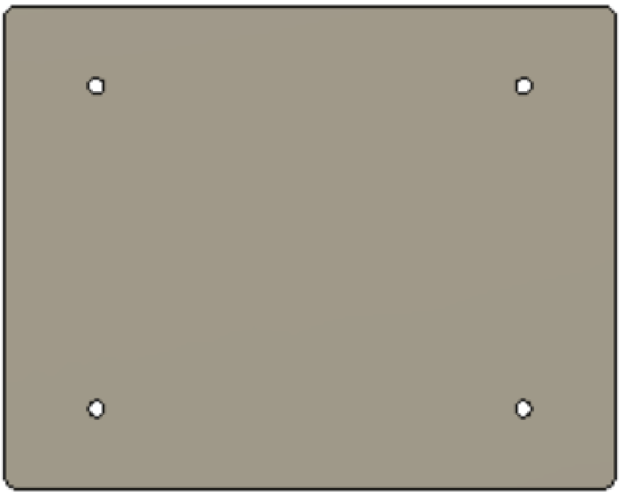


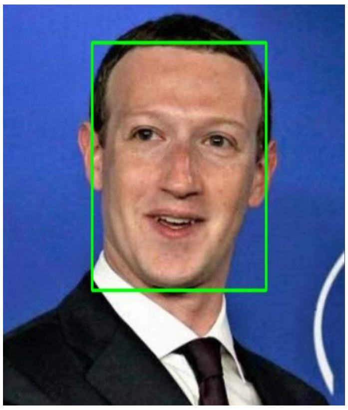
Holder



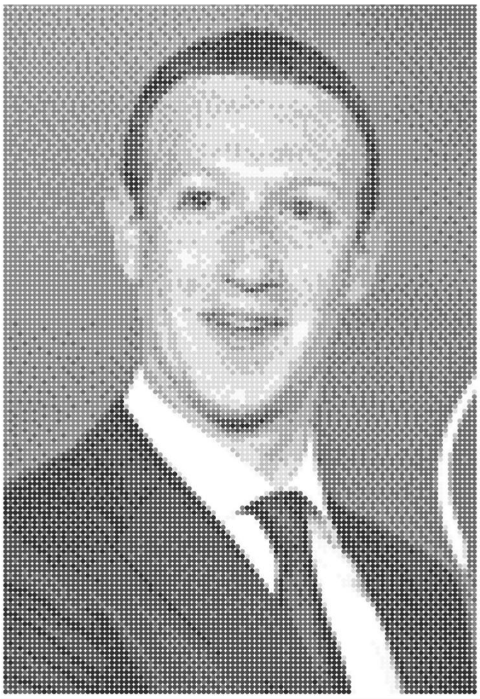


Extracting faces

(Original Photo)

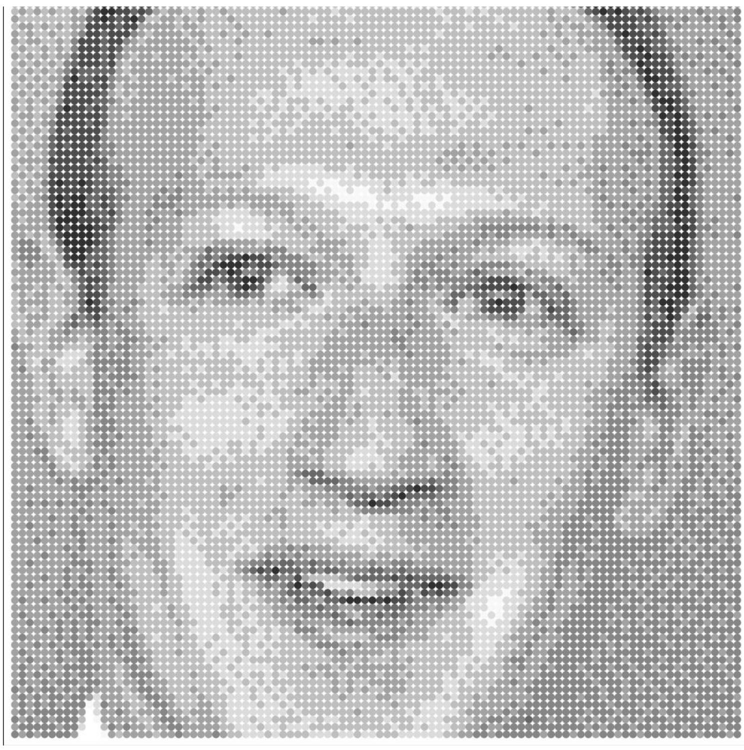


Halftone



(Original Photo)

Combined Effect



7. Conclusion:

We have accomplished most of our objectives, including the extraction of faces and the halftone processing. As a result, the machine is now suitable for family use. However, we have not completed the part where the gCode is directly transferred from the Python code to the machine via USB. This is one of the remaining goals that needs to be achieved.

We are currently researching the best way to transmit the gCode to the machine, to enable a direct transfer from the Python code to the machine, making it more convenient to operate. We believe that once this part is completed, the machine will be even more outstanding and meet the needs of a wider range of users.

We understand that transferring the gCode to the machine is a crucial aspect of the process, as it directly affects the accuracy and precision of the final output. Therefore, we are taking our time to ensure that we implement the best possible method to facilitate this task.

Once we have successfully completed this final stage, we are confident that the machine will be more efficient, reliable, and user-friendly. We are excited about the prospect of delivering a high-quality product that will meet the expectations of our customers and provide them with a rewarding and enjoyable experience.

Work Distribution:

Chaucer Chan	Report, PPT, Poster, Presentation
Aston Ku	CAD, Assembly
John U	Report, PPT, Poster
Hannes Un	Assembly, Report, PPT, Presentation, Technique(Halftone, GRBL, OpenCV), Purchase

8. Reference:

Digital Halftoning

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Stepper Motors Advantages and Disadvantages - RealPars

https://realpars.com/stepper-motors-advantages/

馬達特性與選用 - 國立中興大學

http://www.smim.nchu.edu.tw/DP/mean/10902/%E9%A6%AC%E9%81%94%E7%89%B9%E6%80%A7%E8%88%87%E9%81%B8%E7%94%A8.pdf

The Cheapest Laser Engraver On Amazon - Andy Bird Builds

https://youtu.be/5FzPDWqLqVE

HALFTONE - Dusan C. Stulik | Art Kaplan

https://www.getty.edu/conservation/publications_resources/pdf_publications/pdf/atlas_halftone.pdf

BEGINNER Laser Engraving and cutting tutorial with the Sculpfun S9 from Banggood - Small Fly Creations

https://www.youtube.com/watch?v=oJukNTgHns4

Stepper Motor, Advantages, Disadvantages, Applications, Working - CS Electrical & Electronics

https://cselectricalandelectronics.com/stepper-motor-advantages-disadvantages-applications-working/