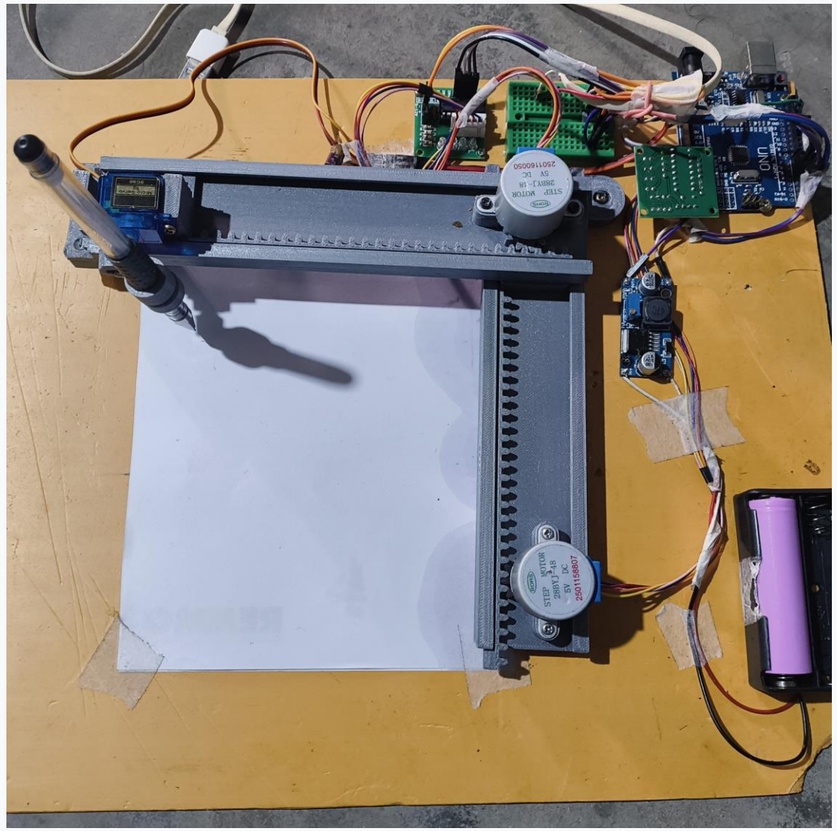
MECHATRONICS ENGINEERING PROJECT

AI-Based CNC Plotter Operator Device

Intelligent Portrait-to-CNC Pipeline with Motor-Verified Execution



40×50
mm Canvas Size

GRBL
0.9j Firmware

AI
Powered Pipeline

Team Lead: Md. Hadi Al-Amin | Class Roll: 632792

Institute: Magura Polytechnic Institute (2021-22)

Project Supervisor: Samir Kundu

Team Members: Saikat Saha, Sibgatullah, Alamin Hossain, Asraful

PROJECT FOUNDATION

Work Under This Project

Understanding Traditional CNC Operations

3D Printing & Prototyping Fundamentals

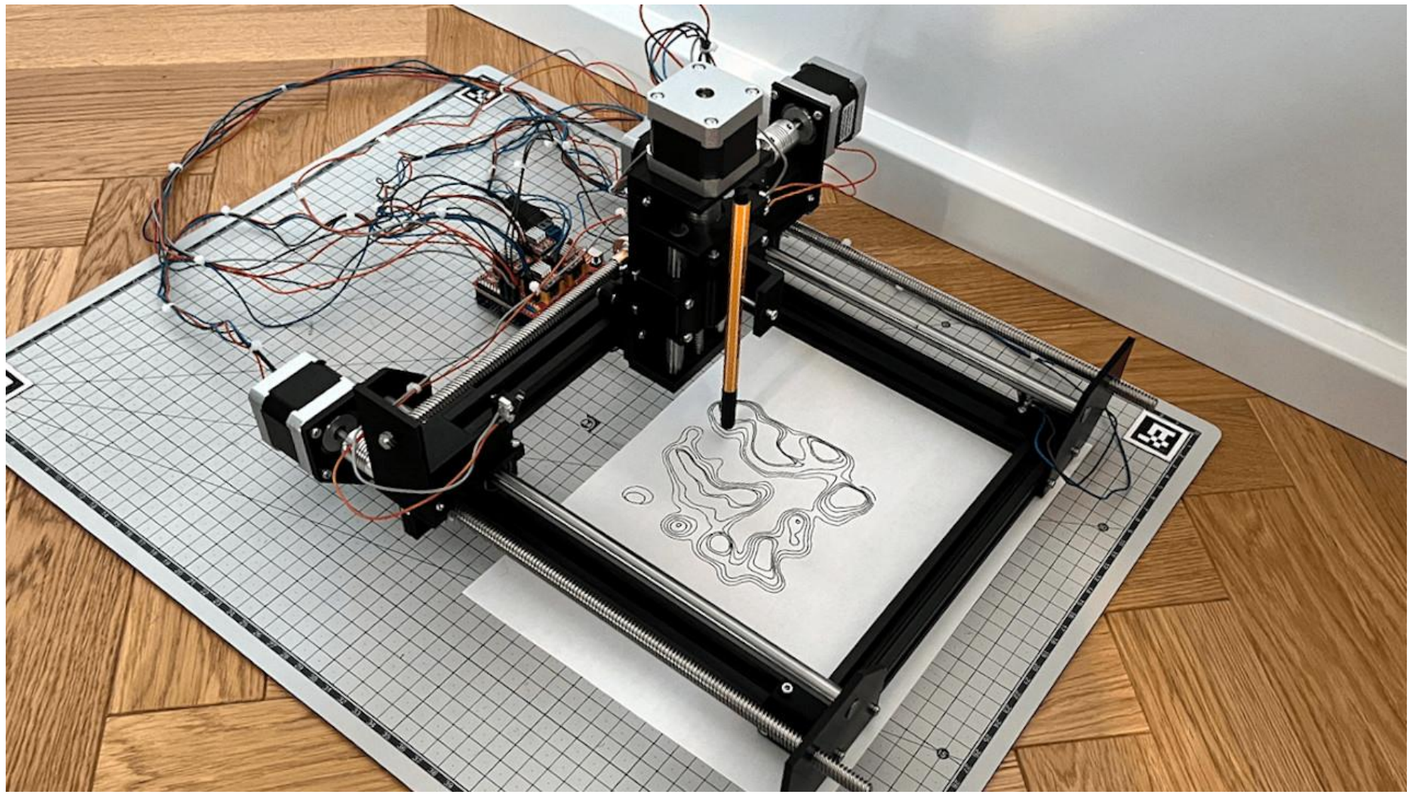
Explored additive manufacturing principles, material properties, and mechanical design considerations for CNC applications.

Manual G-code Generation Workflow

Studied traditional CAM processes, coordinate systems, and manual code optimization techniques for plotter operations.

AI Integration Opportunities

Identified automation gaps in image capture, vectorization, and real-time motor control where AI can provide solutions.



Traditional CNC Prototyping

Using Prusa i3 and similar 3D printers for mechanical prototyping and design validation

15+	40×50	0.2
Prototype Iterations	mm Canvas Size	mm Layer Height

SOFTWARE STACK

Current Requirements for Pen Plotter CNC

GRBL Firmware

Version: GRBL 0.9j

Open-source CNC controller for Arduino

Features:

- G-code interpreter
- Acceleration management
- Stepper motor control

Alternatives: TinyG, Marlin, FluidNC

Inkscape

Purpose: Vector Design

Traditional sketch vectorization with tracing

Capabilities:

- Bitmap to vector conversion
- Bezier curve editing
- G-code export plugins

Limitation: Manual process

UGS

Full Name: Universal G-code Sender

Manual motor control and G-code streaming

Functions:

- Jogging controls
- Real-time G-code send
- Machine status monitoring

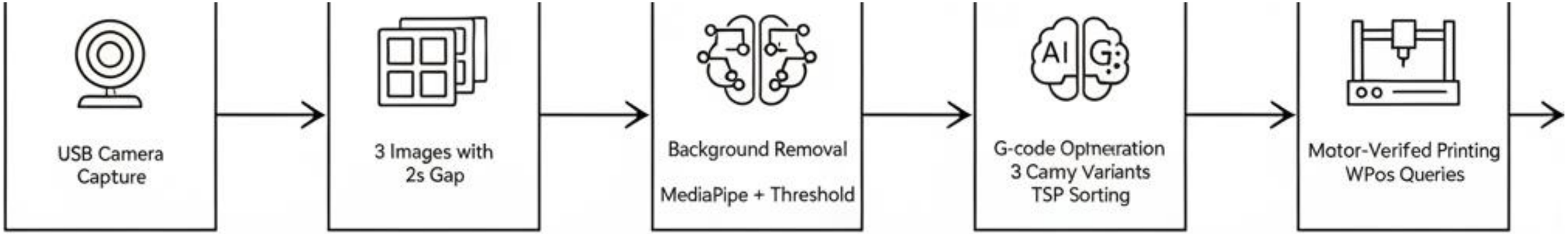
Interface: Java-based, cross-platform

Our Vision: All-in-One AI System

Integrating capture, vectorization, and plotting into a single automated pipeline

AUTOMATED PIPELINE

Complete Automated Workflow



Technical Specifications

- **Canvas:** 40×50mm
- **Feed Rate:** 50mm/min
- **Tolerance:** 0.3mm
- **Power Save:** M18 Command

Hardware Configuration

- **Steppers:** 28BYJ-48
- **Servo:** SG90
- **Camera:** 1280×720
- **Segmentation:** 30-50ms

AI Performance Boost

Optimized for classroom and commercial use

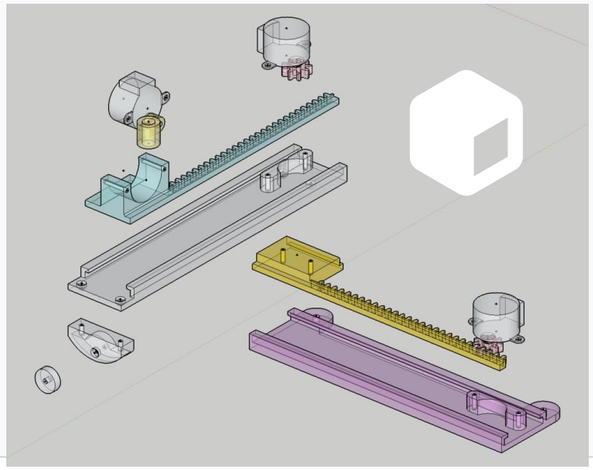
30ms	5s	3-4min
Background Removal	3 Sketch Variants	Total Print Time

HARDWARE PROTOTYPING

Hardware Prototyping Phase

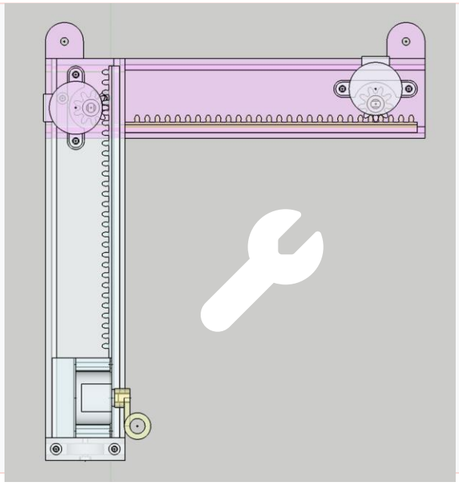
Open Source Design Selection & Modification

Bambu Lab Studio



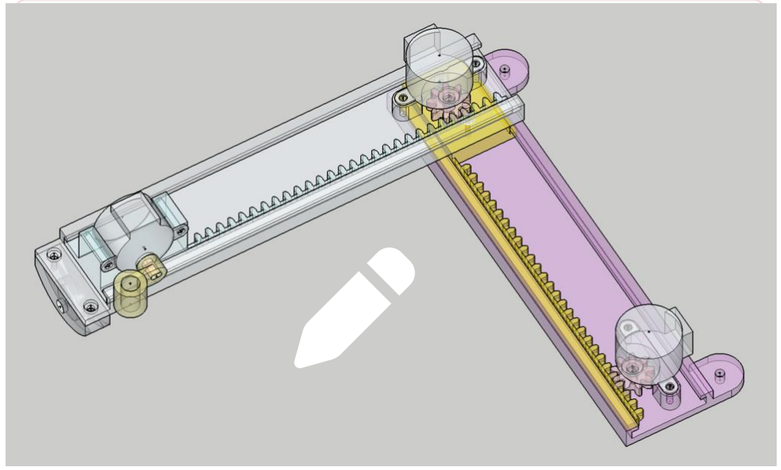
Original Design

Thingiverse:4607077



Modified X-Axis

Belt tensioner added



Custom Pen Holder

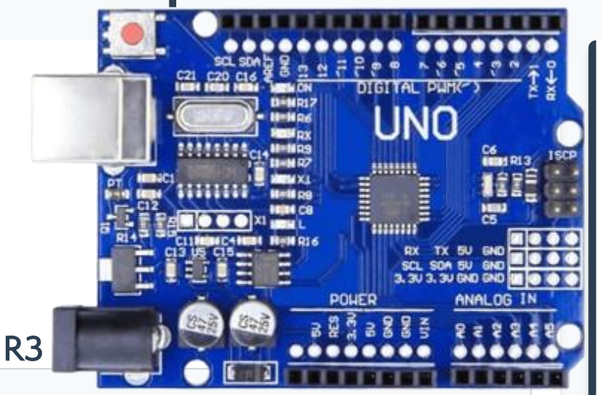
SG90 servo mount

Key Modification: Redesigned for 40×50mm canvas & SG90 servo integration

0.2mm	15+	PLA	Bambu
Layer Height	Iterations	Material	P1P Printer

SYSTEM ARCHITECTURE

System Components



Arduino Uno R3

Firmware: GRBL 0.9j

CNC controller with G-code interpreter and stepper acceleration management

28BYJ-48 Stepper

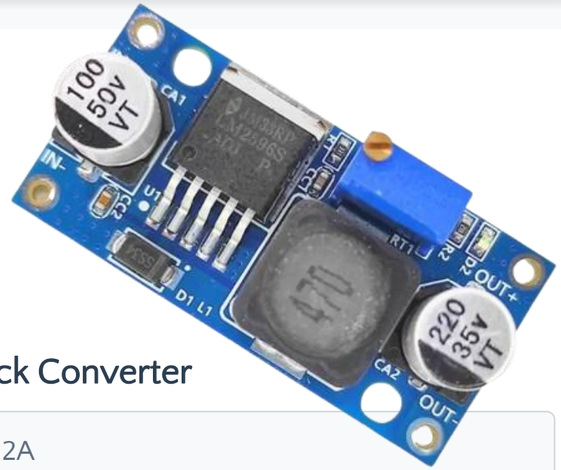
Quantity: 2× motors

ULN2003 drivers, 5V @ 500mA, 4096 steps/revolution

SG90 Servo

Function: Pen lift

8× faster than stepper Z, 180° rotation, 9g torque



LM2596 Buck Converter

Output: 5.0V 2A

470µF cap for servo, powers ULN2003 drivers from 2× 18650

Logitech C270

Resolution: 1280×720

Laplacian variance for sharpness detection

2× 18650 LiPo

Configuration: Series

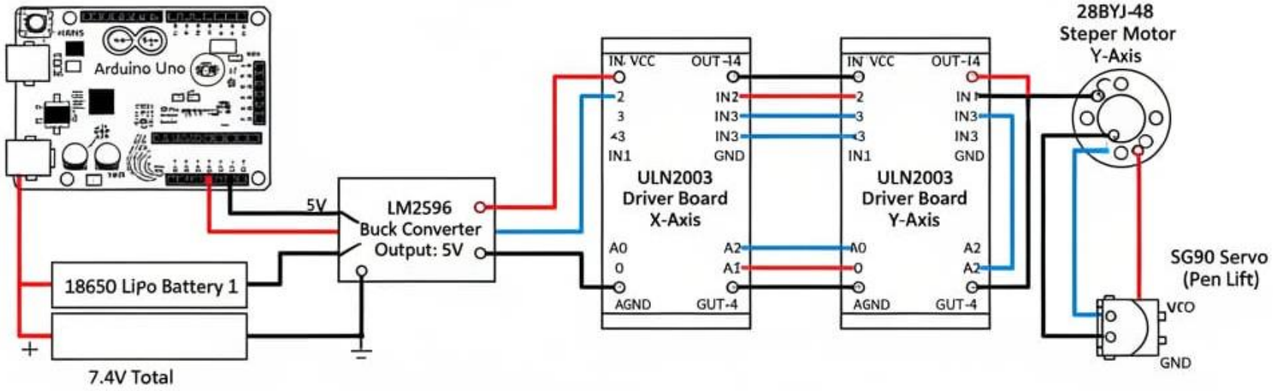
7.4V total, 2000mAh, Runtime: 30-40min with M18

Sourcing: All components sourced online with open-source designs and specifications

ELECTRICAL SYSTEM

Electrical Connections

Complete Wiring Diagram with Power Distribution



Pins 2,3,4,5: X-Axis Stepper (IN1-4 ULN2003)

Pins A0,A1,A2,A3: Y-Axis Stepper (IN1-4 ULN2003)

Pin 11: SG90 Servo Signal

Power: 2× 18650 → LM2596 → 5V

Power Distribution

7.4V →	**2× 18650 Batteries** Series connection, 7.4V nominal
5V →	**LM2596 Buck Converter** Regulated 5V @ 2A output
PWR →	**ULN2003 Drivers** Powers both stepper motors

Key Notes

Servo Power:
VCC from USB, GND common with steppers

Arduino Power:
5V from USB, isolated from steppers

Battery Config:
2× 18650 in series = 7.4V total

Critical Warning

Do NOT power steppers from Arduino 5V (500mA limit)

SOFTWARE DEVELOPMENT

Software Development Status

Libraries Used

CV — OpenCV
Camera capture, image processing, Canny edge detection

MP — MediaPipe
Selfie segmentation for background removal (30-50ms)

PS — PySerial
GRBL communication, WPos parsing, real-time feedback

TK — Tkinter
Cross-platform GUI (thread-safe using `after()`)

NP — NumPy
Line optimization, position calculations, array operations

Testing Methods

Method B: Position Query

Direct motor verification vs 'ok' acknowledgment

Advantage: Real position feedback via WPos queries

Dynamic Timeouts

Learned from `self.move_times` array

Benefit: Adaptive timing based on actual move distances

Error Recovery

Retry with voltage compensation on timeout

Mechanism: Automatic retry with adjusted parameters

Current Status: Testing Phase

85% functional, motor tracking verified

85% Functional

✓ Motor Tracking

AI DIFFERENTIATION

What Makes This AI-Powered?

Intelligent Capture

Selects sharpest frame via Laplacian variance (not random capture). Uses variance of Laplacian to detect blur and automatically choose the clearest image from 3 captures with 2-second intervals.

Adaptive Segmentation

Threshold slider + MediaPipe = classroom-ready background removal. Combines Google's MediaPipe selfie segmentation with adjustable threshold for robust person detection in various lighting conditions.

Sketch Variants

3 Canny presets auto-tuned for 28BYJ-48 speed (fast/balanced/detailed). Generates three sketch variants with different edge detection parameters, optimized for the stepper motor's mechanical limitations.

Motor Learning

Tracks actual move times to predict ETA accurately despite voltage sag. Machine learning from execution data to compensate for battery voltage drop and provide precise time estimates.

AI Performance Metrics

Real-world tested specifications

40×50	32	3–4
Canvas mm	Sketch mm²	Minutes

PROJECT STATUS

Project Status: In Progress

Major Issues Identified

1. Power Drain

2000mAh LiPo lasts only 30 minutes, needs 5000mAh for 2-hour operation

Solution: Upgrade to 5000mAh+ battery

2. Motor Jitter

Voltage sag below 4.5V causes missed steps → add 1000µF capacitor

Fix: Add 1000µF electrolytic capacitor

3. Incomplete UI

Real-time progress bar lagging, needs mutex lock optimization

Resolve: Implement thread-safe GUI updates

Proof of Work

Square Test Completed

32mm square drawn in 2.6 minutes (video recorded)

Verification: Dimensionally accurate within 0.3mm

Motor Verification

WPos tracking accurate to 0.3mm with position query method

Precision: Sub-millimeter accuracy achieved

AI Pipeline Functional

3-image capture + sketch generation working correctly

Performance: 30ms background removal

Next Steps

Priority actions for project completion

Add power management → Complete UI polish → Professor portrait demo

COMMERCIAL VISION

Future Enhancement & Commercial Applications

Solving Current Issues

Power Management

Upgrade to 5000mAh LiPo battery with intelligent power monitoring

Target: 2+ hours continuous operation

Software Optimization

Complete GUI polish, add real-time progress tracking, implement mutex locks

Goal: Production-ready software

Robustness Enhancement

Add voltage monitoring, automatic error recovery, and safety features

Result: Industrial reliability

Commercial Deployment

Trade Fairs & Exhibitions

Live portrait drawing robot attracting visitors to booths and displays

Value: Interactive marketing tool

Commercial Spaces

Malls, cafes, and entertainment venues offering personalized portraits

Revenue: Pay-per-use service

Educational Demonstrations

Schools and colleges showcasing AI, robotics, and mechatronics integration

Impact: STEM education tool

Final Product Vision

A commercial robot that can draw your image in real-time

2min	99%	24/7
Portrait Time	Uptime	Operation

Thank You

Questions & Discussions Welcome

Team Lead:

Md. Hadi Al-Amin

Class Roll: 632792

Magura Polytechnic Institute

Session: 2021-22

Project Supervisor:

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